ADDIS ABABA UNIVERSITY

COLLEGE OF SOCIAL SCIENCES

DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES

ASSESSMENT OF LAND SUITABILITY USING A GIS-BASED MULTI-CRITERIA ANALYSIS FOR RICE CULTIVATION IN FOGERA WOREDA, AMHARA REGIONAL STATE, ETHIOPIA

BY

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STATEMENT OF APPROVAL

This is to certify that the thesis prepared by Melese Getinet, entitled: Assessment of land suitability using a GIS-based multi-criteria analysis for rice cultivation: The case of Fogera Woreda and submitted in partial fulfillment of the requirements for the award of the degree of Master of Arts in Geography and Environmental Studies (specialization in Geographic Information System, Remote Sensing, and Digital Cartography) by the school of graduate studies, Addis Ababa University through the College of Social Science complies with the regulations of the university and meets the accepted standards concerning the originality and quality.

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ABSTRACT

*Land evaluation is a basis for sustainable land resource planning and management. In Ethiopia, national economic growth is highly dependent on agriculture and the land's productivity is low due to mismanagement of the land, land degradation, and intensive cultivation; this condition is worse in Fogera plain. This study evaluates land suitability for rice cultivation in the Fogera Woreda. A GIS technique with a multi-criteria evaluation (*MCE*) approach was applied to evaluate the land appropriateness for rice cultivation. Factors that were considered for the analysis of the land suitability for rice cultivation were rainfall, temperature, slope, land use land cover (LULC), soil type, soil texture, soil depth, and soil pH. The weight of influence of each factor was computed by pair-wise comparison technique which is one of the Analytic Hierarchy Process (AHP) methods. The final rice suitability analysis map was created by combining all factors with their respective weights in the ArcGIS Pro overlay tool. The results of the suitability analysis revealed that 728.5km² (65.9%) was highly suitable, 235.9 km² (21.4%) was moderately suitable, 57.4 km² (5.2%) was less suitable, and 82.7 km² (7.5%) unsuitable for rice cultivation. The results of the research show that the study area has a huge potential area for rice cultivation.*

Keywords: *AHP, MCE, rice cultivation, suitability analysis, weighted overlay analysis*

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Acronyms and Abbreviation

Agro BIG: Agribusiness Induced Growth

AHP: Analytic Hierarchy Process

CR: Consistency Ratio

DM: Decision Makers

DEM: Digital Elevation Model

EIC: Ethiopian Investment Commission

EMA: Ethiopian Meteorological Agency

ERDAS: Earth Resource Data Analysis System

ESA: European Space Agency

ESS: Ethiopian Statistical Service

FAO: Food and Agriculture Organization

GIS: Geographical Information System

IDW: Inverse Distance Weighted

ISRIC: International Soil Reference and Information Centre

LSA: Land Suitability Analysis

LULC: Land Use Land Cover

MoA: Ministry of Agriculture

MCDA: Multi-Criteria Decision-Making Analysis

MCDM: Multi-Criteria Decision Making

MDS: Multi-Dimensional Scaling

MCE: Multi-Criteria Evaluation

MCA: Multi-Criteria Analysis

MoARD: Ministry of Agriculture Research and Development

MODM: Multiple Objective Decision-Making

MADM: Multiple Attribute Decision-Making

MT: Million Metric Tons

OLI: Operational Land Imager

PCM: Pairwise Comparison Matrix

RI: Random Consistency Index

SAA: Sasakawa Africa Association

SNAP: Sentinels Application Platform

SSGI: Space Science and Geospatial Institute

SSA: Sub-Saharan Africa

SNNPR: Southern Nations, Nationalities and Peoples Region

UET: Ultimate Environmental Threshold

USGS: United States Geological Survey

CHAPTER ONE

INTRODUCTION

1.1 Background

Population numbers, particularly in developing countries, increase the pressure on natural and agricultural resources. An increased food supply was required to meet the rising world population's nutritional demands. The population grows rapidly, and the process of urbanization has increased the pressure on agricultural resources. This increased pressure on the presented land resources might result in land degradation (Elaalem et al., 2011). Reliable and accurate land assessment is therefore essential to the decision-making processes involved in developing land use policies that will support sustainable rural development.

Rice is the main food source for more than half of the world's inhabitants, affecting many billion people's livelihoods and economics. Previously, it was so called an Asian product. Currently, rice is produced in many other parts of the world. It is also the most quickly rising source of nutrition in Africa and is significant to food security and food self-sufficiency in an increasing number of low-income food-deficit countries. Therefore, improving the cultivation of rice crops would help hunger eradication, poverty mitigation, countrywide food security, and economic development (FAO, 2015).

Ethiopia is one of the growing African countries with high population insecurity. Agriculture is the backbone of the country's economy involving the largest sizes of its population. The country has vast potential for agricultural crop cultivation due to its enormous arable land, water resources, and wide range of climates that can assist varieties of crops. However, the sector is

still in its primal stage despite significant developments recorded in recent times. Understanding this problem, the government has been framing and applying several strategies that give due emphasis to commercialization as the succeeding step of agricultural development. The strategies include variation and specialization of crop cultivation by farmers to enhance productivity (Mohidem et al., 2022).

Rice is among the target crops that have received deserving emphasis in the promotion of agricultural constituents. It is considered the "Millennium Crop" supposed to contribute to safeguarding food security in the country. Even though, introduced recently, rice is recognized to be a crop that can ensure food security in Ethiopia (Mohidem et al., 2022). Considering the potential of the agricultural land the time can't be too far for Ethiopia to be one of the major producers of rice crops in the whole world (Cai et al., 2022).

Corresponding to this, the Ethiopian Investment Commission (EIC) has identified the main potential rice areas in Amhara, Benshangul, Gambella, SNNPR, Oromia, and Somali areas. However, the suitability of those probable areas has not been well-studied. Therefore, to ensure the higher productivity of rice crops one must encourage the crops where they suit best and for which the first and fundamental requirement is to carry out a land suitability assessment (Nisar Ahamed et al., 2000). Suitability is a determination of crop requirements matching with land characteristics. Land suitability assessment must be evaluated in such a way that local needs and situations are reflected well in the final decision-making process (Anusha et al., 2023).

Multi-criteria decision-making (MCDM) can be thought of as a process that combines and transforms various spatial data inputs into an outcome decision output (Lindfors, 2021). MCE methods are used in some Regional planning processes since they aim at “estimating the potential of land for alternative land uses, among which agricultural land use being the most important area where it is applying” (Chen et al., 2010). This method could play a significant role in future land-use planning (Huang, 2012) (Huang, 2012). Agricultural land suitability classification founded on indigenous knowledge was the key to land use planning. The scientific analysis of land aims to identify potential areas and put into practice future alternative land uses that will best meet the needs of the societies, while at the same time preserving land resources for the future (Boliko, 2019).

In this study, the aim was to assess the suitability of rain-fed rice crop cultivation using a GIS-based multi-criteria decision-making technique to categorize the study area regarding the quality of land for rice crops. The study was applied in the Fogera Woreda, west-central highlands of Amhara Regional State of Ethiopia. This area has been selected as a primary location for rain-fed rice crop cultivation endorsed by the Ethiopian Investment Commission (EIC). This study could support agricultural insurance by the identification and classification of land-based capabilities with socio-economical, biophysical, and environmental potential.

1.2 Statement of the Problem

Ethiopia is among the countries facing significant challenges in terms of population size and food security in Africa. Agriculture serves as the foundation of the country's economy, employing a large portion of its population. With vast arable land, water resources, and diverse climates, Ethiopia has great potential for agricultural crop cultivation. However, accurately selecting suitable land for specific crops remains a persistent and critical issue (Suruliandi et al., 2021). The classification of land into different capability classes based on soil, climate, topography, and other factors is essential to determine the most suitable land for different crops, highlighting the importance of precise land use types (Szarek-Iwaniuk et al., 2022).

Land suitability analysis is important for the planning and sustainable management of land resources, used to assess the land's potential for various uses (Herzberg et al., 2019). With the country's population steadily increasing, the demand for shelter and food has also risen, posing a significant challenge. These factors pose a serious threat to land resources, leading to issues like land degradation. Utilizing land according to its potential is key to ensuring sustainable use (Boliko, 2019). Analyzing the suitability of land for agricultural purposes involves processing spatial data on soil properties, topography, and climate conditions to align land capabilities with the needs of rice cultivation (Arouna et al., 2023).

Despite the significant number of farmers involved in rice cultivation, many fail to realize the extent of their impact through their hard work and dedication. While rice plays a vital role in the livelihoods of many households and serves as a main income source in the Region (Takele, 2010), research on rice cultivation has been limited. Existing studies have mainly focused on aspects like adoption rates, trends, and marketing strategies in rice cultivation. However, there is a lack of systematic information on the potential areas suitable for rice cultivation.

The main objective of this study is to address the underutilization of rice crops in the Amhara Regional State and Ethiopia as a whole, particularly in terms of technological support, especially in geospatial analysis. The agricultural sector is still developing to meet domestic demand and currently relies heavily on imported rice. Therefore, this research aims to assess the suitability of land for rice cultivation in the Fogera Woreda using a GIS-based MCE approach, providing valuable insights for experts in the field.

1.3 Objectives of the Study

1.3.1 General Objective

The main objective of this study was to analyze land suitability for producing an economically important crop, rice, in the Fogera Woreda, using a GIS-based MCE method.

1.3.2 Specific Objectives

The particular goal of the study was to evaluate land suitability for rice cultivation through the use of a GIS-based multi-criteria evaluation approach.

The specific objectives were formulated to:

1. Examine the factors that are necessary for selecting rice cultivation suitability sites.
2. Analyze the suitability of land for rice cultivation areas in the Fogera Woreda using GIS-based MCE approaches.
3. Determine potentially suitable areas for the rice crops and produce its thematic map.

1.4 Research Questions

The research seeks to answer the following questions framed to achieve the above-mentioned objectives about the suitability of land for rice cultivation integrating GIS and MCDM in the case of Fogera Woreda (Ethiopia).

Hence, the critical questions would be:

1. What are the necessary factors for selecting rice cultivation suitability sites?
2. How to analyze the suitability of land for rice production areas in the Fogera Woreda using GIS-based MCE approaches?
3. How to determine potentially suitable areas for the rice crops and produce its thematic map?

1.5 Significance of the Study

The study produced valuable insights on assessing land suitability for rice cultivation through a GIS-based MCE method. This method enabled a comprehensive and accurate analysis of potential rice cultivation areas. The integration of the MCE method with GIS technology in land suitability assessment provides essential data for understanding past land use and predicting future changes.

The study's results assist land managers and planners in identifying areas with physical constraints for different land uses. Additionally, the findings offer a user-friendly tool for decision-makers, including farmers, to improve rice crop cultivation and yield, while also laying the groundwork for researchers to explore innovative approaches to increase rice cultivation and enhance export revenues.

1.6 Scope of the Study

This study was undertaken in one Woreda, namely Fogera which is one of the major rice-producing districts in Amhara National Regional State (ANRS). It covers a total area of around 1111.4 km^2 with 35 rural and 4 Woreta town kebeles. The study was focused on the identification of potential land for rice cultivation by using multi-criteria decision approaches through GIS techniques. Moreover, this study also employed only the following land and climatic factors such as; climate conditions, topography, LULC, and soil properties used to assess land suitability levels of the study area for rice crops.

1.7 Limitations of the Study

This study has attempted to identify potential rice cultivation areas in Fogera Woreda and has successfully achieved its objectives. However, current security issues and the state of emergency in the Region have an impact to move for gathering socio-economic data, collecting and verifying current LULC data, and validating the final result of the study area.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1 Introduction

This chapter tries to present relevant definitions and concepts, and related literature including conceptual issues regarding rice cultivation from global to study area perspectives, rice adoption, trend and expansion in Ethiopia, land suitability analysis for sustainable development, land suitability analysis for rice cultivation, factors that affecting land suitability for rice cultivation, constraints associated with rice cultivation in Fogera Woreda, GIS applications for land suitability assessment and also addresses multi-criteria analysis for land suitability assessments.

2.2 Definitions and Concepts of Terms

To increase understanding of the land suitability and GIS methods, key terms and conceptual issues are described as follows.

Suitability refers to the appropriateness and fitness of a particular kind of soil for a well-outlined purpose. The evaluation might ponder the soil in its current state or take into account any advancements that possibly might be undertaken. The procedure for assessing soil suitability comprises assessing and categorizing distinct pieces of soil grounded on their appropriateness for specific uses. Soil suitability categorization assists us in apprehending which parts of soil are most fitting for different objectives, contemplating both inherent resource characteristics and human soil inhabitation.

Land suitability analysis (LSA) is a method of land evaluation, which measures the degree of suitability of land for a certain usage (Feizizadeh and Blaschke, 2013). Suitability involves aligning crop requirements with land characteristics, and it is a measure of how well the qualities of land units match the requirements of a particular form of land usage (Boliko, 2019). Suitability analysis can respond to the question - to cultivate and where?

Land suitability analysis indicates the assigning of values to alternatives that are evaluated along multiple decisions or criteria (Muzira et al., 2021). These criteria are detrimental to land suitability assessments for different land use types. Land suitability analysis evaluates many alternative land uses under numerous criteria from various disciplines. Analyzing suitability is mostly based on the land potentials such as erosion resistance, water and nutrient availability, rooting condition, drainage, and flood hazard. The value of land quality is a function of the evaluation and grouping of land types into orders and classes based on their appropriateness.

Geographical Information System (GIS) is a method used to determine the suitability of a given area for a specific purpose or activity. The fundamental principle is that each aspect of the landscape has basic characteristics that are either suitable or unsuitable for the planned activities. It involves evaluating many factors, such as environmental conditions, socioeconomic considerations, and land characteristics. GIS provides critical decision support –makers by assisting in site selection and land use planning. GIS enables us to assess land suitability by analyzing spatial data, considering diverse factors, and making informed decisions concerning land use and development.

Multi-criteria decision-making (MCDM) has become a familiar approach used by decision-makers in the daily business of making the best choices at the business or administrative levels of various organizations. It has proved to be a reliable method that performs its functions by incorporating multiple sets of procedures. All the methods that constitute this technique are geared towards supporting decision-makers in executing their roles of decision-making (Jafari and Zaredar, 2010). As MCDM took center stage in decision-making problems, several methods have been formulated to supplement the technique. Some of these very important methods include the Multi-Attribute Utility Theory (Akpan and Morimoto, 2022), and the Analytical Hierarchy Process (Saaty, 1987).

The analytical hierarchy process (AHP) is one of the multi-criteria decision-making systems first discovered by Thomas Saaty (Prof.). It is a theory of measurement through pairwise comparisons and depends on experts' judgments to derive important scales. Its use of pairwise comparisons can allow decision-makers to weigh factors and compare alternatives with relative ease.

2.3 Rice Cultivation: An Overview

The rice crop is the most important source of food around half of the world's population. Rice is the food that people have harvested, eaten, and grown for more than 10,000 years worldwide, longer than any other crop. Global cultivation of rice has enhanced gradually from around 200 million metric tons (MT) of unmilled rice in 1960 to over 678 million MT in 2009. Rice represents 29% of the total output of grain crops produced universally (Belayneh and Tekle, 2017).

In South and East Asia, rice accounts for more than 90% of the worldwide rice crop. China is the world's top producer and consumer nation. Africa accounts for as it were 3% of worldwide cultivation (Junichi, 2022). The major limiting factor for the cultivation of rice is not climate, but water supply. Rice is the only major crop that can be cultivated in standing water in vast areas of flat, low-lying tropical soils and is uniquely adapted for growth in water-logged conditions. Rice is growing in the tropical and subtropical regions of most continents. It is produced under broadly differing conditions because of the great cultivar diversity (Belayneh and Tekle, 2017).

2.4 Rice Cultivation in Africa

In Sub-Saharan Africa (SSA) agricultural development is more significant for poverty reduction and food security (Vetterlein, 2012). Along with the major cereals developed within the area, the significance of rice is presently expanding quickly (Singh et al., 2021). Rice has become a highly strategic and priority product for food security in Africa. Consumption is growing faster than that of any other major essential food in the continent because of high population growth, rapid urbanization, and changes in eating habits (Camacho et al., 2018).

Africa produced an average of 26.4 million tons of rough rice in 2012 (Eves. et al., 2021). By 2020, SAA rice paddy cultivation will have increased from 18.4 million tons (Mt) in 2010 to 46.8 Mt, with the yield improved by research and development activities (Djagba et al., 2019). Rice is becoming an increasingly accepted nutrition in Africa because it is easy to store and cook; it is tasty and can be used for a large variety of dishes. It is grown in more than 75% of African countries, with a joint population of close to 800 million people.

Africa has suitable land and water resources to produce enough rice to feed its population and, in the long term, generate export revenues. Rice cultivars, rice-based cropping systems, and the rice itself will, however, undergo adaptations and expansions to meet future demands for both the food security of the growing population and environmental protection (Omoyajowo et al., 2023). The challenge posed by climate variability and change is a compelling factor in fast-moving the innovation process and this requires cooperation among many scientific disciplines and stakeholders. Rice study and development, including market access, will, therefore, follow consistent paths (Mohamad et al., 2021).

With the rapid development of the rice sector, new actors, and new public-private companies are appearing. Many of these actors are not used to working with each other, and chances for co-learning and negotiation will need to be explored and evaluated. With more and more actors involved in the rice sector in Africa, increasing an understanding of the changing roles and patterns of interaction, and how these can be facilitated, will help improve overall system performance (Djagba et al., 2019).

2.5 Rice Adoption in Ethiopia

Rice is an emerging crop in Ethiopia and one of the economically important crops in the Amhara Region. Some reports have shown that the cultivation of rice in Ethiopia started first at Fogera and followed at Gambella Plains in the early 1970s. It was believed that a Dutch man introduced rice first in 1973 from Fogera to the Gambella Plain in the Gambella Region (Belayneh and Tekle, 2017). Another author Portuguese, in the sixteenth century, brought rice (*Oryza sativa*) with them for the cultivation of this grain crop in Ethiopia (Almgard, 1963).

Other author rice cultivation in Ethiopia is supposed to have started around 1957 in Metahara, along with the Awash River. Later rice adaptation and screening experiments were started and studied at Fogera, Gambella, Melkaworer, Debre Zeit, and Arbaminch from 1968 to 1988 by various organizations (Ndue et al., 2023). Ayanaw (2023) reported that rice cultivation had probably been initiated in Ethiopia when the wild rice (long staminate) was observed in the swampy and waterlogged areas of Fogera (locally known as zurha) and Gambella plains. So, evidence has indicated that cultivation of the rice crop in Ethiopia was first started at Fogera and Gambella plains in the early 1970’s.

Although rice was begun and tested initially in many areas of Ethiopia such as Gambella, Pawe, and Woreta at the beginning of the 1970s, due attention was not given before the mid-1990s (Abera et al., 2021). Since the mid-1990s, however, around seven upland rice diversities including four NERICA varieties have been released. Currently, the released varieties, especially, NERICAs, have been under dissemination and expansion in different agro-ecologies of the country, from lowlands of 750m to areas of about 2000m elevations by different governmental and non-governmental organizations. In addition, the cultivation of rain-fed new rice varieties (NERICA-3 and 4) has been started since 2006 in the Oromia Region in Jimma, Iluababora, and West Wellega Zones and former SNNPR in Hadiya Zone (Dessie and Mulat, 2019).

Ethiopia is known for its diverse agricultural practices, including the cultivation of various rice varieties suited to different regions and climates. These varieties reflect Ethiopia's efforts to enhance rice production through breeding programs, promoting resilience against local challenges such as drought and pests, and improving overall food security in the country. Here are some notable rice varieties grown in Ethiopia:

1. **NERICA (New Rice for Africa)**: These are high-yielding rice varieties developed through a cross between African and Asian rice species. They are known for their adaptability to various African environments, including those in Ethiopia.
2. **Farmer-Preferred Local Varieties**: Many farmers in Ethiopia grow traditional or local rice varieties that have been adapted over generations to local conditions. These varieties often exhibit resilience to local pests, diseases, and climate variations.
3. **Improved Varieties**: Various improved rice varieties have been developed and promoted by research institutions and agricultural organizations in Ethiopia. These varieties are typically bred to be higher-yielding, disease-resistant, and better adapted to local conditions.
4. **Bilikis**: This is a popular variety grown in the Gambella region of Ethiopia, known for its good yield and adaptation to the local environment.
5. **Koumbia**: Another variety grown in Ethiopia, particularly in the Gambella region, is known for its tolerance to drought conditions.

6. **Faro 52**: Developed by the Africa Rice Center (AfricaRice), this variety is known for its high yield potential and suitability to African rice-growing conditions, including those in Ethiopia.
7. **WITA 4**: An improved variety developed by the West Africa Rice Development Association (WARDA), now known as AfricaRice. It is adapted to rainfed lowland ecosystems common in parts of Ethiopia.

2.6 Rice Cultivation and Expansion in Ethiopia

Rice cultivation in Ethiopia began a few decades ago and now the country is proven to have reasonable potential to grow diverse rice types for rain-fed lowland, upland, and irrigated ecosystems. Rice is currently recognized as a strategic food security crop and its use as a food crop, source of income, employment opportunity, and animal feed has been well-known in Ethiopia (Berhe et al., 2024). The demand for improved rice innovations is expanding from time to time from distinctive partners. This, therefore, calls for the desire to establish a strong research and development organization to bring about a productive, sustainable, stable, and profitable rice agricultural system in the country (Tarekegn and Fiseha, 2016).

In Ethiopia, rice is among the target commodities that have received due emphasis in the promotion of agricultural cultivation, and as such it is considered the "millennium crop" expected to contribute to guaranteeing nourishment security in the country. Currently, mainly small-scale farmers grow rice in different parts of the country, but it is also produced by large-scale farms in a few places mainly in the lowlands of the country (Sikuku et al., 2015).

Despite the huge potential of the country to produce various rice types, the crop is not under cultivation in many parts of the country. Nowadays, rice cultivation is concentrated only in a few areas such as Pawe, Gambella, Fogera, Libo Kemkem, Dera, Denbia, Alfetakusa Woreda, Mizan Tefri, Jimma (Gojeb area), Melkaworrer, Arbaminch, North Shewa, South Wollo (Chefa), Dangila-Jewi, Bichena, Quora, Metema and Armachiho (Desta et al., 2019). Rice is a highly productive crop in Ethiopia next to teff, wheat, and maize. Its average cultivation in the 2017/18 fiscal year, a total area of 53,106 ha was covered with rice. That coverage area grew to 63,361 ha in the last fiscal year, while the yield has also increased by 14 to 1.2 million quintals. Amhara Regional State now produces about all of Ethiopia's rice, gathering 1.19

million quintals of rice from 41,700 ha of land that was harvested by 114,000 ranchers within the most recent fiscal year (Beyene et al., 2022).

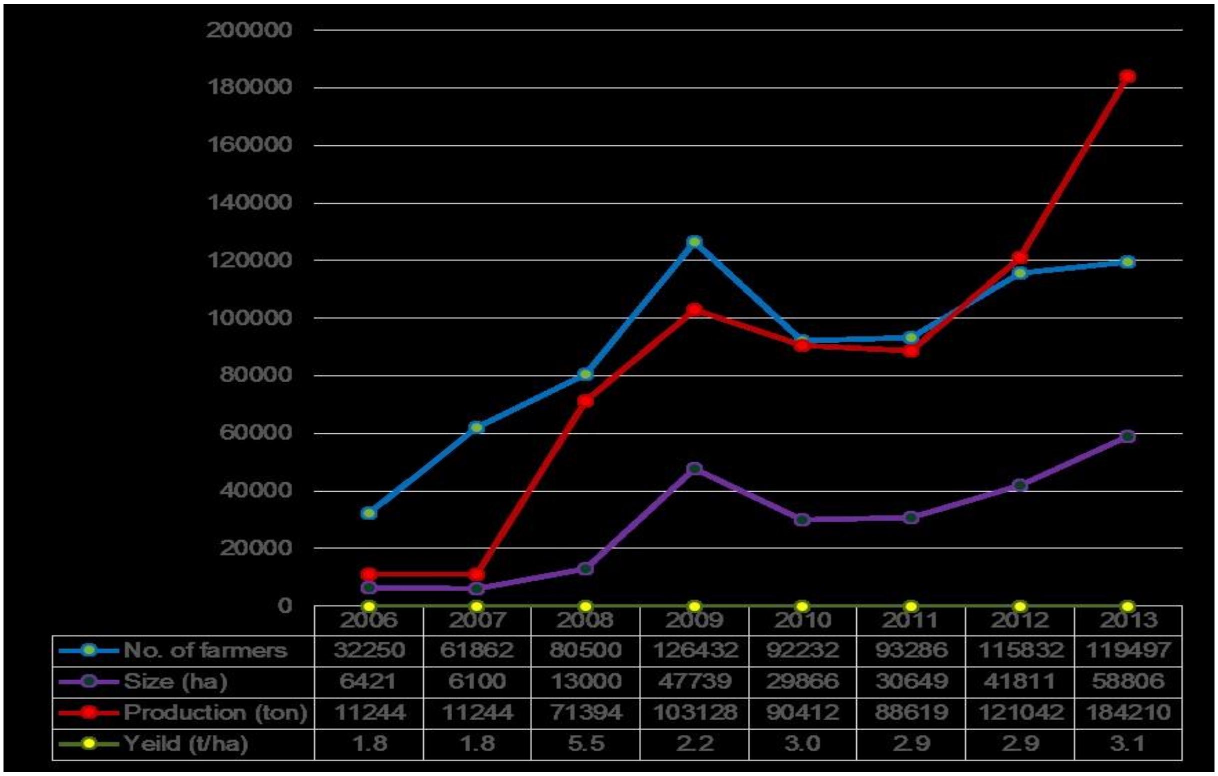

Figure 2. 1 Rice production trend in Ethiopia

Source: (Dawit, 2018)

2.7 Rice Cultivation in Fogera Woreda

Fogera Plain is known as the major provider of rice cultivation in the country. It accounts for 70% of the rice grain amount that comes from this plain. Before starting the cultivation of rice crops in Fogera, the Woreda food was supported in the 1970s and 1980s and so far, the area was recognized typically for grazing land, livestock rearing, small-scale crop cultivation using residual moistures, as well as being sparsely populated (Tilahun et al., 2021).

Rice cultivation started in July 1984 in the seasonally flooded plains of Lake Tana (submerged in water every rainy season) as a pilot project entitled "Ethio-Jigna Development Project'' including the agricultural cooperatives Jigna and Shaga cooperatives with thirty young farmers supported by nine North Korean agricultural experts. The objective of the pilot project was to establish and promote rice and horticultural crops first in the two cooperatives. The introduction of rice cultivation in the Region changed the livelihood of the farmers in the Fogera Plain radically. Apart from playing an important role in abating the problem of food insecurity in the Fogera, rice cultivation increased the revenues of farming households considerably (Hagos and Zemedu, 2015).

Figure 2. 2 Rice value chain processes

Source: (Agro BIG, 2016)

Fogera has become a densely populated area and non-flooded agricultural farming (onions, vegetables) crops are prospering. Nowadays, in local terms, rice farmers from Fogera are “rich” (Asmare and Yayeh, 2018). That is the reason the first introduced variety is still called x.Jigina- the introduction of x. Jigina in the Region changed the livelihood of farmers from the poorest to the wealthiest and currently in the Fogera plain, rice plays an important role in abating the problem of food insecurity in the farming community (Migongo et al., 2012).

Figure 2. 3 Fogera rice cultivation trend by volume

Source: (Agro BIG, 2016)

2.8 Land Suitability Analysis for Sustainable Development

From a land use planning perspective, to ensure long-term productivity and sustained land use, land use systems should be well suited to the inherent characteristics of the land. Land suitability assessment plays an important role in this regard (Xu et al., 2024). Land contains the physical environment to the degree that it affects the capability for land use, including climate, relief, soils, hydrology, and vegetation. This involves the effects of past and current human activity, e.g. sea reclamation, clearing of forests, and even negative results, e.g. soil salinity (Setyowati, 2021).

Evaluation and grouping of areas of land in terms of their suitability for a given use is the process of classification of land capacity. The key objective of the land analysis is to evaluate the intrinsic capacity of a land unit to sustain, for a long period without reduction, the specific use of land to reduce socio-economic and environmental costs (Hirunkul et al., 2003).

The broadly specified study of land suitability aims to determine the most suitable spatial pattern for future land use according to requirements, expectations, or predictors of certain activities (Moisa et al., 2022). Land suitability has been studied in terms of topography, soil, climatic variables, ground cover, and interrelationships between landforms. Land-use suitability methods enable land-use managers and planners to analyze the interactions among three types of factors: location, development action, and environmental elements (Rinner and Voss, 2013).

2.9 Land Suitability Analysis for Rice Cultivation

Land suitability assessment is the separation of the essence or condition of the land into its parts, based on the quality of the land to serve a specific use or purpose. High land suitability implies that the land has a relatively high number of portions that it involves to serve a specific use or purpose. In contrast, low land suitability analysis implies that the land has relatively small numbers of parts that need to serve a specific use or purpose (Keson et al., 2023).

Each part of the Earth's landscape has a different set of characteristics that make it more suitable for certain uses than others. The concept of land suitability for uses was successfully developed by the late Ian McHarg, former professor of urban design and landscape architecture at the University of Pennsylvania. The definition of land suitability can also be discussed in a more specific way through McHarg's discussion of using the land for suitability evaluation (Keson et al., 2023).

The management of natural resources is a cross-boundary issue that should be emphasized in all planning processes within a multi-sectoral approach (administrative and geographical). Land suitability is part of land use planning and defines potential alternatives for future land use and supports to define these relationships (policies, agencies, and data management) (Kalfas et al., 2023). Land suitability is the qualification of a given type of land for a defined use. The classification and grouping of areas of land in terms of their suitability for specified uses is the process of land suitability assessment (Agidew, 2015).

The way society uses the land depends on the available skills, knowledge, culture, and experiences. The land suitability analysis is similar to the identification of a suitable site, except that the aim is not to isolate the best alternatives but to map the suitability index for the entire study area. Kozlowski (1993) combines the UET (Ultimate Environmental Threshold) method with map overlays to evaluate land suitability for development. Labella and Martínez (2020) also use map overlays to define homogeneous zones, but then they apply classification techniques to assess the agricultural land suitability level of each zone.

Combining GIS and MCDA is a powerful approach to land suitability assessments (Mendas and Delali, 2012). Land suitability is analyzed based on the quality of the land. The quality of land is a complex feature of land that directly affects land use (Song et al., 2023). These attributes are properties of soil, landform information (topography), land use, and climatic factors. Most land qualities are determined by the interaction of several land characteristics, which are measurable attributes of the land. The importance of land quality is the role of evaluating and grouping land types in the sense of their fitness into orders and groups.

Land suitability is categorized as suitable (S) and not suitable (N). Whereas S has lands that are ideal for use with better advantages, N denotes land qualities that do not allow the form of use considered or are not suitable for appropriate results (AL-Taani et al., 2021). The suitability of land is significant for the future biological productivity of land. Land productivity can be determined by environmental essentials such as temperature, local topography (roughness, steepness, and exposure), soil type, and LULC.

Land suitability classification is developed by considering different factors of land characteristics. The classification of the suitability of the land is calculated by considering different factors relating to the characteristics of the land. Based on the suitability of each criterion, a weighted value ranging from 4 (least suitable) to 1 (most suitable) is given. The weighted value of each criterion is reclassified for each land use. Each criterion is given a value depending on its suitability for each category. The weighted value of each land characteristics criteria is added and the average value of them is engaged to determine the suitability of land for each land use type. The average value is categorized into four suitable classes to get the final suitability for each parameter.

Table 2. 1: Structure of the land suitability classification (adopted from FAO guidelines)

Order	**Class**	**Description**
Suitable (S)	Highly Suitable (S1)	Land without significant limitations. Include the best 20 - 30% of suitable land as S1. This land is not perfect but that can be expected.
	Moderately Suitable (S2)	Land that is appropriate but has limitations that either reduce productivity or enhance the inputs needed to sustain productivity associated with those needed for S1 land.
	Marginally Suitable (S3)	Land with limitations so severe that profits are reduced and the inputs needed to sustain cultivation are improved so that this cost is only marginally justified.
Not suitable (N)	Currently not Suitable (N1)	Land with restrictions to sustained use that cannot be overwhelmed at a current acceptable cost.

Land suitability assessments using a scientific approach are essential to evaluate the potential and constraints of a given land parcel for agricultural purposes (Brennan and Venigalla, 2016). In recent years, the negative effects of land use on the climate and the environmental sustainability of agricultural cultivation systems have become a matter of concern. The problems of declining soil fertility, stagnant yield levels, and unfettered soil erosion are associated with intensive agriculture in industrialized countries. In contrast, over-exploitation of natural resources and lack of inputs such as chemical fertilizers are associated with intensive farming in developing areas (Kongolo and Dlamini, 2012).

Land evaluation and crop suitability analysis using multicriteria evaluation integrated with GIS would resolve these issues while providing better land-use options to the farmers. Therefore, it is vital to evaluate crop suitability under different systems that could be grown in each Region.

GIS is an important help for decision-making in space (Singha and Swain, 2016). Developments in GIS have led to important improvements in its capability for decision-making procedures in land allocation and environmental management (Gebre et al., 2021).

Suitability analysis is a methodology or a set of analytical procedures that use their geographic feature spatial relationships to simulate real-world situations within a GIS to classify geographic areas that are optimally suitable for specific land use. To identify geographical areas that are optimally suitable for specific land use, the creation of criteria is essential. There can be two types of criteria: factors and constraints. Constraints are Boolean parameters that restrict the analysis to a specific geographical area (i.e. limit). Factors, on the other hand, are criteria that determine a certain level of appropriateness for all geographical regions (Bahaj et al., 2020). The composite effect of physical factors describes the degree of suitability and support to further classify the land into various development classes.

2.10 Factors that Affecting Land Suitability for Rice Cultivation

Rice cultivation is sensitive to biophysical factors such as climate, topography, soil characteristics, and farming practices (Hashim et al., 2024). Landform information, soil properties, LULC, and climate conditions are the criteria required for the cultivation of rice in the study area. The factors, which were stated above, are the major physical factors, which were considered in determining the cultivation of rice crops in the study area. All these factors do not have the same influences on crops. Some crops want one factor more than the others. These factors bring different impacts on cultivation. Therefore, the weight given for the rice crop depends on their requirements.

2.10.1 Climate Conditions

Fogera Wereda’s climate and weather conditions play a significant role in rice cultivation. Rice is typically produced in areas with warm and humid climates, and it desires a substantial amount of water for proper growth. The availability of rainfall, temperature patterns, and the length of the growing season can all impact the success of rice cultivation in the area.

2.10.1.1 Rainfall

Rainfall is the most important factor governing the distribution of rice cultivation areas. The distribution of rainfall varies greatly across the study area, according to season, altitude, and physical features of the landscape. Clear annual patterns are evident, although rainfall is extremely variable. Rice crop requires rainfall ranging between 1000 and 1500 mm per year (Adamu et al., 2012). If the rainfall pattern is well distributed hence favoring the cultivation of rice. Annual rainfall in the rice cultivation Regions of Ethiopia varies from 1300 to 2000mm (Shitu et al., 2023).

2.10.1.2 Temperature

According to (Moat et al., 2017), the ideal average minimum temperature for rice crops is 13 - 15˚C, which in most cases occurs. The ideal average temperature is 18 - 23˚C, with an ideal average maximum (daytime) temperature of 25 - 27˚C. Maximum temperatures of 27 - 30˚C are not harmful if they exist for short periods (hours), and if there is sufficient water available in the soil. According to Joseph et al. (2023), rice does not well under temperatures of 15 and above 28°C. These temperatures overcome in most of the country's rice-producing areas.

2.10.2 Soil Characteristics

Soil fertility can be used to describe the availability of nutrients for plant uptake and in the broader context can result from soil type, soil organic matter status, soil properties including salinity or alkalinity, as well as the concentration of available nutrients should be reflective of land use. The type and quality of soil in the study area can affect rice cultivation. In rice, like any other agricultural activity, soil contributes a larger percentage of influence towards the crop. Rice generally needs fertile soils with good water-retention capabilities. The existence of nutrients, soil pH levels, soil depth level, and soil texture can impact the efficiency and health of rice crops in the area.

2.10.3 Land Availability and Topography

The availability of suitable land for rice cultivation is vital. Flat or gently sloping terrains are favored for rice farming as they facilitate water management and prevent waterlogging. The size and quality of available land for rice cultivation can determine the scale and productivity of rice crops in Fogera Woreda.

According to (Zenna and Berhe, 2009), rice cultivates at various altitudes, ranging from 1700 - 2500m above sea level in the study area. However, the majority of rice crops are produced in altitudes ranging from 1800 - 2300m above mean sea level.

Slope describes the vulnerability of a location to erosion and determines the potential for mechanization. Thus, flat or low slopes are best, as steep slopes desire major soil conservation practices and reduce the efficiency of agricultural practices.

2.10.4 Farming Practices and Technology

The adoption of appropriate farming practices and technologies can significantly influence rice cultivation. Factors such as seed selection, planting methods, crop management techniques, pest and disease control measures, and post-harvest handling practices can impact the yield and quality of rice crops in the Region.

2.10.5 Socioeconomic Factors

Socioeconomic factors, such as the accessibility of credit, farmers' access to information and extension services, land ownership patterns, and government policies, can also influence rice crop cultivation. These factors influence farmers' decision-making processes and their ability to invest in rice cultivation.

2.11 Constraints Associated with Rice Cultivation in Fogera Woreda

Rice cultivation is fundamental for food security and economic development, but it comes with its own set of obstacles. Here are some key constraints identified in the district of Fogera:

2.11.1 Traditional Means and System of Land Preparation

Means of land preparation (tillage, bunding, and leveling) in rice crop cultivation from the study area have been undertaken by all farmers using animal plowing. There is no mechanized way like by using tractor machines. Land preparation for lowland rice cultivation starts with the bunding and leveling of the field to impound water and permit even flooding. The land for rice cultivation has to be plowed repeatedly in summer to acquire the necessary depth. For successful deep-water rice culture extra leveling of land, in addition to deep plowing, is the first aim of land preparation.

2.11.2 Insufficient Mechanization

The lack of modern machinery and equipment for land preparation, planting, and harvesting hinders the efficiency and productivity of rice cultivation. Farmers often rely on traditional methods, which can be time-consuming and less productive.

2.11.3 Market Failure of Improved Varieties

While the trend of rice marketing has improved in terms of supply to the Woreda market over the last decade, there are still market-related challenges. Despite advancements in rice varieties, inadequate market access and awareness prevent farmers from adopting the improved seeds. Market failures for improved rice varieties can impact farmers' income and overall productivity.

2.11.4 Harvest and Post-Harvest Management

Proper handling and storage of rice after harvest are critical for maintaining quality. Inadequate post-harvest practices can lead to yield losses during this phase like pests, diseases, and poor storage conditions.

Agriculturalists didn't use harvesting machines within the last ten years ago among the time interval of 2008 to 2018 in the area of study. Even they didn't get access to and use any harvesting machine since they started rice cultivation in the 1970s. This has been a challenge for quite a long time for the farmers harvesting rice manually which wastes their time, energy, and resources.

2.11.5 Lack of Awareness of Improved Agronomic Practices

Farmers need education and training on best practices, including proper seed rates, fertilization, and other agronomic techniques. Raising awareness about improved techniques can enhance rice productivity.

2.12 The Role of Geospatial Technologies for Land Suitability Analysis

2.12.1 GIS Applications for Land Suitability Analysis

The feature of GIS is its capability for analysis due to the integration of spatial and attribute data. GIS can not only be used to prepare maps automatically but is unique in its capability to interpret and spatially evaluate multi-source data sets like land use data, population, topography, hydrology, climate, vegetation, transport network, public infrastructure, etc. The data is manipulated and analyzed to gain information useful for a particular application like land-use suitability analysis (Ferretti, 2011).

According to Seftin and Wati (2022), the purpose of GIS is to provide support for the way of making spatial decisions. Many data layers need to be treated in multi-criterion evaluation to arrive at suitability that can be easily accomplished using GIS. GIS allows the consumer to assess which locations are most/least fit for purposes in the sense of land suitability assessment. The findings of GIS analysis also may provide help for decision-making in this context. It also enables the creation and modification of any land suitability analysis that makes the best use of available data.

2.12.2 Multicriteria Analysis: For Land Suitability

Multi-criteria decision-making is a concept that includes multiple attribute decision-making (MADM) and multiple objective decision-making (MODM). MADM is functional when a choice out of a set of separate actions is to be made. It is supposed in MODM that the best solution can be found anywhere in the space of feasible alternatives and is therefore viewed as a problem of continuous decision. MADM is often referred to as MCA or MCE. Instead, MODM is like Pareto's optimal search using mathematical programming procedures (Takagi et al., 2023).

To define the suitability of an area for a specific purpose, several criteria need to be evaluated. MCDM or MCE has been developed to improve spatial decision-making when a set of alternatives needs to be evaluated based on incompatible and disproportionate criteria. MCE is an effective tool for multiple criteria decision-making issues and aims to investigate several choice possibilities considering multiple criteria and objectives. Crop-land suitability analysis is a precondition to achieving optimal utilization of the available land resources for sustainable agricultural cultivation (Xiao et al., 2020).

In MCDM, every criterion is weighted to represent its impact on the phenomenon. These are dependent on the nature of the alternatives under consideration, the factor used to compare alternatives, and the weights derived for the factor. MCDM involves input data, the decision maker's preference, and manipulation of both information using identified decision rules. In this spatial, multi-criterion decision-making approach, the input data is geographical. In this study topography, soil properties, and climate variables have been identified for suitability analysis of rice cultivation. Then, the fundamental factors, including slope, soil type, soil texture, soil depth, soil pH, LULC, temperature, and rainfall were chosen based on the expert's knowledge and consideration of literature inputs.

2.12.3 Analytical Hierarchy Process

This method is one of the popular techniques used in any condition where decision-making involves examining the best choice from various alternatives. It is employed by multi-criteria decision-making. In some literature, it is stated as the Saaty method. This is because it was first designed by Thomas Saaty in 1970. The main characteristic of the AHP method is the use of pair-wise comparisons.

Complex problems constantly require a rigorous decision-making process which can break the problems into manageable levels. A problem is revealed to have been completely solved if the best consideration and choice are used to realize the stated goal. By use of hierarchical arrangement on the way to solving any problem, every criterion that may be involved in the process is measured and given a chance to contribute some impact (Taiwo, 2022).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

3.1.1 Data Type and Their Sources

In this study topography, properties of soil, LULC, and climate variables are selected for land suitability assessment of rain-fed rice cultivation. Then, eight causal factors, including slope, LULC, soil type, soil texture, soil depth, soil pH, temperature, and rainfall are identified depending on local expert's knowledge and consideration of different literature inputs.

Table 3. 1: Data and their sources

No.	**Main Criteria/ Datasets**	**Sub-criteria/ Layers**	**Type (data format)**	**Data Sources**	**Resolution**	**Year**	**Purpose**
1	Climate	Temperature & Rainfall	Excel	Ethiopian Meteorology Agency (EMA)		1994 -2023	Temperature and Rainfall map
2	Topography	DEM/elevation and slope	Raster/Tiff	Sentinel1-A (https://scihub.copernicus.eu/.)	10m	2023	Slope map
3	Soil	Soil type, soil depth, and soil pH	Raster/Tiff	Ministry of Agriculture (MoA)	250m	2022	Soil type, texture, pH, and soil depth map
		Soil texture	Raster/Tiff	ISRIC	250m		
4	Land use	LULC	Raster/Tiff	Landsat 8 image from USGS Earth Explorer	30m	2023	Current land use map
5		Administrative boundaries	Shapefile/ Vector	ESS former CSA		2020	Study area delineation

3.1.2 Methods of Data Collection

The achievement of any GIS application depends on the quality of the spatial data used (Xue et al., 2023). Collecting high-quality and up-to-date spatial data input for GIS is a critical stage. Data collection is one of the most time-consuming and expensive, yet important for GIS-based studies. GIS can comprise a wide variety of spatial data types originating from many diverse sources (Mao et al., 2020).

Data acquisition and preparation is the first fundamental step in GIS-based MCDM land suitability analysis. Various spatial and non-spatial datasets are gathered from different organizations related to rice crop suitability and processed using multiple GIS tools for analysis and mapping purposes. Secondary data sources were used to get relevant information and address the specified objectives of the study.

3.1.3 Tools and Software's Use

For this study the following software was used for data organizing, pre-processing, editing, processing, analyzing, visualization, and mapping of the result ArcGIS Pro was used; for satellite image processing, image stacking, classification, and accuracy assessment Erdas Imagine 2015 was used; SNAP (European Space Agency) for DEM generation, and Microsoft Excel was used for data analysis, research writing and presentation.

Table 3. 2: Software used for processing and analysis

No.	Software Type	Purpose
1	ArcGIS Pro 3.0	For suitability analysis
2	Erdas Imagine 2015	For LULC processing
3	SNAP	For DEM generating
4	Microsoft Office Packages (Excel, Word, PowerPoint & Access) 2013	For data analysis, research writing, and presentation

3.2 Description of the Study Area

Fogera is one of the 183 Weredas of the Amhara Regional State and is placed in the South Gondar Zone. It has 35 rural peasant associations (PAs) and 4 urban kebeles. Woreta is the capital city of Fogera Woreda and is found 625 km from Addis Ababa and 55 km north of the Regional capital Bahir Dar City. Fogera is bordered to the south by East Este Woreda, southwest by Dera Woreda, and west by Lake Tana, north by Libo Kemkem Woreda, east by Farta Woreda, and northeast by Ebinat Woreda. Geographically, it is found at 11° 57' 59.99" N and 37° 40' 59.99" E, covering a total area of 1111.4km².

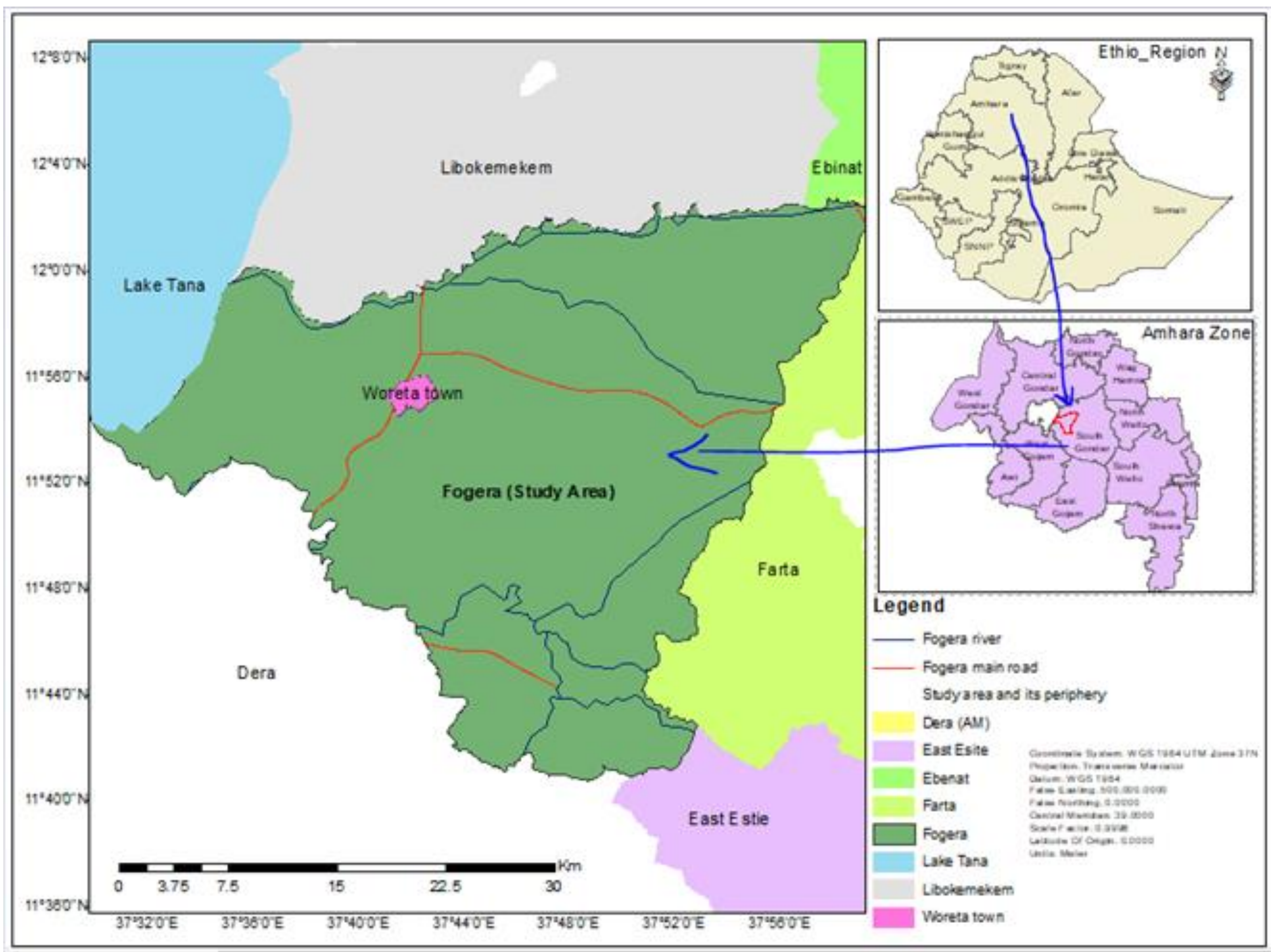

Figure 3. 1 Map of the study area

3.2.1 Physical and Socio-Economic Characteristics

The Woreda, also called the Fogera plane, has an extraordinarily level arrival and is located next to Lake Tana's eastern shore. But as you move east, the terrain becomes more rocky. The range of altitude is 1800–2500 meters. About 76% of the Woreda is made up of flat land, with the other 24% being made up of valley bottoms and mountain slopes. (Tilahun et al., 2017).

The Region is characterized by a subtropical plateau climate, which affects the temperature. In the Region, the mean monthly temperature is roughly 23 °C, the mean monthly maximum temperature is roughly 27.4 °C, and the mean monthly minimum temperature is roughly 15 °C. In Fogera Woreda, the average yearly temperature varies between 15 and 27 °C (NMA, 2018).

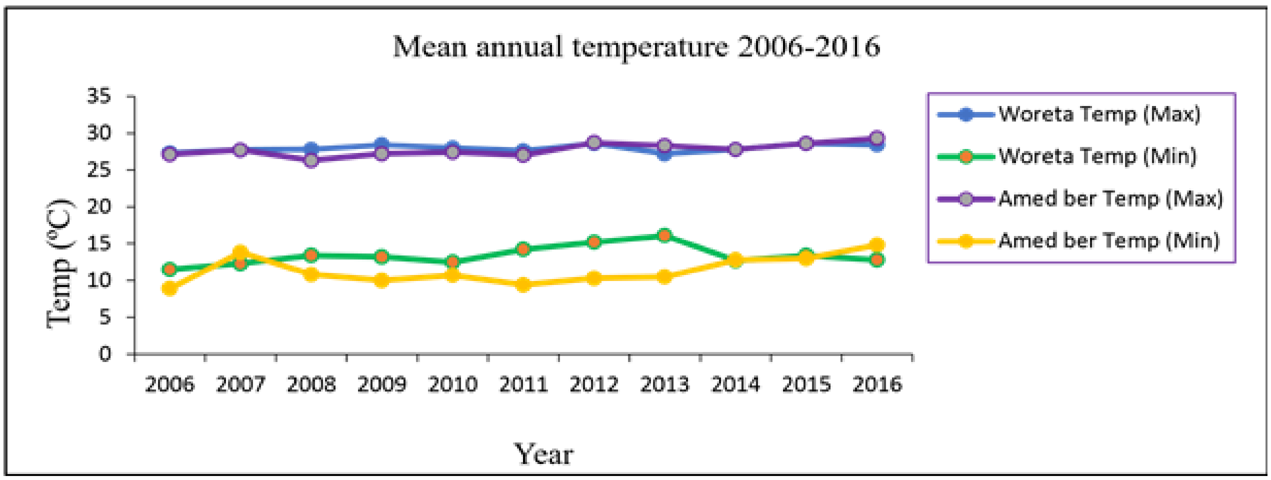

Figure 3. 2 Temperature distribution of the study area

According to the National Metrological Agency (NMA, 2015), the rainfall of the area is characterized by an unimodal distribution with the highest in July. The yearly rainfall ranges from about 1000 to 1500 mm from both the short (March and April) and long rains (June to September). The mean monthly values vary from 0.6 mm (January) to 415.8 mm (July), which shows the poor temporal distribution of rainfall.

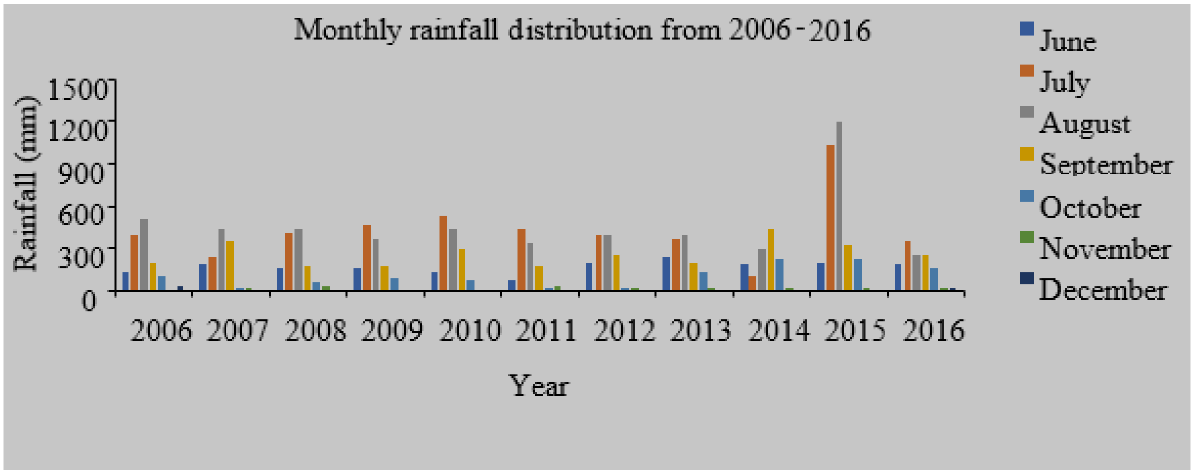

Figure 3. 3 Rainfall distribution of the study area

Source: (NMA, 2017)

Rice cultivation prefers soil with good water-holding capability, fertility, permeability, and a middle pH value. Sandy clay soil is usually the most suitable for rice (Asebu, 2021). The major soil types in the study area reveal a general relationship between altitude and slopes. According to the soil data from the Minister of Agriculture, the area has 9 main soil types. The dominant soil type is haplic xerosols typically in the lowland flat plains, valley bottoms, and river terraces.

In the northern and western Regions of the Woreda, which include the Fogera lowlands and are subject to flooding during the rainy season, the primary agricultural products are rice, fish, horticulture, and livestock. From the lowlands to the highlands, the agricultural products grown in the south and east include grains, oil crops, horticulture, cattle, and beekeepers. Native cattle are abundant throughout the plains. While rearing cattle remains a significant business, crop cultivation has grown in significance. The rice cultivation on the Fogera Plain and its distinction as the home of the rare Fogera Cattle breed set Fogera apart from other Woredas.

The LULC in Woreda is dominated by agricultural land, around 68% of the total land area was allocated to agriculture including farming and grazing land. The quantity of water bodies and swampy areas (wetlands) accounts for 21% of the total Woreda land mass (Mulugeta, 2014).

The main rice sowing season in Fogera is between June to July, grows until September, and is commonly harvested during November with some kebele trailing into December harvests. Most of the time rice is produced during the main rainy season in the study area.

Table 3.3: Study area rice crop calendar

June	July	August	September	October	November
Rice (main; wet season)	Sowing Growing Harvest				

According to the Ethiopian Statistical Service (ESS, 2007), the total population of the Fogera Woreda is around 233,529. The 2014-2017 population projection displays that Wereda's population in both sexes increased by 2%.

3.3 Methods

When analyzing the suitability of land for farming, many different factors must be evaluated to determine the best location for growing rice. GIS techniques integrated with a spatial multi-criteria decision-making approach was a method where geospatial data are combined and transformed into a decision. In MCDM, each criterion is weighted to represent its actual importance to the phenomenon. The study uses a multi-criteria assessment approach to combine environmental datasets such as topography, soil properties, current land use, and climatic conditions to identify suitable locations for rain-fed rice cultivation. Eight basic factors were then selected, including slope, soil type, soil texture, soil depth, soil pH, LULC, temperature, and precipitation, taking into account experts' and various literature. Constraints that limit or restrict the production of rice crops like settlement areas, religious institutions, forest areas, rock areas, grazing land, and water bodies particularly in a study area,

Using AHP as a supportive decision-making tool would help gain a better insight into complex decision problems. Structuring the problem as a hierarchy makes researchers consider possible decision criteria and select the most important parameter concerning the decision objective. Using pairwise comparisons supports the discovery of and corrects logical inconsistencies.

The suitability level of each criterion was classified as high, medium, unsuitable, and poor based on the property suitability classification structure. Factors were assigned weights according to the relative importance of the criteria. Pairwise comparisons were used to evaluate the parameters and the generated priorities were used to assign weights using the weight overlay tool in ArcGIS Pro 3.0. The weights of the criteria depend on the principal eigenvector of the decision matrix.

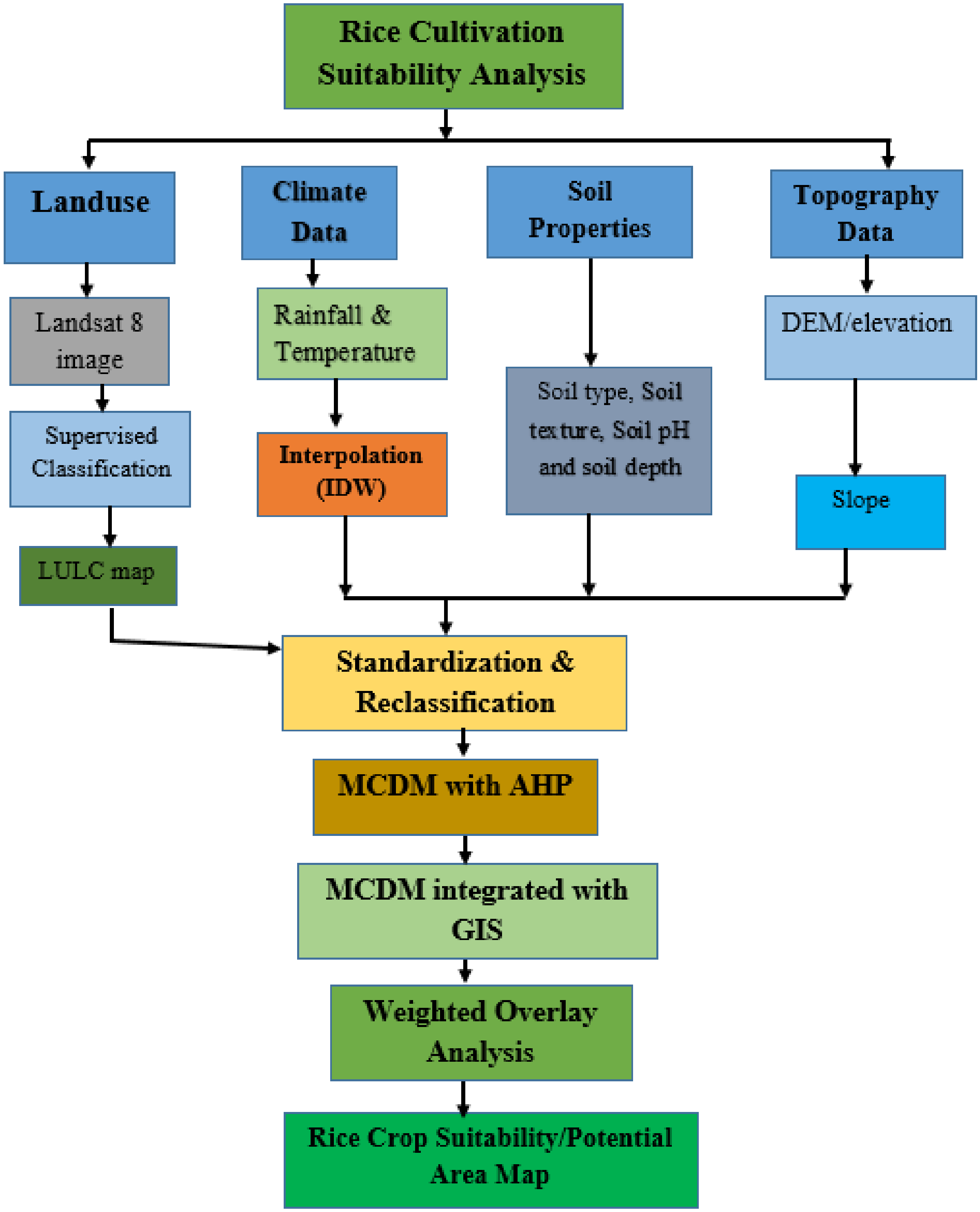

Figure 3. 4 Flow diagram of the method used for suitability analysis

3.4 Rice Suitability Evaluation Factors

3.4.1 Topographic Factors

The landform information of an area is an essential factor for land suitability evaluation in the area of study. The elevation and slope of a given area play a significant role in agricultural activities in general, and specifically for rice cultivation. The workability of the area, erosion hazard, and possible mechanization, especially for rice cultivation areas, depends on the slope or elevation of the area in one or the other way. The slope for cropland suitability assessment is a key variable when used with other variables, a slope is vital in site analysis and estimating suitability (ESRI, 2023). The slope is generally generated from a digital elevation model (DEM) using spatial analyst tools in ArcGIS Pro.

3.4.2 Climate Factors

Climate is one of the most important factors for land suitability analysis mapping. Climate influences the spatial and temporal variations of farming activities and land use patterns. Consequently, in the land suitability analysis climatic variables should be considered as diagnostic land qualities/land characteristics. It influences the growth, development, and yields of crops, including rice, favorably or unfavorably. The majority of the land uses are sustainably affected by rainfall, temperature, and humidity of the area (FAO, 2015). This study has used rainfall and temperature, to assess land suitability as a climatic factor. Rice being a tropical and sub-tropical crop was normally grown at a fairly high temperature – high rainfall regime, ranging from 21 to 27°C and 1300mm to 1530mm of annual rainfall (Sanogo et al., 2023).

3.4.3 Soil Factors

The suitability of soil for rice cultivation is another important factor. It is a vital element in our ecosystem. It provides an anchorage and nutrients to the crops. Thus soil is a fundamental raw material for the cultivation of any crops including rice. Rice generally grows well in fertile soils with good water-holding capacity. Subsequently, the information on soil characteristics is essential for rice cropland suitability analysis and mapping. The presence of nutrients, soil pH levels, soil depth, and soil texture can impact the productivity and health of rice crops in the study area. Soil information of the study area was obtained from the Ministry of Agriculture (Ethiopia) in raster form.

3.4.4 Land use Land cover

For this study, LULC is one of the main factors that are considered for rice suitability analysis. It is one of the most easily detectable indicators of human intervention on land. Because it can change quickly over time, it is also a good representation of the dynamics of the earth's surface resulting from a variety of factors (Chaemiso et al., 2021). Understanding the LULC status of a study area is highly essential for assessing and managing natural resources, land use planning, land evaluation, change detection, and monitoring environmental changes such as deforestation, drought, and land degradation.

3.5 Research Design

There are different types of research approaches. However, for this study, the quantitative research approach was applied to manage, pre-process, classify, and analyze the collected data. All the data was processed and weighted like soil, topography, LULC, and climate datasets related to suitability for rice cultivation and expressed in percent.

3.6 Methods of Data Processing and Analysis

Land suitability for agriculture contains various social, technological, environmental, and economic aspects. GIS-based MCDA is a method that interprets and integrates geographical data and preferences of decision-makers to obtain decision-making information (Malczewski, 2006). GIS-based MCDA provides a unique method that can manage and fit together a wide variety of variables analyzed in different ways, thus providing the decision-maker with valuable assistance in pointing at suitable locations.

3.6.1 Criteria Determination

For land suitability analysis of rice crops, there is no uniform standard in the overall procedure of the operations; rather, it is applied based on nature, situation, and available resources in a given geographic location. The suitability levels for each of the criteria were defined based on national manuals, guidelines, expert knowledge, author’s practical experiences, research station publications, and relevant literature for rice cultivation as clear in the following Table 3.4 (Kihoro et al., 2013; Ayehu and Besufekad, 2015; and Getachew, 2015). Hence, four main criteria and eight parameters namely: topography (slope), climate (temperature and rainfall), soil (type, texture, pH, and depth), and LULC were identified considering the nature of the study area and the available information.

Table 3. 4: Criteria used, data range, and suitability class for rice

General Criteria	Sub Criteria	Level of Suitability				References
		S1	S2	S3	N1	
Topography	Slope (%)	0 - 4	4 - 8	8 - 20	>20	Getachew, 2015, Ayehu & Besufekad, 2015
Climate	Temperature (°C)	23 - 27	19 - 23	15 – 19	<15 or >27	
	Rainfall (mm)	>1300	1200 - 1300	1000 - 1200	<1000	
Soil	Soil type	Haplic xerosols	Chromic vertisols	Eutric nitisols	Calcic xerosols & Orthic luvisols	Ayehu & Besufekad, 2015
	Soil depth (cm)	> 100	50 - 100	30 – 50	0 - 30	Kihoro et al., 2013
	Soil texture (class)	Sandy clay & Sandy clay loam	Clay loam	Sandy Loam and Loam	Sand	
	Soil pH	5.6 - 7.4	7.4 - 7.8	5.1 - 5.6	<5.1 or >7.8	Getachew, 2015
Land_use	LULC (class)	Agricultural land	Waterbody	Grassland	Forest & settlement area	Google Earth Pro

3.6.1.1 Climate Data

Two meteorological stations that are found inside the study area (Woreta and Alem ber) with average monthly rainfall and temperature of 30 (1994 - 2023) years were acquired from the National Metrological Agency of Ethiopia in Excel format. In the MS Excel file containing the climate data, spatial data in terms of latitudes and longitudes of the places of weather stations were entered into corresponding climate data. The results were exported to the ArcGIS Pro software for further manipulation, and then the interpolation technique was applied with the use of the Geostatic analyst tool an Inverse Distance Weighted (IDW) method was made to estimate the overall rainfall and temperature distribution of the area. Finally, the mean temperature and rainfall map was reclassified input to land suitability analysis classification for (Ayehu and Besufekad, 2015) rice crop cultivation.

3.6.1.2 Topography Data

Elevation, also known as altitude, is the height of a place above or below a reference point, such as the mean sea level (MSL). Slope factors are the major influences on land suitability for rice crop cultivation (Topuz and Deniz, 2023). A digital elevation model with high spatial resolution data (10m) was downloaded from Sentinel 1-A on the ESA website and generated by using SNAP software 9.0. From the elevation data, the slope was derived by using ArcGIS Pro software surface analysis. The slope of the Fogera Woreda which was derived from DEM was given in percent and reclassified based on land suitability analysis classification (Getachew, 2015).

3.6.1.3 Soil Data

Soil data (soil type, soil depth, soil pH, and texture) which had 250m spatial resolution were acquired from the Ministry of Agriculture in raster format and then, reclassified depending on rice crop requirements according to agricultural land suitability analysis category (Kihoro et al., 2013). The main soil types in the district include haplic xerosols, chromic vertisols, eutric nitisols, calcic xerosols, and orthic luvisols.

3.6.1.4 Land Use Land CoverFogera

A LULC map was used in this study to distinguish various features on the land surface that are recorded by the Landsat 8 sensor. According to Fritz (2010), for land evaluation, delineating the current land-use boundary was the first stage. Landsat 8 image of 2023 which has 30m spatial resolution was downloaded from the USGS website. It is used to prepare the current LULC map of Fogera Woreda through Erdas Imagine image processing software 2015. For the preparations of the current LULC map of the study area the following key steps must be completed: pre-processing of the downloaded image, LULC classification (supervised classification), and checked accuracy assessment using Google Earth Pro.

1. **Pre-Processing of Satellite Images**

The Landsat 8 (OLI) image has eleven bands. Under this, the corresponding seven bands were stacked together. Band eight was excluded because it has a panchromatic image. The stacked images were calibrated through the calibrate tool in Erdas Imagine 2015. Before classifying LULC, first, the stacked image should be done in preprocessing data operations (atmospheric and radiometric correction). The false-color composite that is red 5, green 4, and blue 3 was used to produce the LULC map of the study area.

2. LULC Classification

For every single class, proper training sites were taken to create signatures. After establishing training sites, each was stored in the signature editor, and color was chosen for the particular feature class. To classify image pixels into spectral classes the supervised classification technique was applied. A supervised classification maximum likelihood algorithm in Erdas imagine was applied in this study to classify LULC using multispectral satellite data obtained from Landsat 8 for 2023. The study area was classified into five main LULC classes. These were agricultural land, water bodies, forests, grassland, and settlement areas.

Table 3. 5: LULC categories of Fogera Woreda

Land cover class	**Description**
Forest land	The land was sheltered by a relatively condensed collection of trees that have closed canopy and eucalyptus plantations.
Agricultural land	This category comprises all cultivated land. It contains holding areas for livestock and land plowed and made ready for sowing.
Waterbody	This category includes rivers, streams, reservoirs and lakes
Settlement	This category contains dispersed rural settlements, residential areas, commercial, and recreational sites, public installations, and infrastructures.
Grassland	Areas permanently covered by grasses are used for grazing and are communal as well.

3. Accuracy Assessment

The accuracy assessment reveals the real difference between classification and the reference map or data. Random selection of reference pixels was used to decrease the biases of using the same pixels for testing classification. Since image classification without accuracy assessment is incomplete, the accuracy assessment for the image was done. Because of that, LULC maps generated from remote sensing imagery always contain some sort of errors due to various factors which range from the method of satellite data capture to classification technique. There were 35 reference points collected randomly in the area of Fogera Woreda by using Google Earth Pro. Then, 13 points from agriculture, 10 points from forest, 6 points from grassland, 4 points from settlement, and 2 points from water bodies were collected depending on the study area. The overall accuracy of classified LULC in the study area was approximately 91%.

3.6.2 Criteria Standardization and Rating

Rice cultivation area requires suitable LULC, slope, rainfall or sufficient moisture content, and fertile soil for cultivation. Those are the most significant requirements common for all crops in general and rice cultivation in specific. Data are measured on various units as well as on different scales of measurement. Thus, it is essential to standardize the criteria before combination and ensure they are transformed, if necessary, all criteria maps are positively correlated with suitability.

Linear scale transformation is the most commonly used GIS-based method for criteria standardization. Thus, all factors have been standardized for this study, by using a reclassified spatial analyst tool (ArcGIS Pro), to make sure that each criterion had a corresponding measurement basis. Simultaneously during reclassification, factor rankings were also assigned for suitability analysis from 1 (highly suitable) to 4 (unsuitable). To have a reasonable contrast, a common standard is required to apply a weighted overlay over each of the input parameters.

3.6.3 Assigning Criterion Weights

A weight is a value assigned to an assessment basis that visualizes its significance relative to the other criteria under consideration. There have been several methods used for evaluating criterion weights. The pairwise comparison method is based on the assumption of spatial homogeneity of selections and assigns a single weight to each criterion.

A pair-wise comparison of the AHP method introduced by Saaty (1987) is used to calculate the required weighting criteria for this study. A pairwise comparison matrix has been calculated in an AHP extension tool (ArcGIS add-on) and cross-checked with an Excel sheet. The pairwise comparison method developed by Saaty in the context of a decision-making procedure is a ratio (reciprocal matrix) where each aspect is compared with the other parameter, relative to its importance on a scale.

Table 3. 6: Scale for pairwise comparisons (Saaty, 1987)

Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute similarly
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Involvement & judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored & its dominance confirmed in practice
9	Extreme importance	The evidence favoring one action over another is the highest possible order of confirmation
2,4,6,8	Intermediate value	When compromise is required
Reciprocals	Value for inverse compression	The inverse value of the comparison

The ratio scales are derived with the support of Principal Eigen Vectors and the consistency index is derived through Principal Eigen Value. To make some decisions compare one or more alternatives with one or more parameters to make some conclusion, this depends on the comparison. Some of the parameters have more effects than others and according to their importance, are assigned their weights.

For this study criteria weight was calculated based on the following formula;

$$W_k = \frac{\sum_{p=1}^{n} c_{kp}^{*}}{n} \ldots..$$

Where: w_k= criteria weight

c_{kp}^{*} =Normalized entire matrix

n = number of criteria

Then, the consistency ratio was computed to check the consistency of comparisons. It was calculated as follows;

$$CR = \frac{CI}{\mathrm{RI}}\text{ , CR <0.10}$$

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

Where:

CR = Consistency Ratio
CI = Consistency index
RI = Random Consistency Index
λ_{max} = Principal Eigen Value
n = number of factors

3.6.4 Weighted Overly Analysis

Weighted overlay applies a common scale of values to diverse and dissimilar inputs to produce an integrated analysis. The weighted overlay roles weigh the individual input raster on a defined scale. The higher favorable places for each input criterion were reclassified to the higher values. In the weighted overlay tool, the percentage influences assigned to all the input raster must equal 100%.

In this study, different map layers characterizing land suitability were weighted using the weights derived from the AHP method. Aggregation of the weight and standardized rated criterion map, the weighted overlay method was applied to joint standardized rated criteria and weighted criteria to map the suitable land.

This was completed as the following formula;

$$S = \sum wixi$$

Where:
S – Suitability
Σ - Sum
wi– Weights assigned to each factor
xi– Factor scores (cells)

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Preprocessing of Data and Reclassification Results

The physical factors of the land as well as climate conditions are the major influences that determine crop suitability of a given land. The physical land properties of the study area, which were analyzed include topography (slope), soil (type, texture, pH, and depth), and current LULC. The climate (temperature and rainfall) of the area was also used for rice cultivation suitability analysis.

4.1.1 Factors of Rice Cultivation Suitability Analysis

4.1.1.1 Rice Suitability Analysis Based on Temperature

Temperature is one of the limiting criteria for rice crop cultivation. The classified temperature data was resampled to 10m spatial resolution before reclassifying its suitability map of the area study. This was done by using ArcGIS Pro (Resample tool). Based on the temperature requirement of rice cultivation, the temperature of the study area was reclassified into four suitability levels affording to the land suitability analysis classification. These were highly suitable (S1), moderately suitable (S2), less suitable (S3), and unsuitable (N1). The temperature that ranges from 23° to 27° (48%) and 19° to 23° (26 %) were classified as highly and moderately suitable respectively for rice crop cultivation.

Table 4. 1: Temperature suitability class

Temperature (^{0}C)	**Level of suitability**	**Value**	**Area (km²)**	**Area coverage (%)**
<15 or >27	N1	4	53.8	4.8
15 - 19	S3	3	240.5	21.6
19 - 23	S2	2	289	26.1
23 - 27	S1	1	528.1	47.5
		Total	1111.4	100

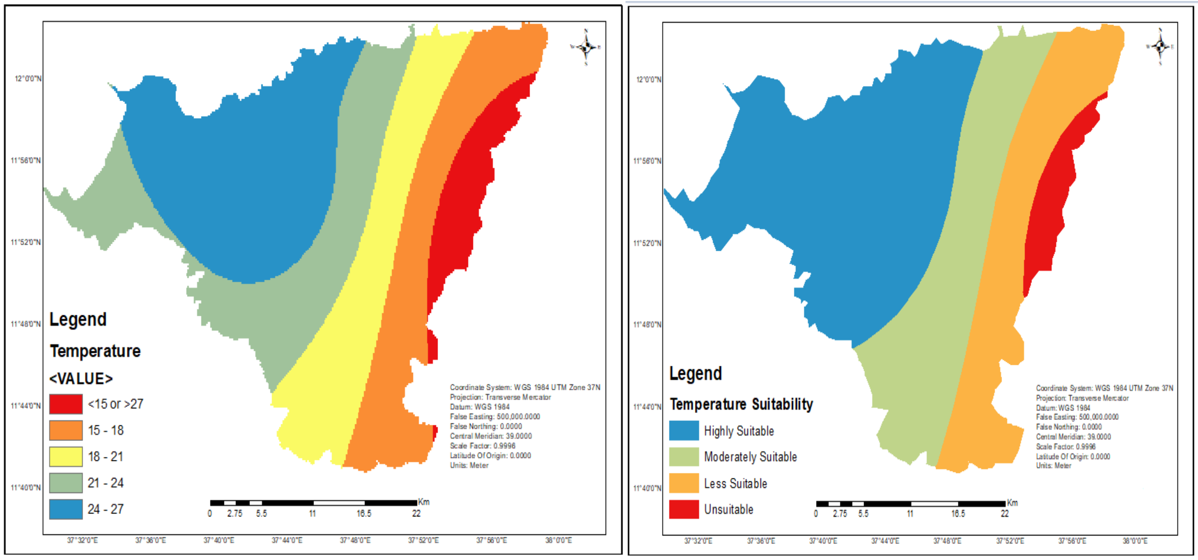

Figure 4. 1 Suitability map for temperature analysis of the study area

4.1.1.2 Rice Suitability Analysis Based on Rainfall

Rainfall distribution plays a significant role in improving agricultural cultivation. Thus, the average rainfall distribution together with its variation in both frequency and extent encompasses its agronomic importance. The classified rainfall data was resampled to 10m spatial resolution before reclassifying its suitability map of the study area. This was done by using the ArcGIS pro software Resample tool. Rainfall requirement for rice crop cultivation in the study area was classified into four suitability classes depending on the land suitability analysis classification standards. Its suitability levels range from highly suitable to unsuitable.

The results (Table 4.2 and Figure 4.2) show that rainfall ranges greater than 1300 mm (26.8%), and 1200 to 1300 mm (24.5%) were classified as highly and moderately suitable for rice cultivation respectively in the study area.

Table 4. 2: Rainfall suitability class

Rainfall (mm)	Level of suitability	Value	Area (km²)	Area coverage (%)
>1300	S1	1	297.5	26.8
1200 - 1300	S2	2	272.9	24.5
1000 - 1200	S3	3	295.6	26.6
<1000	N1	4	245.4	22.1
		Total	1111.4	100

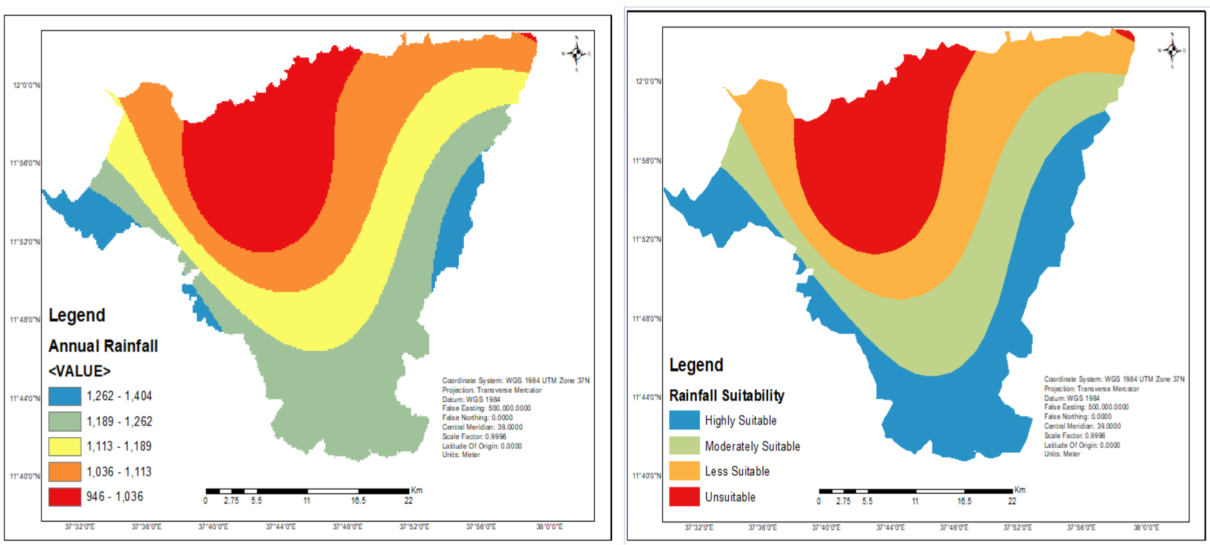

Figure 4. 2 Rainfall suitability map of the study area

The result (Figure 4.3) shows the weight of influences of climate conditions both rainfall (55%) and temperature (45%) for rice crop cultivation suitability in the study area. From the total study area 61.5 km² (5.5%), 520.8 km² (46.8%), 528.2 km² (47.1), and 1.3 km² (0.2%) were classified as highly suitable, moderately suitable, less suitable and unsuitable respectively for rice crop cultivation.

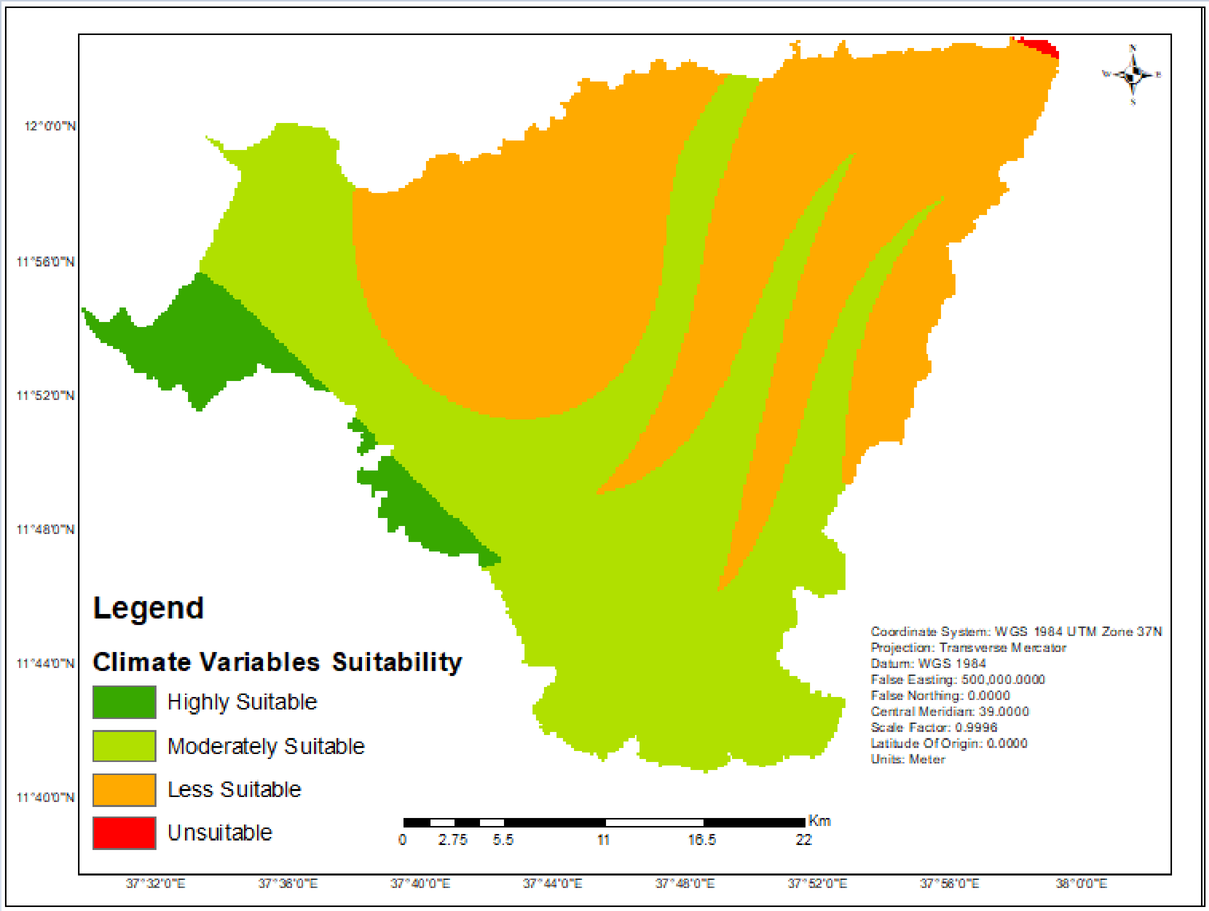

Figure 4. 3 Map of climate variables weight of influence for rice suitability

4.1.1.3 Rice Suitability Analysis Based on Slope

The slope has been considered as one of the evaluation criteria in rice crop suitability assessment. The slope of the study area was reclassified into four classes according to land suitability analysis classification. The classes include highly suitable, moderately suitable, less suitable, and unsuitable. Slopes between 0 to 4 (61.9%), and 4 to 8 (18.3%) were categorized as highly and moderately suitable for rice cultivation respectively.

Table 4. 3: Slope suitability class of the study area

Range (%)	Level of suitability	Value	Area (km²)	Area coverage (%)
0 - 4	S1	1	687.6	61.9
8	S2	2	203.6	18.3
8 - 20	S3	3	200.8	18.1
>20	N1	4	19.4	1.7
		Total	1111.4	100

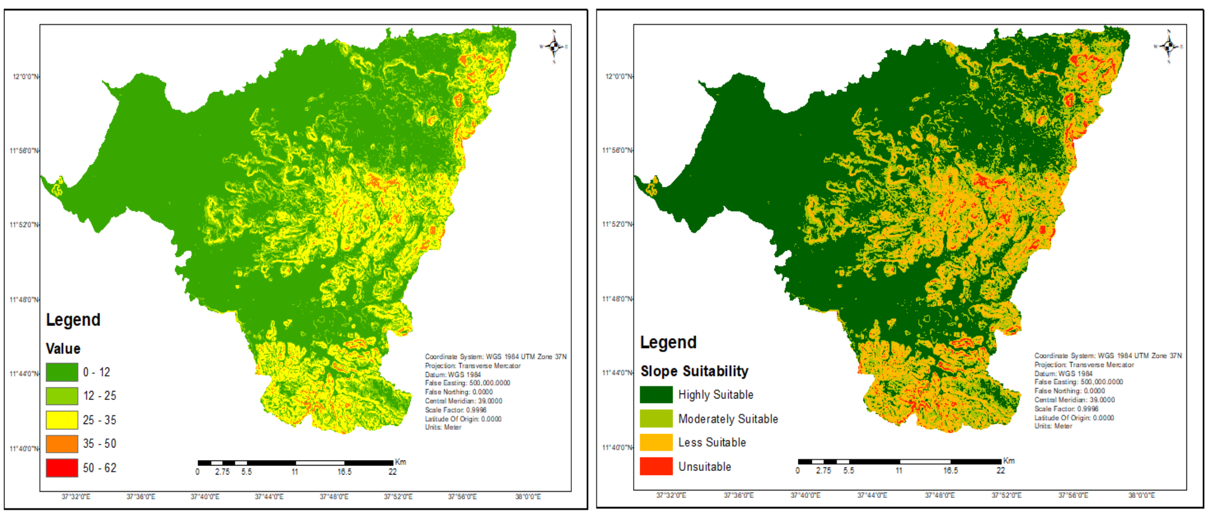

Figure 4. 4 Slope suitability map

4.1.1.4 Rice Suitability Analysis Based on Soil Types

Soil type influences the determination of land suitability potential for suitable crop cultivation. Thus, it was taken as one criterion in developing a rice crop suitability analysis map for the study area. The soil type of the study area which was gained from MoA was extracted by using the study area boundary and resampled to 10m spatial resolution. This was done by using the ArcGIS Pro Resample tool. All types of soils are not suitable for crops in cultivation, in this study area Haplic xerosols are identified as highly suitable soil for rice cultivation due to their highest area coverage (69.1%) and Calcic xerosols & Orthic luvisols were identified as unsuitable (3.7%) soil types for rice crops. Other soil types of the Woreda fall in between this extremity due to their moderate and less suitable. The rasterized soil type of the area was reclassified depending on rice crop requirements.

Table 4. 4: Soil type suitability class of the study area

Soil type	Level of suitability	Value	Area (km²)	Area coverage (%)
Haplic xerosols	S1	1	750.5	69.1
Chromic vertisols	S2	2	196.2	18.0
Eutric nitisols	S3	3	99.4	9.2
Calcic xerosols & Orthic luvisols	N1	4	40.7	3.7
		Total	1086.8	100

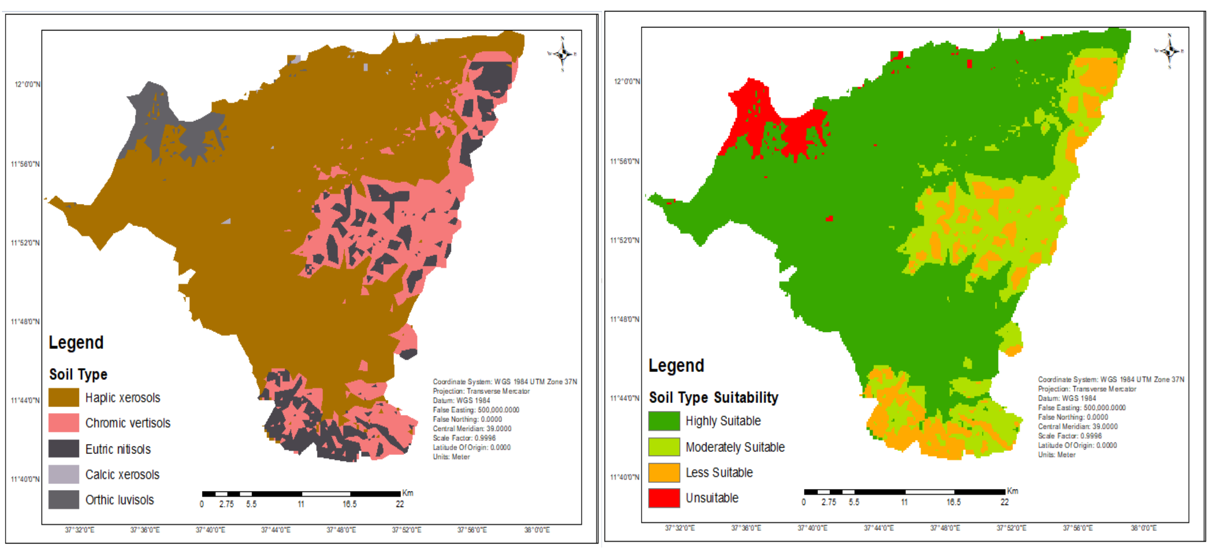

Figure 4. 5 Soil type suitability map

4.1.1.5 Rice Suitability Analysis Based on Soil Texture

Soil texture is the level of coarseness of the soil, and rice being a tropical trim, desires a soil surface that can hold water for a longer period, supportive of the classification of soil suitability for rice. The suitability of soil texture for crops was evaluated through its suitability potential for rice cultivation. The categorized soil texture data was resampled to 10m spatial resolution before reclassifying its suitability analysis map of the study area. This was determined by using ArcGIS Pro (Resample tool). Based on the soil texture requirement for rice cultivation, the soil texture of the study area was reclassified into four suitability classes according to the land suitability analysis classification. Its suitability class ranges from highly suitable to unsuitable.

The results (Table 4.5 and Figure 4.6) display that 83.9 % of the total area of the study area soil texture was dominated by clay loam and was moderately suitable for rice cultivation. Of the total area, 3.9% was sandy clay and sandy clay loam was highly suitable, whereas, 0.5% of the area was sand and unsuitable for rice crop cultivation.

Table 4. 5: Soil texture suitability class of the study area

Soil texture	**Level of suitability**	**Value**	**Area (km^2)**	**Area coverage (%)**
Sandy clay & Sandy clay loam	S1	1	43.9	3.9
Clay loam	S2	2	926.2	83.9
Sandy Loam and Loam	S3	3	129.5	11.7
Sand	N1	4	4.8	0.5
		Total	1104.4	100

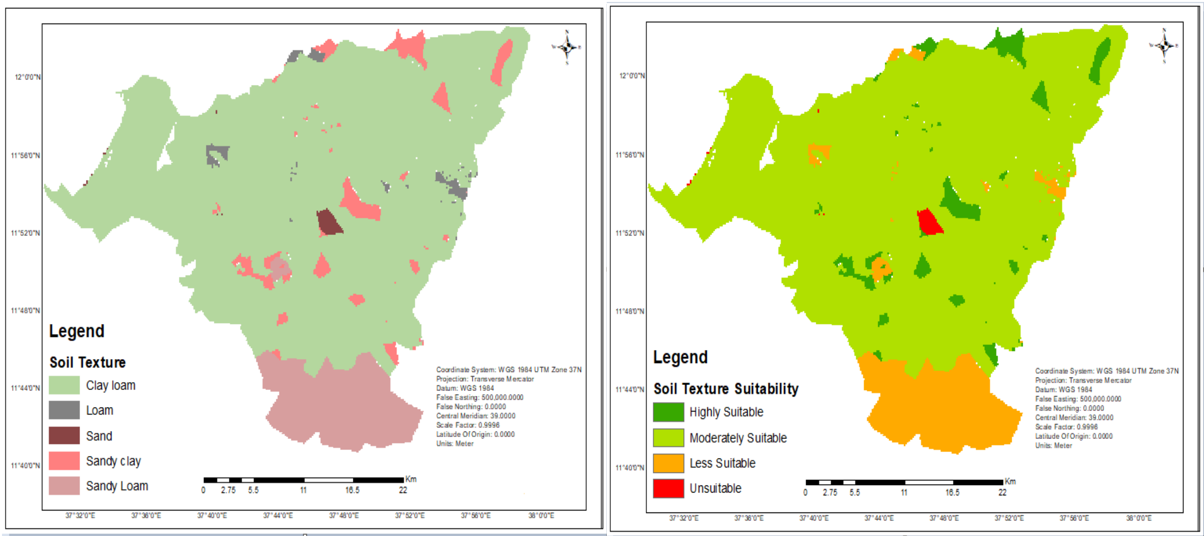

Figure 4. 6 Soil texture suitability map of the study area

4.1.1.6 Rice Suitability Analysis Based on Soil Depth

The soil depth of the study area which was obtained from MoA was extracted by using the study area boundary and resampled to 10m spatial resolution. This was done by using the ArcGIS Pro Resample tool. Based on the soil depth requirement for rice cultivation, the soil depth of the study area was reclassified into four suitability classes according to the land suitability analysis classification. Its suitability classes range from highly suitable to unsuitable classes.

The result (Table 4.6 and Figure 4.7) shows that soil depth greater than 100 cm (85.7%) was classified as highly suitable for rice. Soil depth that ranges from 50 to 100 cm (13.8%), and 30 to 50cm (0.5%) were classified as moderately, and less suitable respectively for rice cultivation.

Table 4. 6: Soil depth suitability class of the study area

Soil depth (cm)	Level of Suitability	Value	Area (km²)	Area coverage (%)
> 100	S1	1	947.6	85.7
50 - 100	S2	2	152.7	13.8
30 - 50	S3	3	4.6	0.5
0 - 30	N1	4	0.0	0.0
		Total	1104.4	100

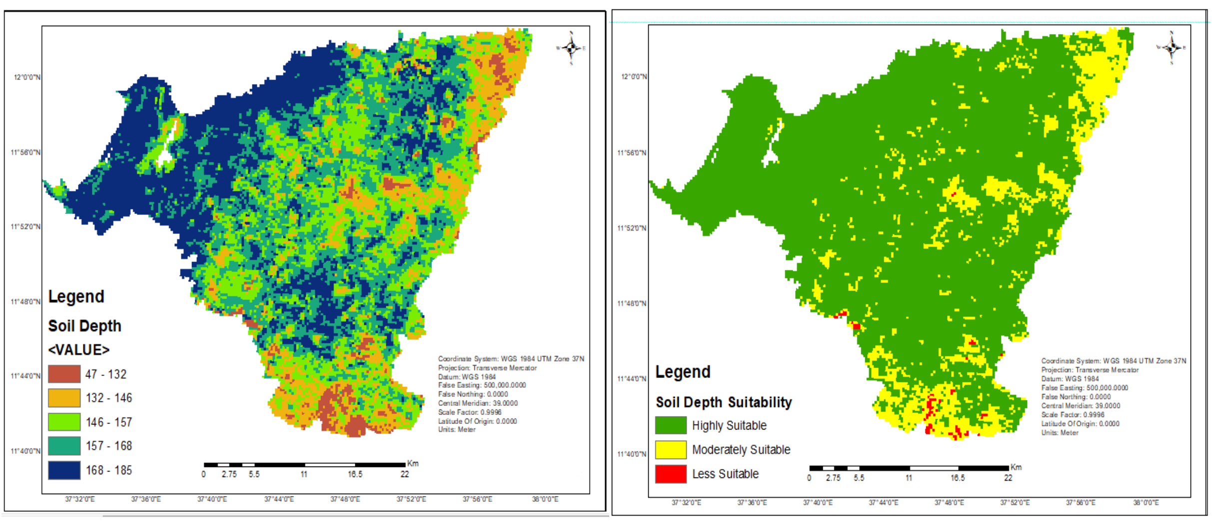

Figure 4. 7 Soil depth suitability analysis map of the study area

4.1.1.7 Rice Suitability Analysis Based on Soil pH

The soil pH value was the other factor that influenced rice cultivation suitability analysis. The classified soil pH data was resampled to 10m spatial resolution before reclassifying its suitability map of the Fogera Woreda. This was done by using the ArcGIS Pro Resample tool. The amount of soil pH in the study area ranges between a minimum value of 5.1 to a maximum value of 7.8. The result was visualized in a map as shown in Figure 4.8.

The Soil pH value of the study area was reclassified into four levels depending on rice cultivation requirements according to land suitability analysis classification. The classes range from highly suitable (S1) to unsuitable (N1).

Table 4. 7: Soil pH suitability class of the study area

Soil pH	Level of suitability	Value	Area (km²)	Area coverage (%)
5.6 - 7.4	S1	1	1062.4	95.6
7.4 - 7.8	S2	2	30.5	2.7
5.1 - 5.6	S3	3	3.4	0.3
<5.1 or>7.8	N1	4	15.1	1.4
		Total	1111.4	100

From the total area of the district (1062.4 km²) 95.5% was highly suitable for rice cultivation regarding soil pH. Of the total study area (30.5 km²) 2.7% was moderately suitable for rice crop cultivation, whereas 1.4% of the study area 15.1 km² of the Woreda was not suitable for rice crop cultivation.

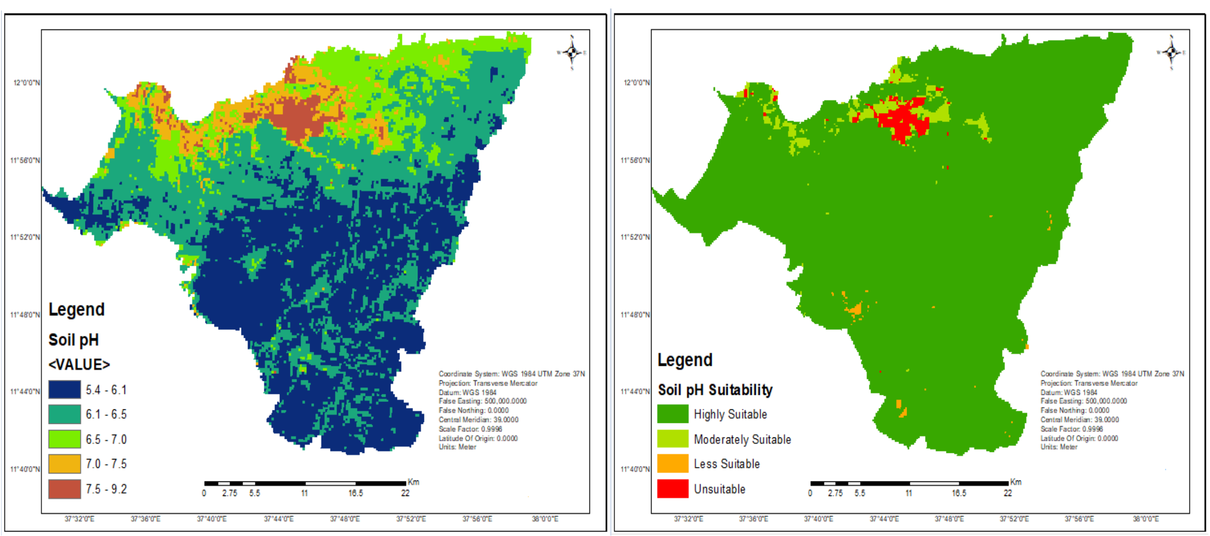

Figure 4. 8 Soil pH suitability map of the study area

The result (Figure 4.9) displayed that soil's physical and chemical properties (Soil type (26%), Soil texture (33%), Soil pH (23%), and Soil depth (18%)) weight influence rice cultivation suitability in the study area. From the total study area 876.1 km² (86.6%), 132.9 km² (13.1%), and 2.5 km² (0.3%) were classified as highly suitable, moderately suitable, and less suitable respectively for rice cultivation.

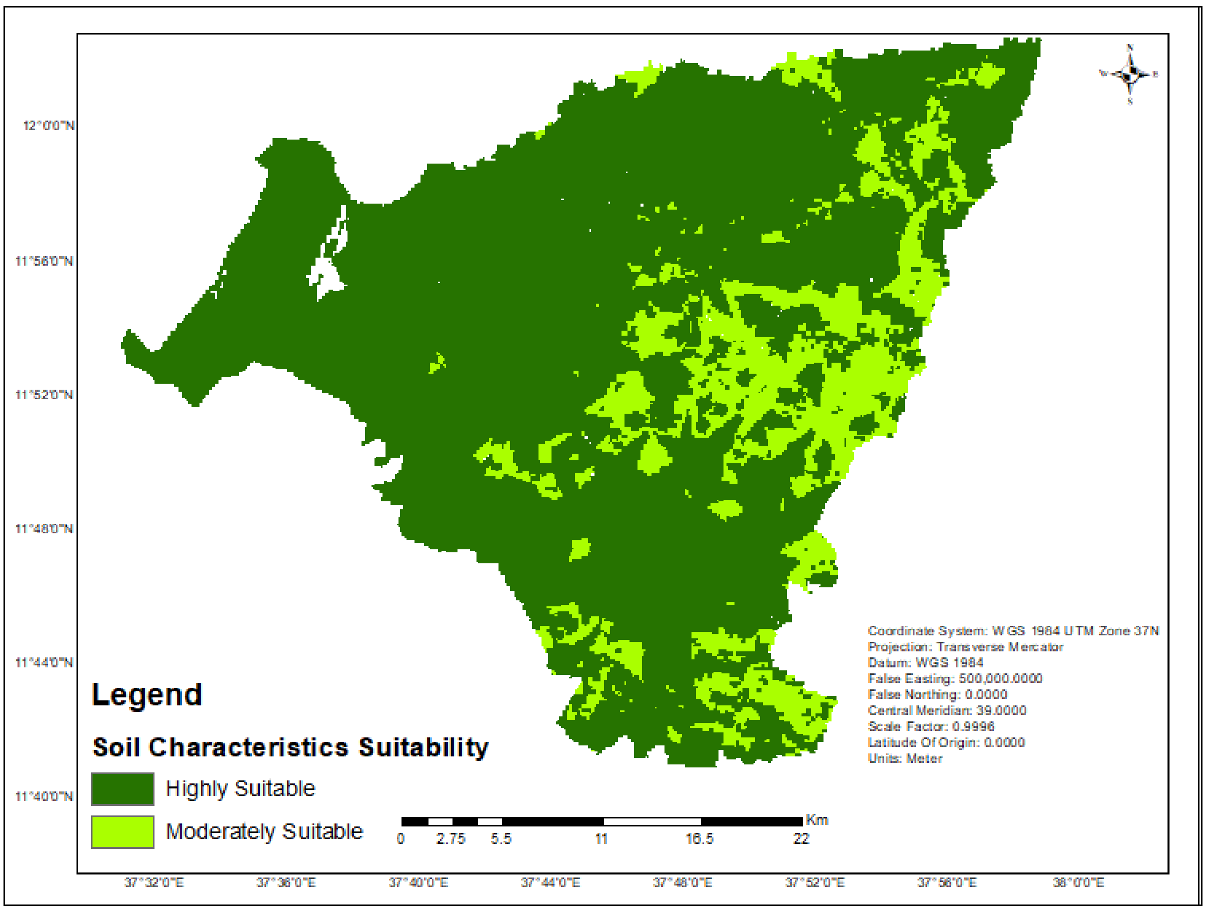

Figure 4. 9 Soil properties weight of influences for rice crop suitability map

4.1.1.8 Rice Suitability Analysis Based on LULC

The primary step in the MCE technique is preparing LULC data to classify the current LULC according to its importance. The classified LULC data was resampled to 10m spatial resolution before reclassifying its suitability map of the study area. This was done by using the ArcGIS Pro software Resample tool. Accordingly, from the LULC classes of the study area agricultural land (82.3%) and water bodies (2.4%) were categorized as highly and moderately suitable for rice crop cultivation respectively. Settlement and forest (8.9%) areas were classified as unsuitable for rice crop cultivation.

Table 4. 8: LULC suitability class of the study area

LULC classes	Level of suitability	Value	Area (km²)	Area coverage (%)
Agricultural land	S1	1	914.2	82.3
Waterbody	S2	2	26.7	2.4
Grassland	S3	3	71.1	6.4
Forest & Settlement Area	N1	4	99.4	8.9
		Total	1111.4	100

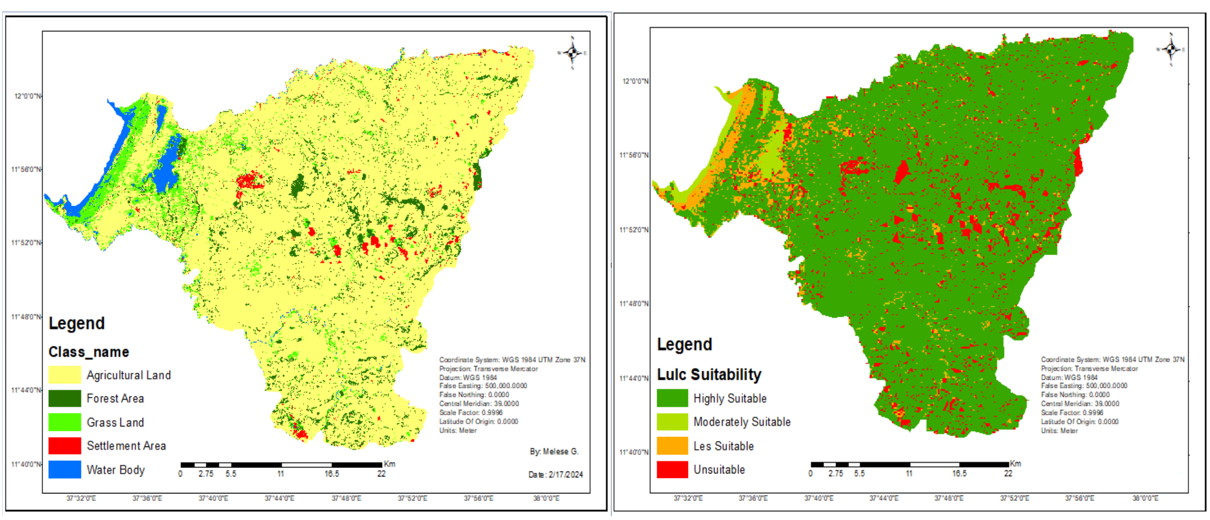

Figure 4. 10 LULC suitability map of the study area

After reclassifying all factors which were used for rice cultivation suitability the following table provides a comparative analysis of those considerations based on their suitability criteria.

Table 4. 9: Overall land suitability class for rice cultivation (Area in %)

Criteria	Area of suitability classes in %			
	S1	S2	S3	N1
Rainfall	26.8	24.5	26.6	22.1
Temperature	47.5	26.1	21.6	4.8
LULC	82.3	2.4	6.4	8.9
Slope	61.9	18.3	18.1	1.7
Soil type	69.1	18.0	9.2	3.7
Soil texture	3.9	83.9	11.7	0.5
Soil depth	85.7	13.8	0.5	0.0
Soil pH	95.6	2.7	0.3	1.4

From the table above large area was classified under highly suitable and moderately suitable for rice cultivation concerning all factors. Of the total area, 48% was highly suitable for rice cultivation regarding to temperature. From the total area, 82% was highly suitable for rice cultivation regarding LULC. From the total area of the study area, 4%, 84%, 11%, and 1% were highly, moderately, less, and unsuitable respectively for rice crop cultivation regarding soil texture. For a better understanding, it can be expressed in Figure 4.11.

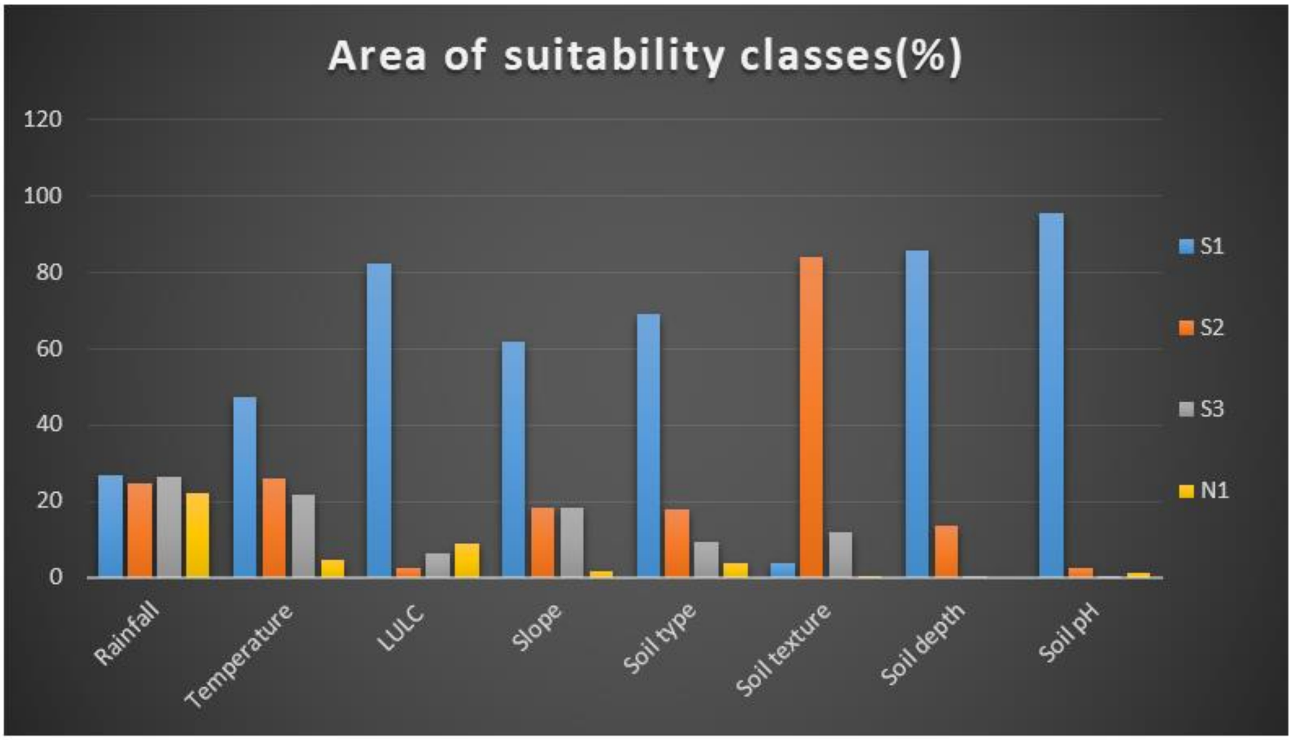

Figure 4.11: Overall land suitability for rice cultivation based on 8 factors (area %)

4.2 Determining Criterion Weights

All factors that were selected for the evaluation of land suitability for rice cultivation in the study area were weighted using a pairwise comparison method. The pairwise comparison matrix (PCM) was created using the analytic hierarchy process on a scale of 1 to 9. This comparison matrix was decided and filled with the review of literature and related field expert opinions were included.

Table 4. 10: Pairwise comparison matrix for multi-criteria decision problems

Factors	Rainfall	Temperature	LULC	Slope	Soil Type	Soil Depth	Soil Texture	Soil pH
Rainfall	1	2	3	3	3	2	3	2
Temperature	0.50	1	3	2	3	2	2	3
LULC	0.33	0.33	1	3	2	3	3	3
Slope	0.33	0.50	0.33	1	3	2	3	2
Soil Type	0.33	0.33	0.50	0.33	1	3	2	3
Soil Depth	0.50	0.50	0.33	0.50	0.33	1	2	2
Soil Texture	0.33	0.50	0.33	0.33	0.50	0.50	1	3
Soil pH	0.50	0.33	0.33	0.50	0.33	0.50	0.33	1
Total	3.83	5.50	8.83	10.67	13.17	14.00	16.33	19

To determine the weight of each criterion, a normalization process was mandatory. To normalize the above comparison matrix value, each cell value was divided by its column total. To get the relative importance weight of each criterion, the mean value of the row was computed.

Table 4. 11: Normalized pairwise comparison matrix

Factors	Rainfall	Temperature	LULC	Slope	Soil Type	Soil Depth	Soil Texture	Soil pH	Sum	Criteria Weights	Influence (%)
Rainfall	0.26	0.36	0.34	0.28	0.23	0.14	0.18	0.11	1.91	0.24	23.81
Temperature	0.13	0.18	0.34	0.19	0.23	0.14	0.12	0.16	1.49	0.19	18.63
LULC	0.09	0.06	0.11	0.28	0.15	0.21	0.18	0.16	1.25	0.16	15.62
Slope	0.09	0.09	0.04	0.09	0.23	0.14	0.18	0.11	0.97	0.12	12.11
Soil Type	0.09	0.06	0.06	0.03	0.08	0.21	0.12	0.16	0.81	0.10	10.07
Soil Depth	0.13	0.09	0.04	0.05	0.03	0.07	0.12	0.11	0.63	0.08	7.88
Soil Texture	0.09	0.09	0.04	0.03	0.04	0.04	0.06	0.16	0.54	0.07	6.75
Soil pH	0.13	0.06	0.04	0.05	0.03	0.04	0.02	0.05	0.41	0.05	5.12

According to the normalized pair-wise comparison results (Table 4.11), climate, soil, LULC, and topographic factors were assigned weight values of 0.43, 0.30, 0.16, and 0.12, respectively. From the climate sub-criteria, rainfall (0.24) followed by temperature (0.19) got high weight values. The contribution of soil type was superior (0.10) over soil depth (0.08) from the soil sub-criteria. Among the main soil characteristics, physical (0.25) followed by chemical (0.05) got higher values.

After the pairwise comparison matrices were calculated, the weight module was used to calculate the consistency ratio and develop the best-fit weights. Furthermore, one of the major properties of the analytic hierarchy process is that it finds and calculates the inconsistencies of decision-makers. The consistency relationship is used to estimate the efficiency criteria of the analytic hierarchy method. The consistency ratio was calculated and the result was 0.09, which was accepted for weighting the criteria to analyze the land suitability of rice in the study area.

Maximum eigenvector = 8.96, n = 8, CI= 0.13, CR= 0.09 which is less than 0.1 (acceptable).

The percentage influence of rainfall was allocated as 24% of the total layers of the study area maps, which was the highest weight. This is because rainfall is the most limiting criterion in the identification of potential areas for rice crop cultivation. The temperature was assigned a percentage influence of 19%. It was the second limiting factor in the identification of land suitability analysis for rice cultivation. The land uses land cover and slope were assigned 15% and 12% percentage influence respectively.

4.3 Suitability Model Used

A land suitability model was established using GIS capabilities and modeling functions. The spatial geo-environmental characteristics (soil, climate, topography, and land use) were combined into the GIS environment as information layers and overlaid to produce an overall land suitability analysis for rice crops.

Using a model builder from ArcGIS toolbox, a suitability assessment model was designed and used for processing the suitability map. The model that produced the preliminary suitability analysis map is shown in Figure 4.12.

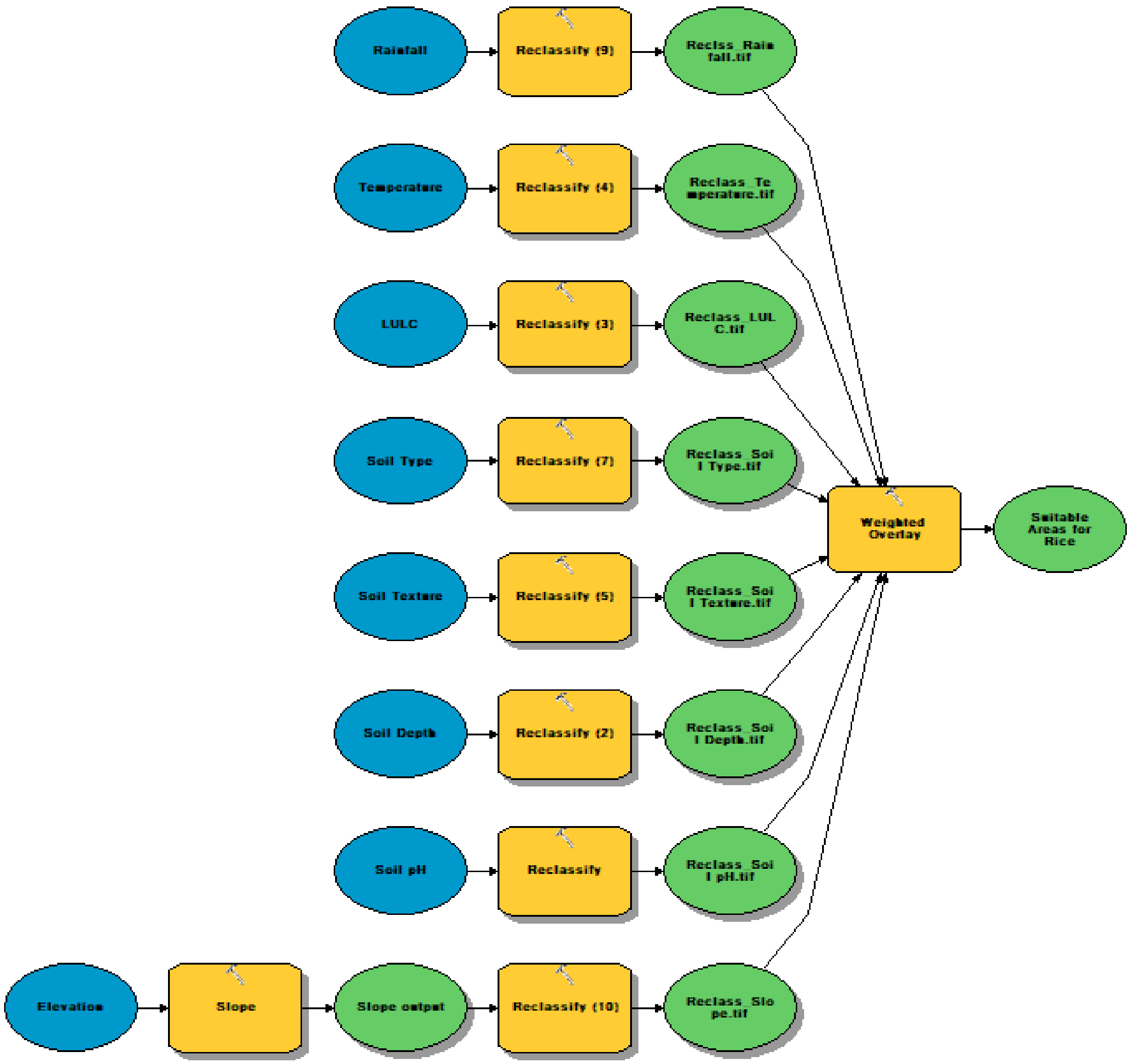

Figure 4. 12 The suitability analysis model used

4.4 Weighted Overlay Analysis

After reclassifying each criterion to a common suitable class and assigning criterion weights to each factor were added to the weighted overlay tool. The factors were rated from 1 to 4 (highly suitable to unsuitable) to their suitability class range in the ranking system. The final appropriate land or suitability map of rice in the study area was established. The map of potential land suitable for rice was further analyzed and queried.

The values which were obtained from the weighted overlay analysis results categorized into four suitability classes. These were highly suitable, moderately suitable, less suitable, and unsuitable for suitable rice crop cultivation areas of the district (as shown in Figure 4.12 below). According to GIS-based MCE methods of the total study area, 728.5km² (65.9%) was highly suitable, 235.9km² (21.4%) was moderately suitable, 57.4km² (5.2%) was less suitable, and the remaining spatial extent which covers 82.7km²(7.5%) was unsuitable for rice crop cultivation.

Table 4. 12: Potential lands of the study area for rice cultivation

No.	**Suitability class**	**Value**	**Area (km²)**	**Area coverage (%)**
1	Highly suitable	1	728.5	65.9
2	Moderately suitable	2	235.9	21.4
3	Less suitable	3	57.4	5.2
4	Unsuitable	4	82.7	7.5
		Total	1104.5	100

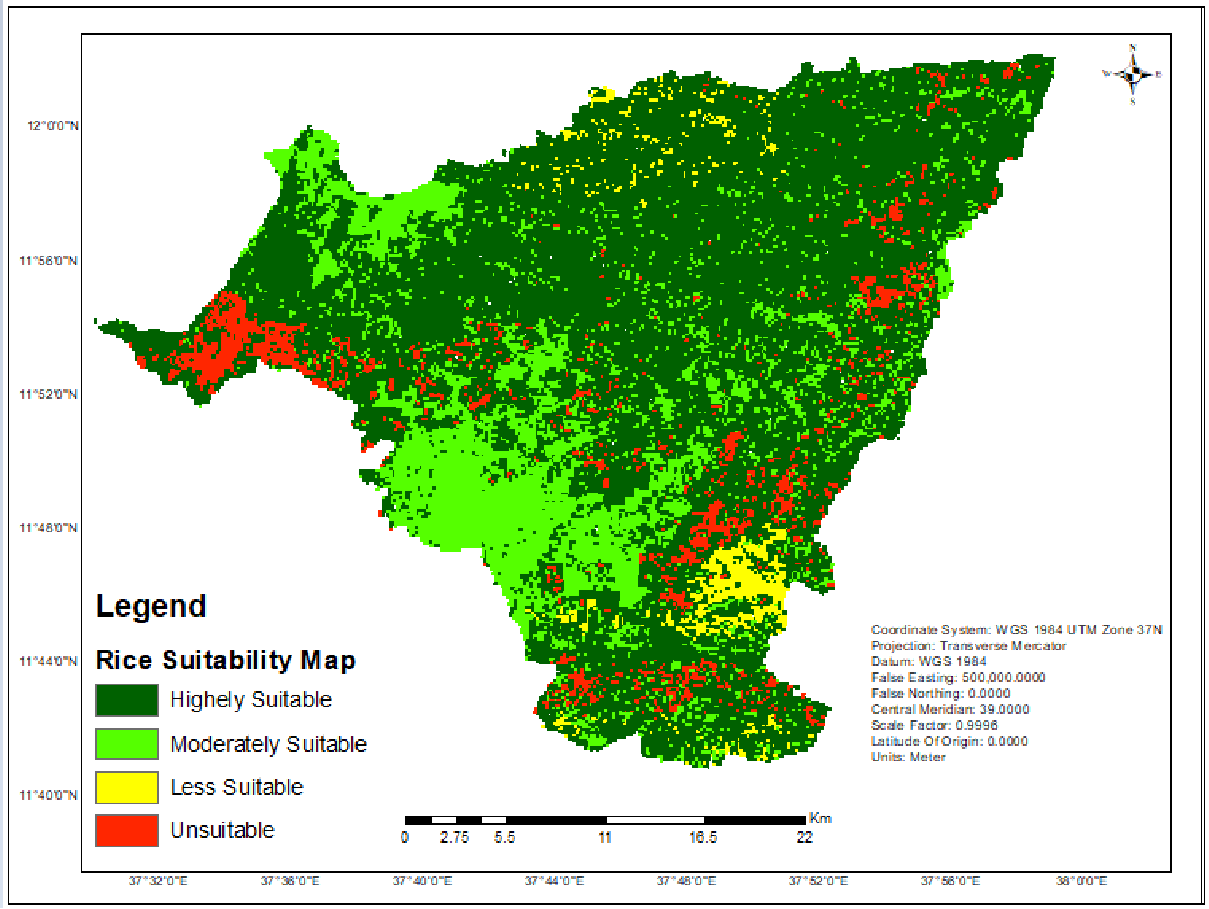

Figure 4. 13 Potential area map for rice crop suitability in Fogera Woreda

The suitability map for rice crop, identified by weighted overlay using Spatial Analyst tools in ArcGIS Pro, was visualized in Figure 4.13. As can be seen from Table 4.12 (above) highly suitable land covers an area of 728.5 km² (65.9%) of the total land. Thus, we could say that a significant part of the study area was highly suitable for rice cultivation.

The final map of the study area shows an enormous potential for rice cultivation. In Fogera Woreda, the proportion of highly and moderately suitable areas for rice crop cultivation covers approximately 87% of the total area. Highly suitable areas were characterized by: slope levels 0 - 4%, soil type Haplic xerosols, soil pH values from 5.6 to 7.4, soil depth levels greater than 100cm, soil texture class sandy clay, rainfall levels >1300mm and temperatures between 23 to 27°C. Therefore, economic levels of agricultural cultivation can be accomplished by encouraging rice crops in highly and moderately suitable areas and practicing diversification of less suitable areas to crops other than rice.

From the result of the rice crop potential map in the study area, 728.5km² (65.9%) was highly suitable. From highly suitable areas, 39.5% were found in Gazen Aridafofot kebele, Chalmana mntura, Wej Arba Amba, Tihua Ena Kokit, and Zeneg kebeles.

Table 4. 13: Highly suitable area coverage of rice in Fogera kebeles

No.	Kebele Name	Area (km^2)	Area (%)	Geographically located
1	Gazen Aridafofot	94.1	12.9	southern
2	Chalmana mntura	54.5	7.5	southeastern
3	Wej Arba Amba	50.6	6.9	central
4	Tihua Ena Kokit	43.5	5.9	northwestern
5	Zeneg	43.3	5.9	northeastern
	Total	286 out of 728.5	39.3 out of 100	

The results gained from the land suitability evaluation for rice crops, highly suitable areas were dominated in the northeastern part of the study area. The southwestern part of the study area was moderately suitable for rice crop cultivation. Along the southern and northern parts of the Fogera Woreda, the land was less suitable for rice crops.

According to the Fogera Woreda Agriculture and Rural Development office report (2021), 380km² (38000 hectares) were covered by rice cultivation which is very low related to its suitability sites. That is 728.5 km² highly suitable and 235.9 km² moderately suitable. The potential area for rice cultivation was much larger than the current cultivated area.

4.5 Discussions

Differentiating from previous studies of the suitability of the Woreda for rice crop cultivation (Belachew, 2022; Enawgaw, 2012; and Getachew, 2015), this study included a greater number of sub-criteria. Furthermore, only one (Getachew, 2015) of the previous studies integrated AHP to rank and weigh the importance of the sub-criteria. In studies of the suitability of the Fogera Woreda for rice crop cultivation, it is common to consider groups of climatological, soil properties, and landform information criteria. However, this study included one group of criteria, that is, current LULC conditions for rice. It should be noted that the criteria used in the analysis of the suitability of the area depend on the focus of the research and the availability of spatial data. For example, future studies may include cost-benefit, productivity, crop rate of return, costs of land use changes, population benefits by the crop, or other economic sub-criteria. However, the main problem lies in the lack of spatial data for the sub-criteria.

In terms of the development of rice cultivation in Fogera Woreda, my study result shows that climate variables (43%), soil physical and chemical properties (30%), LULC (16%), and topographic information (11%) factors play a major role in rice cultivation. However, for Getachew (2015), soil physical and chemical properties parameters were the most important, followed by climatological, and landform information. In contrast, although Getachew (2015) did not analyze LULC conditions. The number and the different sub-criteria used by each group of criteria, the local reality, and the experience of the experts, contributed to differentiating the importance of the criteria. Of course, in my study, the slightly greater importance of the socio-economic criteria was not analyzed because of the current security situation of the Region particularly the study area

In relation to climatological sub-criteria, the average annual rainfall (24%) is the highest, followed by temperature (19%); similarly, Belachew (2022), the rainfall is the most important climatological sub-criterion; for their part, Enawgaw (2012), states that precipitation is the most important. Rice crops are highly sensitive to climate, especially to the rainfall at which they are growing (Enawgaw, 2012 and Getachew, 2015). Additionally, in this type of study, the suitability models are generated under current environmental conditions and must be constantly updated, since climate change is a factor that influences the patterns of climatological sub-criteria (Getachew,2015). This is important for the agricultural sector in Ethiopian highlands particularly in Fogera Plain because it is one of the most affected by climate change.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study primarily focused on identifying a suitable site for rice cultivation in the district of Fogera. The parameters used for this suitability analysis were topography (slope), climate (temperature and rainfall), soil (type, texture, depth, and pH value), and LULC. The GIS-based MCE methods have been used to examine and verify the circumstances that favor the cultivation of rice crops in the Fogera Woreda.

Land suitability assessments were performed using the AHP method by assigning different weights to all parameters and then suitability maps were generated. In this model, all required criteria work together and according to their suitability ratios, highly, moderately, less suitable, and unsuitable areas were identified for rice cultivation. The findings show that the study area has a huge potential for rice cultivation.

The results have shown that 65.9%, 21.4%, 5.2%, and 7.5% of the total study area was highly, moderately, less suitable, and unsuitable for rice cultivation respectively. Hence, the suitability of land classification analysis results shows that more area of land was available which is suitable for rice cultivation. The higher potential area was placed in the northern part and a small amount in the western part of the study area. This is because most of the physical land resource accessibility was suitable for rice crop cultivation. The study concluded that there was a huge potential land in Fogera Woreda for rice cultivation.

5.2 Recommendations

Land suitability analysis should be considered a necessity in any agricultural venture. Hence, the Fogera Woreda Agriculture and Rural Development office and another agricultural research organization should encourage this scientific approach to avoid loss-generating agricultural activities. This is because farmers avoid unnecessary losses before engaging in any farming activity.

According to the findings of this research work, potential areas for rice cultivation were fairly distributed across the Woreda. So, it should be encouraged in the Fogera Woreda to produce rice highly and generate export revenues.

Land suitability for rice crops was analyzed using GIS-based MCE approaches such as soil, topography, climate, and LULC data. It is a benchmark for the future, further studies should be conducted by researchers. Such suitability analysis method guides land use planning, resource management, and sustainable food cultivation. Decision-makers can use these findings to allocate land effectively and enhance rice productivity.

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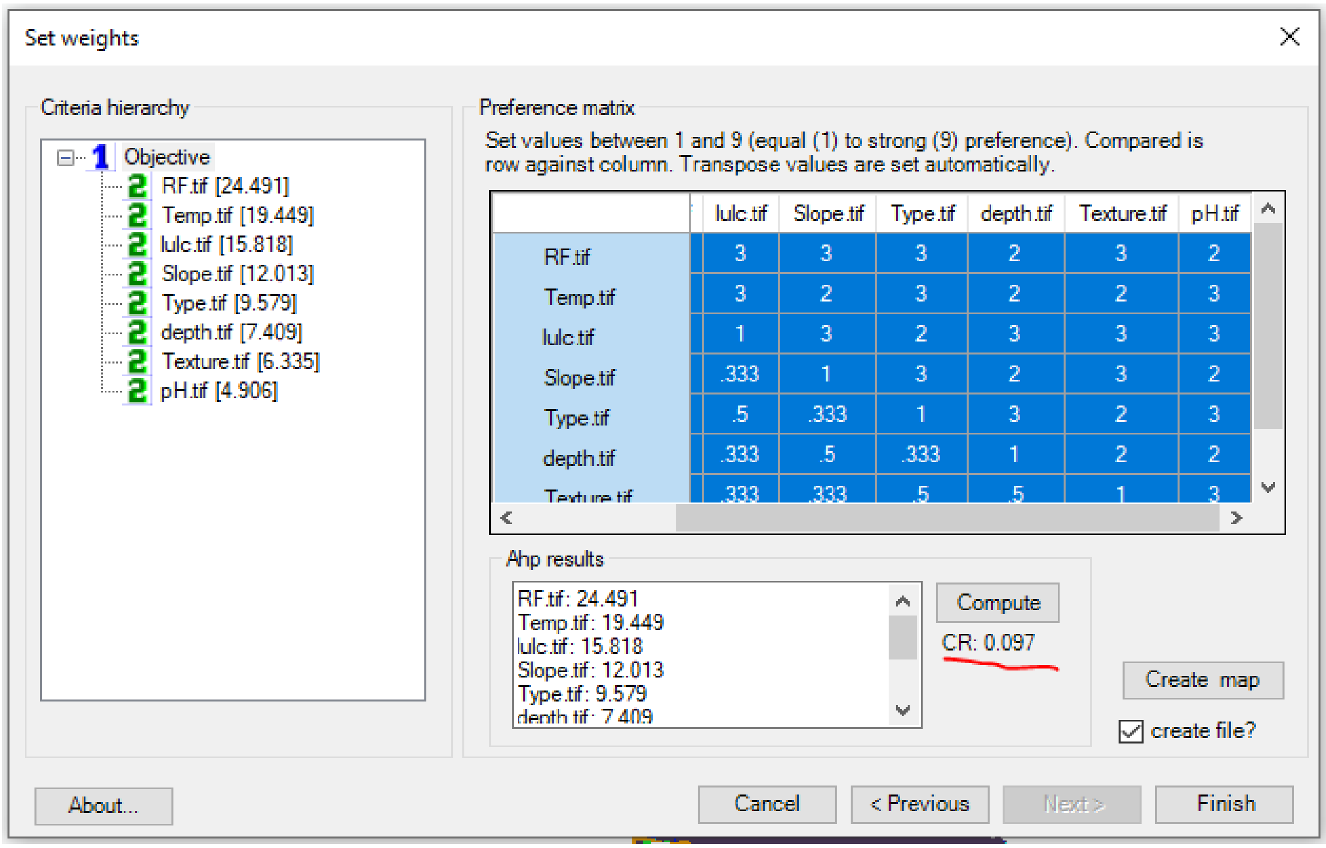
Appendices

Appendix A: LULC accuracy assessment result (confusion matrices table)

	Reference data							
Land cover classes	Agricultural land	Forest land	Water body	Settle ment	Grass land	Total	User's accuracy(%)	Kappa coefficient
Agricultural land	11	0	0	1	1	13	84.60	0.882
Forest land	0	8	1	0	1	10	80.30	
Waterbody	0	0	2	0	0	2	100.00	
Settlement	0	0	0	3	1	4	85.00	
Grassland	1	0	1	0	4	6	86.70	
Total	12	8	5	4	7	35		
Producer's accuracy (%)	91.67	100.0	90.08	88.30	92.00	Overall classification accuracy 90.5%		

Appendix B: Consistency ratio computing using the AHP extension tool (add-on ArcGIS)



Appendix C: Calculating the highest Eigen Value

Factors	Rainfall	Temperature	LULC	Slope	Soil Type	Soil Depth	Soil Texture	Soil pH	Weighted sum value	Criteria Weight	Eigenvalue (WSV/CW)
Rainfall	0.24	0.37	0.47	0.36	0.30	0.16	0.20	0.10	2.21	0.24	9.27
Temperature	0.12	0.19	0.47	0.24	0.30	0.16	0.13	0.15	1.76	0.19	9.47
LULC	0.08	0.06	0.16	0.36	0.20	0.24	0.20	0.15	1.45	0.16	9.31
Slope	0.08	0.09	0.05	0.12	0.30	0.16	0.20	0.10	1.11	0.12	9.17
Soil Type	0.08	0.06	0.08	0.04	0.10	0.24	0.13	0.15	0.89	0.10	8.79
Soil Depth	0.12	0.09	0.05	0.06	0.03	0.08	0.13	0.10	0.67	0.08	8.56
Soil Texture	0.08	0.09	0.05	0.04	0.05	0.04	0.07	0.15	0.58	0.07	8.54
Soil pH	0.12	0.06	0.05	0.06	0.03	0.04	0.02	0.05	0.44	0.05	8.60

The maximum eigenvalue of the pairwise **8.96**