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THE EFFECT OF SAND MINING ON SOIL QUALITY IN GANTAR DISTRICT, WEST JAVA, INDONESIA

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ABSTRACT: At this time in Indonesia, much illegal sand mining is negatively impacting the environment. One area where many Illicit mining activities are found is the Gantar area and its surroundings, West Java Province. Sand mining activities using an open pit mining system. The open pit mining system degrades soil quality by mining sand. This study uses laboratory analysis by measuring the physical, chemical, and mineralogy of soils. The purposive sampling method is used to sample post-mining ex-sand mining soil samples in Gantar District, West Indramayu Regency, West Java Province. Physical soil quality measurement is characterized by increased bulk density, particle density, fine fractions (clay and silt), and decreased porosity and permeability. Chemical examination showed a decrease in C-organic, N-organic, P, and K concentrations (available) and base saturation; however, the CEC level increased. The results showed that sand mining activities have degraded soil quality in the former sand mining area in Gantar District, West Java, Indonesia. This research makes a major contribution to policymakers to pay attention to post-mining activities so that the decline in soil quality can be avoided.

Keywords: Chemistry, Indramayu, Physical, Sand mining, Soil, Quality

1. INTRODUCTION

The United Nations Environment Program (UNEP) states that sand and gravel are natural materials used the most on Earth as raw materials after water utilization, where their use has exceeded the capacity of their natural renewal rates. The same conditions were also stated today, and is an essential natural resource material after fresh water, with the use of sand as the second most consumed material by society after using fresh water on Earth.

Sand is a loose natural aggregate that forms when rocks break down from weathering and eroding over thousands and even millions of years [1]. Evidence shows that in ancient times, building materials, mixtures of clay, sand, and lime, were used to block the barriers of Egyptian pyramids. In addition, the first beads in Egypt consist of volcanic sand c. 3,500-3,000 BC. [2]. Likewise, during the heyday of the Romans 2000 years ago, they used a mixture of limestone and volcanic sand as mortar [3]. Therefore, sand has been essential in preserving buildings over the centuries.

Such conditions are similar to current conditions in various parts of the world and Indonesia, especially in the Gantar District, West Indramayu Regency. The area of Gantar District in the 2000s was a vegetable-producing and rice area that supplied the city of Indramayu and the surrounding region (Fig.1).

However, the number of infrastructure development and construction projects in the West Indramayu Regency and its surroundings. The Cipali Toll Road, Cisandawu Toll Road, Sadawarna Dam, Patimban Port, and others have caused a change in the pattern of society. In the research area and its surroundings, from a rural profession to a sand miner, it has also triggered the exploitation of sand and earth-fill materials from various areas in the West Indramayu Regency, either illegally or legally. Moreover, with the completion of the construction of several infrastructure projects mentioned above, many sand excavations will be discontinued, leaving large ponds and plains of critical land (Fig.2).

Fig.1 Rice plants and horticulture are before sand mining.

Fig.2 Photo showing water ponds and critical land in the sand mining area.

The sand commodity is an essential economic development element in developing and developed countries. Although sand mining activities have many positive impacts, they may cause environmental damage, such as soil degradation, and sometimes the damage can be permanent [4-6]. Sand mining uses an open pit, and sand extraction is to a certain depth. This activity is an example of ecosystem destruction, which can result in the ex-mining land becoming dysfunctional if it is not immediately rehabilitated through reclamation (Fig. 4)

Sand mining in the Gantar District is conducted using the open pit method. Unfortunately, this often occurs in open-pit mining activities; after the land is mined, there is an increase in the content of certain toxic elements in plants, and it causes critical land.

Fig. 3 The activity of sand mining using the open pit mining method.

This study's objective is to obtain information on soil's physical and chemical properties in ex-sand mining areas. Meanwhile, this research aims to provide an essential understanding to policymakers in mining activities related to the effect of sand mining that can increase land productivity due to mining activities.

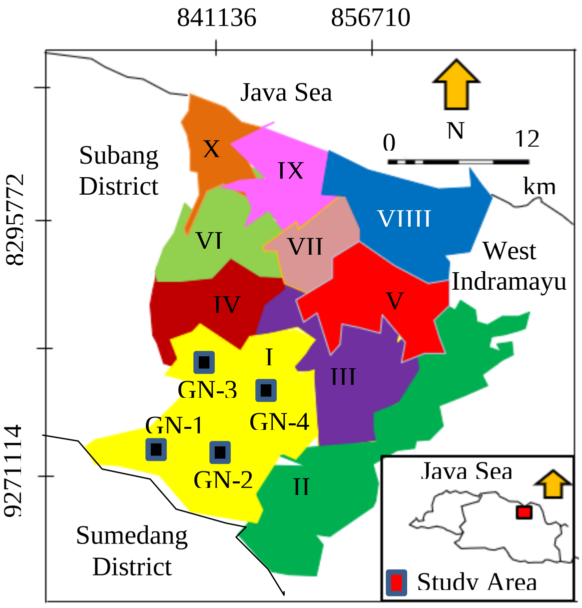
2. RESEARCH SIGNIFICANCE

In 2020, the Energy and Mineral Resources Office of West Java Province recorded 417 sand mining activities without a permit or illegal mining; only 42 have permits. Many miners must carry out the reclamation process after mining activities end to minimize environmental damage. However, in reality, only a few do the reclamation process. So there is much environmental damage. This research is urgently needed to determine the negative impact of sand mining on ecological quality after the end of mining activities. One way is to check the soil quality around the sand mining area.

3. MATERIALS AND METHODS

3.1 Location

We researched 4 locations of former sand mining land in Gantar District, West Indramayu Regency, West Java, during 2020-2021 (Fig. 4).



I : Gantar
II : Terisi
III : Kroya
IV : Haurgelis
V : Gabuswetan
VI : Anjatan
VII : Bongas
VIII : Kandanghaur
IX : Patrol
X : Sukra

Fig. 4 The soil sampling location in Gantar District.

Geologically, this area comprises Quaternary-aged volcanic deposits of medium to coarse-grained tuffaceous, conglomeratic, and claystone. The sand was sourced from tuffaceous rock, refined using a vibrating screen machine, and washed with water to remove the clay material (Fig. 5).

Fig. 5 The sand production process uses a vibrating screen machine (upper photo) and a sand-washing pond (lower photo).

3.2 Laboratory Measurements

Four topsoil samples (0-20 cm) taken from several locations. The soil samples were air-dried, pounded, and sifted using a 2 mm sieve and then put in a labeled plastic bag.

We analysis of Chemical characteristics of soil samples at the Laboratory of Productivity & Aquatic Environment, nt, Bogor Agricultural Institute. The chemical properties of the soil analyzed include pH, C and N-organic content, ratio C/N, P (available; Olsen), K, cation exchange capacity (CEC), and base saturation.

We analysis of physical properties of soil and clay mineralogy composition at the Laboratory of Sedimentology, Department of Geology, University of Padjadjaran. The soil physical properties analyzed include soil textures, water content, bulk density, particle density, porosity, and permeability.

Identification of clay mineralogy by XRD [7-9]. The X-ray diffraction spectra obtained in an X-ray diffractometer (Bruker AXSD8) with CuKa radiation (40 kV, 40 mA) in the angular range of 100–800 (2ɵ) with a 0.020 step interval and a scanning rate of 30 per minute at a wavelength of v =1.54056Å. The sample diffraction in the measuring range 2Θ, between 50 and 350. The obtained diffractogram is evaluated by calculating the intensities of the various peaks and determining the angle 2Θ. For clay minerals, we followed two XRD analytical procedures. These are (1) diffraction of air-dried samples and (2) diffraction of the glycolate sample; ethylene glycol was added to the sample and placed in an oven at 600°C for 12 hours [10]. Use diffraction angle to determine the type of clay because each mineral has a unique diffraction angle (XRD) [11-12] and thus a unique d (Å).

3.3. Analyzes

Field observation data and laboratory soil analysis were analyzed in the description and Minister of Environment Decree No. Kep-43/MENLH/10/1999 to determine the impact damage from sand mining (excavation C) on mineral soils.Figure 6 presents a flow chart of soil degradation research in the Gantar District.

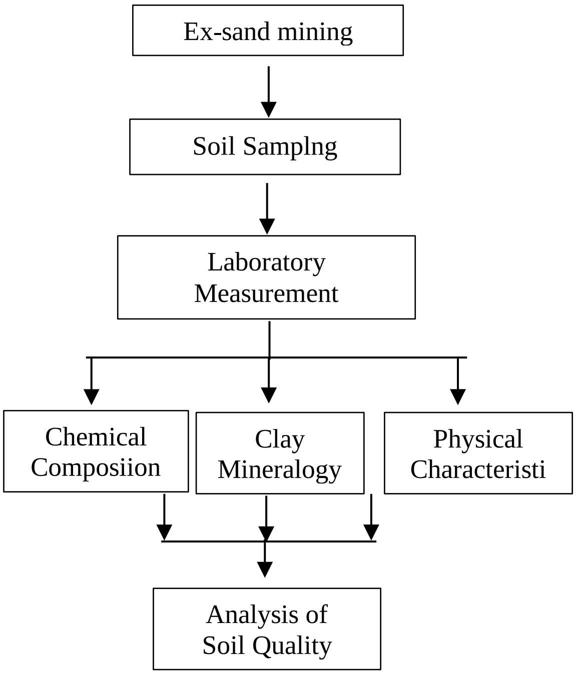


Fig. 6 The flow diagram of the study

4. RESULTS

The sand mining activities at mining sites show loss of topsoil (0 cm), digging holes as deep as 10-15 m, and loss of natural vegetation by 80%. Also found were pieces of wood from uprooted plants and many parts of wood from plants during land clearing at the beginning of mining. Furthermore, cutting down trees will decrease land production of O_2 (oxygen) and absorption of CO_2 (carbon dioxide) because chlorophyll is lost, and the rate of photosynthesis decreases or disappears. Besides, logging trees will disrupt the ecosystem and cause loss of wildlife habitat.

4.1 Physical Soil Properties

The variable soil physical properties observed and measured in this study were soil texture, bulk density, particle density, porosity, and permeability—the results of the laboratory analysis of physical properties tabulated in Table 1. There was an increase in the average bulk density value of post-mining soil samples of 0.025 g/cm^3, indicating soil compaction. The same thing also happened with an increase in the particle density values of all post-mining soil samples with an average rise of 0.04%, that is, from 2.36 g/cm^3 in pre-mining soil it increased to 2.4 g/cm^3 (the average value of bulk density in post-mining. Indicates that there has been damage to the soil structure at the former sand mining.

Sand mining has reduced the average soil porosity by 4.58%, from 47.19% in pre-mining soil to 42.61% in post-mining soil. Likewise, the average permeability parameter has decreased in value due to sand mining activities by 2.78 cm/hour, from 9.14 cm/hour on pre-mining soil to 6.36 cm/hour on post-mining Earth. The average water content in the post-mining soil is 33.64%; there has been a decrease in the value of the water content of 3.83% from the pre-mining soil.

Soil texture is defined as each class's relative proportions (clay, silt, and sand) [13-14]. According to the USDA, the post-mining soil in the ex-sand mining quarry area can grouped into sandy clay loam (Fig. 7). Comparing the composition of the soil texture in the post-mining soil with the pre-mining soil indicates a change in composition related to sand mining activities—either a decrease or an increase in the characteristics the soil texture.

The laboratory measurements show that the sand and clay (clay) textures have decreased while the silt textures have increased. The percentage decrease in sand texture is 11.45-16.78%; the increase in clay texture is 3.89-9.52%; and the increase in silt texture is 5.32-12.89% with excellent porosity (average porosity: 42.61%) and relatively fast permeability, indicated by a value of 6.36 cm/hour [15]. The pre-mining soil type at the sand mining site in Gantar District can be grouped into sandy clay loam as the characteristics of the post-mining and pre-mining soil type.

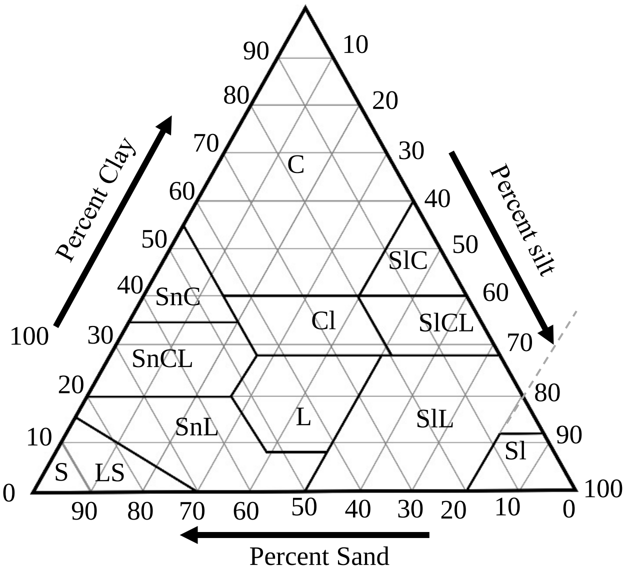


Fig. 7 The triangular diagram of USPA soil classification for soil samples.

🟦 Pre-mining 🟥 GT-1 🟦 GT-2 🟩 GT-3 🟦 GT-4

C : Clay
Cl : Clay Loam
L : Loam
LS. : Loam Sand
SnL : Sandy Loam
S : Sand
SlC : Silty Clay
SnC : Sandy Clay
SnCL : Sandy Clay Loam
SlCL : Silty Clay Loam
SlL : Silty Loam
Sl : Silty

Table 1 Soil physical properties of land former sand mining

No	Physical Parameters	Pre-Mining Soil (2015)	Post-mining soil (2022)				Changes in soil quality			
			GN-1	GN-2	GN-3	GN-4	GN-1	GN-2	GN-3	GN-4
1	Bulk density (g/cm^3)	1.14	1.18	1.17	1.16	1.15	+0.04	+0.03	+0.02	+0.01
2	Particle density (g/cm^3)	2.36	2.40	2.42	2.40	2.38	+0.04	+0.06	+0.04	+0.02
3	Porosity (%)	57.19	41.08	42.04	42.14	45.16	-16.11	-15.15	-15.05	-12.03
4	Permeability (cm/h)	19.14	7.65	5.56	8.76	3.45	-11.49	-13.58	-10.38	-15.69
5	Water content (%)	37.47	34.69	34.20	30.52	35.16	-2.78	-3.27	-6.95	-2.31
6	Soil Texture									
	Sand texture (%)	62.11	47.27	40.66	45.33	46.56	-14.84	-14.45	-16.78	-15.55
	Clay texture (%)	22.24	31.76	28.76	26.13	30.12	+9.52	+6.52	+3.89	+7.88
	Silt texture (%)	15.65	20.97	23.58	28.54	23.32	+5.32	+7.93	+12.89	+7.67

4.2 Soil Chemical Properties

Parameters pH, C, and N-organic content, P (available; Olsen), K, CEC, and base saturation are soil chemical parameters examined in the laboratory. Table 2 is a tabulation of measurement data for the chemical analysis of soil samples.

Laboratory analysis to determine soil chemical characterization indicates that sand mining activity has caused a change in the quality of post-mining soil in the Gantar District. Parameters: pH, C-organic, N-organic, P-available, K-total, and base saturation measured on the post-mining soil showed a decrease in value compared to the pre-mining soil, while the CEC parameter indicated an increase in value. Post-mining soil has lower chemical parameter values than pre-mining. The pH ranges from 0.4-1.2; the C-organic content is 5.67-6.66 %, and the N-organic content is 3.03–11.89 %. While the P (available) content is 15.91-24.49 mg/kg, the K-total content is 34.53-41.07 mg/kg, and the base saturation is 6.51-6.56%, while the increase in CEC parameters ranges from 0.84-7.16 cmol/kg.

4.3 Clay Mineralogy

In general, the results of examining clay minerals from post-mining soil samples using the XRD method are presented in Table 3 and Figure 8. The clay mineral kaolinite (1:1) dominated in all samples, but smectite (2:2) and illite (1:2) were only identified in GN-3 and GN-4 samples.

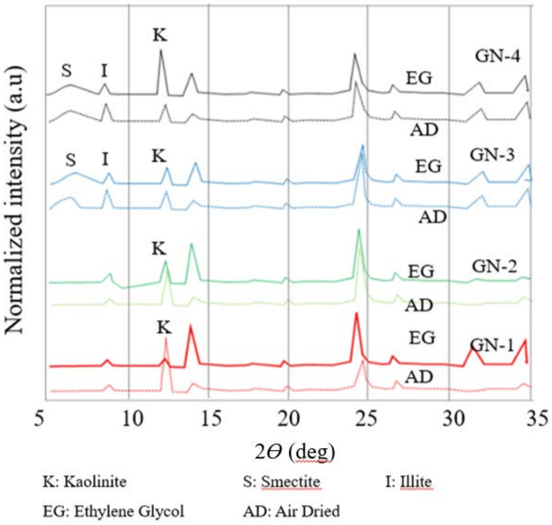


Fig. 8 XRD diffractogram for post-mining soil

Table 2 Soil chemical properties of soil of ex-sand mining

No	Chemical Parameters	Pre-Mining Soil (2015)	Post-mining soil (2022)				Changes in soil quality			
			GN-1	GN-2	GN-3	GN-4	GN-1	GN-2	GN-3	GN-4
1	pH	6.3	5.8	5.5	5.1	5.9	-0.5	-0.8	-1.2	-0.4
2	C-organic (%)	8.14	2.47	1.48	2.40	2.38	-5.67	-6.66	-5.74	-5.76
3	N-organic (%)	17.19	12.24	7.73	14.16	5.30	-4.95	-9.46	-3.03	-11.89
4	P-available (mg/kg)	29.14	11.37	7.00	13.23	4.65	-17.77	-22.14	-15.91	-24.49
5	K-total (mg/kg)	47.47	10.99	6.40	12.94	3.94	-36.48	-41.07	-34.53	-43.53
6	CEC (c.m/kg)	11.54	18.70	18.09	13.23	12.38	+7.16	+6.55	+1.69	+0.84
7	Base saturation (%)	8.11	1.55	1.57	1.55	1.60	-6.56	6.54	-6.56	-6.51

Table 3 XRD reflections (d) in Å of clay minerals after Ethylene glycol (EG.) and Air dried (AD)

No	Treatment	Sample No.				Clay Minerals
		GN-1	GN-2	GN-3	GN-4	
1	d Spacing of Air-Dried Sample (AD), (Å)	7.06	7.06	7.06	7.06	Kaolinite
		nd	nd	9.62	9.62	Illite
		nd	nd	2.56	2.56	Smectite
2	d Spacing of Ethylene Glycol (EG), (Å)	7.06	7.06	12.50	12.50	Kaolinite
		nd	nd	9.20	9.20	Illite
		nd	nd	3.02	6.02	Smectite

5. DISCUSSION

Sand mining activities that pay less attention to the environment can hurt the physical environment and socio-economic conditions. Mining with an open system is more vulnerable to direct environmental damage, and the impact can be felt quickly. The effects of mining activities on the environment include changes in the landscape, a decrease in soil fertility, a threat to biodiversity, a reduction in water quality, and a decline in air quality, environmental pollution due to waste generated by mining activities.

Almost every process in mining activities negatively impacts the environment, starting from land clearing, stripping, excavation, washing, hauling, and post-mining [16-17]. Sand mining is done in various ways, using heavy equipment such as excavators, bulldozers, wheel loaders, graders, stone walls, and trucks. In addition, multiple fuels and other chemicals are used to support mining operations. The use of heavy equipment and chemicals for a long time has degraded the soil quality in the sand mining area in the Gantar district. Changes in soil quality can be seen from the laboratory analysis of the physical and chemical parameters (Fig. 9 a and b).

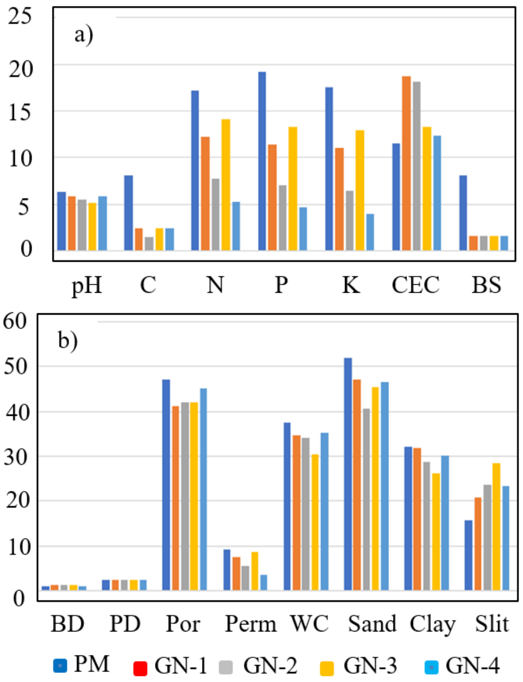


Fig. 9 a) Histogram graph showing changes in soil physical quality and b) Changes in soil physical quality between pre-mining (PM) and post-mining soils (GN-1, GN2, GN-3, and GN-4).

The following discussion relates to changes in post-mining soil quality based on the characteristics of physical and chemical parameters.

As a result of the use of heavy equipment in the mining process, the soil structure becomes unstable. The soil becomes denser and more compact, so the bulk density will increase compared to material not burdened by heavy equipment. The pore space between particles in the soil will be reduced due to the soil compaction process along with the soil particles. Soils with high densities contain a small total pore volume and many large pores. The denser the soil, the more difficult it is to absorb water and the smaller the porosity of the soil. Conversely, the easier it is for the soil to absorb water, the greater the porosity of the soil. This can be seen from laboratory analysis, which shows that post-mining soil's average bulk density value (1.16 g/cm^3) is greater than the pre-mining bulk density value of 1.14 g/cm^3. The same thing has an impact on particle density.

Soils with a high bulk density usually have a close arrangement of particle grains and a secure packing, which causes the soil pores to get smaller (reduced pore space) so that the porosity becomes small, i.e., soil with reduced pore space and soil weight. Each unit increase causes an increase in the bulk density of soil. Soil with a high bulk density makes it difficult for water to pass through or plant roots to penetrate, whereas soil with a low bulk density makes it easier for plant roots to develop [18]. In addition, soil with a high bulk density value will have a small permeability value due to post-mining soil being compacted by heavy equipment and sand trucks. Such conditions show a decrease in the value of porosity and permeability in the post-mining soil compared to the pre-mining (Table 1).

The increase in the clay and silt fraction was due to the rise in the fine fraction in the post-mining soil samples, which is the residue of the sand mining process. Much of the fine fraction is left at the mining site, while the medium-coarse sand fraction is usually sold to end consumers, causing an increase in CEC values in post-mining soil. The level of soil fertility is closely related to the level of CEC. High CEC values are found in clay soils with a high organic matter content compared to sandy soils, which contain little organic matter [19-20]. This is consistent with the results of related studies on the CEC value at the sand mining location, where the pre-mining soil has a high content of the sand fraction and a low CEC. On the other hand, CEC values in post-mining soils show a dominance of fine fractions (clay and silt). Therefore, the value of CEC in post-mining soil is higher than that of pre-mining soil (Table 2).

Due to the loss of vegetation cover and soil solum, C-organic and N-organic element concentrations show lower values in the post-mining soil at the former sand mining site than before mining. The high value of C-organic and N-organic in mining areas comes from the addition of dead plant tissue, stems, and leaves. Cutting down trees and permanent plants during land clearing and sand production causes almost all of the ecosystem's organic matter to disappear, and the infiltration rate will decrease. This lead to increased surface runoff, erosion, and landslides, as well as an increase in the loss of C-organic and N-organic due to leaching and erosion.

Similarly, as the concentrations of organic C and organic N in the post-mining soil decrease, so does the attention of available phosphorus (P) and potassium (K).

In crop production, phosphorus is a limiting nutritional factor for plants. Most of the soil contains enough P elements, but the element P available is deficient; this is related to the slow mineralization of nutrients. Phosphorus also does not leach, even with large amounts of precipitation. The pH value also affects the presence of phosphorus because element P can change into a usable or unusable ionic form. Phosphorus will be available in large quantities in the soil at a pH of 6.5–7.0.

Soil test results report P as an estimate of what is available to plants, not the total P in the soil. A good phosphorus concentration in the soil ranges from 25 to 50 mg/kg. However, the measurement results showed that the concentration of P-available in the post-mining soil samples ranged from 4.65 to 13.23 mg/kg, which indicates that the soil condition is not good.

The low concentration of P (available) in the post-mining soil causes increased surface erosion in the mining area so that sources of P-available nutrients derived from minerals containing P elements and organic matter through the weathering of plant remains become limited. P nutrients will be abundant if the soil has high mineralization [21-23].

Potassium (K-available) is a major plant nutrient, so it is essential for many plant functions and cycles back to the soil from plant residues with rainfall. Potassium is an ion exchangeable that readily binds to charged soil particles, locking them in the mineral structure. The presence of potassium in the soil is slightly affected by soil pH conditions, but if the pH value is low (<5.5), the pH will affect the potassium concentration. The ideal potassium concentration in the soil ranges from 40 to 80 mg/kg. The source of K nutrients in the soil comes from minerals containing K elements. The results of measurements in the laboratory showed that all post-mining soil samples were 3.94-12.94 mg/kg so they can be classified as less fertile soil. The low K value in the mining area is probably due to the loss of K due to leaching by surface erosion processes; other than that, the parent rock is a tuffaceous rock with a little bit of element K.

The soil in the sand mining area is formed by the weathering of volcanic organic matter in the form of tuffaceous, which produces kaolinite (1:1) clay minerals with minor amounts of smectite (2:2) and illite (2:1). Clays such as kaolinite have a CEC of about ten meq/100 g. In contrast, illite and smectite have CECs ranging from 25 to 100 meq/100 g (CUCE, 2007). Soils in the ex-sand mining area have CEC values ranging from 12.38 to 18.70 meq/100 g, so they can be categorized as having a moderate-high CEC value [24-25].

Measurement of groundwater level in the dry season ranges from 3-8 m, while in the rainy season, it ranges from 3 -10 m (PT. Geokonsultan Solusindo, 2020). Although the groundwater level can affect soil quality, especially porosity, permeability, and water content because the fluctuation of the groundwater level is low (< 2.5m), the influence of the groundwater level is not significant to soil quality.

6. CONCLUSIONS

Several conclusions were obtained from the physical and chemical characterization of soils and the mineralogical analysis of post-mining clay samples collected from Gantar, as outlined as follows:

1. The porosity of land decreases post-mining. The decrease in land porosity post-mining results decreases the land's potential to bind nutrients.
2. The land's availability of N, P, and K nutrients decreases post-mining.
3. Low levels of C-organic in the soil after mining result in low availability of organic matter and low soil mineral quality, degrading plants.
4. The Land soil quality in terms of fertility is better before mining than post-mining.
5. Kaolinite dominates the mineralogy type in the clay fraction, whereas illite and smectite are found in small amounts.
6. Sand mining has caused soil changes and damage, namely increased waste density, decreased organic C, decreased and destroyed soil microorganisms and changes in soil physical properties, soil chemical properties and soil biology.

7. ACKNOWLEDGMENTS

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