International Journal of Novel Researches in Science, Technology & Engineering
Vol. 9 No. 1 April, 2026
ISSN 2141 825X
www.oasisinternationaljournal.org

EFFECTS OF LAND USE ON FOOD SECURITY IN MALETE USING MACHINE LEARNING ALGORITHM AND GEOGRAPHIC INFORMATION SYSTEM (GIS)

by

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Abstract
In Malete Kwara State, Nigeria rapid urbanization and population growth particularly following the establishment of the Kwara State University in 2009 have led to increased land use and modifications that threaten food security. However, the impact of these changes has not been systematically evaluated and the lack of comprehensive assessments using advanced technologies such as machine learning algorithms and Geographic Information Systems (GIS) limits our understanding of how LULC changes affect agricultural productivity and food availability. This research aims to detect the effects of land use on food security in Malete by employing machine learning algorithms to analyze the relationship between LULC changes and agricultural outcomes. The results show significant changes in land use of the community including growth in constructed areas, variations in grazing land, increased crop cultivation and changes in forest cover. Data reveals fluctuations in land coverage over the years with forests, cultivations, constructed areas and open range being the main categories studied. In terms of tree coverage, there was a noticeable shift over the studied period. In 2002, the area covered by trees was relatively small, with only 170.01 hectares. However, by 2012, there was a significant increase, indicating a positive trend in tree cover expansion with the area reaching 1596.19 hectares. Surprisingly, by 2022, the area decreased to 500.6 hectares, suggesting a potential reversal or change in land management practices. Similarly, the cultivation of crops showed fluctuating trends. In 2002, there were no crops recorded in the area under study. However, by 2012, a small area of 69.92 hectares was cultivated for crops indicating some level of agricultural activity. This area slightly increased to 92.89 hectares by 2022, suggesting a gradual but limited

expansion of agricultural land use. The expansion of built-up areas was particularly notable over the studied period indicating significant urbanization or infrastructure development. In 2002, the area covered by built-up structures was 104.67 hectares. By 2012, this area more than tripled to 319.16 hectares, reflecting rapid urban expansion. Subsequently, in 2022, there was a further increase to 603.95 hectares, highlighting ongoing urban development and land transformation.
Conversely, the open range area exhibited dynamic changes over time. In 2002, the largest land use category was open range, covering a substantial 3045.24 hectares. However, by 2012, there was a significant decrease in open range area to 1333.86 hectares, indicating potential land use conversion or management shifts. Interestingly, in 2022, there was a notable increase to 2121.69 hectares, suggesting some level of reversion or change in land use patterns. It was recommended that through collaborative partnerships and adaptive management practices, stakeholders can navigate the complex landscape of LULC dynamics and pave the way for a more sustainable and resilient future in Malete.

Keywords: Land use, Food security, Machine learning algorithm & Geographic information system.

Introduction

Food security is a pressing global issue closely tied to changes in land use and land cover (LULC) which are often driven by human activities and significantly affect agricultural productivity, resource availability and socio-economic conditions (Seto*et al.,* 2002; Dwivedi*et al.,* 2005). As human populations grow and urban areas expand, the demand for land increases leading to significant alterations in how land is utilized. In regions like Malete, Kwara State, Nigeria, this rapid urbanization and population growth exert considerable pressure on land resources resulting in the conversion of agricultural land to residential, commercial and industrial uses. Such transformations can disrupt local food systems, reduce the availability of arable land and ultimately threaten food security. By addressing the challenges posed by LULC changes, communities can work towards achieving food security while also fostering economic growth and environmental sustainability. Therefore, a comprehensive understanding of the impacts of land use changes on food security is vital for ensuring that future generations have access to sufficient, safe, and nutritious food.

In Malete, Kwara State, Nigeria, rapid urbanization and population growth particularly following the establishment of the Kwara State University in 2009, have led to increased land uses and modifications that threaten food security. However, the impact of these changes has not been systematically evaluated and the lack of comprehensive assessments using advanced technologies such as machine learning algorithms and Geographic Information Systems (GIS) limits our understanding of how LULC changes affect agricultural productivity and food availability.

GIS is a computer system for capturing, storing, querying, analyzing and displaying geospatial data. Geospatial data describe both the location and characteristics of spatial features. The ability of a GIS to handle and process geospatial data distinguishes GIS from other information systems and allows GIS to be used for integration of geospatial data and other data (Kang-Tsung, 2014).

Geographic information system has been recognized as a computerized system for capturing, storing, retrieving, manipulating, integrating, analyzing and displaying data which are spatially referenced to the earth (Kufoniyi, 1998). Geographic Information Systems are the most valid means of producing different projects with the evaluation of information related to location and analyses (Aronoff, 1989). The fundamental concepts of GIS include data capturing, data analysis and information presentation. This involved geospatial data entry into the computer system through scanning of the available maps, geo-referencing and vectorising the imagery of the study area, designing and creating relational database for the geometric and attribute dataset of the study area, manipulating and analyzing the data set (buffering, query analysis and spatial statistics) as well as information presentation. GIS has been important in natural resource management including land-use planning, natural hazard assessment, disaster management, wildlife habitat analysis, riparian zone monitoring and timber management. It is also very useful for emergency planning, crime analysis, public health, land records management, transportation applications, precision farming and economic recovery (Kang-Tsung, 2014).

This research aims to detect the effects of land use on food security in Malete by employing machine learning algorithms to analyze the relationship between LULC changes and agricultural outcomes. Previous studies have primarily relied on traditional methods which may not adequately capture the complexities of land use dynamics. By integrating machine learning with GIS, this study will provide understanding of how land use changes influence food security, offering valuable insights for policymakers and local stakeholders.

Location of the Study Area

The study area is located in Moro Local Government Area of Kwara State, Nigeria. It lies within the latitude $08^0\ 41'40''$ N to $08^0\ 43'\ 20''$ N and longitude $04^0\ 25'\ 50''$ E to $04^0\ 30'\ 0''$ E of Greenwich Meridian. It comprises of Malate, KWASU Campus and the adjourning communities covering an area of about 4,000 Hectares of land as shown in Figure 1.

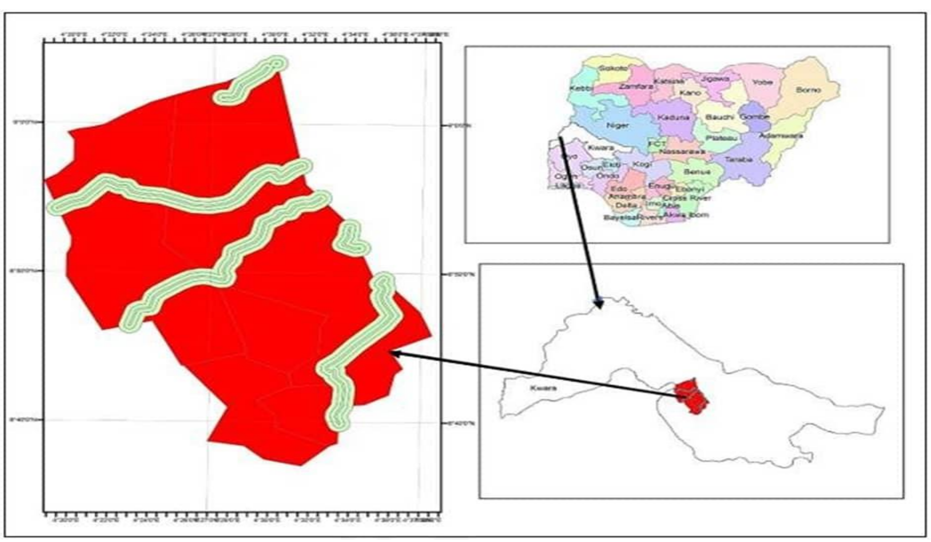

Figure 1: Map of the Study Area

Study Approach and Methodology

This study employs a multi-facet approach that integrates machine learning algorithms with Remote Sensing and Geographic Information System (GIS) techniques to analyze land use and land cover (LULC) data and its effects on food security in Malete, Kwara State, Nigeria. The comprehensive approach involves several key components including the selection of appropriate satellite imagery, the use of specialized software for data processing and analysis and the application of machine learning models to derive insights from the data.

Data Requirement and System Selection

The data required involved the 2.5-D datasets i.e. Easting, Northing and Height of the study area from the field measurement as well as attribute datasets. An imagery of the study area was used as a geospatial data. Certain criteria informed the selection of the system configuration that is fit for this study which includes the following: User requirement; In-house data acquisition system; Terrain and scope of coverage; Database Management System and Vector data format. The consideration based on the above mentioned criteria led to the selection of the following system configuration namely:

Hardware Requirement

(i) HP Laptop computer with the configuration such as: 40 GB hard disk drive; 128 MB RAM; 1.44 MB Floppy disk drive; CD-ROM drive; and CD-ROM Writer.
(ii) Mustek A3 Scanner
(iii) Deskjet 840C A4 printer

Software Requirement

(i) AutoCAD Map R_2
(ii) ArcGIS
(iii) Window XP Operating System
(iv) QGIS
(v) ENVI
(vi) Google Earth

Data Acquisition

Data are needed for mapping analysis and modeling in a GIS and remotely sensed satellite data are familiar to GIS users. GIS involves both spatial and attribute data. Spatial data relate to the geometries of spatial features and attribute data describes the characteristics of the spatial features. The spatial resolution of a satellite image relates to the ground pixel size. In this study, the two data sets were synchronized so that they can be queried, analysed, and displayed in union.

The source of data for this study is satellite imagery from the Landsat program, specifically using the following satellites:

(i) Landsat 5 (Thematic Mapper): Operational from 1984 to 2013. This satellite provides valuable historical data for analyzing LULC changes over time.
(ii) Landsat 7 (Enhanced Thematic Mapper Plus): Launched in 1999, it offers improved spatial resolution and spectral bands for detailed land cover classification.
(iii) Landsat 8 (Operational Land Imager and Thermal Infrared Sensor): Launched in 2013, it provides enhanced data quality and additional spectral bands, which are crucial for distinguishing between different land cover types.

In addition to Landsat imagery, other satellite data sources would be utilized, such as:

(i) Sentinel-2: Part of the European Space Agency's Copernicus program, Sentinel-2 provides high-resolution optical imagery that can complement Landsat data, particularly for vegetation analysis.
(ii) MODIS (Moderate Resolution Imaging Spectro-radiometer): This satellite offers

daily global coverage and can be used for monitoring land cover changes and vegetation health over larger temporal scales.

Machine Learning Algorithms

To analyze the LULC data and its effects on food security, various machine learning algorithms were implemented including:

(i) **Random Forest:** This is a robust ensemble learning method that was used for land cover classification due to its ability to handle large datasets and provide high accuracy.

(ii) **Support Vector Machines (SVM):** This algorithm was employed for its effectiveness in high-dimensional spaces, making it suitable for distinguishing between different land cover types.

(iii) **Artificial Neural Networks (ANN):** This is a deep learning approach that captures complex relationships in the data, particularly useful for predicting future trends in land use and their implications for food security.

Data Pre-processing

Satellite imageries were digitally processed to produce a thematic data for the study. Each satellite imagery was scanned using Mustek A3 scanner. The scanned satellite imagery was then imported to Arc Map environment where it was geo-referenced and vectorised and exported to ArcGIS environment for further spatial analysis. A newly digitized map was then edited to remove digitizing and topological errors and geometric transformation to convert the digitized map into a projected coordinate system. To complete the digitizing process, a scanned file was vectorised in order to turn raster lines into vector lines in a process called tracing. A new data was digitized from satellite imagery, field survey and text files with x-, y-coordinates. Attribute data were entered into a GIS through digitizing and editing and stored as a collection of tables in a relational database management system.

Database Design and Creation

A database is a collection of interrelated tables in digital format. At least four types of database designs have been proposed in the literature: flat file, hierarchical, network and relational (Jackson, 1999). In this study, a flat file format which contains all data in a large table was used. This is the representation of the data structure in the format of the implementation software and was carried out at the commencement of database design and creation. The physical design was auto-generated by the software ArcGIS and is called theme attribute table.

Entering attribute data into a relational table is like digitizing a paper map. The process requires the setup of attributes to be entered, the choice of a digitizing method and the verification of attribute values. The first step taken in the attribute data entry is the definition of each field in the tables which includes field name, data width, data type and number of decimal digits. The field definition becomes a property of the field.

Spatial Analysis and Information Presentation

Geographic Information System (GIS) is uniquely distinguished from every other information system by reason of its spatial analytical capabilities. It integrates spatial and non-spatial data to answer generic questions relating to real world situations in which location is a critical factor.

There are varieties of spatial analytical operations carried out in this study ranging from spatial query operations whereby structured query languages (SQL) were issued to the computer for the purpose of retrieving particular set of spatial or attribute information that meets certain conditions/requirements and buffering analysis to show the extent of coverage area of the land. Therefore, the integration of Remote Sensing, GIS and machine learning has facilitated a comprehensive analysis of how land use changes impact agricultural productivity and food security in Malate.

LULC for the Year (2002, 2012, And 2022) Using Landsat Images.

The results show significant changes in land use of the community including growth in constructed areas, variations in grazing land, increased crop cultivation and changes in forest cover. Data reveals fluctuations in land coverage over the years with forests, cultivations, constructed areas and open range being the main categories studied. Research conducted with R programming underscores the impact of urbanization, agriculture and infrastructure on land use dynamics in Malete. Analysis indicates strong correlations between variables in 2002 and 2022.

A comprehensive analysis of a large data set over a period of twenty years was carried out in order to thoroughly investigate the intricate network of land use and land cover within the Malete community. The four main land use groups that were the subject of this extensive research were built-up areas, rangeland, crops, and trees. Finding the minute modifications and shifts that have taken place in the community's surroundings was the aim. Fig 1-3 visually represents the study results and serves as narratives that effectively illustrate how the spatial dynamics have changed during the years under consideration. These graphics, which illustrate how inhabited regions change in size and distribution, how rangelands are progressively farmed, how crops are gradually cultivated and how notable differences in tree cover occur, highlight the key results of the study. The visual representations of these figures give a clear and intuitive insight of the developing Malete community, going beyond simply data points.Together with the visual narrative, Table 1 offers a statistically arranged summary of the measured aerial extents and matching coverage percentages for every land use class in the three critical years of 2002, 2012, and 2022.

The integrated methods used in this study include the use of graphical representations to illustrate the extent of land usage, quantification of land usage, and finally, the distribution of questionnaires to obtain additional data about the study area from Malete residents. By exploring the study area using the outlined methods, this research has observed various factors contributing to changes in land use and land cover. These factors include urbanization, which involves converting farmlands and vegetative areas to different land uses; immigration, with individuals relocating to the Malete community in search of opportunities and institutional changes which also play a significant role in altering environments, as evidenced by the rapid changes in Malete from the establishment of KWASU until 2022.

These findings align with previous research by Suleiman *et al*. (2014), on land use dynamics in Ilorin Metropolis, although there are differences in timing and nature of growth. While Suleiman *et al*. (2014), reported more generalized changes in Ilorin over time, Malete's growth documented from 2002 to 2022 appears more organized and potentially faster. Unlike the broader impact observed in Ilorin, Malete's urbanization seems more focused.

Furthermore, this study delved deeper into Malete's land use and land cover changes by conducting questionnaire surveys. These surveys revealed that socioeconomic factors including the presence of hospitals, roads, educational facilities and other opportunities also influence land use and land cover changes in the Malete community. These findings echo the insights of Lambin*et al*. (2001) and Verburg*et al*. (2015), highlighting the intricate relationship between socioeconomic factors, land use policies, and demographic trends in shaping land use and land cover patterns. Understanding these context-specific factors is crucial for developing tailored strategies to address the diverse challenges and opportunities presented by urbanization and land use dynamics in different regions.

Table 1: Quantification of Land Coverage for 2022, 2012 and 2002

Name	Value	2022	2012	2002
Trees	2	500.6	1596.19	170.01
Crops	5	92.89	69.92	0.00
Built-Up	7	603.95	319.16	104.67
Open range	11	2121.69	1333.86	3045.24

It is worth mentioning that the use of Landsat 7 and Sentinel 2 data demonstrates a dedication to using sophisticated remote sensing technology to obtain precise and trustworthy information regarding Malete's land cover characteristics. The provided table presents land use and land cover data for three different categories—Trees, Crops, Built-Up areas, and Open range—for the years 2002, 2012 and 2022. The values in the table represent the area coverage in hectares for each category in the respective years.

In terms of tree coverage, there was a noticeable shift over the studied period. In 2002, the area covered by trees was relatively small, with only 170.01 hectares. However, by 2012, there was a significant increase, indicating a positive trend in tree cover expansion with the area reaching 1596.19 hectares. Surprisingly, by 2022, the area decreased to 500.6 hectares, suggesting a potential reversal or change in land management practices.

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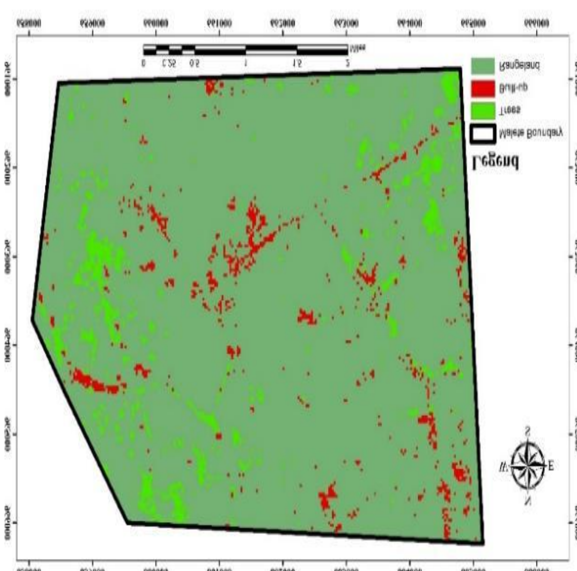
These results underscore the dynamic nature of land use and land cover changes over time. Similar studies assessing land use dynamics have been conducted globally, with findings often reflecting patterns of urbanization, agricultural expansion, and environmental changes. For instance, research by Smith *et al.* (2018) observed similar trends of urban expansion and deforestation leading to changes in land cover. Additionally, studies by Johnson and Brown (2016), highlighted the impact of agricultural expansion on land use patterns resembling the observed increase in crop area over time. Such research contributes to our understanding of land use dynamics and provides valuable insights for land management and policy formulation. This data is essential for making sound decisions about land use planning, environmental conservation, and community development.

Table 2: Reliability (Cronbach's Alpha) Reliability Statistics

Cronbach's Alpha value	No of Items
0.090	2

A Cronbach's alpha value of 0.90 is generally considered to be very good and suggests high internal consistency among the items in the scale. This means that the items in the scale are strongly related and the scale is likely to be reliable for measuring the construct of interest (Tavakol and Dennick, 2011). In the context of socioeconomic effects, a high Cronbach's alpha value could indicate that the items or indicators used to measure socioeconomic effects are consistently capturing the underlying construct. Therefore, a cronbach's alpha of 0.90 suggests that the scale is reliable in assessing the consistent impact of the intervention on various socioeconomic indicators.



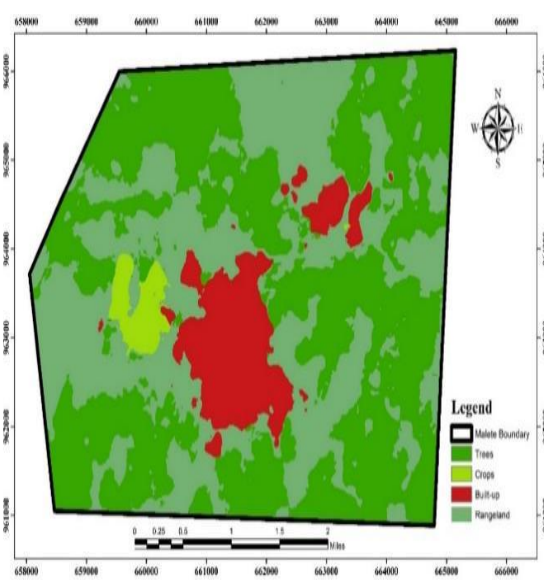


Figure 3a: ***LULC Malete, 2002*** **Figure 3b:** ***LULC Malete, 2012***

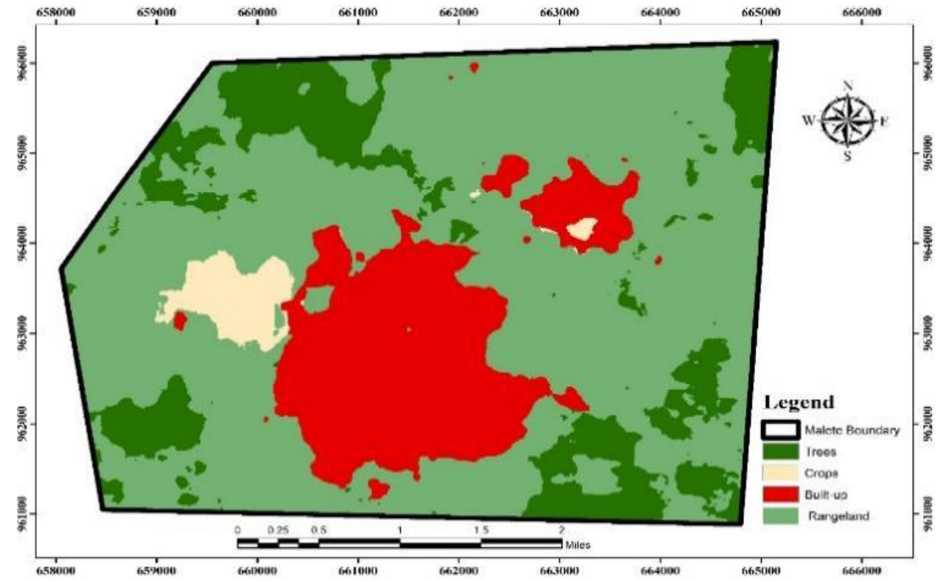


Figure 3c: ***LULC Malete 2022***

As part of the study's analysis of the distribution of land use and land cover, five alternative categories were found and analysed. Crops, rangeland, trees, built-up areas and the border are among the categories. Figures 3a-3c depict the researched period for 2002, 2012 and 2022 with a different colour code allocated to each class. Table 1 displays the percentages of coverage for each class as well as the aerial extents in hectares. This comprehensive study provides a visual representation of the geographical distribution and changes in land use and land cover across the studied time period. By giving particular colour codes (signatures) to each class, the distribution patterns become easier to recognize and analysed using the classification schemes in the following chapter.

Table 3: Classification Schemes

Code	Land use/Land cover categories
1	**Built-up land**
2	**Rangeland**
3	**Crops**
4	**Trees**

Correlation Analysis

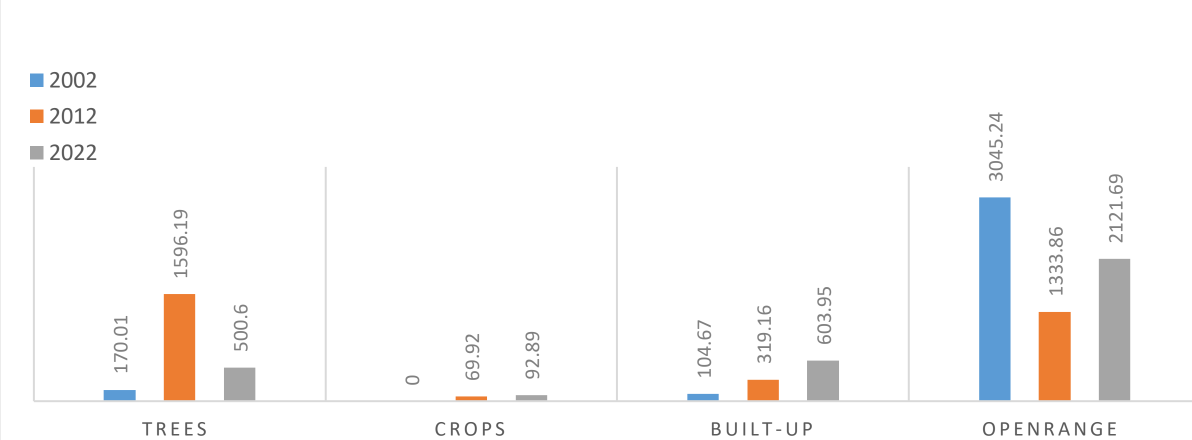


Fig.4: Graphical representation of changes across the years

Pearson's product moment of correlation analysis was conducted using the R programming language software R version 4.3.0 (2023-04-21) on data spanning the years 2002, 2012 and 2022 providing an in-depth exploration of the relationships between the variables under consideration. To examine the results for each pair of years and clarify the observed disparities in land use and land cover dynamics, year 2002 and 2012 shows a correlation value (r): 0.4856796 and P value: 0.5143, hence the correlation between the variables in 2002 and 2012 is moderate (r = 0.4856796) suggesting a discernible but not strong relationship. However, the p value of 0.5143 indicates that this correlation is not statistically significant at conventional significance levels (typically 0.05).

Therefore, any observed correlation might be due to random chance rather than a true relationship. Year 2002 and 2022 gives correlation value (r): 0.9774436, P value: **0.02256**, the correlation between the variables in 2002 and 2022 is notably high (r = 0.9774436), indicating a strong positive relationship. Moreover, the low p value of 0.02256 suggests that this correlation is statistically significant meaning it is unlikely to have occurred by chance. The data suggests a robust and meaningful association between the variables over the two time periods. This could however, due to the following reasons; The notably high correlation value (r = 0.9774436) and low p value (0.02256) observed between land use and land cover variables in the study area for the years 2002 and 2022 signify a statistically significant and robust positive relationship. The significance of this finding is underscored by several reasons, shedding light on the dynamics of land use and land cover activities in the study area over the two time periods.

The correlation analysis reveals varying degrees of association between the variables across the different years. While the relationship between the variables in 2002 and 2022 appears to be strong and statistically significant and statistically not significant for 2002 and 2012 as well as 2012 and 2022.

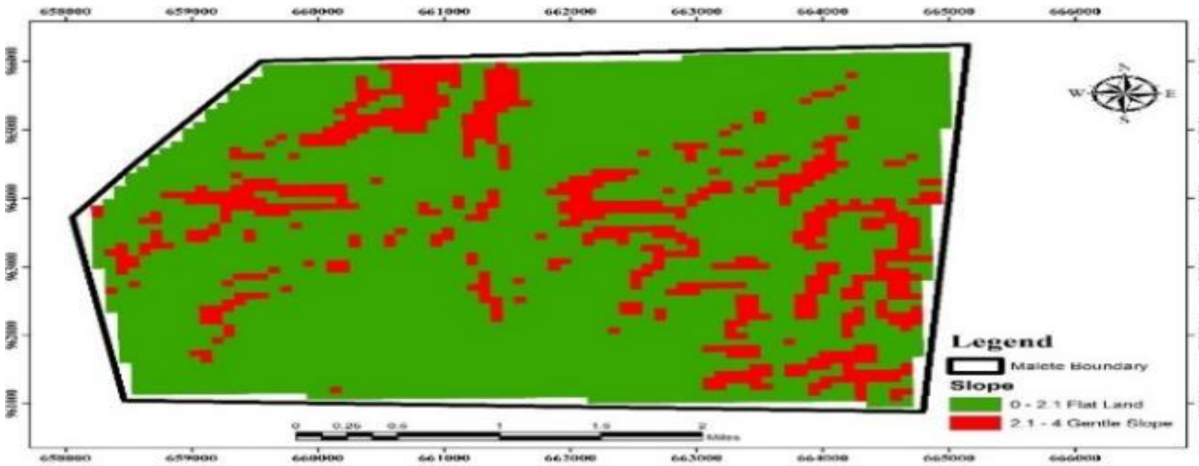


Figure 5: Slope analysis of Malete Community.

Slope

The research indicates that 2985.2 hectares or approximately 89.93% of the whole study area are categorized as flat terrain. Gently sloping areas make up the remaining 333.92 hectares or around 10.06% of the total area. Because it provides meaningful information on the geography of the study location, this categorization is helpful. The bulk of the land is classed as flat allowing for little height variations throughout the region for a range of land uses such as urban development, agriculture or infrastructure projects that don't need substantial slope considerations. Still, the rest of the research region, classified as having a mild slope, indicates a gradual change in elevation. Because of this, these domains are helpful for assessing soil erosion, modeling hydrological processes and choosing suitable building locations that could be influenced by slope constraints. For applications like development, land use and planning knowing that gentle slopes exist is extremely beneficial since it allows for the making of educated decisions on land management. Overall, the analysis of the slope resulted into valuable new insights into the landforms of the study region, which are typified by a residual section that slopes gently and a mainly level topography.

Conclusions/Recommendation

In conclusion, addressing the persistent challenges of LULC dynamics in Malete requires collaborative efforts from policymakers, researchers and local communities. Adopting interdisciplinary approaches, innovative solutions and inclusive governance mechanisms is essential for managing land resources sustainably. Through collaborative partnerships and adaptive management practices, stakeholders can navigate the complex landscape of LULC dynamics and pave the way for a more sustainable and resilient future in Malete. The findings underscore the importance of balanced development, conservation efforts, community engagement, and policy interventions to ensure a prosperous and sustainable future for the malete community.

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