Application of GIS and Remote Sensing for the Assessment of Surface Irrigation Potential for Winter Wheat Suitability: The Case of Dendi District on Upper Awash Basin, Oromia, Ethiopia

Belay Beko Legesse

A Thesis Submitted to the Department of Geomatics Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Geo-Informatics

Office of Graduate Studies

Adama Science and Technology University

June, 2024

Adama, Ethiopia

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Approval Sheet

I, the advisors of the thesis entitled "Application of GIS and Remote Sensing for the Assessment of Surface Irrigation Potential for Winter Wheat Suitability: The Case of Dendi District on Upper Awash Basin, Oromia, Ethiopia" and developed by Belay Beko Legesse, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Roba Gemechu (PhD) ______________________ _______________

Major Advisor Signature Date

We, the undersigned, members of the Board of Examiners of the thesis by Belay Beko Legesse have read and evaluated the thesis entitled "Application of GIS and Remote Sensing for the Assessment of Surface Irrigation Potential for Winter Wheat Suitability: The Case of Dendi District on Upper Awash Basin, Oromia, Ethiopia" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfilment of the requirement of the degree of Master of Science in Geo-informatics.

Dejene Tesema (PhD) ______ __________________ _______________

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External Examiner Signature Date

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

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Department Head Signature Date

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School Dean Signature Date

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Office of Postgraduate Studies, Dean Signature Date

Declaration

I hereby declare that this Master Thesis entitled "Application of GIS and Remote Sensing for the Assessment of Surface Irrigation Potential for Winter Wheat Suitability: The Case of Dendi District on Upper Awash Basin, Oromia, Ethiopia" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Belay Beko Legesse	______________________	_______________
Name of Student	Signature	Date

Recommendation

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "Application of GIS and Remote Sensing for the Assessment of Surface Irrigation Potential for Winter Wheat Suitability: The Case of Dendi District on Upper Awash Basin, Oromia, Ethiopia" prepared under my guidance by Belay Beko Legesse submitted in partial fulfilment of the requirements for the degree of Mater's of Science in Geo-informatics. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Roba Gemechu (PhD)	____________________	_______
Major Advisor	Signature	Date

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List of Acronyms and Abbreviation

AHP	Analytical Hierarchy Process
GDP	Gross Domestic Product
FAO	Food and Agricultural Organization
GIS	Geographic Information System
IFC	International Finance Corporation
LULC	Land Use Land Cover
MCDA	Multi-Criteria Decision Analysis
SSGI	Space Science and Geospatial Institute
UNDESA	United Nations Department of Economic and Social Affairs, Population Division

Abstract

Assessment of the surface irrigation potential for winter wheat production using GIS and remote sensing technology enables to indicate suitable land for winter wheat production. Prior to engage in crop production via irrigation, land suitability analysis for surface irrigation and winter wheat is essential to gain food security and reducing improper land use resulting in land degradation. In this regard, geospatial technologies play a crucial role in indicating a well-suited location for surface irrigation and winter wheat suitability by integrating numerous spatial data on ArcMap. Thus, in this research, different types of software's are used for spatial analysis and extraction of data, which encompasses ArcMap 10.8, ERDAS Imagine 2015, and IDRIS Selva to calculate the 'weight' of each parameter based on the AHP pairwise comparison matrix. In order to locate the suitable site, various types' of geospatial data's are used, including slope, proximity to the river, soil (type, texture, depth, drainage, and ph.), LULC, temperature, and elevation. To show the suitability of these factors, classification of the suitability of these parameters is conducted by the 'reclassify tool' of ArcMap software, and the suitability of each criteria indicated as highly suitable, moderately suitable, marginally suitable and unsuitable classes. Subsequently, in order to find the suitable site for surface irrigation and winter wheat 'weight overlay' tool of ArcMap is utilized to overlay these reclassified parameters over a model builder, and indicated as highly suitable, moderately suitable, marginally suitable and unsuitable classes. Accordingly, the land suitable for surface irrigation is estimated to be about 3.21% highly suitable, 23.63% moderately suitable, 33.47% marginally suitable, and about 39.68% unsuitable, whereas around 4.56%, 20.98%, 41.95%, and 32.51% are classified as highly suitable, moderately suitable, marginally suitable, and unsuitable, respectively for winter wheat suitability assessment. Identifying suitable land for both surface irrigation and winter wheat production requires a multi-faceted approach. This study supports local government and other stakeholder involved in agriculture sector to plan land for irrigation development, and helps farmers to practice surface irrigation in high and moderately suitable areas to improve productivity of land, increase livelihood income and reduce food insecurity.

Keywords: AHP, GIS, Remote Sensing, Surface Irrigation, Suitability, Upper Awash Basin, Parameters

CHAPTER I INTRODUCTION

1.1 Background of the Study

Currently world's population has been increasing very fast with a consistent growth pattern. According to UNDESA 2022, world population trends estimated that currently, the world population has tripled since 1950s reached around 8.1 billion, and projected to reach 8.5 billion in 2030, and 9.7 billion in 2050. Similarly, nowadays, Ethiopia's population is also increasing very fast. According to Worldometer UN data used for estimations Ethiopia’s current (June, 2024) population is estimated greater than 129 million people and within 50 years population increased by 50 million people from 17.71 million in 1950 G.C. to 67.03 million in 2000 G.C.. However, population increased very fast in just 20 years, which increased by 50.17 million, and reached 117.2 million in 2020 G.C. (https://www.worldometers.info/world-population/ethiopia-population/).

With rising population, food demand also rising rapidly (UNDESA, 2020). So, in addition to producing crop in rainy season, to meet the demands of the rising population, it is vital to expand crop growing season and maximize productivity by utilizing water resource in dry or winter season through irrigation. So, assessment of a land suitable for irrigation is vital to produce different types of crops in dry season to enhance the food security and livelihood income. In the assessment of land suitability, the term land suitability defined as the appropriateness a specific type of land for a defined use. The process of land suitability classification is the assessment and grouping of specific areas of and in terms of their suitability for the defined specific uses (FAO, 1976). So, in dry season produce crop, the crop land get moisture via irrigation, which is the application of water to soils for crop growth. Thus, to achieve food security and safeguard land from degradation as it caused by improper use of land, assessment of suitable land for irrigation is crucial step.

Earlier to irrigating a land, it is essential to assess the suitability of the land for surface irrigation. Hence, GIS and remote sensing technologies are crucial tools in assessing the suitability of land for surface irrigation. GIS plays a crucial role in assessment of surface irrigation suitability by providing a powerful tool for analyzing and visualizing spatial data, and it allows for the integration of various data layers, such as slope, elevation, soil (type, texture, depth, drainage, and ph.), LULC, and water resources, to generate accurate maps that highlight areas suitable for irrigation development. By overlaying these layers and applying spatial analysis techniques, GIS can identify optimal locations for surface irrigation suitability and winter wheat. This spatial analysis enables decision-makers to prioritize areas for irrigation development, design efficient irrigation systems, and maximize agricultural productivity while minimizing environmental impacts. Thus, these geospatial technologies can provide a system of framework for building database and management, analysis models, and mapping to enable decision makers (Bwambale et.al, 2022; Baroudy et al., 2020; Elnashar et al., 2021; Seif-Ennasr et al., 2020).

Therefore, producing crops by irrigation supports Ethiopian economy, as Ethiopian economy is primarily reliant on agriculture. Crop production is one component of agriculture, and it serves as the primary source of food security, livelihood and economic income. However, the majority of crop production heavily relies on rainfall. The process of harvesting crops in the country is entirely dependent on the availability and consistency of rainfall. This means that it is highly sensitive to a rainfall. This crop production, in Ethiopia, which is dependent on rainfall, makes it susceptible to the effects of climate variability. Since the livelihood and food security of farmers, and the economy of a country, are closely related to crop production, the decline or damage caused by the rainfall variability affects the livelihood of many people and the economy of a country (Shitu and Almaw, 2021; Bedane et al., 2022, Climate Resilient Food Systems Alliance, 2022).

Like many other places of Ethiopia, crop harvesting in the study area depends on rainfall. Producing crops depending only on rainfall can’t bring the expected food security and income for the producers, since rainfall become unpredictable and as well impact of flood problem. Flooding is very disastrous problem which result in the total or partial destructive of the crop, and causes the farmers to be victim to food shortage and decline in income obtained from their product. Additionally, in study area top soil erosion is a problem as in some areas irrigation activities are available without proper assessment of the slope of the topography, and this resulted in soil erosion. Hence, producing crop in addition to depending on rainfall, irrigation is the key mechanism which enables to harvest crops in dry season. Thus, the study area has endowed by Perennial River like Awash River, and using it for crop production via irrigation can enable to get extra food and generate income.

Hence, in this research, assessment of irrigation potential and winter wheat is based on multiple parameters, including proximity to the Perennial River, LULC, slope, elevation, soil type, soil texture, soil ph., soil depth, and drainage. Suitability of each factor is classified by reclassify tool, and indicated in the form map. Then, finally the suitable land for surface irrigation and winter wheat is generated by overlaying these factors over weight overlay tool.

1.2 Statement of the Problem

Still now in Ethiopia, wheat harvesting is dominated by a subsistent smallholding farming system and the productivity is low. For many years wheat productivity remained very low levels, and food production has remained behind population growth. Hence, to fill the broadening gap between wheat consumption and wheat production the country imported substantial amount of wheat for nearly half of the past century both in the form of commercial import and food aid. Nowadays the initiative to increase wheat production taken into consideration, as wheat utilization is growing at faster rate than any other food crops due rapid population growth, consumption preferences towards wheat based food items, and foreign exchange problem to pay for import (Senbeta & Worku, 2023).

So, achieving food self-sufficiency and reducing the spending of scarce foreign currency reserves for wheat import is a national priority. Thus, the government of Ethiopia plans to ensure wheat self-sufficiency through irrigation mechanism in dry season. Currently, the Ethiopian government planned irrigation expansion as one of the pillars for wheat self-sufficiency and to improve the income of small-scale farmers (Senbeta & Worku, 2023).

However, like many developing countries, in Ethiopia, a land use practice is not based on assessment of suitability; hence, there is a need to use land in the rational and promising way (Beyene, 2008). Thus, GIS and remote sensing technologies enable to analyze and indicate suitable land by integrating many data.

In addition to fruit and vegetable, currently, wheat production by irrigation in winter season got high attention to attain food security, enhance income for the farmers and earn foreign currency by exporting. However, the problem is even though water and land is available there, earlier to starting farming at given land there is no suitability assessment. As an option to obtain food security and earn foreign currency, even though there is no suitability assessment, the Ethiopian government initiated wheat production by irrigation system. This launching of large-scale irrigation based wheat production by Ethiopian government enabled to obtain food security. The initiative started on 3,500 hectares of land devoted to irrigate wheat farming, marking a strategic shift from dependence on rain-fed agriculture. Following this initiative, the amount of land irrigated to produce wheat continuously increased in the successive years, showing its potential to guarantee a consistent food supplies and even Ethiopia exporting wheat crop. This initiation created a good job opportunity in winter season for farmers and intensifies income acquired, and as well the country minimize food insecurity problem and obtain foreign currency by exporting the product to other countries.

There a number of problem hindering self-sufficiency of wheat in the study area. Thus, the study area characterized problem such as flooding, dependency on rainfall, soil erosion, and available water resource but unexpanded cropping season. In this study area, the farmers depend on rainfall to produce crops for food consumption and livelihood income. However, depending only on rainfall for cultivation of crop poses a great challenge for crop producers, which leads the crop vulnerable to the unpredictable and increasingly erratic rainfall patterns. Moreover, the timing and distribution of rainfall may not align with the critical stages of crop growth, can affects crop productivity. Depending merely on rainfall can limit the ability to optimize yields, livelihood income and ensure food security.

The other challenging problem is annual flooding of the Awash River, which has profound impacts on crop damage and losses, with the overflow of water submerging farmlands, causing waterlogging, uprooting crops, and depositing debris and sediment on fields. The resulting crop damage and losses not only jeopardize the livelihoods of farmers but also contribute to food shortages, financial hardship, and increased vulnerability to hunger and poverty within communities.

Furthermore, improper irrigation practices can exacerbate soil erosion, which affects negatively agricultural productivity. When irrigation is not practiced in proper slope of land, distributed water can erode the topsoil, which is rich in nutrients and organic matter essential for plant growth, leading to reducing soil fertility and diminished crop yields.

Regarding winter wheat suitability assessment, limited number of study done in Ethiopia. For instance, a researcher Fekadu and Negese, 2020 conducted a GIS-based AHP technique in an investigation of winter wheat suitability assessment at the Yikalo sub-watershed in Ethiopia by employing soil properties, topographic features, and climate data. In order to show suitable map the reclassified factors are overlaid using a weighted overlay tool, where each raster cell's suitability value was multiplied by its layer weight and the values were totaled to produce the final suitability maps. But, in this study, the researcher didn’t included vital factors like LULC and elevation in suitability analysis, which has its own significant influence in determining land suitability analysis. Ignoring LULC in suitability assessment is unnecessary, since the identified suitable site may fall on LULC which is not suitable (like water body, forest and settlement) for crop harvesting via irrigation. Here, data gap identified is identified in suitability analysis for wheat production, and this research work can fill this identified gap. Therefore, it is a must to incorporate LULC data in any tasks of suitability analysis.

The other observed gap is when ‘weight overlay tool’ used to find suitable site for surface irrigation potential, many researcher’s didn’t restricted some LULC in their analysis; since some of these LULC is totally unsuitable for surface irrigation and wheat growth. These LULC which should be restricted in the suitability analysis comprises water body, forest and settlement, since these LULC are completely permanently unsuitable for surface irrigation and winter wheat.

Moreover, in many research papers gap identified on the formula utilized for weight overlay analysis to indicate the suitable site. In many research papers the formula used by many researchers is $S = \sum_{i=1}^{n} Wi * Xi$, however, this formula didn’t restrict the LULC which has to be totally restricted. Thus, this research can fill this gap using $S = [\sum_{i=1}^{n} Wi * Xi] \prod_{cj}$,since on permanently unsuitable LULC other factors which are suitable for surface irrigation assessment and winter wheat, may coincide on it, and on this LULC the overlay analysis result may show as moderately or marginally suitable or highly suitable, which is unacceptable, so this formula better in showing accurately suitable site.

Thus, this research can fill the stated gap in above. In this research, the potential site for surface irrigation and winter wheat sites assessed using various spatial data such as slope, elevation, soil properties, LULC and proximity to river.

1.3 Objective

1.3.1 General Objectives

"The general objective of this research is to assess the surface irrigation potential for winter wheat production using GIS and remote sensing technology in Dendi District, Upper Awash."

1.3.2 Specific Objectives

The specific objectives of this research are:

- To assess the parameters determining surface irrigation potential and suitable site for winter wheat production,
- to map the suitable the parameters (slope, proximity to river, soil properties, LULC and elevation) for surface irrigation and winter wheat,
- to build geospatial data model for surface irrigation potential and winter wheat suitability analysis and
- to map the surface irrigation potential and winter wheat suitable site.

1.4 Research Questions

Research question for this research are:

1. What are the parameters determining the assessment of surface irrigation potential and winter wheat suitability?
2. What is the technique to indicate the suitable classes of the parameters for irrigation potential and winter wheat?
3. How to build geospatial data model for assessment of surface irrigation potential and winter wheat suitability?
4. What method applied to map surface irrigation potential and winter wheat suitable site?

1.5 Significance of the Study

The significances of this research are:

- It helps to produce geo-database of surface irrigation and winter wheat suitability at national or regional or zone or district level

- Based on the model developed, it enables to estimate surface irrigation coverage suitable and winter wheat at national or regional or zone or district level.
- It enables government or decision makers, by indicating surface irrigation potential and winter wheat suitability, when interest for winter wheat production via irrigation.

1.6 Scope of the Study

This research is limited in terms of content, time framework and geographical coverage. In terms of content and geographical coverage, the scope of this research is confined to application of GIS and remote sensing for the assessment of surface irrigation potential for winter wheat suitability the case of Dendi District on Upper Awash Basin, Oromia, Ethiopia. Furthermore, from multi-criteria decision analysis, the research is done based on the principle of Analytical Hierarchy Process (AHP) method and as well it is limited in the timeframe of work and the specific objectives to achieve stated in this research.

1.7 Organization of the Thesis

This thesis is organized into five major chapters. The first chapter presents an introduction, which encompasses a background of the study, statement of the problem, objectives of the study, significance of the study, research question, and scope. The second chapter introduces review literature which is theoretical and empirical related to the research title. The third chapter provides deals with methodology, with a sub-content detailed description of the study area, data collection and sources, material used, data preparation, and general methodology utilized in the study. The fourth chapter of the thesis encompasses result and discussion, which explain and discuss finding of the research. Finally, chapter five deals with conclusion and recommendation section.

CHAPTER II LITERATURE REVIEW

2.1 Theoretical Framework

2.1.1 The Concept of Irrigation and Suitability

The term irrigation broadly defined as the practice of applying water (beyond rainfall) to agricultural land or a land covered by vegetation to enable or enhance the plant growth and harvest better yield, and the quality of foliage or harvested plant parts. It is the supply or transportation of water to land of crops or vegetation by the human made canals or water channel or other mechanism. This artificial application of water through irrigation provides moisture content for soil which is an essential one for the growth and healthy stay of plants. Irrigation process is introducing water to the soil where plants can extract it to satisfy their requirements', mainly evapotranspiration. The source of water for the irrigation purpose can be from different sources. The water sources could be groundwater pumped to the surface, or surface water like river or lakes diverted from one position to the other. Construction of dam to hold water for irrigation purpose is also additional water sources utilized in crop production (Eisenhauer et al., 2021, Reddy, 2010).

Irrigation is crucial especially in arid and semiarid areas to promote plant growth and mitigate the effects of drought. It has enabled the transformation of previously barren lands into productive crop-growing regions, such as the Nile Valley in Egypt and the Central Valley of California. Without irrigation, these regions would struggle to produce enough food to sustain their populations. In addition, irrigation is essential for maintaining stable food production and achieving food security, as well as increasing food production in regions where rainfall is limited (Ranjan et al., 2022 and Eisenhauer et al., 2021).

In the context of irrigation, surface irrigation is a widely used and conventional method for providing water to crops. This technique is defined as the distribution or supply of water through a canal on the soil surface, utilizing gravity to pump the water. Surface irrigation is the most commonly employed irrigation method among farmers, and it encompasses various techniques. For instance, the entire field may be flooded for rice cultivation, or water may be directed to flow in furrows between crop rows (Anjum et al., 2023).

When proceed to define the term suitability, it is defined by FAO as a degree of how fine the qualities of a land unit fit or match the requirements of a specific form of land use;

intended to engage whatever a certain activities to obtain the desired best outcome. FAO defines it as the fitness or appropriateness of a given a specific type of land for a defined use, which enables that the suggested suitable location more productive over the other actives according to the parameters employed to determine the best suitable site for a certain activities. Indication of the land suitability for a specific land use may consider in current condition without improvement over the land or after a modification of the land to improve the land according to requirements of the specific activities land use. Therefore, the procedure of land suitability classification is the appraisal and grouping of specific areas of land according to their suitability for an intended uses (FAO, 1976; 2007).

2.1.2 Irrigation in Ethiopia

Irrigation was invented in Sumer, currently known as Iraq, near around 5,500 BC by the ancient Sumerians. It was developed because of local use and saving the crops at the time of deficiency of rain. Even though it was started in Iraq near 5,500 BC, some archaeological evidence shows it had been started prior to 5000 BC at about back to 6000 B.C. founded at the Middle East's Jordan Valley. According to this archaeological investigation, there is evidence of barley crop producing through irrigation in Mesopotamia, Egypt and Iran back to the 6th millennium BC (Ranjan et al., 2022,).

Irrigation is vital to the production of agricultural crops. For instance, nearly one-third of the world's 21% cultivated area is produced with agricultural crops that are grown through irrigation. In the USA approximately half of the entire crop sales value originates from irrigation, which arises from 28% of the cultivated land (Eisenhauer et al., 2021).

On the other hand, growing crops by irrigation has a long history, when considering Ethiopia's irrigation history. Ethiopia has a long history of traditional irrigation, dating back several centuries, and is linked to the ancient culture of the Axumite people. It was mainly practiced in the highlands of Ethiopia to produce food crops for subsistence. But, a two-sided contract between the Ethiopian government and the Dutch company HVA Ethiopia to create commercial irrigated sugar estates for the production of industrial crops like cotton and sugarcane on the upper Awash Basin is credited with starting "modern" irrigation in the early 1950s. These crops were irrigated by less effective pressurized irrigation systems and surface irrigation methods (FAO, 2016; Haile and Kasa, 2015).

A private investor then began to work in irrigation. Private firms implemented large-scale irrigation in the Lower Rift Valley and the entire Awash Basin throughout the 1960s. While community programs to combat the devastating droughts and famines, particularly the 1973 one, led to the introduction of modern small-scale irrigation in the 1970s. Modern private irrigation returned in the 1990s as a result of the government's attempt to liberalize the economy following the overthrow of the Dergue government (FAO, 2016).

The irrigation system in Ethiopia is seen as a vital tool for reducing poverty and guaranteeing food security. It assists in converting the rainfall-dependent rain-fed agricultural system into an irrigation-and rain-fed system. This approach is thought to be the most successful in achieving sustainable development inside the nation. To completely comprehend the beginnings and subsequent advancement of irrigation practices in Ethiopia, however, a thorough investigation of their history and evolution is necessary. In order to ensure food security and eradicate or drastically reduce poverty, irrigation is necessary. Ethiopia presents a considerable prospect for irrigation development because of its plentiful water supplies, pleasant environment, appropriate terrain, and affordable labor, especially in the country's dry areas (Haile and Kasa, 2015).

Ethiopia is home to numerous river basins, each of which has a unique potential capacity for irrigation purpose (the potential of the river basins is displayed in the table below). There are twelve river basins in Ethiopia. An estimated 124.25 billion metric cubes of water flow annually are estimated from the entire 12 river basin (Awulachew et al., 2007).

Regarding the estimations reports of irrigation potential, in Ethiopia, various researchers' or organizations report is not uniform. According to the estimation of FAO, from the total area coverage, Ethiopia has around 2.7 million hectares of potential irrigable land, taking into consideration the availability of water, the availability of land resources, technology, and finance (FAO, 2016; FAO/IFC, 2015). But studies conducted by Master Plan of River Basin show that the potential irrigable land is greater than FAO studies. According to the "Master Plan of River Basin" studies, the maximum irrigation potential estimation are about 5.7 million hectares of land, but about 3.7 million hectares of land are commonly repeated (FAO, 2016). The study on the amount of irrigation potential by Awulachew et al., 2007; Asrat & Anteneh, 2019 also strength the irrigation potential study estimated by

“Master Plan of River Basin.” Accordingly, Ethiopia expected to have more than 5.3 million hectares of potential for irrigation.

Table 1: The 12 River Basins of Ethiopia

No	River Basin Name	Area (km2)	Runoff (Bm3)	Potential irrigable land (ha)
1	Abay	199,812	54.8	815,581
2	Awash	112,696	4.9	134,121
3	Tekeze	82,350	8.2	83,368
4	Omo-Ghibe	79,000	16.6	67,928
5	Rift Valley	52,739	5.6	139,300
6	Mereb	77,121	0.65	67,560
7	Denakil	74,002	0.86	158,776
8	Baro-Akobo	75,912	23.6	1,019,523
9	Wabi-Shebelle	202,697	3.16	237,905
10	Genale-Dawa	171,042	5.88	1,074,720
11	Aysha	-	-	-
12	Ogaden	-	-	-
	Total	1,135,494	124.25	3,798,782

Source: (Awulachew, 2007; Ayalew, 2018)

2.1.3. GIS and Remote Sensing for Assessment of Surface Irrigation and Suitability

A Geographic Information System (GIS) is a computer-based information system for spatial data analysis, and output generating of geographic data and information. It deals with collection, storage, retrieval, manipulation, analysis, and display of spatially related information. It is utilized for the collecting, storage, and analysis of objects when the geographical position is an essential property or vital to the research (Erion et al., 2022).

Remote sensing is a science and technology of obtaining data about the Earth’s surface without physically contact to the object sensed. It achieves this mission by using sensors mounted on platforms like satellites, aircraft, or drones. These sensors can detect electromagnetic radiation reflected or emitted from the Earth's surface, enabling us to capture valuable spatial data (Janga, et al., 2023)

Remote sensing is very essential tool for irrigation potential assessment. Satellites, a prominent remote sensing technology, offer images that can be evaluated by image classification methods to extract information relevant to surface irrigation assessment. In this regard, LULC data often obtained from satellite images using remote sensing tools, which serves as a vital input layer in assessment of surface irrigation potential (Arab, and Ahamed, 2022).

GIS and remote sensing technologies are powerful technologies that can enable in the assessment of the potential sites for irrigation. Understanding the role of these technologies in the assessment of irrigation potential, currently, these technologies have been applied in irrigation potential assessment for favorable site location in agricultural crop harvesting. It allows the integration of various spatial data sources, including LULC, topographic data, soil properties and water resource data. By analyzing these spatial data, GIS helps to identify areas suitable for irrigation based on factors such as soil properties, water availability, proximity to water sources, slope, LULC and other spatial data (Baroudy et al., 2020; Elnashar et al., 2021; Seif-Ennasr et al., 2020).

2.1.4. Surface Irrigation and Winter Wheat Suitability Assessment Parameters

Certainly, not all lands possess the necessary attributes for irrigation. In fact, the suitability of lands for irrigation depends on several factors. To evaluate land suitability for surface irrigation various parameters are considered. Among these parameters are topography, soil properties, water resource, and climatic conditions. Topography comprises slope and elevation, soil properties characterized by texture, type, drainage, ph., and depth, which influence water holding ability and the capacity to sustain plant growth. For surface irrigation purpose, water resources is the perennial river, is also crucial for crop production via irrigation. Climate factors like rainfall patterns and evapotranspiration rates determine the water requirements of crops. By evaluating these parameters, areas with the greatest potential for successful and sustainable irrigation can be identified. Thus, to locate suitable land, these spatial data were analyzed by a GIS environment (Mandal et al., 2018).

To assess the appropriate land for surface irrigation site identification, significant parameters recognized as determinants are selected on the basis of a review of current literature, data availability, and expert opinions. These parameters encompass slope, LULC, elevation, soil physical and chemical properties, and proximity to rivers (Hussien et al., 2019; Mandal et al., 2017; and FAO, 1996).

Slope and elevation were selected among the topographic elements affecting cropland suitability. It influences the movement of materials along the land surface; as a result, soil depth, drainage, and nutrient availability are reduced, and the rate of soil formation is retarded with increasing steepness (Bozdag et al., 2016).

Slope is the inclination of the surface of land and is commonly expressed as a percentage. It affects irrigation type, erosion, drainage, and runoff. It has a direct impact on the rate at which rainwater infiltrates; in other words, a steeper slope lowers the rate at which water recharges since it flows off the surface quickly, causing soil erosion and vice versa. Moreover, it has an impact on soil depth, irrigation technique, production costs, irrigation operation, and erosion control (Attia, 2022, FAO, 1999, Mandal et al. 2018).

A land having a gentle slopes are optimum for farming and it is easy way to build irrigation canals (Balew et al., 2021; Esa 2022; Hagos et al., 2022). Slopes too steep for irrigation should not be used (Ubaydullayevich et al. 2020).

The other criterion is the distance of land from a river, which is a crucial factor in the assessment of surface irrigation. It is one of the fundamental criteria in determining the land suitable for surface irrigation development (Paul et al., 2020). Therefore, assessment and classification of the proximity of a land to a river is essential in land suitability analyses for crop production.

Furthermore, additional factors taken into account in the evaluation of surface irrigation potential and the suitability of winter wheat include the physical and chemical characteristics of the soils. It is essential that to assess the suitability of the physical and chemical characteristics of soil for surface irrigation and crop harvesting, so, soil suitability assessments are essential prior to irrigation activities. Soil ph., moisture content, depth, and drainage can influences suitability for surface irrigation and crop growth (Wubalem, 2023).

The ph. of a soil is an essential quality derived from its chemical properties that influences the healthy growth of crops (Mulugeta et al., 2021; Lake, 2000). According to Mohammed et al. (2020), the ideal soil pH range for micronutrient availability and wheat growth is between 6.0 and 7.0. The term ph. of a soil often refers to the concentration of hydrogen ions in the soil and indicates its acidity or alkalinity (Lake, 2000).

Apart from its chemical composition, the physical characteristics of soil play a significant role in the well-being of crops. They are essential factors in the analysis of winter wheat adaptability and surface irrigation (Muhaimeed & Jaf, 2016; Dadhich et al., 2017; Nachtergael et al., 2009). Crop growth is influenced by several physical features of soil, such as soil type, depth, texture, moisture content, and drainage (Mulugeta et al., 2021). In general, crop productivity is influenced by these elements.

Physical and chemical properties of soil like soil texture and depth are vital elements that play a great role in the growth and development of crops. Soil texture is one of the most ultimate properties of a soil, and it is defined as the relative proportion of each class such clay, silt and sand, or the size range particles in the soil. It influences the soil's capacity to hold water, air, and other essential elements for plant growth, and offers necessary information about porosity, infiltration rate, and available water capacity. Soil depth denotes the distance from the top soil's surface to its bottom, and affects root development, moisture availability, and nutrient content in the soil. It ranges from a few centimeters to several meters, and insufficient depth can obstruct root growth, reduce moisture and nutrient availability, and impact soil permeability and tillage options. Soil depth is categorized as very deep (>150cm), deep (75-150cm), moderately deep (50-75cm), moderately shallow (25-50cm), and shallow (< 25cm) (Dadhich et al., 2017).

Other soil properties that are necessary for the healthy growth of crops are influenced by soil texture, including organic matter content, drainage, water holding capacity, aeration, susceptibility to erosion, and ph. capacity (Muhaimeed & Jaf, 2016).

Furthermore, the other physical property of soil that affects the growth and productivity of crops is soil drainage. Soil drainage is the internal water drainage or permeability, which is one of the major elements that affect crop productivity. It is the rate at which excess water moves through the soil. It describes the soil's ability to shed surplus water after rainfall, irrigation, or any other source. In classification of soil drainage, ‘good drainage’ is defined as the rapidity of free water infiltration from the soil strata. Well-drained soils are more appropriate than poorly or excessively drained ones because of excessive waterlogging are minimal. In general, for better oxygen availability to the plants well-drained soils is required (Chen et al., 2007).

Together with the previously mentioned elements, LULC is also a critical component in determining if a particular piece of land is appropriate for winter wheat farming and crop production by surface irrigation. LULC has an impact on the selection of suitable land for surface irrigation (Worqlul et al., 2017; Yohannes & Soromessa 2018; Hagos et al., 2022, Wubalem, 2023).

2.1.5 Multi-Criteria Decision Analysis (MCDA)

In many situations, making decisions is a difficult task that requires the analysis of many amounts of data. In such cases, decision-making methods, particularly MCDA methods, can be employed to solve complex problems and are therefore an essential tool in the decision-making process. It is essential to mitigate the multifaceted problems that arise in day-to-day life, and MCDA techniques can be applied to resolve these problems. No verdict can be decided without considering to the decision-making process, which is reasoning, complex process aimed at determining a desired result by taking in to account several criteria. Currently, complex decision-making problems can be resolved by utilizing mathematical equations, multiple statistics, mathematics, economic theories, and computer devices that automatically calculate and estimate solutions to decision-making problems. MCDA is one of the most precise methods of decision-making, considered the foremost means of decision-making as it takes into account numerous factors in the decision-making process (Taherdoost and Madanchian, 2023).

MCDA is a process that involves the assessment of many alternatives based on numerous criteria, and picking the optimum choice based on the criteria. The principal aims of MCDA systems are to establish the relative importance of each criterion, and integrate several criteria to compare each criterion against the other criterion. To achieve this, the MCDA method utilizes a comprehensive value that is derived by aggregating the values and weights of the criteria. In real-world circumstances to solve the problem, MCDA typically involve numerous aspects, and it is indispensable to consider the interactions between the criteria to make an informed decision (He-Hua et al., 2018).

Furthermore, MCDA is a decision-making tool that considers multidimensional parameters and permits the comparison of parameters by combining individual parameters into one overall evaluation. It can enable complex decision-making processes, and in the 1960s, it was applied in geographic information systems (Baran-Kooiker, et al., (2018).

AHP is a MCDA technique that is utilized to address problems for decision makers. It is user-friendly, despite facing challenges resulting from the dependence of criteria and alternatives (Zlaugotne, et al., 2020). Developed by Thomas Saaty in 1977, the AHP method is characterized as "a scaling method for priorities in hierarchical structures which compares alternatives in pairs." It is often referred to as a ranking method due to its ability to prioritize various things, objects, or concepts. AHP is a well-known and widely used decision-making method that allows users to calculate the rankings of all alternatives based on a series of in-depth questions about comparing two selected alternatives. The AHP method is still one of the most popular MCDM techniques worldwide, and it is preferred over other branches of MCDA when solving decision-making problems related to geospatial issues. This is because the AHP method employs the consistency ratio to determine whether to accept or reject (repeat) the parameters' degree of influence or weight of each parameter (Kułakowski, 2021).

The AHP method is extensively a practical method for solving complex decisions involving different criteria and is a popular tool for multi-standard decision making. This tool is a mathematical and psychological research technique based on a series of pairwise comparisons to determine a standard weighting for each factor involved as an alternative in decision making. In addition, the AHP ensures reliable decision making and decreases nonconformity in decision-making analyses. Therefore, the AHP method helps decision makers solve complex problems by employing the method to determine the weight of the evaluation parameter for indicating the suitable site location (Jiang, 2022).

Saaty introduced a fundamental scale for comparing alternatives in the AHP method. The fundamental scale for pairwise comparison in AHP scaled in the range {1/9, 1/8... 1/2, 1, 2... 9} and it is very often presented in the form of a table (Kułakowski, 2021).

2.1.6 Classification Method of Surface Irrigation and Winter Wheat Suitability

Irrigation potential assessment shows the degree of land favorable for irrigation. The analysis of surface irrigation potential identified illustrated or produced is based on the framework of the FAO (1976) land suitability classification method. According to the FAO (1976), land suitability maps are generally classified into two classes, i.e. suitable and not suitable. These suitable and unsuitable classes are further classified on the basis of their benefits and limitations. Yet again, suitable was classified into three categories as highly suitable, moderately suitable, and marginally suitable, whereas unsuitable was classified into two categories as currently not suitable and permanently not suitable.

Table 2: Land Suitability Classes (FAO, 1976 Framework)

Land Suitability Classes	Description
Highly Suitable	Land without significant limitations. Include the best 20% to 30% of suitable land as S1.this land is not perfect but that can be hoped for.
Moderately Suitable	Land that is clearly suitable but which has limitations that either reduces productivity or increase the inputs need to sustain productivity compared with those needed for S1 land.
Marginally Suitable	Land with limitations so severe that benefits are reduced and/or the inputs needed to sustain production are increased so that this cost is only marginally justified.
Not Suitable	Land with limitations to sustained use that cannot be overcome at a current acceptable cost.
Permanently unsuitable	Land with limitations to sustained use that can't be overcome

Source: (FAO, 1976)

2.1.7. Fuzzy Set Theory to Land Suitability Assessment

The need to assess the suitability of land for specific agricultural commodities is as old as man's need for food. From the earliest time, farmers have been deciding which crops are the best for the land they possess. A basic feature of land evaluation is the comparison requirements for a particular land use with the resources offered by an area of land. Fundamental to the land evaluation process is the fact that various kinds of land uses have different requirements. Thus, the objective of land evaluation is to match, as accurately and efficiently as possible, land use requirements and land characteristics or land qualities in order to provide planners and decision-makers with the ability to make comparisons and to identify promising courses of action (Tang et al., 2014).

The theory of fuzzy set, originally proposed by Zadeh (Tang et al., 2014) is a body of concepts and a technique that gives a form of mathematical precision to human thought processes that are imprecise and ambiguous in many ways. It was developed to deal with vaguely defined expressions, classes or categories; like “important” and “less important” land characteristics.

Recently there has been an interest in the use of fuzzy set theory in land valuation which is also easy to apply with cartographic algebra. Land suitability assessment using fuzzy set methodology can be summarized in four steps as follow: 1) determination of land units or mapping units to be evaluated; selection of land characteristics or land qualities to be used; 2) selection of appropriate membership functions for each land characteristic or land quality, we need to define a standard index value for crop requirements; 3) determination of weight values to relate the importance of the land characteristics or land qualities to each other; 4) selection of an overall composite or overall operator to combine the evaluation of each land characteristic or quality into an overall land suitability class or suitability index.

Physical evaluation of a land unit for a specific crop implies the determination of the degree of membership of each land characteristic or quality considered. All membership values of a land characteristics or qualities considered for each land unit are arranged in a matrix, called the characteristic matrix (Tang et al., 1991). Each land characteristics or land quality has a different impact on crop performance. The relative importance with regard to crop yield or degree of importance of a land characteristic or quality on land suitability can be expressed by a weight factor. Weight values for different land properties can be either calculated by the fuzzy relation model the multiple linear regression technique or can be derived by empirical values from expert judgement. The weight values for all considered land characteristics or land qualities form a weight matrix (Tang et al., 2014).

The final overall land suitability classification can be obtained either convex combination or fuzzy relational model (Tang et al., 2014).

2.2 Empirical Review

2.2.1. Global and Local Experiences

Research has been conducted on irrigation assessment using geospatial technology based on multi-criteria methods, specifically based on the principle of AHP. Using GIS, several scholars have evaluated the suitability of surface irrigation land in various parts of the world, including Ethiopia. Some of them from global experience, scholars Mishra et al., 2023, conducted using six factors to locate the suitable site. These six factors comprise slope, distance to the nearest road, LULC, population density, soil texture, and rainfall deficit. The weighted overlay tool of GIS was used to create suitable land for irrigation, and finally map was finally divided into land suitability classes. However, the author did not incorporate vital data like proximity to river, soil type, soil ph., soil depth, and elevation in finding suitable site analysis. Excluding these data will create inaccurate suitability result. Without this information, the analysis provides an incomplete picture of the site's potential and limitations.

Furthermore, regarding winter wheat suitability a study was conducted by Mohammed et al., 2020 using 14 parameters, including topography and soil properties (which contain many specific factors), and mapped suitable site various classes. However, data like soil drainage, soil type, and elevation didn't incorporated in this suitability analysis, which are important in determining the suitability analysis. Excluding data on soil drainage, soil type, and elevation weakens the result of winter suitability analysis. Without these vital data, the analysis provides somewhat inaccurate result of land suitable for winter.

In Ethiopia, research has been conducted on the assessment of surface irrigation potential by GIS and remote sensing method. Weight overlay tool of Arcmap was used to find the suitable sites. In this way, the researchers didn't restrict some LULC, which is permanently unsuitable (water body, forest and settlement) for surface irrigation and winter wheat suitability analysis. Thus, these LULCs should be completely restricted in the analysis.

For instance, a study conducted on the assessment of surface irrigation by Hagos et al., 2022, utilizing geospatial technology. In this study, geospatial and multi-criteria decision-making methods were integrated to indicate the suitable site using on eight criteria, comprising slope, LULC, elevation, proximity to a water, soil (drainage, depth, texture), and available water storage capacity. To indicate the optimum site for surface irrigation, the values were weighted and combined using the weighted overlay tool. The suitability of the spatial data overlay and each parameter was categorized into four classes as (highly, moderately, and marginally) suitable and unsuitable on the basis of the FAO guidelines. However, the researchers didn't used soil (type, and ph.) data in the surface irrigation assessment. These soil properties play a critical role in determining surface irrigation assessment. Omitting these data from the assessment of surface irrigation potential creates a significant blind spot in suitability. These factors greatly impact water infiltration, drainage, and nutrient availability, as they are crucial aspects for plant growth. Without this data, the assessment of irrigation suitability might miss key limitations that could hinder the irrigation system.

Additionally, researchers Haile & Abebe (2022), Birhanu et al., 2019, implemented GIS to study surface irrigation assessment, with factors such as slope, LULC, proximity to water, rainfall deficit, soil texture, soil depth, soil drainage, and proximity to road are considered in assessing the potential irrigable land by surface water. However, soil ph., elevation and temperature didn't included, and as well including rainfall deficit is avoidable. The criteria are categorized into four suitability classes using GIS technique. Using weight overlay tool of ArcGIS, the above criteria overlaid to locate surface irrigation potential and the potential land broadly classified as least, marginally, moderately and highly suitable.

Regarding, winter wheat suitability analysis, Fekadu and Negese, 2020 conducted a GIS-based AHP technique in an investigation of winter wheat suitability at the Yikalo sub-watershed in Ethiopia. Using soil properties, topographic features, and climate data, the researchers determined whether an area was suitable for growing winter wheat. The study site suitability classified into (highly, moderately, marginally) suitable, currently, and permanently. But, the researcher didn't included vital factors like LULC and elevation in suitability analysis, which has their own influence in determining land suitability. Ignoring LULC in suitability assessment is unnecessary, since the identified suitable site may fall on LULC which is not suitable (water body, forest and settlement) for crop production via irrigation. Therefore, it is a must to incorporate these LULC data in the suitability analysis to indicate the accurate suitable site for surface irrigation assessment.

CHAPTER III METHODOLOGY

This chapter provides a comprehensive clear description about the study area, materials used, methods, workflow, data collection and analysis employed during conducting a this study. This section serves as a roadmap for readers to understand how the study has been conducted that ensures the transparency and reliability of the thesis.

3.1 Description of the Study Area

3.1.1 Location of Dendi District

Dendi is one of a district which found in west Shewa zone, Oromia regional state. It is located latitudinal from 8°45' N to 9°11' N and longitudinal from 37°55' W to 38°20' W. The district is very large in terms of areal coverage and it is bordered by the south west Shewa zone to the South, Naannawa Ambo in the west, Jeldu district to the north, and Ejerie district to the east. The district lies to the west of Addis Ababa and it is approximately 80km west of Addis Ababa along the Addis Ababa-Nekemte route. Ginchi town is the capital city of the district and it serves as administrative center for the district.

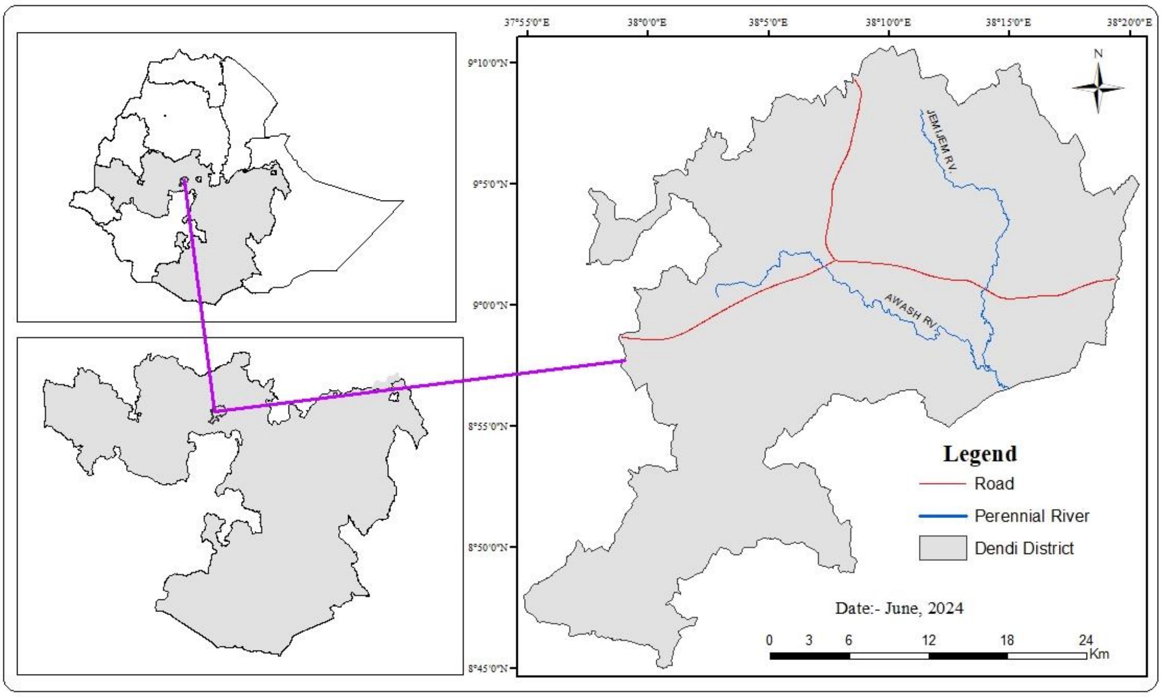

Figure 1: Location map of Dendi District

3.1.2 Topography of Dendi District

Dendi district, found within the Ethiopian Central Highlands, boasts a diverse topography. Mountains like Mount Dendi mark its highest altitude lies within this district, while the district itself likely encompasses a mix of rolling hills, and plateaus. The rolling hills and plateaus dominate the eastern and central parts of the district, offering fertile grounds for agriculture. The district has also Chilimo forest that covers a significant portion of the eastern side. The altitude of the study area ranges from a lowest 2069 m to the maximum 3307 m above sea level.

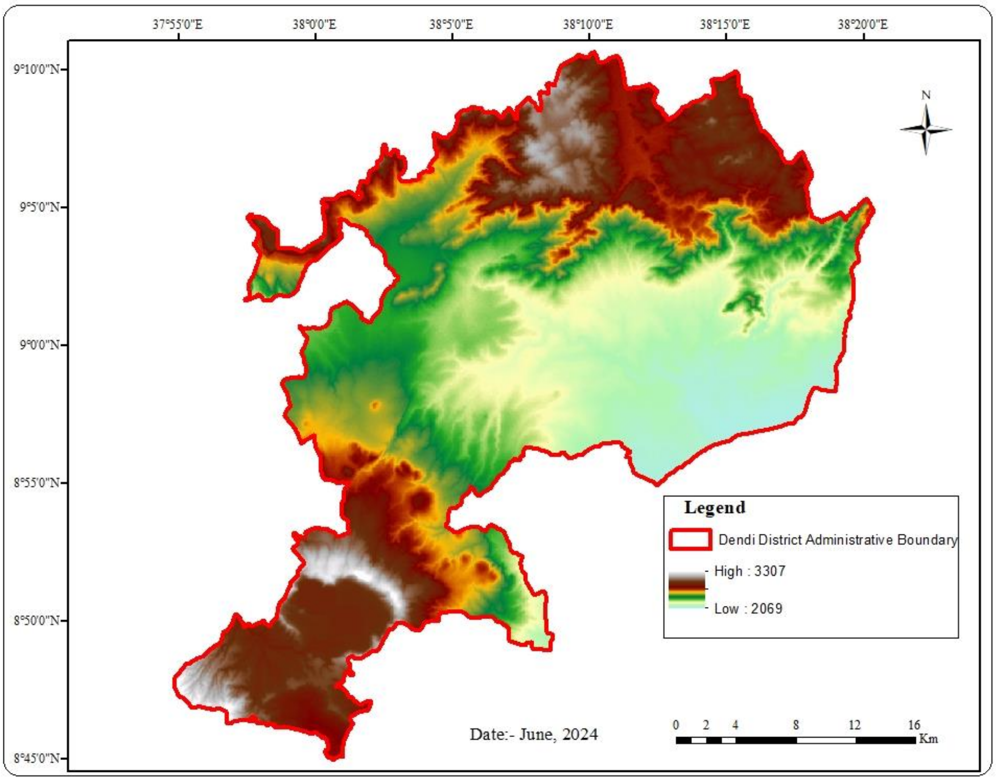

Figure 2: Topography map of Dendi District

3.1.3 Temperature of Dendi District

Dendi District characterized by a distinct rainy season from June to September and a dry season for the rest of the year. As seen from below figure (figure 3), the average annual temperature floats approximately 20°C with average annual maximum reaching 17°C and minimum dropping to 11 °C.

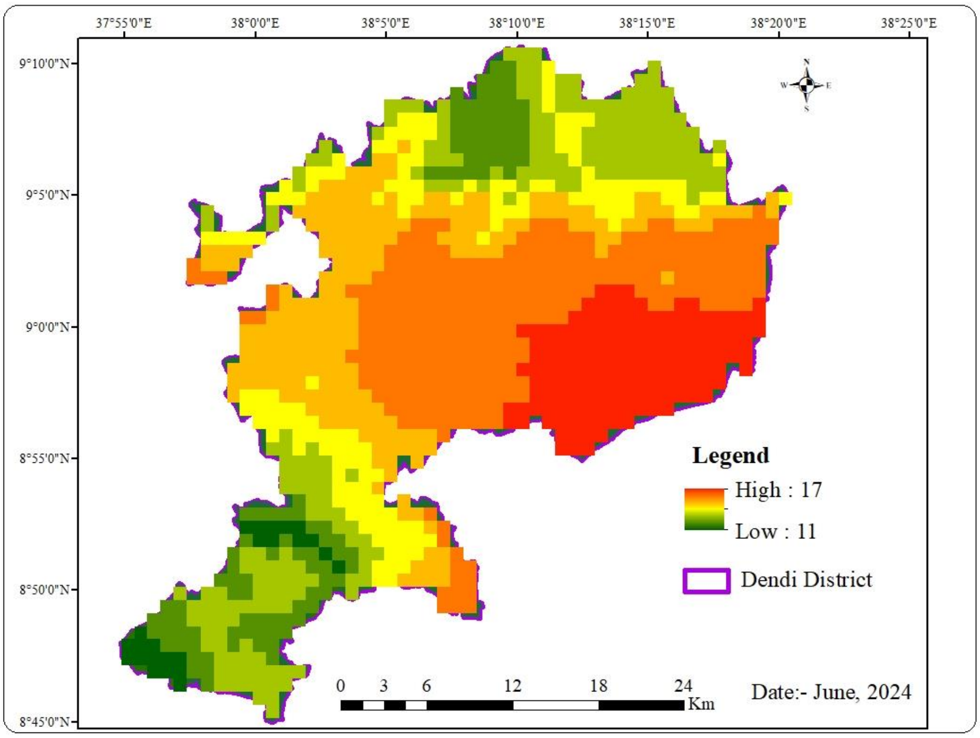

Figure 3: Temperature map of Dendi district

3.1.4 Population of Dendi District

As July 2023 report, Dendi district has a total population 254,866 of which male accounts 128,337 and female 126,529 (https://www.statsethiopia.gov.et/wp-content/uploads/2023/08/Population-of-Zones-and-Weredas-Projected-as-of-July-2023.pdf).

According to 2022 data, population density of the district is 254.3/km² and while the population increases annually by 2.7% from 2007 to 2022 (https://www.citypopulation.de/en/ethiopia/admin/oromia/ET040510__dendi/). The district is inhabited mostly with the Oromo ethnic group, and the language spoken and dominated the district is Afaan Oromo. It is a home of many inhabitants living both rural and urban. The majority of the population resides in rural areas, engaged in agricultural activities and small number of population living in town.

3.1.5 Soil Type of Dendi District

The district is known for its diverse soil types. It is covered by different soil type including Luvisols, Vertisols, Leptosols, Cambisols, and Nitisols. In the study area, Vertisols is a dominant soil type, which is black soil with high clay content. This type of soil cracks in arid seasons and in wet seasons it will become. It contains large amount of clay soil texture, which is well suited for some crops. Luvisols is another soil type, widely spread at the study area and it comprises a high clay content horizon that shows good drainage characteristics and medium fertility. Leptosols also found at the study area and its depth low and commonly situated on steep slopes lead to the removal of the top soil. Due to their limited depth and more susceptible to erosion, it may not be suitable for sustained agriculture without amendments. Furthermore, the other soil type found in the study area is Cambisols and Nitisos. Cambisols covers a small area of the study area; it is moderately developed soils with a brownish topsoil layer. Like Cambisols, Nitisols also covers a small portion (figure 4).

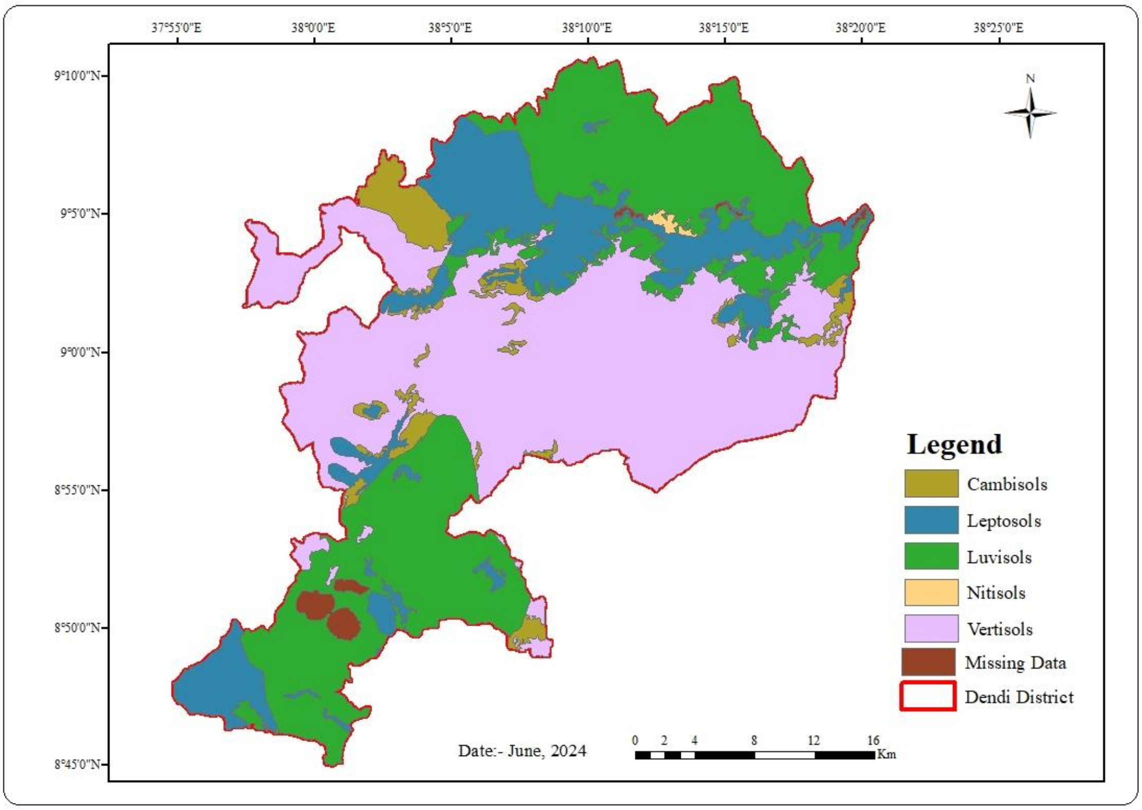

Figure 4: Soil Type map of Dendi District

3.2. Methods

3.2.1 Data Collection and Sources

This thesis objectives obtained by utilizing both primary and secondary data. Different types of geospatial data's has been collected for this thesis, involving that gathering of spatial data and then, it is analyzed and interpreted.

Table 3: Types of Data Collected

No	Data Type	Spatial Resolution	Sources of Data	Data model type
1	Supervised LULC	15m	Extracted from satellite image (https://earthexplorer.usgs.gov/)	Raster
2	DEM to extract Slope & Elevation	12.5m	SSGI	Raster
3	Soil (type, ph., texture, drainage, depth)	-	Oromia Construction Corporation	Vector
4	Perennial River	-	SSGI	Vector
5	Temperature	-	https://www.worldclim.org/data/worldclim21.html	

The original spatial resolution of the raster data converted to the same pixel size, as into 10m. And also, the vector converted to the raster data with 10m spatial resolution.

3.2.2 Workflow of Methodology

While conducting this study a systematic methodology is developed to obtain the specific objectives of the study. In this case, the first step is gathering relevant data such as satellite imagery, topographic, soil, Perennial River and temperature data of the study area. Subsequently, to identify suitable areas for surface irrigation and winter wheat, the collected data is processed and analyzed by GIS software. The methodology for conducting this study involves several key steps. These key steps are explained as follow:

The first step is gathering relevant spatial data, including satellite imagery, slope, elevation, soil properties, temperature, and perennial river of the study area. Then, these data pre-processed by GIS and remote sensing tools. Pre-processing is crucial as it ensures the compatibility, quality and usability of the data. Some of pre-processing techniques used in this research are extracting, image enhancement, clipping, projection, conversion tool. After pre-processing of the data is done, the suitability of each factor analyzed and classified into different suitability classes by ‘reclassify tool’ of ArcMap. For this study, factors such as soil (type, texture, depth, drainage and ph.), slope, proximity to river, elevation and temperature analyzed and classified according to scientific literature. Finally, GIS modeling techniques utilized to integrate the data layers and generate maps showing the suitability of surface irrigation and winter wheat using the weight of each factor calculated by AHP principle by IDRIS software on weight overlay tool.

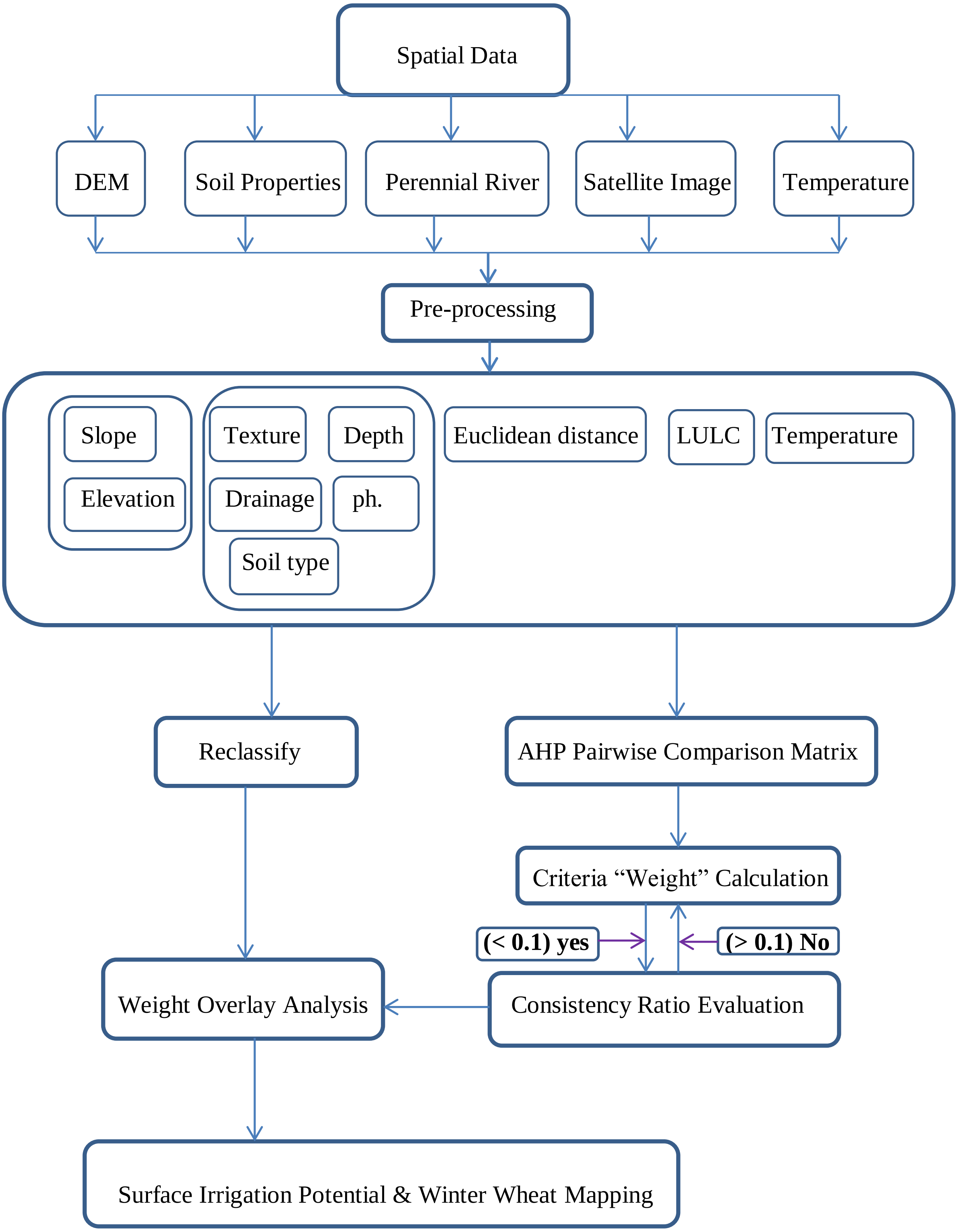

Figure 5: Workflow of the study

Note: in this research temperature data isn't used in surface irrigation potential assessment, rather it is used only in winter wheat suitability assessment.

3.2.3 Data Analysis Method

This study utilized GIS and remote sensing technologies to assess the surface irrigation potential for winter wheat suitability. To do this research clear data analysis method is used to meet the stated specific objectives of the research. Thus, various tools are used for analyzing geospatial data. This data analysis method includes the following key process:

Spatial Data collection: To assess the suitability of land for both surface irrigation and winter wheat, it is necessary to collect spatial data relevant for this study. This includes slope, DEM, soil (type, texture, depth, drainage and ph.), Perennial River, temperature, and current LULC.

Extraction by mask and Clipping: is a tool used for preprocessing operation that involves creating a new dataset by extracting a portion of an input layer based on the boundary of another layer. This process allows users to limit the extent of a dataset to a specific geographic area defined by a vector feature, such as a polygon boundary. Clipping is commonly used to extract and focus on a specific region of interest within a larger dataset, create custom map boundaries, or prepare data for analysis within a defined area.

Conversion tool: to convert data from vector to raster or raster to vector to ensure all data formats are compatible in the entire analysis (weight overlay analysis).

Resampling: a tool used to adjust the spatial resolution of datasets to ensure consistent analysis across all layers (e.g., matching pixel sizes) for weight overlay analysis.

Projection transformation tool: Verifying and potentially transforming the spatial data to a common coordinate system for accurate spatial overlay and area measurement.

Pan-sharpening: a tool used to enhance the spatial resolution of satellite image; used for LULC classification.

Slope: it is an Arcmap tool used to generate a slope of a land from DEM.

Reclassification: Reclassification tool of ArcMap is a function that allows to modify the values of raster datasets by reassigning them to different categories or classes based on specified criteria. This tool enables to simplify complex raster data by grouping values together, reassigning values based on ranges, or creating new categories that better suit the analysis or visualization needs. It can help in data simplification, thematic mapping, and preparing data for further analysis or modeling within the ArcMap environment.

Weight Overlay: it is a spatial analysis technique that combines multiple raster datasets by assigning different weights to each layer based on their relative importance or influence in a decision-making process. This process involves overlaying multiple raster layers, each representing various criteria, and assigning a weight to each layer to indicate suitable site. The weighted overlay tool calculates a new output raster where the values are a combination of the input raster's, weighted according to the user-defined criteria.

3.3 Material Used

In this study, various software materials are utilized, which are listed in the table below.

Table 4: Material used

No	Software's	Purpose	Tool used
1	ArcGIS 10.8	Data management, spatial analysis, map creation, and suitability modeling	Spatial Analyst tool, Geo-processing tools (extract, projection, clip, conversion)
2	IDRIS Selva 17.02	For 'weight' calculation of factors	Weight Analysis
3	ERDAS Imagine 2015	LULC classification	Image enhancement (pan sharpening), Subset
4	Google Earth	For LULC Validation	-

3.4 Weighing/Assigning Weight of Parameter

The weight of parameters is calculated according to the importance or preference of each criterion; it is prepared based on a review of related literature and the judgment of an expert to fill out a pairwise comparison matrix from which a set of weights, referred to as Eigenvectors, is generated along with consistency ratios (Ghorbanzadeh et al., 2018; Gizachew and Yihenew, 2015).

To calculate the weight of each parameter, the AHP method is used to create a hierarchical framework in table form. The weights must be carefully determined in order to avoid arbitrary assigning of weight to the factor, since they represent the proportional relevance of each condition. Pairwise comparisons between the criteria can be made using AHP, which minimizes the complexity (Saaty 1977). The relative weights of each criterion are compared pairwise, and the weights are calculated by comparing the criteria. The eigenvectors and relative weights of Saaty's technique are computed once the pairwise matrix has been created. By using AHP pairwise comparisons matrix the weight of each factor can be calculated by IDIRIS software (Mishra et al., 2023).

For the comparison of factors by applying a scale {9, 7, 5, 3, 1, 1/3, 1/5, 1/7, 1/9} (table 5), the AHP pairwise comparisons method developed by Saaty (1977) is the most powerful method in the decision-making process and comparing factors. For instance, an expert can decide that a specific parameter is essentially more important than the other parameter, and then, as a result of the comparisons, the expert assumes 5 (table 5) for comparing the specific parameter with all the other parameters (Kułakowski, 2021).

Table 5: Rating scale of AHP method

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong Importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another, it dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2,4,6,8 can be used to express intermediate values. If predominance of one alternative over another fits in between the scale degrees defined above		

Source: Saaty, 1987, Pinar, et al., 2017, Kułakowski, 2021

The AHP method helps to assess criterion against criterion by calculating the consistency ratio between them as well as the overall consistency ratio of the parameters (Saaty, 1987; Jiang, 2022; Pinar et al., 2017). According to Pinar et al. (2017, to ensure the consistency of the calculated weights, pairwise comparisons need to be verified by the consistency ratio (CR). The CR is calculated by dividing the consistency index by the random index (CR = CI/RI). Where CI is the consistency index and RI is the random consistency index. Consistency index (CI) is calculated as: $CI = (\lambda max - n) / (n - 1)$; where λmax is the maximum eigenvalue of each comparison matrix and n is the number of criteria. Random index is a constant value in respect to the number of factors. Table below shows the number of factors (n) and standards used to obtain the random index (RI)

Table 6: Random index

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

Source: Pinar, et al., 2017

At the end, it is essential to decide whether the established AHP hierarchical structure for weight calculation is acceptable or not. In this case, the consistency ratio (CR) calculated by the software or manual supports identifying whether the structure is consistent or inconsistent. This calculated CR shows that the calculated weight of each factor is either acceptable or rejected. According to the standard, if the CR is not accepted, the process is repeated again until an acceptable CR is obtained. CR below 10% (0.1) is considered to be consistent, while consistency ratios above 10% (0.1) are considered inconsistent, and the AHP comparison matrix is revised again. When $CR \leq 0.1$ (10%), the consistency is acceptable, whereas if $CR \geq 0.1$ (10%), it is not accepted (Saaty, 1987; Jiang et al., 2022).

3.5. Land Suitability Assessment for Surface Irrigation and Winter Wheat

Assessment of surface irrigation potential and winter wheat is evaluated using multiple parameters, including proximity to the Perennial River, LULC, slope, elevation, soil type, soil texture, soil ph., soil depth, and drainage. The suitability assessment of each parameter is elaborated clearly based on a review of related literature. Each parameter used in this study is standardized or classified using the reclassify tool so that the results represent a common numeric range. Reclassification is the system of allocating the values of a favorite to a raster. In this study, the suitability of the parameter is determined on the basis of the FAO, 1976, land suitability classification framework.

CHAPTER IV RESULTS AND DISCUSSIONS

In this chapter, the results of the study interpreted and discussed which meets the specific objectives listed in the chapter one under specific objective section.

4.1. Parameters Suitability Mapping for Surface Irrigation Winter Wheat

The analysis results of each factor suitable for surface irrigation and winter wheat presented in the form of map and table.

4.1.1 Slope Suitability

Slope is an essential factor in assessment of surface irrigation because of its influence on runoff, drainage, erosion, and selection of irrigation types. The slope gradient of the land greatly influences the selection of irrigation methods. According to the FAO standard guidelines for the evaluation of slope gradient, slopes less than 2% are very suitable crop production via surface irrigation, but slopes greater than 8% are not generally recommended (FAO, 1999).

Consequently, slope of study area is classified as indicated in the figure 6 and table 5, slope suitability classes for surface irrigation and winter wheat are classified into four suitable classes as 0% -2% (highly suitable), 2% - 5% (moderately suitable), 5% - 8% (marginally suitable), and greater than 8% as unsuitable. This slope suitability classes determined based on the factors such as impacts of slope on runoff, erosion impacts, slope challenges on canal construction, slope impacts on water transporting and cost of leveling the slope of the land. Thus, figure 6 shows the classified slope suitable for surface irrigation and winter wheat production. After suitability of the slope classified, then the area of each class calculated in hectare, as shown in table 7 below. The statistical analysis shows the area of each suitable class of the slope for surface irrigation and winter wheat, and the proportion of each suitable class.

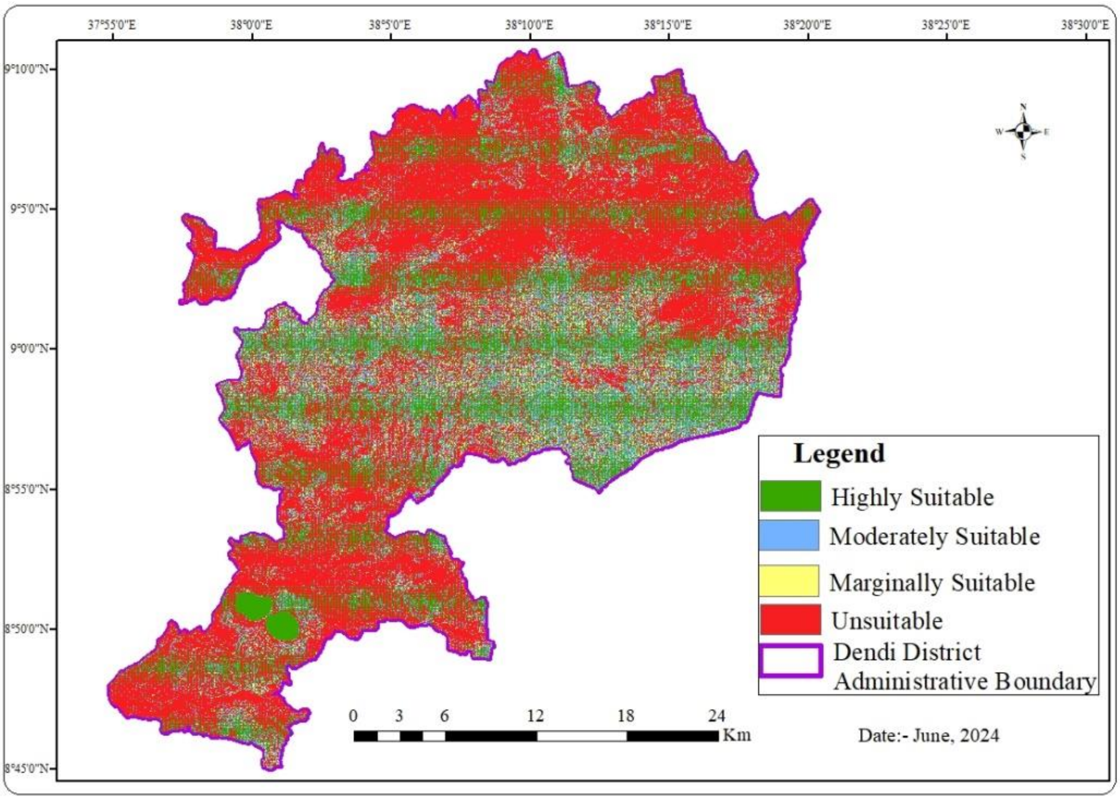

Figure 6: Suitable slope for surface irrigation and winter wheat

According to table 7 below, the analysis of the slope of land suitability in the study area reveals a strong relationship between slope and the viability of surface irrigation and winter wheat farming. As seen from the figure 6 and table 7, the optimum site suitable for surface irrigation and what farming is on highly suitable land that encompasses a substantial area of (23.12%) 22,794.93 hectares. This highly suitable slope of a land is covered by gentle slope, having a slope between 0% to 2%. This gentle slope causes marginal difficulty for water delivery, so it makes best for irrigation and crop growth.

Moreover, table 7 below shows that, moderately suitable land ranging from 2% to 5% which covers about 17.46% (17,178.58) hectares from the entire area of the study area. Compared to the highly suitable slope of a land, moderately suitable slope of a land is somewhat steeper topography, which is somewhat obstacle to transport water to crop field.

Furthermore, from the whole coverage of the study area, marginally suitable land encompasses around 4,938.96 (5.04%) hectares of land and presents the greatest challenge for irrigation and crop farming. These lands have slopes ranging from 5% to 8%, which are considerably steeper than the best conditions for surface irrigation and crop production.

Lastly, of the total coverage of the study area, the largest portion of the land, greater than 50% of the total area, that of 54.38% (53,483.62) hectares of the area found within the unsuitable slope class. This unsuitable slope of the land is greater than 8%, which is very steep topography, and it is unsuitable for water delivery to crop field. It is difficult to distribute water via canal and potential occurrence of erosion on steep slopes is high and it is obstacles for surface irrigation.

Table 7: Slope suitable for surface irrigation and winter wheat

No	Slope (%)	Suitability Classes	Area (ha)	Area (%)
1	0-2	Highly Suitable	22,794.93	23.12
2	2-5	Moderately Suitable	17,178.58	17.46
3	5-8	Marginally Suitable	4,938.96	5.04
4	>8	Unsuitable	53,483.62	54.38
		Total	98,660.6	100

4.1.2 Proximity to River Suitability

The other vital parameter in the assessment of surface irrigation and winter wheat is the distance between land and a river. In surface irrigation potential and winter wheat assessment, there is no common standard available regarding the suitability of a land to a river. For instance, a research done on the assessment of surface irrigation by Paul et al., 2020 classified the study area's distance of a land from a river as (0–0.721 km highly suitable, 0.721–1.442 km moderately suitable, and 1.442–2.163.5 km marginally suitable). Wubalem, 2023 classified the suitable distance of a land from a river classified 0-1.23km (highly suitable), 1.23–2.5 km (moderately suitable), 2.5–3.7 km (marginally suitable), and > 3.7km (unsuitable).

Consequently, for this study, proximity to a river is classified as 0km-1km (highly suitable), 1km-2km (moderately suitable), 2km-3km (marginally suitable), and greater than 3km (unsuitable). It is classified based on cost of canal construction, power and capacity of pumping engine and cost of high power engines. Since these factors influences the suitability of proximity to river, places with a shorter distance from a river are more suitable for surface irrigation as it is easy to transport water from the river to cropland, and the suitability of land decreases as distance increases from the river. Thus, the figure 7 below shows the classified proximity of land to a river suitable for surface irrigation and winter wheat.

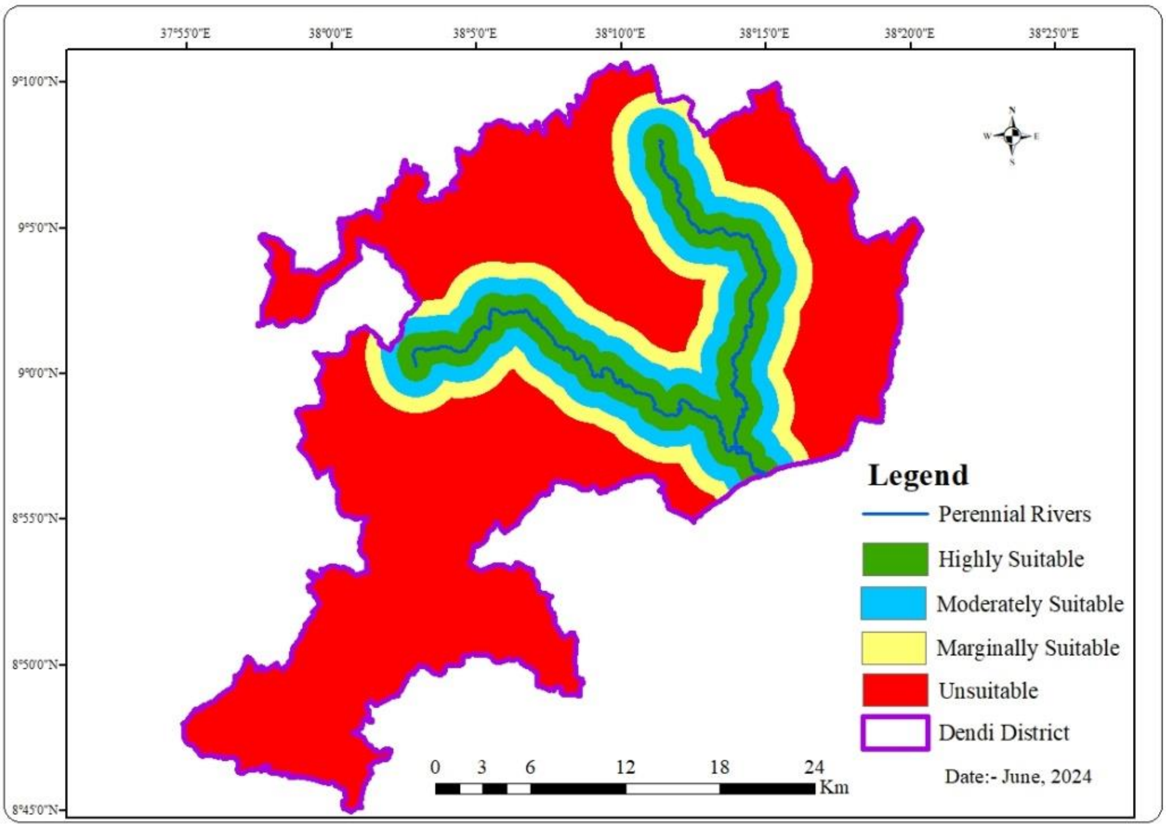

Figure 7: Suitable proximity to river for surface irrigation and winter wheat

The proximity to a river, as shown in the table 8 below, indicates the area of land suitable for surface irrigation and winter wheat. Proximity of a land to a river for surface irrigation and winter wheat assessment unveils highly suitable land is that land found very close to the river. The reclassified analysis of proximity to river indicates that a substantial part of the land covering about 11.67% (11,514.72) hectares falls within the highly suitable class, which is found very nearby to the rivers. It includes a land within a distance of 1 km from the river. This is the major site that makes it highly convenient for surface irrigation and producing wheat via surface irrigation. Furthermore, table 8 shows that moderately suitable land for surface irrigation and winter wheat accounts another substantial coverage of about 10.55% (10,410.19) hectares that is situated in range of 1km to 2km from the river. These areas are also promising for crop by surface irrigation; but, it might need the application of somewhat elongated canal construction to deliver water the farm land.

In addition to the above two suitability classes, marginally suitable land denotes 9,998.04 hectares (10.13%), and it is situated far away from the perennial river ranging from 2km to 3km. Delivering water through irrigation to these land is encountered hardship as it is costly to construct long distance water canal, to take it to the crop land, and demand more wide-ranging irrigation infrastructure construction to effectively carry water to land. At the end, the largest areal coverage of land about 67.65% (66,737.65) hectares is categorized as not suitable since there a great challenges in carrying water far away from the river. These areas are located a long distance from the perennial river, which is greater than 3km. As the cost of construction of canal is expensive and carrying the water over a long distances, irrigating the crop land via surface irrigation is not advised at these places.

Table 8: Proximity to river suitable for surface irrigation and winter wheat

No	Euclidean Distance (km)	Suitability Classes	Area (ha)	Area (%)
1	0-1	Highly Suitable	11,514.72	11.67
2	1-2	Moderately Suitable	10,410.19	10.55
3	2-3	Marginally Suitable	99,98.04	10.13
4	>3	Unsuitable	66,737.65	67.65
	Total		98,660.6	100

4.1.3. Land Use Land Cover Suitability

For surface irrigation assessment and winter wheat, LULC is a vital parameter employed in suitable site analysis. This parameter is useful for indicating the types of LULC in the area relevant to crop production. According to the FAO method, some LULCs suitable for agricultures is: cropland is grouped as highly suitable, grassland assessed as moderately suitable, woodland/shrub/bush is classified as marginally suitable because it requires initial investment for land preparation, and forest/barren land/water body/settlements are classified as not suitable. Furthermore, in the assessment of suitable land for surface irrigation and wheat farming, a land covered by forest, water bodies, occupied by people or settlement (built-up areas), and exposed rock surfaces having scattered shrubs or barren lands are unsuitable for surface irrigation. These LULCs are unsuitable for irrigation because they are completely restricted for cultivation (Worqlul et al., 2017; Yohannes & Soromessa 2018; Hagos et al., 2022, Wubalem, 2023).

Consequently, the study area's LULC is classified on the basis of FAO and other scientific literature classification standards. The LULC suitability class of the study area is classified as highly suitable, moderately suitable, marginally suitable, and unsuitable for surface irrigation and winter wheat suitability assessment. Hence, figure 8 below shows the classified LULC suitable for surface irrigation and winter wheat farming.

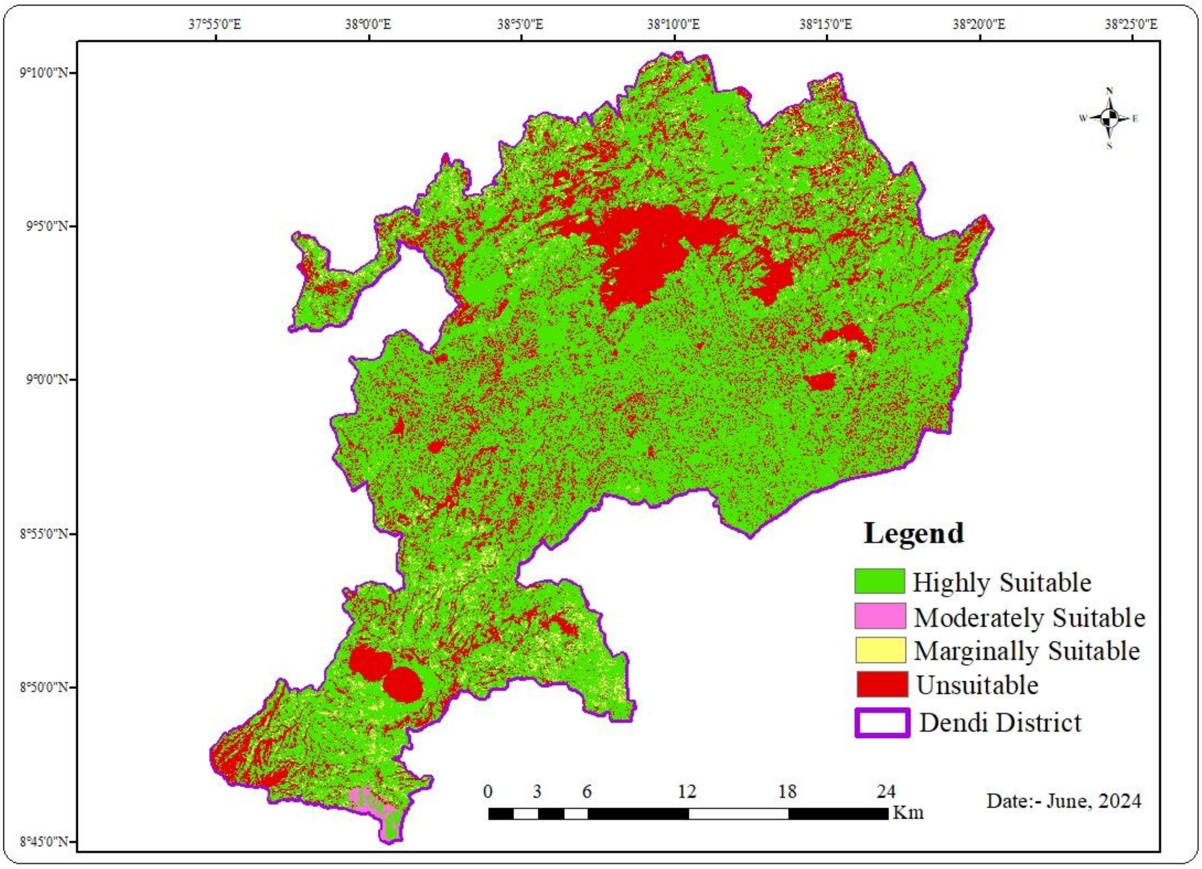

Figure 8: Suitable LULC for surface irrigation and winter wheat

Table 9 below condenses the suitable categories of LULC of the study area. The suitable classes grouped into four classes as highly suitable, moderately suitable, marginally suitable, and unsuitable LULC for surface irrigation and wheat harvesting. From the total area coverage of the study area, the highest proportion of the area is enclosed by highly suitable LULC. This highly suitable categorizes of LULC includes cropland covering about 69,210.7 hectares (70.15065%) of the total area, while moderately suitable LULC that of grassland enclosed the smallest areal coverage around 0.296% (292.23) hectares compared to the other suitability classes.

Likewise, marginally suitable LULC covered by open shrub land, cover relatively a small area about 3,697.1 hectare (3.74731%). And lastly, the study area's LULC, covered by forest, settlement, built-up, water body, and bare land, is classified as unsuitable for surface irrigation assessment, and it is restricted from the participation in suitability analysis. From the total area, this unsuitable class covers around 25,460.0908 ha or 25.80582%.

Table 9: LULC suitable for surface irrigation and winter wheat

No	LULC	Suitability Classes	Area (ha)	Area (%)
1	Cropland	Highly Suitable	69,210.7	70.1506
2	Grassland	Moderately Suitable	292.23	0.296199
3	Shrub land	Marginally Suitable	3,697.1	3.74731
4	Forest, bare land, water body, settlement	Unsuitable	25,460.0908	25.80582
	Total		98,660.60	100.00

4.1.4. Soil Type Suitability

Soil type is a key factor in surface irrigation and winter wheat suitability assessment assessment. The study area is covered by various soil types, comprising Luvisols, Vertisols, Leptosols, Cambisols, and Nitisols. The suitability classes of these soil types are categorized as Luvisols and Nitisols soil types are classified as highly suitable, whereas Vertisols and Cambisols soil types are considered moderately suitable for crop harvesting by irrigation (USDIBR, 2003; Worqlul et al., 2015; Nigussie et al., 2019; Balew et al., 2021). Furthermore, the study area is covered by the Leptosol soil type, and it is classified as marginally suitable for surface irrigation and wheat cultivation (Girma, 2019).

Accordingly, figure 9 below shows the classified soil type suitable for surface irrigation and winter wheat cultivation. Table 10 below, shows the statistical analysis of suitable soil type for surface irrigation and winter wheat calculated in hectares, and the proportion each suitable class.

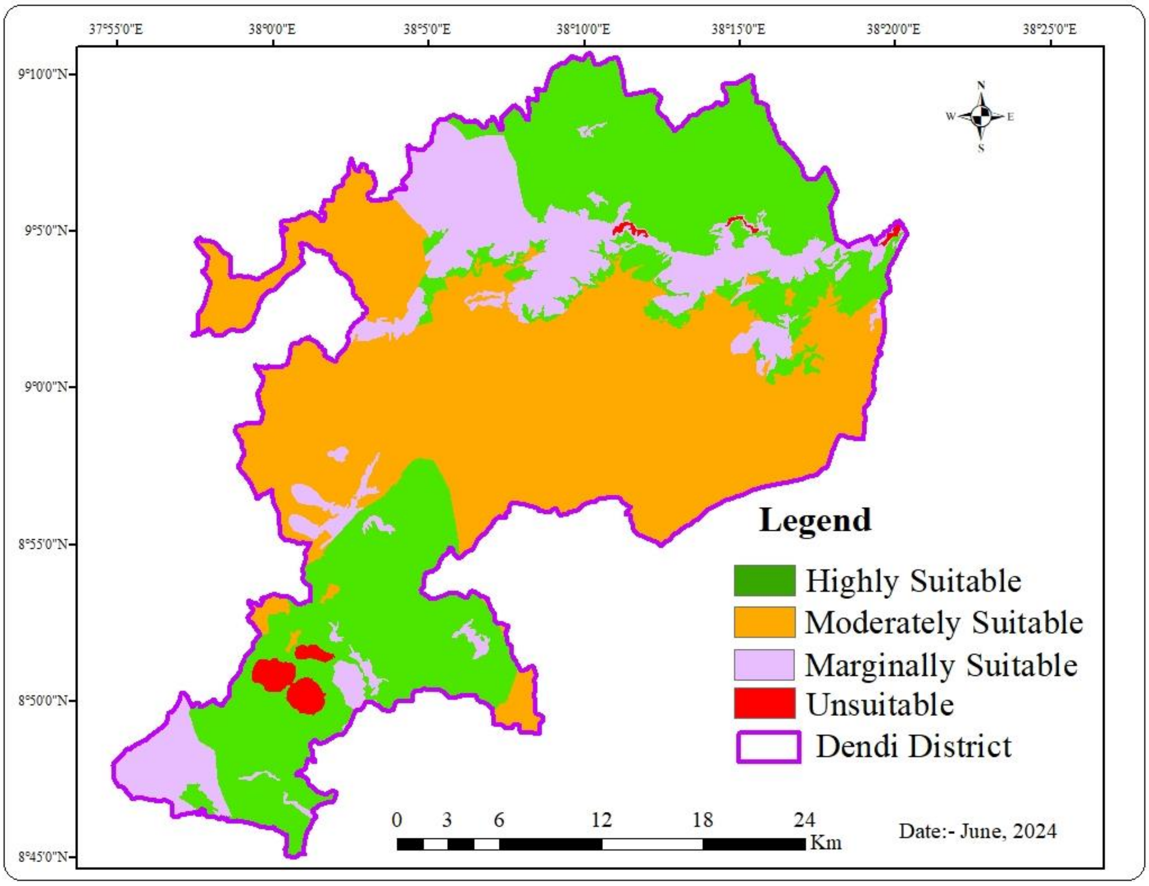

Figure 9: Suitable soil type for surface irrigation and winter wheat

Table 10 below shows the area and proportion of the suitability of soil type for surface irrigation and winter wheat. As it is indicated in table 10 below, the highly suitable soil types is covered by Luvisols and Nitisols comprise almost 36% (35,598.9) hectares. It is privileged principally, since they have good drainage features. Likewise, the study areas' soil type, which covers about 46% (45,985.8) hectares, is classified as moderately suitable soils for surface irrigation and winter wheat, and this moderately suitable soil types comprise Vertisols and Cambisols.

Yet again, a small area about 16% (15,989.6 hectares) is categorized as marginally suitable, and it is covered by Leptosols soil type. This soil type has restrictions that hamper the suitability for surface irrigation and wheat cultivation. Shallow depth of this soil limits water holding capacity, making it difficult to hoard adequate water for crop growth. As a final point, unsuitable soil type covers a smaller portion of the land 1.10% (1,085.55) hectares, which is restricted in assessment of suitability due to no data available about soil type. Even though, no data regarding the soil type, the missing areas are enclosed by water bodies and escarpment landforms. So, logically, these land cover is restricted in suitability analysis of surface irrigation and winter wheat, since it is impossible to conduct any activities on these land cover.

Table 10: Soil type suitable for surface irrigation and winter wheat

No	Soil Type	Suitability Classes	Area (ha)	Area (%)
1	Luvisols and Nitisols	Highly Suitable	35,598.9	36.0824
2	Vertisols and Cambisols	Moderately Suitable	45,985.8	46.6104
3	Leptosols	Marginally Suitable	15,989.6	16.2069
4	Missing data	Unsuitable	1,085.55	1.1003
	Total		98,660.60	100.00

4.1.5 Soil Texture Suitability

Soil texture determines the growth of crop roots by maintaining moisture (water), air circulation, and other factors for the normal growth of crops. In the study area, five soil textures are identified like clay loam, loam, clay, silt loam, and sandy clay loam. According to Nasir et al., 2019; Balew et al., 2021; Negasa, 2021; Hagos et al., 2022, the study area's suitability classes of soil textures are classified as highly suitable soil texture: loam and clay, moderately suitable soil texture: silt loam and clay loam, and marginally suitable soil texture: sandy clay loam. Hence, figure 10 below shows the classified soil texture suitable for surface irrigation and winter wheat.

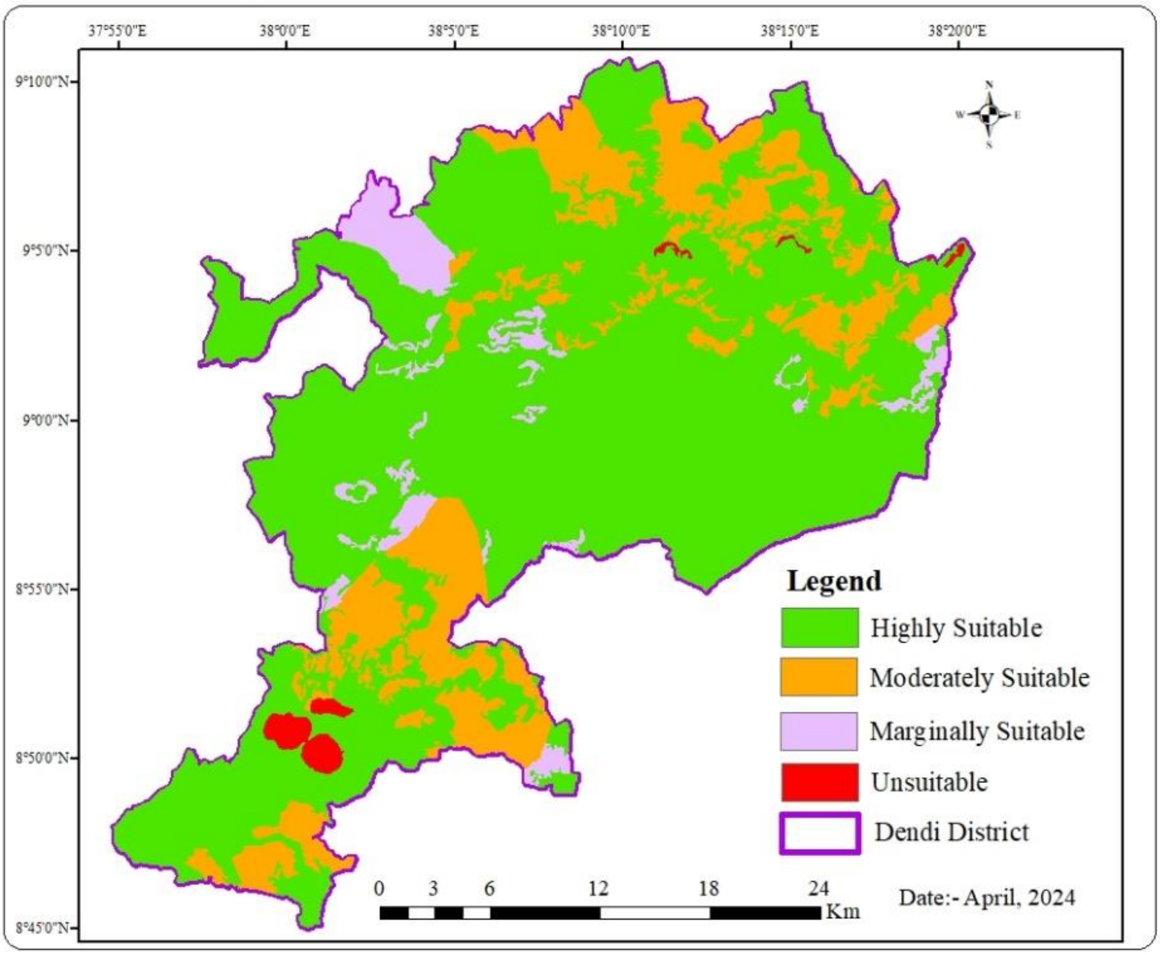

Figure 10: Suitable soil texture for surface irrigation and winter wheat

Table 11 below condenses the miscellaneous soil textures appropriate for the assessment of surface irrigation and winter wheat. For surface irrigation assessment and wheat suitability analysis, the study area soil texture is classified into three categories (highly suitable, moderately suitable and marginally suitable). Accordingly, loam and clay soil texture found in the study area classified as highly suitable and covers 74.67% (73,664.8) hectares. It is the best soil texture, because it has optimal drainage, water retention, and nutrient availability for a healthy crop growth.

Moreover, moderately suitable soil texture includes silt loam and clay loam covers about 19.55% (19,283.8) hectares. This moderately suitable soil texture, yet again suitable, but their properties hinder crop growth. Compared to moderately suitable soil texture, at the study area the smallest area is covered by sandy clay loam covering about 4.69% (4635.52) hectares and it is classified as marginally suitable soil texture.

Besides the above suitability classes, unsuitable soil texture cover a smaller proportion of land 1.10% (1,085.55) hectares, which is restricted in suitability analysis due to missing data of soil texture. This missing area covered by water bodies and escarpment landforms. Therefore, these LULC is restricted in surface irrigation assessment and winter wheat suitability analysis, as from the nature of these LULC is impossible to conduct any activities on this land cover types.

Table 11: Soil texture suitable for surface irrigation and winter wheat

No	Soil Texture	Suitability Classes	Area (ha)	Area (%)
1	loam and clay	Highly Suitable	73,664.8	74.6656
2	silt loam & clay loam	Moderately Suitable	19,283.8	19.5458
3	sandy clay loam	Marginally Suitable	4,625.52	4.6883
4	Missing Data	Unsuitable	1,085.56	1.1003
	Total		98,660.60	100.00

4.1.6. Soil Depth Suitability

Soil depth is another critical parameter for the assessment of surface irrigation potential and winter wheat suitability analysis. Soil depth provides a clue about the growth of roots and indicates air and moisture in the soil. According to Teshome and Halefom, 2020; Hagos et al., 2022; FAO, 1997, Fekadu, & Negese, 2020, soil depth suitable for crop production via surface irrigation is classified as highly suitable when the soil depth is greater than 100 cm (very deep soil), moderately suitable when the soil depth is in the range of 80cm – 100cm (moderately deep soil), marginally suitable when the soil depth between 50cm – 80cm (shallow soil), and unsuitable when the soil depth is less than 50cm (very shallow).

Accordingly, the study area's soil depth is classified as highly suitable greater than 100cm, moderately suitable in range of 80cm – 100cm, marginally suitable between 50cm – 80cm and unsuitable less than 50cm. Thus, figure 11 below shows the classified soil depth suitable for surface irrigation and winter wheat cultivation.

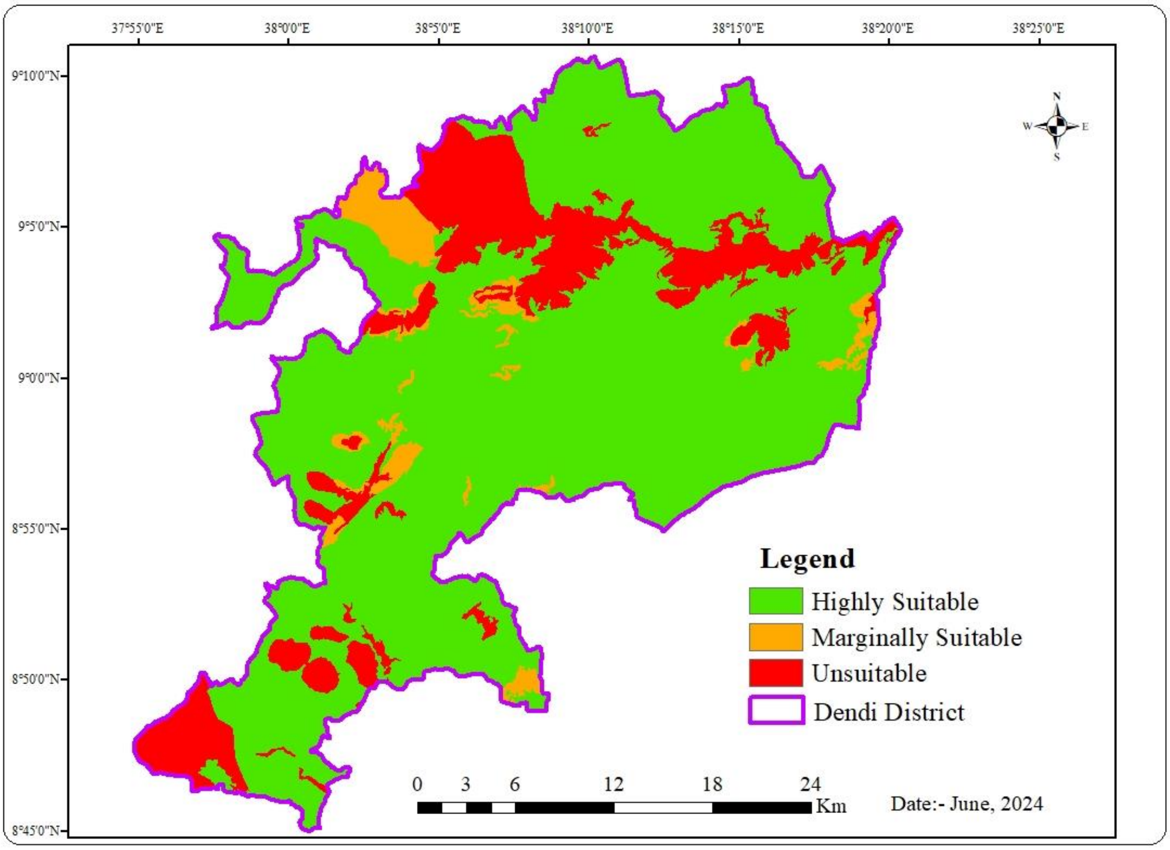

Figure 11: Suitable soil depth for surface irrigation and winter wheat

Table 12 below shows the soil depth suitability categorizes for surface irrigation and winter wheat suitability assessment. Thus, the vast area of the study area is covered by a soil depth greater 1m, and its area measures around 78% (76,958.79) hectares of a land. This soil depth greater than 1m falls within the highly suitable category, and it is best soil depth which allows for an excellent water infiltration and storing within the soil and it is very profitable for surface irrigation and wheat production. In addition highly suitable soil depth, table 12 below shows a smaller part of the soil depth covering about 4.69% (4,625.5) hectares is categorized as marginally suitable for surface irrigation and wheat harvesting. This soil depth category incorporates places containing a shallower soil depth between 50cm to 80 cm.

Additionally, in the study areas, totaling the missing data about 1.10% on the unsuitable class 16.207%, almost 17.31% (16,075.36) hectares of land is estimated to be unsuitable for surface irrigation and wheat yield due to the shallowest soil depth and missing data is on unsuitable LULC. This unsuitable class of soil depth is a soil having less than 50 cm.

This low depth of a soil hampers water storing capacity and it is challenging to preserve sufficient amount of moisture for crops. The missing data, covers a small area of the land about 1.10% (1,085.56) hectares is unsuitable; due to the missing data of the area is covered by water bodies and escarpment landforms. Thus, these LULC is restricted in surface irrigation and winter wheat suitability analysis, as it is impossible to conduct any activities on these areas.

Table 12: Soil depth suitable for surface irrigation and winter wheat

No	Soil depth in cm	Suitability Classes	Area (ha)	Area (%)
1	Greater than 100 cm	Highly Suitable	76,958.79	78.00427
2	50 cm – 80 cm	Marginally Suitable	4,625.50	4.68834
3	Less than 50 cm	Unsuitable	15,989.80	16.207
4	Missing Data	Unsuitable	1,085.56	1.10031
	Total		98,660.60	100.00

4.1.7. Soil pH Suitability

From the chemical property of a soil, ph. of a soil is one vital property affecting the healthy growth of crops and in the analysis of surface irrigation. The degree of soil acidity is one of the factors that need to be examined for surface irrigation suitability because it affects crop yield (USDIBR, 2003). Soil ph. value less than 4.4 is characterized as acidic and more than 8.5 affects crop growth and is unsuitable for surface irrigation, whereas a ph. value between 5.4 to 6.5 is considered highly suitable because the soil acidity or alkalinity level is low that has better nutrient availability for most crops to grow. Soil ph. values ranging from 6.5 to 7.8 are considered moderately suitable, and a soil ph. values vary between 4.4 and 5.4, and between 7.8 to 8.5 the land is considered marginally suitable for surface irrigation as some crops such as tea and pineapple are tolerant to this high acid or alkaline level (Balew et al., 2021; Hussien et al., 2019).

Soil ph. of the study areas is in the range of 4.9 to 7.0. Accordingly, the study area's soil ph. suitability for surface irrigation classified in to highly suitable ranging from 5.5 – 6.5, moderately suitable 6.5 – 7.0, and marginally suitable 4.4 – 5.5. Hence, figure 12 below shows the classified soil ph. suitable for surface irrigation and the suitable class.

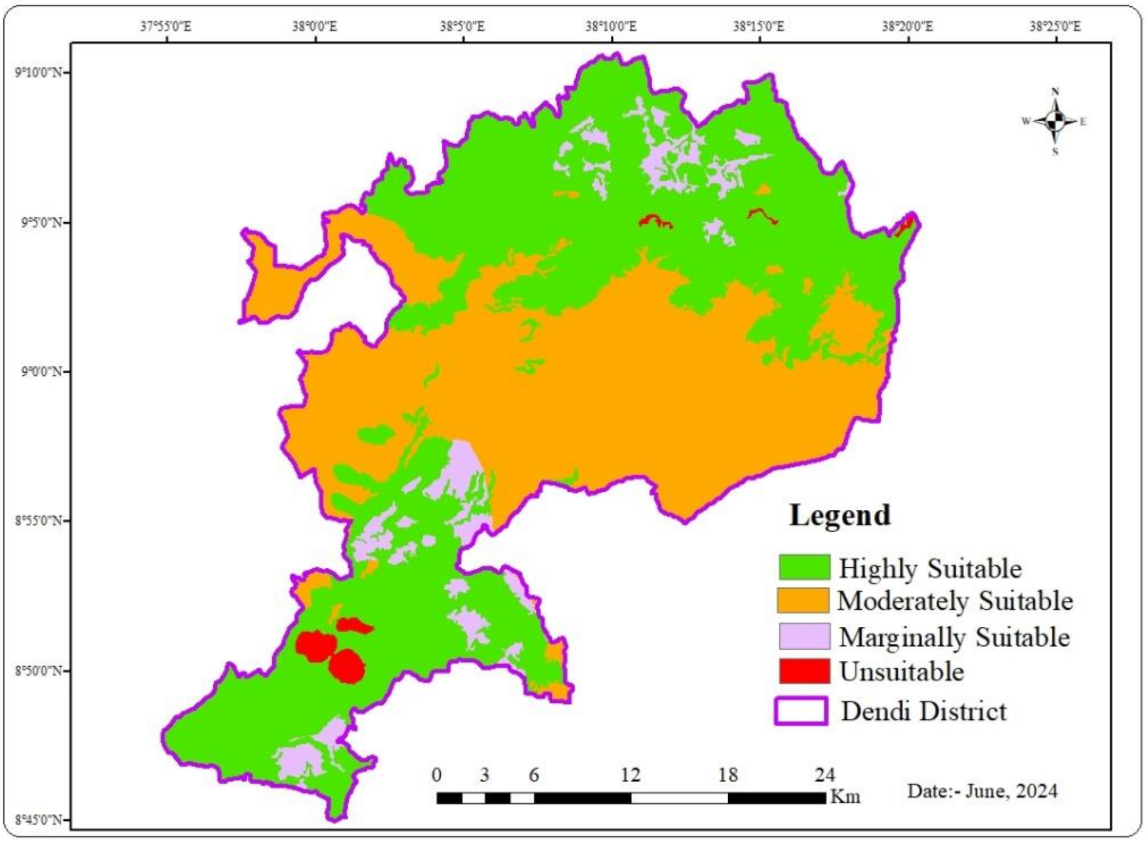

Figure 12: Suitable soil ph. for surface irrigation

Table 13 below illustrates that the suitability categories of the soil ph. for surface irrigation. As it is shown in the table, the maximum amount of the land about 51% (50,763) hectares is covered by highly suitable soil ph. (5.5–6.5) class. This optimum soil ph. range is the best soil ph. situations for nutrient accessibility in the soil and it helps crops to obtain sufficient water and nutrients leading to successful crop growth.

Moreover, a substantial amount of the land about 42% (41,451) hectares, is categorized as moderately suitable, which comprises places with a soil ph. from 6.5 to 7.0. This soil ph. is somewhat neutral to alkaline. Yet again, below table (table 13) displays that a smaller portion about 5.4% (5,359) hectares is categorized into marginally suitable soil ph., which extends from 4.4 to 5.5. Here, surface irrigation is yet-again possible, but here the problems are more probable due to the lower soil ph., which is more acidic and significantly restricts the disposal of nutrients in the soil.

Finally, in the study area, unsuitable soil ph. covers the smallest area about 1.10% (1,085) hectares, and it is restricted in suitability analysis due to the missing data of the soil ph.

These missing data areas covered by water bodies and escarpment landforms. So, these LULCs are restricted in suitability analysis as they are impossible for any activities.

Table 13: Soil ph. suitable for surface irrigation

No	Soil ph.	Suitability Classes	Area (ha)	Area (%)
1	5.5 – 6.5	Highly Suitable	50,763.23	51.45
2	6.5 – 7.0	Moderately Suitable	41,451.42	42.02
3	4.4 – 5.5	Marginally Suitable	5,359.94	5.43
4	Missing Data	Unsuitable	1,085.52	1.10
		Total	98,660.60	100.00

Whereas, according to Mohammed, 2020 the suitability classes' of soil ph. classified as highly suitable from 6.5–7.5, moderately suitable from 7.5–8.5 and 5.5–6.4, marginally suitable ranging from 8.6 – 10 and unsuitable above 10 or less than 5.5 for wheat crop production.

The study area's soil has a ph. value in the range of 4.9 to 7.0, which is classified into different suitability classes. For this research, the study area of soil ph. is classified into highly suitable ph. in the range of 6.5 –7.0, moderately suitable ph. in the range of 5.5 – 6.5, and unsuitable ph. less than 5.0. Thus, figure 21 below shows the soil ph. suitable for winter wheat and the statistical analysis of the classified soil ph. The statistical analysis shows the area of suitable soil ph. for winter wheat in hectares and the percentage of each suitable class.

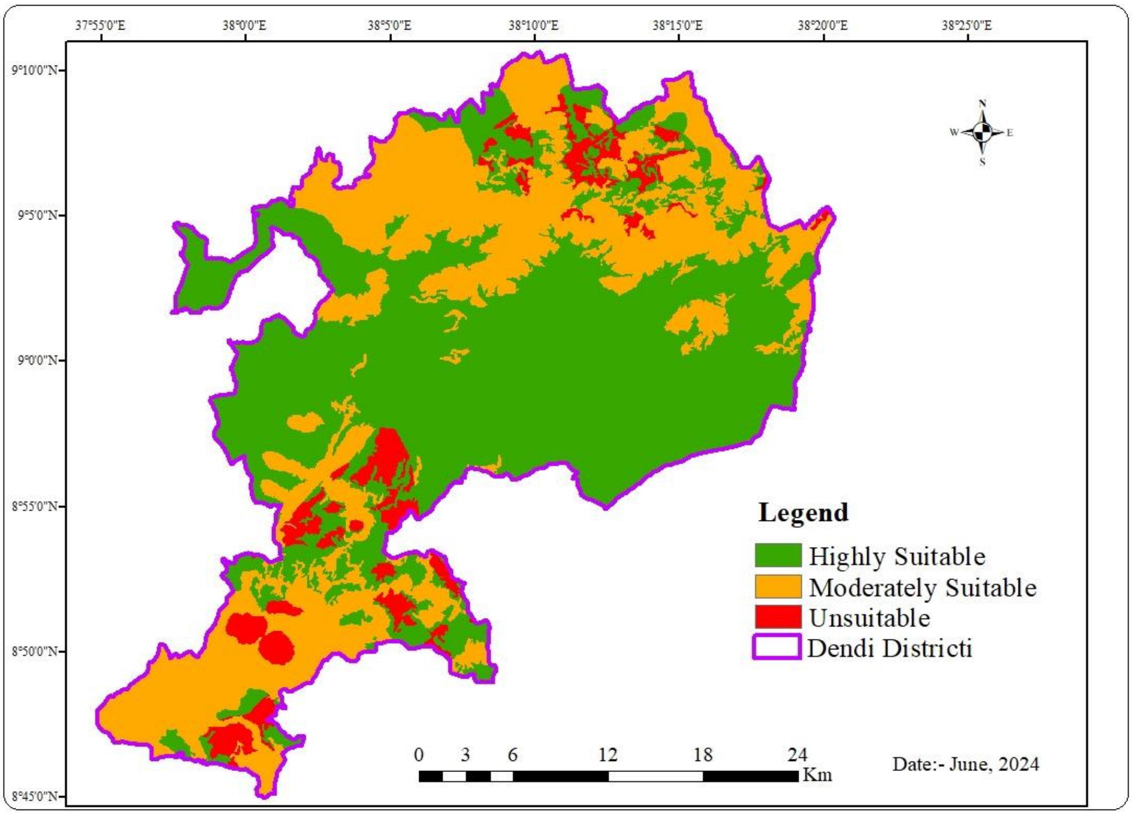

Figure 13: Suitable soil ph. for winter wheat

As seen from table 14 below, the utmost well suited soil ph. value envelopes about 56% (55,289.62) hectares and it is classified into the highly suitable group. This highly suitable soil ph. value ranges from 6.5 to 7, and it supports optimum circumstances for nutrient accessibility within the soil. And also, a significant portion of the study area is classified as moderately suitable, encompasses a soil pH ranging from 5.5 to 6.5, and covers around 37.43% (36,925.02) hectares.

Furthermore, as summarized in the below table (table 14), a smaller area, which covers about 6.4% of the total area or 6,445.46 hectares, is classified as unsuitable soil ph. for wheat farming via surface irrigation. This unsuitable soil ph. includes a soil ph. less than 5.5 and missing data. This low ph. is highly acidic and significantly restricts nutrient availability in the soil. Finally, from unsuitable soil ph., a small portion of the land, 1.10% (1,085.52 hectares), is restricted due to missing data on soil ph. in the suitability analysis. This missing area is covered by a water body and an escarpment landform. These LULCs is restricted in the suitability analysis, since it is impossible to produce any crops on these LULC.

Table 14: Soil ph. suitable for winter wheat

No	Soil ph.	Suitability Classes	Area (ha)	Area (%)
1	6.5 – 7.0	Highly Suitable	55,289.68	56.0405
2	5.5 – 6.5	Moderately Suitable	36,925.02	37.4265
3	< 5.0	Unsuitable	5,359.94	5.4327
4	Missing Data	Unsuitable	1,085.52	1.1003
	Total		98,660.16	100.00

4.1.8. Soil Drainage Suitability

Soil drainage is another vital factor required to evaluate surface irrigation and winter wheat suitability analysis. Thus, well-drained soil allows the normal growth of plants, making it highly suitable for surface irrigation. According to Balew et al., 2021; Negasa, 2021, soil drainage suitable is classified as follows: 'well-drained', moderately well-drained', 'imperfectly drained', and 'poorly drained' as highly suitable, moderately suitable, marginally suitable, and unsuitable, respectively, for surface irrigation assessment and winter wheat suitability analysis.

Consequently, the study area's soil drainage is classified in a similar way as the above classification method: soils that are 'well, moderately well, imperfect, and poorly drained' are classified as highly suitable, moderately suitable, marginally suitable, and unsuitable for surface irrigation and winter wheat respectively. Thus, figure 14 below shows the classified soil drainage suitable for surface irrigation and winter wheat cultivation.

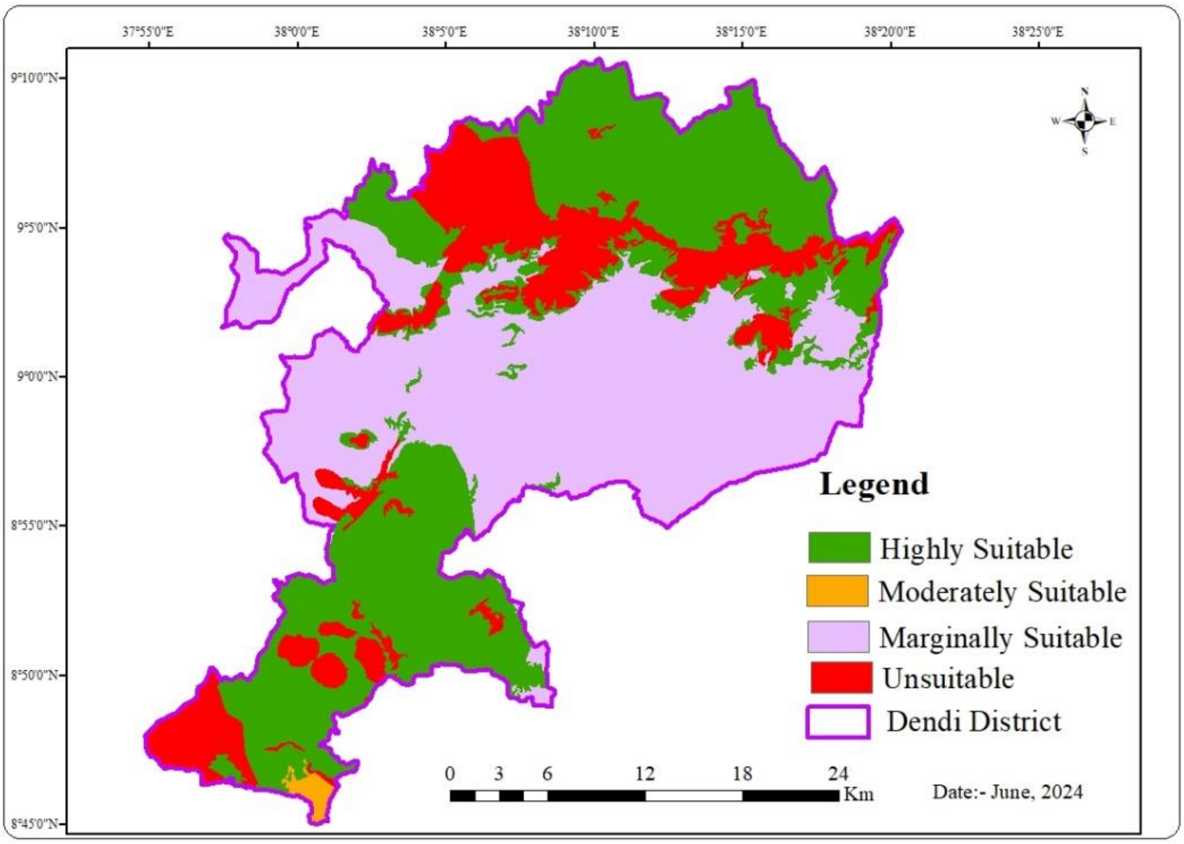

Figure 14: Suitable soil drainage for surface irrigation and winter wheat

Table 15 below unveils the suitability of soil drainage for surface irrigation and winter wheat farming. Table 15 below indicates that, the highly suitable soil drainage covers about 40 percent (40,097.2) hectares and this highly suitable soil drainage is known as well-drained soil category. This well-drained soil enables crops to obtain an optimal water infiltration, aeration, and root growth. Furthermore, as observed from table 15, the smallest parts of the area almost 0.55% (546.32) hectares is categorized into moderately suitable soil drainage. This moderately suitable soil drainage covered by moderately well-drained soils. Although surface irrigation applied in this part, water infiltration and drainage may be to some extent slower compared to well-drained soil, and this possibly leads to temporary periods of waterlogging or aridity that might strain the crops.

Beside the above categories, a vast area of the land about 41% (40,941.1) hectares is covered by marginally suitable soil drainage, which is known as imperfectly drained soil. This soil drainage has inadequate drainage ability, and it might causes waterlogging and constrain oxygen disposal for roots of crops. Yet again table 15 below shows that, a sum of unsuitable soil drainage (16.21%) and missing data of soil drainage about 1.10%, covers a relatively smaller area about 17.21% (17,075.05) hectares is classified to not suitable, since it is covered by poorly or excessively drained soils and missing data of soil drainage. This soil situation severely limits water penetration and oxygen for the roots of plant and can affects the normal growth of crops and harvest. The missing data covering a small area about 1.10% (1,085.55) hectares is covered by a water body and an escarpment landform. Hence, by their nature these LULC is unsuitable for crop production and it is restricted from the involvement in suitability analysis, as it is impossible for crop production by surface irrigation.

Table 15: Soil drainage suitable for surface irrigation and winter wheat

No	Soil Drainage	Suitability Classes	Area (ha)	Area (%)
1	Well-drained	Highly Suitable	40,097.2	40.64
2	Moderately well-drained	Moderately Suitable	546.32	0.55
3	Imperfect-drained	Marginally Suitable	40,941.1	41.50
4	Poorly/Excessive drained	Unsuitable	15,989.5	16.21
5	Missing Data	Unsuitable	1,085.55	1.10
	Total		98,660.6	100.00

4.1.9. Elevation Suitability

Elevation is one of the topographic elements affecting surface irrigation suitability site analysis. For surface irrigation assessment, Hagos et al., 2022 classified the suitability classes of elevation as highly suitable from 2000 m to 3000 m, moderately suitable from 1500m to 2000m and 3000m to 3300m, marginally suitable from 3300 m to 3800 m, and unsuitable less than 1500 m and greater than 3800 m. Accordingly, the study area’s elevation is categorized as highly suitable between 2000 m and 3000 m, moderately suitable between 3000 m and 3300 m, and marginally suitable greater than 3300m. Hence, figure 15 below shows the suitable elevation for surface irrigation and the suitable classes.

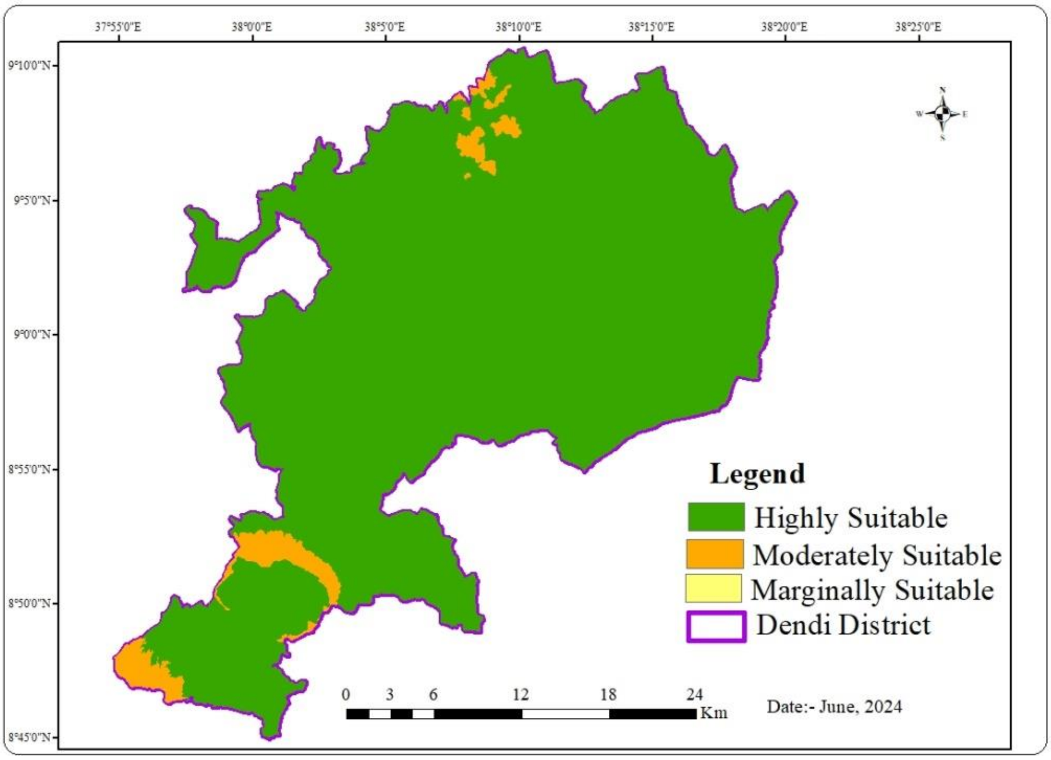

Figure 15: Suitable elevation for surface irrigation

As observed from table 16 below, suitable elevation for surface irrigation is categorized into 3 classes as highly, moderately, and marginally suitable. It is clearly observed that, it is preferred low elevation places. Hence, the vast majority of the land, about 96% (95,173.3) hectares, grouped into the highly suitable elevation from 2000m to 3000m. Yet again, a moderately suitable elevation envelope about 34,842.9 hectares (3.53%) and it is somewhat higher altitude extending from 3000m to 3300m. And also, altitude of topography above 3300m is categorized as marginally suitable, comprising the smallest amount around 1.5 hectares (0.002% from the entire extent of the study area).

Table 16: Elevation suitable for surface irrigation

No	Elevation	Suitability Classes	Area (ha)	Area (%)
1	2069m–3000m	Highly Suitable	95,173.3	96.468
2	3000m–3300m	Moderately Suitable	3,482.93	3.530
3	3300m–3307m	Marginally Suitable	1.5	0.002
	Total		98,660.6	100.00

While, in winter wheat suitability analysis, elevation is one factors required for suitability analysis. It is one of the topographic elements affecting the healthy growth of crops. The most suitable agro-ecological zones for wheat production fall between 1900 and 2700 meters above sea level. Accordingly, the study area's elevation suitability classes for winter wheat production are categorized as highly suitable from 2000m to 2500m, moderately suitable from 2500m to 3000m, marginally suitable from 3000m to 3300 m, and not suitable greater than 3300m.

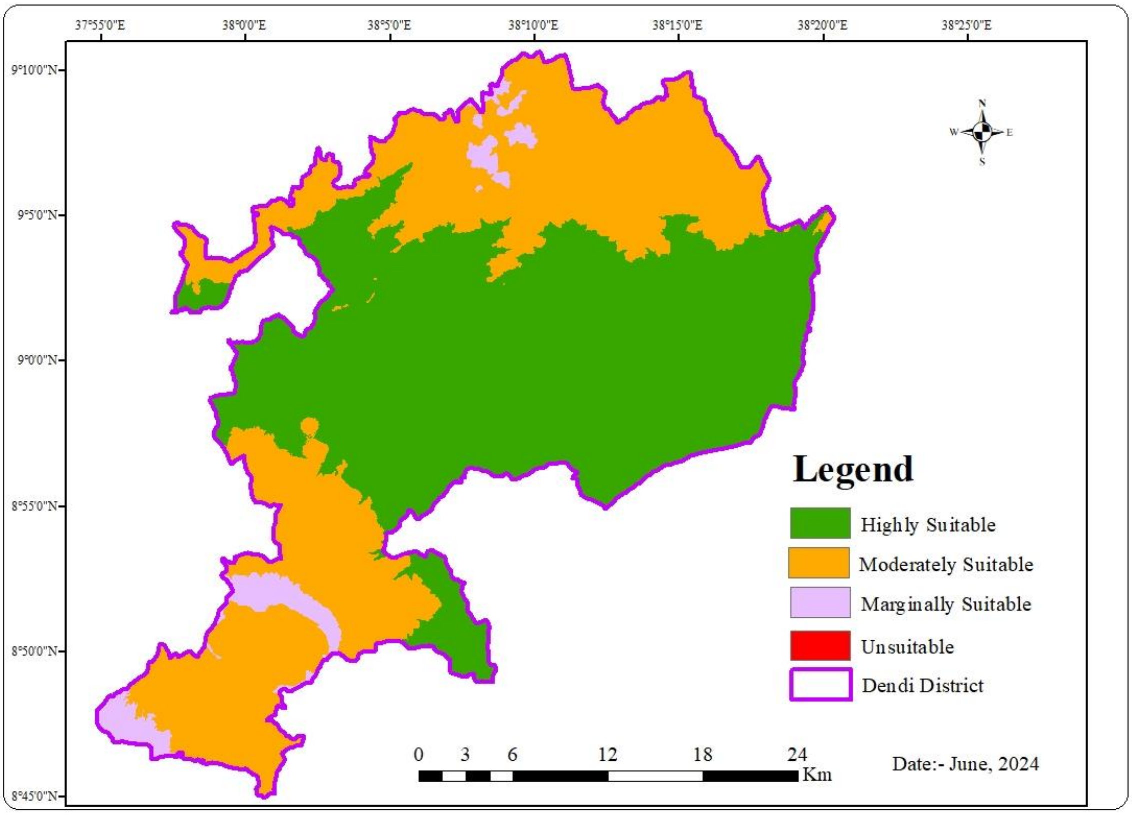

Figure 16: Suitable elevation for winter wheat

Table 17 below shows the elevation suitability for winter wheat farming. The analysis of elevation suitability for winter wheat cultivation shows that a favorite elevation is a lower elevation. Greater than 50% about 55.45% of the land, comprising a substantial area of 54,705.22 hectares, falls within the highly suitable elevation between 2000m to 2500m. These lower altitudes offer the optimum temperature and growing situations essential for effective winter wheat cultivation. Yet again, a substantial proportion of the area about 40,468.08 (41.02%) hectares, is classified as moderately suitable elevation ranging from

2500 to 3000m. As altitude increases, temperature will decreases, so cooler temperatures at these higher elevations could potentially impact winter wheat growing.

Moreover, a small proportion about 3,482.93 (3.48%) hectares, falls within the marginally suitable elevation range of 3000 to 3300m. These areas might experience harsher conditions that could potentially limit growth or lead to crop failure. Lastly, the smallest area less than 0.01% (1.5) hectares, is classified into unsuitable elevation (>3300m). The extreme conditions at high altitudes make it unsuitable for winter wheat cultivation.

Table 17: Elevation suitable for winter wheat

No	Elevation Range	Suitability Classes	Area (ha)	Area (%)
1	2069m –2500m	Highly Suitable	54,705.22	55.449
2	2500m – 3000m	Moderately Suitable	40,468.08	41.019
3	3000m – 3300m	Marginally Suitable	3,482.93	3.530
4	>3300m	Unsuitable	1.5	0.002
		Total	98,660.6	100.00

4.1.10. Temperature Suitability

Temperature plays a significant role in site selection for wheat cultivation (Oyewole, 2016). According to Fekadu & Negese, 2020; Gebreegziabher et al., 2018,) for maximum productivity wheat prefers a temperature range of 15°C to 20°C. The minimum, optimum, and maximum average temperatures at which the wheat grows optimally are 15 °C, 23 °C, and 27 °C, respectively. Accordingly, the temperature suitability classes of the study area for winter wheat suitability analysis were classified as highly suitable (15 °C–17 °C) and marginally suitable (14 °C–15 °C) and unsuitable (11 °C–14 °C). Thus, figure 17 shows temperature suitability for winter wheat and the suitable classes.

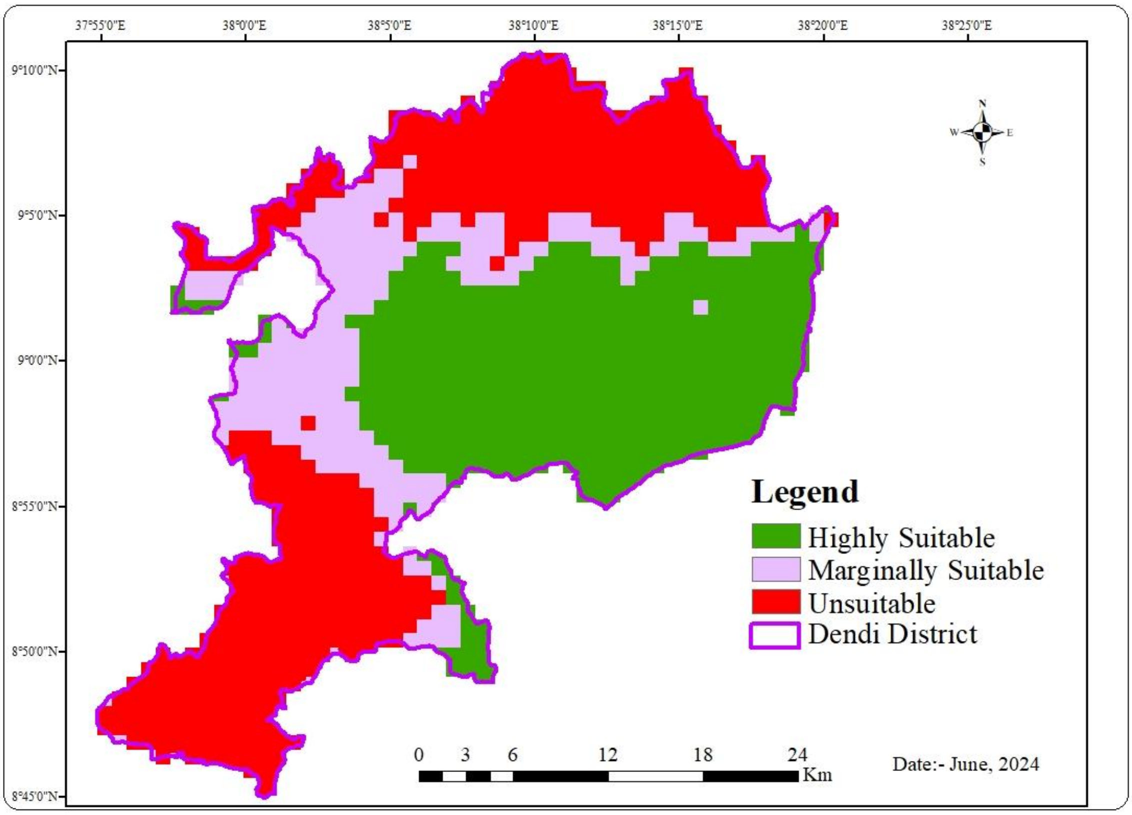

Figure 17: Suitable temperature for winter wheat

As understood from the table 18 below, highly suitable temperatures ranging from 15 °C to 17°C cover about 38.8216% (38,577.5) hectares, whereas marginally suitable temperatures ranging from 14°C to 15°C cover around 19.1951% (41,719.28) hectares and unsuitable temperature ranging from 11°C to 14°C covers about 41.9833% or 41, 719.3 hectares.

Table 18: Temperature suitable for winter wheat

No	Temperature	Suitability Classes	Area (ha)	Area (%)
1	15 °C – 17°C	Highly Suitable	38,577.5	38.8216
2	14°C – 15°C	Marginally Suitable	19,074.4	19.1951
3	11°C – 14°C	Unsuitable	41,719.3	41,9833
	Total		98,659.8	100.00

4.2. Model for Surface Irrigation and Winter Wheat Suitability

In order to construct the model indicating suitable site for surface irrigation and winter wheat, the parameters overlaid together, first calculating the weight of each factors.

Table 19: AHP pair-wise comparison matrix for surface irrigation assessment

Factors	Proximity to River	Slope	Soil Type	LULC	Soil Depth	Soil Drainage	Soil texture	Soil Ph.	Elevation	Weight
Proximity to River	1	3	8	9	9	9	9	9	9	40.74%
Slope	1/3	1	8	9	9	9	9	9	9	31.15%
Soil Type	1/8	1/8	1	2	2	2	3	3	3	7.09%
LULC	1/9	1/9	1/2	1	1	1	2	2	2	4.35%
Soil Depth	1/9	1/9	1/2	1	1	1	2	2	2	4.35%
Soil Drainage	1/9	1/9	1/2	1	1	1	2	2	2	4.35%
Soil texture	1/9	1/9	1/3	1/2	1/2	1/2	1	1	1	2.66%
Soil Ph.	1/9	1/9	1/3	1/2	1/2	1/2	1	1	1	2.66%
Elevation	1/9	1/9	1/3	1/2	1/2	1/2	1	1	1	2.66%

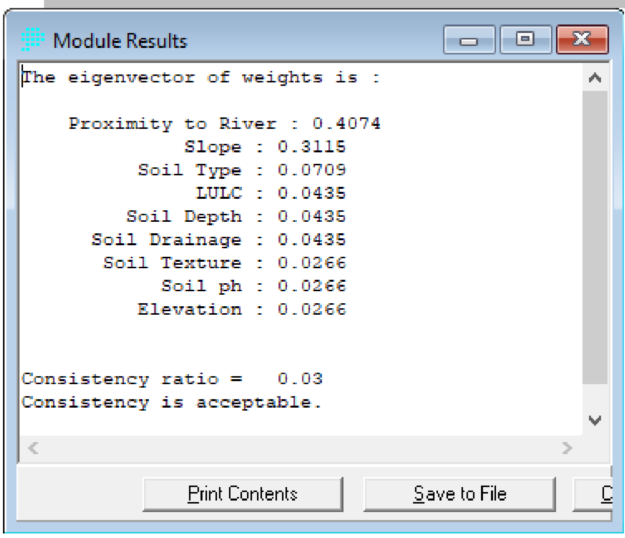

Figure 18: Weight and CR of factors

As seen from above figure 18, the calculated CR is 0.03 (3%), which is less than 10%, and it is acceptable, so it is possible to find the suitable site for surface irrigation.

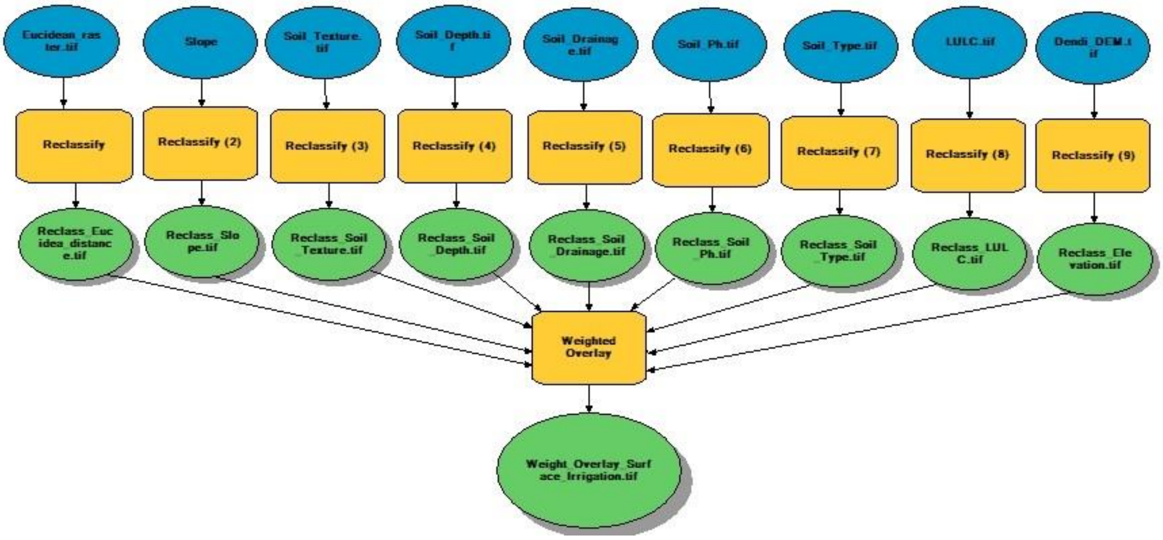

Figure 19: Suitability model for surface irrigation

Table 20: AHP pair-wise comparison matrix for winter wheat suitability assessment

Factors	Proximity to River	Slope	Temperature	Soil Type	LULC	Soil Depth	Soil Drainage	Soil Texture	Soil ph.	Elevation	Weight
Proximity to River	1	3	7	8	9	9	9	9	9	9	37.75%
Slope	1/3	1	7	8	9	9	9	9	9	9	29.72%
Temper.	1/7	1/7	1	2	2	3	3	3	3	4	7.90%
Soil Type	1/8	1/8	1/2	1	2	2	2	3	3	4	6.10%
LULC	1/9	1/9	1/2	1/2	1	1	1	2	2	3	3.96%
Soil Depth	1/9	1/9	1/3	1/2	1	1	1	2	2	3	3.84%
Soil Drainage	1/9	1/9	1/3	1/2	1	1	1	2	2	3	3.84%
Soil Texture	1/9	1/9	1/3	1/3	1/2	1/2	1/2	1	1	2	2.53%
Soil ph.	1/9	1/9	1/3	1/3	1/2	1/2	1/2	1	1	2	2.53%
Elevation	1/9	1/9	1/4	1/4	1/3	1/3	1/3	1/2	1/2	1	1.83%

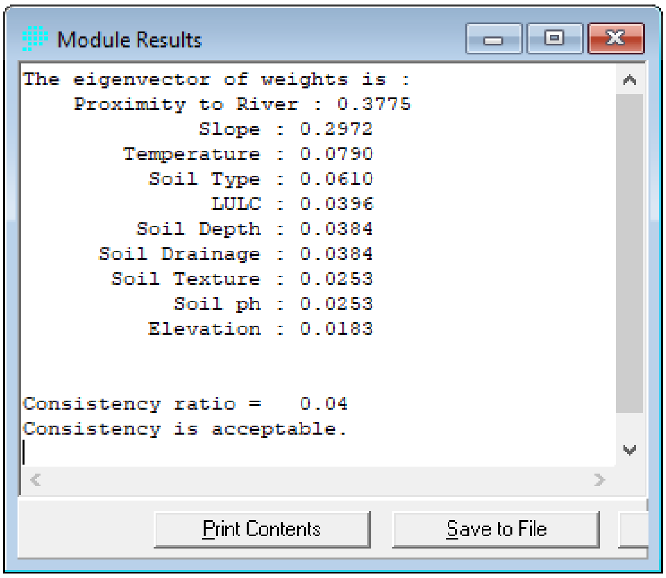

Figure 20: Weight and CR of factors

As seen from the above figure 21, the CR for this study is 0.04 (4%), which is less than 10% so it is acceptable and possible to apply the calculated weight value to find a suitable site for winter wheat.

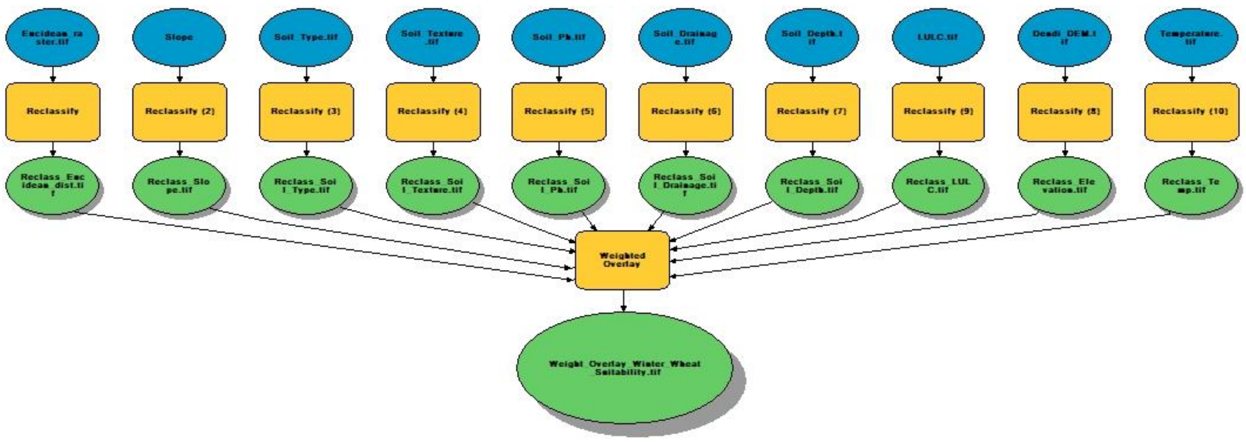

Figure 21: Suitability model for winter wheat

4.3. Suitable Land for Surface Irrigation

A study on land suitability assessment for surface irrigation development at Ethiopian highlands using GIS technology by Hagos et al., 2022 employed eight factors. The overall suitable land for surface irrigation classified in to four suitable classes as (highly, moderately and marginally) suitable. However, the number of suitability classes of the factors used in analysis is not equal, for instance slope and LULC classified in to four classes as highly, moderately and marginally) suitable, proximity to river classified in to three classes as (highly, moderately and marginally) suitable, whereas the remaining factors such as soil (depth, texture, drainage), elevation, and available water storage capacity classified into two suitability classes.

Additionally, Wubalem, 2023 studied land suitability for surface irrigation using analytical hierarchy process method in Belessa Districts, northwestern Ethiopia, and classified the suitability result in to four classes (highly, moderately, and marginally) suitable and unsuitable. However, the number of suitability classes each factors is not equal, for instance proximity to river, slope, LULC, elevation, and soil type classified into four classes (highly, moderately, and marginally) suitable and unsuitable. While factors like soil depth and soil texture classified into two and three suitable classes respectively.

Yet again, Tesfay, 2023 assessed surface irrigation potential of Mannisa watershed using GIS and remote sensing technologies, and the suitable site for surface irrigation classified as very suitable, moderately suitable, slightly suitable, temporarily unsuitable and permanently unsuitable. But, the number of suitable classes of each factors isn't equal; as some factor classified into four classes such as slope, proximity to river, soil ph., and soil organic carbon, other in to five classes like LULC. Whereas, the other factors classified in to two suitable classes like soil (type, texture), rainfall, temperature, and three suitable classes like soil depth, and one classes like soil drainage.

In this research, also the numbers of suitable classes of the factors are not equal, as some factors classified into two classes, others into three classes, and four classes. While, the final suitable site classified into four classes.

In order to locate the suitable land for surface irrigation and winter wheat, each reclassified parameters are overlaid together over GIS environment. GIS permits the user to derive knowledge from different sources of spatial parameters in order to assess land suitability site. Then, after the consistency ratio evaluated (has to be accepted), the land suitability class for surface irrigation is generated using weight overlay methods (Mohammed et al., 2020) of ArcGIS applying the following equation 1:

$$S = \left[\sum_{i=1}^{n} Wi * Xi\right] \prod_{cj} \quad \text{................ equation 1}$$

Where: S: Suitability index, wi: Weight of criterion i, xi: Rank of criterion i, cj: Boolean value of restricted criterion, n is number of criteria or parameter

The suitable site for surface irrigation classified into different classes according to the FAO classification method. Thus, figure 22 below shows the suitable land for surface irrigation, having spatial resolution 10m, and it is classified into four different suitability classes.

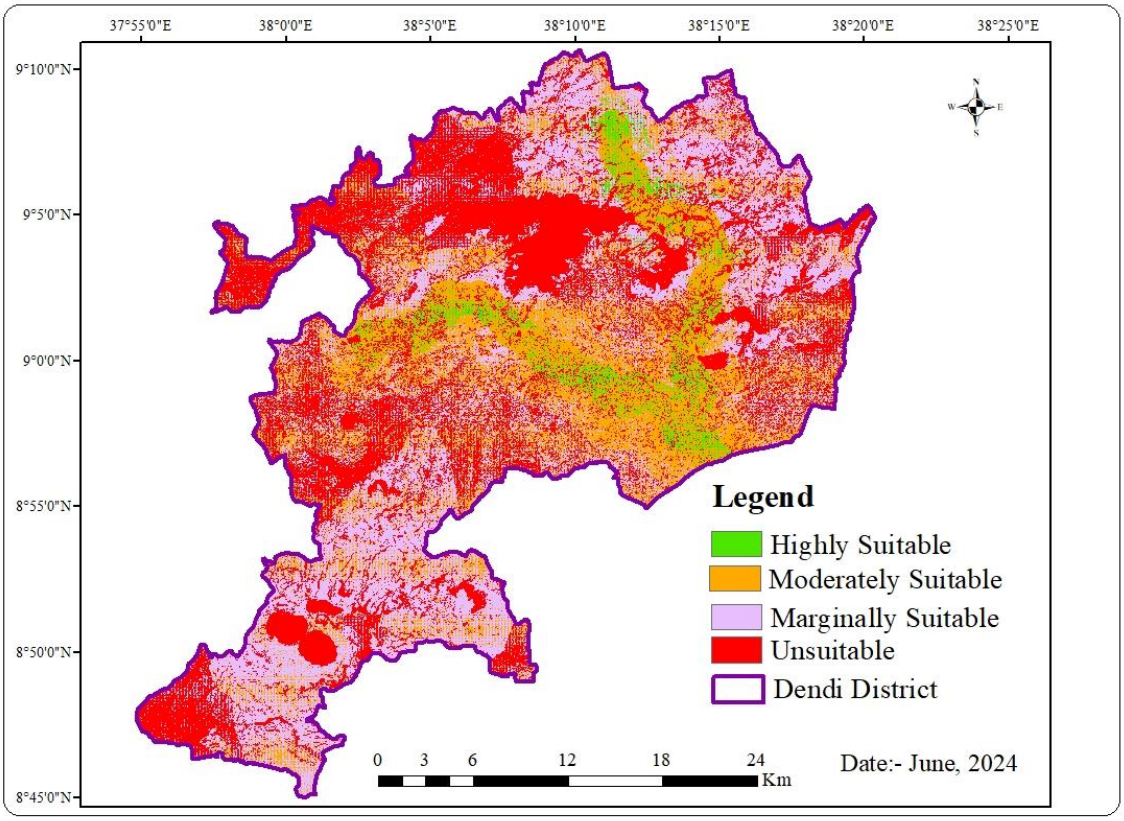

Figure 22: Suitable land for surface irrigation

Table 21 below shows the study area suitable land for surface irrigation, which is classified into four diverse classes as (highly, moderately and marginally) suitable and unsuitable. Highly suitable land for surface irrigation is covered the smallest area about 3.21% (3,160.22) hectares. This land has good characteristics to implement surface irrigation systems with insignificant modifications. Here, factors like proximity to river, slope, soil texture, and drainage are conducive for growing crop via surface irrigation. Furthermore, moderately suitable land for surface irrigation covers around 23.63% (23,252) hectares. Though surface irrigation possible, it might need further modifications to factors that hinder effectively utilizing it. Factors such as slopes or other factors might pose a challenge to fully utilizing the land for irrigation purposes. In addition, marginally suitable land for surface irrigation covers about 33.47% (32,935.1hectares) of the land. This land class has the potential for surface irrigation, but careful planning and management practices are crucial to implement effectively. Obstacles like steeper slopes or far away from a river hinder surface irrigation implementation. The largest portion of the area, from the total area about 39.68% (39,047.5) hectares of land, is classified as "unsuitable" for surface irrigation. This land likely holds features that make it impossible to utilize surface irrigation methods. Factors like extreme slopes, poor drainage, proximity to rivers, or unsuitable soil types could contribute to this classification. Implementing surface irrigation on this land would be challenging and might not yield optimal results.

Table 21: Suitable land for surface irrigation

No	Suitability Classes	Area (ha)	Area (%)
1	Highly Suitable	3,160.22	3.21
2	Moderately Suitable	23,252	23.63
3	Marginally Suitable	32,935.1	33.47
4	Unsuitable	39,047.5	39.68
	Total	98,660.6	100.00

4.4. Suitable Land for Winter Wheat Production by Surface Irrigation

To find the suitable site for winter wheat, a suitability model is built using the model builder. On the created suitability model, ‘weight overlay’ tool utilized to determine the suitable land.

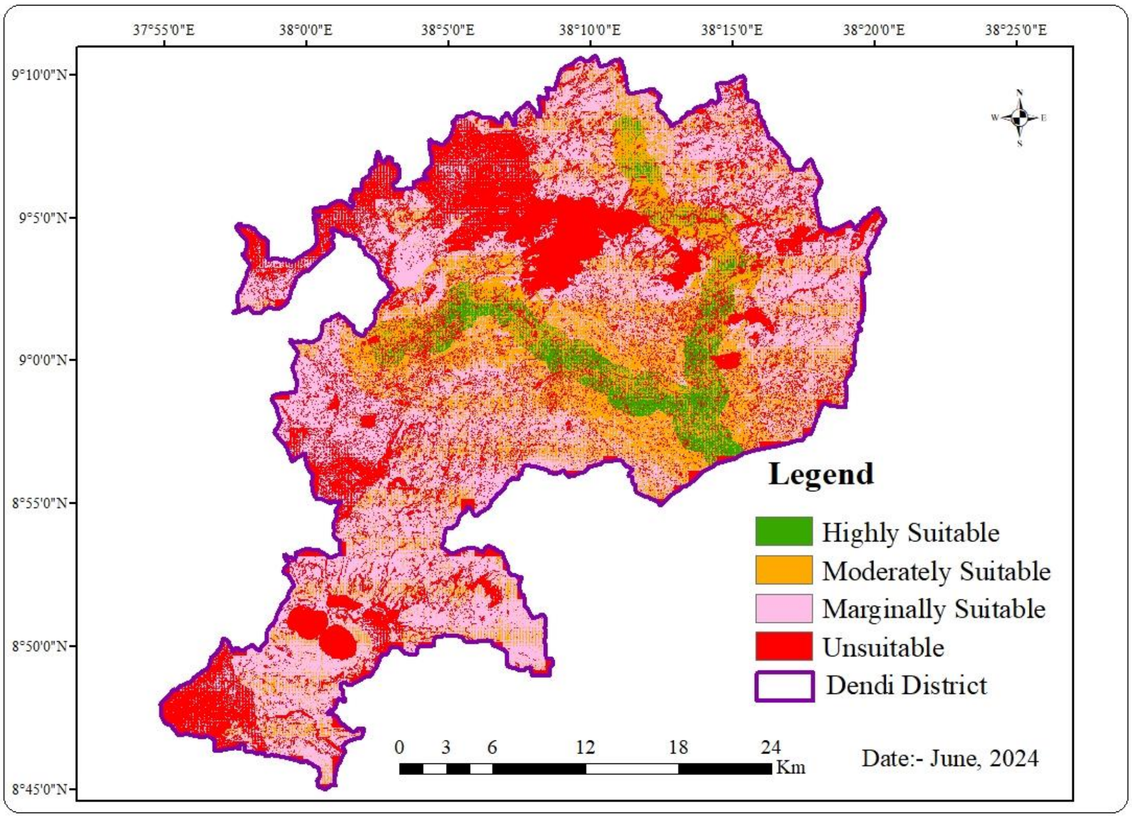

Figure 23: Suitable land for winter wheat via surface irrigation

As seen from the table 22 below, the study area's suitable land for winter wheat farming via surface irrigation is classified into four distinct classes as highly suitable, moderately suitable, marginally suitable, and unsuitable. From the four suitable land classes, in the study area, highly suitable land for winter wheat is covered the smallest area about 4.56%, or 4,389.73hectares from the total area. This land has optimum characteristics for applying winter wheat production with minimal modifications. Here, factors like proximity to the river, slope, soil texture, and drainage are conducive to crop growth. Furthermore, as observed from table 22, moderately suitable land for winter wheat covers around 20.98% or 20,176.1hectares from the whole coverage. While winter wheat farming is possible here, it may require further adjustments of the factors that hinder effective utilization for healthy growth of wheat. It is challenged by factors such as distance from rivers, slopes, or other factors that may cause a challenge for fully utilizing the land for irrigation purposes.

In addition to highly and moderately suitable land, a small area of a land is categorized as marginally suitable for winter wheat. It covers about 41.95% (40,355.3) hectares of land. This land class has a potential to grow wheat, but careful planning and management practices are critical for successfully transporting water land. In this marginally suitable land, constraints such as steeper slopes or other factors may necessitate major adjustments to make the land favorable for farming purpose and obtain optimum yield.

Furthermore, from the entire area about 32.51% (31,268.08) hectares of land is unsuitable land for winter wheat via surface irrigation. This land likely possesses challenging factors that make it impractical or inefficient to produce crops. Elements such as steep slopes, poor drainage, proximity to rivers, or unsuitable soil types resulted in unsuitable land for wheat growing. It is impossible to grow wheat on this land, and even applying winter wheat farming on this land is likely challenging and may not yield optimal results.

Table 22: Suitable land for winter wheat production by surface irrigation

No	Suitability Classes	Area (ha)	Area (%)
1	Highly Suitable	4,389.73	4.56
2	Moderately Suitable	20,176.1	20.98
3	Marginally Suitable	40,355.3	41.95
4	Unsuitable	31,268.08	32.51
	Total	98,660.6	100.00

As seen from the table 21 and 22 above, large-scale wheat and other crop production through surface irrigation is difficult in this study area. Because of slope and proximity to river, the highly suitable land covers small area; as a result large-scale irrigation for wheat and other crop production cannot be possible. These factors causes very costly and challenging to construct canal and it can limit for effectively distribution of water to the crop land, so that the factors will hinder to exploit the land effectively for irrigation. And also, there's still potential for some level of crop production using targeted irrigation strategies on moderately, considering the limitations and implementing improvements where possible. However, producing crops on marginally suitable land is very challenging, since there are so severe limitations in factors, and it is challenging to take water long distance and slope leveling to construct canal for irrigation. So, cost-benefit analysis essential that considers the economic viability of irrigation development in these areas.

In this research, assessment of surface irrigation is done by nine factors, while in the winter wheat suitability assessment ten factors (additional temperature). This creates the weight influence difference among the two result of suitability analysis. So, the reason, why wheat production suitability area is greater than the area of suitable for surface irrigation is the weight of the most influencing factors like proximity to river and slope is reduced by adding temperature data in the winter wheat suitability analysis. At the assessment of surface irrigation the weight of influence slope and proximity is greater than the weight used in winter wheat suitability analysis, which causes the reduction of suitability in surface irrigation. Hence, to obtain suitable area of wheat production less than area of surface irrigation, weight of the factors in winter wheat suitability analysis should be greater than the weight of surface irrigation assessment and equal factors has to be used to calculate the weight factors applied suitability analysis

4.4. Discussions

Regarding surface irrigation, a study by Girma et al., 2019 on the 'assessment of physical land suitability for surface irrigation by using GIS and remote sensing in Loma District, South Western Ethiopia', was conducted by using factors like soil type, slope, LULC, market accessibility, mean annual temperature and rainfall, and distance from water sources. Based on these factors, the author used 'weight overlay tool' to determine the suitable land for surface irrigation and classified as (highly, moderately, and marginally) suitable and currently unsuitable. Thus, this research work incorporated soil ph., soil depth, soil texture and elevation, along with proximity to river, soil type, slope, LULC, and soil drainage in finding the suitable site. Thus, the suitable land for surface irrigation classified into highly suitable 3.21%, moderately suitable 23.63%, marginally suitable 33.47% and unsuitable 39.68%.

Furthermore, a study on land suitability analysis for surface irrigation by Labiso and Yagaso (2021), utilized factors such as soil type, LULC, slope and proximity to the river. Based on these criteria, the authors generated the suitable map using the 'weight overlay' of ArcGIS 10.2, and classified it into four classes as (highly, moderately and marginally) suitable and unsuitable. Hence, this research work incorporated soil (ph., depth, texture and drainage) and elevation, along with proximity to river, soil type, slope, and LULC in finding the suitable site. Accordingly, the suitable land for surface irrigation classified into highly suitable, moderately suitable, marginally suitable and unsuitable.

Additionally, Tesfay, 2023 assessed irrigation potential of Mannisa watershed by GIS and remote sensing technologies in Offa woreda, Southern Ethiopia, using various factors encompassing slope, distance to river, LULC, soil (type, drainage, texture, ph., depth, and organic carbon), rainfall and temperature. Based on these criteria, suitable map generated using the 'weight overlay' of ArcMap 10.8 software, and it is classified and mapped into five classes as (highly, moderately, and marginally) suitable, currently not suitable and permanently not suitable. This research incorporated soil (ph., depth, texture and drainage) and elevation, along with proximity to river, soil type, slope, and LULC in finding the suitable site. Thus, the suitable land for surface irrigation classified into highly suitable 3.21%, moderately suitable 23.63%, marginally suitable 33.47% and unsuitable 39.68%.

Moreover, Nasir et.al., (2019) and Gurara 2020 assessed land suitability for surface irrigation potential considering factors such as slope, soil type, soil texture, soil depth, soil drainage, LULC, and water resources availability. After individual suitability of each factor was analyzed, potentially irrigable land was predicted by weighting overlay analysis. This research work incorporated soil (ph., depth, texture and drainage), elevation, proximity to river, soil type, slope, and LULC to find the suitable site. Thus, the suitable land for surface irrigation classified into highly suitable 3.21%, moderately suitable 23.63%, marginally suitable 33.47% and unsuitable 39.68%.

Regarding winter wheat suitability analysis, Fekadu and Negese, 2020 studied the suitability of winter wheat using GIS-based AHP technique by employing slope, temperature, rainfall, elevation, soil depth, soil texture, bulk density, available water content, ph., organic carbon, total Nitrogen, available Phosphorous, cation exchange capacity, percent base saturation. Each factor reclassified to show the suitability of the factors and suitable land determined by using weight overlay analysis tool of ArcMap. Accordingly, the suitable land classified and mapped as (highly, moderately, marginally) suitable, currently not suitable, and permanently not suitable. However, this research used soil (ph., depth, texture and drainage), proximity to river, soil type, slope, elevation, temperature, and LULC to find the suitable site. Thus, the suitable land for surface irrigation classified and mapped as highly suitable 4.56%, moderately suitable 20.98%, marginally suitable 41.95%, and unsuitable 32.51%.

CHAPTER V CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The primary objective of this research is to pinpoint the optimum land assessment for surface irrigation and winter wheat in the upper Awash Basin, Dendi district. This study approach can provide valuable insights of suitable land that enables to guide the favorable site for crop production in the study area. This research employed GIS and remote sensing to assess systematically the potential of surface irrigation for winter wheat. Numerous parameters are used to assess land suitability for surface irrigation and winter wheat, including proximity to rivers, soil (type, depth, drainage, texture, and ph.), temperature, elevation slope, and LULC. To indicate the suitability of these parameters for surface irrigation and winter wheat, these parameters are reclassified by the 'reclassify tool' of ArcMap and mapped as (highly, moderately, and marginally) suitable and unsuitable.

In this research, land suitable for surface irrigation and winter wheat is determined by using the 'weight overlay tool' of Arcmap on the developed model for this purpose. Hence, to find suitable land for surface irrigation and winter wheat, all reclassified parameters are overlaid together on developed model of ArcMap environment. Accordingly, the land suitable for surface irrigation and winter wheat is classified into four classes as (highly, moderately, and marginally) suitable and unsuitable based on the FAO classification standard. In terms of area, the land suitable for surface irrigation is estimated about 3.21% highly suitable, 23.63% moderately suitable, 33.47% marginally suitable, and the vast land about 39.68% is unsuitable. Moreover, the suitable land for winter wheat farming by surface irrigation, about 4.56%, 20.98%, 41.95%, and 32.51% are classified as highly suitable, moderately suitable, marginally suitable and unsuitable respectively.

Identifying suitable map of surface irrigation potential for winter wheat is a crucial tool for many purposes. It can serve for crop land planning by emphasizing suitable areas; as the map can guide policy makers and farmers in allocating land resources for winter wheat cultivation with high potential for success. This suitable map provides vital information for agricultural planning and decision-making at various levels. At government level it enables to prioritize areas for investment in irrigation infrastructure development based on suitability and water availability. It serves extension worker to target their efforts with farmers in identified suitable areas, providing them with guidance on winter wheat cultivation and irrigation practices. And also, farmers can utilize the map to identify areas with high potential for winter wheat production using surface irrigation, leading to informed land-use decisions and potentially higher crop yields.

Furthermore, this suitable site is important for improved resource utilization for focusing irrigation development efforts on these identified suitable areas to optimize water resource utilization and ensures efficient water delivery for crop production. This study can contribute in enhancing food security by expanding winter wheat production through surface irrigation over the identified potential areas, and increased agricultural productivity which leads to economic growth and improved livelihoods for farmers.

5.2 Recommendation

- ❖ It is recommended that the district agricultural bureau should have to prioritize highly suitable areas for initial surface irrigation development efforts within the study area as it enables to ensure efficient water utilization and exploits high productivity from the area. Rather than irrigating here and there without assessment of land suitability, focusing on the indicated high potential areas, decision makers can target resources where they are most needed, leading to increased agricultural productivity and sustainable water management practices. This prioritization not only enhances the effectiveness of surface irrigation projects but also contributes to long term food security and economic development in the study area.
- ❖ This study is crucial for decision makers as it provides valuable insights on expanding wheat production in areas that are most suitable for wheat crop harvesting. By identifying these specific regions, decision makers can strategically allocate resources and support to farmers, ultimately increasing wheat production in the study area.
- ❖ Based on the findings, the study area is not well suited for large-scale farming systems; instead, it is mainly favourable for small-scale farming that is practiced at the individual farmers' level. Because, the area is not a flat land, rather the area characterized by steep slope which is not good enough for irrigation development. Large-scale farming needs extensive flat terrain land, however the area is not suitable for this mechanism as the area mostly covered by steep slope.
- ❖ The developed model enables to estimate surface irrigation potential and crop suitability assessment at country, region, zone, or district level. And it recommended

that by adding additional factors, it is also powerful method to build geo-database of suitable land for surface irrigation.

- ❖ It is recommended that in every part of the country the concerned organization should practice assess land suitability analysis prior to engage in crop production, to reduce soil erosion and keep land from degradation
- ❖ This study focuses only on the assessment of land suitability for surface irrigation and winter wheat, so other researchers should have to deal with other irrigation methods and crop types to increase productivity.
- ❖ This study utilized a limited number of factors like soil type, soil depth, soil ph., soil drainage, soil texture, temperature, LULC, elevation, and slope. However, the suitability assessment of a land for surface irrigation and winter wheat can be influenced by other criteria. Hence, while conducting a research on this issue; other researcher should incorporate other vital parameters.

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