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Original Article

Soil fertility mapping on *Ficus* trees for rehabilitation of degraded land in Kuningan Regency, Indonesia

Mapeamento da fertilidade do solo em árvores do gênero *Ficus* para reabilitação de terras degradadas no Distrito de Kuningan, Indonésia

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Abstract

Land degradation poses a global challenge to ecosystem sustainability and human well-being, driven primarily by deforestation, intensive agriculture, and mining. Rehabilitation efforts, particularly through Ficus species, offer effective solutions to restore soil fertility and ecosystem functions. This study analyzed soil fertility around Ficus trees in three land-use types in Kuningan Regency, Indonesia: sand mining areas, community gardens, and secondary forests. Soil samples (0-30 cm depth) were analyzed for physical and chemical parameters, including pH, organic C, total N, C/N ratio, P_2O_5, K_2O, cation exchange capacity, and texture. Results revealed variations in soil fertility across locations: low to medium in sand mining areas, low to high in community gardens, and low to high in secondary forests. Ficus species observed included *Ficus benjamina* and *Ficus septica* in sand mining areas; *F. benjamina*, *F. septica*, *F. fistulosa*, and *F. variegata* in community gardens; and *F. benjamina*, *F. septica*, *F. variegata*, and *F. virens* in secondary forests. Among these, *Ficus benjamina* and *Ficus septica* are recommended for land rehabilitation due to their adaptability and contributions to soil restoration.

Keywords: land degradation, land rehabilitation, soil fertility, *Ficus*.

Resumo

A degradação dos solos representa um desafio global para a sustentabilidade dos ecossistemas e para o bem-estar humano, impulsionada principalmente pelo desmatamento, pela agricultura intensiva e pela mineração. Os esforços de reabilitação, especialmente por meio de espécies do gênero *Ficus*, oferecem soluções eficazes para restaurar a fertilidade do solo e as funções dos ecossistemas. Este estudo analisou a fertilidade do solo ao redor das árvores *Ficus* em três tipos de uso da terra no Distrito de Kuningan, na Indonésia: áreas de mineração de areia, hortas comunitárias e florestas secundárias. Amostras de solo (0-30 cm de profundidade) foram analisadas quanto a parâmetros físicos e químicos, incluindo pH, carbono orgânico, nitrogênio total, relação C/N, P_2O_5, K_2O, capacidade de troca de cátions e textura. Os resultados revelaram variações na fertilidade do solo entre locais: baixa a média em áreas de mineração de areia, baixa a alta em hortas comunitárias e baixa a alta em florestas secundárias. As espécies de *Ficus* observadas incluíram *Ficus benjamina* e *Ficus septica* em áreas de mineração de areia; *F. benjamina*, *F. septica*, *F. fistulosa* e *F. variegata* em hortas comunitárias; e *F. benjamina*, *F. septica*, *F. variegata* e *F. virens* em florestas secundárias. Entre estes, *Ficus benjamina* e *Ficus septica* são recomendados para reabilitação de terrenos devido à sua adaptabilidade e contribuições para a restauração do solo.

Palavras-chave: degradação do solo, reabilitação da terra, fertilidade do solo, *Ficus*.

1. Introduction

The rehabilitation of degraded land is a global challenge that affects ecosystem sustainability and human well-being (Raj et al., 2023). Land degradation is primarily caused by human activities such as deforestation (Kunte and Bhat, 2024), intensive agriculture (Drobitko et al., 2023), and mining (Hadzi et al., 2024), leading to decreased soil fertility, ecosystem damage, and loss of biodiversity. Between 2015 and 2019, the world lost at least 100 million hectares of healthy and productive land (Arora and Mishra, 2024). In response, many countries have adopted rehabilitation strategies focused on forest restoration through the planting of native trees (Parr et al., 2024). Agroforestry and revegetation approaches are being used to diversify crops and restore disturbed ecosystems (Zhang et al., 2024). Community-based land rehabilitation involves active local participation in the care and management of degraded

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lands (Furo et al., 2024; Putri et al., 2024). These diverse rehabilitation strategies reflect various responses to the global challenge of land degradation, with the ultimate goals of restoring healthy ecosystem functions (Overton et al., 2024), enhancing food security (Deng et al., 2024), and promoting environmental sustainability (Heydari and Osanloo, 2024).

Previous research on land rehabilitation has covered various aspects and strategies based on tree planting. Early studies focused on physical restoration techniques, such as terracing and vegetation planting. Subsequent research explored the application of agroforestry, integrating trees into agricultural systems to improve soil structure (Pandey et al., 2024). The use of pioneer plant species, which can grow in less fertile soil conditions, has also become a focus to accelerate the rehabilitation process (Kusuma et al., 2023; Alves et al., 2024). More recently, holistic and sustainable approaches involving local communities have gained attention, recognizing the importance of local knowledge and socio-economic sustainability (Ortega and Senante, 2023).

Land degradation has become one of the most pressing environmental issues, especially in tropical regions that are vulnerable to land-use changes and human activities. This degradation not only leads to soil quality decline but also threatens ecosystem sustainability and food security (Hossain et al., 2021). Therefore, efforts to rehabilitate degraded land are crucial for restoring ecological functions and supporting environmental sustainability. One effective approach in land rehabilitation is the use of plant species (Hooke and Sandercock, 2012) that can improve soil structure and fertility, such as the Ficus tree. Ficus, commonly known as the banyan tree, plays a vital ecological role in maintaining environmental balance (Rahayuningsih et al., 2020). This tree is highly adaptable to various soil conditions, including degraded soils (Iryna et al., 2023). Moreover, Ficus has an extensive root network and the ability to interact with soil microorganisms, which helps enhance soil fertility, prevent erosion, increase water infiltration (Martins et al., 2024), and sequester carbon (Hendrayana et al., 2019). Through processes like nitrogen fixation, organic matter addition, and boosting biological activity in the soil, Ficus can serve as a key agent in restoring degraded land (Stavi, 2022).

Previous land rehabilitation research aimed to address land degradation in high-rainfall areas as a crucial step in maintaining productivity and reducing land pressure (Lovejoy, 1985). The implementation of traditional knowledge-based approaches and the exploration of agroforestry systems have enhanced both economic and ecological benefits (Maikhuri et al., 1997). Soil compaction issues in agricultural lands negatively impact ecosystem functions, but rehabilitation efforts utilizing earthworms have shown positive outcomes (Larink and Schrader, 2000). Forest rehabilitation programs targeting recovery from deforestation have successfully involved local communities in environmentally friendly practices (Kobayashi, 2004). However, land degradation challenges still affect agricultural productivity and economic sustainability, indicating the need for improved rehabilitation strategies (Temesgen et al., 2014).

While some rehabilitation efforts have led to further soil damage, erosion, and fertility loss, revegetation has proven effective in soil restoration (Mensah, 2015). Research on sustainable land management through soil conservation in catchment areas suggests that more investigation is needed on its impact on recovery (Ombega et al., 2017). Moreover, native drought-resistant grasses offer potential solutions for combating land degradation, improving vegetation cover, and soil quality (Mganga et al., 2019). Recent studies focus on selecting soil and water conservation technologies and native tree species to restore degraded land, supporting tree growth and survival in degraded environments (Eshete et al., 2023).

Based on previous studies, most research has focused on general land rehabilitation techniques, both mechanical and vegetative, without specifically addressing the role of Ficus species in rehabilitation efforts or providing information on soil fertility across different land uses. Apart from that, rehabilitation of former mining areas has been carried out with the Shorea bangaleran plant species (Lestari et al., 2018) and *Pongamia pinnata* L (Maimunah et al., 2023) which have shown quite good results as alternative plants for restoration of forests and former mining areas. Therefore, this study aims to analyze soil fertility around Ficus trees used in degraded land rehabilitation efforts. By conducting an in-depth analysis of various soil fertility parameters, this research is expected to provide a more comprehensive understanding of the contribution of Ficus species to improving soil quality. The results of this study are anticipated to provide a strong scientific foundation for developing more effective and sustainable land rehabilitation strategies, while also contributing to soil conservation efforts and ecosystem restoration in areas affected by degradation.

2. Research Methods

2.1. Study area

This study was conducted in Kuningan Regency, West Java, Indonesia, located at coordinates 108.23° – 108.47° East Longitude and 6.47° – 7.12° South Latitude. The topography of the area ranges from flat and gently sloping to moderately steep and steep, with elevations ranging from 47 to 3,085 meters above sea level (m asl). The annual rainfall varies between 26.32 and 271.14 mm. Soil samples were taken from three types of land use: sand mining, which is located in the Cidahu and Ciawigebang sub-districts at elevations of 47-262 m asl; community gardens found in the Ciniru and Hantara sub-districts at elevations of 269-647 m asl; and secondary forests located in the Selajambe, Subang, and Cilebak sub-districts at elevations of 301-827 m asl. The location of soil sampling can be seen in Figure 1.

2.2. Experimental design

This research will be conducted both in the field and in the laboratory. The study population includes various types of land use, specifically in sand mining areas, community gardens, and secondary forests where Ficus trees are present. Soil samples will be taken from the

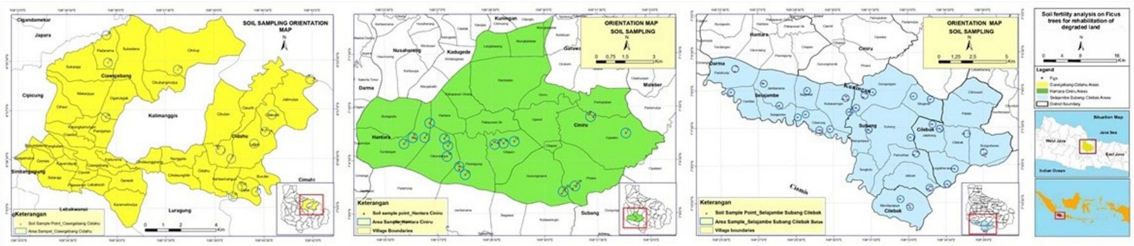

Figure 1. Location of soil sampling.

Table 1. Soil Testing Parameters and Methods.

Number	Test Parameters	Test Method
1	pH (H_2O dan *N* KCl)	Potentiometric
2	organic carbon content	Spectrophotometric
3	total nitrogen	Kjeldahl
4	C/N-Ratio	Counting
5	P_2O_5	Spectrophotometric-Olsen
6	Potential K_2O	AAS
7	Exchangeable Cations (K^+, Na^+, Ca^{2+}, Mg^{2+})	AAS
8	cation exchange capacity	Titrimetri
9	base saturation	Counting
10	soil texture (Sand, Dust, Klei)	Gravimetric

vicinity of the Ficus trees at the three types of land use to analyze and compare soil fertility at each location. In this study, the independent variable is the type of Ficus tree. Meanwhile, the dependent variable being measured is the level of soil fertility, which encompasses various chemical and physical soil parameters.

2.3. Data collection

Field data collection began with the creation of a sample plot with an area of 0.04 hectares when Ficus tree species were found at sand excavation sites, community gardens and secondary forests in 34 villages. Next, the data obtained is analyzed for each land use using the Important Value Index (IVI= RA+RCC+RF). To find out the selected species for each land use, the Species Similarity Index is used. The Jaccard index is used with qualitative data (e.g., species lists) to compare two sites based on the presence or absence of a species. It is based on the idea that the more species that both sites have in common, the more similar they are.

Data collection will be conducted at locations where selected Ficus species are growing, namely *Ficus benjamina*, *Ficus fistulosa*, *Ficus septica*, *Ficus variegata*, *Ficus ampelas*, and *Ficus virens*, in sand mining areas (7 points), community gardens (7 points), and secondary forests (12 points). The surrounding environmental conditions will be recorded, including temperature, humidity, and altitude. Soil samples will be taken from the soil layer at a depth of 0-30 cm at observation points using a composite method, where soil will be collected at a distance of about 1 meter in a specific direction, then mixed thoroughly. Approximately 1 kg of soil will be taken as the sample.

The analysis will cover various soil fertility parameters, including soil pH (Potentiometric), organic carbon content (Spectrophotometric), total nitrogen (Kjeldahl), C/N ratio, P_2O_5 (Spectrophotometric-Olsen), potential K_2O (AAS), cation exchange capacity (CEC) (Titrimetric), exchangeable cations (AAS), base saturation, and soil texture (Gravimetric) (Table 1).

2.4. Data analysis

The data obtained will be analyzed using vegetation analysis with Formulas 1 to 4:

$$IVI = RA + RCC + RF \tag{1}$$

$$\text{Relative desity (RD)} = \frac{\text{The density of a species}}{\text{Total density of all species}} x100\% \tag{2}$$

$$\text{Relative canopy cover (RCC)} = \frac{\text{Canopy cover of a species}}{\text{Total cover of all species}} x100\% \tag{3}$$

$$\text{Relative frequency (RF)} = \frac{\text{Frequensy value of a species}}{\text{Sum of frequency of all species studied}} x100\% \tag{4}$$

The proportion of species out of the total species list of the two sites, which is common to both sites (Formula 5):

$$SJ = c \ / \ \left(a + b + c\right) \tag{5}$$

where a and b represent the number of species unique to each site, c represents the number of shared species between the two sites, and SJ is the similarity index.

After obtaining the Ficus tree, the soil data was compared with the observational parameter data resulting from laboratory analysis with the criteria for assessing soil chemical properties in accordance with technical guidelines for evaluating land resources (Siswanto, 2006). Next, we will combine the criteria for soil chemical properties resulting from laboratory analysis with the technical guidelines for evaluating soil fertility from PPT (1995) to determine the fertility status of the soil where Ficus trees grow (Table 2).

The data analysis in this study will employ descriptive statistics to outline the characteristics of soil fertility for each sample. The results of this analysis will then be mapped based on the levels of soil fertility, enabling the identification and understanding of soil fertility variations across different research locations. The research procedures conducted in this study are as follows:

1. Selecting locations for soil sampling;
2. Determining specific spots for composite soil sampling within each research object;
3. Cleaning the soil surface of debris, grass, or other ground cover plants;
4. Taking soil samples from the cultivated layer at a depth of 0-20 cm, considering that most nutrients are primarily located at this depth;
5. The collected soil samples will then undergo laboratory analysis in the laboratory.

3. Results and Discussion

Based on the results of the field data collection, soil samples were obtained representing three land uses: sand extraction (7 soil samples), community gardens (7 soil samples), and secondary forests (12 soil samples). In the sand extraction area, the tree species found were banyan (Ficus benjamina) and awar-awar (*Ficus septica*). In the community garden area, the species found were more diverse, including beringin (*Ficus benjamina*), awar-awar (*Ficus septica*), beunying (*Ficus fistulosa*), and gondang (*Ficus variegata*). Meanwhile, in the secondary forest area, the species found were beringin (*Ficus benjamina*), awar-awar (*Ficus septica*), gondang (*Ficus variegata*), and kiara bunut (*Ficus virens*).

Based on Table 3, the results of the soil analysis across all locations indicate that the C-Organic values range from low to high. The lowest C-Organic value is found in the community garden location (0.27%), while the highest C-Organic value is recorded in the secondary forest location at 3.99%. This variation in C-Organic values reflects the organic matter content in the soil. Higher C-Organic levels indicate better soil quality (Supriyadi et al., 2021). The community gardens tend to have less organic matter because plant residues are often removed or cleaned up after harvest, disrupting the nutrient cycling from decomposed organic matter. Most community gardens also practice monoculture, which typically produces little organic material to enrich the soil. In contrast, the secondary forest has a more diverse and denser vegetation cover. Fallen leaves, dead wood, and undergrowth continually contribute organic matter to the soil. This natural decomposition process gradually enriches the soil's C-Organic content (Wang et al., 2021).

The total nitrogen content at the research locations shows values ranging from low to moderate, with the lowest total nitrogen value found in the community garden location (0.01%) and the highest in the secondary forest location (0.43%). The secondary forest has richer and more diverse vegetation compared to the community gardens. The deep roots of forest plants and the complex ecosystem networks allow for better absorption and cycling of nitrogen in the soil, which enhances nitrogen levels (Rivero et al., 2020). Community gardens are typically planted with monoculture or short-term crops that do not have as extensive root systems and organic matter as forest plants. Nitrogen is a type of nutrient that is easily soluble and regenerates, especially during rainy seasons when fertilizers are applied. This is in line with findings by Nurmegawati et al. (2012), which reported that most nitrogen is mobilized during harvest, with the remainder returned to the atmosphere as plant residues, evaporated, or leached through runoff.

The P_2O_5 parameter based on laboratory analysis shows values ranging from very low to moderate. The very low value is found at the sand mining location, which is 5.94, while the moderate value is observed in the secondary forest at 37.54. The sand mining location generally has low organic matter content because the fertile topsoil has been eroded or excavated. Organic matter plays a crucial role in the phosphate cycle in the soil as soil microorganisms help

Table 2. Criteria for assessing soil properties.

Soil Properties		VL	L	M	H	VH
C%		<1.00	1.00-2.00	2.01-3.00	3.01-5,00	>5.00
N%		<0.10	0.11-0.20	0.21-0.50	0.51-0.75	>0.75
P_2O_5 Olsen (ppm)		<10	11-25	26-45	46-60	>60
K (me 100 g^{-1})		<0.1	0.1-0.2	0.3-0.5	0.6-1.0	>1.0
KTK (mg 100 g^{-1})		<5	5-16	17-24	25-40	>40
Kejenuhan basa (%)		<20	21-35	36-50	51-70	>70
pH	Very Sour	Sour	Slightly Sour	Neutral	Slightly Alkaline	Alkaline
	<4.5	4.5-5.5	5.6-6.5	6.6-7.5	7.6-8.5	>8.5

Information: VL = Very Low; L = Low; M = Medium; H = High; VH = Very High.

Table 3. Results of laboratory analysis of soil properties criteria at all land use locations.

Location	Type	Organic Carbon	N Total	P_2O_5	K_2O	CEC	Base saturation	pH
Sand mining	*Ficus benjamina*	1.47 $_{L}$	0.11 $_{L}$	14.94 $_{L}$	49.53 $_{H}$	34.49 $_{H}$	68 $_{H}$	6.8 $_{N}$
	Ficus septica	1 $_{L}$	0.12 $_{L}$	5.94 $_{VL}$	109.38 $_{VH}$	51.94 $_{VH}$	100 $_{VH}$	8.2 $_{SA}$
	Ficus benjamina	1.59 $_{L}$	0.18 $_{L}$	8.57 $_{VL}$	30.79 $_{M}$	29.43 $_{H}$	56 $_{H}$	8.3 $_{SA}$
	Ficus septica	1.87 $_{L}$	0.19 $_{L}$	14.51 $_{L}$	94.98 $_{VH}$	27.98 $_{H}$	100 $_{VH}$	8.1 $_{SA}$
	Ficus benjamina	3.47 $_{H}$	0.27 $_{M}$	15.32 $_{L}$	31.37 $_{M}$	30.92 $_{H}$	100 $_{VH}$	7 $_{N}$
	Ficus septica	1.82 $_{L}$	0.14 $_{L}$	10.97 $_{L}$	54.3 $_{H}$	24.41 $_{M}$	91 $_{VH}$	7.7 $_{SA}$
	Ficus benjamina	2.08 $_{M}$	0.18 $_{L}$	30.53 $_{M}$	644.44 $_{VH}$	43.1 $_{VH}$	100 $_{VH}$	8.2 $_{SA}$
Community garden	*Ficus fistulosa*	0.41 $_{VL}$	0.01 $_{VL}$	6.03 $_{VL}$	45.08 $_{H}$	31.94 $_{H}$	100 $_{VH}$	7.4 $_{N}$
	Ficus septica	2.81 $_{M}$	0.24 $_{M}$	9.23 $_{VL}$	50.62 $_{H}$	33.26 $_{H}$	100 $_{VH}$	7.4 $_{N}$
	Ficus benjamina	3.18 $_{H}$	0.28 $_{M}$	11.87 $_{L}$	238.63 $_{VH}$	46.36 $_{VH}$	100 $_{VH}$	7.3 $_{N}$
	Ficus variegata	3.96 $_{H}$	0.21 $_{M}$	11.12 $_{L}$	40.68 $_{M}$	19.27 $_{M}$	100 $_{VH}$	7.9 $_{SA}$
	Ficus septica	0.52 $_{VL}$	0.07 $_{VL}$	6.95 $_{VL}$	59.05 $_{H}$	49.36 $_{VH}$	100 $_{VH}$	7 $_{N}$
	Ficus septica	0.75 $_{VL}$	0.07 $_{VL}$	18 $_{L}$	44.75 $_{H}$	37.52 $_{H}$	100 $_{VH}$	8.3 $_{SA}$
	Ficus septica	0.53 $_{VL}$	0.06 $_{VL}$	29.05 $_{M}$	56.32 $_{H}$	54.93 $_{VH}$	23 $_{L}$	8 $_{SA}$
Secondary forest	*Ficus benjamina*	3.99 $_{H}$	0.36 $_{M}$	17.95 $_{L}$	33.34 $_{M}$	51.39 $_{VH}$	100 $_{VH}$	6.8 $_{N}$
	Ficus virens	1.1 $_{L}$	0.11 $_{L}$	5.06 $_{VL}$	69.77 $_{H}$	50.51 $_{VH}$	100 $_{VH}$	6.6 $_{N}$
	Ficus benjamina	0.99 $_{VL}$	0.12 $_{L}$	6.54 $_{VL}$	90.01 $_{VH}$	55.55 $_{VH}$	100 $_{VH}$	7 $_{N}$
	Ficus virens	0.27 $_{VL}$	0.11 $_{L}$	20.63 $_{L}$	43.58 $_{H}$	61.49 $_{VH}$	94 $_{VH}$	7.3 $_{N}$
	Ficus virens	1.87 $_{L}$	0.43 $_{M}$	11.13 $_{L}$	17.28 $_{L}$	39.02 $_{H}$	100 $_{VH}$	6.8 $_{N}$
	Ficus septica	0.51 $_{VL}$	0.13 $_{L}$	37.54 $_{M}$	39.86 $_{M}$	45.25 $_{VH}$	89 $_{VH}$	6.9 $_{N}$
	Ficus virens	0.58 $_{VL}$	0.12 $_{L}$	5.05 $_{VL}$	78.52 $_{VH}$	38.89 $_{H}$	69 $_{H}$	6.2 $_{SS}$
	Ficus benjamina	1.3 $_{L}$	0.19 $_{L}$	9.59 $_{VL}$	73.96 $_{VH}$	45.19 $_{VH}$	100 $_{VH}$	6.3 $_{SS}$
	Ficus benjamina	2.31 $_{M}$	0.26 $_{L}$	26.25 $_{M}$	74.6 $_{VH}$	43.64 $_{VH}$	100 $_{VH}$	7 $_{N}$
	Ficus benjamina	1.21 $_{L}$	0.26 $_{L}$	1.79 $_{VL}$	136.84 $_{VH}$	34.65 $_{H}$	100 $_{VH}$	5.7 $_{SS}$
	Ficus virens	2.85 $_{M}$	0.29 $_{L}$	10.02 $_{L}$	117.11 $_{VH}$	44.27 $_{VH}$	100 $_{VH}$	6.2 $_{SS}$
	Ficus variegata	1.34 $_{L}$	0.21 $_{L}$	14.32 $_{L}$	66.93 $_{H}$	32.84 $_{H}$	100 $_{VH}$	6.4 $_{SS}$

Information: VL =Very Low; L = Low; M = Medium; H = High; VH = Very High; VS = Very Sour; S = Sour; SS = Slightly Sour; N = Neutral; SA = Slightly Alkaline; A = Alkaline.

release available phosphates for plants (Rawat et al., 2021). In contrast, the secondary forest has denser vegetation and a significant amount of decomposed plant residues that provide more organic matter, contributing to higher P_2O_5 content (Sharma et al., 2020).

Additionally, sand mining locations often experience significant soil erosion, leading to the loss of nutrient-rich topsoil, including phosphates. In the secondary forest, the soil layer is better protected by vegetation cover, which minimizes erosion and maintains phosphate content in the soil. Furthermore, the soil at sand mining sites typically consists of coarser, sandy textures that have a lower capacity to retain nutrients like phosphates. Conversely, the soil in the secondary forest tends to have a finer texture, allowing for better phosphate retention, thus resulting in higher P_2O_5 concentrations. In the secondary forest, biological activity is more intense due to soil fauna and microorganisms that decompose organic matter and release phosphates into the soil. In sand mining locations, this biological activity decreases due to environmental degradation and the lack of organic matter to support the survival of soil microorganisms (Lin et al., 2022).

The K_2O values at the research locations range from low to very high. The low value (17.8) is found in the secondary forest, while the very high value (644.44) is observed in the sand mining location. At the sand mining site, due to excavation, deeper, unweathered soil may be more exposed. The underlying soil layers, rich in minerals including potassium, are more exposed, resulting in a very high K_2O content (Hoy et al., 2023). Conversely, in the secondary forest, the soil is protected by organic layers and vegetation and has undergone natural nutrient cycling, which facilitates the release of potassium into the plant ecosystem. The potassium present in the soil of the secondary forest has been utilized by plants, leading to lower potassium content in the soil.

The Cation Exchange Capacity (CEC) values from the research locations range from moderate to very high. The smallest moderate value (19.27) is found in the community gardens, while the very high value (61.49) is observed in the secondary forest. Secondary forests generally have a higher organic matter content compared to community gardens. Organic matter, such as humus formed from the decomposition of leaves and plant residues, plays a crucial role in enhancing CEC as it can effectively absorb and release cations. Therefore, secondary forests tend to have higher CEC (Takoutsing et al., 2016). In community gardens, the soil is often more degraded due to agricultural activities, such as soil tillage and chemical usage, which can diminish soil texture and its capacity to retain cations. Conversely, the soil in secondary forests is usually less disturbed, resulting in a more stable soil structure that can maintain a high cation exchange capacity (Liu et al., 2024).

The base saturation values from the three locations range from low to very high. The low value (23) is found in the community gardens, while the very high value (100) is observed in all land use locations. Secondary forests tend to have a higher organic matter content due to the abundant naturally decomposing plant residues, such as leaves, branches, and wood. This decomposition process enriches the soil with essential nutrients such as calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na), which are base cations (Marimon-Junior et al., 2020). As a result, the base saturation in the secondary forest reaches the maximum value of 100.

The high organic matter content helps maintain a good nutrient cycle and enhances the soil's capacity to absorb and retain base cations. Conversely, community gardens often experience a decline in organic matter content due to more intensive land management practices, including weeding, tillage, and monoculture planting. These repetitive agricultural activities can lead to a reduction in organic matter in the soil, consequently lowering the base cation content. As a result, the base saturation in community gardens is significantly lower.

The soil pH values at the research locations range from slightly acidic to slightly alkaline. The slightly acidic value (5.7) is found in the secondary forest, while the slightly alkaline value (8.3) is observed in the sand mining sites and community gardens. Soil in the secondary forest typically has a high organic matter content from decomposed plant residues, such as leaves and branches. The decomposition process carried out by microorganisms often produces organic acids, such as humic and fulvic acids. These acids tend to lower the soil pH, making it more acidic (Bayazitova et al., 2023). Therefore, the secondary forest locations usually exhibit a slightly acidic pH.

In contrast, the community gardens and sand mining locations generally have lower organic matter content. This reduction in organic matter decreases the production of organic acids that play a role in lowering soil pH. Additionally, the soil in sand mining areas often consists more of mineral materials that have a basic effect, resulting in a slightly alkaline pH (8.3). In community gardens, certain agricultural practices, such as liming or using alkaline fertilizers, can also raise the soil pH (Wang et al., 2020).

3.1. Analysis of soil fertility parameters on Ficus trees

3.1.1. Parameter C-Organic

In the analysis of the C-Organic parameter, various species of Ficus were evaluated based on their C-Organic values, ranging from the lowest to the highest. The species **Ficus virens** was found to thrive well at the lowest C-Organic value, while **Ficus benjamina** exhibited optimal growth at the highest C-Organic value. Notably, **Ficus benjamina** can also grow in conditions with low C-Organic content (0.99%), indicating that this species is adaptable and can survive in a range of C-Organic levels, from low to high. This adaptability highlights the ecological importance of **Ficus benjamina** as a resilient species that can contribute to soil fertility and overall ecosystem health, even in less-than-ideal soil conditions. The C-Organic parameter map can be seen in Figure 2.

3.1.2. Total nitrogen parameters

In the Total Nitrogen parameter, the Ficus fistulosa type can grow at the lowest conditions, while the *Ficus virens* type is at the highest value. However, these two types are not evenly distributed in each location with varying Total Nitrogen values. The Total Nitrogen parameter map can be seen in Figure 3.

3.1.3. Parameters P_2O_5

In this phosphate parameter, the Ficus benjamina type can grow at the lowest value and the *Ficus septica* type is found at the highest phosphate value. However, the Ficus benjamina type also has the second highest phosphate value. The P_2O_5 parameter map can be seen in Figure 4.

3.1.4. K_2O parameters

In this parameter, the types of *Ficus virens* and *Ficus benjamina* can be found at the lowest K_2O value and also at the same type of value, namely Ficus benjamina is found at the highest K_2O value. The K_2O Parameter Map can be seen in Figure 5.

3.1.5. Cation exchange capacity parameter

In the cation exchange capacity parameter, the *Ficus variegata* type is at the lowest value (19.27) and the *Ficus virens* type is at the highest value (61.49). The CEC Parameter Map can be seen in Figure 6.

3.1.6. Base saturation parameters

In the base saturation parameter, the *Ficus septica* type is at the lowest value (23) and also has the highest base saturation value along with the types *Ficus benjamina*, *Ficus fistulosa*, *Ficus variegata*, and *Ficus virens* with a base saturation value of 100. The base saturation parameter map can be seen in Figure 7.

3.1.7. pH parameters

In terms of pH parameters, the Ficus benjamina type is at the lowest pH value (5.7) and the *Ficus septica* type is found at the highest pH value (8.3). The pH parameter map can be seen in Figure 8.

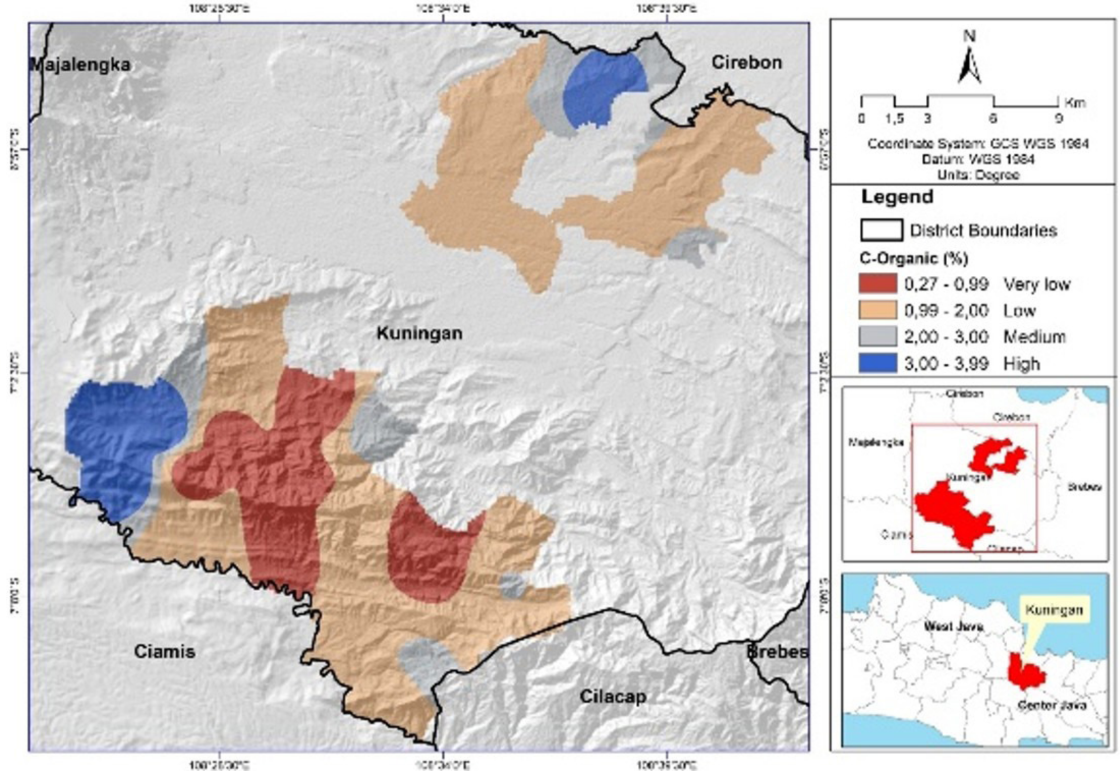

Figure 2. C-Organic parameter map.

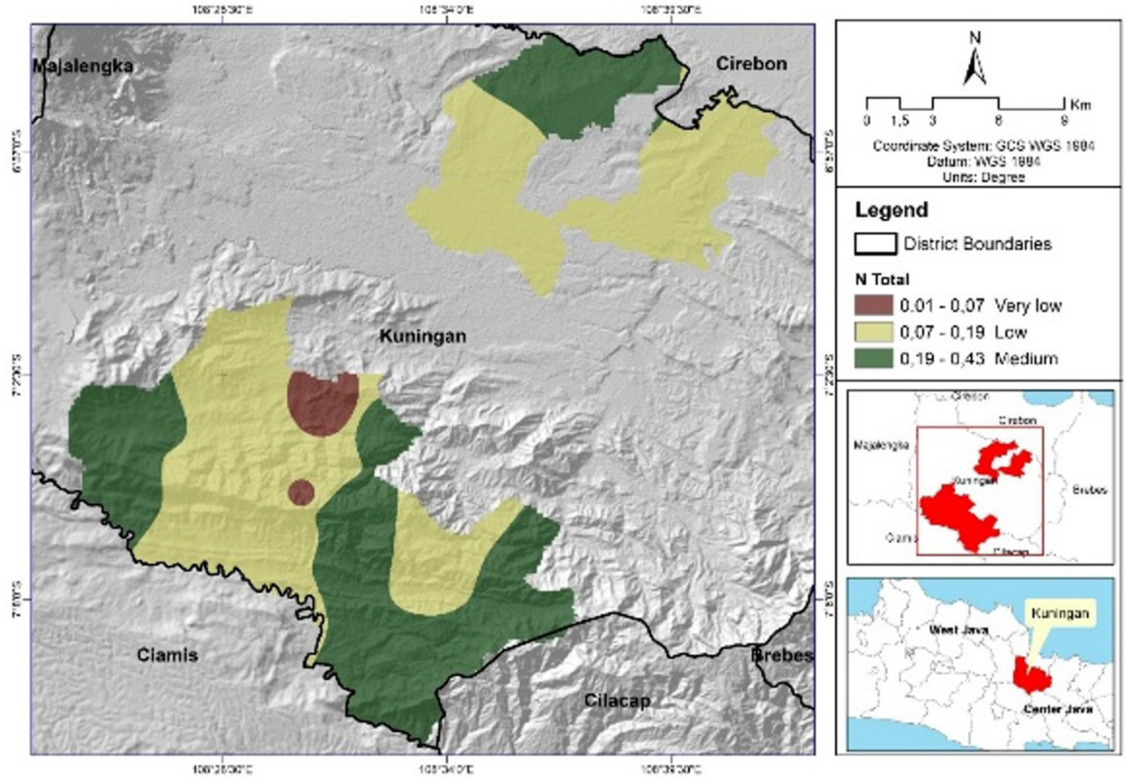

Figure 3. Total Nitrogen parameter map.

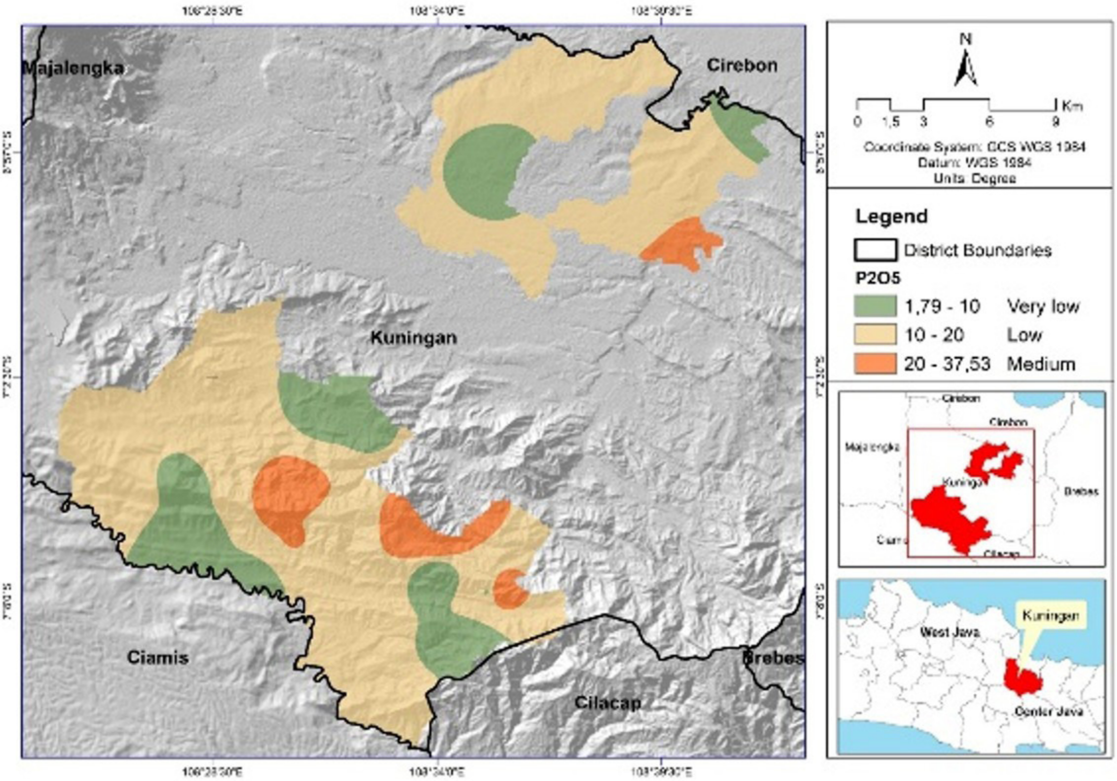

Figure 4. P_2O_5 parameter map.

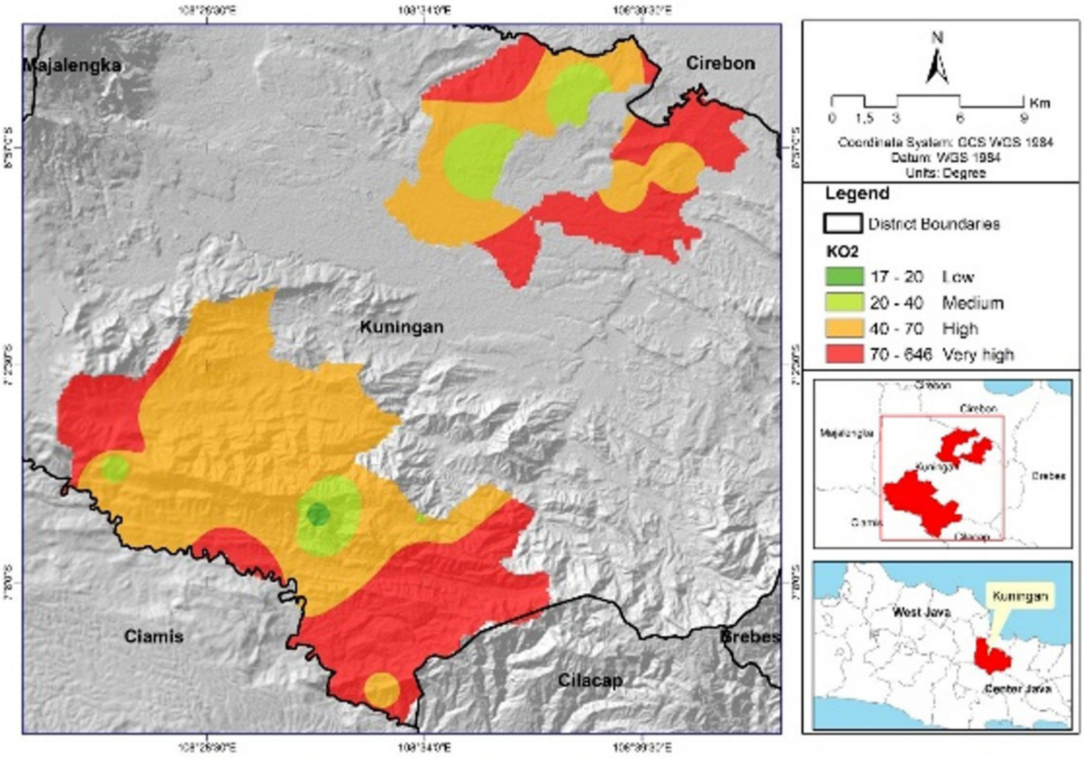

Figure 5. K_2O Parameter map.

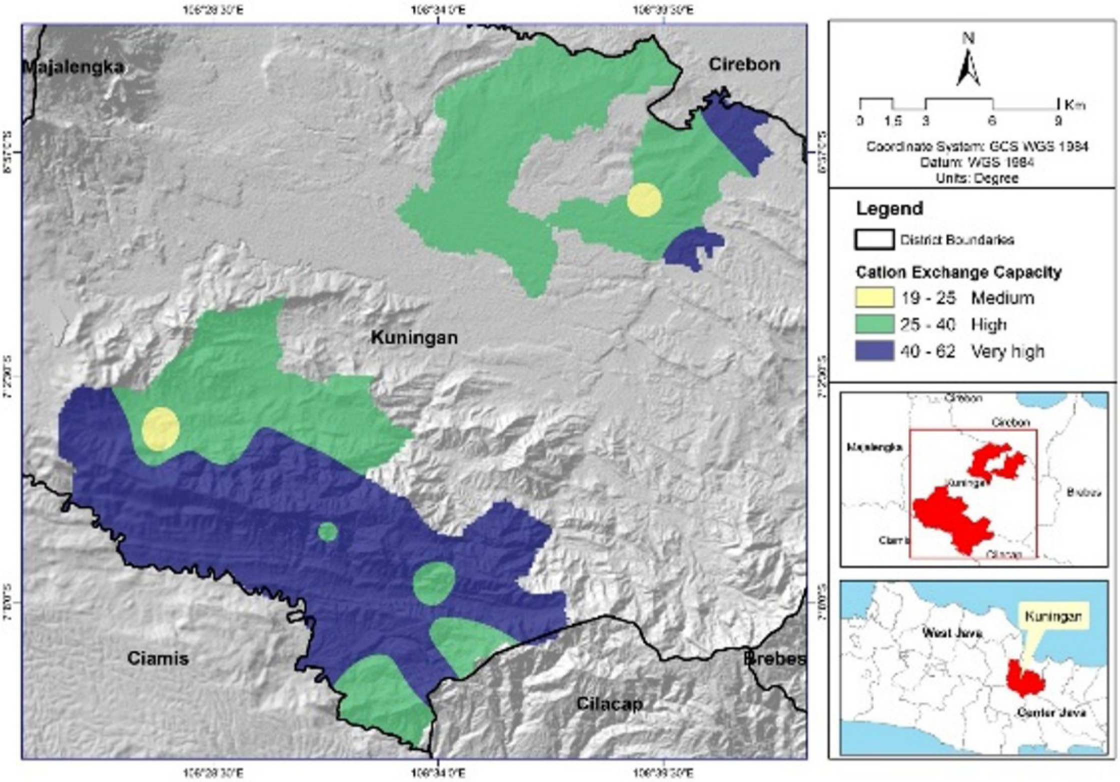

Figure 6. CEC Parameter map.

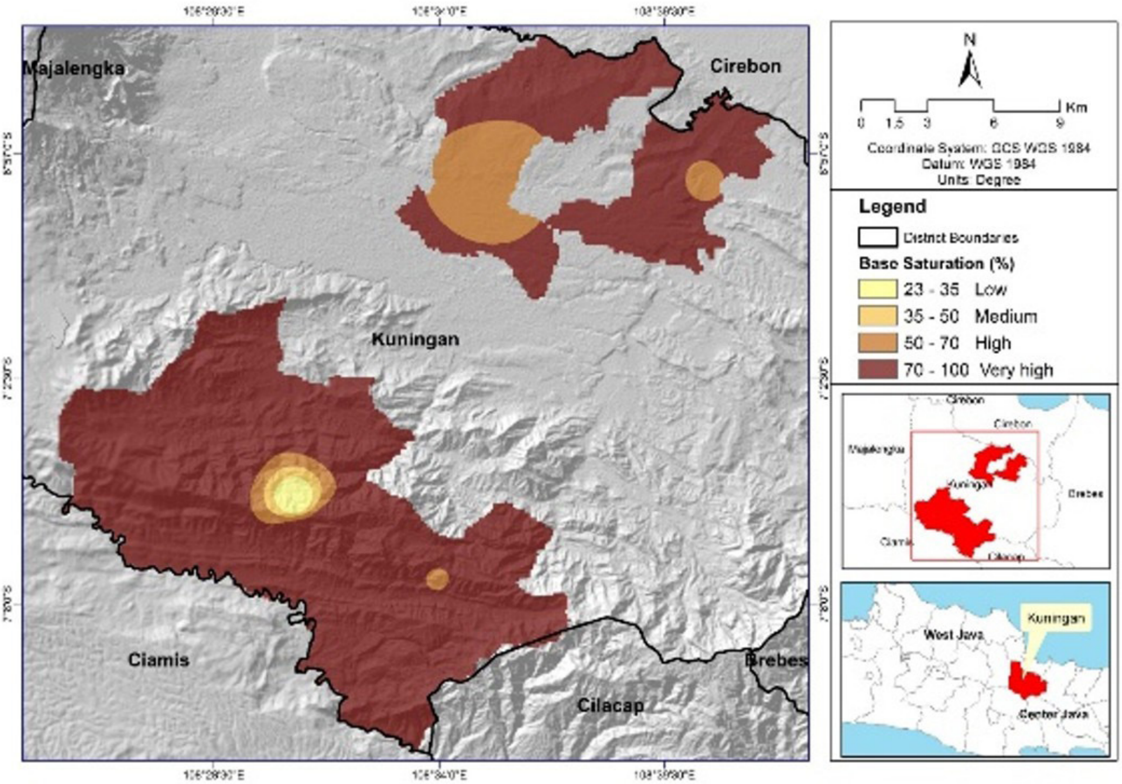

Figure 7. Map of base saturation parameters.

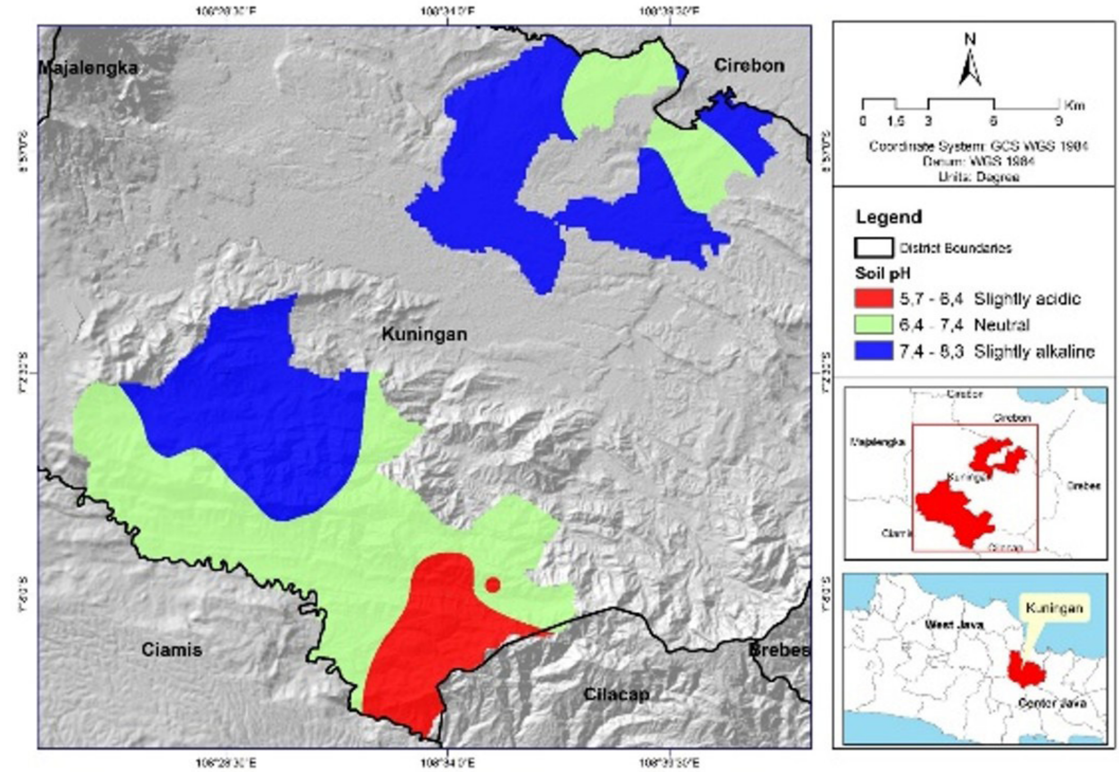

Figure 8. pH parameter map.

4. Conclusion

Soil fertility parameters at sand mining sites range from low to medium, at community garden sites have very low to high values and at secondary forest sites have very low to very high values. The types of ficus that can be found in sand excavation locations are *Ficus benjamina* and *Ficus septica*, in community garden locations the types are *Ficus septica*, *Ficus fistulosa*, *Ficus variegata* and *Ficus benjamina* while in secondary forest locations the types of ficus found are *Ficus benjamina*, *Ficus virens*, *Ficus septica* and *Ficus variegata*.

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