

Web-Based GIS for Oil Palm Land Suitability Assessment Using MAUT in Mandailing Natal Regency

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ABSTRACT

Land suitability assessment plays a critical role in plantation development planning, particularly for oil palm cultivation, which requires specific environmental conditions for optimal growth. Mandailing Natal Regency, a region with significant agricultural potential, necessitates a scientific approach to identify suitable areas for oil palm development. This study aims to develop a web-based Geographic Information System (GIS) integrated with the Multi-Attribute Utility Theory (MAUT) method to evaluate and map land suitability. The analysis utilizes both spatial and attribute data based on six key criteria: soil texture, rainfall, drainage, land slope, temperature, and soil pH. Each criterion is weighted according to its relative importance, and the MAUT method is applied to compute the overall utility value for each sub-district. The results are then visualized through an interactive GIS platform developed using the CodeIgniter framework. The system classifies land into four suitability categories: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N). The findings indicate that a substantial portion of the study area falls within the suitable and highly suitable categories, demonstrating strong potential for oil palm cultivation. This study provides a robust, data-driven tool to support decision-making in sustainable plantation development and improve land-use efficiency in Mandailing Natal Regency.

INTRODUCTION

Geographic Information Systems (GIS) are technologies used to collect, manage, analyze, and visualize data related to locations on the Earth's surface. By integrating geographic and attribute data, GIS enables users to understand spatial patterns, relationships, and trends (Tang et al, 2020). The application of GIS is extensive, ranging from urban planning and natural resource management to environmental monitoring. GIS has the capability to link various types of data to specific geographic locations, integrate them, perform analyses, and ultimately present the results in the form of maps (Muthmainnah et al, 2023). The data processed in GIS are spatial data, which are geographically referenced and associated with specific coordinate systems as their basis. GIS applications can address various questions related to location, condition, trends, patterns, and modeling. With its ability to generate interactive maps and perform spatial analysis, GIS has become an essential tool for data-driven decision-making across multiple sectors, including government, business, and research (Mauliza et al, 2024).

Land suitability is a fundamental concept in land-use planning and natural resource management. It refers to the capacity of a particular area to support specific activities based on its physical, biological, and socio-economic characteristics (Nurkholis & Sitanggang, 2020). Land suitability assessment involves analyzing factors such as soil type, topography, climate, and water availability to determine whether a given land area is appropriate for particular uses, such as agriculture, settlement, or conservation. From an agricultural perspective, land suitability has a significant impact on crop productivity (Ndun et al, 2021).. Therefore, a better understanding of land suitability supports the development of sustainable and efficient agricultural strategies. As pressure on natural resources continues to increase, land suitability assessment becomes increasingly important for maintaining environmental sustainability and meeting global food demands. In addition, one of the essential land-use needs for human populations is housing and settlements, which are basic human necessities that must be fulfilled (Nisa et al, 2023).

To facilitate the selection of land suitability according to its classification level, a system is required. This system can be developed by utilizing Geographic Information System technology. Land suitability analysis in this study employs the Multi-Attribute Utility Theory (MAUT) method. This method is used to determine land suitability classes based on multiple parameters or criteria, such as air temperature, drainage, soil texture, and other relevant factors. Therefore, this study aims to: (1) develop an accurate land suitability map using a Geographic Information System; (2) implement a web-based application for determining land suitability; (3) apply the MAUT method to evaluate land suitability based on relevant criteria within the study area; and (4) analyze the spatial distribution of oil palm land suitability levels to optimize sustainable plantation development planning in Mandailing Natal Regency.



LITERATURE REVIEW

Geographic Information Systems (GIS) have become an essential technology for managing spatial data and supporting decision-making processes across various domains (Dewi, 2020). GIS integrates spatial and attribute data to enable the collection, storage, analysis, and visualization of geographically referenced information. Spatial data represent real-world objects with geographic coordinates and are typically derived from sources such as maps, satellite imagery, aerial photography, field surveys, and Global Positioning System (GPS) measurements (Savira et al, 2022) (Sudrajat, 2020). These data can be modeled in two primary forms, namely vector and raster formats. The vector model represents spatial features using points, lines, and polygons, while the raster model represents geographic phenomena in a grid-based structure where each cell (pixel) contains specific attribute information. The accuracy of raster data is highly dependent on spatial resolution. In contrast, attribute data provide descriptive information about spatial features, either in qualitative or quantitative forms, and are obtained from statistical records, field observations, or census data (Ahyarosidi & Susanti, 2024). The integration of spatial and attribute data enables GIS to analyze patterns, relationships, and trends, making it a powerful tool in fields such as environmental monitoring, urban planning, and resource management.

Land suitability is a fundamental concept in land-use planning and natural resource management, referring to the capacity of land to support specific uses based on its physical, biological, and socio-economic characteristics. Land is defined as a complex system that includes climate, topography, hydrology, soil conditions, vegetation, and the impacts of human activities. These factors collectively determine the potential and limitations of land for various purposes (Koesman et al, 2020). Land quality reflects the inherent characteristics of land that influence its suitability for particular uses and is typically assessed through measurable indicators such as soil properties, terrain conditions, and environmental factors [8]. Land suitability assessment can be classified into actual suitability, which reflects current conditions, and potential suitability, which considers possible improvements. Furthermore, land suitability classification is hierarchically structured into order, class, subclass, and unit levels. At the class level, land is generally categorized into highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N), depending on the degree of limitations affecting land use (Dewantara & Azis, 2021). This classification system provides a systematic framework for evaluating land resources and supporting sustainable land management.

In decision-making contexts involving multiple criteria, the Multi-Attribute Utility Theory (MAUT) has been widely adopted as an effective method for evaluating alternatives. MAUT facilitates decision-making by transforming various criteria into a unified utility scale, typically ranging from 0 to 1, allowing for direct comparison between alternatives (Yamin & Sumijan, 2024). The method involves several key steps, including identifying relevant criteria, assigning weights based on their importance, normalizing attribute values, and calculating the overall utility score for each alternative. The normalization process ensures that different measurement scales can be compared consistently, while the weighted aggregation produces an objective ranking of alternatives (Trisianti, 2024), (Dewantara, 2021). Due to its ability to incorporate both quantitative and qualitative factors, MAUT is particularly suitable for complex evaluations such as land suitability analysis, where multiple environmental and physical parameters must be considered simultaneously.

The integration of GIS and MAUT provides a robust framework for spatial decision support systems, particularly in land suitability assessment. GIS offers powerful capabilities for spatial data processing and visualization, while MAUT provides a systematic approach for multi-criteria evaluation. By combining these two approaches, it becomes possible to generate spatially explicit suitability maps that not only represent geographic distributions but also incorporate weighted decision criteria. This integration enhances the accuracy and effectiveness of land-use planning, enabling stakeholders to make informed, data-driven decisions. In the context of agricultural planning, particularly for oil palm cultivation, such an integrated approach is crucial for optimizing land utilization, improving productivity, and ensuring sustainability (Sakiah et al, 2021).

METHOD

This study employs a quantitative approach by utilizing the Multi-Attribute Utility Theory (MAUT) method integrated with a Geographic Information System (GIS) to determine land suitability for oil palm cultivation in Mandailing Natal Regency. The research process begins with the collection of both primary and secondary data, including land use maps, climate data, soil types, and topographic information. These datasets are subsequently processed and analyzed using GIS to visualize land potential spatially. The MAUT method is then applied to evaluate and compare multiple attributes influencing land suitability by assigning weights to each criterion based on their relative importance. The outcome of this analysis is a geographic land suitability map that identifies optimal areas for oil palm cultivation.

Data collection in this study is conducted through several techniques. First, observation is carried out by directly examining selected oil palm plantation areas in Mandailing Natal. Second, interviews are conducted with relevant stakeholders, particularly the secretary of the Land Agency, to obtain necessary data and insights. Third, a literature study is performed by reviewing scientific sources such as journal articles, books, and related publications to support the research framework and methodology.



The system development process begins with data collection, followed by system design based on the identified requirements. After the design phase, the system is developed and implemented. The next stage involves inputting data related to criteria, sub-criteria, and alternatives. The criteria considered in this study include temperature, rainfall, soil texture, drainage, soil pH, soil depth, slope gradient, and soil type, while the alternatives consist of sub-districts within Mandailing Natal Regency. The system then performs calculations using the MAUT method to determine land suitability classes, categorized as highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N) for each sub-district. The final output of the system is a GIS-based land suitability information platform for oil palm cultivation.

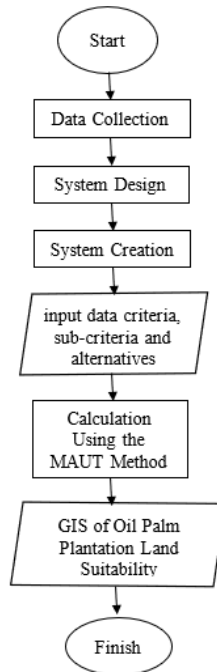


Figure 1. System Schema

Furthermore, the analysis phase is conducted to identify problems, constraints, and system requirements in determining land suitability. The system integrates spatial data (location-based information) and attribute data (such as soil pH, texture, rainfall, temperature, and others), which are processed using the MAUT method. The result is a web-based interactive land suitability map that facilitates users in making informed decisions regarding oil palm plantation development.

RESULT

Based on the results of the analysis conducted using the Multi-Attribute Utility Theory (MAUT) method, it can be concluded that the level of land suitability for oil palm cultivation in Mandailing Natal Regency is classified into four main categories. Areas with scores below 0.40 are categorized as marginally suitable. Scores ranging from 0.40 to 0.59 fall into the moderately suitable category. Values between 0.60 and 0.79 indicate that the land is suitable, while scores ≥ 0.80 represent land that is highly suitable for oil palm cultivation. Based on this classification, it can be observed that the majority of sub-districts in Mandailing Natal Regency fall within the suitable and highly suitable categories, indicating significant potential for increasing oil palm production through optimal land utilization, as follows:

Table 1. Decision Results Based on the MAUT Method

Rank	Subdistrict	MAUT Score	Percentage	Category
1	Panyabungan Utara	0.8517	85.17%	Highly Suitable
2	Panyabungan Selatan	0.8517	85.17%	Highly Suitable
3	Kotanopan	0.8133	81.33%	Highly Suitable
4	Tambangan	0.8133	81.33%	Highly Suitable
5	Panyabungan Timur	0.7892	78.92%	Suitable
6	Panyabungan	0.7817	78.17%	Suitable
7	Ranto Baek	0.7600	76.00%	Suitable
8	Siabu	0.7492	74.92%	Suitable
9	Panyabungan Barat	0.7417	74.17%	Suitable

10	Puncak Sorik Marapi	0.7217	72.17%	Suitable
11	Lembah Sorik Marapi	0.7108	71.08%	Suitable
12	Bukit Malintang	0.6975	69.75%	Suitable
13	Huta Bargot	0.6975	69.75%	Suitable
14	Naga Juang	0.6975	69.75%	Suitable
15	Muara Sipongi	0.6267	62.67%	Suitable
16	Batang Natal	0.6117	61.17%	Suitable
17	Ulu Pungkut	0.5825	58.25%	Marginally Suitable
18	Pakantan	0.5825	58.25%	Marginally Suitable
19	Lingga Bayu	0.5292	52.92%	Marginally Suitable
20	Natal	0.2025	20.25%	Not Suitable
21	Batahan	0.2025	20.25%	Not Suitable
22	Sinunukan	0.2025	20.25%	Not Suitable
23	Muara Batang Gadis	0.1325	13.25%	Not Suitable

The results of the calculations using the Multi-Attribute Utility Theory (MAUT) method for determining the classification of oil palm land suitability are subsequently visualized in the form of a Geographic Information System (GIS) using the geojson.io platform. This mapping aims to provide a spatial representation of land suitability levels in Mandailing Natal Regency, serving as a basis for decision-making in efforts to enhance oil palm production.

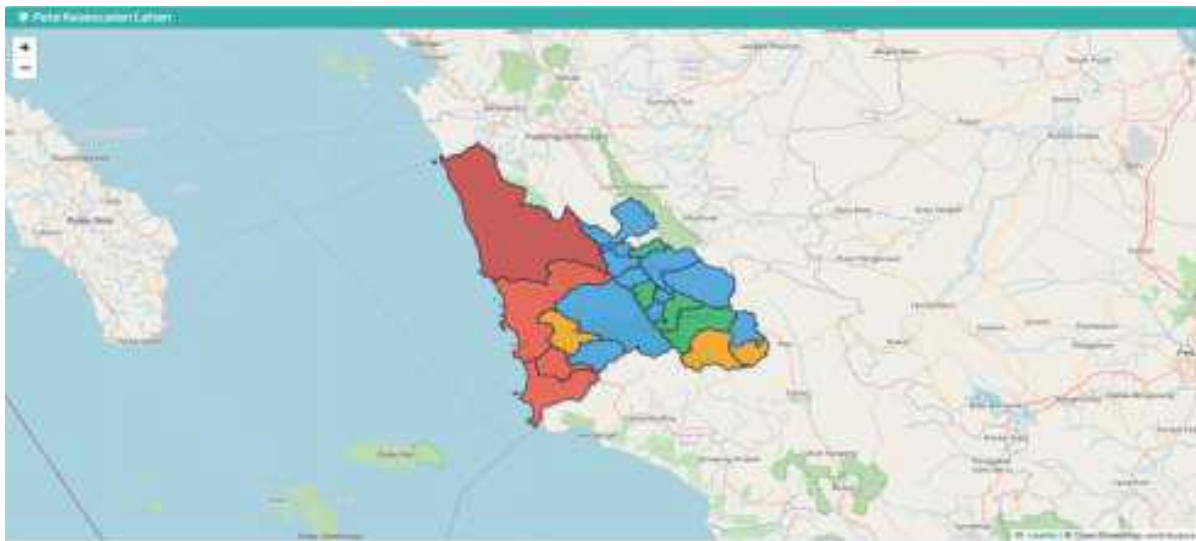


Figure 2. Land Suitability Map

After obtaining the results of the MAUT method calculations, the next step is system implementation. The implementation process begins with the design of the system interface, which serves as a medium for inputting, updating, and deleting the data to be managed. Once the interface design is completed, the system can be operated by users. The following presents the implementation of the Geographic Information System (GIS) for oil palm land suitability in Mandailing Natal Regency using the Multi-Attribute Utility Theory (MAUT) method.



Figure 3. Main Page of the Website

The main page represents the initial interface displayed when users access the system. This page provides general information about the application, along with navigation to the login page for both users and administrators to access the system features.

In addition, an administrative page is provided to serve as the system management interface.



Figure 4. Admin Dashboard Page

The admin page serves as the central control panel of the system, accessible only to users with administrative privileges. Through this interface, administrators can manage essential data, including criteria, sub-criteria, sub-district data (alternatives), MAUT evaluations, final results, and land suitability classifications. In addition, the page provides access to GIS-based mapping features for oil palm land suitability in Mandailing Natal Regency.

Furthermore, there is a user interface that begins with a login page, which serves as the initial access point for users to enter the system.



Figure 5. User Login Page

The user page is an interface provided for general users with limited access rights. Through this page, users can view information on the results of oil palm land suitability analysis, including GIS-based mapping, as well as access their respective user profile data.

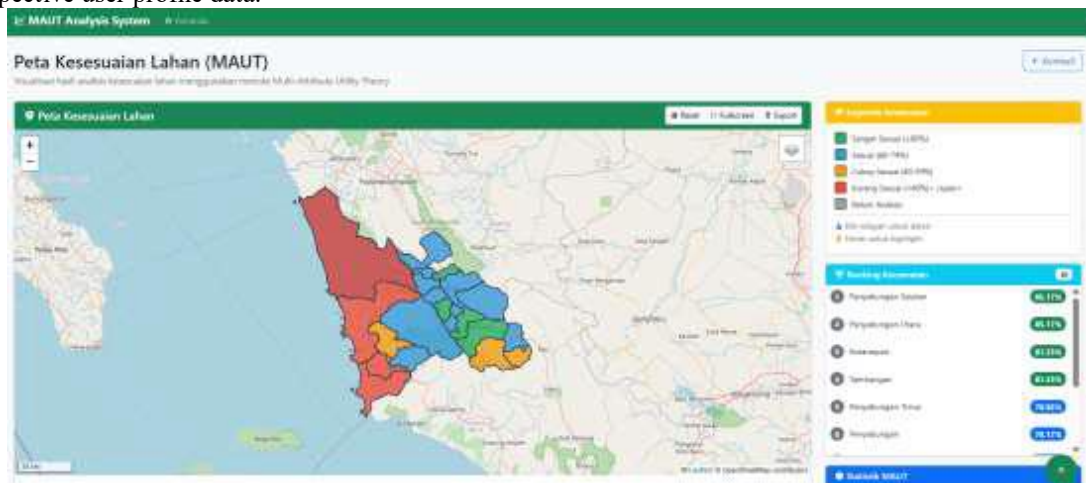


Figure 6. User Dashboard Page

DISCUSSION

The results of this study indicate that the integration of the Multi-Attribute Utility Theory (MAUT) method with a Geographic Information System (GIS) provides a reliable framework for assessing land suitability for oil palm cultivation. The classification outcomes show that a significant proportion of the study area falls into the suitable and highly suitable categories, which suggests that Mandailing Natal Regency possesses considerable potential for expanding oil palm plantations. This finding aligns with the environmental characteristics of the region, where key factors such as soil texture, rainfall, and topography generally meet the requirements for optimal oil palm growth.

From a methodological perspective, the application of MAUT enables a structured and quantitative evaluation of multiple criteria, allowing each factor to contribute proportionally based on its assigned weight. The normalization process ensures comparability across different parameters, resulting in an objective ranking of land suitability. When integrated with GIS, the analytical results are transformed into spatial visualizations, which significantly enhance interpretability. The interactive mapping output provides a practical advantage, as it allows stakeholders to easily identify priority areas for development and supports spatially informed decision-making.

The development of a web-based GIS platform further strengthens the applicability of this research. By providing an accessible interface for both administrators and general users, the system facilitates data management, analysis, and dissemination in a user-friendly manner. This indicates that the system is not only technically functional

but also practically implementable in real-world scenarios, particularly for regional planning and agricultural management.

However, several aspects require further consideration. The weighting of criteria in the MAUT method, although systematic, may still involve subjectivity depending on expert judgment. Additionally, the reliance on static datasets may limit the system's ability to reflect temporal environmental changes, such as climate variability or land-use dynamics. These factors could influence the accuracy and relevance of the suitability classification over time.

Overall, the results demonstrate that the proposed approach is effective in supporting land suitability analysis, yet there is room for improvement in terms of data integration, methodological refinement, and system scalability. Future enhancements could include incorporating dynamic data sources, applying advanced analytical techniques, and conducting comparative studies with other decision-making methods to further validate and strengthen the robustness of the findings.

CONCLUSION

Based on the results of this study, it can be concluded that the development of a spatial land suitability map for oil palm plantations using a Geographic Information System (GIS) has been successfully carried out, covering all 23 sub-districts in Mandailing Natal Regency. The generated map effectively represents the geographic distribution of potential land through interactive visualization utilizing GeoJSON and Leaflet JS technologies, classifying areas into four suitability categories: highly suitable, suitable, marginally suitable, and not suitable.

Furthermore, the Multi-Attribute Utility Theory (MAUT) method was effectively implemented to evaluate land suitability based on six key criteria, namely soil texture, rainfall, soil drainage, land slope, temperature, and soil pH, each assigned a specific weight according to its level of importance. The normalization of values into a 0–1 scale and the calculation of weighted scores produced an objective ranking of sub-districts, with Panyabungan Utara and Panyabungan Selatan achieving the highest scores, while Muara Batang Gadis recorded the lowest.

In addition, the integration of MAUT analysis into the GIS platform enabled the generation of comprehensive spatial visualizations, identifying a significant proportion of sub-districts within the highly suitable and suitable categories, thereby indicating strong potential for enhancing oil palm plantation productivity. This integration provides substantial support for data-driven decision-making in land-use planning.

Moreover, the development of a web-based system using the CodeIgniter framework and MySQL database has successfully combined land suitability analysis with geographic mapping into a single platform. The system is equipped with a user-friendly interface, complete data management features, an automated MAUT calculation mechanism, and interactive map visualization, making it accessible and practical for both administrators and general users.

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