MAKERERE UNIVERSITY

COLLEGE OF AGRICULTURAL AND ENVIRONMENTAL SCIENCES

SCHOOL OF FOOD TECHNOLOGY, NUTRITION AND BIO-ENGINEERING

DEPARTMENT OF AGRICULTURAL AND BIOSYSTEMS ENGINEERING

ASSESSING IRRIGATION POTENTIAL UNDER DROUGHT SCENARIOS IN THE LWAMPANGA SUB-CATCHMENT OF NAKASONGOLA DISTRICT.

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A FINAL YEAR PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL AND BIO-SYSTEMS ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF SCIENCE IN AGRICULTURAL ENGINEERING

AUGUST, 2026

DECLARATION

I, MUWANGUZI ENOTH**,** do hereby declare that this final year project is my original work and a true representation of my own effort. It has not been submitted for the award of any degree in Engineering or any other academic qualification at Makerere University or any other institution of higher learning.

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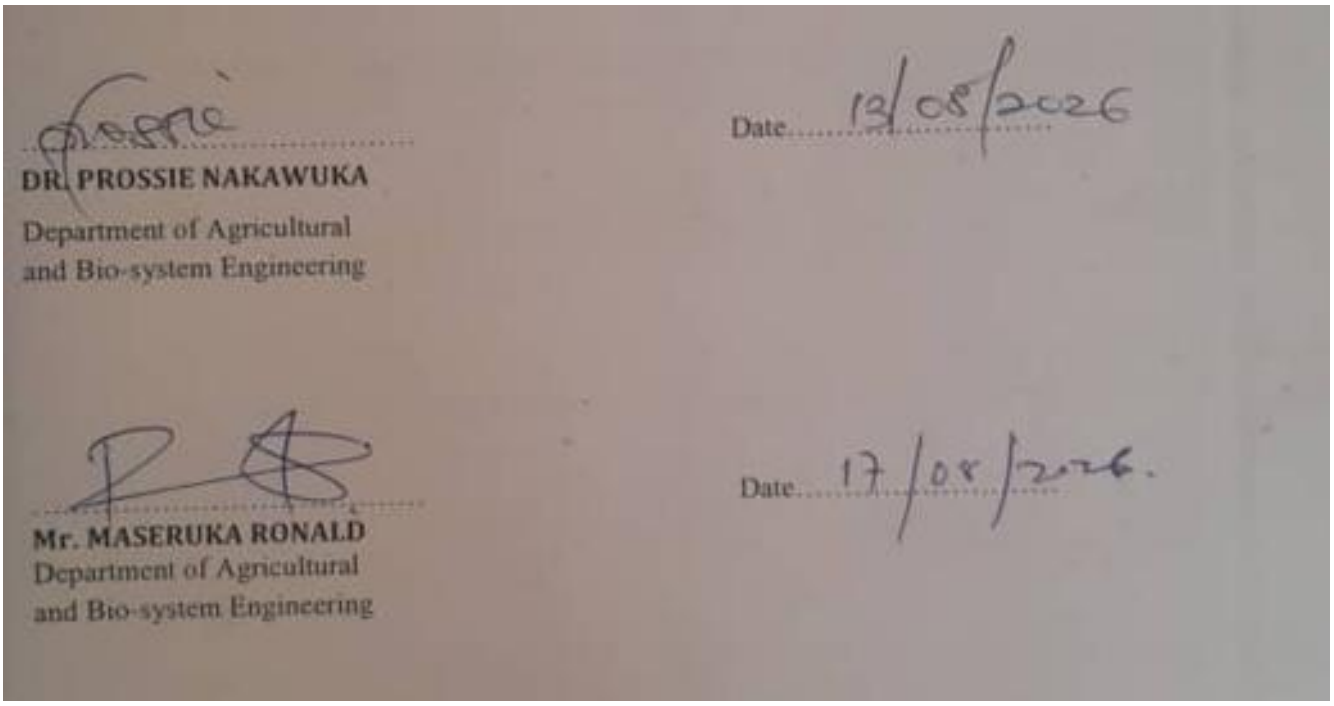
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APPROVAL

This is to certify that the research work entitled **"**Assessing Irrigation Potential under Drought Scenarios in the Lwampanga Sub-Catchment, Nakasongola District**"** has been carried out and submitted by Muwanguzi Enoth, a student in the Department of Agricultural and Biosystems Engineering, Makerere University, under my supervision and guidance in partial fulfillment of the requirements for the award of the degree of Bachelor of Science in Agricultural Engineering**.**

I have read and approved it for submission to the department for further consideration.

Approved by,



ACKNOWLEDGEMENT

I am sincerely grateful to the Almighty God for the gift of life, wisdom, guidance, and protection that have enabled me to undertake and complete this research successfully. I wish to express my sincere appreciation to Makerere University particularly the Department of Agricultural and Biosystems Engineering, for providing the academic foundation, resources and environment that made this research possible. I am profoundly grateful to my research supervisors, Dr. Prossie Nakawuka and Mr. Maseruka Ronald for their guidance, continuous encouragement and insightful advice during the development of this study. I am equally thankful to my parents, Mrs. Kiboma Rebecca and Ms. Damali Betty, and my elder brother, Wambutu Isaac, my sister, Caro, and Mr. Soddo Paul for their continuous prayers, moral support, and financial assistance throughout my academic journey. May the Almighty God bless you abundantly.

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LIST OF ACRONYMS

Acronym	Full Meaning
AHP	Analytical Hierarchy Process
CI	Consistency Index
CR	Consistency Ratio
DEM	Digital Elevation Model
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GPS	Global Positioning System
ISRIC	International Soil Reference and Information Centre
LULC	Land Use/Land Cover
MCDA	Multi-Criteria Decision Analysis
MWE	Ministry of Water and Environment
N	Not Suitable
OSM	OpenStreetMap
S1	Highly Suitable
S2	Moderately Suitable
S3	Marginally Suitable
SI	Suitability Index
UBOS	Uganda Bureau of Statistics
UTM	Universal Transverse Mercator
USGS	United States Geological Survey
WGS 84	World Geodetic System 1984

ABSTRACT

The Lwampanga Sub- County in Nakasongola District is frequently affected by drought, resulting in reduced agricultural productivity and increased vulnerability of communities that depend on rainfed agriculture. Although irrigation has been identified as key adaptation strategy, limited information on the spatial distribution of land suitable for irrigation development under varying drought conditions. This study investigated irrigation potential under normal, moderate drought, and severe drought scenarios in the Lwampanga Sub- County using Geographic Information systems (GIS), Remote sensing, and multi-Criteria Decision Analysis (MCDA). Spatial datasets, including Digital elevation Model (DEM) of 30m resolution, soil properties, land-use/land-cover, road networks, and water resources, were processed and integrated within a GIS environment. The analytical Hierarchy Process (AHP) was used to assign weights to irrigation suitability factors which included distance from water resources 42%, slope 18%, elevation 13%, land-use/land-cover 13%, drainage 5%, soil depth 4%, soil type 3%, distance from the road 2% as per calculations from pairwise matrix and weighted overlay analysis was performed to generate suitability maps. Drought scenarios of normal, moderate, severe were developed by progressively reducing available surface water resources by considering all rivers, streams and other water bodies available for irrigation, excluding seasonal streams and wetlands for moderate and considering only major water bodies like permanent rivers lakes for severe drought. The results showed that water availability, slope, soil characteristics, and land-use/ land-cover strongly influenced irrigation suitability. Under normal- conditions, the sub-catchment contained areas classified as 67.68ha (0.7%) highly suitable 5886ha (61%) moderately suitable, and 3688ha (38.3%) marginally suitable for irrigation development. Irrigation potential declined as drought severity increased due to reduced available water resources as seen with increase of land from 67.68ha highly suitable during normal conditions to 190.84ha located near perennial water resources and characterized by favorable soil and topographic conditions remained suitable, even water under severe drought conditions

1 INTRODUCTION

1.1 Background of the study

Agriculture remains the backbone of Uganda's economy, employing more than 70% of the population and contributing significantly to national food security, household incomes, and economic development (Bamwesigye et al., 2020). Agriculture in Uganda, still depends on rainfall, which makes it highly vulnerable to shifts in weather patterns and recurrent droughts. The changes in timing of rainfall, prolonged dry spells and increasing temperatures have put considerable strain on the nation's water resources, hence a situation of severe in the cattle corridors which includes districts such as Nakasongola.

The greatest climatic threats to agriculture in Uganda is drought, long periods of dryness have resulted in poor crop yields, livestock losses, food scarcity and a decrease in household incomes (Omona, 2023). The impacts are most severe in semi-arid regions where rainfall is already limited and erratic, as climate changes rainfall and water distribution, droughts becomes more common and cause greater damage which calls for more efforts to address the issues even more challenging (Muzammal et al., 2024).

Irrigation has become a big part of helping farmers to over changes and damage caused by drought which gives farmer away to add water when the rain fails and maintains steady food production and helps with food security. Faurès et al. (2002) irrigation is crucial at every stage of a crop's growth, which has motivated the Ugandan government to expand irrigation as a priority. Policies like the National Wetlands Policy from 2014 back it up and programs like Micro-scale Irrigation Scheme through the Ministry of Agriculture, Animal Industry and Fisheries are putting it into action. The whole point is to grow more food and make communities less vulnerable to climate changes (Echeverría et al., 2016).

Irrigation to be successful it depends on having both suitable land and adequate water and other factors like topography, soil properties, drainage, current land use and water availability (Wanyama et al., 2024). Identifying areas with high irrigation potential is critical for good planning and for using resources sustainably while performing an irrigation land suitability assessment that provides the evidence needed to determine where land can support irrigation. This helps maximize benefits while minimizing environmental harm and economic losses.

Using Geographic Information Systems (GIS) and Remote Sensing, different types of spatial data can now be integrated and analyzed much more quickly which enables planners and decision makers to identify the most suitable locations for irrigation with greater accuracy and less effort. Methods such as Multi-Criteria Decision Analysis (MCDA), including the Analytical Hierarchy Process (AHP), allow researcher to weigh various factors and combine them into a single suitability model.

Nakasongola District where Lwampanga Sub-catchment is located experiences recurrent droughts continue to affect agriculture production and the livelihoods of local communities (Nalwanga et al., 2025). Despite the presence of rivers, wetlands and other water resources, there is still limited understanding of how well these resources can support irrigation under drought conditions.

The aim of this study is to assess irrigation potential under drought conditions in the Lwampanga Sub-catchment. It uses GIS, remote sensing and multi-criteria evaluation methods. The study also integrates biophysical factors, such as soil characteristics, slope and land-use/land-cover with data on water resource availability to identify areas best suited for irrigation development.

1.2 Problem Statement

The major challenge facing the Lwampanga Sub-Catchment of Nakasongola District is the limited availability of spatial information on areas suitable for irrigation development. Recurrent drought scenarios in the sub-catchment continue to threaten crop production, food security, and livelihoods, yet irrigation as a response strategy remains poorly planned due to this data gap. Specifically, the lack of a comprehensive assessment of critical factors such as soil characteristics, terrain, land-use/land-cover, and water availability limit the identification of suitable irrigation sites and undermines effects to enhance agricultural resilience and productivity.

1.3 Objectives of the Study

1.3.1 Main Objective

To assess irrigation land suitability potential under drought scenarios in Lwampanga Sub-Catchment, Nakasongola District.

1.3.2 Specific Objectives

i. To characterize the biophysical factors influencing irrigation land suitability potential in Lwampanga Sub-Catchment.
ii. To develop a baseline irrigation suitability map using GIS based multi-criteria analysis
iii. To evaluate irrigation potential under different drought scenarios, normal, moderate and severe drought conditions

1.4 Scope of the Study

1.4.1 Geographical Scope

The study was conducted in Lwampanga Sub- Catchment in Nakasongola District, Uganda. The Sub-Catchment forms part of Lake Kyoga basin and is characterized by semi-arid climatic conditions, seasonal rainfall variability, and frequent drought occurrences. The assessment focused on areas within the boundaries of the sub-catchment.

1.4.2 Content Scope

The study focused on assessing irrigation potential through analysis of selected biophysical factors that influence irrigation suitability. Factors considered were soil types, slope, land-use/land-cover, soil drainage, and water resource availability. GIS and multi-criteria evaluation methods were then used to integrate these factors and generate maps showing suitable areas for irrigation.

1.5 Justification of the Study

Frequent droughts in the Lwampanga Sub-Catchment, threats farm output and livelihoods of rural communities. This matches broader findings that Uganda's smallholder farmers are facing more unpredictable rainfall and repeated dry spells, which reduce crop yields and makes for insecurity worse (Babyenda et al., 2023). Enhancing irrigation development is one of the most viable strategies for reducing over dependence on unreliable rainfall and improving food security, particularly in semi-arid parts of the central cattle corridor such as Nakasongola District, where

climate shocks have been shown to disrupt agricultural production cycles more severely than in other regions (Galiwango et al., 2025).

However, irrigation investments require accurate identification of suitable areas to ensure technical feasibility, economic viability and environmental sustainability. This study is justified by the need to provide a scientific basis for irrigation planning through spatial analysis of critical suitability factors. The integration of GIS and Multi-Criteria Evaluation techniques offer a cost effective and reliable approach for assessing irrigation potential, an approach already demonstrated at national scale in Uganda, where suitability was mapped using factors such as soil texture, slope, land-use/land-cover and drainage and proximity to water sources (Kebede et al., 2025). The results of the study will support sustainable agricultural development and climate change adaptation efforts within drought prone regions of Uganda.

1.6 Conceptual Framework

The research was conducted with the idea of determining land is suitable for irrigation depends on several biophysical factors such as soil properties that affect how much water the soil can hold, how easily water moves through it and how well crops can grow. Slope influences water movement, erosion risk and irrigation efficiency. Land use/ land-cover affects land availability and management practices, while water resources determine the feasibility of supplying adequate water for irrigation.

These factors are treated as independent variable and are analyzed using GIS along with multi-criteria Evaluation methods. Once combined, the analysis classifies land into different irrigation suitability levels: Highly suitable (S1), Moderate (S2), Marginally (S3) and Not Suitable (N). The final suitability map then gives useful information to help with irrigation planning and decision making, especially in areas facing drought.

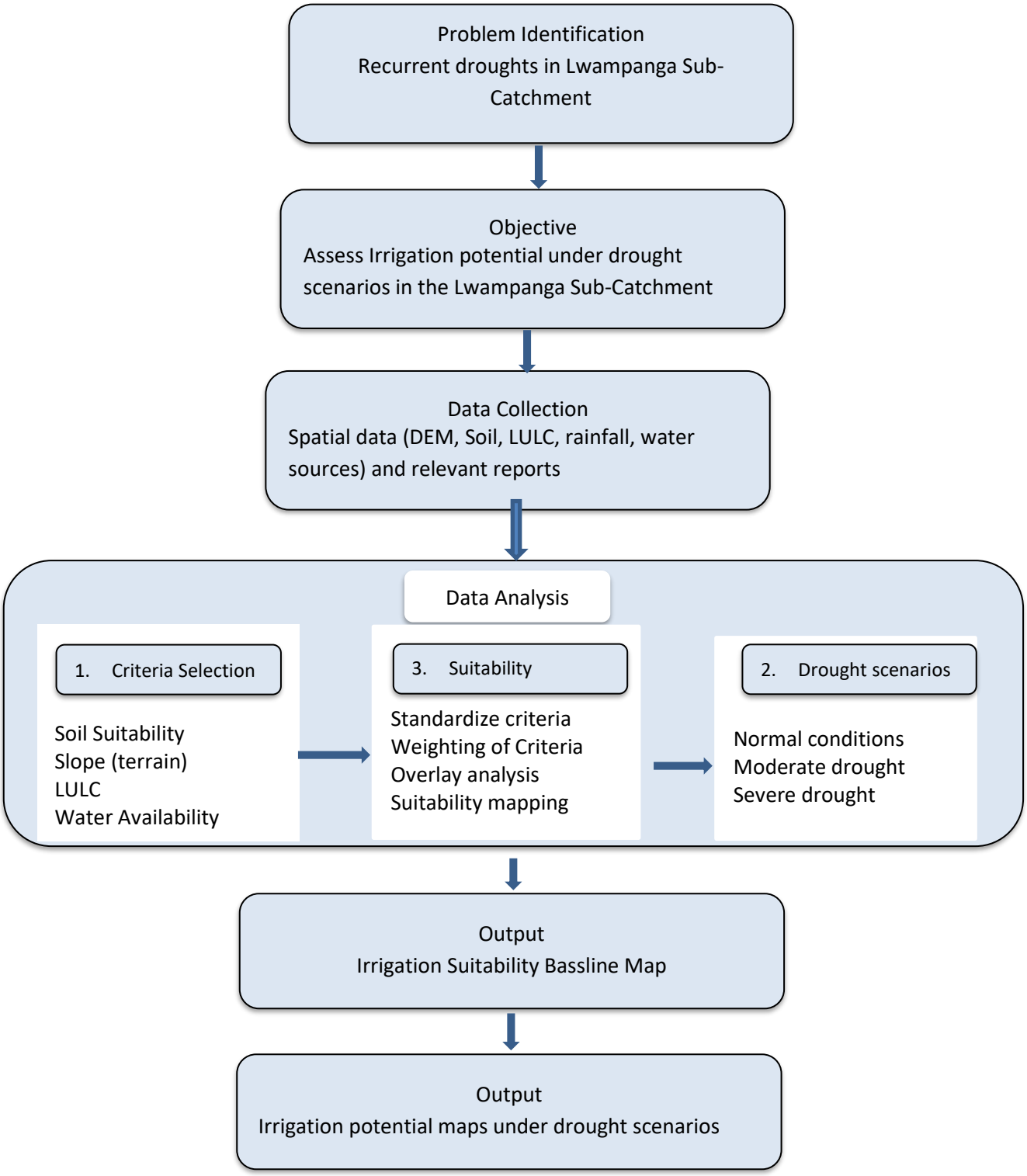


Figure 1: Conceptual Framework

2 LITERATURE REVIEW

2.1 Introduction

Irrigation is widely seen as one of the best ways to boost farm productivity and help farmers cope with changing weather, especially in semi-arid areas where rainfall is unpredictable. across parts of Sub-Saharan African, repeated droughts have made rainfed farming risker. This has put food security and rural livelihoods under serious pressure, because of this, there is increasing interest in using modern geospatial tools like Geographic Information Systems (GIS) and Remote Sensing (RS) to identify where to install irrigation system. These technologies have been used to combine different environmental factors, such as water availability, soil characteristics, topography, and land-use patterns, to support irrigation planning.

2.2 Irrigation Potential and Agricultural Water Resources

Irrigation is widely recognized as a practice for increasing crop yields and securing food supplies, particularly in areas with unreliable rainfall and frequent droughts. Food and Agriculture Organization (FAO), irrigation is the deliberate application of water to crops to compensate for low rainfall and maintain soil moisture for optimal plant growth (Zoebl, 2002). Farmers are able to grow crops during dry seasons, practice multiple cropping and improve land productivity. Although irrigated areas account for less than 25% of global cultivated land, they contribute to about 40% of the total food production. Zhang et al. (2022) irrigation in increasing agricultural output and helping farming systems adapt to climate change.

Irrigation potential refers to the capacity of an area to support irrigation sustainably, based on water availability and environmental conditions. Factors that influence, includes access to water, soil quality, topography, climate and current land use (Dessalegn et al., 2014). Locations with dependable water sources, good soils and gentle slopes tend to be more suitable for irrigation than areas without these characteristics. With increasing population pressure, assessing these factors critical for guiding decisions on where irrigation can be developed.

Water is fundamental to any irrigation system, as its success depends on a reliable and sufficient supply throughout the year, its sources include rivers, streams, lakes, reservoirs and wetlands while groundwater also plays a key role in many regions (Stewart & Howell, 2003). Water availability varies significantly by location and season, in semi-arid areas, highly variable rainfall directly

affects river flows and water storage, making it essential to understand both the quantity and reliability of water when planning irrigation. Proximity to a water source is also critical. Research indicates that greater distances increase costs related to pumping, water conveyance and infrastructure development (Awulachew et al., 2011).

Sub-Saharan Africa, irrigation development remains limited despite the availability of land and water resources suitable for irrigation, since most agriculture is still rainfed, making it highly susceptible to climate variability and droughts (Aryal et al., 2020). Uganda faces similar challenges where agriculture drives the economy and sustains the majority of rural households (Magunda, 2020). The government of Uganda has prioritized irrigation expansion to increase agricultural productivity, enhance food security and strength resilience to climate change which has led to new policies and investment programs aimed at promoting irrigation in drought-prone regions.

The Lwampanga Sub-Catchment in Nakasongola District falls within Uganda's cattle corridors, a zone characterized by recurrent droughts and highly variable rainfall, these conditions often result in reduced agricultural productivity and increased vulnerability among smallholder farmers. Assessing irrigation potential in such environments requires not only the identification of suitable land and water resources but also an understanding of how water availability changes under different drought conditions. Therefore, evaluating irrigation potential under normal, moderate and severe drought scenarios can provide valuable information for climate resilient irrigation planning and sustainable water resource management in the Sub-Catchment

2.3 Drought and Its Implications for Irrigation Development

Drought is among the most destructive natural hazards affecting agricultural production worldwide. Unlike other natural disasters that occur suddenly, develops gradually over time and may persist for months or even years, resulting in prolonged water shortages and significant socio-economic impacts. According to, Kumar et al. (2025), drought is generally characterized by a prolonged period of below normal precipitation that leads to deficits in the environment. The World Meteorological Organization (WMO) (Cammalleri, 2021) identifies drought as a recurring climatic phenomenon that affects water availability, agricultural productivity, ecosystem functioning and human livelihoods. Due to its slow onset and widespread impacts, drought remains

one of the most challenging environmental issues facing agricultural systems, particularly in developing countries where rain-fed agriculture dominates.

Several forms of drought have been identified in the literature, including meteorological, agricultural, hydrological and socio-economic drought. Metrological drought happens when rainfall drops for below the long-term average. Agricultural drought occurs when there isn't enough soil moisture to meet crop water needs (Sreekesh et al., 2019). Hydrological drought is characterized by reduced river flows, lower reservoir storage, poor groundwater recharge, and declining water levels in rivers and lakes. Socio-economic drought occurs when water shortages begin to affect businesses, livelihoods and community well-being. Although distinct, these types of droughts are closely linked. Prolonged low rainfall can lead to both agricultural and hydrological drought, with effects that extend to the economy and society. Understanding these differences is essential for irrigation planning, as they determine both water availability and its reliability for agriculture.

The impacts of drought on agriculture are most severe in rain-fed farming systems. When rainfall declines and soils dry out, crop growth is affected, yields decrease and risk of complete crop failure increases. Drought also affects livestock production by reducing pasture availability and limiting access to water. According to the Intergovernmental Panel on Climate Change (Guivarch et al., 2023), climate change is expected to increase the frequency, duration and intensity of drought events in many regions of the world including parts of Africa.

These changes are expected to put more strain on both water supplies and farming systems. As a result, there will be a greater need for practical adaptation measures because of this, irrigation development has been pointed to as one of the key ways to make agriculture less vulnerable to drought and changing climate conditions.

Despite its potential benefits, irrigation development is itself affected by drought because irrigation systems depend on the availability of reliable water resources. During periods of moderate drought, seasonal streams and small water bodies may dry up, reducing the number of potential water sources available for irrigation. Under severe drought conditions, even permanent rivers, reservoirs and wetland may experience substantial declines in water levels, limiting their capacity to support irrigation activities (CLIMA & Te, 2024). Therefore, irrigation suitability assessments that assume

constant water availability may overestimate the actual extent of land that can be irrigated during drought periods. This has led researchers to advocate for the incorporation of drought scenarios into irrigation planning in order to better understand how irrigation potential changes under varying levels of water scarcity.

In Uganda, drought remains a major challenge to agricultural development, particularly in semi-arid regions located within the cattle corridors. Nakasongola District is among the districts that is frequently experiencing prolonged dry spells and recurrent drought events which often results in crop losses, livestock mortality and declining household incomes (Mabziira, 2022). These conditions have increased interest in developing irrigation systems capable for supporting agricultural production during periods of reduced rainfall. However, the success of such interventions depends on understanding how drought affects the availability water resources required for irrigation. Assessing irrigation potential under normal, moderate and severe drought conditions is therefore essential for the identifying areas that remain suitable for irrigation despite increasing water stress. Such information can support climate resilient irrigation planning and contribute to sustainable agricultural development within the Lwampanga Sub-Cutchment.

2.4 Biophysical Factors Influencing Irrigation Suitability

The suitability of land for irrigation is determined by the interaction of several biophysical factors that influence the feasibility, efficiency and sustainability of irrigation development. Areas with enough water, it may still not be suitable for irrigation because of other factors such as steep terrain, poor soils and land uses that are not compatible. This is why assessing irrigation suitability requires looking at several environmental factors together. Food and Agriculture Organization (Gonfa et al., 2021), effective irrigation planning must consider water availability, soil properties, terrain, climate and land use patterns simultaneously. This integrated approach helps ensure that natural resources are used sustainably.

The relative importance of each bio-physical factor can vary with local conditions, and research from different regions consistently shows that the same factors, water availability, slope, soil characteristics and land-use/land-cover (Tesfaye & Defersha, 2024)), influence not only the technical feasibility of irrigation but also its economic viability and environmental sustainability.

That's why mapping where these factors occur it important for identifying the best areas for irrigation development.

Geographic Information Systems (GIS) and Remote Sensing (RS) have made this assessment much easier as they allow different types of spatial data to be combined and analyzed together. Using GIS based analyses multiple criteria, several factors can be assessed at same time to produce irrigation suitability maps that help decision makers make better choices.

2.4.1 Water Resource Availability

Water availability is usually considered the most important factors for irrigation suitability, because any irrigation system depends on having reliable water supply. As noted by Howell et al. (2015), having enough water available throughout the growing season is essential for irrigation. Common surface water sources include rivers, streams, lakes, reservoirs and wetlands provide the primary sources of irrigation water in many regions of the world while groundwater resources serve as important supplementary sources where surface water is limited. Access to reliable water sources ultimately decides whether irrigation can be started and maintained on a long term.

The spatial distribution and reliability of water resources are key determinants of irrigation potential where areas located near rivers, lake and reservoirs are prioritized for irrigation because of shorter distances which reduce the costs of water abstraction, pumping and conveyance infrastructure (Awulachew et al., 2011). Areas far from water sources often require substantial infrastructure investments, making irrigation economically unfeasible whereas, distance to a water source is commonly included as a primary criterion in irrigation suitability assessments. Worqlul et al. (2017) access to surface water as one of the strongest factors influencing irrigation suitability in the Ethiopian Highlands, showing the importance of water source proximity in planning.

Water availability becomes even more critical during drought, seasonal streams and small ponds may dry up entirely, leaving only permanent rivers and reservoirs as viable sources during severe drought can also reduce river flows and reservoir storage, hence inadequate water for agriculture. Therefore, suitability of an area for irrigation can vary significantly with drought severity. To address this, recent studies incorporate drought scenarios into assessments to examine how changes in water availability affect irrigation potential. Drought prone areas such as Lwampanga

Sub-Catchment, evaluating suitability under different water availability levels is essential to identify locations that can still support irrigation stress.

Belessa District, Northwestern Ethiopia, distance to water source was assigned the highest weights of 44%, compared to 18% for slope, 23% for elevation, 13% for soil texture and 5% for soil drainage (Wubalem, 2023). Wama watershed of western Ethiopia, distance from streams received the highest weight of 44% while slope, elevation and land-use ranged between 13% and 18%. These results indicate that in many semi-arid and drought affected settings, proximity to a reliable water source is considered factor for irrigation suitability often outweighing soil and topographic factors combined.

2.4.2 Topography and Slope

Topography is one of the key physical factors in irrigation suitability assessment because it affects how water moves, how efficiently irrigation works, how much it costs to build and whether the system can last on a long term. Of all topographic factors, slope is the most commonly used to evaluate irrigation suitability. According to FAO, slope determines how easily water can be moved and spread across farm fields, gentle slopes allow water to be applied evenly and help reduce losses, steep slopes however, lead to more runoff, less water infiltration into the soil and makes irrigation harder to manage. Consequently, slope is frequently incorporated as a key criterion in irrigation suitability studies conducted using GIS and Multi-criteria decision analysis methods.

Flat and gently sloping land is considered most suitable because water can be distributed efficiently and little land preparation is needed before installing irrigation structures. Steep areas are more challenging. They usually require costly engineering work like terracing, leveling, and erosion control, which raises the cost of developing irrigation (Chapagain & Raizada, 2017). Without proper conservation measures, irrigation on steep land can accelerate soil erosion and land degradation. Several studies emphasize the importance of slope in determining irrigation potential (Jat et al.) slope is identified as one of the most influential factors in watershed studies, as it affects both water conveyance and soil stability. Worqlul et al. (2017) areas with gentle terrain are more suitable for irrigation due to lower construction costs and reduced risk of soil erosion. In GIS based assessments digital elevation models are commonly used to generate slope maps, these maps

support the classification of land into different suitability classes and spatial data are valuable for identifying areas where irrigation can be developed efficiently and sustainably.

Steep slopes often lead to rapid runoff during rainfall, reducing water storage and groundwater recharge but gently sloping land retains water more effectively and supports more efficient irrigation practices. Lwampanga Sub-catchment, slope analysis is an essential component of the suitability assessment and identifying locations where irrigation infrastructure can be established with fewer environmental and economic constraints.

2.4.3 Soil Characteristics

Properties of soil are important in determining irrigation suitability because they influence infiltration, water storage, drainage, nutrient supply and crop productivity. An irrigation system can only be successful if water availability and if the soil is capable of retaining and supplying that water to crops. FAO, soils suitable for irrigation should be sufficiently deep, have appropriate texture, good drainage and adequate water holding capacity to support sustainable crop production.

Soil properties such as texture, depth, permeability, drainage and water holding capacity are important and considered during irrigation development. Soil texture which contains sand, silt and clay is particularly important as it governs water movement through the soil. Sandy soils drain rapidly and have low water retention, requiring more frequent irrigation. Clay soils retain more water but are prone to poor drainage and water logging under excessive irrigation (SANI et al., 2026). Loam soils with a balanced mixture of sand, silt and clay are generally considered ideal for irrigation because they combine good water retention with effective drainage.

Soil depth is also considered as deep soils typically 150cm or more provide a larger root zone and greater capacity to store water and nutrients, supporting better crop performance under irrigation. Shallow soils, ranging from 0-50 cm, restrict root development and limit water storage within the soil profile (Yu et al., 2007). Drainage is important in setting up irrigation because poorly drained soils are susceptible to waterlogging, which reduces oxygen availability to plant roots and negatively affects crop growth. Well drained soils are preferred because they allow excess water to percolate while retaining sufficient moisture for crops.

Naseri et al. (2009) found that soil texture, depth and drainage were among the most influential factors in southwestern Iran while Awulachew et al. (2011) also noted that favorable soil conditions enhance irrigation by improving water use efficiency and promoting sustainable agriculture. GIS suitability assessments which use soil maps to classify land according to soil properties and these maps identify areas where irrigation investments are most likely to be successful and where environmental risks can be minimized.

Lwampanga Sub-Catchment with areas affected by drought, soil characteristics is used to determine how effectively soils can store limited water during extended dry periods. Soils with high water-holding capacity can sustain crops for longer between irrigation events, improving water use efficiency and reducing irrigation demand. Therefore, evaluating soil properties alongside other biophysical factors is essential for identifying areas that can support sustainable irrigation under normal, moderate, and severe drought conditions.

2.4.4 Land Use and Land Cover

Land cover refers to what is physically on the ground, such as vegetation, water bodies, forests, and bare land while land use describes how people use the land, for example for farming, settlement, grazing, or conservation (Elias et al., 2019). Understanding current land-use and land-cover patterns is essential for identifying areas with potential for irrigation development while minimizing conflicts with other land uses and protecting environmentally sensitive areas.

Land where agricultural activities are carried on is considered the most suitable for irrigation because it is where crop production is taking place and requires minimal modification for irrigation infrastructure, but some factors like built-up areas, forests, wetlands and fragile ecosystems are often classified as unsuitable for irrigation due to environmental and socio-economic consideration. They perform critical ecological functions such as water storage, groundwater recharge and biodiversity support. Converting wetlands to irrigated agriculture can lead to environmental degradation and loss of these ecosystem services. As a result, most irrigation suitability assessments exclude wetlands, urban areas and protected lands from consideration.

Remote sensing has become an important tool for mapping and monitoring land cover changes, it provides current spatial information over large areas, making it easier to track how land use changes over time. (Abdulmajid, 2021) Satellite imagery enables researchers to classify land cover

into different categories and assess their suitability for various land management activities, including irrigation development. Studies conducted in Ethiopia, India, and other developing countries have demonstrated that integrating land use and land cover data into GIS-based suitability models improves the accuracy of irrigation potential assessments by ensuring that only environmentally and socially are considered for irrigation expansion (Haile & Abebe, 2022).

Weighting of Land use and land cover (LULC) together with other factors such as soil, slope and water related factors has instead been incorporated as a criterion within the pairwise comparison matrix, its relative importance has varied considerably between studies. In the Belessa District of Northwestern Ethiopia, land cover assigned the lowest weights among the eight factors considered at only 3%, well behind distance from a water source 44% and slope 18% (Wubalem, 2023). Also, in the Wama watershed of western Ethiopia, land-use/ land cover was weighted more heavily at 13% (Usman et al., 2023), placing it at the same weight as elevation and behind only distance to stream and slope

In the Lwampanga Sub-Catchment, land-use/land-cover assessment is particularly important because the area contains a mixture of agricultural land, grazing areas, wetlands, settlements and natural vegetation. Identifying existing land use patterns can help determine which areas are available and appropriate for irrigation development under different drought scenarios. The integration of land use and land cover information with other biophysical factors such as water availability, slope and soil characteristics therefore, providing a more comprehensive assessment of irrigation suitability and supports informed decision making for climate resilient agricultural development.

2.5 GIS and Remote Sensing in Irrigation Suitability Assessment

In natural resource management and agricultural planning, Geographic Information Systems (GIS) and Remote Sensing (RS) have become essential tools for efficiently collecting, managing, analyzing, and visualizing spatial data. Land suitability assessments depended heavily on field surveys and manual mapping in the past, but these methods were slow, costly, and hard to apply across large areas, but with advances in geospatial technology, suitability assessments are now faster and more accurate. GIS allows multiple types of data to be combined and analyzed within a single framework (Malczewski & Jankowski, 2020). As a result, GIS and RS are now used in

irrigation planning, watershed management, drought monitoring, and agricultural resource assessment.

In irrigation suitability studies, GIS now serves as a platform for storing, processing and analyzing spatial data from different sources, it makes it possible to combine key biophysical factors like slope, soil properties, land use/land cover, and water availability to map out where irrigation is most feasible. Burrough et al. (2015), GIS allows researchers to overlay several thematic layers and assess how they interact to influence land suitability which is especially important for irrigation planning, because suitability depends on how several environmental factors work together. Hence, by using spatial analysis, GIS can produce suitability maps that support decisions and help allocate resources more efficiently.

Remote sensing together with GIS provides timely and reliable information about the aerial data about the nature of the earth. Satellite imagery obtained can be used to track changes in land cover, vegetation health, water resources, and the environment across large areas at a relatively low cost and time (Degife et al., 2019). Satellite platforms that are used in agriculture and water studies include Landsat, Sentinel, and many others. They provide useful data for mapping and assessing land use, identifying water bodies, and monitoring drought, the spatial information obtained, is essential for irrigation suitability assessment, especially in areas where field data are scarce or hard to collect.

GIS together with remote sensing have greatly improved irrigation suitability analysis by allowing satellite-based datasets to be merged with environmental and hydrological data in one analysis. Different studies show how GIS and remote sensing are used to identify suitable areas for irrigation around the world. Awulachew et al. (2011), linking remote sensing data with GIS analysis improved the accuracy of irrigation potential assessments in Ethiopia and also (Perera et al., 2021) found that GIS and remote sensing provided an effective way to evaluate irrigation suitability by analyzing multiple criteria at the same time.

GIS and remote sensing can also be used in drought monitoring and climate adaptation apart from suitability mapping. Several indicators such as vegetation indices, land surface temperature, and the extent of water bodies can be used to assess drought impacts and track changes in water availability over time (Bhaga et al., 2020), this information is especially useful in drought-prone

areas where irrigation depends on having reliable water sources. Integrating GIS and remote sensing in Lwampanga Sub-Catchment offers an efficient way to assess irrigation potential under different drought scenarios. It makes it possible to analyze environmental conditions and water availability across the catchment.

2.6 GIS-Based Multi-Criteria Analysis for Irrigation Suitability Mapping

Irrigation suitability assessment requires evaluating several environmental factors together, because no single factor can decide if an area is fit for irrigation. Because of this, researchers often use Multi-Criteria Decision Analysis (MCDA) to bring different criteria together into one decision-making framework. MCDA refers to a set of analytical methods used to compare alternatives based on multiple, sometimes competing, criteria (Malczewski & Rinner, 2015). In land suitability studies, MCDA provides a structured way to combine environmental variables such as slope, soil properties, water availability, and land use into one overall assessment. The method has become popular in irrigation planning because it helps decision-makers consider how important each factor is, while reducing personal bias

Linking MCDA with Geographic Information Systems has greatly improved spatial decision-making in natural resource management. GIS handles the spatial analysis needed to process and combine different thematic layers, while MCDA provides a way to assign relative importance to each criterion (AGBAJE, 2025). Through this combination, spatial data for different environmental factors can be standardized, weighted, and merged to produce suitability maps. According to Malczewski and Jankowski (2020), GIS-MCDA approaches work well for land suitability analysis because they allow complex environmental interactions to be evaluated and make the decision process more transparent. GIS-MCDA methods are now one of the most widely used methods for irrigation suitability assessment around the world.

Multi-Criteria Decision Analysis methods used in irrigation studies are the Analytical Hierarchy Process (AHP), developed by Saaty (Wind & Saaty, 1980). AHP is a structured decision-making method that lets researchers assign weights to criteria based on their relative importance using pairwise comparisons. Each criterion is compared against every other criterion to determine how much it contributes to the overall goal.

The weights obtained from the pairwise matrix are then used to combine the criteria within a GIS. A key feature of AHP is the consistency ratio, which checks how reliable the judgments are made during pairwise comparison. According to (Wind & Saaty, 1980), a consistency ratio below 0.1 shows that the weights assigned to the criteria are reliable enough for decision-making. Once the criteria weights are set, weighted overlay analysis is usually used to create irrigation suitability maps.

Overlay analysis is performed to assign weights and standardize the criterion layer, and then all the weighted layers are combined to produce a single suitability index (Jemal, 2022). Areas with low scores are classified as less suitable or unsuitable. This method is best to assess how multiple factors work together and to group land into categories such as highly suitable, moderately suitable, marginally suitable, and unsuitable. The maps produced give useful information for planning irrigation infrastructure and for deciding which areas to prioritize for agricultural development.

GIS-based MCDA and AHP methods have been used in many studies to assess the suitability of irrigation development. For example, Perera et al. (2021) used GIS and AHP to assess irrigation suitability in Sri Lanka and found that the approach successfully combined different environmental factors into one model; similar studies used GIS and Multi-Criteria Decision Analysis to evaluate irrigation potential in Ethiopia and showed that weighted overlay analysis gave reliable results for identifying suitable areas. The results from these studies showed that GIS-based MCDA approaches are effective for supporting irrigation planning and resource management. For the Lwampanga Sub-Catchment, combining GIS with MCDA provides a strong framework for assessing irrigation potential under different drought scenarios. It does this by combining multiple biophysical factors into one comprehensive suitability analysis.

3 METHODOLOGY

3.1 Study Area Description

This study was carried out in the Lwampanga Sub-Catchment, located in Nakasongola District in Central Uganda. It lies between latitudes 1°28′10.27″ N and longitudes 32°30′38.50″ E. The sub-catchment is part of the Lake Kyoga Basin and falls within Uganda's cattle corridor. This region is known for frequent droughts, irregular rainfall, and high rates of evapotranspiration.

The area has a tropical semi-arid climate. Annual rainfall ranges from about 800 mm to 1200 mm (Salimah, 2019) and follows a bimodal pattern, with two rainy seasons each year. However, rainfall variability has increased in recent years, resulting in frequent agricultural droughts.

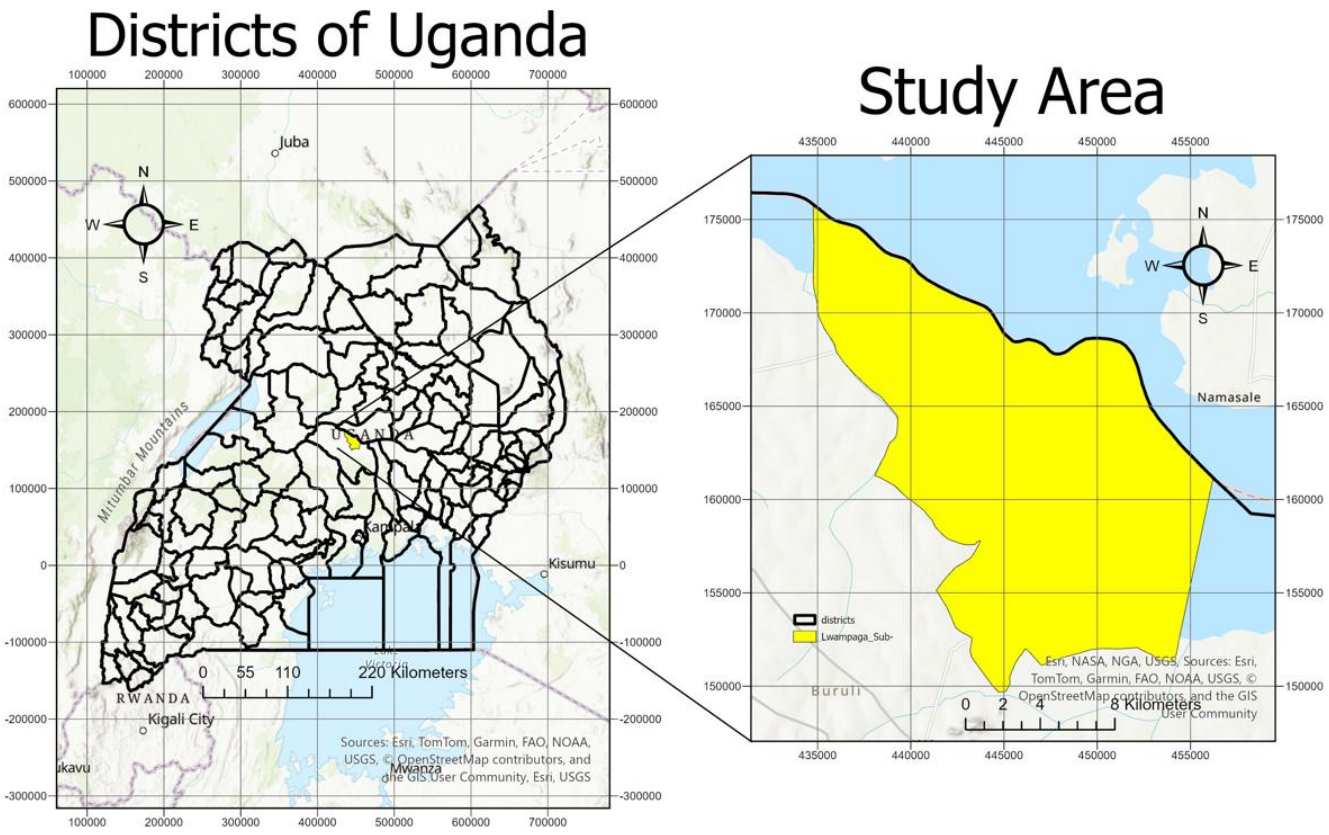


Figure 2: Study Area Lwampanga Sub-Catchment

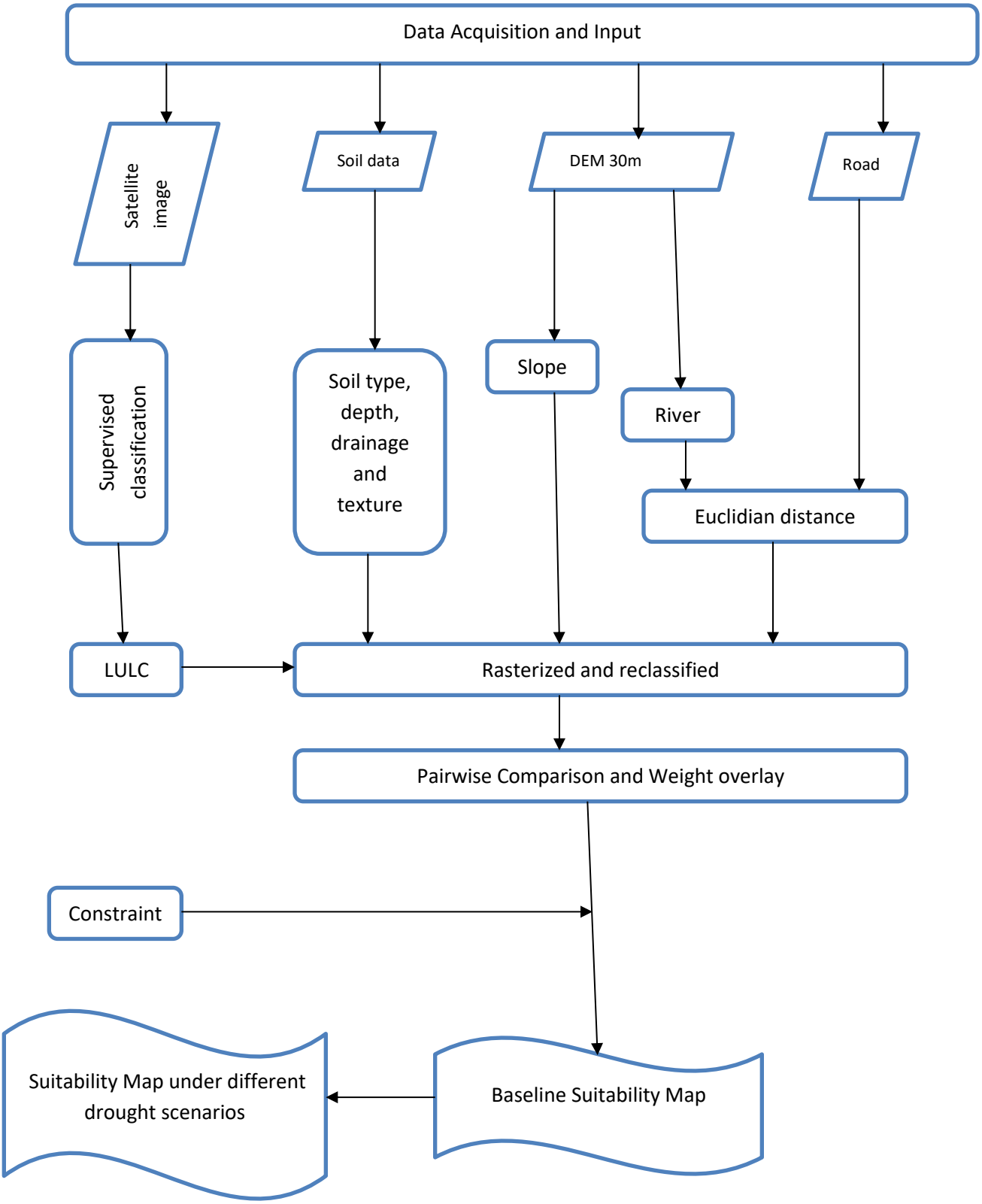
Agriculture is the dominant economic activity, with most farmers relying on rain-fed crop production and livestock keeping. Due to increasing climate variability and prolonged dry spells.

crop failures have become common, making irrigation development an important strategy for enhancing agricultural productivity and resilience.

The sub-catchment contains several rivers, seasonal streams, wetlands and groundwater resources that can potentially support irrigation development. However, the suitability of land for irrigation varies spatially due to differences in topography, soils, drainage conditions, water availability and land use patterns.

The study therefore seeks to identify and map areas suitable for irrigation development under drought conditions through the integration of geographic information system (GIS), remote sensing and multi-criteria decision analysis (MCDA)

3.1.1 Work flow



3.2 Data Sources

The study utilized both spatial and non-spatial datasets obtained from various source.

Table 1: Data Requirements and Sources

Data	Purpose	Source
Digital Elevation model (DEM) 30m	Slope and drainage extraction	USGS Earth Explorer
Soil data	Soil texture, soil depth and drainage analysis	FOA soils
Land use/land cover data 10m	Land cover classification	Sentinel-2 Imagery
Administrative boundaries	Delineation of the study area	UBOS
Road network	Accessibility assessment	OpenStreetMap

3.3 Data Pre-Processing

Data pre-processing was an important step in the irrigation suitability assessment to make sure that all datasets were consistent, accurate, and ready to be used together in a GIS environment. The datasets used in this study were obtained from different sources and had different spatial resolutions, formats, and coordinate systems.

Several pre-processing steps were carried out before being used in the software, like projection of all datasets into a unified coordinate system. Next, I converted the data into raster format, clipping to fit the Lwampanga Sub-Catchment boundary. These steps were crucial for minimizing errors and enhancing the reliability of the final irrigation suitability maps.

3.3.1 Digital Elevation Model (DEM) Processing

A 30 m resolution Digital Elevation Model (DEM) was obtained from the United States Geological Survey (USGS) to derive the topographic parameters necessary for assessing irrigation suitability Figure 3. The raw Digital Elevation Model datasets often come with depressions or sinks that can complicate hydrological analysis, I performed sink filling using the hydrological tools available in ArcGIS. After correcting for these sinks, I generated flow direction and flow accumulation layers to map out drainage patterns within the Lwampanga Sub-Catchment.

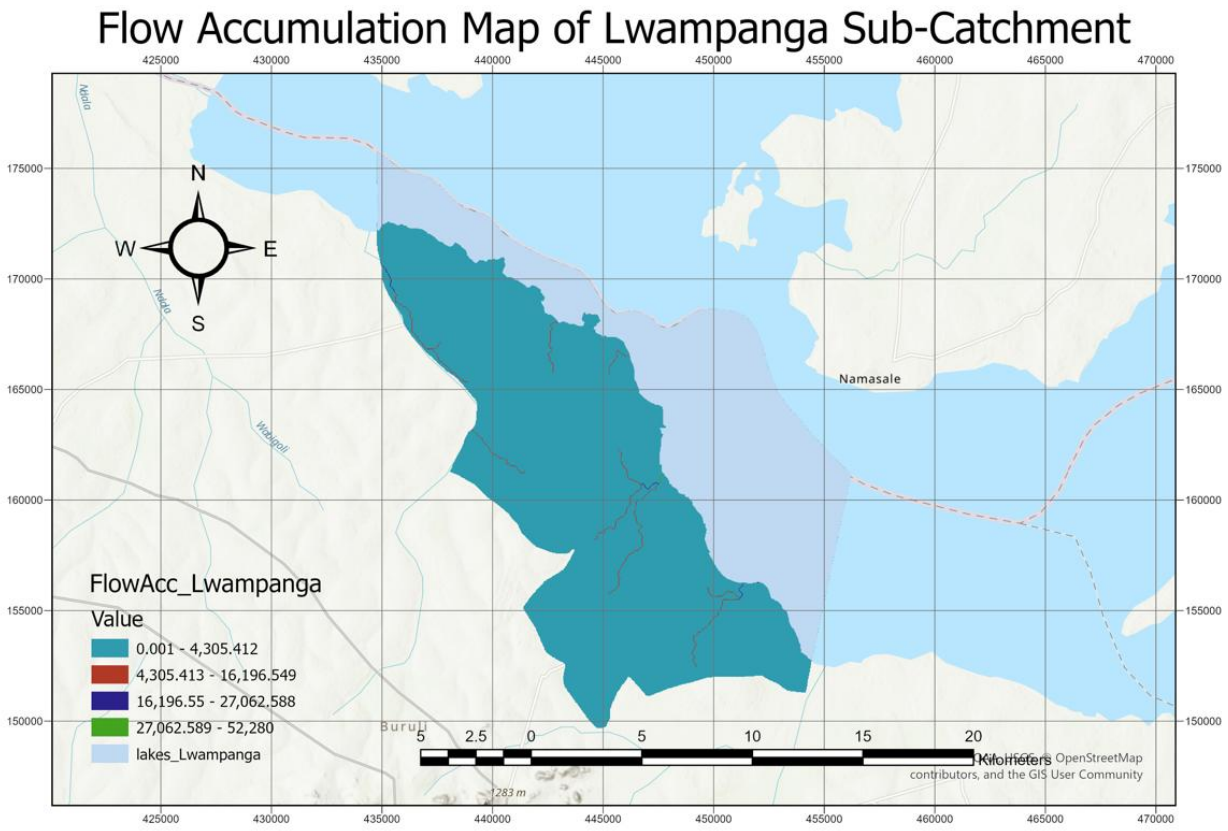


Figure 3: Flow Accumulation, Drainage channels

The Digital Elevation Model (DEM) obtained at a resolution of 30m was used to create a slope map and to evaluate how suitable the terrain is for irrigation development, as shown in Figure 4. Slope is one of the most important factors in irrigation planning. Steep slopes lead to faster runoff, lower infiltration, and increased soil erosion, which makes them less ideal for irrigation. The resulting slope layer was subsequently reclassified into suitability classes according to FAO land evaluation guidelines for irrigation development.

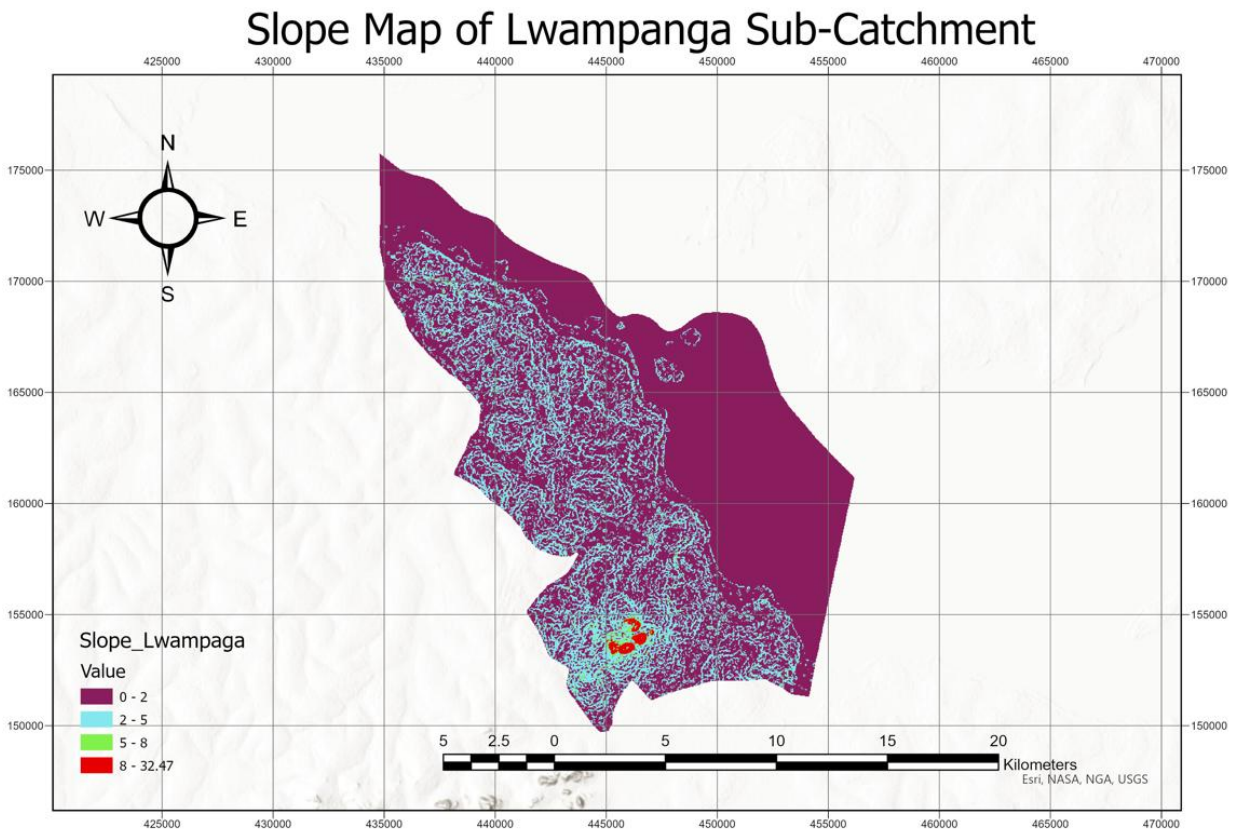


Figure 4: Slope Distribution in the Lwampanga Sub-Catchment

3.3.2 Land Use/Land Cover Data Processing

A land-use/Land-cover (LULC) map was generated from sentinel-2 imagery to support irrigation suitability analysis (figure 5). Sentinel-2 imagery was acquired during the most recent dry season to minimize cloud contamination and vegetation variability. The imagery was selected because of its high spatial resolution (10m) and frequent revisit period, making it suitable for detailed land cover mapping. Supervised classification using the maximum likelihood classification algorithm was employed to classify the imagery into major land use categories, including cropland, grassland, forest, wetland, water bodies and built-up areas. Training samples were collected from high-resolution Google Earth imagery. Classification accuracy and Kappa statistics. Only classification results achieving acceptable accuracy levels (greater than 80%) were used in the suitability analysis.

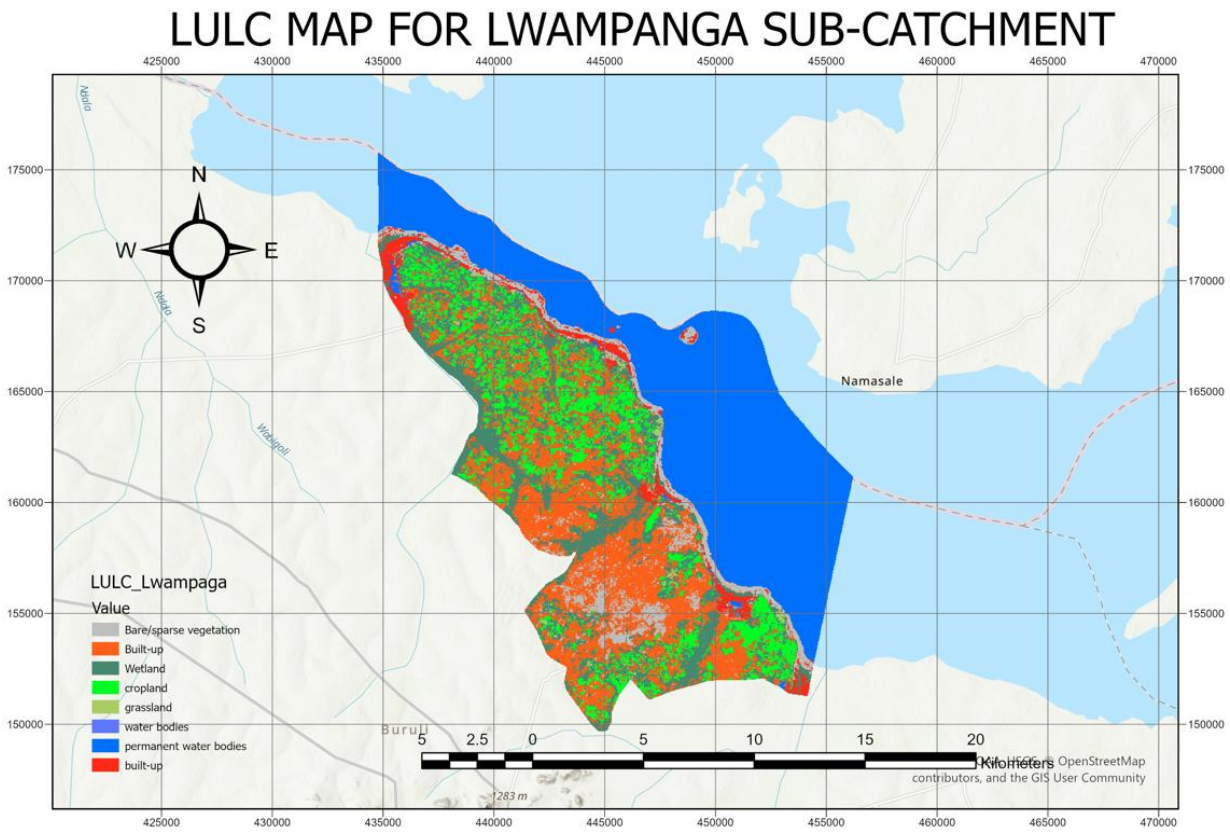


Figure 5: Land Use/Land Cover Distribution in the Lwampanga Sub-Catchment

Land cover type	Suitability class	Score
Cropland	S1	4
Grassland	S2	3
Bare land	S3	2
Wetlands	N	1
Built-up areas	N	1
Water bodies	N	1

3.3.3 Soil Data Processing

Soil data was obtained from the FAO soils database and supplemented with available national soil information. The soil parameters considered in this study include soil texture, soil depth and soil drainage characteristics.

The downloaded soil datasets were clipped to the Lwampanga Sub-Catchment boundary and converted into raster format.

Soil texture data were used to assess infiltration rates and water holding capacity, while soil depth data were used to indicate the rooting depth available for crops. Soil drainage characteristics were used to evaluate the potential occurrence of waterlogging and surface runoff. Each soil parameter was reclassified into suitability categories based on FAO irrigation land evaluation standards.

3.3.4 River Network and Water Resource Processing

River network data was obtained from the Ministry of Water and Environment and supplemented by drainage extraction from the DEM. The river network was converted into raster format and subjected to Euclidean distance analysis to determine the proximity of different locations to potential irrigation water sources.

Perennial rivers and streams were given greater consideration because they provide more reliable water supplies during prolonged drought periods. Areas located closer to perennial water sources had lower irrigation infrastructure costs and greater feasibility for irrigation development. The resulting distance to river map was subsequently reclassified into suitability classes.

3.3.5 Road Network Processing

Road accessibility influenced irrigation development by affecting the transportation of construction materials, farm inputs, equipment and agricultural produce. Road network data obtained from OpenStreetMap and national datasets were therefore incorporated into the analysis. The road layers were converted into raster format and Euclidean distance analysis was performed to determine accessibility levels within the sub-catchment. Areas located near major roads were generally considered more suitable because of reduced transportation and operational costs. The generated distance to road raster was standardized and reclassified into suitability classes for integration into the multi-criteria evaluation process.

3.3.6 Data Standardization

To facilitate integration of suitability factors, all datasets were transformed into raster format and projected into a common coordinate reference system (WGS 84 UTM Zone 36N) layers were resampled to a uniform spatial resolution of 30 m x 30m.

Each factor was then standardized and reclassified into four irrigation suitability categories following FAO land evaluation guidelines.

The standardized raster layers were subsequently used in the analytical Hierarchy Process (AHP) and weighted overlay analysis to generate the final irrigation suitability map.

3.4 Suitability Classification of Irrigation Factors

The biophysical factors were classified into suitability classes, following the Food and Agriculture Organization (FAO) land evaluation framework for irrigation. This classification involved assigning suitability scores to various classes within each factor based on their impact on irrigation performance.

Table 2 below shows the suitability classes according to the guidelines set by FAO:

Table 2: suitability classes (Bagheri Bodaghabadi et al., 2015)

Class	Description
S1	Highly Suitable
S2	Moderately Suitable
S3	Marginally Suitable
N	Not Suitable

FAO irrigation guidelines were followed during the suitability ratings and review of existing literature. Factors that create favorable conditions for irrigation were given higher scores, while factors that limit irrigation potential received lower scores.

3.4.1 Slope Suitability Classification

Irrigation efficiency is influenced by the conditions of slope because it affects runoff, soil erosion, infiltration, and how evenly water is distributed. Areas with gentle slopes are easier to irrigate and require less land preparation. The slope layer derived from the DEM was grouped into four suitability classes following FAO guidelines for surface irrigation.

Table 3: Slope Suitability Classification *(Pereira & Duckstein, 1993)*

Slope (%)	Suitability Class	Score
0 – 2	S1	4
2 – 5	S2	3
5 – 8	S3	2
>8	N	1

Slopes of less than 2% were rated as highly suitable because they allow uniform water application and have minimal erosion risk. As slope increases, suitability drops because runoff becomes higher and more land leveling is needed.

3.4.2 Soil Texture Suitability Classification

Soil texture was included as a factor in the irrigation suitability assessment because it affects infiltration rate, water holding capacity, and overall irrigation efficiency. Different soil texture classes were evaluated and ranked based on how suitable they are for irrigation. Medium-textured soils received the highest suitability scores because they have a good balance of drainage and moisture retention.

Table 4: Soil Texture Suitability Classification (Sadiq et al., 2025)

Soil Texture	Suitability Class	Score
Clay loam	S1	4
Loam	S1	4
Sandy clay loam	S2	3
Sandy loam	S3	2
Sand	N	1

3.4.3 Soil Depth Suitability Classification

Soil depth was considered an important factor in the irrigation suitability assessment because it influences rooting depth, water storage, and crop productivity. The soil depth classes were reclassified into suitability categories and scored based on how well they support irrigation. Deeper soils received higher suitability ratings because they provide more space for root growth and can hold more water.

Table 5: Soil Depth Suitability Classification (Hussien et al., 2019)

Soil Depth (cm)	Suitability Class	Score
>100	S1	4
80–100	S2	3
50–80	S3	2
<50	N	1

3.4.4 Soil Drainage Suitability Classification

Soil drainage classes were reclassified into suitability categories and assigned scores based on their suitability for irrigation development. Moderate well drained soils were given higher suitability ratings while poorly drained soils and excessively drained soils received lower ratings due to the risks of waterlogging and rapid moisture loss respectively.

Table 6: Soil Drainage Suitability Classification (Hussien et al., 2019)

Drainage Condition	Suitability Class	Score
Well-drained (w)	S1	4
Moderately drained (m)	S2	3
Imperfectly drained (I)	S3	2
Poorly drained (p)	N	1

3.4.5 Land Use/Land Cover Suitability Classification

Land use and land cover were incorporated into the irrigation suitability assessment because they influence irrigation feasibility, environmental suitability and implementation costs. LULC classes were reclassified into suitability categories and assigned scores based on their appropriateness for irrigation development. Areas with land uses favorable for agricultural activities were assigned higher suitability ratings while built-up areas, wetlands and other restricted land cover type received lower suitability ratings.

Table 7: Land Use/Land Cover Suitability Classification (Hussien et al., 2019)

Land cover type	Suitability class	Score
Cropland	S1	4
Grassland	S2	3
Shrubland	S3	2
Wetlands	N	1
Built-up areas	N	1
Water bodies	N	1

3.4.6 Distance to Water Source Suitability

Distance from the perennial rivers and streams was analyzed and reclassified into suitability categories, with areas closer to water sources assigned higher suitability ratings due to the reduced infrastructure requirements and costs associated with water abstraction and conveyance.

Table 8: Distance to Water Source Suitability Classification (Hussien et al., 2019)

Distance (km)	Suitability Class	Score
0–1	S1	4
1–3	S2	3
3–5	S3	2
>5	N	1

The Euclidean distance tool was used to generate distance buffers around perennial water sources.

3.5 Determination of Factor Weights Using the Analytical Hierarchy Process

To evaluate irrigation suitability, the relative importance of the selected factors was determined. The Analytical Hierarchy Process (AHP) developed by Thomas L. Saaty was used to assign weights to each criterion through pairwise comparison matrix.

The selected criteria include:

- Distance to water source
- Slope
- Soil texture
- Soil drainage
- Soil depth
- Land-use/land-cover
- DEM
- Distance to the road

A pairwise comparison matrix was developed by comparing each criterion against all others using Saaty's nine-point scale.

Table 9: Saaty's Pairwise Comparison Scale *(Pereira & Duckstein, 1993; Sadiq et al., 2025)*

Scale	Interpretation
1	Equal Importance
3	Moderate Importance

5	Strong Importance
7	Very Strong Importance
9	Extreme Importance
2,4,6,8	Intermediate Values

Factor	Dist. to water	Slope	Elvation	LULC	Drainage	Soil Depth	Soil texture	Dist. To Road
Dist. to water	1.00	5.00	7.00	9.00	9.00	9.00	9.00	9.00
Slope	0.20	1.00	3.00	2.00	5.00	7.00	7.00	7.00
Elvation	0.14	0.33	1.00	2.00	7.00	5.00	5.00	5.00
LULC	0.11	0.50	0.50	1.00	5.00	7.00	7.00	7.00
Drainage	0.11	0.20	0.14	0.20	1.00	1.00	2.00	5.00
Soil depth	0.11	0.14	0.20	0.14	1.00	1.00	2.00	2.00
Soil Type	0.11	0.14	0.20	0.14	0.50	0.50	1.00	2.00
Dist. To rd	0.11	0.14	0.20	0.14	0.20	0.50	0.50	1.00
Sum	1.90	7.46	12.24	14.63	28.70	31.00	33.50	38.00

Table 10: Standardizing and Normalizing of Factors

Factor	Dist. to Water	Slope	Elvation	LULC	Drainage	Soil Depth	Soil type	Dist. To Road	Total	Average	Consistancy Measure (λmax)	(λmax -n)/n-1
Dist. to Water	0.53	0.67	0.57	0.62	0.31	0.29	0.27	0.24	3.49	0.44	10.41	0.34
Slope	0.11	0.13	0.25	0.14	0.17	0.23	0.21	0.18	1.41	0.18	9.75	0.25
Elvation	0.08	0.04	0.08	0.14	0.24	0.16	0.15	0.13	1.02	0.13	9.75	0.25
LULC	0.06	0.07	0.04	0.07	0.17	0.23	0.21	0.18	1.03	0.13	8.93	0.13
Drainage	0.06	0.03	0.01	0.01	0.03	0.03	0.06	0.13	0.37	0.05	8.01	0.00
Soil depth	0.06	0.02	0.02	0.01	0.03	0.03	0.06	0.05	0.28	0.04	8.37	0.05
Soil Type	0.06	0.02	0.02	0.01	0.02	0.02	0.03	0.05	0.22	0.03	8.01	0.00
Dist. To rd	0.06	0.02	0.02	0.01	0.01	0.02	0.01	0.03	0.17	0.02	8.97	0.14
Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	8.00	1.00	CI	0.15

The normalized matrix was used to calculate factor weights. The consistency of judgement was assessed using the Consistency Index (CI) and Consistency Ratio (CR). A CR value below 0.10 indicated acceptable consistency.

Table 11: Random inconsistency index

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.46	1.49

Where N- number of parameters considered

Consistency Ratio (CR) = $\frac{CI}{RI}$ ... ... $equation\ 1$

•But CI - Consistent Index and

- RI - Random Index

CR = $\frac{0.15}{1.41}$

CR = 0.106

3.6 Constraint Identification and Baseline Irrigation Suitability Assessment

After the suitability factors had been standardized and weighted, it was necessary to identify areas where irrigation development was physically, environmentally or socially constrained. Constraint analysis was important because some areas may appear suitable based on biophysical characteristics but cannot be used for irrigation development in practice due to existing land uses environmental regulations or physical limitations.

In this study, constraint mapping was conducted before the final irrigation suitability assessment. Constraint areas were excluded from the analysis through the application of FAO suitability scale, whereby unsuitable areas were assigned a value of one (1) and potential suitable areas were assigned a value of (2,3 and 4) which indicates marginally, moderately and highly suitable respectively.

The identified constraint layers were then integrated with the weighted suitability map to generate the baseline irrigation suitability map for the Lwampanga Sub-Catchment.

3.6.1 Identification of Constraint Areas

The constraint analysis focused on areas where irrigation development was either prohibited or technically infeasible. The major constraint factors considered in this study included;

- Permanent water bodies
- Wetlands
- Built-up areas and settlements
- Protected forests and conservation areas

These areas were extracted from land use/land cover maps and relevant environmental datasets.

3.6.2 Generation of Baseline Irrigation Suitability Map

The baseline irrigation suitability map represents irrigation potential under existing climatic conditions within the Lwampanga Sub-Catchment. The map was generated through weighted overlay analysis of all standardized criteria using the weights derived from the analytical hierarchy process.

The suitability index was computed as;

$$SI = \sum(W_i X_i)$$

where:

- SI = Suitability Index, W_i = Weight of criterion i, X_i = Standardized suitability score

The resulting suitability index raster was subsequently classified into four suitability categories.

Table 12: Baseline Irrigation Suitability Classes

Suitability class	Description
S1	Highly Suitable
S2	Moderately Suitable
S3	Marginally Suitable
N	Not Suitable

The baseline suitability map provided a spatial representation of areas currently suitable for irrigation development and will serve as the reference condition for evaluating the impacts of drought scenarios.

3.7 Development of Drought Scenarios

To evaluate irrigation potential under varying climatic stress conditions, three drought scenarios will be developed:

- ✓ Normal Drought Scenario
- ✓ Moderate Drought Scenario
- ✓ Severe Drought Scenario

The scenario analysis was enabled to evaluate changes in irrigation suitability under increasing drought severity and provide insights into the resilience of irrigation development options within the sub-catchment.

3.7.1 Normal Condition Scenario

The normal condition scenario considered that all rivers, streams and water bodies were available for irrigation within Lwampanga Sub-Catchment. The baseline irrigation suitability map generated in section 3.7 represents the irrigation potential under normal conditions.

3.7.2 Moderate Drought Scenario

The moderate drought scenario was considered when seasonal streams were excluded. Only permanent rivers and reservoirs were considered within the Lwampanga Sub-catchment.

3.7.3 Severe Drought Scenario

The severe drought Scenarios was considered with only major permanent water bodies remaining available within the Lwampanga Sub-Catchment.

4 RESULTS

4.1.1 Introduction

The section presents the results from the irrigation potential assessment in the Lwampanga Sub-Catchment under different drought scenarios. The results provide a comprehensive understanding of the spatial distribution of irrigation suitability, the influence of biophysical factors and the impacts of drought severity on irrigation potential.

This was organized according to the study objectives and includes characterization of biophysical factors, a baseline irrigation suitability assessment and drought scenario analysis.

4.1.2 Characterization of Biophysical Factors Influencing Irrigation Potential

The spatial distribution and suitability of he selected biophysical factors influencing irrigation development in the study areas were examined in this section. The outputs included thematic maps and interpretations of each factor.

4.1.2.1 Slope Characteristics

Slope map in (figure 6), derived from the digital elevation model (DEM) revealed variations in terrain across the Lwampanga Sub-Catchment.

Slope Suitability Distribution Map

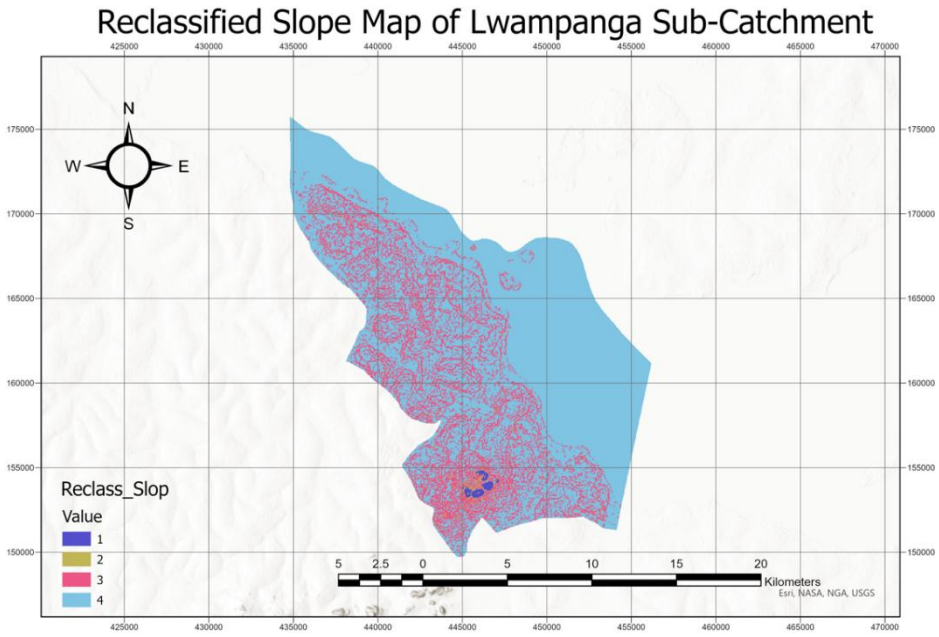


Figure 6:Slope Suitability for Irrigation Development in the Lwampanga Sub-Catchment

4.1.2.2 Soil Characteristics

Soil suitability maps for texture, depth and drainage showed variation in the agricultural potential of the sub-catchment. Areas dominated by deep clay loam and loam soils exhibited higher suitability sue their superior water retention capacity as shown in (figure 7)

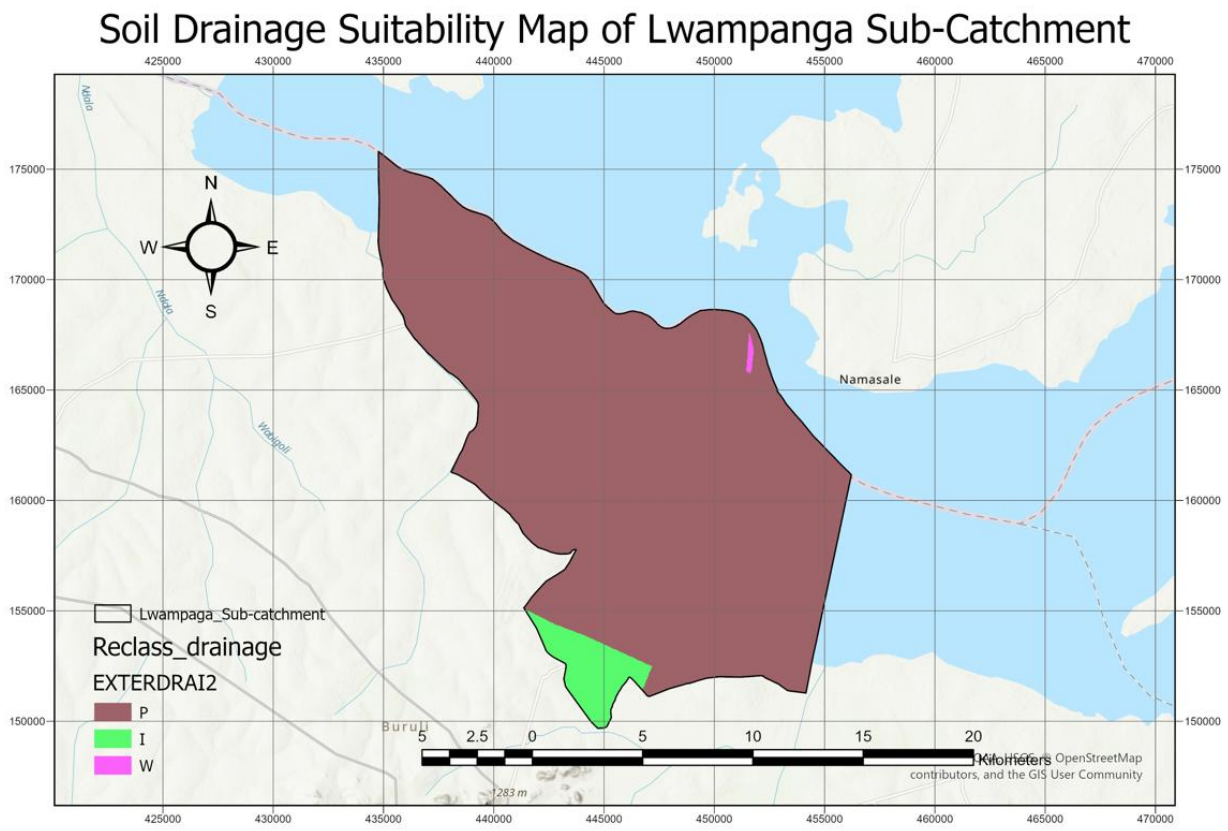


Figure 7: Soil Drainage Suitability

Interpretation of soil drainage key

Drainage Condition	Area (ha)	Suitability Class	Score
Well-drained (w)	13.11	S1	4
Imperfectly drained (I)	352.72	S3	2
Poorly drained (p)	9276.95	N	1

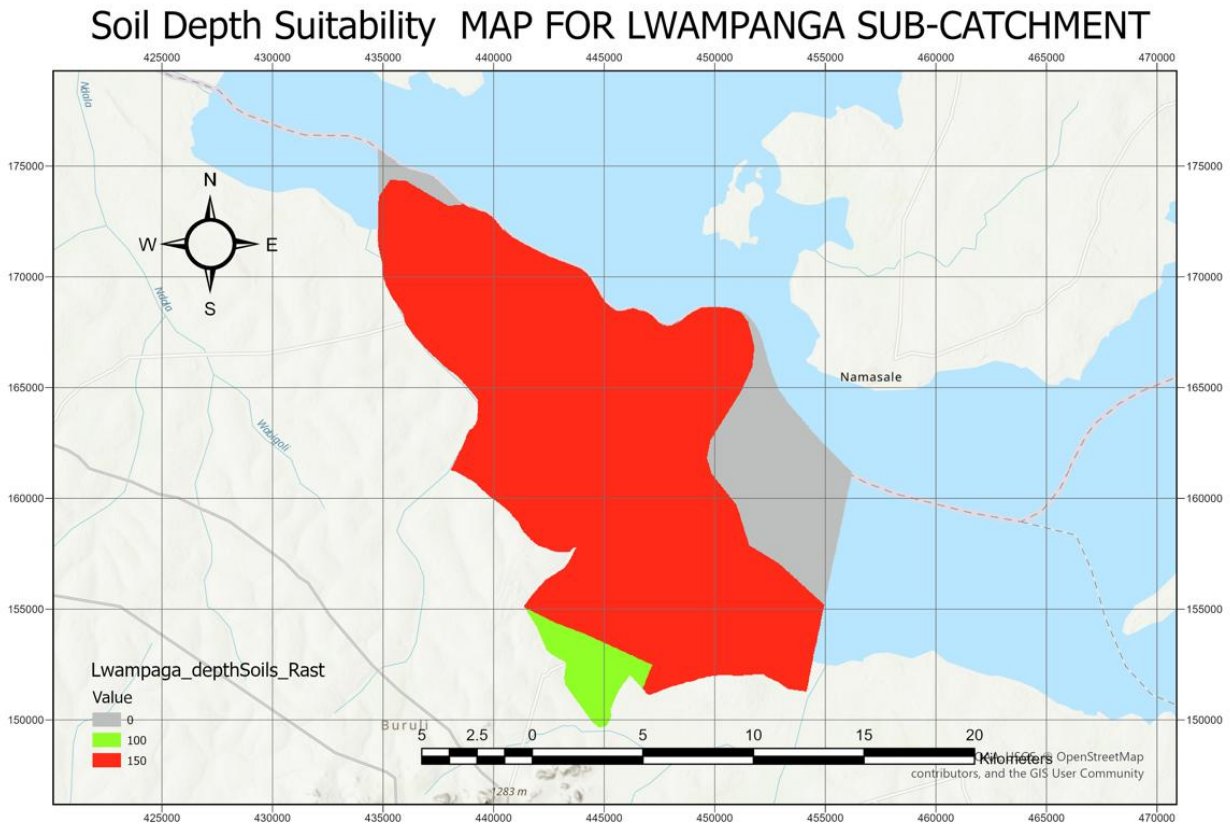


Figure 8: Soil Depth Suitability classes

Interpretation of Key

Soil Depth (cm)	Area (ha)	Suitability scale
150	7741.72	Highly suitable
100	352.72	Moderate suitable
0-80	1548.34	Marginally Suitable

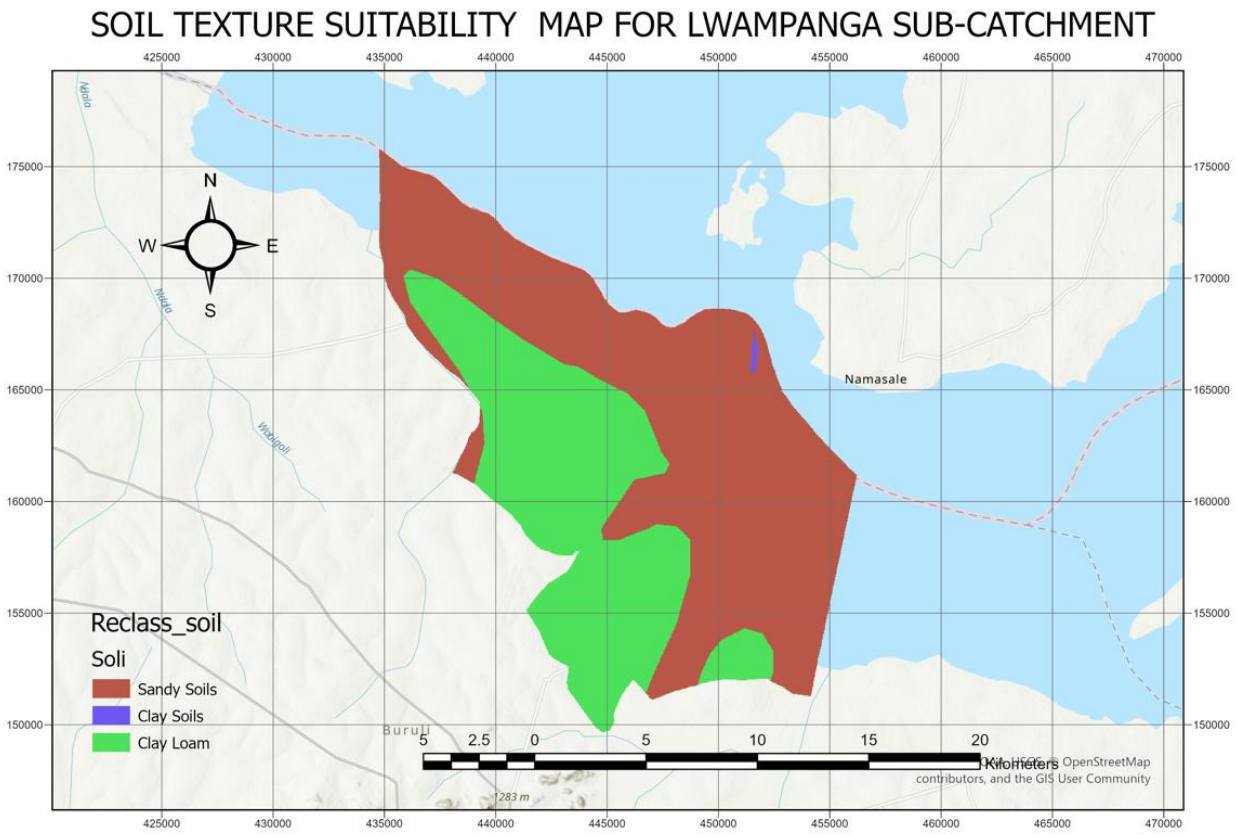


Figure 9: Soil Texture Suitability

Drainage Condition	**Area (ha)**
Sandy soil	5947.58
Clay soils	3682.09
Clay loam	13.11

4.1.2.3 Land Use/Land Cover Characteristics

The land use and land cover analysis identified existing agricultural land, grasslands, wetlands, built-up areas and water bodies. Croplands covered a significant proportion of the study area and provided opportunities for irrigation expansion.

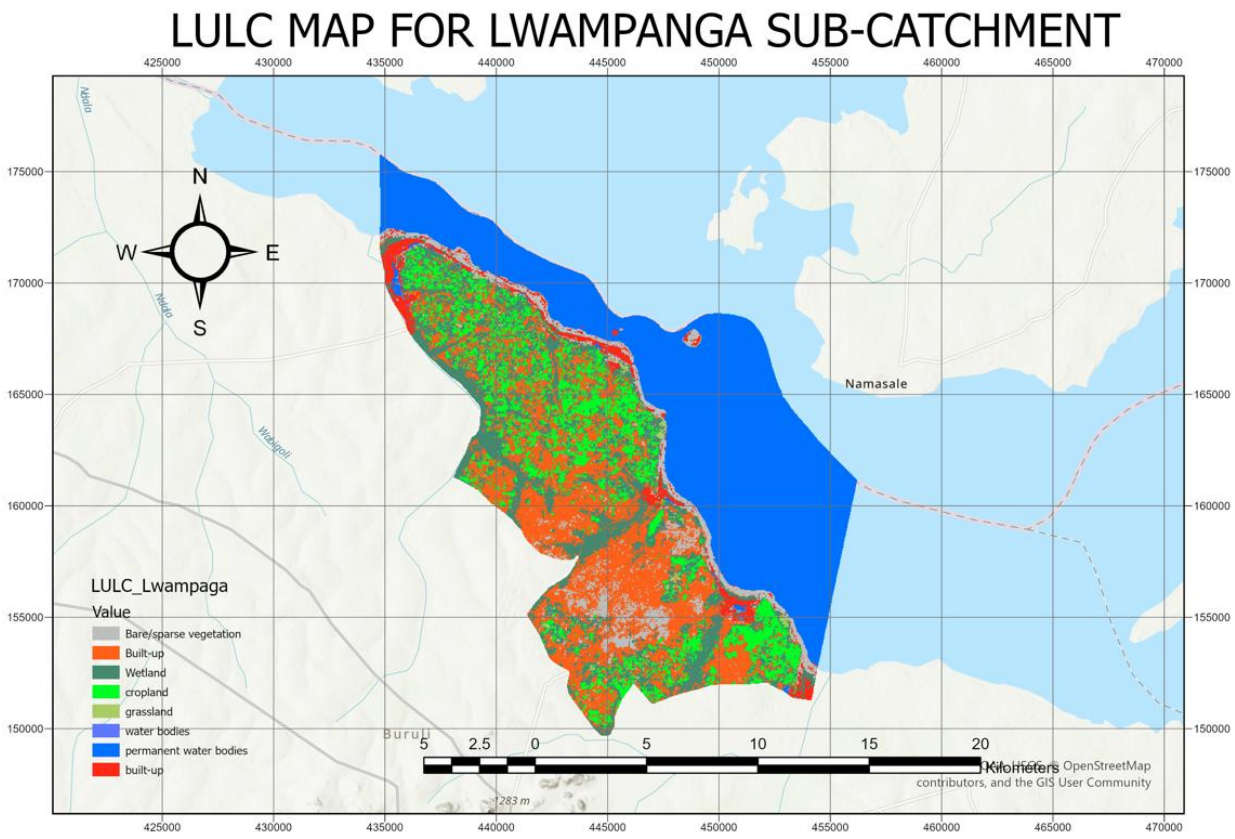


Figure 10: LULC of Lwampanga Sub-Catchment

Land cover type	**Area (ha)**
Cropland	2673.68
Grassland	39.74
Bare land	706.82
Wetlands	5703.67
Built-up areas	6222.53
Water bodies	13375.75

4.1.2.4 Water Resource Characteristics

The water resource analysis identified perennial rivers, wetlands and lakes within and around the Lwampanga Sub-catchment that serve as potential sources of water for irrigation development.

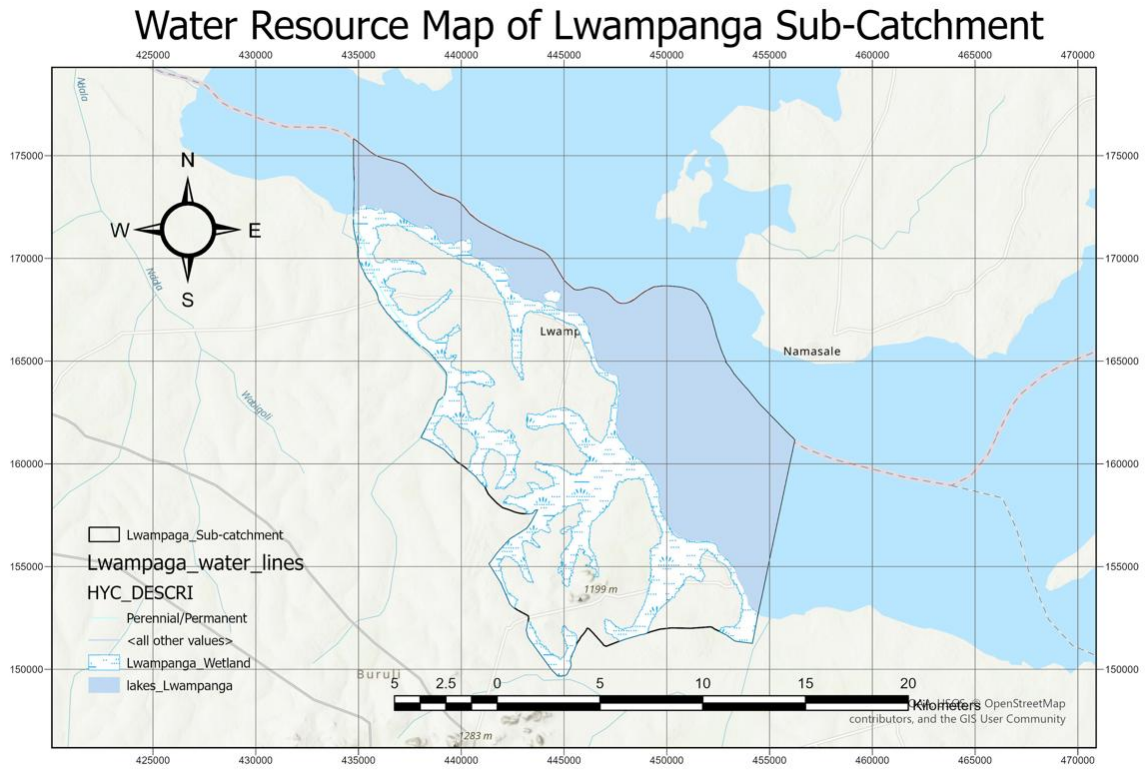


Figure 11: Surface Water Resources in Lwampanga Sub-catchment

4.2 Baseline Irrigation Suitability Assessment

The section presents the baseline irrigation suitability map generated through GIS based Multi-criteria Decision Analysis. The weighted overlay analysis integrated all suitability factors and produced four irrigation suitability classes considering factors supporting surface irrigation potential.

4.2.1 Factor Weights Obtained from AHP

The AHP analysis was used to assign varying levels of importance to different factors, for the Lwampanga Sub-catchment, proximity to water sources was assigned the highest weights because irrigation development was strongly constrained by drought and water availability.

Table 13: Weights of each considered factor

Factor	Weight (%)
Distance to water resources	42
Slope	18
Elevation	13
LULC	13
Drainage	5

Soil depth	4
Soil type	3
Distance to the road	2

4.2.2 Baseline Irrigation Suitability Map

The baseline suitability map was classified into:

- Highly Suitable (S1)
- Moderately Suitable (S2)
- Marginally Suitable (S3)
- Not Suitable (N)

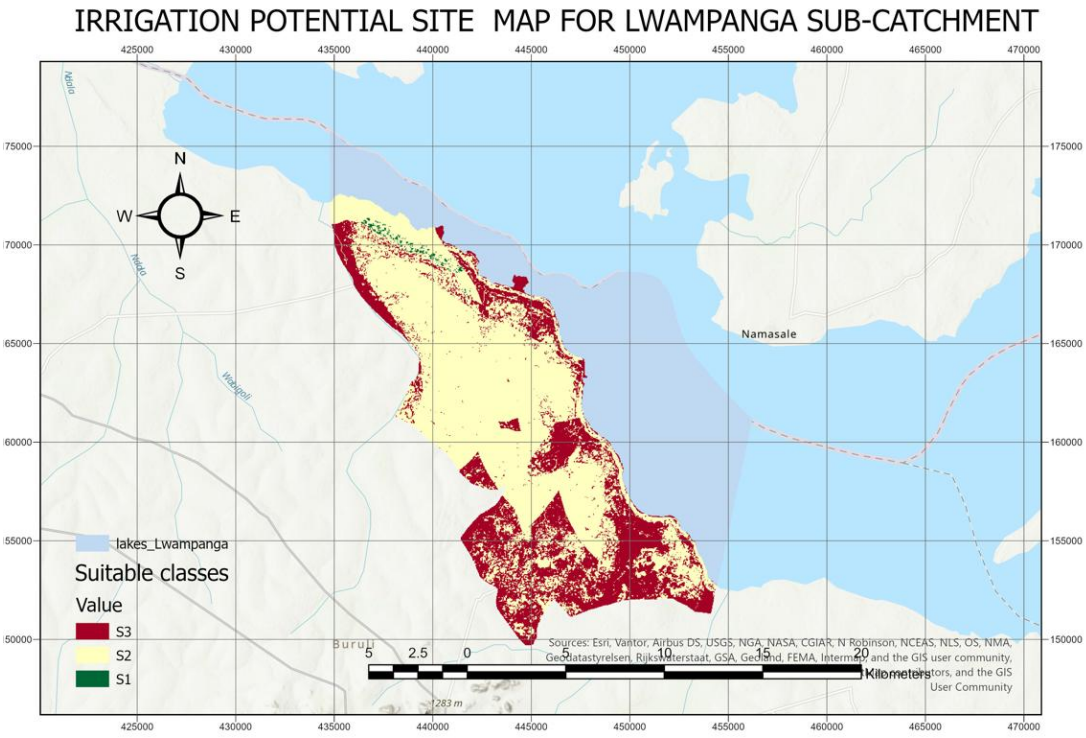


Figure 12:Baseline Irrigation Suitability Map of the Lwampanga Sub-Catchment

Table 14: Baseline Suitability Results

Suitability class	Area (ha)	Percentage (%)
S1	67.68	0.7
S2	5,886.6	61
S3	3,688.5	38.3

4.3 Irrigation Potential Under Different Drought Scenarios

This section evaluated changes in irrigation suitability under normal, moderate drought, and severe drought conditions.

4.3.1 Irrigation Potential Under Normal Conditions

The normal condition scenario represents the baseline irrigation suitability of the Lwampanga Sub-catchment under existing hydrological conditions. Under this scenario, the extent of suitable land influenced by the presence of wetlands, seasonal streams, and other water-related features

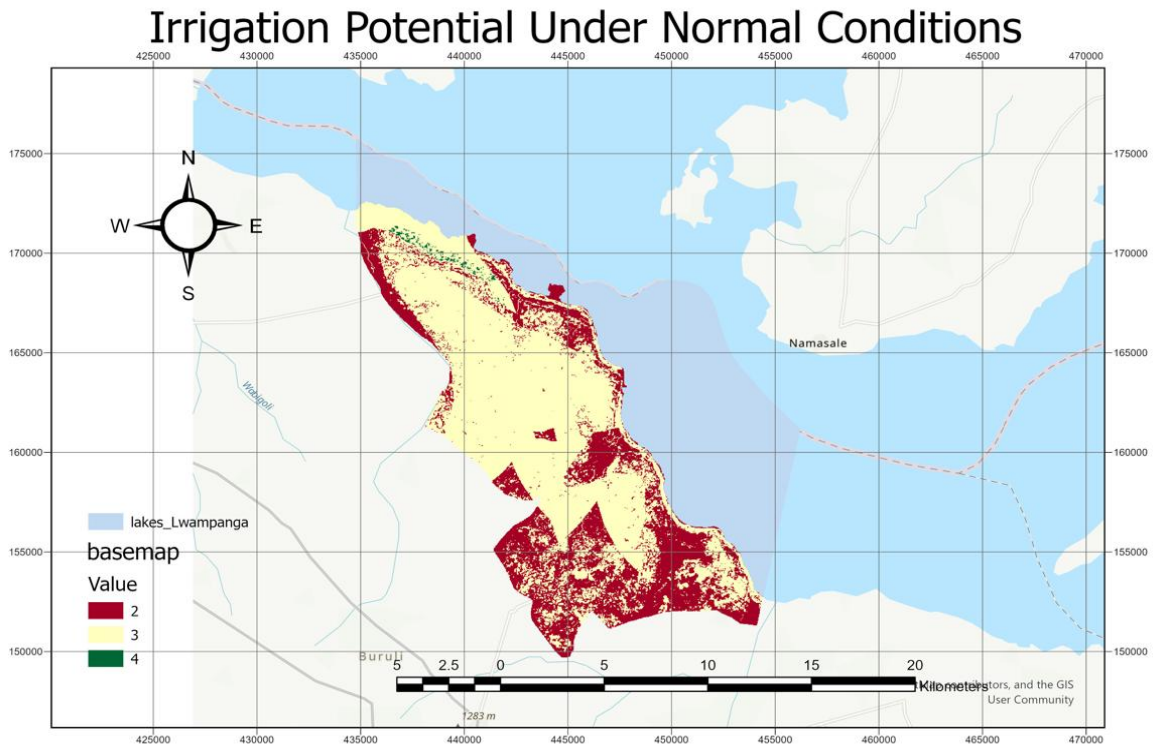


Figure 13: Irrigation Potential Under Potential in Lwampanga Sub-Catchment

4.3.2 Irrigation Potential Under Moderate Drought Conditions

Under moderate drought conditions, an increase in irrigation suitability was observed as the reduction in the extent of seasonal streams and wetlands exposed additional land for irrigation development. Consequently, the proportion of highly suitable and moderately suitable land increased compared to the baseline condition. that occupy a significant portion of the landscape, thereby limiting the area available for irrigation development.

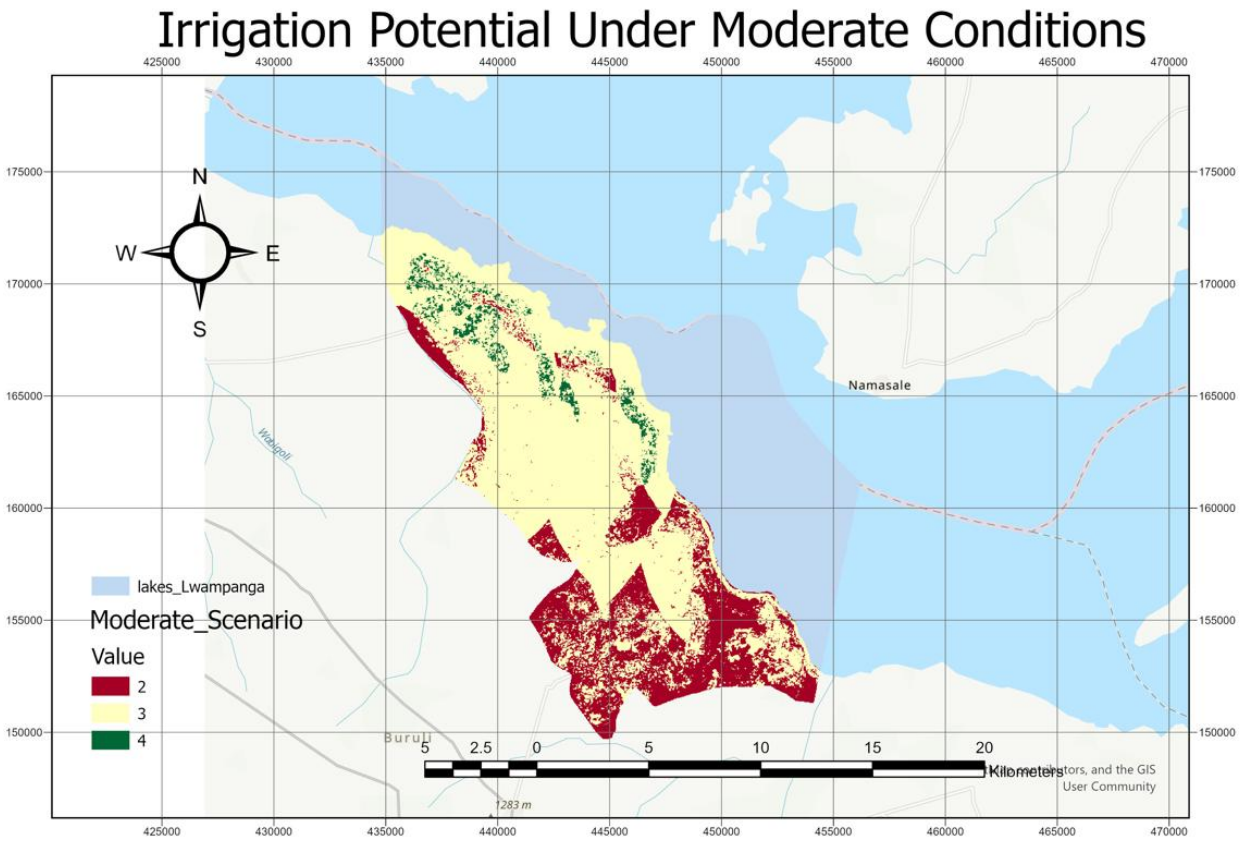


Figure 14: Irrigation Suitability under Moderate Drought Conditions

Table 15: Suitability Results under Moderate Scenario

Suitability class	Area (ha)	Percentage (%)
S1	542.7	5.6
S2	8111.3	84.1
S3	988.77	10.3

4.3.3 Irrigation Potential Under Severe Drought Conditions

The severe drought scenario represents conditions of extreme water scarcity within the Lwampanga Sub-catchment. Under these conditions, reduced water availability becomes a major constraint to irrigation development, limiting the extent of suitable irrigation land. This scenario was analysed to evaluate the impact of severe drought on irrigation potential and identify areas that remain suitable under extreme water stress.

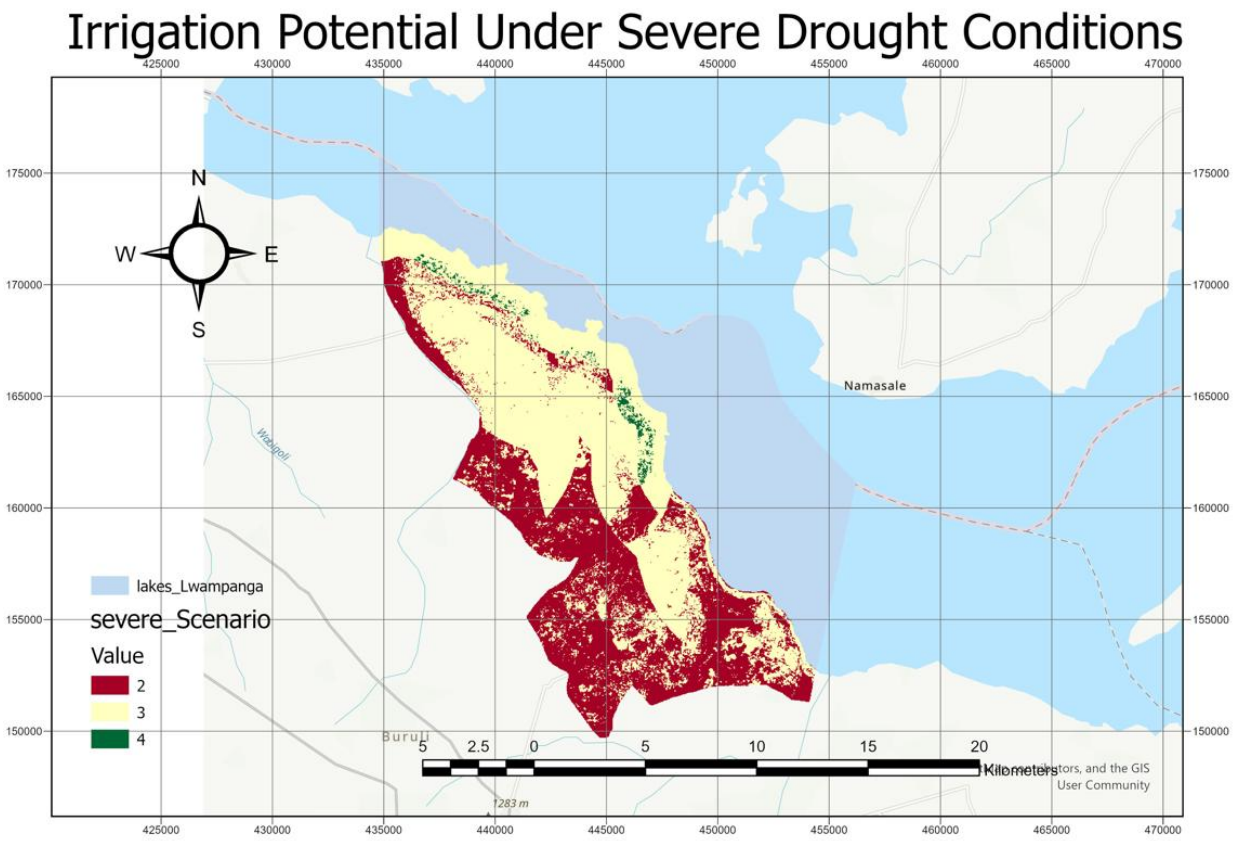


Figure 15: Irrigation Suitability under Severe Drought Conditions

Table 16: Suitability Results under Severe Scenario

Suitability class	Area (ha)	Percentage (%)
S1	190.8	2
S2	6006.3	62.3
S3	3445.7	35.7

5 DISCUSSION

5.1 Introduction

Biophysical factors that included topographic characteristics, soil properties, land-use/ land- cover and water resources were considered in this study of assessing irrigation potential under different drought scenarios of normal, moderate and severe in Lwampanga Sub-catchment. The following is the discussion of each factor considered in detail;

5.1.1.1 Topographic Characteristics

The slope suitability map for Lwampanga Sub-Catchment (Figure 9) shows that gentle slopes dominate the study area. This favors the installation of an irrigation system due to several reasons: water spreading more evenly across gently sloping fields, improved infiltration, and reduced runoff and soil erosion.

Steeper areas were assigned lower suitability ratings because of the higher runoff risk and the added cost of land preparation like terracing and levelling; since the topography of the Sub-Catchment was largely gentle, it favors irrigation development following the FAO slope suitability guidelines.

5.1.1.2 Soil Characteristics

Soil suitability across the study area varied in different soil properties of soil drainage, depth, and texture as shown in (figures 10–12). Clay loam soils showed higher suitability because these types of soil have a good balance between moisture retention and drainage.

Deeper soils of about 150cm were more suitable for holding water and supporting deeper root growth. Well-drained soils are particularly favorable for irrigation since they help prevent waterlogging. These soil properties are important for irrigation potential and are consistent with other research that highlights soil texture, depth and drainage as crucial factors for irrigation suitability.

5.1.1.3 Land Use and Land Cover Characteristics

A significant portion of Lwampanga Sub-catchment was covered by crops, as seen in the land-use/landcover map in (figure 13) making it more suitable for irrigation development. Since these areas are already used for agriculture, introducing irrigation infrastructure can be done with minimal land conversion.

Wetlands, waterbodies and built-up areas were excluded from consideration because they play a vital role in providing ecological services like groundwater recharge and water storage and settlement for built-up areas.

5.1.1.4 Water Resource Characteristics

The water resources map in (figure 14) shows perennial rivers, wetlands and lakes that potentially support irrigation development in the Sub-Catchment. Areas situated near these water sources exhibited greater irrigation potential, hence easy access to water resources for successful agriculture practices.

5.1.2 Discussion of Baseline Irrigation Suitability

67.68ha (0.7%) of the suitability assessment showed that only of the Sub-Catchment was highly suitable (S1) for irrigation, 5,888.6 ha (61%) was moderately suitable (S2) and 3,688.5 ha (38.3%) was marginally suitable (S3) under normal drought conditions, which was considered as a baseline map.

The small proportion of the sub-catchment shows that while irrigation development is feasible, several biophysical factor limitations, such as wetlands and built-up areas, reduced the area classified as highly suitable.

5.1.3 Comparison Analysis of Drought Scenarios

Table 17 below shows the percentages of land in the Sub-catchment under different drought scenarios, which were compared according to suitability classes and discussed.

Table 17: Comparative Irrigation Suitability Results

Suitability class	Normal (%)	Moderate drought (%)	Severe drought (%)
S1	0.7	5.6	2
S2	61	84.1	62.3
S3	38.3	10.3	35.7

0.7% of the Sub-catchment is classified as highly suitable, while 61.0% and 38.3% were classified as moderately and marginally suitable, respectively. 0.7% of the land is mainly due to the large coverage of wetlands, seasonal streams, and other water-related features that limit land available for irrigation development.

Highly suitable land increased to 5.6%, moderately suitable land increased to 84.1%, and marginally suitable land dropped to 10.3%. The improvement in the percentage is mainly because seasonal streams and wetlands dried up during moderate drought, exposing more land that became available and suitable for irrigation. As a result, much of the land that was constrained under normal conditions moved into higher suitability classes.

The percentage of highly suitable land fell to 2.0% under severe drought conditions, and irrigation suitability declined; moderately suitable land fell to 62.3% from 84.1% during moderate drought conditions, and marginally suitable land rose to 35.7%. This decline is due to increased water scarcity and reduced access to reliable water sources. Even though some land remained physically suitable for irrigation, limited water availability lowered its overall irrigation potential.

Based on the results obtained above, irrigation suitability in the Lwampanga Sub-Catchment depends strongly on the balance between land availability and water availability. While moderate drought temporarily increased irrigable land as wetlands and seasonal water bodies dry up, severe drought reduced irrigation potential because of insufficient water. The results also show that areas near permanent rivers, streams, and other reliable water sources maintained relatively higher suitability across all scenarios.

6 CONCLUSTION AND RECOMMENDATIONS

6.1 Conclusions

Irrigation potential in the Lwampanga Sub-Catchment under normal, moderate and severe drought conditions using GIS-based multi-criteria analysis indicated that irrigation suitability is significantly affected by the presence of wetlands, seasonal water bodies and access to dependable water sources.

The results obtained above showed that irrigation potential increased from normal to moderate drought conditions, as seasonal streams and wetlands diminished, more land became available for irrigation, resulting in a rise in highly suitable land from 0.7% normal conditions to 5.6% moderate but later dropped to 2% during severe drought.

6.2 Recommendations

Installation of irrigation system in Lwampanga Sub-Catchment, should be placed on areas close to the permanent rivers and other dependable water sources, because these areas remained suitable across all drought scenarios.

Construction of water storage infrastructure like reservoirs and rainwater harvesting systems should be prioritized to enhance water availability during prolonged dry spells.,

Protection of water resources and sustainable water management practices should be strengthened for effective irrigation for the long term.

Irrigation planning should be considered both on land suitability and water availability. This will help reduce the impacts of severe drought on agricultural production.

Reference

Abdulmajid, A. (2021). A remote sensing assessment of irrigation land use land cover change in the Sokoto Rima River Basin, Nigeria.

Agbaje, i. T. (2025). *Gis-based multi-criteria decision analysis of suitable locations for landfill in edo south local government area in nigeria* department of environmental management and toxicology, faculty of life …].

Aryal, J. P., Sapkota, T. B., Khurana, R., Khatri-Chhetri, A., Rahut, D. B., & Jat, M. L. (2020). Climate change and agriculture in South Asia: adaptation options in smallholder production systems: JP Aryal et al. *Environment, development and sustainability*, *22*(6), 5045-5075.

Awulachew, S. B., Erkossa, T., & Balcha, Y. (2011). Irrigation and water for sustainable development: proceedings of the second forum, Addis Ababa, Ethiopia, 15-16 December 2008.

Bamwesigye, D., Doli, A., Adamu, K. J., & Mansaray, S. K. (2020). A review of the political economy of agriculture in Uganda: Women, property rights, and other challenges. *Universal Journal of Agricultural Research*, *8*(1), 1-10.

Bhaga, T. D., Dube, T., Shekede, M. D., & Shoko, C. (2020). Impacts of climate variability and drought on surface water resources in Sub-Saharan Africa using remote sensing: A review. *Remote Sensing*, *12*(24), 4184.

Burrough, P. A., McDonnell, R. A., & Lloyd, C. D. (2015). *Principles of geographical information systems*. Oxford university press.

Cammalleri, C. (2021). GAR Special Report on Drought 2021. In *GAR Special Report on Drought 2021* (pp. 22-78). United Nations Office for Disaster Risk Reduction.

Chapagain, T., & Raizada, M. N. (2017). Agronomic challenges and opportunities for smallholder terrace agriculture in developing countries. *Frontiers in plant science*, *8*, 331.

CLIMA, T., & Te, W. (2024). State of Global Water Resources 2023.

Degife, A., Worku, H., Gizaw, S., & Legesse, A. (2019). Land use land cover dynamics, its drivers and environmental implications in Lake Hawassa Watershed of Ethiopia. *Remote sensing applications: society and environment*, *14*, 178-190.

Dessalegn, D., Beyene, S., Ram, N., Walley, F., & Gala, T. S. (2014). Effects of topography and land use on soil characteristics along the toposequence of Ele watershed in southern Ethiopia. *Catena*, *115*, 47-54.

Echeverría, D., Terton, A., & Crawford, A. (2016). Review of current and planned adaptation action in Uganda.

Elias, E., Seifu, W., Tesfaye, B., & Girmay, W. (2019). Impact of land use/cover changes on lake ecosystem of Ethiopia central rift valley. *Cogent Food & Agriculture*, *5*(1), 1595876.

Faurès, J.-M., Hoogeveen, J., & Bruinsma, J. (2002). The FAO irrigated area forecast for 2030. *FAO, Rome, Italy*, 1-14.

Gonfa, B. G., Hatiye, S. D., & Finssa, M. M. (2021). Land suitability and surface water resources potential for irrigation in Becho Plain, upper Awash basin, Ethiopia. *Irrigation and drainage*, *70*(4), 936-957.

Guivarch, C., Kriegler, E., Portugal-Pereira, J., Bosetti, V., Edmonds, J., Fischedick, M., Havlik, P., Jaramillo, P., Krey, V., & Lecocq, F. (2023). Intergovernmental Panel on Climate Change (IPCC) 2022. Annex III: Scenarios and Modelling Methods. In *Climate change 2022: Mitigation of climate change. Contribution of working group III to the sixth assessment report of the intergovernmental panel on climate change* (pp. 1841-1908). Cambridge University Press.

Haile, M. M., & Abebe, A. K. (2022). GIS and fuzzy logic integration in land suitability assessment for surface irrigation: the case of Guder watershed, Upper Blue Nile Basin, Ethiopia. *Applied Water Science*, *12*(10), 240.

Howell, K. R., Shrestha, P., & Dodd, I. C. (2015). Alternate wetting and drying irrigation maintained rice yields despite half the irrigation volume, but is currently unlikely to be adopted by smallholder lowland rice farmers in Nepal. *Food and energy security*, *4*(2), 144-157.

Jat, R. A., Jinger, D., Kumawat, A., Karc, S. K., Rawatd, I., Kumar, S., Paramesh, V., Meena, V. S., Kaushal, R., & Kumar, K. Watershed Ecology and the Environment.

Jemal, A. (2022). *Land Suitability Analysis For Industrial Area Using Integrated Geospatial Tools: A Case Of Adama City, Ethiopia* ASTU].

Kumar, S., Mishra, A., Dwivedi, A. K., & Singh, D. (2025). Drought trends and climate variability in India's Mahi River Basin.

Mabziira, J. (2022). Drought and shifts in agropastoral coping strategies in Uganda's cattle corridor. *African Journal of Rural Development, 7*(3), 325-342.

Magunda, M. (2020). Situational analysis study of the agriculture sector in Uganda.

Malczewski, J., & Jankowski, P. (2020). Emerging trends and research frontiers in spatial multicriteria analysis. *International Journal of Geographical Information Science*, *34*(7), 1257-1282.

Malczewski, J., & Rinner, C. (2015). Introduction to GIS-mcda. In *Multicriteria decision analysis in geographic information science* (pp. 23-54). Springer.

Muzammal, H., Zaman, M., Safdar, M., Adnan Shahid, M., Sabir, M. K., Khil, A., Raza, A., Faheem, M., Ahmed, J., & Sattar, J. (2024). Climate change impacts on water resources and implications for agricultural management. In *Transforming agricultural management for a sustainable future: Climate change and machine learning perspectives* (pp. 21-45). Springer.

Nalwanga, F., Kisira, Y., & Mukwaya, P. I. (2025). Resilience to drought in Uganda's cattle corridor: gendered assets, expenditure, and decision-making. *BMC Environmental Science*, *2*(1), 14.

Naseri, A., Rezania, A. R., & Albaji, M. (2009). Investigation of soil quality for different irrigation systems in Lali Plain, Iran. *Journal of Food, Agriculture & Environment*, *7*(3&4), 955-960.

Omona, A. D. (2023). Effect of climate change and food security in Uganda. In *The Palgrave Handbook of Global Social Change* (pp. 1-21). Springer.

Perera, K., Tateishi, R., Akihiko, K., & Herath, S. (2021). A combined approach of remote sensing, GIS, and social media to create and disseminate bushfire warning contents to rural Australia. *Earth*, *2*(4), 715-730.

Salimah, K. (2019). *Constraints and Opportunities for Community-Based Adaptation to Climate Change in Nakasongola district* Makerere University].

SANI, S., MUSA, A., & ABDULKADIR, A. (2026). Evaluation of soil physical properties under different land uses in semi-arid Nigeria. *Moroccan Journal of Agricultural Sciences• e-ISSN*, *2550*, 553X.

Sreekesh, S., Kaur, N., & Sreerama Naik, S. (2019). Agricultural drought and soil moisture analysis using satellite image based indices. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *42*, 507-514.

Stewart, B. A., & Howell, T. (2003). *Encyclopedia of Water Science (Print)*. CRC press.

Tesfaye, A. T., & Defersha, D. T. (2024). Contribution to the land suitability analysis for potential surface irrigation development using remote sensing and GIS-MCE of the Soroka watershed, northwestern Ethiopia. *Sustainable Water Resources Management*, *10*(2), 51.

Wanyama, J., Nakawuka, P., Bwambale, E., Kiraga, S., Kiggundu, N., Barasa, B., & Katimbo, A. (2024). Evaluation of land suitability for surface irrigation under changing climate in a tropical setting of Uganda, East Africa. *Agricultural Systems*, *217*, 103937.

Wind, Y., & Saaty, T. L. (1980). Marketing applications of the analytic hierarchy process. *Management science*, *26*(7), 641-658.

Worqlul, A. W., Jeong, J., Dile, Y. T., Osorio, J., Schmitter, P., Gerik, T., Srinivasan, R., & Clark, N. (2017). Assessing potential land suitable for surface irrigation using groundwater in Ethiopia. *Applied geography*, *85*, 1-13.

Yu, G.-R., Zhuang, J., Nakayama, K., & Jin, Y. (2007). Root water uptake and profile soil water as affected by vertical root distribution. *Plant Ecology*, *189*(1), 15-30.

Zhang, C., Dong, J., & Ge, Q. (2022). Mapping 20 years of irrigated croplands in China using MODIS and statistics and existing irrigation products. *Scientific Data*, *9*(1), 407.

Zoebl, D. (2002). Crop water requirements revisited: the human dimensions of irrigation science and crop water management with special reference to the FAO approach. *Agriculture and Human Values*, *19*(3), 173-187.