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Soil quality and vegetation identification in closed sand-gravel mining area in West Java, Indonesia

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ABSTRACT

This paper examines the soil quality and vegetation identification in a closed sand gravel mining area in West Java, Indonesia. Revegetation of disturbed mining areas is crucial in restoring soil quality and environmental function. The native plants play a pivotal role in accelerating this process. The goal of this mixed-methods study in closed sand-gravel mining was to look at the nutrient profile, texture, and microbial count of the soil in two places in the foothills of a closed mine, as well as to find and name the plant species that naturally grow well and to find and name the plant species that naturally grow well when it rains. The observation showed that the soil near the spring was more fertile than the soil away from the spring, and the soil surrounding the spring supported a higher plant density. The study area supported the growth of 22 plants, including two trees, 13 shrubs, two sedges, four grasses, and one fern. Notably, two perennial trees–Mexican lilac and beech wood–were successfully grown during the initial greening program conducted three years ago. The bacterial and fungal counts for both soils were 10^9 colony-forming units (CFU) per g and 10^4 CFU/g, respectively. We found different morphology in the soil fungal colonies, while the bacteria colonies remained homogenous. The results underscore that the soil in the disturbed mine area still supported the native plant growth. These findings are crucial for the preservation of these native plants, making them crucial for the intensive revegetation of the mining area prior to the introduction of suitable perennial trees.

Contribution/Originality: This is the first published study about the soil properties of closed sand-gravel mining in West Java, Indonesia. The areas' intense mining has reduced vegetation, yet the study of the post-mining vegetation remains unexplored. For initial revegetation, soil and vegetation data are essential.

1. INTRODUCTION

Indonesia, known as the global Ring of Fire, is home to Java Island, which has 34 active volcanoes. The repeated volcanic eruptions have led to the formation of hills or mountains with layers of rock, sand, and ash [1]. On the hills' tops, shallow soil often forms where native vegetation grows. From a volumetric perspective, the aggregate sand, gravel, and crushed stone in the rock hills represent the most essential non-metal and rock materials [2]. Indonesia's sand and rock extraction increased from 3,663 locations in 2018 to 4,600 in 2020. The reserve of granite, the most valuable igneous rock in Indonesia, will be more than 258 million tons in 2022 [3].

Private sand-gravel mining activity has been conducted for five years in the rock hills at Rancabawang in West Java. Due to environmental issues, sand and gravel extraction ceased in 2014. we are now imitating the rehabilitation process of the former mining area to prevent broader environmental degradation. Mining damages the natural landscape and destroys biodiversity; it eradicates plants, animals, and microbes; and it eliminates natural soils [4]. Currently, the threat of environmental damage at former mining sites is the loss of parts of the hills, soil, and natural vegetation. The soil loss due to material extraction threatens vegetation and intensifies soil erosion. Moreover, parts of the mountain have not yet stored enough water, resulting in dryness during the dry season. In the case of ex-mine Rancabawang, fortunately, the sand-rock extraction was conducted in less than 4 ha of 14 ha of rock hills.

Despite limited topsoil depth, the hills are greening in the rainy season; however, food crop cultivation has not yet occurred. Ceasing the sand and gravel extraction provides enough space and nutrients for natural and successful plants to grow. Plant roots contribute to gathering belowground resources, including water and nutrients for plant shoots [5]; they also interact with the rhizosphere, a soil surrounding and in the vicinity of plant roots [6]. Roots exudate fixed carbon, amino acids, organic acids, and enzymes that serve as energy and nutrients for various soil microbial processes in the rhizosphere [7]. Microbes surrounding the soil continuously decompose the roots, leading to an increase in organic matter that enhances and sustains soil physics and chemistry [8], as well as the population and diversity of soil microbes [9]. Both functions ensure nutrient and water availability, benefiting plant growth and crop production.

Vegetation coverage in the ex-mining area is an essential indicator for recovering ecological environment quality during land reclamation [10]. Vegetation restores soil quality, maintains soil water, and modifies the microclimate around plants that determine food crop production [11]. The identification and evaluation of soil properties is the first step in determining the area's suitability for other types of land use, including agriculture and forest. Moreover, vegetation identification is also needed for slope stabilization, landslide prevention, and plant community establishment [12, 13]. Therefore, the study has been performed to analyze the soil properties of closed sand-gravel mining hills and to identify the species of survival and successor plants after the mining has been closed.

2. METHODOLOGY

The study was conducted in the closed sand-gravel mining area at Rancabawang, Cinanjung Village, Tanjungsari District, Sumedang Regency, West Java 45362, at the coordinates of -6.921 and 107.799 (Figure 1). The peak of Gunung Batu was 930 m above sea level. According to Schmidt & Fergusson, Sumedang has a tropical climate type of B, which is a wet climate with a Q of 0.32%. this means that nearly all tropical vegetation, including food crops and plantations, can thrive in this area. The average annual temperature and humidity are between 20°C -36°C and 55%-70%, respectively, while the annual rainfall was 2,570 mm.

Figure 1. Map of study area in Rancabawang, Tanjung Sari, Sumedang Regency of West Java.

We used a qualitative and quantitative descriptive mixed method to conduct the study. Primary data included chemical composition, texture, and microbial population of four soil samples taken by purposive sampling. The soil samples were taken by purposive sampling from the foot of the hills where the gravel extraction occurred. We collected two samples from the moist soil near the spring (A) and the dry soil adjacent to the hills (B), 15 meters from the spring. We collected the soil using Auger at a depth of 30 cm using a composite method. We collected the soil from five sampling points at each location and thoroughly mixed it before conducting the soil analysis. The chemical characteristics of soil were determined by proximate chemical analysis [14], while the carbon-to-nitrogen (C/N) ratio was calculated from the organic C and total N. We performed the texture determination using the gravimetric method [15]. We counted the bacterial and fungal populations in duplicate by using the serial dilution plate method for nutrient agar and potato dextrose agar [16].

The vegetation, which included trees, shrubs, weeds, and ferns grown naturally covering the hills and foothills, was identified based on their common name, taxonomy, and local utilization. The weeds included narrow leaves (grasses), grasslike plants (sedges), and broad leaves. We used the Pl@ntNet application to identify plants by photographing them with a smartphone. The Guide Book of Invasive Plant Species In Indonesia has been used to identify vegetation species [17]. Discussions with local people allowed us to understand the local function of certain plants.

3. RESULTS AND DISCUSSION

3.1. Soil Fertility

Table 1 shows the chemical and physical characteristics of soil collected from the center of the mining area. Both soils were slightly acidic, with distinctive differences in organic C, total N, and C-to-N (C/N) ratio in both samples.

Table 1. Nutrient profile and texture of the soil in closed sand-gravel mining area.

Soil properties	Unit	Location A		Location B	
		Value	Status	Value	Status
pH_{H2O}	-	6.29	Slightly acid	6.02	Slightly acid
Organic C	%	3.86	High	0.85	Poor
Total N	%	0.28	Medium	0.13	Low
C/N[1]	-	14	Medium	7	Low
Potential P_2O_5	mg/100 g	40.32	Medium	73.32	Very high
Available P_2O_5	mg/kg	1.92	Poor	4.02	Poor
Potential K_2O	mg/100 g	14.63	Low	19.32	Low
Exchangeable cations					
K-dd	cmol/kg	0.12	Low	0.08	Poor
Na-dd	cmol/kg	0.23	Low	0.45	Medium
Ca-dd	cmol/kg	14.90	High	10.79	High
Mg-dd	cmol/kg	11.60	Very high	6.05	High
CEC[2]	cmol/kg	43.74	Very high	19.34	Medium
Base saturation	(%)	61.40	High	89.93	Very high
Al-dd	cmol/kg	0.61	-	0.20	-
H-dd	cmol/kg	0.24	-	0.25	-
Al saturation	%	0.22	Poor	1.15	Poor
Solid fraction composition					
Sand	%	11	Low	11	Low
Silt	%	84	Very high	55	High
Clay	%	5	Very low	34	Medium

Note: [1]Carbon-to-Nitrogen ratio, [2]Cation exchange capacity.

Due to the low levels of organic C and total N, the B soil had a lower C/N ratio. The B soil has a higher concentration of potential P_2O_5 than B soil, but both soils contained very low available P_2O_5 and low K_2O. In general, the concentration of the Ca and Mg in B soil resulted in higher cation exchange capacity (CEC); however, the BS of both soils was high. Both the soils lack exchangeable Al and H acid cations, indicating the soil is not acidic. Based on the solid fraction composition, the texture of A soil is silt, with an approximately 84% silt fraction. B soil had a better texture because of its relatively good sand, silt, and clay composition. Both soils had a porosity of about 43%-44%.

3.2. Fungal and Bacterial Population

The fungal and bacterial count of soil in both samples was similar (Figure 2a). Both soils contained approximately 10^9 CFU g^{-1} of bacteria (equal to 9 on the log scale) and less than 10^4 CFU g^{-1} of fungi. Despite the different soil chemical characteristics, the heterotrophic fungi and bacteria likely survived at a similar proliferation rate. In this study, we found different morphologies of fungal colonies. While the colony of bacteria in the plate agar was homogenous (Figures 2b and 2c).

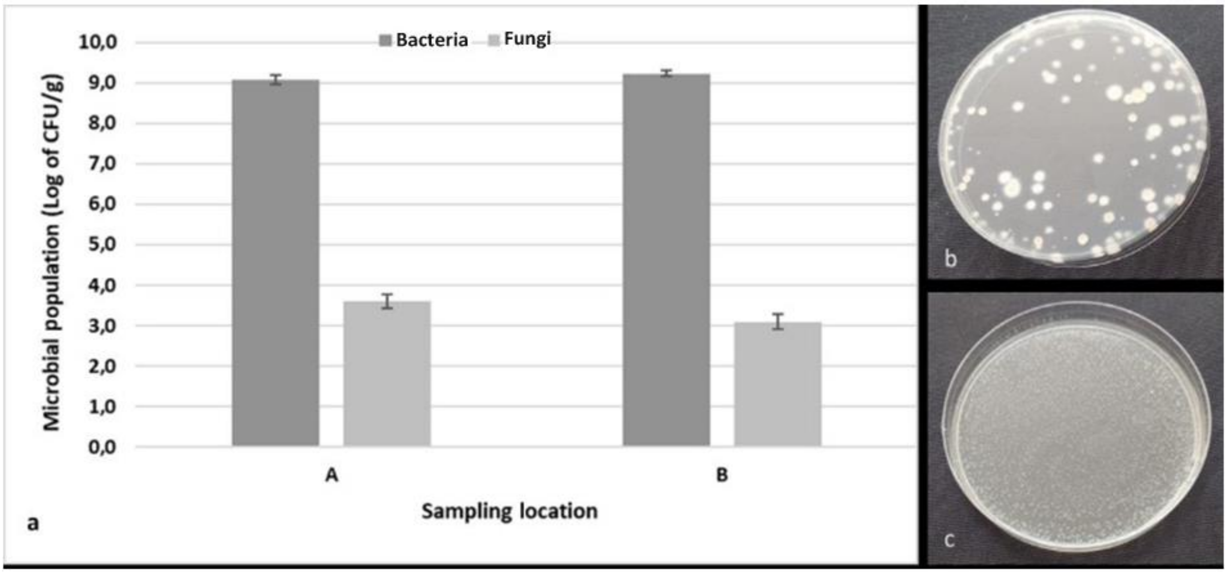

Figure 2. a. Population of total soil fungi and bacteria in the foothills of the former mining area; b. Fungal and c. Bacterial colony on plate agar. A similar letter indicates the insignificant difference between values.

3.3. Vegetation Species

Vegetation coverage is limited during the dry season due to water scarcity, and it changes distinctly in the wet season (Figure 3).

Figure 3. The natural vegetation of closed sand-gravel mining in the dry season (a) and wet season (b).

We conducted the identification of vegetation in the study area during the rainy season. We found 22 species of plant in the foot's hills area, composed of two trees, 13 shrubs, two sedges, four grasses, and one fern (Table 2 and Table 3). We found all species in both locations, with the exception of lantana, which only grew in the dry area outside the spring and fern, which we only found near the spring. However, in the spring area, the density of all species is higher. Two species of trees, Mexican Lilac and Beechwood, were grown in the initial and limited revegetation program after closing the mine. We used the leaves of Mexican lilac (legume tree) as an essential feed for the goats and purchased the log of Beechwood.

Table 2. Trees and Shrubs in the closed mining area.

No.	Local name, common name	Binomial name	Order, Family	Function-based ethnobotany
Tree				
1	Gamal, Mexican Lilac	*Gliricidia sepium* (Jacq.) Walp	Fabales, Fabaceae	Pest trap, fodder, greening tree
2	Jati Putih, Beechwood	*Gmelina arborea* Roxb. ex Sm.	Lamiales, Lamiaceae	Wood, fodder, greening tree
Shrubs				
1	Ara sungsang, Chinese violet	*Asystasia gangetica* L.	Lamiales Acanthaceae	Traditional medicine
2	Ketul or Ajeran, Spanish Needles	*Bidens Pilosa* L.	Asterales Asteraceae	Traditional medicine
3	Pecut kuda, Blue porterweed, blue snake	*Stachytarpheta jamaicensis* (L.) Vahl	Lamiales Verbenaceae	Traditional medicine
4	Balakacida, Slam weed	*Chromolaena orodata* L. Syn. *Eupatorium odoratum*	Asterales Asteraceae	Traditional medicine
5	Putri Malu, Shameplants	*Mimosa pudica* Linn.	Fabales Fabaceae	Traditional medicine
6	Kembang kangkung, Morning glory,	*Ipomoea obscura* (L.) Ker Gawl	Solanales. Convulvulaceae	Traditional medicine
7	Kalopo, calopo	*Calopogonium mucunoides* Desv.	Fabales Fabaceae	Legume Cover Crops Green manure
8	Kate Mas, Mexican fireplant	Euphorbia heterophylla L.	Malpighiales Euphorbiaceae	Medicine
9	Sintrong, Fireweed	*Crassocephalum crepidioides* (Benth.) S. Moore	Asterales Asteraceae	Food and traditional medicine
10	Sambiloto, Green chiretta shrub	*Andrographis paniculata* (Burm. f.) Ness	Lamiales Acanthaceae	Traditional medicine
11	Saliara, Lantana	*Lantana camara* L.	Lamiales Verbenaceae	Ornamental plants, traditional medicine, natural insecticide
12	Bayam merah, Elephant-head amaranth	*Amaranthus gangeticus* L.	Caryophyllales Amarantaceae	Traditional medicine
13	Calincing, Oxalis corniculate	*Oxalis corniculate* L.	Oxalidales Oxalidaceae	Traditional medicine

Among 13 species of shrubs (Table 2), there were cover crops of the species Calopo (Figure 4a), as well as morning glory and wood sorrel (*Oxalis* sp), which helped to protect the soil from high evapotranspiration in the tropics. Calopo is a trailing legume that forms a symbiosis with nitrogen-fixing bacteria in its root nodule, increasing nitrogen (N) availability in soil. Morning Glory and Oxalis are creeping shrubs that cover the soil quickly. The perennial shrubs *Asystasia gangetica* L. and Lantana camara L. can protect the soil from erosion. Moreover, commercialization of lantana (Figure 4b) as an ornamental plant has begun.

In the rainy season, the sedges grew naturally between the gravel and sand on the foothills and rock hills (Table 3). Bullrush sedges, *Typha latifolia* L. (Figure 4c), are found in dense clumps in the foothills near spring. In Indonesia, people believe this sedge to be effective in filtering water, making it clear and less soluble in solids. Among four grass species, slender tuft grass (Figure 4d) and summer grass were picked up periodically in the rainy season for goat fodder. They were growing not only in the rock but also in the soil of the foothills. High humidity around the spring allowed a tropical fern, *Cheilanthes covillei*, to grow; these pioneer plants usually die during the dry season, but the soil keeps its spores from germinating in the next wet season.

Table 3. Sedge, Grass, and Fern in the closed mining area.

No.	Local name, common name	Binomial name	Order, family	Function-based on local ethnobotany
SEDGE				
1	Ekor kucing, Bul rush sedges	*Typha latifolia* L.	Poales Typhaceae	Wastewater biofilter
2	Kacang Palsu, Nutsedges sedge	*Cyperus strigosus* L.	Poales Poaceae syn. Gramineae	-
Grass				
1	Alang–alang, cogon grass grass	*Imperata cylindrica* L.	Poales Poaceae	Traditional medicine
2	Rumput bambu, Slender Tuft Grass	*Pogonatherum crinitum* (Thunb.) Kunth	Poales Poaceae syn. Gramineae	Fodder
3	Rumput brandjangan, Itchgrass	*Rottbellia cochinchinensis* (Lour.) Clayton	Poales Poaceae	Bird fodder, invasive species
4	Rumput, Summer grass	*Alloteropsis cimicina* (L.) Stapf	Poales Poaceae	Fodder
Fern				
1	Pakis bibir, Coville's lip fern	*Cheilanthes covillei* (Maxon)	Polypodiales. Pteridaceae.	Ornamental plants

Figure 4. Prominent pioneer plants in the hills of the mining area included a. Calopo (*Calopogonium mucunoides* Desv.), b. lantana (*Lantana camara* L), c. bull rush sedge (*Typha latifolia* L), and d. slender turf grass (*Pogonatherum crinitum* (Thunb.) Kunth).

4. DISCUSSION

The current study verified that the A soil surrounding the spring was more fertile than the B soil. Because of water availability, the moist soil adjacent to the spring allows diverse vegetation to grow. Therefore, the vegetation in this area was more varied and denser. Roots contribute to the organic matter and total-N content increment in soil; organic matters provide the nutrients for microbes, and their decomposition contributes to organic carbon (C). The organic-C, total-N, and C/N ratio are the essential soil parameters to determine N availability for root uptake.

A lower C/N ratio of B soil indicates that the N, a major nutrient essential for plant growth, is available but susceptible to leaching out. A higher C/N ratio up to 25 allows organic matter decomposition into carbon dioxide and nutrients such as N and phosphor (P) essential for plant metabolisms [18]. High organic matter usually induces microbial population and diversity, mainly heterotrophs. Roots exudate provide energy and nutrients for various soil microbial processes in the rhizosphere [7]. However, the A and B soils had similar counts of fungi and bacteria. The nutrient agar and potato dextrose agar only isolated nonspecific microbes. The microbial diversity in both soils is likely different. The most important things that affect the activity of heterotropic microbes and the make-up of the microbial community vary depending on the type of soil and climate [19]. These are acidity, organic carbon content, and the C:N ratio. Microbes that have heterotrophic metabolism in soil are very dependent on organic material. Soil C/N ratio influences bacterial communities and determines the diversity of bacterial phylum, classes, orders, and families [20]. Conversely, fungi adapt to a C/N ratio ranging from 7 to 126 [21].

This increase in vegetation cover is essential for greening the former mining area and further vegetation management. Precipitation from the rain is the only water source for the vegetation of rock hills away from the spring; meanwhile, the spring at the foot of the hills provides enough water for surrounding plants. The study's wet season saw an average monthly rainfall of 273 mm, while the dry season may see a reduction to 37mm.

The data on plants grown naturally or intentionally in the closed mining area is essential for considering several factors in initiating the revegetation program and crop cultivation. This consideration is crucial for successful greening, as it enhances the spring function and reduces water debt. In this area, vegetation was adaptive to low-fertility soil; they are fast-growing plants when water is available. Animal activities, wind, and water facilitate their natural growth at the rock hills through seed dispersal mechanisms [22]. Roots are also significant and complex in regulating plant development under water scarcity [23]. This study showed that soil supports the growth of pioneer vegetation and introduced plants. This interest encourages the use of native plants in the revegetation of disturbed sites before growing agricultural plants. The vegetation enhances soil quality and supports the growth of other successor plants. Land use conversion from natural to intensive agriculture can focus on food crop production in the foothills and timber production on the top of the hills. People now cultivate food crops near the foothills, while perennial trees naturally grow on the hill peak. However, soil characterization and microclimate identification of both areas is needed to analyze the land suitability for both commodities.

5. CONCLUSION

The soil near the spring was more fertile than dry soil away from the spring, indicated by high organic-C, total-N, and C-to-N ratios. Still, the microbial population of both locations was similar. The more fertile soil supports almost identical plants to the less fertile soil, but more plant density was present near the spring (A location). The foothills area of the sand-gravel mining area supports the growth of 22 pieces of vegetation in the wet season, including species of two trees, 13 shrubs, two sedges, four types of grasses, and one fern. Two perennial trees– Mexican Lilac and beechwood-were grown during initial revegetation. We should maintain the native vegetation to further revegetate disturbed areas before introducing suitable perennial plants.

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