RESEARCH PAPER

ASSESSMENT OF LAND POTENTIAL FOR FOOD CROP DEVELOPMENT IN THE KARST LANDSCAPE OF GUNUNGSEWU HILLS, INDONESIA

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ABSTRACT. Gunungkidul region in Indonesia, though considered arid and agriculturally limited, has shown notable productivity in food crops, especially upland rice, cassava, groundnut, and maize cultivation. Main challenges of agricultural development in this region are limited accessibility to land due to its hilly and steep topography, as well as water scarcity. Accurate land-use planning tools are needed to allocate land resources to support regional agricultural activity. Therefore, a systematic assessment of land potential for food crop agriculture is needed using geoinformation techniques to enable well-planned development. This study segmented research area into doline units as mapping units. Accessibility, soil, and water factors were employed in evaluating land potential classes. The Analytical Hierarchy Process (AHP) method was used to determine the weights of parameters and parameter classes scores for each factor. Potential of dolines for food crop agriculture in Gunungkidul was assessed using 10 parameters including distance from road, distance from settlements, area of doline's valley, rasio of valley's area and doline's area, soil depth, soil texture, pH, Soil Organic Matter (SOM), Cation Exchange Capacity (CEC), and uppermost rock. Among these parameters, distance from roads (weight: 0.26), distance from settlements (weight: 0.20), and doline valley area (weight: 0.14) were identified as the most significant accessibility factors. Results indicated that 52% of the karst and karstic areas of Gunungkidul, characterized by arid hills, have potential for food crop agriculture development. This study provides valuable insights for policymakers and stakeholders aiming to promote sustainable agricultural systems in karst landscapes more broadly in arid regions.

KEYWORDS: agriculture, doline, food crop, karst, Gunungsewu hills

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INTRODUCTION

Food is the most essential basic need for human survival. Food security refers to the state where food is consistently available, easily accessible, safe for consumption, and affordable (Ahmad et al. 2021). Population growth is directly proportional to the increasing demand for food. Contrarily, food production is highly dependent on natural conditions and the availability of agricultural land. Certain food commodities can only be produced under specific natural conditions. This condition makes critical lands like Gunungkidul prone to food crises due to the limited range of agricultural commodities grown for household food production.

Small farmers make up about 70% of Gunungkidul's population. Most farmers face numerous challenges due to dry lands from its karst topography. Water shortages and bad soil quality make it hard for traditional farming to thrive, which slows down the area's economic growth (Antriyandarti et al. 2022). Dependence on food crops makes households highly vulnerable to fluctuations in agricultural yields, which can lead to food insecurity (Christanti et al. 2023). This condition also contributes to structural poverty in Gunungkidul.

Dolines are distinctive geomorphological features in karst landscapes that regulate the movement and distribution of water and air, shaping local conditions such as soil moisture, depth, temperature, and humidity. Their structure enables water accumulation, storage, and efficient drainage, which supports vegetation growth and helps reduce flood risks (Damayanti et al., 2025). Ecologically, dolines function as important microhabitats and refuges, promoting biodiversity, vegetation development, and organic carbon absorption (Valjavec et al., 2022). Typically, the land at the bottom of dolines (doline valleys) holds potential for agricultural development due to relatively thicker soil layers. Much organic matter builds up at the bottom of dolines, which makes the soil very healthy. Optimal utilization of doline valleys for agriculture can increase land productivity in karst areas, which are generally less fertile.

Assessing land potential in doline valleys is urged for optimal agricultural production. Doline valleys are sediment and organic material accumulation zones transported by erosion, creating thicker soils with better fertility than slopes or other karst plains. However, the hilly topography makes them difficult to access. The diverse dimensions of doline valley in Gunungsewu Karst form varying valley sizes, which must be considered in the assessment. Evaluating the land potential for agriculture facilitates the achievement of sustainable agriculture (Vaghela et al. 2018).

Assessing doline valley's potential for agricultural development involves integrating various criteria, which can be effectively achieved through Multi-Criteria Decision-Making (MCDM) techniques. MCDM aims to predict land potential for various applications, including agriculture. In the land potential assessment process using MCDM techniques, the AHP is adopted to estimate and assign weights in the MCDM process. AHP addresses complex decision-making processes involving various criteria, scenarios, and factors. AHP involves structuring multiple-choice criteria into a hierarchy, assessing the relative importance of each criterion, comparing alternatives for each criterion, and determining the overall ranking of alternatives (Everest et al.2021). Integrating AHP analysis in Geographic Information Systems (GIS) provides robust and efficient spatial decision-support information.

The study is expected to produce a spatially explicit assessment of agricultural land potential in karst areas by delineating doline units and integrating accessibility, soil, and water factors using AHP-GIS methods, hereinafter referred to in this paper as the ASW Approach. It aims to identify and quantify the proportion and distribution of land suitable for food crop development, particularly highlighting areas with high, moderate, and low potential. Notably, the findings are expected to assist Gunungkidul stakeholders in boosting land productivity, the local economy, and food security. The study's objectives align with the Sustainable Development Goals (SDGs), particularly Goal 1 (no poverty), Goal 2 (zero hunger), Goal 10 (reduced inequalities), and Goal 11 (sustainable cities and communities).

MATERIALS AND METHODS

Study area

This study was conducted in the Gunungsewu Karst area in Gunungkidul Regency in the Special Region of Yogyakarta Province (7°46′ - 8°09′ S and 110°21′ - 110°50′ E) as shown in Figure 1. The topography of Gunungkidul is highly diverse, ranging from hills and valleys to caves formed by limestone dissolution. Geographically, Gunungkidul Regency is situated in the southeastern part of Special Region of Yogyakarta Province, bordering the Indian Ocean to the south. Gunungkidul Regency experiences a monsoonal climate, with the rainy season occurring from October to April, receiving an average annual rainfall exceeding 2,000 mm. The dry season spans from May to September and is characterized by minimal or absent rainfall. The average temperature is approximately 27°C, accompanied by high humidity during the rainy season.

Gunungsewu Karst area which belongs to the the Southern Mountains of Java and was formed through tectonic uplift since the Late Pliocene, producing a well-developed tropical karst landscape. The geology is dominated by thick Neogene limestone of the Wonosari–Punung Formation, consisting of reef and bedded limestones overlying older volcanic and volcaniclastic formations. Structurally, the area is influenced by tectonic compression that generated fractures and faults, controlling both karst development and subsurface drainage systems. As a result, Gunungsewu karst area exhibits advanced karstification characterized by cone karst morphology, dolines, underground rivers, and limited surface water due to dominant subsurface hydrological processes.

To further support the geological characterization of the study area, the spatial distribution and field identification of uppermost rock formations are also presented. The uppermost rock layer plays a significant role in controlling surface water retention and infiltration processes, which are critical in karst environments. In the Gunungsewu Karst area within Gunungkidul Regency, variations in lithology such as coral limestone and marly tuffaceous limestone influence the development of dolines and the hydrological behavior of the landscape. These lithological differences determine the permeability and storage capacity of the subsurface, thereby affecting the availability of water for agricultural use. Figure 2 presents the geological map of the study area, while Figure 3 illustrates the uppermost rock identification, including representative field conditions of marly tuffaceous limestone and coral limestone.

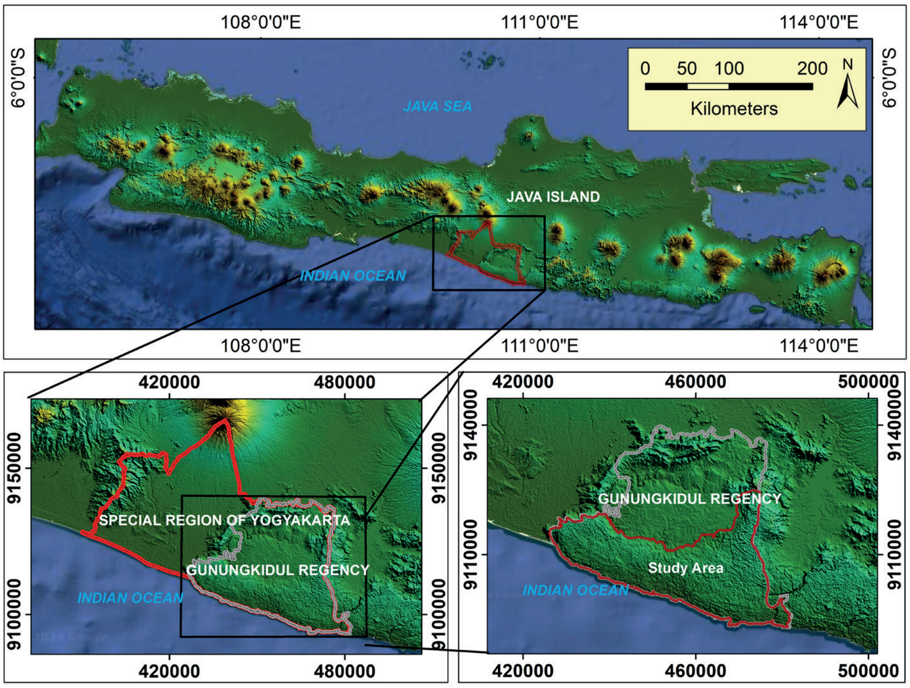

Fig. 1. Study area

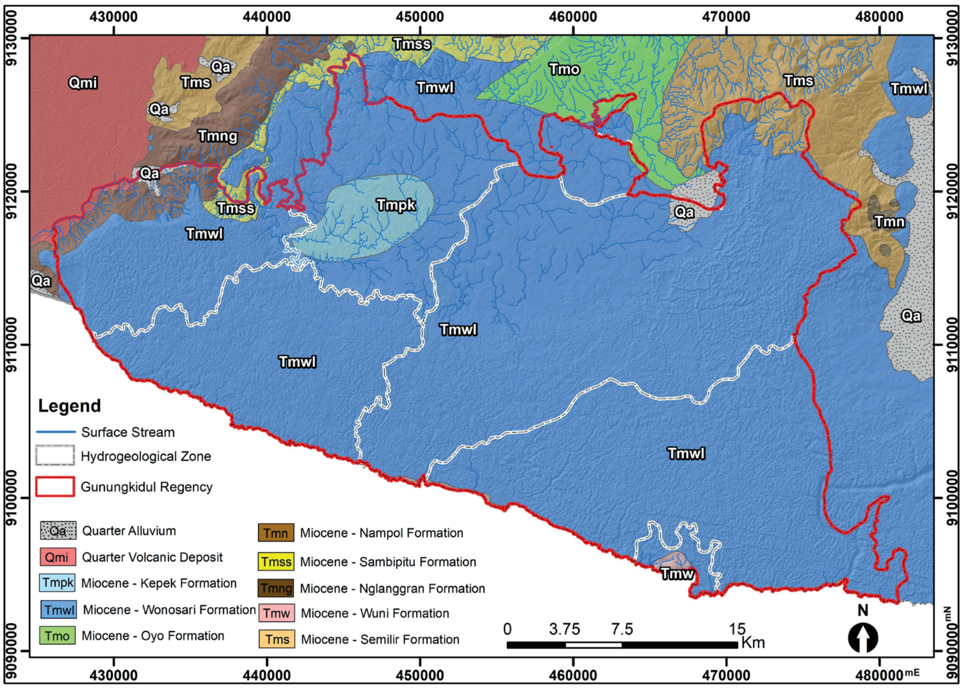

Fig. 2. Geological map of study area

ASW-approach and data collection

ASW (Accessibility-Soil-Water) is a framework designed to assess agricultural land potential within dolines in karst landscapes by considering accessibility, soil characteristics, and the capacity of the uppermost rock to retain water. The first factor, accessibility, assesses at how close land is to important amenities like roads and settlements. This element also determines the doline valley's agricultural carrying capacity by comparing it to its catchment. The second factor, soil, examines the suitability of soil characteristics for the dominant food crops in Gunungkidul. This assessment includes physical and chemical properties such as thickness, texture, cation exchange capacity (CEC), pH, and soil organic matter (SOM). The third factor, water, focuses on the ability of the uppermost rock to retain water, particularly in water storage in reservoirs or ponds. Karst's porous structure and rapid infiltration make the rock with the highest ability to hold surface water vital for agriculture, especially in the dry season. This study examines rock types' capacity to maintain sustainable reservoirs for irrigation under water scarcity. Figure 4 illustrates the workflow of the study, including the methodological steps and the input data used.

Digital Elevation Model (DEM) data comes from 1:25,000 Indonesian Topographic Map's (RBI) contour data. Relief roughness interpretation was based on the Terrain Ruggedness Index (TRI), reclassified into three categories: rough (A), moderately rough (B), and smooth (C). The hydrogeological zone map was obtained from the study by Haryono et al. (2023). Furthermore, the hydrogeological zones are divided into five zones: Panggang (1), East (2), Bribin-Baron (3), Volcanic (4), and Ponjong (5). Capital letters and numbers were used to classify the study region into landform units with similar relief and hydrogeological characteristics. Finally, the study area was classified into 13 landform units as shown in Figure 5.

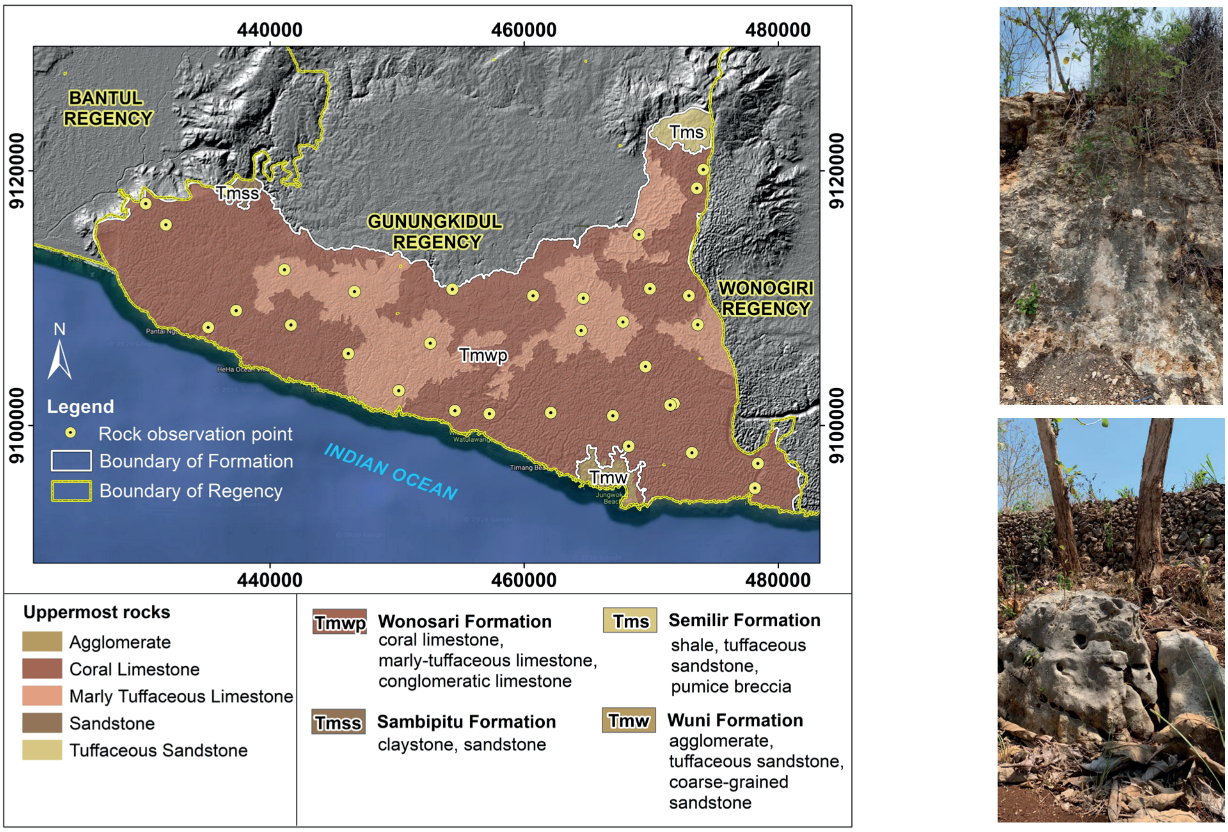

Fig. 3. Uppermost rocks identification map (a); marly tuffaceous limestone (b); coral limestone (c)

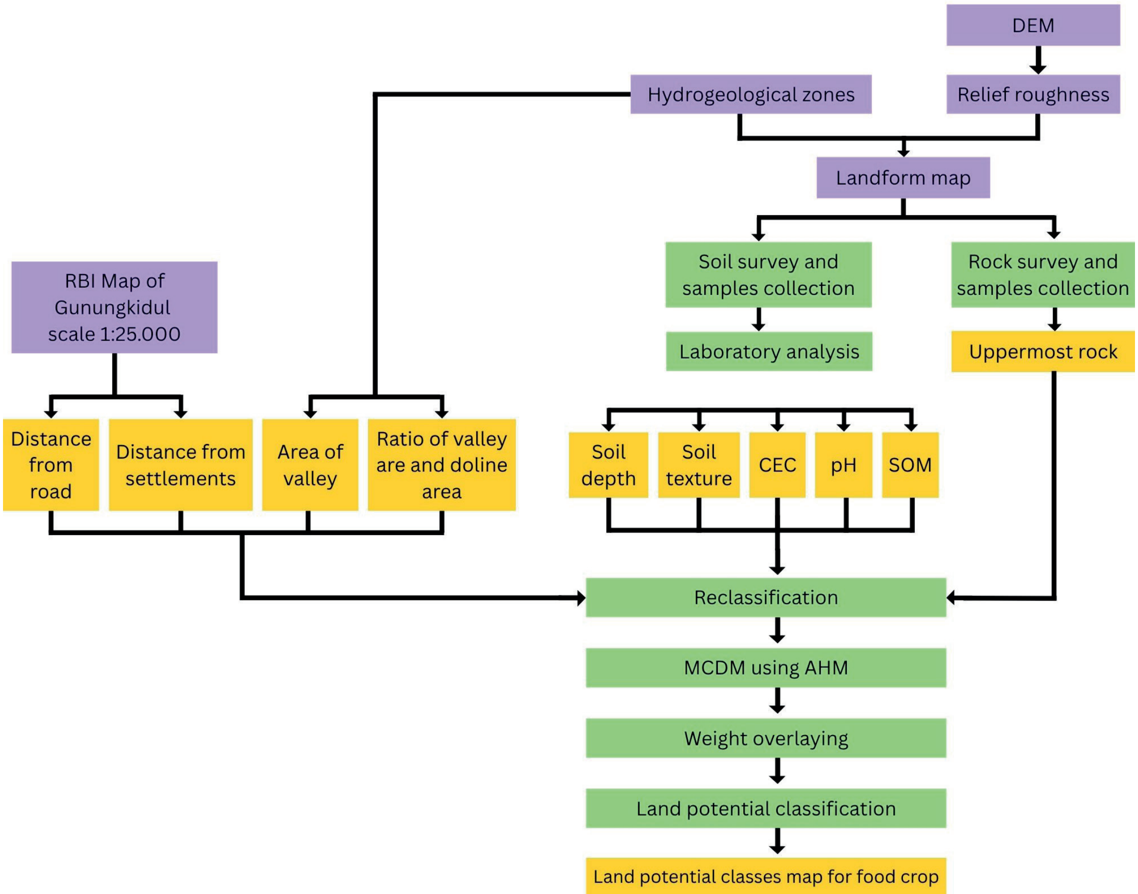

Fig. 4. Flowchart of the study methodology and input data

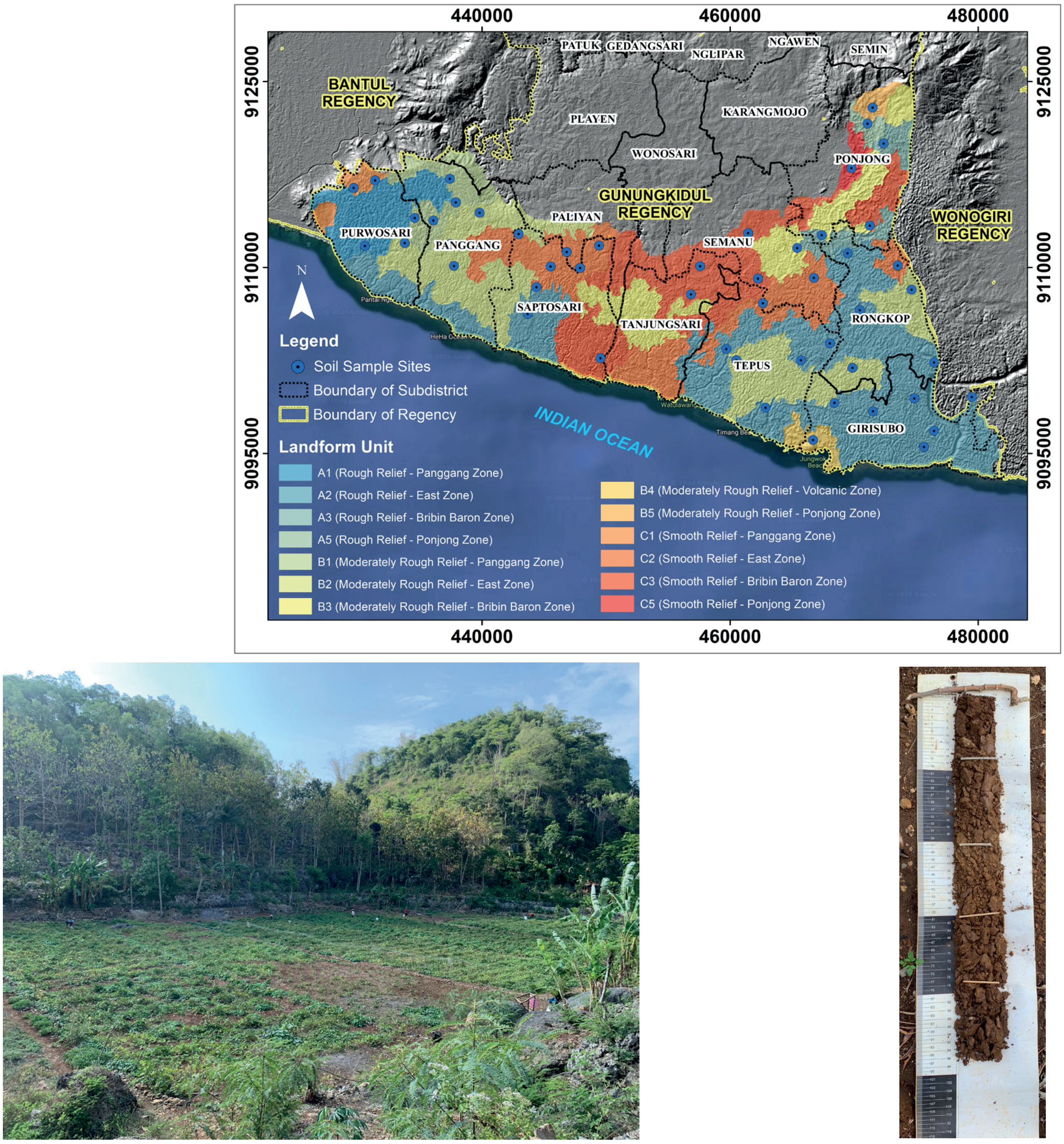

Fig. 5. Landform unit (a); doline valley (b); soil profile (c)

This study employed the watershed algorithm to delineate dolines or closed depressions. Hilltop data were extracted from a 6.25-meter resolution DEM using the terrain analysis function available in SAGA 9.3.1 software. Manual digitization was performed using ArcGIS 10.8 software at a 1:50,000 scale. 2,725 dolines or depressions were identified and subsequently used as mapping units.

Fieldwork involved the observation of land characteristics and soil sampling. Observation points and soil sampling were conducted through purposive sampling at each landform unit. Soil samples were collected to a depth of one meter or until bedrock was reached. Samples were brought to the lab in plastic bags for physical and chemical analysis. The chemical characteristics considered were pH, CEC, and soil organic matter (SOM). Its texture was part of its physical characteristics. Soil depth was recorded during field soil characterization. Laboratory analysis followed the technical guidelines for soil sample testing outlined by the Soil and Fertilizer Instrument Testing Center (Eviati et al. 2023).

Generating land potential map using AHP and GIS

Each data vector is classified into three classes: high potential (P1), moderate potential (P2), and low potential (P3) for food crop development. Reclassified criteria indicate how different suitability levels for each criterion are distributed both spatially and geographically. The weighting of parameters and parameter classes was performed using AHP, which compares one parameter with another or one class with another using a pairwise comparison matrix (PWCM), as explained by Saaty (2014). Nine types of relationships between criteria were used in this method, defined on a scale from one to nine. These relationships represent the relative importance between criteria (Everest et al. 2021). As the scale increases, the criterion gains greater importance relative to its counterpart (Insani, 2023). In the PWCM, the importance of parameters was decided by considering the opinion of experts. The PWCM value for each parameter is mentioned in Table 1.

AHP mathematical model calculates the relative weights of criteria and the scores for alternatives through eigenvector methods. The eigenvector corresponding to λmax represents the underlying standard scale and thus ranks each element in the ratio matrix (Nungula et al. 2024). The consistency of the parameter weights was evaluated by calculating the consistency ratio (CR). Consistency Ratio (CR) is calculated using (Equation 1). During the assessment, the evaluation matrix is considered consistent only if its ratio is < 0.1.

$$CR = \frac{CI}{RI} \tag{1}$$

Where *CI* = Consistency Index; *RI* = Random Index. The Consistency Index *(CI)* value is calculated using the eigenvalue *(λmax)* obtained from the AHP calculator and the number of parameters *(n)* from the AHP calculator. Random Index *(RI)* is simply obtained from the Random Index table provided by Saaty [16] as mentioned in Table 1.

$$CI = \frac{\lambda max - n}{n - 1} \tag{2}$$

In creating the doline potential map for food crop agriculture, the reclassified layers, including accessibility, soil, and water criteria, covering ten parameters, were scored and weighted through AHP and integrated into the ArcGIS environment. The weighted layers for each parameter were overlaid using the weighted overlay analysis tool (Equation 3), where *P* = potential value; *Wi* = weight of the i-th parameter; *Xi* = class score of the i-th parameter; *n* = number of parameters.

$$P = \sum_{i=1}^{n} Wixi \tag{3}$$

RESULTS

Accessibility Potential

Distance from the road has the highest weight among the land potential class assessment parameters, with a value of 0.26, followed by distance from settlements with 0.20 and the area of the doline valley with 0.14 as stated in Table 5. These three parameters belong to the accessibility criterion. Figure 6 shows the distribution of accessibility parameter maps. Karst regions generally feature rugged terrain with hilly topography and isolated doline depressions. Proximity to roads and settlements facilitates farmers in monitoring and maintaining the land regularly, thus increasing the potential for optimal harvest yields compared to lands that are difficult to access.

Distance from the road is crucial in assessing land potential for agriculture in the basins of dolines in karst areas, as physical accessibility to the land affects the ease of transportation for agricultural activities. the distance of land from roads can influence the efficiency of agricultural activities. Land close to main roads facilitates farmers in transporting tools, seeds, fertilizers, and harvests and accelerating product marketing. In karst and karstic areas, poor accessibility due to steep topography can increase transportation costs and hinder production efficiency. Therefore, the distance from roads can serve as an important indicator in evaluating the feasibility of land for agricultural development.

Distance from settlements is another critical parameter in the accessibility criterion. Farmers may access property near settlements faster, decreasing travel time and making daily agricultural monitoring easier. Land nearer to settlements is considered to have more potential due to its

Table 1. Random Index (RI)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51

Table 2. AHP pairwise comparison matrix

	Distance from road (m)	Distance from settlements (m)	Area of doline valley (ha)	Ratio of doline area and valley area	Soil depth (cm)	pH	Soil texture	SOM (%)	CEC (cmol)	Uppermost rock	Weightage	CR < 0.1	CI
Distance from road (m)	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	8.00	1.00	0.26	0.07	0.11
Distance from settlements (m)	0.50	1.00	2.00	3.00	4.00	5.00	6.00	7.00	7.00	2.00	0.20		
Area of doline valley (ha)	0.33	0.50	1.00	2.00	3.00	4.00	5.00	6.00	6.00	1.00	0.14		
Ratio of doline area and valley area	0.25	0.33	0.50	1.00	2.00	3.00	4.00	5.00	5.00	2.00	0.11		
Soil depth (cm)	0.20	0.25	0.33	0.50	1.00	2.00	3.00	4.00	4.00	1.00	0.07		
pH	0.17	0.20	0.25	0.33	0.50	1.00	2.00	3.00	3.00	1.00	0.05		
Soil texture	0.14	0.17	0.20	0.25	0.33	0.50	1.00	2.00	2.00	1.00	0.04		
SOM (%)	0.13	0.14	0.17	0.20	0.25	0.33	0.50	1.00	1.00	1.00	0.03		
CEC (cmol)	0.13	0.14	0.17	0.20	0.25	0.33	0.50	1.00	1.00	1.00	0.03		
Uppermost rock	1.00	0.17	1.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00	0.07		

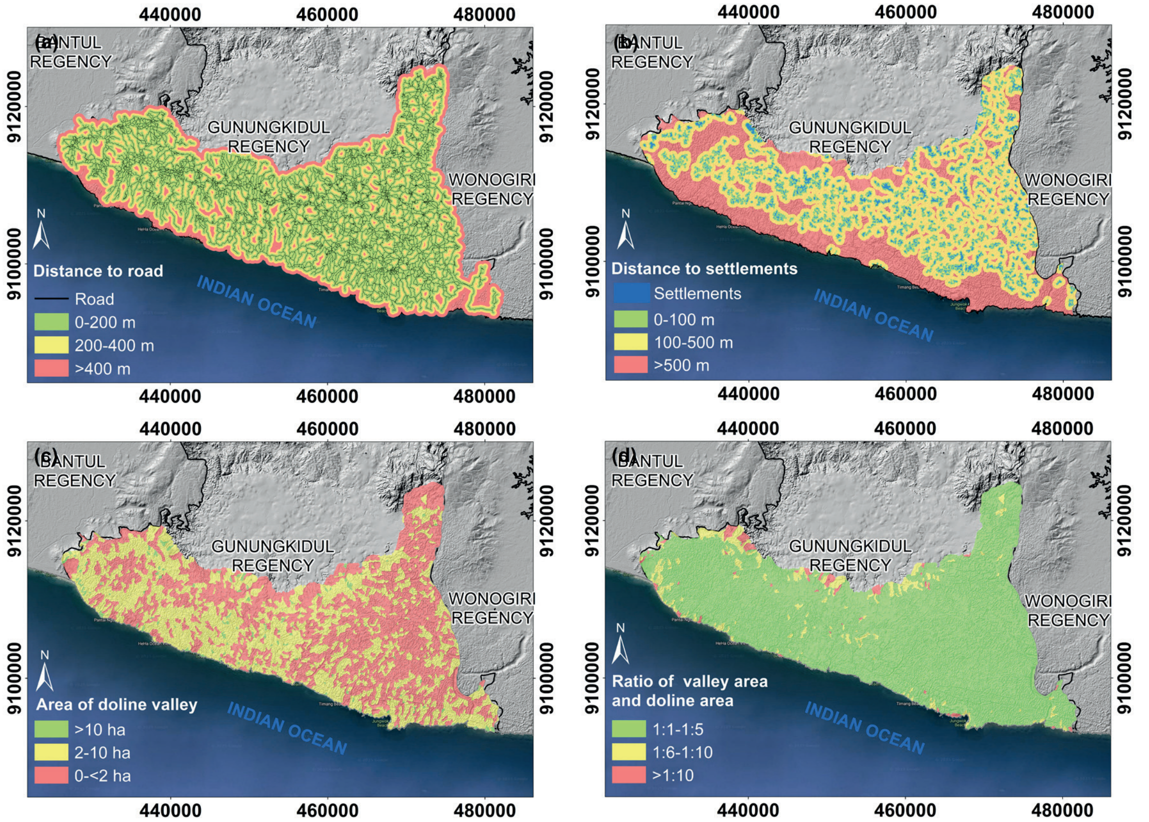

Fig. 6. Spatial distribution of: distance from road (a); distance from settlements (b); doline valley area (c); ratio of valley area and doline area (d)

ability to improve labor efficiency and safeguard harvests. Additionally, closeness to settlements allows land to be used as food crop fields for local consumption. Something else that is highly significant is the area of the doline valley, which shows how much land is open for farming. Differences in the dimensions of dolines and limestone hills allow for variations in the size of doline valleys. A sufficiently large doline enables more flexible and diverse land management, such as crop rotation or intercropping. Larger dolines have more significant potential to increase crop productivity and land use efficiency.

The ratio between area of doline valley and total doline area provides insight into the proportion of relatively flat land suitable for intensive agriculture. A lower ratio indicates that valley area is large enough for agriculture. Large land area correlates with agricultural production outcomes and land productivity. In other words, the agricultural inputs and labour invested in cultivation can yield profitable outputs. Furthermore, the ratio of doline valley area to the total doline area was classified into three classes: highly potential (P1) ranging from 1:1 to 1:5, moderately potential (P2) ranging from 1:6 to 1:10, and low potential (P3) with ratios greater than 1:10. The study area is predominantly classified as highly potential. The characteristics of class P1 include relatively flat valley areas close to the doline's size, enabling the use of mechanical tools, and low erosion potential.

Soil properties potential

Soil is a fundamental component in the cultivation of food crops. The selection of suitable crops for cultivation on land with various limitations determines the land's productivity value and the income generated from agricultural activities. However, the soil assessment factors were tailored to the food crops grown in Gunungkidul. Cassava remains a leading food crop in Gunungkidul, as nearly the entire region is suitable for cassava cultivation. Other commodities such as upland rice, groundnut, and maize are significant crops widely cultivated by the local community in Gunungkidul. Table 3 shows the suitability class of soil parameters for each food crop that is predominantly cultivated in Gunungkidul.

Following the evaluation of food crops predominantly cultivated in Gunungkidul Regency and their soil suitability characteristics presented in Table 3, it is also important

Table 3. Land potential classes for each food crop commodity

Food crop commodity	Soil depth (cm)			Soil Texture			CEC (meq/100g)			pH			SOM (%)		
	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Rainfed rice	>50	40-50	25-40	Fine	Fine	Coarse	>16	<16		5.5-8.2	5.0-5.5	<5	>1.5	0.8-1.5	<0.8
Cassava	>50	20-50	10-20	Fine	Fine	Coarse	>16	<16		6.0-8.2	5.6-6.0	<5.6	>0.4	<0.4	
Maize	>60	40-60	25-40	Fine	Fine	Coarse	>16	<16		5.5-8.2	5.3-5.5	<5.3	>0.4	<0.4	
Groundnut	>75	50-75	25-50	Fine	Fine	Coarse	>16	<16		5.6-7.6	5.4-5.6	<5.4	>1.2	0.8-1.2	<0.8

Source: Djaenudin et al. (2011) modified to understand how these soil properties relate to the actual distribution of agricultural activities across the region. Land Use and Land Cover (LULC) analysis provides additional insight into current land utilization, particularly in identifying areas dominated by food crop cultivation such as cassava, maize, upland rice, and groundnut. By integrating soil suitability with existing land use patterns, this approach helps to better interpret the alignment between land potential and agricultural practices in the study area. Furthermore, the LULC map enables a clearer visualization of the spatial distribution of food crop commodities, thereby supporting a more comprehensive assessment of soil property potential. The Land Use and Land Cover map of the study area is presented in Figure 7.

Soil texture directly influences soil aeration and its ability to retain and absorb water. Analysis shows that the study area's soil texture is clay. Fine-textured soils in karst areas prone to drought play a significant role in water retention. Soil depth is crucial as it affects the availability of space for plant roots and the soil's capacity to retain water and nutrients. Most of soil depth in the Doline Valley at the study site is classified as deep (>50 cm) As presented in Figure 8, making it relatively suitable for food crop cultivation.

From a chemical perspective, CEC, pH, and SOM are critical to determining soil fertility and plant nutrient availability. Soil pH affects nutrient solubility, while SOM provides a source of nutrients and improves soil structure. CEC indicates the soil's ability to absorb and supply essential nutrients to plants. Based on laboratory tests as displayed in Table 4, the pH, SOM, and CEC values at the study site are dominated by class P1, indicating that the soil has a high potential for supporting agricultural activities. Combining these three parameters ensures that the doline soils provide a chemical environment conducive to the growth of major food crops in the karst area.

To further support the interpretation of soil characteristics presented in Table 4, spatial visualization is essential to capture the variability of soil properties across the study area. Although the overall soil conditions indicate dominance of high-potential classes (P1), their distribution is not entirely uniform within doline units. Variations in soil depth, texture, and chemical properties such as pH, SOM, and CEC influence the spatial heterogeneity of land suitability for food crop development. Understanding these spatial patterns allows for a more precise identification of areas with optimal and suboptimal soil conditions, thereby improving the accuracy of land potential assessment. Figure 9 illustrates the spatial distribution of soil variables, providing a comprehensive overview of how these parameters are distributed across the landscape and their contribution to agricultural potential in the study area.

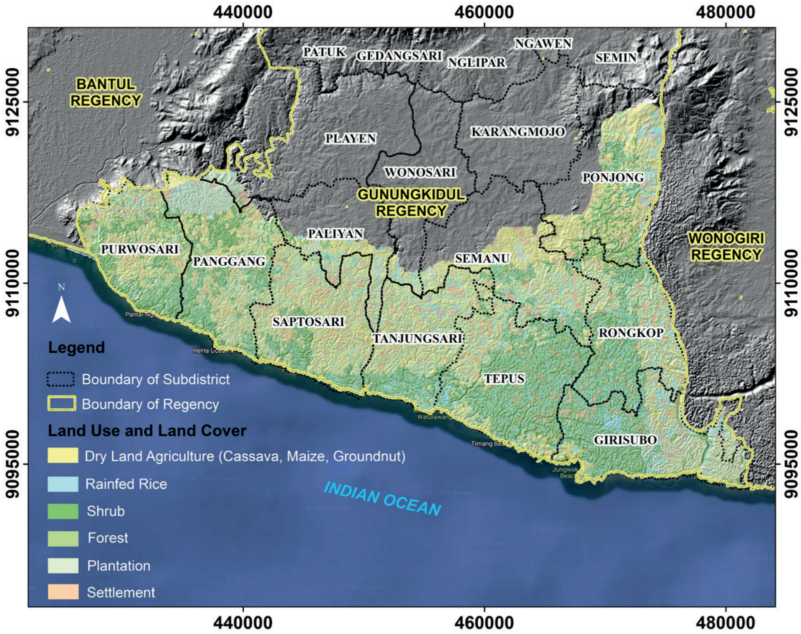

Fig. 7. Land use and land cover (LULC) map of the study area

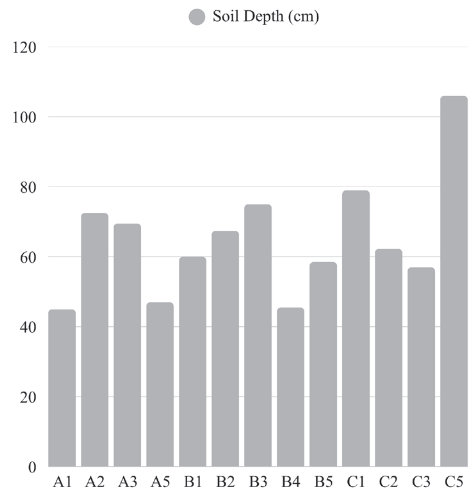

Fig. 8. Soil depth in research area

Table 4. Soil properties characteristic

Landform	Soil texture		CEC (meq/100g)		pH		SOM (%)	
	Class	Group	Value	Class	Value	Class	Value	Class
A1	Clay	Fine	36.87	High	7.75	Slightly alkaline	2.89	Medium
A2	Clay	Fine	24.04	Moderate	6.53	Slightly acidic	2.60	Medium
A3	Clay	Fine	27.40	High	6.45	Slightly acidic	2.08	Medium
A5	Clay	Fine	19.41	Moderate	5.30	Strongly acidic	3.19	Medium
B1	Clay	Fine	30.97	High	6.70	Neutral	2.06	Medium
B2	Clay	Fine	24.36	Moderate	6.80	Neutral	2.46	Medium
B3	Clay	Fine	14.33	Moderate	6.50	Slightly acidic	2.48	Medium
B4	Clay	Fine	28.92	High	7.20	Neutral	3.37	Medium
B5	Clay	Fine	25.04	High	6.00	Slightly acidic	2.83	Medium
C1	Clay	Fine	25.43	High	7.80	Slightly alkaline	1.76	Medium
C2	Clay	Fine	18.13	Moderate	7.09	Neutral	2.19	Medium
C3	Clay	Fine	26.71	High	6.38	Slightly acidic	2.41	Medium
C5	Clay	Fine	13.27	Moderate	6.50	Slightly acidic	2.44	Medium
Classification References	(Djaenudin et al. 2011)		(Diatta et al. 2014)		Islam et al. 2021)		Islam et al. 2021)	

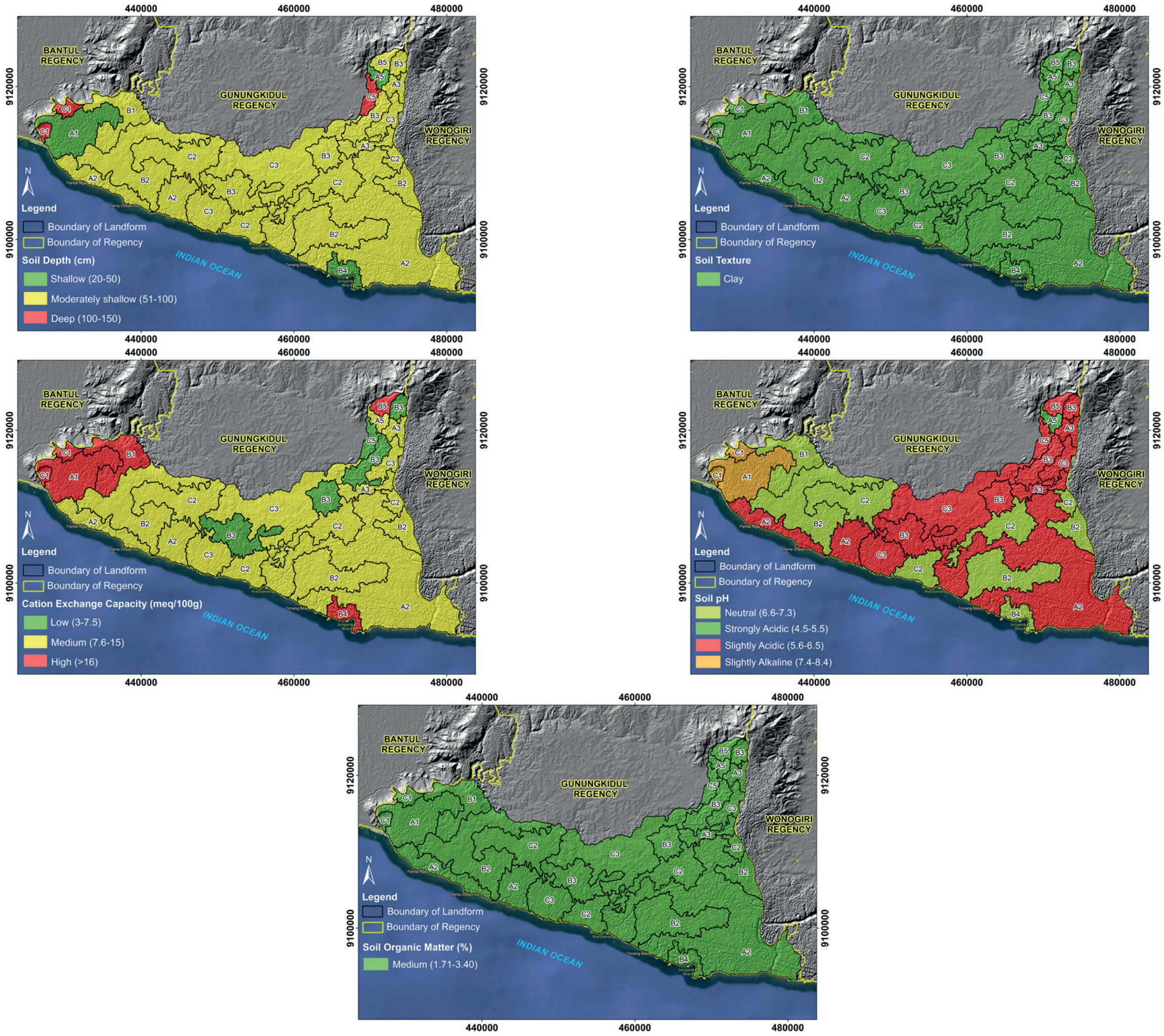

Fig. 9. Spatial distribution of soil variables: soil depth (a); soil texture (b); CEC (c); soil pH (d); SOM (e)

Water holding potential

Uppermost rock parameters are considered when assessing doline valley land potential for agriculture, presuming impermeable rock layers can store water and sustain micro-reservoirs for rainfall collection. Impermeable rocks do not contain water and cannot transmit it. The stratigraphy of rocks was predicted through the uppermost rock identification and the composition of the rocks forming each formation. Coral limestone stratigraphy over marly tuffaceous and conglomeratic limestone layers in the Wonosari Formation creates an optimum impermeable barrier for water retention. On the opposite, coral limestone at the base allows water to easily permeate the lower levels, causing leaks in micro-dams or ponds due to coral rocks' porous structure.

In the Wuni Formation, the stratigraphy of agglomerate over tuffaceous sandstone and coarse-grained sandstone creates a slightly impermeable layer. Although less effective than the rocks in other formations, this combination retains some surface water and supports rainwater harvesting through micro-reservoirs. This layer has lower porosity and permeability than others, making it suitable for micro-reservoir construction, though with more limited storage capacity. Further, in the Semilir and Sambipitu Formations, layers rich in tuffaceous sandstone, shale, and claystone are assumed to be effective in water retention. Tuffaceous sandstone in the Semilir Formation and claystone in the Sambipitu Formation create impermeable layers that strongly support the construction of micro-reservoirs at the base of dolines. These layers prevent seepage and allow more effective rainwater storage in regions prone to surface water retention difficulties. Figure 3 illustrates the distribution of uppermost rocks across each formation, derived from field observations.

Overall potential

The final map indicating land potential classes was created after all parameter weights and parameter class scores from the AHP matrix were integrated. Parameter weights and parameter class scores of the AHP matrix are shown in Table 5. The doline potential map for agricultural development was created by summing the weighted scores for all parameters. The resulting maximum sigma and CR values were 0.64 and 0.07 below the allowed threshold, respectively.

The maximum sigma value was classified into three classes using the natural breaks (Jenks) function in ArcGIS software, resulting in classes as shown in Figure 10. The research findings indicate that 52% (13,032 ha) of the land at the base of the doline has high potential, 37% (9,232 ha) has moderate potential, and 12% (2,950 ha) has low potential. Doline areas with high potential are predominantly located in the central part of the study area, where road access is very convenient, and settlements are closely located.

The classification of land potential into high (P1), moderate (P2), and low (P3) categories reflects the integrated suitability of accessibility, soil characteristics, and water availability for food crop cultivation in Gunungkidul Regency. Areas classified as high potential (P1) exhibit favorable conditions across these parameters, including adequate road access, suitable soil physical and chemical properties, and relatively better water retention capacity. These conditions support the cultivation of major food crops such as rainfed rice, cassava, maize, and groundnut with relatively low operational constraints. In addition, high potential areas are generally associated with more stable geomorphological conditions within doline valleys, where thicker soil accumulation and gentler slopes reduce the likelihood of surface instability. Consequently, these areas not only offer higher agricultural productivity but also present lower relative risk for land degradation and subsidence compared to less suitable zones.

In contrast, moderate (P2) and low (P3) potential classes indicate increasing limitations that affect both cultivation suitability and land management feasibility. Moderate potential areas are characterized by partial constraints, particularly in terms of accessibility and seasonal water

Table 5. Classes score for every parameter

Criteria	Parameters	Parameter Classes	Potential Classes	Area (ha)	%	Scores	Weight	References
Accessibility	Distance from road (m)	0-200	P1	22,168	88	0.68	0.26	(Widiatmaka et al. 2016) modified
		200-400	P2	2,203	9	0.20		
		>400	P3	843	3	0.12		
	Distance from settlements (m)	0-100	P1	9,382	37	0.61	0.2	(Tanjung et al. 2021) modified
		100-500	P2	9,742	39	0.27		
		>500	P3	6,090	24	0.12		
	Area of doline's valley (ha)	>10	P1	14,589	58	0.54	0.14	(FAO, 2022) modified
		2-10	P2	10,458	41	0.30		
		0-<2	P3	166	1	0.16		
	Rasio of valley's area and doline's area	1:1-1:5	P1	24,450	97	0.54	0.11	Interpretation
		1:6-1:10	P2	678	3	0.30		
		>1:10	P3	85	0	0.16		

Soil	Soil depth (cm)	>50	P1	23,774	94	0.67	0.07	(Djaenudin et al. 2011) modified
		40-50	P2	1,440	6	0.33		
	pH	6-8.2	P1	24,923	99	0.67	0.05	
		5-6	P2	291	1	0.33		
	Soil texture	Halus	P1	25,214	100	0.67	0.04	
		Agak Kasar	P2	-	0	0.33		
	SOM (%)	>1.5	P1	25,214	100	0.67	0.03	
		0.8-1.5	P2	-	0	0.33		
	CEC (cmol)	>16	P1	22,874	91	0.75	0.03	
		0-16	P2	2,339	9	0.25		
Water	Uppermost	Coral Limestone	P1	18,032	72	0.28	0.07	Interpretation and survey
		Tuffaceous Sandstone	P1	385	2	0.28		
		Sandstone	P1	55	0	0.28		
		Agglomerate	P2	250	1	0.10		
		Marly Tuffaceous Limestone	P3	6,492	26	0.07		

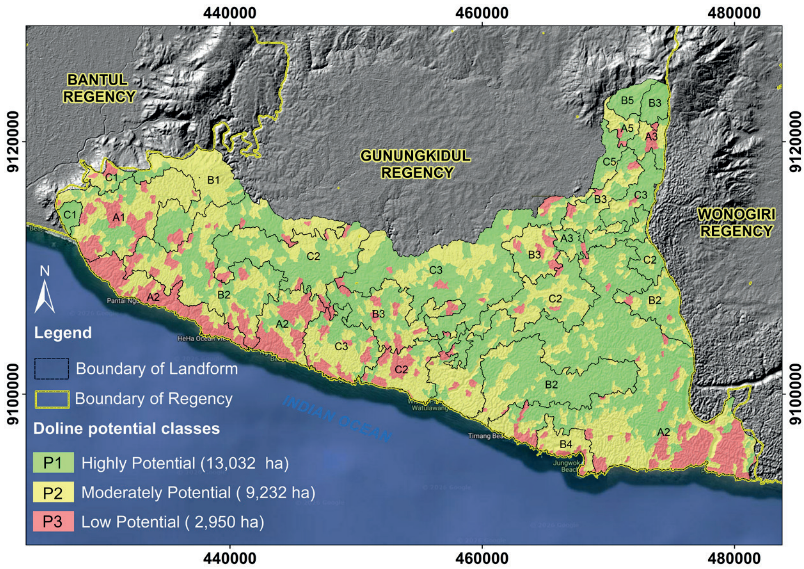

Fig. 10. Doline potential classes map

availability, which may reduce agricultural efficiency but can still be improved through infrastructural interventions such as road development and water management systems. Low potential areas, on the other hand, are typically located in more isolated dolines with steep surrounding terrain and limited connectivity, making access and resource distribution more challenging. Although these areas may possess relatively fertile soils, their limited water availability and difficult terrain increase the complexity of agricultural utilization and may elevate the risk of geomorphological instability if improperly managed. Across all potential classes, water scarcity remains a critical constraint in karst environments; however, this limitation can be mitigated through the construction of micro-reservoirs at water accumulation points and the adjustment of cropping patterns in accordance with seasonal rainfall variability, thereby enhancing the practical applicability of land potential classifications.

DISCUSSION

Most of the study sites have a very high potential for agriculture, indicating that doline valley has significant potential for agricultural development despite facing several obstacles. Challenges in developing agricultural areas can be overcome through land modification efforts and increasing accessibility. Accessibility is a critical factor for agricultural development in Gunungssewu karst area, where steep and hilly terrain complicates access to dolines, increasing production costs and reducing cultivation efficiency. Prioritizing road construction to isolated dolines can enhance land utilization, integrate agricultural areas with markets and distribution centers, and improve food security. Improved market access enables farmers to respond quickly to consumer demand, adapt to climate-induced uncertainties, and reduce post-harvest losses. This study aligns with the findings of Rahma Dayanti and Soetjipto (2024), who emphasize that farmers with reliable market access are better equipped to manage risks and adapt to evolving market conditions.

Doline valley tends to have thicker and more fertile soil layers than the slopes or other plains in karst areas. These deeper soil layers allow plant roots to absorb more water and nutrients, supporting plant resilience against drought and enhancing land productivity. This advantage makes the doline area a potential sustainable food crop development zone. With proper soil conservation techniques, doline land can be effectively managed to support main food crops such as upland rice, cassava, maize, and legumes. Soil conservation in dolines can be achieved through agroforestry and contour terracing, with tree planting on slopes anchoring the soil and regulating the microclimate (Cao et al. 2024). As one of the dominant vegetation types in Gunungkidul, teak trees can be planted on doline slopes for conservation purposes while simultaneously providing additional income for farmers. The findings of this study are consistent with Ribolzi et al. (2017), who demonstrated that teak plantations significantly influence overland flow and sediment yield, both of which are critical components of soil conservation efforts.

Water scarcity during the dry season can be addressed by modifying planting patterns and constructing micro-reservoirs. The construction of micro-reservoirs in doline valleys helps farmers access rainwater during the dry season through rainwater harvesting. Mganga et al. (2022) discuss how in situ rainwater harvesting techniques, including the use of micro-catchment can stabilize dryland landscapes and restore degraded areas, making them more productive. The placement of the reservoirs should focus on points of water flow accumulation to ensure their effectiveness as illustrated in Figure 11. The dimensions of the reservoirs are adjusted to the area of land and the crops to be cultivated. Local governments can assist with materials such as geomembranes to line the reservoirs, making them impermeable, thereby allowing stored water to last longer and supporting irrigation activities in the surrounding areas.

In addition to infrastructure assistance, the government is also expected to actively monitor the climate and disseminate accurate weather forecasts to the community, especially in light of climate change, which affects weather patterns and planting seasons. Extension services and guidance to revise traditional practices such as *pranoto mongso*[1] with more scientific weather information will assist farmers in determining the appropriate planting time and selecting crops suited to current weather conditions. These efforts, alongside the development of infrastructure and the provision of irrigation facilities in doline valleys, are expected to improve food security and the local economy of communities in the karst area. Table 6 illustrates the modifications in food crop cultivation over a one-year period, considering the availability of water from rainfall.

Agricultural land potential assessments have been extensively studied; however, limited research has focused on evaluating agricultural potential in karst hill regions, which are often perceived as arid and infertile. Despite this perception, karst landscapes, particularly doline bases, exhibit significant potential for agricultural utilization, warranting further exploration. A key limitation of the current research lies in the exclusion of climate factors from the assessment framework. Climate considerations are critical to the viability and productivity of agricultural systems, particularly for rainfed crops such as rice, maize, cassava, and groundnut, as they significantly influence water availability, crop growth cycles, and overall agricultural sustainability. This omission limits the comprehensiveness of the assessment. Future studies should address this limitation by incorporating climate variables into the assessment framework, thereby enabling a more holistic evaluation and supporting more effective planning for agricultural development in karst landscapes.

CONCLUSIONS

In conclusion, 52% of the total study area, comprising 2,513 doline units, falls into class P1 (highly potential) for food crop agricultural development, 37% into class P2 (moderately potential), and 12% into class P3 (low potential). The utilization of areas with potential for agricultural development can involve the cultivation of food crops such as rice, cassava, maize, and groundnut.

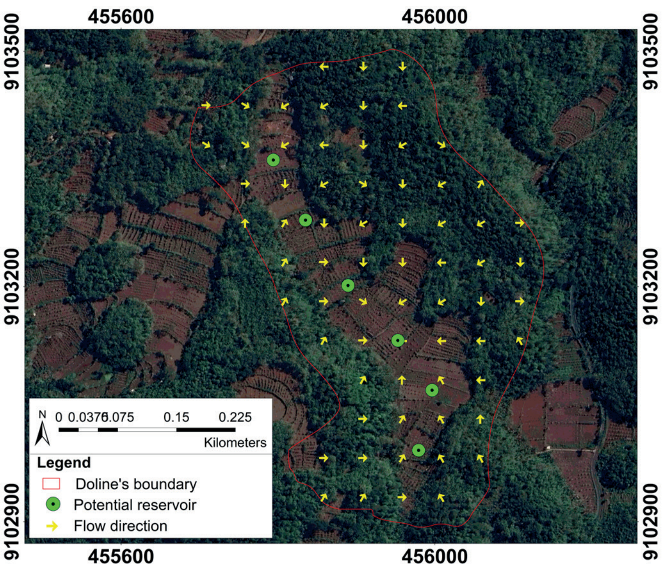

Fig. 11. Potential reservoir point

[1] Pranoto Mongso is a traditional Javanese concept of understanding seasonal and ecological cycles to guide agricultural practices, reflecting harmony with nature.

Table 6. Planting season modification of food crops

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AGT	SEP	OCT	NOV	DEC
Monthly average rainfall (2012-2022)	410	299	313	195	87	115	37	25	43	172	337	361
Water Availability	320	216	231	126	23	54	-28	-57	-57	65	240	271
Type of month	WM	WM	WM	WM	DM	DM	DM	DM	DM	DM	WM	WM
Potential commodity	DR	MA, GN, CS	MA, GN, CS	MA, GN, CS	GN	GN	CS	CS	CS	MA, GN, CS	DR	DR

Type of month. WM – wet month; DM – dry month; Potential commodity. DR – Dryland rice, MA – Maize, CS – Cassava, GN – Groundnut.
Note: red color indicates months when there is a water deficit

The success of crop production is highly dependent on the planting pattern, which is based on the availability of rainfall, particularly during the early stages of planting. Therefore, climate prediction becomes a key factor for ensuring successful crop growth. Water conservation practices aimed at capturing a portion of rainfall can serve as a safeguard to ensure harvest success. Despite providing a comprehensive assessment of agricultural land potential in the karst landscape of Gunungkidul Regency using ten parameters, this study is limited by the inherent subjectivity of the AHP method, as the final results are highly dependent on the pairwise comparison and weighting assigned by key informants. Future research is recommended to incorporate additional assessment factors and develop alternative weighting scenarios or sensitivity analyses to improve the robustness and reliability of land potential evaluation in karst environments.

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