LAND SUITABILITY ASSESSMENT USING MULTICRITERIA EVALUATION FOR SUGARCANE PRODUCTION IN AMURU DISTRICT

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DECLARATION

I, Juliet Kebirungi, hereby affirm that the content contained in this report is of my own creation, entirely original, and has not been previously submitted for any academic recognition at any educational institution. In case where external sources were referenced, proper citations have been provided

Signature: …………………………………… Date: ……………………………………

JULIET KEBIRUNGI

APPROVAL

I confirm that I have overseen the preparation of this research report entitled 'Land suitability Assessment using Multicriteria evaluation for Surgarcane in Amuru District' and it is now prepared for submission to the Graduate School Board of Examiners with my endorsement as the academic supervisor.

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DEDICATION

I dedicate this thesis report to my parents, my husband and dear children who emerged exceedingly inspirational towards academics; siblings and friends who offered encouragement and support in hard times, and as well to the supervisors who equipped us with knowledge and skills.

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ACRONYMS

AHP	Analytical Hierarchical Process
ALES	Automated Land Evaluation System
B/C	Benefit and Cost ratio
CEC	Cation Exchange Capacity
DEM	Digital Elevation Model
FAO	Food and Agricultural Organization
GDP	Gross Domestic Product
GIS	Geographical Information System
GM	Net Margin
GOU	Government of Uganda
KWS	Kakira Sugar Works
LULC	Land Use Land Cover
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries
NARL	National Agricultural Research Laboratories
NARO	National Agricultural Research Organization
NEMA	National Environmental Management Authority
NFI	Net Farm Income
NPV	Net Present Value
NRM	National Resistance Movement
SCOUL	Sugar Coperation of Uganda
SMCE	Spatial Multi-criteria Evaluation
TFC	Total Fixed Cost

TR	Total Farm Revenue
UBOS	Uganda Bureau of Statistics
UNMA	Uganda National Meterological Authority
MDMP	Multicriteria Dicision Making Process
USGS	United States Geological Survey

ABSTRACT

This study conducted a land suitability assessment and economic analysis for sugarcane production in Amuru District, Northern Uganda, to address three objectives: 1) to determine the land use/cover types, 2) to assess land suitability for sugarcane production using a multicriteria evaluation tool, and 3) to determine its economic benefits.

The methodology involved a mixed-methods approach. Land use/cover was mapped via supervised classification of Landsat imagery, achieving a 97% accuracy. For suitability analysis, key soil (pH, CEC, OC, N, P, K, texture, drainage), climate (rainfall, temperature), and topographic (slope) factors were evaluated. These criterias were standardized and integrated using a GIS-based Multicriteria Decision Analysis (MCDA) anchored by the Analytical Hierarchy Process (AHP) to derive expert-weighted importance. The resulting layers were synthesized using a weighted overlay technique to produce the final suitability map. Economically, a cost-benefit analysis was performed using primary cost and revenue data from Atiak sugarcane estates to calculate Net Farm Income (NFI) and the Benefit-Cost Ratio (BCR) over a full crop cycle.

The land use/cover analysis revealed a landscape dominated by grassland (46%) and cropland (33%). The suitability results classified a vast majority (99%) of the district's arable land as moderately suitable (S2) and only 1% as highly suitable (S1) for sugarcane, with no land deemed unsuitable. The primary constraints were soil-related, specifically low pH and Cation Exchange Capacity (CEC). Economically, sugarcane cultivation was found to be highly viable, with an average yield of 80 tons/ha, a profit of UGX 4,832,467 per hectare, and a robust average B/C ratio of 2.0, indicating strong financial returns.

The study concludes that while Amuru District is largely moderately suitable for sugarcane and the venture is financially profitable, achieving optimal productivity is contingent on addressing soil fertility limitations. It is recommended that farmers and investors adopt targeted soil management strategies, including the application of phosphatic fertilizers and soil amendments to improve pH and CEC. Policymakers should utilize the generated suitability maps for informed land use planning to prevent conflicts. Furthermore, future research should integrate socio-economic factors and investigate irrigation potential to enhance the sustainability and resilience of sugarcane production in the district.

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Sugarcane is one of the significant enterprises emerging cash crop in Uganda. Initially it was carried out by the colonial period but on a little scale (Baker, 1956, Hoyle, 1963). The wet, warm weather conditions and fertile soils supported Sugarcane farming especially Busoga region (O'Connor, 1965). Profitable Sugarcane farming was majorly for two firms owned by two Asian families (Jorgensen, 1981: 64) and the two firms were Kakira Sugar Works (KSW) in Jinja owned by the Madhvan family is a prominent Ugandan family that has been involved in various business, including the sugar factory. They are known for their significant contributions to the development of the sugar industry in Uganda. In the past, they have been associated with Lugazi Sugar Estates, which is part of the Sugar Corporation of Uganda Limited (SCOUL). SCOUL is one of the largest sugar companies and is involved in the cultivation of sugarcane, Sugar processing and related activities (Hoyle, 1963; Frank, 1965; O'Connor, 1975; Smith 1970).

From the late 1980s, sugar production in Uganda has increased and is attributed to the return of the industries to the original owners under the current government (NRM) and introduction of competititors in the sugar industry. In 2013, Uganda had 13 licenced sugar-producing companies, astark contrast to the mere 4 in the 1970s (Matsiko, 2013). The sugar production in the country was 350,000 ton/year as of 2013, with production expected to double by 2030 (Matsiko, 2013). As of 2013, Sugar production in Uganda was primarily under the control of three main private firms;

Kakira sugar works Limited, under the ownership of the Madhvani Group of companies; the sugar corporation of Uganda (SCOUL), formerly known as Luganda Sugar Estates and owned by the Mehta family; and Kinyara Sugar Works, jointly owned by the Rain Group from Mauritius (70% and the Government of Uganda. As more private enetrprises,both domestic and international, enter the sugar industry, there is a growing possibility of an uptick in land acquisition for sugarcane production (Richardson *et al.,* 2012; Oxfarm 2013).

As sugarcane production continues to be a significant contributor to employment, income, and food security, particularly in the regions where it is cultivated, in Uganda (Mwavu et al,2018), many parts of Uganda has been proposed to starting growing sugarcane primarily with much prospects to reach Northern Uganda region (Mwavu *et al*., 2010). With recent observations from the central government of Uganda encouraging farmers to invest in commercial agricultural enterprises as one of the efforts for poverty alleviation and wealth creation an alarming call for prospective projects of growing sugarcane in districts of the country like Amuru.

The expansion proposals for sugarcane cultivation in Uganda have been driven by the need to address the energy crisis and meet the rising demand for sugarcane products due to increased population and external markets. Unfortunately, these expansion efforts often neglect the assessment of land potential and suitability. This oversight has resulted in various issues, including land management, environmental challenges, and mounting debts (Mwavu *et al*., 2010).

Land suitability assessment involves the evalauation of land's potential for various uses and planning, as noted by Rasheed et al., (2009). To determine land suitability for specific crop cultivation, a range of factors must be taken into account. Kumar et al., (2010) emphasizes that while land quality may differ by location, approaches for assessing land use and suitability typically consider a combination of climate, soil, topography, and water availability. Kway et al.,

(2013) points out that conducting a land use and suitability assessment contributes to optmising the development of specific crops, such as sugarcane, and increasing overall productivity.

This study aimed to assess the suitability of land for sugarcane growing and production in Amuru district using Multicriteria evaluation. The district's major economic activity is subsistence agriculture, which employs about 98% of Ugandans. Arable land, which makes up 90 % of the total land area in the district, is very fertile. Amuru district currently lacks significant industries, not to mention the advance the absence of even a few grinding mills, rice hullers, and visible construction sites. Nevertheless, if sustained peace, the construction of the great Juba Road, and the availability of a ready market in South Sudan are realized, it's probable that agriculture will shift from its current status as subsistence production to a thriving large-scale commercial farming sector. This transformation may lead to an upsurge in economic activity within the district.

Despite the expanded commercial cultivation of sugarcane in different Ugandan regions, the scale of sugarcane production has remained limited due to challenges associated with inadequate land assessment techniques frequently employed across the country. Consequently, the spatial data generated by this study can serve as a valuable tool for enhancing land suitability assessment for sugarcane production in Amuru District. This, in turn, can mitigate environmental issues and lead to increased income for individual farmers by promoting effective land use, ultimately resulting in improved household earnings and contributing to the country's GDP.

1.2 Statement of the problem

Smallholder farmers in Amuru District, as in many parts of Uganda, continue to cultivate Sugarcane crop without considering the suitability of soil and climate conditions. Traditional practices used in sugarcane cultivation have become increasingly unsustainable, largely due to declining soil fertility. This study examined the soil physical and chemical properties including climate to develop land suitability map for sugarcane production for Amuru district by using Multicriteria evaluation tool. This helped in identifying areas with soil nutrient deficiencies and areas for exapansion. Uganda Vision 2040 aspires to transform the country from a predominantly peasant society into a modern and prosperous nation by the year 2040 (Ngubwagye, 2019). Agriculture is expected to serve as the foundation for this transformation, propelling Uganda towards middle-income status. There fore assessing land suitability in Amuru can contribute to maximizing Land productivity and land-use planning, while minimizing environmental harm. This research could guide both government policies and private sector investments in sustainable sugarcane farming.

Cost benefit analysis: Understanding the financial viability of sugarcane farming is crucial for farmers to make informed decisions, yet many lack accurate assessments of their profitability. As a capital-intensive crop, sugarcane requires significant investment in land, labor, and inputs, making it essential to evaluate financial performance using Gross Farm Income (GFI) and the Benefit-Cost Ratio (B/CR). GFI measures total revenue, while B/CR assesses whether benefits outweigh costs, helping farmers determine profitability.

Without these evaluations, farmers risk inefficient resource use, increased debt, and unsustainable farming practices. A comprehensive analysis of GFI and B/CR will provide essential financial insights, enabling farmers to adopt strategies that enhance income, reduce risks, and ensure long-term farm sustainability.

1.3 Objectives

1.3.1 Main objective

The purpose of the study was to assess land suitability using Multicriteria evaluation tool for Sugarcane in Amuru district.

1.3.2 Specific objectives

i. To determine available land use types
ii. To asses land suitability for sugarcane production using a multicriteria evaluation tool in Amuru
iii. To determine the economic benefits of sugarcane growing in Amuru District.

1.4 Research Questions

The study was sought to answer the following questions:-

i. What is the extent of land available for sugarcane production in Amuru
ii. What are the are the physical and chemical properties for sugarcane production in Amuru
iii. Is sugarcane a profitable business in Amuru?

1.5 Significance of the study

The study analysis was expected to generate detailed suitability maps for sugarcane production areas in Amuru district that would be used as the basis of decision making and planning by government, private agricultural commercial campanies and farmers before adopting to sugarcane production as a food security and income potential export crop not only in Amuru district but the same idea will be adopted to other areas. Furthermore the results from this study will form a basis for future research with interests in using GIS based land suitability assessment for sugar cane production in different districts of Uganda but also throughout the African continent. This research is unquestionably unique as it assesses land suitability prospects of Amuru district for sugarcane production proposed projects and the study will provide stakeholders in the Agricultural sector with a GIS based integrated assessment approach to evaluate the suitability of land for crop production in Uganda as a whole and Amuru district in particular.

1.6 Justification of the study.

The indication of how different areas of Amuru district are varied in terms of suitability for sugarcane production. The knowledge of soil physical and chemical characteristics of each area is very important to sugar cane research scientists. This information can also direct breeding work towards producing sugarcane varieties. This information will guide policies, decisions, and regards to financing, transporting and marketing of sugarcane production. Further, this research will aid the farmers within Amuru district and the neighboring areas in selecting areas with highest prospects of sugarcane production.

1.7 Scope of the Study

This research study focused on land suitability (Independent variable) assessment using Multicriteria evaluation, for sugar cane production (Dependent Variable) in Amuru district. Components of GIS based land use assessment included; mapping major land use types, Climate, land characteristics/quality, soils, evaluation of more suitable land use options, Comparison of suitability of sugar cane growing.

1.8 Time scope

The study covered the period 2015-2017 the time government had set priorities for Uganda to be a middle income country by 2020 through wealth creation very solid in the Uganda's vision 2040 targets of a transformed Ugandan society from a peasant to a modern and asuccessful country (GoU, 2007).

CHAPTER TWO: LITERATURE REVIEW

2.1 Status of soil in Uganda and soil mapping

In Uganda, soil classification follows the FAO (Food and Agriculture Organization) system. The country boasts highly productive ferrisols and eutrophic soils that are distributed throughout (Kamanyire, 200). Ferruginous soils are found sporadically across the nation but are primarily concentrated in Tororo and Gulu districts (NEMA, 1996). Research suggests that soils rich in iron are less productive and require cautious management to protect the underdeveloped topsoil. Additionally, lighter soils, as opposed to heavier ones, are more vulnerable to leaching. A recent national soil survey initiative has further emphasized the need for updated classifications to reflect current land use pressures (Tukahirwa et al., 2023).

When utilizing soil data dating back to the 1950s to address contemporary issues, such as conducting land suitability assessments and enhancing land management practices in different regions of the country, including Amuru district, some of the data may appear obsolete. For instance, soil nutrients could have been depleted in certain areas, and erosion processes may have altered soil textures and pH levels over time. Furthermore, the generalized information based on soil types does not directly inform soil resource managers about which specific nutrients might be limiting for particular crop cultivation. Existing soil data frequently falls short in supplying the necessary information for effective land resource management. To meet the demands of users, there is a pressing need for new, high-quality soil data that can augment existing databases and offer the essential spatial precision (Kabasomi, 2017). Modern geospatial techniques are now being deployed to create more accurate and detailed soil maps for agricultural planning (Musinguzi et al., 2022).

2.2 Land suitability assessment in Uganda

Land suitability pertains to the degree to which a particular type of land is suitable for a specific purpose or application. This evaluation can account for the land's existing condition or its potential suitability following certain enhancements. The process of assessing land suitability involves the evaluation and categorization of specific land areas based on their appropriateness for defined purposes (FAO, 1976). Fundamentally, the assessment of physical suitability primarily concentrates on the land's physical characteristics and properties. It considers elements such as soil type, topography, climate, water availability, and other natural attributes that influence land utilization. Economic factors are often secondary importance within this approach (Rossiter et al. 1997). Land suitability assessments are often conducted to determine the suitability of land for specific purposes or types of land use. These purposes can include various activities such as rained agriculture, livestock production, forestry, urban development, conservation, or any other relevant land use. (Ande, 2011).

According to FAO (1976), two stage approaches are commonly used in resource inventories for broader planning purposes. They are also applied in studies aimed at assessing the biological productive potential of land. This approach involves a systematic process that typically includes an initial assessment, followed by a more detailed evaluation. (Ziadat et al., 2006). The output of a land suitability evaluations, therefore, is more than just about recommending suitable land use but also about detailing the challenges and constraints that need to be addressed or a managed to make the land use sustainable and productive (Ziadat et al., 2007).

A land assessment framework established by FAO in 1976, commonly employed in land suitability assessments, recommends the consideration of biophysical factors (such as landforms, soil, vegetation, climate etc), economic, and social elements when categorizing land suitability. Nonetheless, this framework does not provide detailed guidance on the criteria and indicators for assessing economic and social suitability (Liambila, 2015). Consequently, numerous studies on land suitability have predominantly concentrated on exploring the biophysical aspects exclusively (Walke et al., 2011). Recent studies continue to highlight this challenge, calling for more integrated frameworks that combine biophysical and socio-economic factors for a holistic assessment (Bag et al., 2022).

In Uganda, little has been done on land suitability assessment for sugarcane production using GIS and those who have done related studies have focused on different crops like rice (Ojara et al., 2017) for the whole of Uganda which is too coarse since the study does not give detailed information on land suitability assessment per district. Furthermore a study conducted by (Nuwategeka et al., 2016) only focused on the Indigenous technique of land evaluation assessment system of the Acholi tribe of Northern Uganda (Amuru district) whose results cannot be relied on the basis of land suitability assessment for the prospect production of a particular crop in Amuru district. A recent review confirms the scarcity of localized, GIS-based sugarcane suitability studies in the country, underscoring the necessity for this research (Omoding et al., 2021).

2.3 Sugarcane production in Uganda

Sugar cane (Saccharum officinarum L.) belongs to the tall, perennial grasses in the family Poaceae, tribe Andropogoneae, and is indigenous to the warm temperature and tropical regions of the World (Wada et al., 2017). Sugarcane is characterized by sturdy, segmented, fibrous stalk that can be reach heights of over 3 meters (Bigman, 2001). It possesses significant biomass production potential and offers several advantages, including perennial growth, adaptability to various soil types, resistance to most diseases, and erosion control properties (Tew, 1980). While traditionally cultivated for sugar production, sugarcane is increasingly viewed as a versatile crop with the potential to play a vital role in diverse industries, including biofuel production, electricity generation, medicine, chemistry, soil fertility enhancement, and soil improvement (Suheang, 2005; Forum for Agriculture Research in Africa (FARA), 2008; Sielhorst et al., 2008). Its role in bioenergy is particularly promoted as a renewable energy source in East Africa (Aworo et al., 2022).

2.4 Production systems

Farmers in the study area practice subsistence agriculture and the crops grown include Maize, Sesame, beans, Upland rice, pigeons peas, Millet, Cassava among others (Nuwategeka et al., 2019).

2.5 Sugarcane and other crops in Amuru

Sugarcane is likely to compete with other main crops widely grown in Amuru and reduce their production. So farmers have to be careful in choosing sugarcane growing because sugar cane may affect their diet and income as it has been observed in other regions like Busoga where sugarcane has taken over all land. So farmers have to be mindful also on price fluctuations that has hit in other Ugandan sugarcane regions (Busoga) where sugarcane prices were low and farmers had to abandon the plantations and in this case poverty hit them. This very hard for them to uproot the sugarcane production since it needs labor and resources. The Major crops like maize is likely to reduce since already used land for maize production is the same land that are likely to be used for sugarcane growing. According to NEMA, 2010, the sugarcane cane was compared with maize production and the results revealed that there are no potential conflict areas except in few areas of south eastern Amuru. Recent analyses show that such crop competition and land use conflicts are recurring challenges in new sugarcane growing frontiers (Mukwaya et al., 2023).

2.6 Agronomic practices of Sugarcane

Land preparation and fertilizer application

Land preparation. The land is prepared before planting time. Land clearing (tillage and harrowing) Levelling and grading of the land is done during dry season. This is followed by planting and applying fertilizers. The fertilizers help in adding inadequate nutrients in the soil. DAP is the most fertilizer type added in the sugarcane plantations. This helps the plant to meet the soil nutrient demands for growth and improve crop yields (Dercas et al., 2008). If added in the soil the yields can reach to 80 tons per ha. Recent research emphasizes integrated soil fertility management to sustain high yields in successive ratoons (Namusoke et al., 2022).

Earthling up and removing trashes: Earthling up means heaping the the soil around a plant. It is done in sugarcane growing because it increases soil temperature needed by sugarcane, it also helps root growth (Ackbar, 2007). This is done every season (ratoon) in sugarcane production. Normally when sugarcane is harvested, the strips and the top parts remains in the field. They have to be removed in order the second ratoon to sprout well. At times these trashes are burnt.

Weeding: This is done in sugarcane because weeds can harbour pest and diseases and compete nutrients reducing sugarcane yields. Weeding is done twice a year in ratoon crops. In Atiaka sugarcane estate, it is done twice normally by using herbicides. Normally it is done at the stage of three months of sugarcane growth. Two methods of weeding are used (mechanical and chemical). Manual weeding method is used by out growers.

Pests and diseases control: The Major pests include Rodents, Termites, moth bores and white grubs. This is done using agricultural methods. Diseases of sugarcane are caused by biological agents (fungi, viruses and Bacteria). The major diseases include red rot, rust (Dercas et al., 2008) sugarcane mosaic, ratoon stunting diseases downy mildew, smut among others (Ackbar, 2007). Normally the company has to select resistant varieties for disease control to avoid making losses. Treatment is done to some of sugarcane varieties eg long hot-water treatments (50^0^ Cat 3hours) for ratoon stunting diseases (Ackbar, 2007). Emerging pests and disease pressures under changing climates are a current focus of research (Ogenga et al., 2023).

Irrigation: Sugarcane is a high demanding water crop. At times irrigation is done when rainfall is not sufficient /less than 800mm (Dercas et al., 2008) so that the crop can have high yields. Sprinkler irrigation method is commonly used in Atiak.

2.7 Sugarcane varieties grown in Uganda

Most sugarcane varieties grown in Uganda are primarily for sugar production. Some of the sugarcane grown in Uganda include:

Kakira 6 (K6). This variety was developed in Kakira sugar works, south eastern Uganda. It is tailored for local conditions and is utilized in Sugar production.

CO419: This variety is known for its high sugar content and good yield Potential. It's widely cultivated in various sugarcane producing regions.

CO6806: This variety is preferred for its adaptability to different agro-ecological zones and its resistance to pests and diseases.

CO1148: This sis favored for its high sugar yields and diseases resistant, making it popular choice among Ugandan sugarcane out growers and companies.

CO8011: This variety is known for its vigorous growth and high sugar content. It’s often cultivated in areas with favorable growing conditions.

CO8371: This is another variety that is valued for its good yield potential and adaptability to varying climates. Breeding programs continue to develop new varieties with higher sucrose content and drought tolerance (Uganda Sugar Factory, 2021).

2.8 Sugarcane consumption in Uganda

Consumption of Sugar in Uganda stands at 9kg per head per annum and it is expected to increase by 1% over the next 15 years. It is one of the source of the income for the households who live close to the estates commonly known as out growers. 20 km is a critical distance beyond which cultivation of sugarcane at high input level ceases to beneficial. Intermediate sugarcane LUT is marginally suitable at 20 km. and ceases beyond 20km (NEMA, 2010). Low input sugarcane cultivation is not economically suitable beyond 25km. Uganda has three main three sugarcane companies that is Kakira sugar works LTD, Kinyara and Lugazi. Sugar is the main product from these industries and today the population of 42m consumes 250000 tons of sugar. However, the population is expected to increase by 2030 then the country will require about 500000 tons of sugar for its population. Current industry reports estimate annual sugar production has surpassed 300,000 metric tons to meet growing demand (USWA, 2023).

Sucrose, also known as table sugar, is the primary product derived from sugarcane and typically accumulates in the stalk internodes of the plant. Specialized mill factories, as described by Ophardt in 2003, are responsible for the extraction and purification of sucrose. This purified sucrose serves as crucial raw material in various human food industries, or it can undergo fermentation, as discussed by Mino in 2010, to produce ethanol.

While there are established knowledge and experienced organizations in countries like Brazil and South Africa to efficiently manage proactive sugarcane production, Uganda and other Eastern African countries currently face a deficit in such organized efforts. Consequently, various challenges have been identified concerning the cultivation of sugarcane in Uganda, although it it is worth noting that the overall environment impact is not significantly greater than that of other crops, as noted by Lagercrantz in 2006. Among the specific and general production difficulties associated with sugarcane in Uganda and across other African countries are elevated transportation expenses, as highlighted by Chethmrongchai and colleagues in 2001, as well as biotic and abiotic stresses, infrastructure limitations, technical constraints, environmental concerns, limited capacity building, insufficient skill acquisition, and a lack of effective technology transfer and development, as discussed by Makinde and colleagues in 2009. A recent study specifically identified access to credit and extension services as major constraints for Ugandan out growers (Banage et al., 2020).

Over the past decade, a renewed focus on agricultural commercialization in Africa has emerged, coinciding with the significant increase in global food prices and the surge in large-scale land and agricultural investments in 2007-2008. This resurgence of interest has been observed among governments, donors, development agencies, the private sector, civil society, and academics. The growing attention from investors in African agriculture appears to be supplanting the previously pessimistic outlook, which characterized the approaches of international financial institutions and governments during the years of structural adjustment plans. This is driven by perceived availability of cost-effective land and the potential for increased profitability in a sector that was traditionally considered risky by financial capital, as discussed by Giuliano Martiniello in 2015.

2.9 GIS based technologic system

A geographic information System (GIS) is a potent utility employed for the acquisition, retention, organization, scrutiny and exhibition of geographic data and information. It empowers users to engage with diverse forms of spatial data, including maps, satellite imagery, and geographic databases, enabling them to execute a broad spectrum of tasks pertaining to geography and location.

GIS has found widespread application in spatial analysis, specifically in assessing land use and suitability. It provides to be a highly efficient method, particularly when evaluating factors such as soil texture, slope, soil moisture content, depth of the water table, and soluble salt content, especially in the context of sugar cane production. Research done by Bera et al., 2002 and Khoram et al., in 2014 supports the effectiveness of GIS in this regard. The integration of GIS with Remote Sensing and machine learning models has further enhanced its precision for agricultural land use planning (Kumar et al., 2021).

GIS also provides greater reliability with lesser time and cost compared with manual operation (Bera et al., 2002). The integrated information perform is highly useful especially when it is used to support decision-making towards farming activities (Ghaffari et al., 2000; Rasheed et al., 2003). Charuppat (2002) adopted GIS to develop models for land suitability evaluation and found that the system is highly effective for the evaluation of land suitability for crop growing.

2.10 An overview of land suitability assessment using mult-criteria land evaluation tools

According to the Food and Agriculture Organization (FAO) in 1983, the term land suitability assessment refers to the process of evaluating how well a piece of land performs for a specific use or designated purpose. The primary objectives of land allocation for agricultural purposes, often referred to as land suitability analysis, are to enhance land productivity, expand farming operations, and safeguard the environment, addressing issues like Wetland over-exploitation and soil erosion management, as noted by Nyeko in 2012.

The process of suitability analysis is vital component in achieving the optimal utilization of available land resources, as emphasized by Kihoro and colleagues in 2013. It provides a valuable insight into identifying the best combination of elements or factors that are conducive to crop production and contribute to high yields, as highlighted by Ojara et al. (2017). The results of such analysis can be assessed qualitatively, classifying land as highly suitable, moderately suitable, or unsuitable, as proposed by Masoud in 2006 and Kihoro 2013.

Additionally, Quantitative evaluation of land suitability can be expressed in the form of numerical indicators, derived from various parameters related to soil and plant growth, measured at different assessment levels. These indicators serve as quantitative measure of agricultural land suitability, as explained by Kurtener and others in 1999.

In essence suitability is determined by the congruence between the requirements of a specific crop or land use and the inherent characteristics of the land, as elucidated by Mustafa et al. in 2011. It quantifies how well the qualities of a given land unit align with the needs of a particular crop or land use, in accordance with FAO publications from 1979, 1983 and 2001.

There are varies approaches that have been used in producing the suitability of land for particular use and each has its own merits and demerits. In Mid 1970's, the Spatial Analytical Hierarchy (AHP) method was introduced and was developed in 1980's as one of best method which is suitable for analysis of land (Ojara et al., 2017). In 2009, (NEMA, 2009), used overlay analysis in GIS to evaluate the suitability of Japhtroper as an alternative source of biofuel in Uganda, the results of overlay analysis is widely accepted for adoption in Uganda, however; overlay procedure used in GIS does not enable the evaluators to take into account that the variables are not equally important (Janssen et al., 1990). Recent applications of the AHP method in East Africa have demonstrated its robustness in handling the complex, multi-factorial nature of land suitability analysis for perennial crops (Mugo et al., 2022).

Over the last two decades, GIS-based land use suitability techniques have significantly grown in importance and have become integral components of urban, regional, and environmental planning activities. These techniques play a crucial role in facilitating informed decision making and sustainable development in these areas. (Malczewski, 2004; Brailet al,. 2001; Collins et al., 2001; Hall et al.1992) in their study also use map overlays to define the suitability for particular crops.

The primary goal of assessing agricultural land suitability is to anticipate a piece of land's potential and limitations for crop production, as stated by pan and pan in 2012. This process involves evaluating the land's Capacity to meet the ecological requirements necessary for a specific type of land use. Unfortunately, Uganda lacks well-defined criteria for optimizing sugar cane productivity, which has already posed challenges in some African countries like South Africa (Ogwang et al., 2017).

Considering the projected global population increase by 2050, where there is a need to double crop production to ensure an adequate food supply for the growing populace (Tomlinson, 2013; Thomas, 2010) the importance of addressing agricultural productivity becomes even more evident. In Africa, the rise in the middle-income population is leading to shifts in dietary preferences from Carbohydrate-rich staples (such as rice, roots, and tubers) to vegetable oils and animal products. In this context, sugar and sugarcane production play crucial roles in the rural economy by contributing to farming income, job opportunities, and the support of rural economies.

Sugarcane and its cultivation make substantial contributions to rural economies by bolstering farm incomes, generating employment opportunities, and sustaining the livelihoods of numerous individuals in rural regions. Consequently, suitability hinges on the alignment of crop requirements with characteristics (Mustafa et al., 2011). Knowledge about the geographical distribution and aptness of different soil types for various crops is of paramount importance for planners and agricultural experts. It allows them to promote and guide farmers in adopting cropping systems that leverage the soil's potential for diverse crop categories, especially in the face of climate change challenges.

2.11 Land suitability evaluations.

The need for optimum use of land has become increasingly critical, especially given the challenges posed by rapid population growth and urban expansion. As the global population continues to grow and more people move to urban areas, several key factors contribute to the increasing scarcity of land available for agriculture. The increasing demand for intensification of existing cultivation and opening of new areas of land can only be satisfied without damage to the environment if land is classified according to its suitability for different kinds of use (FAO, 1984).

Land evaluation is the process of assessing and estimating the potential of a piece of land for various types of uses or land uses. This process is critical in land planning, land management, and land development to make informed decisions about how a specific parcel of land can be utilized. The primary goal of land evaluation is to determine the suitability of land for a particular purpose, taking into account various physical, environmental, economic, and social factors.

One of the fundamental features of land evaluation is the comparison of the requirements of land use with the resources and attributes offered by the land. This involves assessing the suitability of a particular piece of land for various uses by examining how well the land's characteristics align with the demands and constraints associated with those uses. Land evaluation involves the collection and interpretation of very large amounts of data. Thus, data concerned with land evaluation will be stored in a way that re-evaluation can readily be made when any or all of these factors change significantly, as techniques improve, and more data become available.

2.12 Economic analysis of Sugarcane in Uganda.

In Uganda sugarcane production is increasing every year. This is due to local market available and the high demand to the neighboring countries (Mbowa et al., 2022). It can as well be evidenced by the number of sugar factories within the country. So far, Uganda has more than 12 sugarcane factories (Mbowa et al., 2022). However, between 2016 and 2021 the demand for sugarcane was low, a number of farmers shifted to other crops due low prices of sugarcane

(Publications, 2023). Therefore, this section of study quantified if the sugarcane production in Amuru district is financially viable.

2.13 Costs and benefits.

The investment expenses associated with sugarcane production encompass various elements, including equipment, expenses related to managing pests and diseases, fertilizer application, land preparation, as well as the development of infrastructure and building essential for sustainable farming. Fixed costs, which are incurred irrespective of farming activities, typically include depreciation and interests.

Operating costs, on the other hand, are directly linked to the day-to-day operations of farming and can fluctuate based on factors such as the frequency of irrigation, the volume of water used per irrigation, fuel consumption, and the extent of irrigated land. Among these, labour costs represent a significant variable expense, covering activities such as land cultivation, irrigation, maintenance, and harvesting. Additionally, material costs encompass expenditures for seeds and fertilizers, along with annual expenses for repair and maintenance of irrigation systems. A recent cost-benefit analysis in a similar agro-ecology confirmed the financial viability of sugarcane, but highlighted the sensitivity of profits to input costs and yield levels (Kisame et al., 2024).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Description of the study area

The study was carried out in Amuru district located in the northern part of Uganda (Figure 1) bounded by Longitudes: 31.359° E and 32.415° E, Latitudes: 2.671° N and 3.563°N. Amuru district boarders Adjumani District to the north, South Sudan and Lamwo District to the northeast, Gulu District to the east, Nwoya District to the south, Nebbi District to the southwest and Arua District to the west. The Amuru administrative headquarters is located approximately 60 kilometres (37 mi), by road, northwest of Gulu, the largest town in the sub-region. It is covered by 4 Sub-counties (Amuru, Atiak, Pabo, and Lamogi) and a municipal council. It covers a total area of 3620 km^2 and a population of 190,516 (UBOS, 2014) and its elevation ranges from 615-1382m a.s.l.

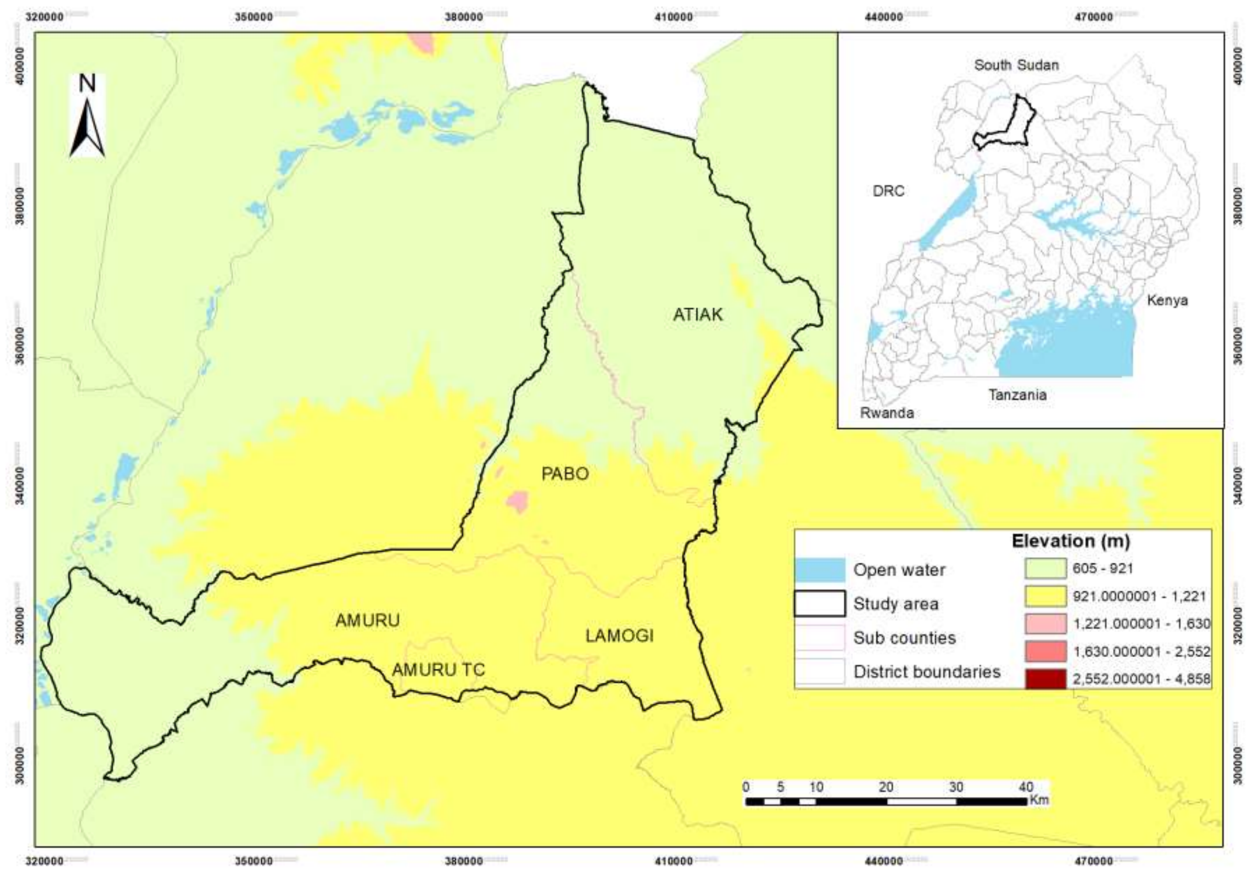

Figure 1: The location of the study area

Climate: The average annual rainfall of 30 years (from 1988-2018) was 1423.6mm recorded by Uganda national meteorological authority (UNMA) and it was found to be marginally suitable(S3) for sugarcane growing (The potential of biofuel in Uganda, 2010). In addition to this, mean temperature of the area was 31.1$°_C$ which also puts the suitability for sugarcane in the study area higly suitable (S1) and min temp for the area was 20 $^0{}_C$ to marginally suitable (S3) (Nema, 2010). All the rasters were crossed (Figure 5) and it showed that the area is moderately suitable (S2) for sugarcane growing (Figure 2).

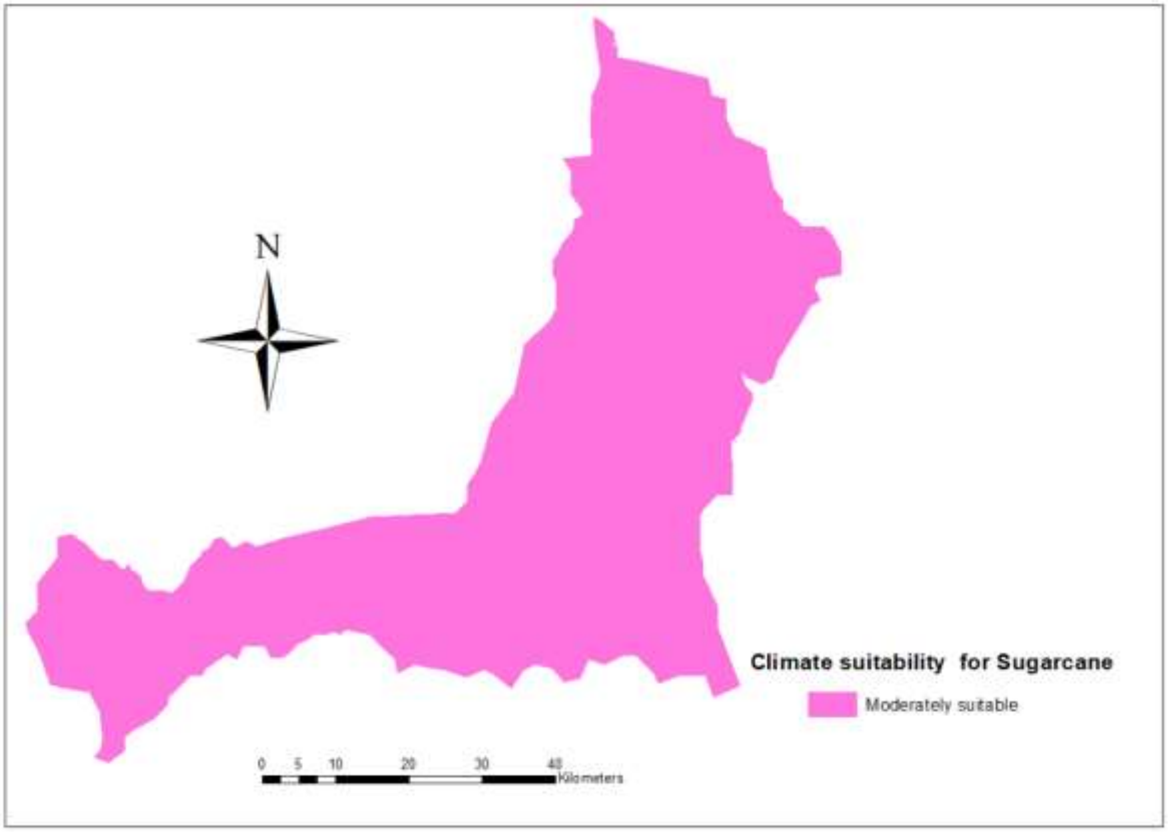

Figure 2: Climate suitability for sugarcane in Amuru district

Lithology: Based on geology of ministry of energy and mineral development, the parent material for Amuru's soils include: Basement complex quartzites, granites, gneisses, and alluvium.

Soil types of the study area

Soils: According to Isabirye, et al., (2010), the soils of Amuru district is largely covered by four soils classes as it is indicated in Figure 3.

Leptosols are characterized by their minimal soil depth, with a prevalence of course fragments covering a continuous layer of rock. These soils are typically encountered at moderate to elevated altitudes. Their thin nature limit Sugarcane production. These soils are prone to erosion and thus management should focus on soil and water conservation. This type of soil covers 62.5% of the total land area for agriculture in Amuru District.

Regosols: Very weakly developed soils with no clear soil horizonation (young soils): these soils generally have low Sugarcane production potential since they have low water and nutrient levels; therefore, soil management practices like irrigation and fertilizer application are recommended. Regosols cover 3.0%.

Ferralsols: These are highly weathered soils characterized by low nutrients supply from mineral weathering and dominated by aluminum and iron oxides. Adding organic matter and fertilizers is highly recommended but they are deep enough to support sugarcane production. Ferralsols cover 34.1 % of the total land area for agriculture in Amuru district.

Plinthosols: Shallow soils with cemented horizon and poor natural soil fertility. planting shallow rooted Sugarcane varities are recommended. Soil and water conservation measures are highly recommended in this type of soil. Plinthosols cover 0.4 % of the total land area for agriculture in the district.

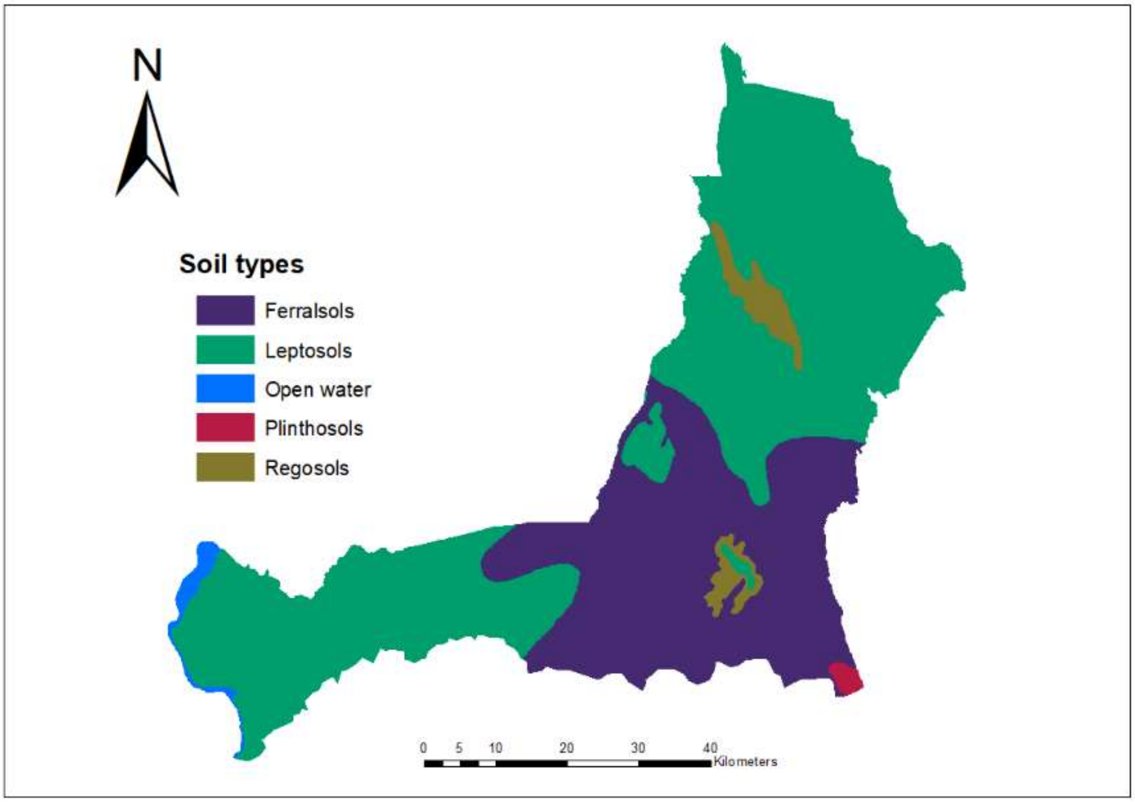

Figure 3: Soils of Amuru (Source: Isabirye et al., 2010)

3.2 Determining land use/cover type of Amuru

Remote sensing satellite data (Landsat imagery) of 30m meters resolution for 2018 were obtained from https://earthexplorer.usgs.gov/. Landsat images (30m) are developed by United Sates geological survey (USGS) and it has been widely used by different researchers in land use /cover change analysis because of their high spatial resolution.

3.2.1 Image pre-processing, analysis and classification

Prior to data analysis, image preprocessing was undertaken to rectify any distortions. This process involved several procedures aimed at enhancing the quality of images, including radiometric correction to address uneven sensor responses, geometric correction to rectify distortions a rising from the Earth's rotation or to align with specific map projection systems, and image georeferencing, which involved the use of ground control points (GCPs) for spatial alignment.

3.2.2 Image classification

In the image analysis for the year 2003, I applied the maximum likelihood (Supervised classification) method within ArcGIS 10.8. This technique utilizes spectral signatures defining classes and designating training samples for various land use/cover types. This workflow included the creation of training areas, generating a signature file, and classifying the image for all the time periods. Eight land use/cover types were caterogrised which include (1) Forests, including woodlot stands of existing indigenous tree species and established trees by planting. (2) Cropland, including land under crop cultivation, for annual and perennial crops including Sugarcane. (3) Grasslands, including land covered with grass ranges and scattered trees, often used for grazing and ranching. (4) Wetlands, including land saturated with water either permanently or seasonally. (5) Settlement, including industrial and residential areas. (6) Open water, areas covered by water permanently. (7) Woodlands are areas covered shrubs. (8) Bushland describes areas with sparse trees and shrubs (Figure 8).

3.2.3 Accuracy assessment of land use/cover map for Amuru

Accuracy assessment of the 2018 land use/cover map was done using the confusion matrix in ArcGIS 10.8. The confusion matrix was based on the hypothetical land classification of the composite image and a field ground truthing. The ground data was used for the columns; while the classified data was used for the rows as it is seen in table 1. The producer's accuracy, user's accuracy and overall map accuracy were then calculated.

The overall average accuracy of the classified land use/cover map for 2018 was 97 % (Table 2) which is regarded as excellent (Gumindonga *et al*., 2014).

3.2.4 Accuracy assessment of an image classification

Accuracy quantification

Overall accuracy (proportional of correctly classified samples) = (total correct pixels) ∗100

Producer's accuracy (Accuracy at the producers perspective i.e. how well does the used model recognize the class types

$$= \frac{\text{(correct pixels from the reference class)}}{\text{Total reference pixels}} * 100$$

User's accuracy (accuracy at the perspective of the map user i.e. the probability that the pixel predicted as eg water is actually water)

$$= \frac{\text{(correct pixels identified in the class field class map)}}{\text{Total map pixels}} * 100$$

Table 1: The confusion matrix of land classification of the composite image and field ground truth

		Reference data									
satellite image data 2018	Land Use/Cover	Bushland	Cropland	Forests	Grassland	Open water	Settlement	Wetland	Woodland	Row totals	User's accuracy (%)
	Bushland	**38**	1	0	1	0	0	3	3	46	83
	Cropland	3	**37**	0	2	0	0	1	3	46	80
	Forests	0	0	**41**	0		1	4	2	48	85
	Grassland	1	2	0	**35**	0	0	0	1	39	90
	Open water		0	0	0	**36**	0	2	0	38	95
	Settlement	3	0	0	2	0	**35**	0	6	46	76
	Wetland	3	1	1	0	0	0	**47**	1	53	89
	Woodland	2	0	2	0	0	0	1	**39**	44	89
	Column totals	50	41	44	40	36	36	58	55	**360**	
	Producer's accuracy (%)	76	90	93	88	100	97	81	71		
	Number of pixels correctly classified		308								

Table 2 : Precision assessment (confusion matrix) of LULC of the study area.

Land Use/Cover	Producer's accuracy	User's accuracy (%)	Overall accuracy (%)
Bushland	76	83	97
Cropland	90	80	
Forests	93	85	
Grassland	88	90	
Open water	100	95	
Settlement	97	76	
Wetland	81	89	
Woodland	71	89	

3.3 Soil physical and chemical properties

Soils data for land suitability were retrieved from the National Agricultural research Laboratories (NARL, 2014) and it was checked for outliers. The ArcGIS software was used to run interpolation of soils data to create surface maps (pH, OC, K, P and CEC) and converting the vector to raster file format (Drainage and soil texture). Ordinary kriging which is under geostatistical analysis tool was chosen as the best method of interpolation. The model was checked for its validity and had Root mean square error was close to zero (0.415). All parameter maps were resampled to the same resolution (3 by 3m).

3.3.1 Reclassification of land suitability parameters.

The following factors were used in evaluating the performance of land with the knowledge of agronomist, and other experts' opinions, reviewing previous literature (Table 4) and FAO guidelines for rainfed agriculture; Soil pH, soil texture, drainage, Organic carbon , CEC, available Phosphorous, potassium and total nitrogen. Climatic data (rainfall and temperature) have been used as well as Land form information (Yohannes et al., 2018).

After interpolation, a model was built as shown below which helped in matching land qualities with crop enterprise (Sugarcane). This was based on FAO (1976, 1983, 2007b; Sys et al., 1993) guidelines for land suitability for Sugarcane (Yohannes et al., 2018).

3.3.2 Multi Criteria Decision making tool

After reclassifying all the datasets required (Sys et al., 1993), a Spatial multi-criteria technique was employed in the analysis of land suitability (Kamau et al, 2015; Kahsay et al., 018) which is called AHP (Analytical Hierarchical process). This was used to determine relative importance of each criterion and the resulting weights were used to construct suitability maps/layers using ArcGIS (10.6) software after confirming that the consistency ratio was less than 0.1. AHP is Multi Criteria decision-making technique initialy developed by Proffessor by Prof.Thomas Saaty (Ebrahim et al., 2017) and it has found extensive application in assessing land suitability for various crops and in diverse research areas (Kahsay et al., 2018; Bozdağ, et al, 2016). To use this method, soil scientist had to join hands with me in order to know the importance in relation to the factors (Table 3).

Table 3: Scale of relative importance

Intensity of importance	Definition	Description
1	Equivalent significance	Two factors contribute in tandem to the objective
3	Moderate priority of one factor over another	Both experience and wisdom give a slight advantage
5	Crutial importance	Experience and judgment favor strongly one of the other
7	Paramount importance	Experience and judgement very strongly favor the other
9	Critical importance	The evidence favoring one of the other is of the highest
2,4,6 and 8	Middle range values	When compromise is needed
Reciprocals		Values for inverse comparison

(Source: Layomi et al., 2019): 9 is of the highest importance and 1 is the least of importance

3.3.3 Weighted overlay analysis

After AHP analysis, weighted overlay analysis tool, which is under spatial analyst tools in ArcGIS (10.8) software was used in the model. Each parameter was assigned the percentage computed by AHp and the overall suitability map for Sugarcane of the study area was then produced (Figure 6).

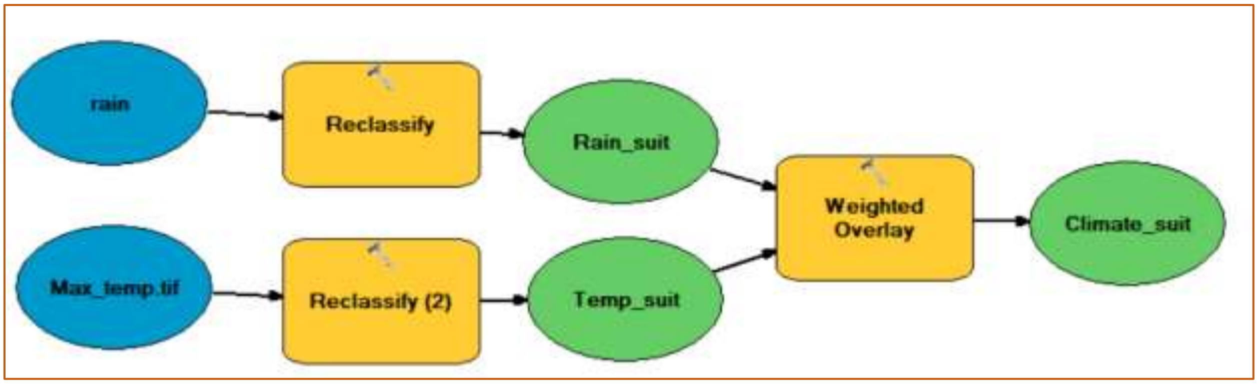

Figure 4: Weighted overlay model used to derive climate suitability for Sugarcane production in the study area.

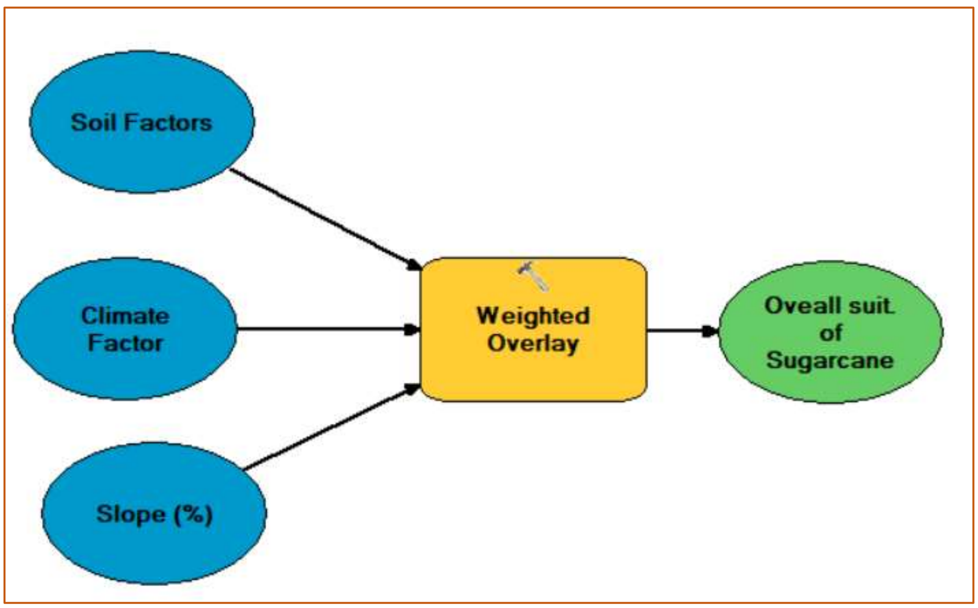

Figure 5: Weighted overlay model used to derive the land sutability of sugarcane production in the study area

3.3.4 Assessing areas under restrictions in Amuru

The restricted areas are removed from agricultural areas because they play important roles; Wetlands are water storage areas and this water can be used during dry season. In addition to that , Uganda has a policy of protecting wetlands (The wetland policy, 1995). National parks and game reserves are areas where wild animals and act as a source of tourism which help Uganda to earn revenue. Forests regulate climate, reduce green house gasses among others (Streck, 2009).

Upon confirming the accuracy of the land use/cover in the study area, the areas under restrictions were eliminated especially the protected areas, Wetland and open water areas including built up areas (Figure 6). This was achieved by overlaying the layers using ArcGIS 10.8 to visualize the areas under conflict with poroposed sugarcane suitability map. The vector datasets were obtained from the ministry of water and environment. More Scholers have used the same method to derive on land suitability assessment reports for sugarcane (Ackbar, 2007). The proportion of available land for agriculture in the study area covers 87.6 %, (Table 4) which is equivalent to 315427 ha of the total area.

Table 4: The ratio of land that is officially designated for Agriculture

Proportion of land for Amuru	**Hectare**	**%**
Total land area	**359,942**	**100**
Gazetted areas (National parks, forests and game reserves)	25,536	7.1
Wetland	17,560	4.9
Open water	1,090	0.3
Settlement	329	0.1
Available land for Sugarcane	**315427**	**87.6**

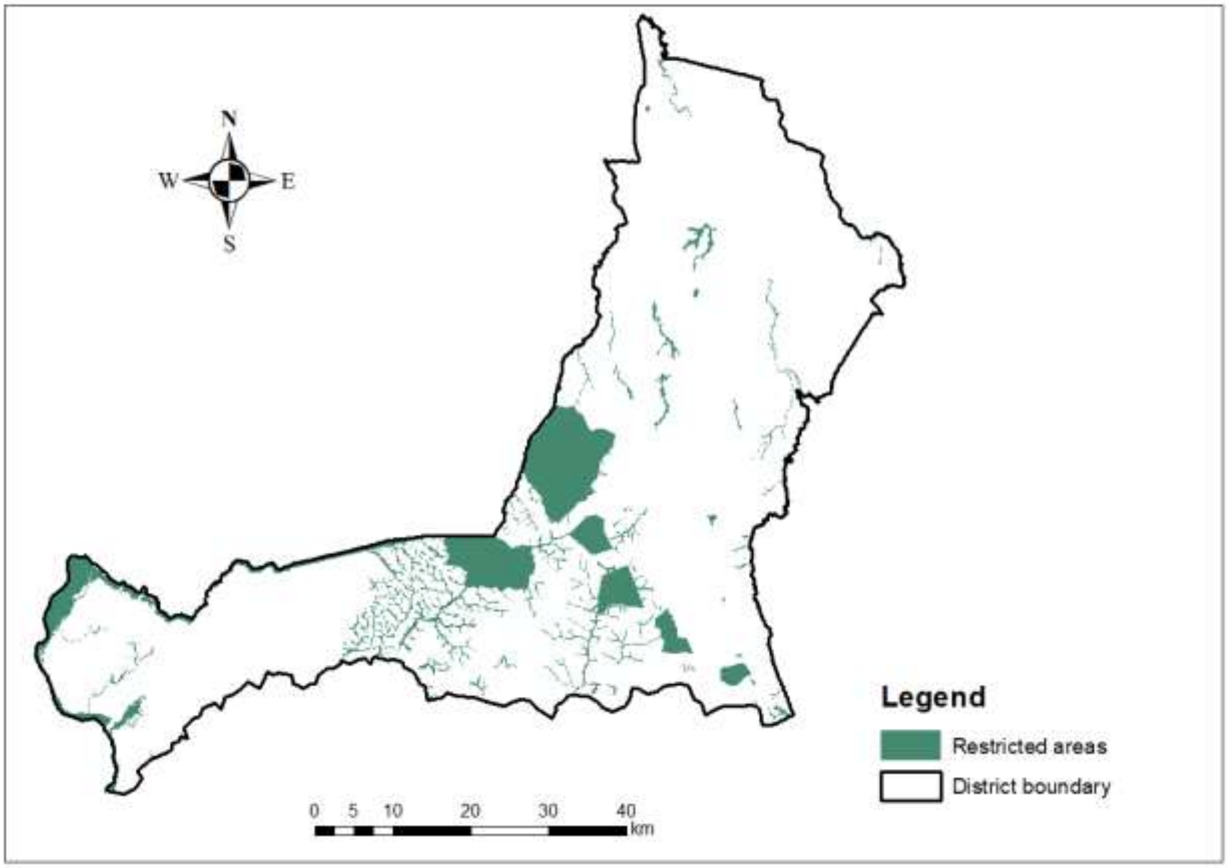

Figure 6: Restricted areas in the study area

Table 5: Harmonization criteria used in sugarcane suitability assessment (Source: Sys et al. 1993)

Factors	**S1**	**S2**	**S3**	**N1**
Slope (%)	Level to gentle	Undulating	moderate	Steep
Soil texture	Clay, clay loam	Sandy/ Loam	Sandy , Clay loam	Too sandy
Drainage	Well drained	moderately drained	Imperfect	Poor/excessive
Soil depth	Deep	moderately deep	Shallow	very shallow
Soil pH	slightly acidic	neutral/alkaline	Moderately alkaline	too alkaline/acidity
Nitrogen (%)	>0.25		0.15-0.05	<0.05
Phosphorous (ppm)	>36	35.5-23	22.5-12.5	<12
Potassium (ppm)	>73	72.5-41	40.5-20.5	<20
CEC(cmols)	>24	<16(-)	<16(+)	NA
Organic Carbon (%)	>2.5	1.5-1	<1	NA

S1 = Highly suitable; S2 = Moderatly Suitable; S3 = Marginal; N1 = Currently not suitable, N2=Inherently unsuitable permanently (Relevant, 2020)

Table 6: Revised land suitability categorization (source: Relevant, 2020)

Symbol	Suitability	Description
S1	High	Land with no significant limitation for any specific use
S2	Moderate	Land with moderate limitation which reduce productivity or increase required input
S3	Marginal	Land with severe limitations to specified use
N1	Currently not suitable	Severe limitations which cannot be corrected with existing knowledge within acceptable cost units. Land having limitations which may be surmountable in time but which can't be corrected with exisiting knowledge at currently acceptable cost, the limitations are so severe as to disqualify successibly sustainable use use of the land in given time manner.
N2	Permanently not suitable	Land having limitations which appear so severe as to disqualify any possibilities of succesfull sustained use of the land in a given manner

Validation of results

Already in the study area, Sugarcane production is ongoing especially in Atiak sub-county. To validate the results / findings, the researcher had a discussion with agricultural extension officers who work in Sugarcane estate and found out that the modelled suitability class was falling in the existing Sugarcane cultivation areas. Different researchers have used this method and it has been approved (Layomi Jayasinghe et al., 2019).

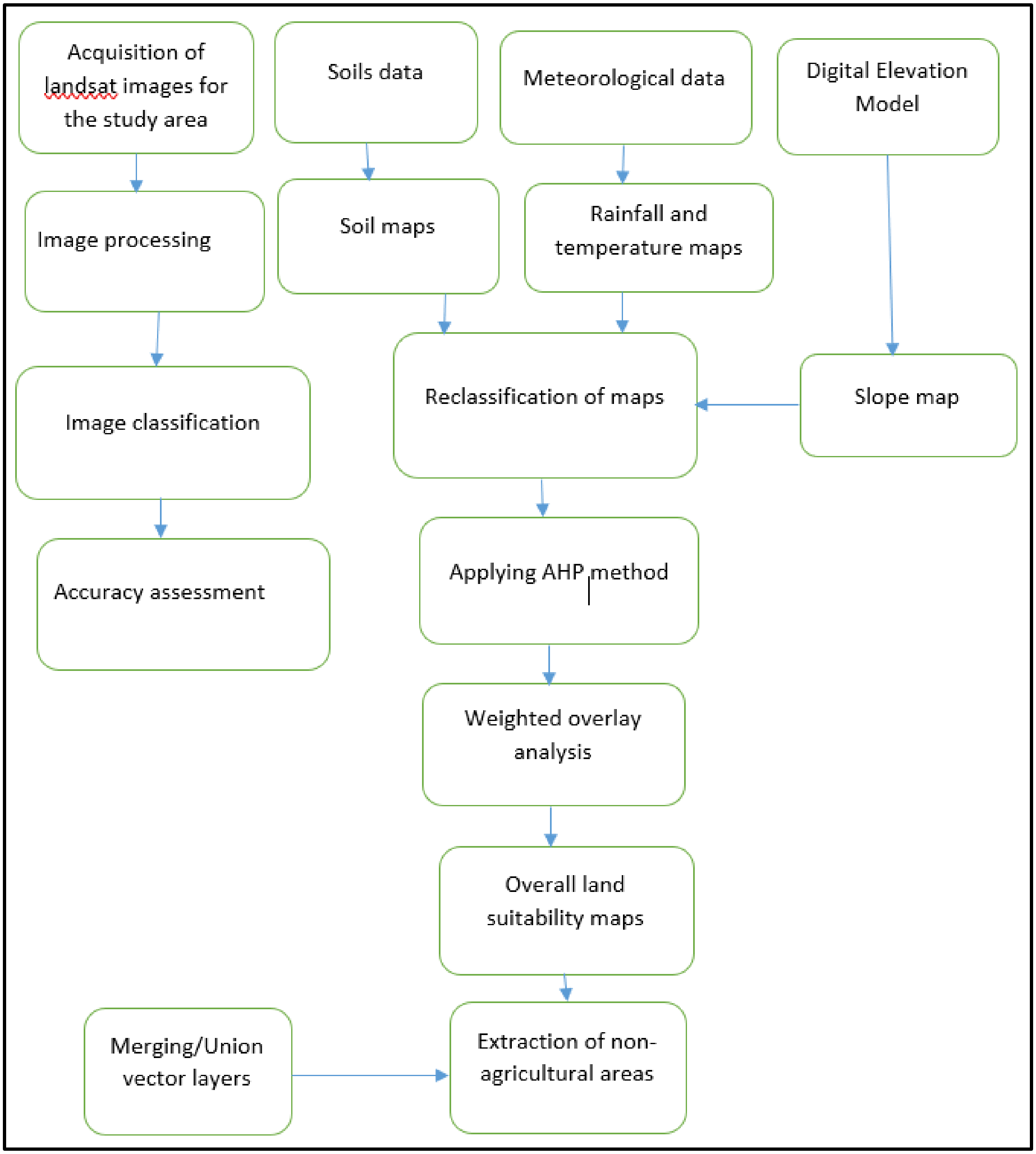

Figure 7: Methodological framework in MCDM process for Sugarcane production in the study area

3.4 Determining the Cost-Benefit Analysis of Sugarcane in Amuru District

This study employed a farm-level cost-benefit analysis (CBA) to evaluate the economic viability and profitability of sugarcane cultivation in Amuru District to ascertain whether sugarcane growing is a financially beneficial enterprise for farmers in the district.

3.4.1 Data Collection.

The analysis was conducted for sugarcane production in Amuru District, with a specific focus on data representative of the Atiak sugarcane growing estates.

Primary data on the costs and revenues associated with sugarcane cultivation were collected. This included detailed records of all activities from land preparation to harvesting. The data was sourced directly from the extension workers responsible for maintaining farm records at the Atiak sugar cane estates. This ensured that the figures used were actual and reflective of the local operational context (Khan et al., 2021).

3.4.2 Analytical Framework

The economic performance was assessed using two key metrics: Net Farm Income (NFI) and the Benefit-Cost Ratio (BCR). The formulas used for the calculations are as follows:

a) Total Cost (TC) Calculation:

Total cost is the sum of all expenses incurred in the production process.It is disaggregated into Total Variable Costs (TVC) and Total Fixed Costs (TFC).

$$TC = TVC + TFC$$

Total Variable Costs (TVC): These are costs that vary with the level of production. For sugarcane, this includes expenses for inputs and activities such as land preparation, seedlings, planting, weeding, fertilizer, pesticides, irrigation, and harvesting labour (Ogwuche et al., 2020).

Total Fixed Costs (TFC): These are costs that do not change with the level of production in the short term. This includes depreciation on farm machinery and equipment, land rent (if applicable), and permanent labour salaries (Adeyemo et al., 2019).

b) Net Farm Income (NFI) Calculation:

The Net Farm Income represents the profit earned from the sugarcane enterprise after accounting for all costs. NFI = Total Revenue (TR) – Total Cost (TC)

Total Revenue (TR): This is the gross income from the sale of the sugarcane harvest. It is calculated as the total quantity of sugarcane produced (in tonnes) multiplied by the prevailing farm-gate price per tonne.

3.4.3 Benefit-Cost Ratio (BCR) Calculation:

The Benefit-Cost Ratio is a relative measure of profitability that compares the projected benefits of a project to its costs. BCR = Total Revenue (TR) / Total Cost (TC). The BCR provides a quick indicator of viability: BCR > 1.0: The project is profitable, as benefits exceed costs. BCR = 1.0: The project breaks even. BCR < 1.0: The project is not economically viable, as costs exceed benefits (Pandey et al., 2021).

3.4.4 Data Analysis.

The collected data on costs and revenues were systematically categorized into variable and fixed costs. The formulas outlined above were then applied to compute the Net Farm Income and the

Benefit-Cost Ratio. A sensitivity analysis may also be conducted to understand how changes in key variables (e.g., yield or input prices) affect the NFI and BCR, providing a more robust assessment of risk (Ogwuche et al., 2020).

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Land use/cover classes of the study area

Land use/cover analysis is a fundamental precursor to land suitability assessment, as it provides a snapshot of the existing landscape and identifies areas available for agricultural development (Musa & Eludoyin, 2018). In this study, land use/cover classes were categorized into eight distinct groups (Table 7 and Figure 8). The analysis revealed that Amuru landscape is predominantly covered by grassland (46%) and cropland (33%), which together constitute 79% of the total land area. Bushland accounted for 14.6%, while forests, woodland, wetland, open water, and settlements made up the remaining 6.4% (Table 7).

The dominance of grassland and cropland indicates a significant potential area for agricultural expansion, including sugarcane cultivation. However, this also implies potential competition with existing agricultural activities and pastoral lands. The very small proportion of land under settlement (0.1%) suggests minimal immediate conflict with urban expansion, a common challenge in other regions undergoing agricultural commercialization (Mukwaya et al., 2023). The identification of protected areas (forests, wetlands) is critical for sustainable planning, as their conservation is mandated by national policies (NEMA, 1996) and they provide essential ecosystem services (Streck, 2009).

Table 7: Land use/cover types, area (ha) and % of the study area (Amuru District)

LULC types	Area		Remarks
	Ha	%	
Bushland	46115	14.6	Suitable for agricuture
Cropland	104663	33.0	Suitable for sugarcane growing but conflicting with other native crops
Forests	13880	4.4	Not suitable for sugarcane growing because of the forest and Wildlife policy in Uganda
Grassland	145901	46.0	Suitable for agriculture but some land area within this land use type conflict with wildlife and native crops
Open water	806	0.3	Permanently not suitable for sugarcane growing
Settlement	326	0.1	Not suitable for sugarcane growing
Wetland	836	0.3	Not suitable for sugarcane because of the wetland policy in Uganda
Woodland	4319	1.4	Not suitable for agriculture because of wildlife, and gazatted areas policy.
Total	316846	100	

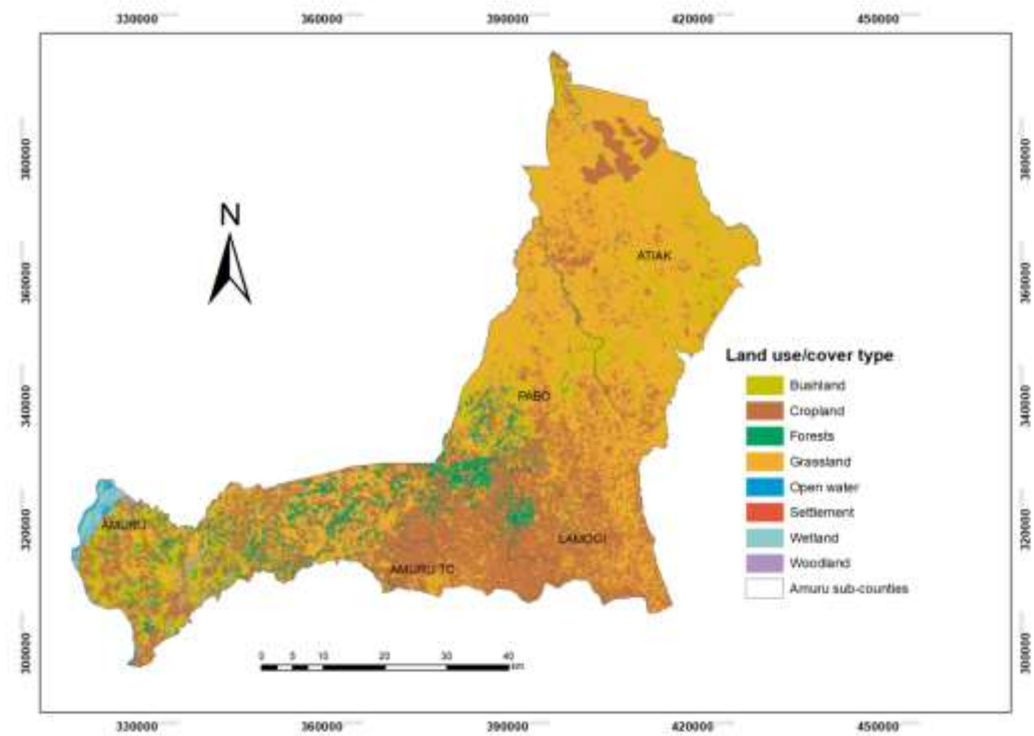

Figure 8: Land use/cover map for the Amuru District

4.2 Assessing the physical and chemical properties using multicriteria evaluation tool.

4.2.1 Soil pH:

Soil pH is a master variable that controls numerous soil chemical processes and nutrient availability. The results showed that the soil pH in Amuru ranges from 5.43 to 8.82. A significant 98.7% of the arable land was found to be within the suitable range (4.5-8.5) for sugarcane, with the optimum pH for yield (5.5-7.5) covering a substantial portion. This finding aligns with the general suitability of many tropical soils for sugarcane (Sys et al., 1993). However, the small percentage (1.3%) of land with pH constraints may require targeted lime application to correct acidity, a common recommendation for optimizing sugarcane productivity in similar agro-ecologies (Namusoke et al., 2022).

4.2.2 Soil organic Carbon (SOC).

The SOC levels, ranging from 1.6 to 3.7%, placed the vast majority (95.5%) of the land in the moderately suitable class. This is a common characteristic in intensively cropped or managed grassland systems where organic matter mineralization is high. The critical role of SOC in enhancing soil structure, water retention, and nutrient cycling is well-documented (Ogwang et al., 2017). The spatial concentration of higher SOC in Amuru sub-county suggests variations in land management history or soil type. The low SOC in other areas underscores the need for integrated soil fertility management practices, such as incorporating organic amendments, to build soil health and sustain long-term sugarcane yields (Kisame et al., 2024).

4.2.3 Slope suitability of the land for sugarcane production

The terrain analysis revealed that 94.7% of the land is suitable (level to gentle) for sugarcane production. This is a highly favourable condition, as gentle slopes are conducive to mechanization, reduce the risk of soil erosion, and facilitate efficient farm management (FAO, 1976). The small areas with steeper slopes, located in western Amuru and Pabo, may require conservation measures if cultivated, but their limited extent means they do not pose a significant constraint to large-scale sugarcane development in the district.

4.2.4 Suitability of Cation exchange Capacity (CEC)

The CEC results were a critical finding, with 95% of the land being only marginally suitable due to low values (2.21-30.2 cmol/kg). CEC is a key indicator of a soil's ability to hold and supply essential nutrients like Ca, Mg, and K (Sys et al., 1993). The predominantly low CEC across Amuru suggests soils with low fertility retention capacity, likely associated with the dominant kaolinitic clay minerals in highly weathered Ferralsols and Leptosols (Isabirye et al., 2010). This necessitates a careful and efficient fertilizer management strategy, as nutrients are more prone to leaching, making split applications more beneficial (Adeyemo et al., 2019).

4.2.5 Soil texture, Nitrogen, Phosphorous, and Potassium

The soil texture was largely classified as moderately suitable, which is acceptable for sugarcane, which is adaptable to a range of loamy soils. The analysis of primary nutrients revealed widespread limitations. Nitrogen levels were predominantly moderate (92% of the area), reflecting a common constraint in tropical soils. Phosphorus showed a mix of moderate (70%) and suitable (25%) conditions, while Potassium was found to be highly suitable across the entire district. These results highlight that nitrogen and, to a lesser extent, phosphorus are the most limiting nutrients and should be the primary focus of fertilizer programs to unlock the yield potential of sugarcane in Amuru (Ogwuche et al., 2020).

4.2.6 Soil drainage:

Soil drainage refers to the ability of soil to allow water to move downward through it. It's a crucial aspect of soil behaviour that affects plant growth, soil health, and various land uses. Proper drainage is essential for maintaining a healthy soil environment and preventing issues like waterlogging and soil erosion. The study area has two types of drainage. Poor drained and well drained.

4.2.7 Land suitability for Sugarcane production

The integration of all factors using the Analytic Hierarchy Process (AHP) provided a scientifically robust weighting for the suitability model (Table 8, Table 9). The AHP derived weights correctly identified soil pH (27.8%) and CEC (25.0%) as the most critical factors, which aligns with agronomic principles where these parameters govern the fundamental chemical environment and nutrient holding capacity of the soil (Kahsay et al., 2018). The low consistency ratio (0.0254) confirmed the reliability of the expert judgments used in the pairwise comparison.

The final integrated suitability map (Figure 10) presents a clear and decisive picture: 99% of Amuru's arable land is moderately suitable (S2) for sugarcane production, with only 1% being highly suitable (S1) (Table 12). This finding is significant. It indicates that while there are no severe limitations that would preclude sugarcane cultivation (i.e., no N1 or N2 classes), the widespread soil fertility constraints particularly low CEC and less-than-optimal levels of SOC, N, and P prevent the land from being classified as highly suitable.

This result corroborates the findings of Ogwang et al. (2017), who also identified Amuru as having moderate potential. The divergence from Semyalo (2010), who reported a higher proportion of highly suitable land, can likely be attributed to this study's use of more recent and detailed soil data, and a multi-factorial AHP approach that provides a more nuanced assessment than traditional overlay methods.

The moderately suitable classification should not be interpreted as a deterrent but as a guide for action. It implies that sugarcane can be successfully grown, but achieving high and sustainable yields is contingent upon proactive and informed soil management. The recommendation for supplemental irrigation and specific NPK fertilizer inputs is directly derived from these results and is essential for bridging the yield gap between rainfed and irrigated systems (Dercas & Johnson, 2008) The integration of all factors using the Analytic Hierarchy Process (AHP) provided a scientifically robust weighting for the suitability model (Table 8, Table 9). The AHP-derived weights correctly identified soil pH (27.8%) and CEC (25.0%) as the most critical factors, which aligns with agronomic principles where these parameters govern the fundamental chemical environment and nutrient holding capacity of the soil (Kahsay et al., 2018). The low consistency ratio (0.0254) confirmed the reliability of the expert judgments used in the pairwise comparison.

The final integrated suitability map (Figure 10) presents a clear and decisive picture: 99% of Amuru's arable land is moderately suitable (S2) for sugarcane production, with only 1% being highly suitable (S1) (Table 10). This finding is significant. It indicates that while there are no severe limitations that would preclude sugarcane cultivation (i.e., no N1 or N2 classes), the widespread soil fertility constraints particularly low CEC and less-than-optimal levels of SOC, N, and P prevent the land from being classified as highly suitable.

This result corroborates the findings of Ogwang et al. (2017), who also identified Amuru as having moderate potential. The divergence from Semyalo (2010), who reported a higher proportion of highly suitable land, can likely be attributed to this study's use of more recent and detailed soil data, and a multi-factorial AHP approach that provides a more nuanced assessment than traditional overlay methods.

The moderately suitable classification should not be interpreted as a deterrent but as a guide for action. It implies that sugarcane can be successfully grown, but achieving high and sustainable yields is contingent upon proactive and informed soil management. The recommendation for supplemental irrigation and specific NPK fertilizer inputs is directly derived from these results and is essential for bridging the yield gap between rainfed and irrigated systems (Dercas & Johnson, 2008).

Table 8: Matrix comparing the relative importance of land use requirements for Sugarcane production.

Soil quality factors	**OC**	**P**	**N**	**Drainage**	**CEC**	**K**	**Texture**	**PH**
OC (%)	**1**	2	2	3	0.33	2	3	0.333

P(ppm)	0.5	**1**	0.5	2	0.25	1	2	0.25
N (%)	0.5	2	**1**	3	0.5	3	2	0.333
Drainage (class)	0.333	0.5	0.333	**1**	0.25	0.5	2	0.2
CEC(cmol(+)kg soil)	3	4	2	4	**1**	3	6	1
K(ppm)	0.5	1	0.333	2	0.333	**1**	2	0.25
Texture (class)	0.333	0.5	0.5	0.5	0.167	0.5	**1**	0.167
PH (H20)	3	4	3	5	1	4	6	**1**

Table 9: Criteria weights for Sugarcane production regarding diagnostic soil factors calculated by AHP Weight derived model.

Soil factors	**Weight**	**%**
OC (%)	0.13	13.0
P (PPM)	0.069	6.9
N (%)	0.117	11.7
Drainage (Class)	0.048	4.8
CEC (cmol(+)kg soil)	0.25	25.0
K (ppm)	0.069	6.9
Texture (Class)	0.039	3.9
PH (H20)	0.278	27.8
Total	**1**	**100.0**
Consistency ratio		**0.0254**

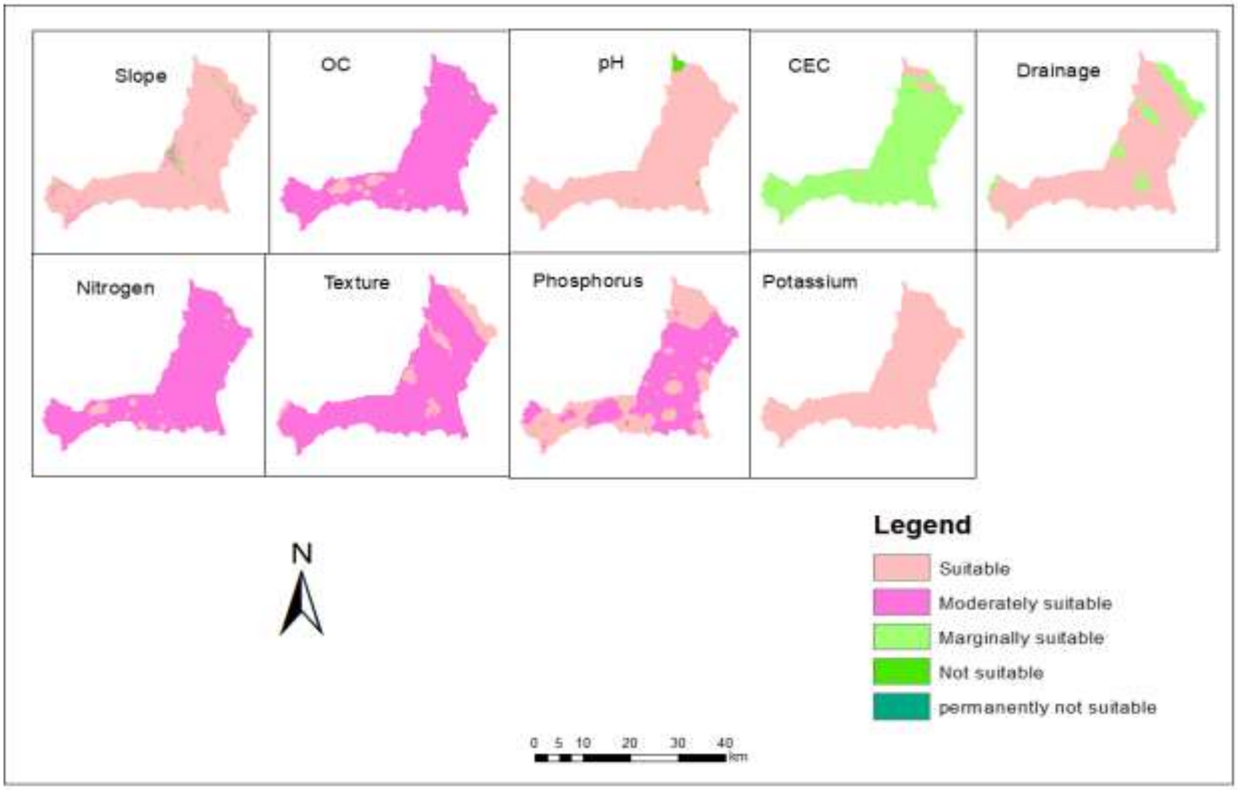

Figure 9:Individual suitability maps for Sugarcane production in the study area.

Table 10: Spatial coverage of land suitability for Sugarcane production in Amuru district

Suitability ratings	Hectares	% coverage
Highly Suitable (S1)	3483	1
Moderatly Suitable (S2)	315087	99
Total	**318570**	**100**

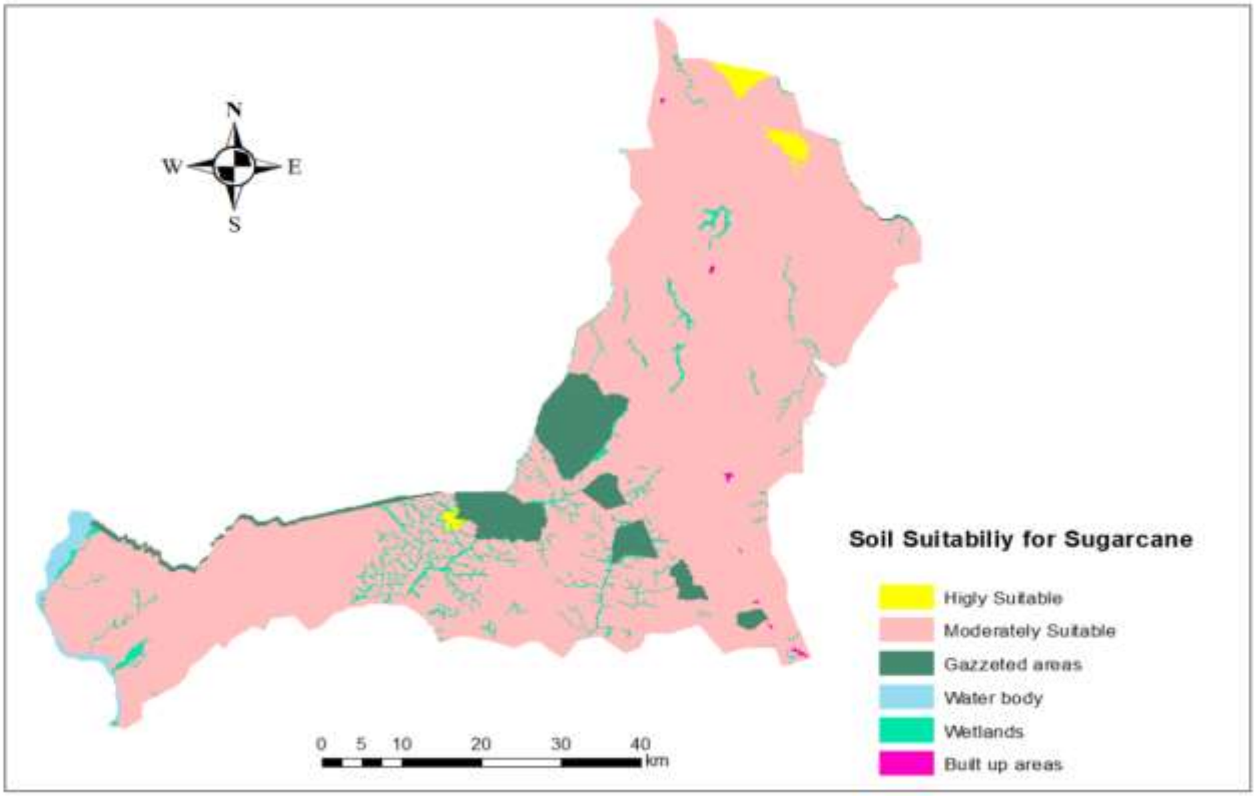

Figure 10: Overall land suitability for Sugarcane in Amuru district

4.3 Ecomic benefits of sugarcane production in Amuru district

The results from the economic analysis of sugarcane production in Amuru District over three ratoon cycles demonstrate that the venture is profitable. The data in Table 13 confirms this, showing an average Benefit-Cost (B/C) ratio of 2.0. A B/C ratio greater than 1.0 indicates a profitable project (Pandey et al., 2021), and the average result of 2.0 firmly classifies sugarcane growing in the study area as an economically beneficial enterprise.

The analysis reveals a clear trend of increasing profitability from Ratoon 1 to Ratoon 3. As shown in Tables 12 and 13, the cost of production decreases slightly across the ratoon cycles, from UGX 5,043,200 in Ratoon 1 to UGX 4,843,200 in Ratoon 3. This decline in cost is consistent with established knowledge, as ratoon crops require lower inputs for land preparation and seed materials (Adeyemo et al., 2019). However, the most significant factor driving the increase in profitability is the substantial rise in the selling price per ton in Ratoon 3. The price increased to UGX 175,000, compared to UGX 95,000 and UGX 96,000 in Ratoon 1 and 2, respectively. This price surge directly resulted in the net income rising from UGX 2,366,800 in Ratoon 1 to UGX 9,156,800 in Ratoon 3, and the B/C ratio improving from 1.5 to 2.9. This underscores that market price fluctuations are a critical determinant of farm-level profitability (Khan et al., 2021).

It is important to contrast the profitable ratoon cycles with the first season's results, provided in Table 11. The first season recorded a net loss of UGX 257,200 and a B/C ratio of 0.96, which is below the profitable threshold. This initial loss is typical and can be attributed to the high initial establishment costs, such as land preparation and purchase of seed cane, which are characteristic of perennial crop investments (Ogwuche et al., 2020). Therefore, the profitability of sugarcane must be assessed over the entire cycle of the plant cane and its ratoons, rather than on the first season alone.

In summary, the economics of sugarcane production in Amuru District are positive. The venture yields a strong average profit and B/C ratio over the cultivation cycle. The improving profitability across ratoons, driven by slightly lower costs and significantly higher output prices, confirms its financial viability. Stakeholders should note the importance of the ratoon system for economic sustainability and the critical impact of market prices on ultimate returns.

Table 11: Cost of Sugarcane production and Gross income for the first season

S/N	Activities	Sub-activities	Unit	Amount (UGX)
1	Land preparation	Ploughing		400,000
2	Seed materials	seed cane	ton	1,000,000
3	Planting (Labour)	Seed planting	Labour	364,000
		Furrows	Lumpsum	175,000
		Irrigation costs	Lumpsum	650,000
		Weeding (mechanical)	Lumpsum	425,000
		Fertilizer (DAP 100kgs @3500	kgs	350,000
		Labour for appling fertilizer		145,000
	Harvesting	Harvesting and loading trucks costs (4 trucks)+Trasnport	Lumpsum	3,294,000
4	TVC			**6,803,000**
	Fixed costs	Land rent		494,200
	Total cost of prod			**7,297,200**
5	Yield		tons	64
6	Price		tons	110,000
7	Gross Income		NRS	7,040,000
8	B/C			0.96
9	Net Income		NRS	-257,200

Table 12: Costs of Sugarcane production in ratoon 1, 2 and 3

	Activities	Units	Ratoon1	Ratoon2	Ratoon3
Variable costs	Removing grass, earthing up		165000	170000	160000
	Using herbicides		195000	140000	135000
	Irrigation costs		460000	410000	380000
	Fertilizer costs (DAP 60kg@ 3500		210000	180000	160000
	Labour for applying fertilizer		145000	110000	100000
	Insect/disease control		80000	100000	120000
	Loading and harvesting +Transport		3294000	3294000	3294000
TVC			4549000	4404000	4349000
Fixed Cost	Land rent	Ha	494200	494200	494200
Total cost of prod			**5043200**	**4898200**	**4843200**
Yield		tons	78	82	80
Price		tons	95000	96000	175000
Gross Income		NRS	7410000	7872000	14000000
B/C			1.5	1.6	2.9
Net Income		NRS	2366800	2973800	9156800

Table 13: Total and average costs of Sugarcane production, gross income, profit and Benefit cost ratio for ratoon 1, 2 & 3.

Ratoon	Cost of production	Yield/Ha	Price/ton	Gross income	Profit (UGX)	B/C
Ratoon 1	5043200	78	95000	7410000	2366800	1.5
Ratoon 2	4898200	82	96000	7872000	2973800	1.6
Ratoon 3	4843200	80	175000	14000000	9156800	2.9
Total cost	14784600	240	366000	29282000	14497400	6
Average	4928200	80	122000	9760666.667	4832466.7	2

CHAPTER FIVE: CONCLUSIONS AND RECCOMMENDATIONS

5.1 Conclussions

This study successfully employed a GIS-based Multicriteria Evaluation, integrating the Analytical Hierarchy Process (AHP), to assess the land suitability for sugarcane production in Amuru District. The following key conclusions are drawn from the findings:

Dominant Land Use: The land use/cover analysis reveals that the Amuru landscape is predominantly covered by grassland (46%) and cropland (33%), indicating a significant area with potential for agricultural expansion, albeit with existing land use commitments.

Predominantly Moderate Suitability: The overall land suitability assessment concludes that the vast majority (99%) of the arable land in Amuru District is moderately suitable (S2) for sugarcane cultivation. A very small fraction (1%) is classified as highly suitable (S1). Crucially, no land was found to be marginally (S3) or permanently unsuitable (N2), which is a positive indicator for agricultural development.

Key Limiting Factors: The moderate suitability classification is primarily attributed to soil fertility constraints. The most critical limiting factors, as determined by the AHP model, are low soil pH and low Cation Exchange Capacity (CEC), which affect nutrient availability. Additionally, levels of Organic Carbon (OC), Nitrogen (N), and Phosphorus (P) were also identified as being in the moderate range, requiring management to achieve optimal yields.

Favourable Physical Conditions: The study found that physical land characteristics are generally well-suited for sugarcane. Slope, drainage, and soil texture across most of the district pose no significant limitations and are conducive to mechanized agriculture.

Economic Viability: The economic analysis demonstrates that sugarcane production in Amuru is a financially viable and profitable venture. With an average yield of 80 tons/ha, the enterprise yields an average profit of UGX 4,832,467 per hectare and a robust average Benefit-Cost Ratio (B/C) of 2.0 over three ratoon cycles, confirming its potential for economic returns.

In summary, while Amuru District presents a strong case for sugarcane expansion due to its favourable physical terrain and economic prospects, the widespread moderate suitability underscores that successful cultivation is contingent upon proactive and sustained soil fertility management.

5.2 Recommendations

Based on the conclusions of this study, the following recommendations are proposed for various stakeholders, including farmers, investors, policy makers, and researchers:

For Farmers and Agricultural Investors:

Implement Integrated Soil Fertility Management (ISFM): To address the widespread moderate suitability, farmers should adopt targeted soil amendment practices. This includes the application of:

Phosphatic fertilizers (e.g., DAP, TSP) to correct phosphorus deficiencies identified in the soils.

Nitrogenous fertilizers and practices that boost soil organic matter, such as incorporating crop residues or applying compost/manure, to improve Nitrogen and Organic Carbon levels.

Soil amendments like lime should be considered in specific areas where soil pH is a limiting factor, to enhance nutrient availability and CEC.

5.3 For Policy Makers and District Planners:

Utilize the Suitability Map for Land Use Planning: The GIS-generated suitability maps produced in this study should be adopted as a decision-support tool. They can guide zoning for sugarcane expansion, minimize land-use conflicts with food crops, and promote sustainable agricultural development in the district.

Promote Access to Inputs and Credit: Develop policies and programs that facilitate farmers' access to quality fertilizers, improved sugarcane varieties, and affordable credit to enable them to meet the initial investment and recurrent costs of sugarcane cultivation.

5.4 For Sugarcane Companies and Outgrower Schemes:

Establish Robust Extension Services: Companies like Atiak Sugar Factory should strengthen their extension services to educate outgrowers on optimal agronomic practices, including precise fertilizer application, weed control, and efficient irrigation techniques to maximize yields and profitability.

Ensure Fair and Stable Pricing: As evidenced by the price fluctuations in the economic analysis, stable and remunerative pricing is critical for farmer retention and long-term sustainability of the outgrower model.

5.5 For Future Research:

Incorporate Socio-Economic Factors: Future research should integrate socio-economic criteria (e.g., land tenure, market access, labour availability) with the biophysical factors used in this study to provide a more holistic land suitability assessment.

Investigate Irrigation Potential: Given the marginal suitability of rainfall, further research is recommended to design and map potential sites for cost-effective irrigation systems to buffer against rainfall variability and enhance yield stability.

Conduct More Detailed Soil Sampling: To address the data quality limitation noted, a future, more intensive soil sampling campaign across the district is recommended to generate higher resolution soil maps for even more precise recommendations.

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