GIS-Based Analysis of Land Suitability for Rice Production in Food Buffer Area of New Capital City Indonesia

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Abstract. Land suitability plays a crucial role in increasing food production including rice. This research aims to analyze land suitability for rice production using Geospatial and Geographic Information System (GIS) approaches. Five indicators presented in GIS raster maps, such as topography (land elevation), land slope, annual rainfall, flood hazard, and soil type were used for land suitability assessment and applied in the Paser Regency, East Kalimantan Province, Indonesia. Quantitative assessment using scoring was applied to classify the indicator values and categorize land suitability into four categories, namely highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N). The result indicated that the study area was covered by three zone categories of land suitability i.e., moderately suitable (8.49%), marginally suitable (77.9%), and not suitable (13.61%). The characteristics of land elevation, land slope and rainfall were relatively suitable for rice crop cultivation. Whereas the characteristics of the soil, which was peat and acidic, were constraining factors in cultivating rice crops. Flood disasters in areas with low slopes and elevations significantly threatened rice fields. This study provides a valuable reference for assisting decision-makers in planning optimal land use for rice production particularly under tropical climate.

1 Introduction

After the enactment of Law No. 3 of 2022 regarding the new capital city or Ibu Kota Negara (IKN) has become the center of attention at various levels, both in local and international media. Many ideas for infrastructure development and city layouts have emerged in efforts to build a new capital city that will become an icon of Indonesia in the future. However, development in IKN Nusantara is not only related to physical infrastructure. Beyond that, food security is very important to be prepared, considering that the population in IKN will increase significantly. Therefore, the need for food supply in terms of quantity and quality is essential to be prepared.

Paser Regency, geographically close to IKN, is a strategically important location for supplying food needs. The Regent and vice regent of Paser are determined to make this regency a rice and food granary, as well as prepare themselves to meet the increased food demand in the development of IKN with a focus on agricultural sector improvement. To anticipate the increased food demand, developing potential agricultural land in this area is crucial. One of the efforts being undertaken is to enhance the suitability of land for food crops by determining land capability specifications and suitability systems. The primary purpose of agricultural land suitability evaluation is to predict the potential and limiting factors for crop production [1, 2]. Land suitability criteria and land capability are determined based on land use requirements aligned with the quality data characteristics of the land in a region [3]. Land suitability for agricultural purposes must be considered based on the crops or commodities to be cultivated so that land allocation and agricultural planning can be optimal, ultimately contributing to the sustainable growth of the new capital city and the welfare of its residents. This study used GIS based spatial analysis to specifically identify land suitability for cultivating food crops, particularly rice in IKN.

2 Methodology

2.1 Study site

This study was conducted in Paser Regency, East Kalimantan Province, Indonesia, with a total area of approximately 11,603.94 km^2 (Figure 1). The study site is dominated by areas with low land elevation and slope, especially in the eastern and southern part. The average annual rainfall reaches more than 3000 mm, with soil type dominated by peat soil. The western and northern areas are still largely dominated by forests, while settlements and farmland or plantations dominate the eastern and the southern regions.

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 https://doi.org/10.1051/e3sconf/202346808004

Fig. 1. Map of the study site (Paser Regency)

2.2 Indicators of the study

This research was conducted using overlay techniques in ArcGIS 10.8. The analysis involves the use of the "Union" feature within the ArcMap to combine information from two or more different spatial data layers. Subsequently, this data is scored or assessed using a tool known as the "Field Calculator," available within the attribute table. Each indicator, such as topography (land elevation), land slope, annual rainfall, soil type, and flood risk, was assessed in four different categories such as highly suitable (score=5), moderately suitable (score=3), marginally suitable (score=1), or not suitable (score=0), with the category of each indicator determined based on standard and reference values from various sources. The map attribute table shows all relevant information regarding raster maps (indicators). The total score is the sum of all indicator scores [4].

2.2.1 Land elevation and slope

For land elevation and slope, data (maps) were obtained from the Indonesian Topographic Map issued by the geospatial information agency of Indonesia. Topography was categorized into four categories based on the elevation of the land. Four categories were proposed for this indicator, namely highly suitable (score = 5) for elevations of 0-1500 meters above sea level (masl), moderately suitable (score = 3) for elevations of 1500-2000 masl, marginally suitable (score = 1) for elevations of 2000-3000 masl, and not suitable (score = 0) for elevations >3000 masl.

Land slope was classified and categorized into four classes as well, namely highly suitable (score = 5), moderately suitable (score = 3), marginally suitable (score = 1), and not suitable (score = 1) for areas with land slope classes of 0-15%, 15-30%, 30-45%, and >45%, respectively. The slope of the land can affect land management and soil erosion control. Too much slope can make it difficult to cultivate rice and increase the risk of soil erosion. Map of land elevation and slope are presented in Figure 2.

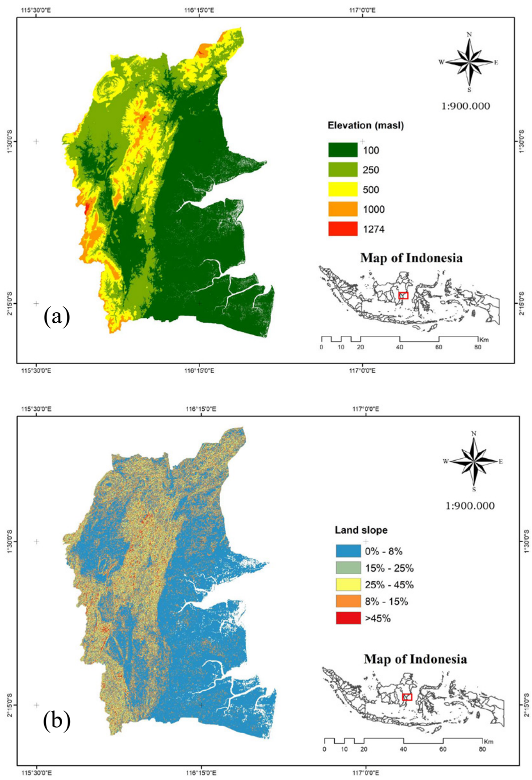

Fig. 2. Elevation (a) and land slope (b) maps of the study site

2.2.2 Annual rainfall and soil type

The categories and scores for annual rainfall values are determined based on the water requirements for evapotranspiration and refer to Technical Guidelines for Land Evaluation for Agricultural Commodities in Indonesia. Four categories are proposed for this indicator: highly suitable (score = 5) for annual rainfall between 1,500-2,000 mm, moderately suitable (score = 3) for annual rainfall between 1,000-1,500 mm or 2,000-2,500 mm, marginally suitable (score = 1) for annual rainfall between 500-1,000 mm or 2,500-3,000 mm, and not suitable (score = 0) for annual rainfall between 0-500 mm or >3,000 mm. Rainfall data was obtained from the GPM (Global Precipitation Measurement) satellite validated with ground data from rainfall stations in the study site. Rainfall is one of the crucial factors because rice is a crop that requires a large amount of water for its growth.

The soil type map is divided into three categories of soil types commonly found in Paser Regency. The categories used in this research are moderately suitable and marginally suitable. For soil types such as acrisols and histosols & fluvisols, nitisols, and cambisols (Figure 3b), they fall under the moderately suitable category (score = 3), and arenosols fall under the marginally suitable category (score = 1). The type of soil has a significant influence on the suitability of land for rice cultivation. Soils with good clay texture can retain water effectively, making them ideal for rice plants that require consistent moisture. Additionally, good drainage is essential to prevent waterlogging, which can harm rice crops. Sufficient soil depth allows rice plant roots to grow well and reach deeper water sources. The quality of groundwater, not overly saline, and near-neutral soil pH are also important factors. Collectively, these factors play a crucial role in determining whether a piece of land is suitable for rice farming or requires improvements to become suitable. Map of rainfall and soil type are presented in Figure 3.

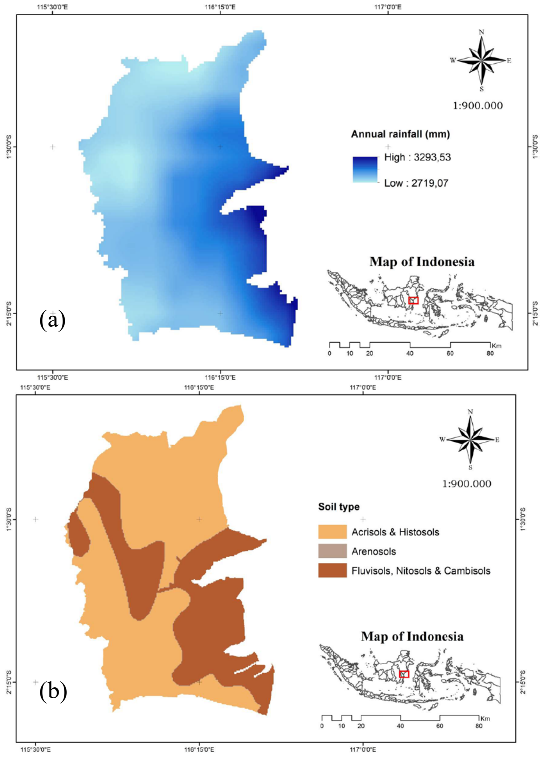

Fig. 3. Annual rainfall (a) and soil type (b) maps of the study site

The range of values for categories and scores on land elevation, land slope, rainfall and soil type indicators are determined by referring to the Technical Guidelines for Land Evaluation for Agricultural Commodities, Center for Agricultural Land Resources Research and Development of Indonesia [5].

2.2.3 Flood hazards

Information about flood hazards enables better planning for drainage and irrigation systems. By knowing flood-prone areas, water management systems can be designed to address the potential for flooding and minimize the risk of damaging waterlogging. Floods can have negative environmental impacts, including soil erosion, water pollution, and damage to aquatic ecosystems. Understanding flood hazards helps in planning appropriate environmental protection measures. There are three proposed categories for this indicator such as highly suitable (score = 5) for low risk, moderately suitable (score = 3) for moderate risk, and marginally suitable (score = 1) for high risk as shown in Figure 4.

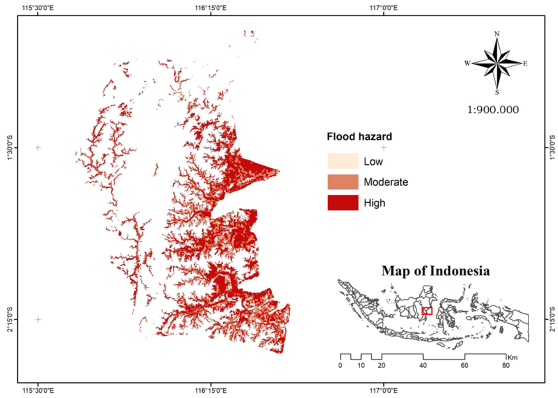

Fig. 4. Flood hazard map of the study site

2.3 Criteria for land suitability

The current status of land suitability level is determined based on the total score of indicators as described in Table 1. Five categories were proposed and used to describe the current status of land suitability level for rice (osativa). Using more categories for classifying land suitability condition status provides more specific information about the status and issues related to land specifications and capabilities.

Table 1. Land suitability level based on the total score of indicators

Total score of indicators	Land suitability level
21-25	Highly suitable (S1)
16-20	Moderately suitable (S2)
11-15	Marginally suitable (S3)
0-10	Not suitable (N)

3 Result and Discussions

The overlay method using the "Union" feature in ArcMap of ArcGIS 10.8 combines information from two or more different spatial data layers. It assesses or calculates data using a tool known as the "Field Calculator," available in the attribute table. The results of spatial modeling for the suitability assessment of Oryza sativa land in a Geographic Information System (GIS) are presented in Figure 5. There are three types of land suitability classes (areas) at the study site (moderately suitable, marginally suitable, and unsuitable) with the highest and lowest values being nineteen (moderately suitable category) and zero (unsuitable category).

The moderately suitable class indicates that the land has limiting factors, and these limiting factors will affect its productivity, requiring additional inputs. These limitations are typically manageable by the farmers themselves. The marginally suitable class indicates that the land has severe limiting factors, which will significantly impact its productivity, requiring more inputs compared to moderately suitable land. Overcoming these limitations in this class requires a high capital investment, necessitating government or private sector assistance or intervention. Without such assistance, farmers may not be able to overcome them. The unsuitable class indicates that the land is problematic due to very severe and difficult-to-address limiting factors [5].

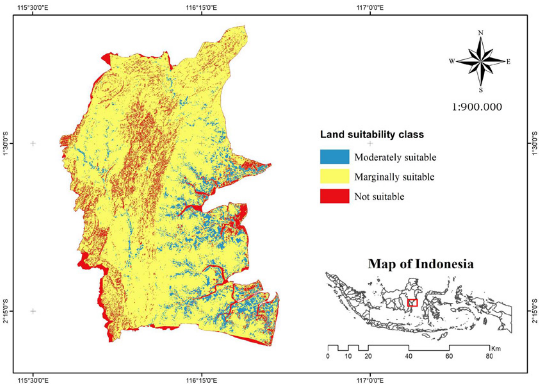

Fig. 5. Land suitability class for rice production in the study site (Paser Regency)

The optimal land suitability for rice crops sets the boundary for the most suitable land class, which is "highly suitable," while land quality below the optimum falls within the land suitability classes of "moderately suitable" and/or "marginally suitable" [6]. Beyond that, it categorizes land that is physically unsuitable as "not suitable" The results of spatial land suitability modeling show that the area of land moderately suitable for rice cultivation is 915.3 km² (8.49%), the area marginally suitable for rice cultivation is 8394.33 km² (77.9%), and the unsuitable land area is 1466.98 km² (13.61%). The land suitability areas in each district can be seen in Table 2.

Table 2. Land Suitability for Oryza sativa in Paser Regency

No.	Suitability	Area (km^2)	%
1	Moderately suitable	915.3	8.49
2	Marginally suitable	8394.33	77.9
3	Not suitable	1466.98	13.61

Land with naturally low soil quality can be improved to higher-quality land through the use of technology [7]. This process often involves the application of various methods such as fertilization, irrigation, and pest control. However, it is important to remember that not all soil qualities or characteristics can be improved with the technology currently available. There are situations where land may have structural issues that are difficult to address without very high levels of processing. In some cases, extensive land restoration efforts may be necessary to restore its quality to a better level. Therefore, a deep understanding of land conditions and the level of improvement required is crucial in the sustainable management of land resources.

The use of GIS allows for faster land suitability assessments by considering spatial aspects. GIS-based modeling has been proven capable of providing analytical results to support decision making in various scientific fields including agriculture. GIS-based modeling is easy to apply in various climatic conditions [8,9,10]

4 Conclusion

In this study, it was found that there are three main categories in the land suitability level within the research area. First, there is the "moderately suitable" class (8.49%), indicating that the land has limiting factors, and these limiting factors will affect its productivity, requiring additional inputs. Second, there is the "marginally suitable" class (77.9%), which describes its suitability level as having severe limiting factors that will significantly impact its productivity, necessitating more inputs compared to moderately suitable land. Finally, there is the "not suitable" class (13.61%), indicating that the land is not suitable or even unsuitable due to challenging limiting factors that are difficult to overcome.

The results of this research provide crucial insights into land use planning and regional development in that area. Information regarding land suitability can assist farmers and other stakeholders in making more informed decisions on how to allocate their resources and optimize rice farming outcomes. Furthermore, an understanding of land suitability levels can stimulate further discussions and actions to enhance sustainable and efficient land utilization in the region. Thus, spatial modeling in GIS not only facilitates a better understanding of land conditions but also provides a solid foundation for sustainable decision-making in land and natural resource management.

Acknowledgments

We would like to express our sincere gratitude to the Directorate of Research Universitas Gadjah Mada for their generous financial support through Research Grant Number 5075/UN1.P.II/Dit-Lit/PT.01.01/2023. This funding played a crucial role in the successful execution of our research.

References

1. G. Pan, J. Pan, *Comp. and Comp. Tech. in Agric.* **V,** 369, (2012).
2. M. Utomo, B. Rusman, T. Sabrina, J. Lumbanraja, Wawan (Jakarta, Prenadamedia Group, 2016).
3. I. M. H. Wijaya, L. B. Prasetyo, O. Rusdiana, jpsl, **5**, 2 (2015).
4. C. Setyawan, S. Susanto, and C. Lee, *IOP Conf. Ser.: Earth Environ. Sci.* **355,** (2019).
5. D. Djaenudin, H. Marwan, H. Subagjo, A. Hidayat (Center for Agricultural Land Resources Research and Development, 2011).
6. F. F. Muhsoni and E. Murniyanto, *Agrovigor*, **7**, 1, (2014).
7. F. R. Fauzi, S. H. Abdullah, A. Priyati, *JRPB* **6**, 2 (2018).
8. C. Setyawan, C.Y. Lee, M. Prawitasari, Nat. Hazard **98** (2019).
9. A. Prasetyo, C. Setyawan, Ngadisih, R. Tirtalistyani, IOP Conf. Series: Earth and Enviro. Sci. **653** (2021)
10. A.N. Seika, C. Setyawan C, Ngadisih, R. Tirtalistyani, IOP Conf. Series: Earth and Env. Sci. **686** (2021).