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Integration of geographical information systems in the land suitability assessment for rice crops in Sleman District, Indonesia

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ABSTRACT

Land suitability assessment is a crucial step in sustainable agricultural planning, especially in areas with dynamic land use change such as Sleman District, Indonesia. The study aimed to use geographic information system (GIS) and multicriteria evaluation (MCE) to assess land suitability for rice cultivation based on biophysical and environmental parameters, including soil type, topography, climate, and hydrology. The results showed that 73.39% (42,150.82 ha) of the land was classified as moderately suitable (S2), spread across the sub-districts of Gamping, Depok, Ngaglik, Prambanan, Kalasan, Sleman, Cangkringan, Pakem, and Turi. Highly suitable land (S1) covered 18.50% (10,624.97 ha) in the sub-districts of Minggir, Moyudan, Godean, Berbah, Ngemplak, Tempel, Mlati, and Seyegan. Marginal land (S3) covered 8.01% (4,598.34 ha), requiring intensive management, while 0.10% (59.72 ha) was unsuitable (N) due to limiting factors such as extreme topography and disaster risk. More than 90% of the land classified as suitable to highly suitable, these results confirm Sleman's great potential for organic rice development. Land management strategies should optimise S1 land and increase S2 productivity through sustainable agricultural practices, while further studies are needed to rehabilitate S3 land. The integration of GIS in land suitability analysis provides a decision support tool for policymakers and farmers, enabling more effective land management, increasing rice productivity, and reducing environmental degradation. The results of this study contribute to sustainable agricultural planning in Sleman, ensuring food security and land use efficiency.

Keywords: geographic information systems, land potential, land suitability, regional planning, rice plants

INTRODUCTION

The goal of regional growth and development in Indonesia is to provide life and welfare for the community (Widiatmaka et al., 2014). The participation of diverse sectors, such as services, manufacturing, and agriculture, in achieving these goals is critical (Makhamreh, 2019). Agriculture is one of Indonesia's most important industries, and it includes plantation commodities (coffee, tea, rubber, tobacco, cocoa, palm oil), food crop commodities (rice, corn, tubers), and horticulture commodities (fruit) (Albaji & Alboshokeh, 2017). The rising demand for land, as well as the decrease of fertile and prospective agricultural land, as well as rivalry for land use between the agricultural and non-agricultural sectors, need the adoption of appropriate technologies to maximize land usage in a sustainable way (Wondimu & Ayansa, 2022). To be able to use land resources in a targeted and efficient manner, full data and information about climatic conditions, soil and other physical environmental factors, as well as the growth requirements of the plants being farmed, must be available (Dharumarajan et al., 2022).

Land use identification is vital for determining if human activity on land is following its potential or carrying capacity, and it may also be used to determine how much land use has changed (Li et al., 2017a). Integration of remote sensing technology is a potential method of viewing land usage reasonably precisely without doing surveys at every current place, however it can only use samples from remote sensing findings (Romadhona et al., 2020). As a result, it may generate data on the distribution of land usage (Singha & Swain, 2016).

A rice field's production is affected by management patterns such as fertilization, land cultivation, irrigation systems, and the return of organic material, in addition to the fertility quality of the soil. Aside from that, variables in system diversity, soil type, and terrain or altitude all have an impact on soil quality (Rasheed & Naz, 2017). Land evaluation is the process of appraising the potential of land for numerous alternative purposes while taking physical, socioeconomic, and environmental issues into account for long-term usage (Sappe et al., 2022). The purpose of this study is to assess land for lowland rice (*Oryza sativa* L.). The agricultural industry in Sleman District is a strategic sector that plays a key role in the regional economy and community survival, particularly in terms of its contribution to the Regional Revenue and Expenditure Budget, job creation, and food provision (Romadhona et al., 2024). As a result, in Sleman District, the notion of spatial planning corresponds to the growth center model, which prioritizes services for the agricultural product processing industry (Abdullah et al., 2020).

This research contributes to the development of a Geographic Information System (GIS) integration approach in evaluating land suitability for rice. Previous studies have shown the importance of GIS in mapping land potential based on physical and climatic parameters, but studies focusing on specific land suitability for rice in the Sleman District are limited. This approach becomes relevant given the dynamics of land use due to urbanization and climate change in the tropics. This study introduces a more in-depth GIS-based spatial analysis to identify significant variations between regions, filling the knowledge gap on optimal land potential in Sleman. The findings serve as a scientific foundation for sustainable and efficient land use planning, supporting Indonesia's food security and sustainable development targets. The objective of this research was to used Geographic Information System (GIS) and multicriteria evaluation (MCE) to assess land suitability for rice cultivation based on biophysical and environmental parameters, including soil type, topography, climate, and hydrology.

MATERIALS AND METHODS

Characteristics of the Research Location

Sleman District was an area with a variety of climate, soil, and physiographic features. The diversity of features of the land could influence plant growth and development, and consequently plant yield. Plants grown in proper climatic and land circumstances could produce optimally, but plants grown in unsuitable climatic and land conditions have a negative influence on output. Land evaluation in a specific region was important in the context of restructuring existing land use, as well as aiding in making land use planning decisions, in overcoming rivalry between several viable land uses, and in maximizing land use efficiency (Figure 1).

Land suitability evaluation was required in overall research as a basis for land allocation in land use change models. Land quality and features were matched with land use needs utilizing a limiting factor method, which identifies land elements that harm a certain type of land use (Priyadharshini et al., 2019). Land suitability refers to land potential based on compatibility for certain agricultural applications such as rice. Land suitability was determined by comparing the features and quality of the land to the land use criteria for a certain plant (Akpoti et al., 2019). The existence of inhibitory variables and the amount of these inhibiting elements define the land suitability value. The more restricting elements there were, the less suitable the land became. Aside from considering the appropriateness of the site, information on the viability, whether economic, social, or financial, of land use was also required.

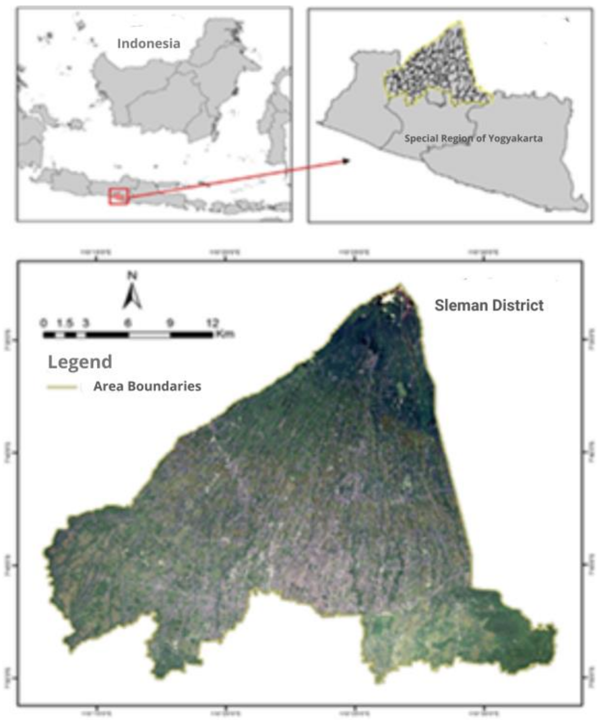

Figure 1. Research location

Land evaluation was carried out by comparing land quality to land suitability criteria and evaluating qualitative land suitability (Nasution et al., 2019). This research was carried out in numerous stages, including research preparation, pre-survey, data collecting, field observations, soil sampling, soil analysis in the laboratory, and data analysis. (1) The matching method, which compares land characteristics as parameters measured in the field and laboratory with land suitability class criteria prepared based on plant growth requirements to determine minimum limiting factors based on guidelines (Bozdağ et al., 2016) (Table 1). (2) The overlay method was used by assigning balanced scores and weights to climate and soil characteristics using the extension model builder, so that the land suitability class of the area suitable for food crop development could be determined and interpreted into the soil fertility level criteria for the land suitability class could be determined (Yalew et al., 2016). The land method of evaluation was defined by comparing land features with the growth requirements for rice (*Oryza sativa* L) as specified in the technical instructions for agricultural commodity land evaluation. Leibig's minimal law was utilized in the matching process to discover limiting parameters that will affect classes and subclasses.

Analysis Method Used in This Study

Climate, physical-chemical, and environmental factors of the land were matched to the needs for cultivating lowland rice, therefore, the emphasis was on the level of suitability. S1 (very suitable) land had light restrictions and required no additional input, S2 (quite suitable) land had moderate restrictions and requires moderate additional input, S3 (marginally suitable) land had heavy restrictions and requires more input than S2, and class N (unsuitable) had very severe limiting factors that were difficult to overcome. Providing a balanced score between climatic and soil qualities was done with the idea that these two factors have the same impact on land suitability for excellent food crops. To obtain an overall score for the observation parameters, climate characteristics such as air temperature and rainfall were given a score of 50, while soil characteristics such as drainage, texture, coarse material, effective depth, CEC, pH, C-Organic, slope, and surface rock were given a score of 50. Weighting was done based on land characteristics' suitability to the criterion for land suitability for food crops, with a weight value of 4 for S1 suitability, 3 for S2 suitability, 2 for S3 suitability, and 1 for N suitability.

Providing a balanced score between climate and soil characteristics was carried out with the assumption that these characteristics have the same influence on the availability of land for superior food crops. Climate characteristics were given a score of 50 which includes air temperature and rainfall, while soil characteristics were given a score of 50 which includes drainage, texture, coarse material, effective depth, CEC, pH, C-Organic, slope and surface rock to obtain an overall score for the observation parameters was 100. Weighting was carried out based on the suitability of land characteristics to the criteria for land suitability for food crops with a weight value of 4 for S1 suitability, weight of 3 for S2 suitability, weight of 2 for S3 suitability and weight of 1 for N suitability (Table 2).

Table 1. Laboratory analysis methods

Unit Analysis	Unit	Method
Soil Texture	%	Pipette
Cation Exchange Capacity (CEC)	cmol kg-1	NH4-Ac 1 M, pH 7+ NaCl 10%; Titrimetry
Base Saturation (KB)	%	
pH (H2O)	-	Electrode Glass 1:1
C - Organic	%	Walkley & Black
Nitrogen - total	%	Kjeldahl; Titrimetry
P2O5	ppm	Olsen: Spectrophotometer
Kdd	cmol kg-1	NH4-Ac 1 M, pH 7; AAS

Source: (Mugiyo et al., 2021)

Table 2. Criteria for land suitability for rice crops

Landuse Requirements/Characteristics	Land Suitability Class			
	S1	S2	S3	N
Temperature (tc)				
Average temperature (°C)	24–29	22–24 29–32	18–22 32–35	< 18–> 35
Water availability (wa)				
Rainfall (mm)	1.000–2.000	500–1.000–2.000–3.000	250–500–3.000–4.000	< 250 > 4.000
Humidity (%)	> 42	36–42	30–36	< 30
Oxygen availability (oa)				
Drainage	Obstructed	Obstructed	Highly obstructed	Clear
Rooting medium (rc)				
Texture	Fine -Moderately fine	Medium	Moderately coarse	Coarse
Coarse material (%)	< 3	3–15	15–35	> 35
Soil depth (cm)	> 50	40–15	25–40	< 25
Nutrient Retention (nr)				
Clay CEC (cmol)	> 16	≤ 16		
Base saturation (%)	> 50	35–50	< 20	
pH H2O	5.5–8.2	4.5–5.5 8.2–8.5	< 4.5 > 8.5	
C-organic (%)	> 1.5	0.8–1.5	< 0.8	
Toxicity (xc)				
Salinity (dS/m)	< 2	2–4	4–6	> 6
Sodicity (xn)				
Alkalinity/ESP (%)	< 20	20–30	30–40	> 40
Sulfic Hazard (xs)				
Sulfide depth (cm)	> 100	75–100	40–75	< 40
Erosion Danger (eh)				
Slope (%)	< 3	3–5	5–8	> 8
Erosion Danger	Very low	Low Currently	Heavy	Very heavy
Flood danger (fh)				
Puddle	F0			> F0

Source: (Sofyan et al., 2007)

To create a suitability map for each parameter, primary and secondary data were evaluated. Soil data was used to generate soil texture and c-organic suitability maps. The rainfall map was used to generate a rainfall suitability map as well as a dry month suitability map. DEM data was used to generate height and slope suitability maps. A temperature suitability map was created using temperature data. After that, all suitability maps were overlaid, integrated, or added up based on the weight of each class, and the results were classed based on the land suitability criteria, namely S1, S2, S3, and N. Land suitability analysis was used, which was based on land suitability classifications and was studied using ArcGIS software. Based on each criterion, the land suitability map was converted into a Geographical Indication table. The land suitability of a location must be known at the class level as well as the main limiting factors, so appropriate plans for the implementation of appropriate land use must be made by paying attention to and making efforts to improve the main limiting factors in businesses that could be carried out with both resource and financial capabilities (Pimenta et al., 2021).

RESULTS

Land Suitability Analysis for Rice Cultivation in Sleman District Based on Various Indicators

Because of the diversity of land and natural resources, the potential and limiting factors for agricultural commodities change from place to region. As an archipelagic country surrounded by oceans, Indonesia had an impact on the temperature and weather in diverse places. Climate and weather have essential roles in the creation of soil, water, growth, and plant production (Neswati et al., 2021). As a result, Indonesia had distinct biophysical conditions between its areas. This was what fosters the creation of outstanding agricultural goods in each location, Sleman District being one of the

The ability of soil to give nutrients and water to plants was influenced by soil type. Some soils may be more fertile and capable of supporting plant growth than others. This will directly affect agricultural land production (Paul et al., 2020). The ability of soil to store water and manage drainage was influenced by soil type. Drought danger could be reduced by soil that stores water well, while soil with efficient drainage could avoid severe waterlogging (Li et al., 2017b). The actual land suitability was determined by analyzing and observing the quality and features of land for rice plants in each land unit, as shown in Table 3. The actual land suitability was land suitability that was derived using existing data and did not take assumptions or improvement efforts into consideration as well as the current level of management.

The results of the land suitability class assessment in the region were as followed: on the grumusol soil type with a coverage area of 7037.18 Ha or a percentage of 12.25%, on the cambisol soil type with an area coverage area of 7097.34% or a percentage of 12.35%, and finally on the latosol soil type with an area coverage area of 4174.93 Ha or a percentage of 7.26%. The last one, namely the regosol soil type, had the greatest area coverage, with the regosol land type accounting for 39,124.37 Ha or 68.12% of the Sleman District area.

Temperature was a critical physical component in agriculture because it influences plant growth and development (Montgomery et al., 2016). Plants have temperature ranges that were ideal for photosynthesis, respiration, and other biochemical activities. Plants could maximize their water and nutrient utilization when the temperature was just perfect. Temperature had an impact on microbial activity in the soil as well. Bacteria and fungi in the soil control nutrient cycles and break down organic matter. Higher temperatures could stimulate microbial activity, accelerating the mineralization of organic materials and making nutrients more accessible to plants (Abdelrahman et al., 2016). The assessment of land suitability in Sleman District based on temperature criteria resulted in criteria S1 (highly suitable), precisely in the temperature suitability class 24-29 with an area coverage area of 9544.46 Ha or a percentage of 16.62%. Furthermore, the suitability class value with the majority of regions was at a temperature of 29-32 with an area of 31,0489 Ha, or 54.06%. Under these conditions, it matched the S2 land suitability class criterion (very good), with an area of 1132.31 Ha or a percentage of 1.97%. Furthermore, the conditions for class S3 (according to marginal) were a temperature of 18 - 22 degeess and an area coverage of 394.67 ha or 0.69%. Following that, it joined the S3 criterion (according to marginal) with an area coverage of 12629.30 Ha and a percentage of 21.09% in the same criteria class. The last one was with criterion class N (very unfavorable), particularly at a temperature >35 and an area of 2684.11 or 4.67% (Figure 2).

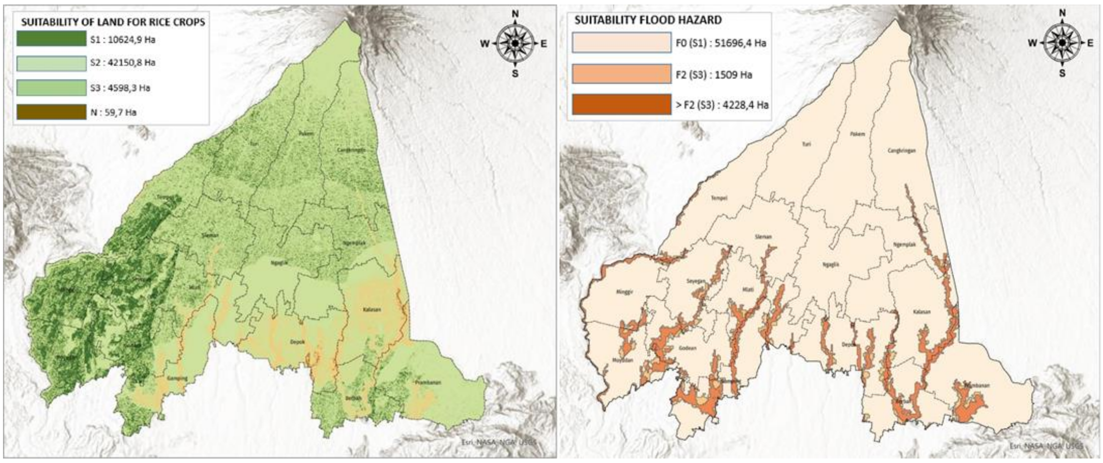

Figure 2. Land suitability map based on soil type and temperature

Table 3. Land suitability based on soil type, temperature, landslide danger, rainfall, flood danger and land suitability analysis for rice crops in Sleman District

Soil Type	Coverage Area (Ha)	Percentage (%)
Grumusol	7037.18	12.25
Kambisol	7097.34	12.35
Latosol	4174.93	7.26
Regosol	39124.37	68.12
Temperature	Coverage Area (Ha)	Percentage (%)
18 – 22 (S3)	394.67	0.69
22 – 24 (S2)	1132.31	1.97
24 – 29 (S1)	9544.46	16.62
29 – 32 (S2)	31049.00	54.06
32 – 35 (S3)	12629.30	21.99
>35 (N)	2684.11	4.67
Landslide	Coverage Area (Ha)	Percentage (%)
<3	8690.7	15.1
3 – 5	10865.6	18.9
5 – 8	14424.8	25.1
> 8	23452.8	40.8
Rainfall	Coverage Area (Ha)	Percentage (%)
>1500 mm/year	45954.90	80.01
< 800 – 200 mm/year	1423.57	2.48
1200 – 1500 mm/year	10055.40	17.51
Flood Hazard	Coverage Area (Ha)	Percentage (%)
F0	51696.40	90.01
F2	1509.07	2.62
>F2	4228.40	7.36
Suitability	Coverage Area (Ha)	Percentage (%)
N	59.72	0.10
S1	10624.97	18.50
S2	42150.82	73.39
S3	4598.34	8.01

Source: Data Processing

Landslides may significantly erode soil. Landslides carry away dirt, reducing the rich soil layer, damaging the texture and structure of the soil, and removing critical nutrients for plants. This had the potential to significantly impair agricultural land production (Mugiyo et al., 2021). Landslides have the potential to erode the top layer of soil, which was rich in nutrients. This limits fertilizer availability for plants and could lead to a drop in land production. The land suitability results based on landslide hazard were dominated by a value of >8 with suitability class N (very unsuitable), with an area coverage of 23452.80 Ha or 40.8%. Furthermore, grades 5–8 met the criteria for land suitability class S3 (marginal suitability) with an area coverage of 14424.8 Ha or 25.1%. Furthermore, grades 3–5 were included in the land suitability class S2 (very suitable) with a total area of 10865.6 Ha or 18.9%. Finally, the S1 (highly suitable) land suitability factor was 3 with an area coverage of 8690.7 Ha or a percentage of 15.1%. Because rainfall had acidic properties, it could influence soil pH. Because soil pH regulates nutrient availability and plant growth, physical and chemical explanations for the effect of rainfall on soil pH were critical. Soil pH changes may necessitate remedial intervention, such as liming (Figure 3).

In the results of land suitability based on rainfall, most of the research area, namely Sleman District, had rainfall >1500 mm/yr. This condition was included in suitability class S1 (very suitable) with an area of 45954.90 Ha, or a percentage reaching 80.01%. Next, what was also dominant was the rainfall class < 800 - 200 mm/yr in the land suitability class S2 (quite suitable) with an area coverage of 10055.40 or a percentage of 17.51%. Lastly, with rainfall of 1200 - 1500 mm/year, it was in suitability class S3 (marginal suitability) with an area of 1423.57 Ha or a percentage of 2.48%. The results of the flood hazard land suitability class assessment in the flood hazard class F0 with an area of 51696.40 Ha or with an area percentage of 90% fell into the land suitability criteria S1 (very suitable). Furthermore, the flood hazard class F2 with an area of 1509.07 Ha or with a percentage of 2.62% falls into the land suitability class S3 (marginal suitability) (Table 4). Furthermore, the flood hazard class >F2 with an area of 4228.4 Ha or with a percentage of 7.36% in this area fell into suitability class N (not suitable) (Figure 4). Floods frequently move organic soil layers containing organic materials, such as humus. This organic layer was critical for enhancing soil fertility, and its depletion could limit the soil's capacity to support plants (Bilas et al., 2022). Floods could take nutrients from the soil by dissolving them in water. This could impair plant development and production by reducing the availability of vital nutrients. Based on all of the characteristics employed, an overall suitability evaluation was achieved in the last step of the land suitability assessment findings. The results revealed that the land area coverage in the S1 class (very suitable) was 10624.97 Ha, or 18.5%. Furthermore, the area coverage in suitability class S2 (very suitable) was 42,150.82 Ha, or 73.39%. In the case where the suitability class S2 was the most dominant in the research region, the suitability class S3 (marginal suitability) came in second with a covering area of 4598.34 Ha or an 8.01% percentage. Finally, land suitability class N (very unsuitable) with an area of 59.72 Ha or 0.10%.

Poor soil drainage also causes the soil to become anaerobic because all the soil pores were filled with water. This causes The soil become acidic so plants cannot grow grow well or even die. Another impact was that soil organisms cannot carry out the decomposition of organic materials due to lack of oxygen. The slope was important factor influencing soil loss and nutrients. Soil loss rate, nitrogen total, and total phosphate in the soil will increase along with increasing slope gradient. Soil depth was related to plant growth, especially in the roots. Generally, plant roots could grow with good on soil with deep soil in (Kadam et al., 2021). This was due to depth which in the plant roots will be more free to grow rather than in soil at a greater depth shallow. The boundary layer on the soil could be rock or soil that had a high density tall. This high soil density could caused by strong pressure from above and the high clay fraction in the soil (Karimi et al., 2018).

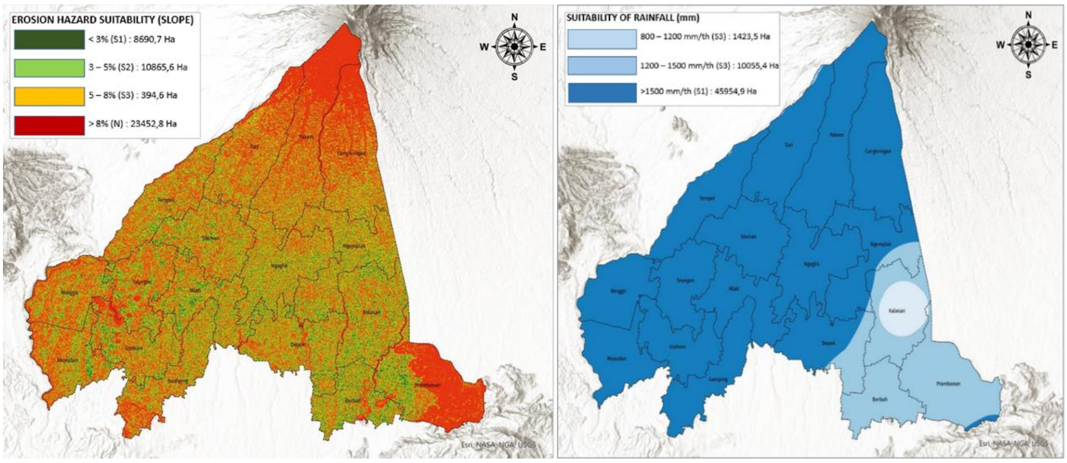

Figure 3. Land suitability map based on landslide hazard and rainfall

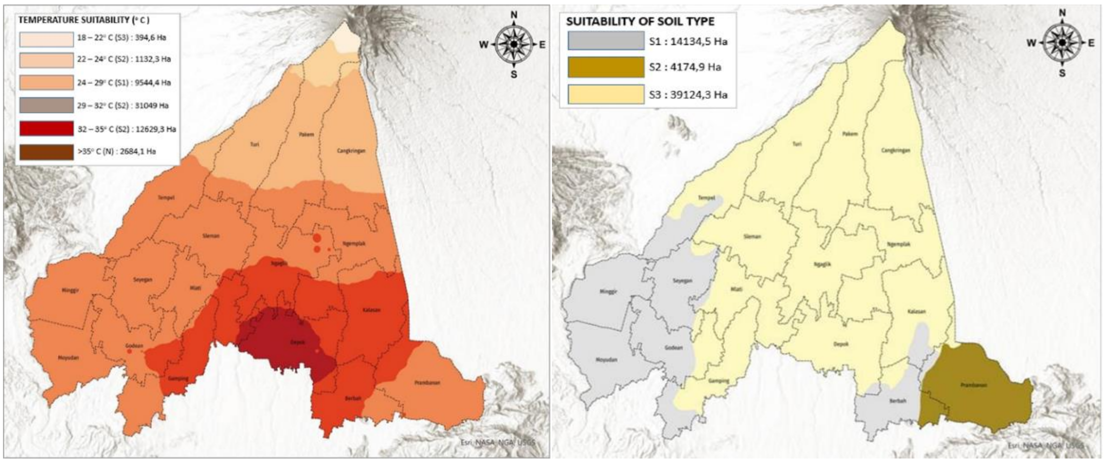

Figure 4. Land suitability map based on flood hazard and land suitability results

Table 4. Results of assessing data on the suitability of paddy fields

Land Units	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Temperature (tc)								
Average annual temperature	22.8	20	23.8	22.3	19	21.8	21	20.8
water availability (wa)								
Rainfall (mm year-1)	2141	2141	2141	2141	2141	2141	2141	2141
Humidity (%)	75	75	75	75	75	75	75	75
Rooting Media (rc)								
Drainage	Good	Hindered	Hindered	Hindered	Good	Good	Hindered	fast
Texture	Coarse	Moderate	Moderate	Medium	Coarse	Medium	fine	Coarse
Soil depth	113	123	118	116	121	120	132	115
Nutrient retention (nr)								
KTK soil	26.11	12.78	23.88	16.92	16.4	17.16	19.78	24.88
pH	7.48	5.63	6.28	6.20	5.71	6.48	6.63	6.68
C-organic	1.02	1.55	0.91	1.58	0.62	1.02	1.55	1.6
Base Saturation	23.17	24.01	29.53	28.17	24.47	27.42	29.65	15.67
Toxicity (xc)								
Salinity (Ds/m)	2	2	1	2	1	2	3	2
Sulphidic Hazard (cm)								
Sulfide Depth (cm)	110	114	120	125	121	128	140	135
Sodicity (xn)								
Alkalinity/esp (%)	35	30	28	35	22	20	24	32
Nutrient availability (na)								
N-total	0.07	0.08	0.10	0.8	0.06	0.14	0.07	0.08
K2O available	0.66	0.77	0.90	0.32	0.94	0.90	0.65	0.90
P2O5 available	2.30	2.55	2.16	3.65	2.62	1.82	1.54	2.40
Erosion Hazard (eh)	Low risk	Medium risk	Low risk	Medium risk	Low risk	Low risk	Medium risk	Medium risk
slope (%)	6	3	2	6	7	9	8	3

Source: Data Processing 2023

Efforts Made to Improve Limiting Factors From Actual to Potential

Land suitability evaluation yields land suitability classifications as well as limiting variables that reduce soil fertility. Temperature (tc), water availability (wa), oxygen availability (oa), rooting media (rc), nutrient availability (nr), and erosion hazard (eh) were all limiting variables. There were two sorts of limiting factors: (1) limiting elements that were permanent or uneconomical to repair, such as temperature, rainfall, dry period duration, and humidity; and (2) limiting factors that were temporary or uneconomical to repair. This was according to popular belief (Table 5).

One of the most significant limiting considerations was the risk of erosion. This situation increases the risk of erosion, which could occur on agricultural land. The state of slopes on agricultural land was an essential element that must be addressed by local communities (Mulyani et al., 2023). To lessen the risk of erosion, treatment could be carried out utilizing land conservation measures designed particularly for sloping ground. Rainfall was one of the limiting elements because excessive rainfall promotes nutrient leaching, making fertilizer application less efficient (Asmarhansyah et al., 2017). The rooting media condition in the research area, as indicated by the soil drainage class with the criteria distribution being good and fairly fast and the soil texture class being medium and somewhat rough, indicates that the research area was still suitable for use as agricultural cultivation land. Actual land suitability concerning the limiting element in water availability, namely rainfall. Rainfall cannot be improved on the potential land suitability class and other factors that could be improved were the rooting media, namely drainage and nutrient retention (Deka & Rashmi, 2015).

The findings of the assessment of land suitability classes for rice plants were classified as S2 and S3, with limiting criteria such as water availability (wa), erosion hazard (eh), rooting media (rc), and nutrient retention (nr). Soil texture (rc1) was a permanent limiting factor for root media that cannot be corrected, however drainage (rc2) was a limiting element that could still be addressed. Efforts were made to address each limiting element to raise the land suitability class from S3 (marginally suitable) to S2 (very suitable) and then to S1 (highly suitable). The relative ratio of sand, silt, and clay fractions in a soil mass was defined as soil texture. Based on the findings of the soil study, it was determined that the soil texture on each land unit was clay. The clay content of each unit of land increases as the depth of the soil increases. The distribution of soil textures could be included in the highly suitable class (S1) to be prominent in the research area for the criterion for land suitability for rice crops (Table 6 & Table 7).

Table 5. Land suitability and improvement efforts

Land Unit	Land Suitability		
	Actual	Potential	Limiting Factors
LU 1	S2rcnrxcxneh	S2rc	Texture, Soil CEC, alkalinity, erosion hazard
LU 2	S2tcrcnrxcxneh	S2tc	Temperature, Texture, Soil CEC, Alkalinity, Erosion hazard
LU 3	S2rcnrxcxn	S1	Drainage, C-Organic, toxicity, alkalinity
LU 4	S2rcnrxn	S1	Soil CEC Drainage, sodicity
LU 5	S2rcnrxneh	S2rc	Texture, C-Organics, alkalinity, erosion hazard
LU 6	S3nr	S2	Land CEC
LU 7	S3nreh	S1	Soil CEC, Erosion Danger
LU 8	S3nrxneh	S1	C-Organic, alkalinity, Erosion Hazard
LU 9	S3rcnreh	S2rc	Texture, C-Organic, Erosion hazard
LU 10	S3rcnrxneh	S2rc	Drainage, Soil CEC, Alkalinity, Erosion Danger
LU 11	S3tcnr	S2tc	Temperature, C-Organic,
LU 12	S3tcrcxneh	S2tcrc	Temperature, texture, alkalinity, erosion hazard

Note: temperature (tc), water availability (wa), oxygen availability (oa), rooting media (rc), nutrient availability (nr), alkalinity (xn), erosion hazard (eh)
Source: Data Processing 2023

Table 6. Land suitability and improvement efforts

Land Unit	Land Suitability		Improvement Efforts
	Actual	Potential	
LU 1	S2rcnrxcxneh	S2rc	Addition of organic material, reclamation, and planting parallel to the contour
LU 2	S2tcrcnrxcxneh	S2tc	Addition of organic material, reclamation, and planting parallel to the contour
LU 3	S2rcnrxcxn	S1	Improvements to the drainage system, such as creating drainage channels
LU 4	S2rcnrxn	S1	Improvement of drainage systems, liming or adding organic materials, reclamation
LU 5	S2rcnrxneh	S2rc	Addition of organic material, reclamation, and planting parallel to the contour
LU 6	S3nr	S2	Liming or adding organic materials
LU 7	S3nreh	S1	Addition of organic material, planting parallel to the contour
LU 8	S3nrxneh	S1	Liming or adding organic materials, reclamation, and planting efforts parallel to contours
LU 9	S3rcnreh	S2rc	Liming or adding organic material, Efforts to reduce the rate of erosion, making terraces, planting parallel to contours, Reclamation
LU 10	S3rcnrxneh	S2rc	Improvements to the drainage system, such as creating drainage channels, adding organic material
LU 11	S3tcnrn	S2tc	Liming or adding organic materials, Fertilization
LU 12	S3tcrcxneh	S2tcrc	Reclamation, efforts to reduce the rate of erosion

Note: temperature (tc), water availability (wa), oxygen availability (oa), rooting media (rc), nutrient availability (nr), alkalinity (xn), erosion hazard (eh)

Table 7. Land area in actual and potential conditions

Actual Condition	Potential Condition	Land Area (Ha)
N	-	9786.67
S1	-	4030.61
S2rcnrxcxneh	S2rc	623.36
S2tcrcnrxcxneh	S2tc	2.29
S2rcnrxcxn	S1	6.54
S2rcnrxn	S1	134.19
S2rcnrxneh	S2rc	233.66
S3nr	S2	13.23
S3nreh	S1	28.464.86
S3nrxneh	S1	442.46
S3rcnreh	S2rc	686.67
S3rcnrxneh	S2rc	11315.07
S3tcnr	S2tc	713.15
S3tcrcxneh	S1	407.69

Source: Data processing results

CEC could improve the soil's ability to offer accessible nutrients for plant development. As a result, this procedure will improve tobacco plant yield. CEC was a soil chemical characteristic that was directly linked to soil fertility. Soil with a high CEC could absorb and supply nutrients effectively. To keep the soil's cation balance, the soil's low CEC must be enhanced. Low CEC values suggest a poor ability of the soil to exchange and retain cations. Soil CEC, pH, and soil C-organic levels suggest that nutrient retention conditions in the research region were in the low to high range. The pH levels in the research region were appropriate for agricultural land. C-organic levels in the research region were quite high. Thus, it was required to improve soil CEC levels to raise soil CEC levels in the research area (Figure 5).

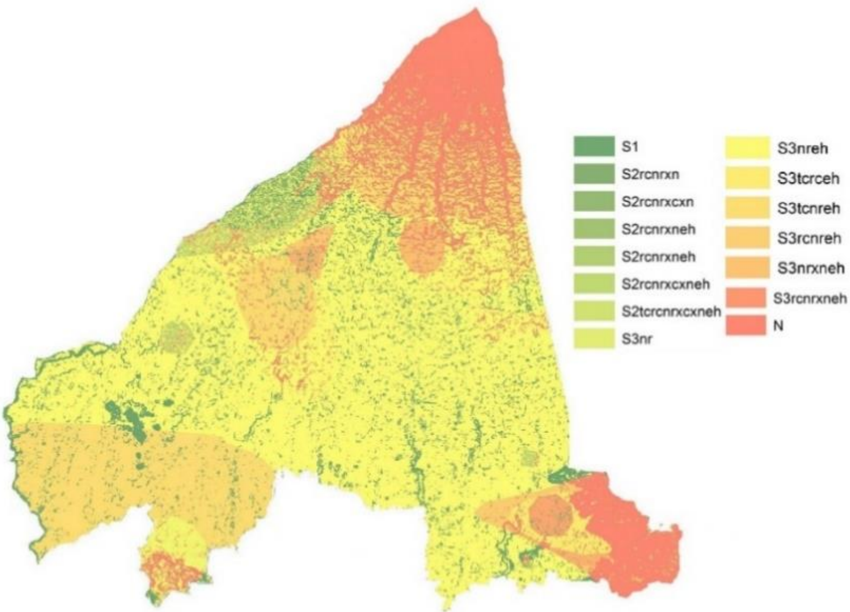

Figure 5. Map of land suitability and limiting factors

Land Suitability Analysis Under Actual and Potential Conditions

The greater the CEC content in the soil, the higher the soil fertility. Zeolite and biochar were soil additives that could raise soil CEC levels. This was consistent with the statement of (Sumani et al., 2018), who stated that land limiting factors were of two types: (1) permanent limiting factors that were difficult to repair if it was to be opened for agricultural business, such as temperature, soil texture, and altitude, and (2) limiting factors that could be improved, such as land fertility, toxic Al elements, and soil acidity. Aside from temperature, the major limiting element in the rooting medium was soil texture, because soil texture does not change quickly, for example, sand was difficult to convert to clay or clay was difficult to change to sand. Furthermore, organic matter in the soil serves to improve the physical properties of the soil (the soil structure was more crumbly, facilitating the development of plant roots and increasing the capacity to hold water and nutrients), the chemical and physical-chemical properties of the soil (as a source of nutrient N, increasing soil CEC or capacity to hold and release nutrients), and the soil microbiology.

The actual and potential circumstances attained S1 (highly suitable) with an area of 4030.61 Ha when the findings were calculated. Furthermore, under condition S2 (very suitable), with numerous limiting parameters such as temperature (tc), texture (rc), soil CEC (nr1), alkalinity (xn), erosion hazard (eh), and organic C (nr4), land had quite substantial constraints for sustainable usage. With an area of 1000.36 Ha, barriers affected production and increased intake under this circumstance. Furthermore, the land conditions in the research area were in suitability class S3 (marginal suitability), with several limiting factors, including temperature (tc), drainage (rc1), texture (rc), soil CEC (nr1), alkalinity (xn), hazard erosion (eh), and C-organic (nr4). The characteristics of this area showed that the land had very heavy restrictions to maintain the level of management, which must be carried out immediately because the limiting factors will reduce productivity and profits. In this state, with a land size of 13614 Ha and a land suitability value of N (not suitable), the condition of this land had more significant limits that could be solved, but it did not allow for sustainable usage. In the state of this land with a land size of 9786.67 Ha, barriers cannot be fixed with regular management and capital.

DISCUSSION

The evaluation of land suitability provides valuable insights into the potential and constraints of agricultural land use. This process not only classifies the land based on its suitability for various crops but also identifies limiting variables that affect soil fertility. The primary limiting factors identified in this study include temperature (tc), water availability (wa), oxygen availability (oa), rooting media (rc), nutrient availability (nr), and erosion hazard (eh) (Mulyani et al., 2023).

These limiting factors can be broadly categorized into two types: permanent or uneconomical to repair, and temporary or feasible to address. Persistent constraints, including temperature, precipitation levels, dry spell duration, and humidity, present substantial challenges due to their intrinsic connection to the region's climate and environmental characteristics. These factors are beyond human control and directly influence agricultural productivity, ecosystem stability, and overall land suitability (Sappe et al., 2022).

Their variability and extremity can exacerbate vulnerabilities, making it essential to develop adaptive strategies that mitigate their impact on sustainable land use and resource management (Li et al., 2017b). These factors are often beyond human control or require substantial resources to mitigate, making them impractical to address on a large scale. In some cases, efforts to overcome these limiting factors require complex technological interventions, such as large-scale irrigation systems, microclimate modifications, or the use of crop varieties that are more tolerant to extreme conditions. However, the implementation of these strategies often requires significant financial investment, adequate infrastructure, and sustained policy support (Wondimu & Ayansa, 2022).

Floods frequently transport organic soil layers, including essential organic materials such as humus, which play a vital role in enhancing soil fertility. The depletion of this organic layer can severely limit the soil's capacity to support plant growth (Bilas et al., 2022). Additionally, floods can dissolve nutrients from the soil, reducing the availability of vital elements necessary for plant development and production. This nutrient loss can impair plant growth, leading to decreased crop yields.

Poor soil drainage is another critical factor affecting soil health, as it causes anaerobic conditions due to water-filled soil pores. These anaerobic conditions lead to increased soil acidity, adversely affecting plant growth and potentially causing plant death. Moreover, the lack of oxygen inhibits soil organisms from decomposing organic materials, further deteriorating soil quality (Sumani et al., 2018).

The slope gradient significantly influences soil erosion and nutrient loss. As the slope gradient increases, the rate of soil loss, total nitrogen, and total phosphate in the soil also rise. This increased erosion and nutrient runoff can lead to substantial declines in soil fertility, further challenging agricultural productivity (Makhamreh, 2019). In conclusion, the findings highlight the importance of managing flood impacts, improving soil drainage, and addressing slope-related soil erosion to enhance land suitability and agricultural productivity. Implementing appropriate land management practices can mitigate these adverse effects, ensuring sustainable agricultural development in the region.

CONCLUSSION

The suitability evaluation based on all of the characteristics employed revealed that the land area coverage was 10624.97 Ha, or 18.5%, in the S1 class (highly suitable). Furthermore, the area coverage in suitability class S2 (quite suitable) was 42,150.82 Ha or 73.39%. The S2 appropriateness class dominates the research field under this scenario. The S3 suitability class (marginal suitability) comes next, with a covered area of 4598.34 Ha and a percentage of 8.01%. Finally, land suitability class N (very unsuitable) with an area of 59.72 Ha or 0.10%.

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