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Research Article

Changes in soil characteristics and estimated cost on reclamation of former sand mining land

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Abstract

The utilization of natural resources in recent decades is not accompanied by proper and effective management. This has a major impact on environmental degradation in watershed scale and climate change. The study aimed to evaluate changes in soil characteristics at various ages of sand mining and the cost of reclamation of environmental degradation due to sand mining activities. The study was conducted in Sumberbulu Micro Watershed, which is located in Wajak Sub-District, Malang Regency. Soil sampling was collected from un-mined, 2 to 6 years old sand mining and post-mining lands. Natural resource equivalency analysis (REA) was applied for environmental damage assessment and reclamation cost calculation required to restore natural resource services to their original condition. The findings show that sand mining activities significantly decreased soil organic C in 0-40 cm soil depth, resulting in increased soil bulk density and decreased soil porosity at 20-40 cm depth of soil. Sand mining activities by using truck traffic carrying mining products, soil erosion, and the removal of topsoil during mining activities determined changes in soil properties. REA shows that the total area of land that must be reclaimed is 21,487 ha. The land will be reclaimed by revegetation (with maize) to restore the lost function of environmental services and income of local farmers, assuming a reclamation cost of 36,767,500 IDR/ha. Therefore, post-mining land reclamation should be encouraged by the government for mining business actors in Indonesia so that the land can be reused as before.

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Introduction

Today, mining is one of the main sources of income for economic activity in many countries (Walsh et al., 2017). In general, mining activities have tremendous potential (Pegg, 2006; Balanay et al., 2014; Mobtaker and Osanloo, 2014; Tiainen et al., 2014;). Many studies outline that the mining process has a positive (social and economic) impact on society, such as labor absorption, income distribution and economic development on a local and national scale (Sreebha and Padmalal, 2011; Mobtaker and Osanloo, 2014; Devi and Rongmei, 2017). Various methods of mining are carried out, such as underground exploitation (Bury, 2002; Bebbington et al., 2008; Canel et al., 2010). Indonesia is known as a country with abundant natural resource potential; one of these natural resources is minerals. Sand is a natural resource derived from minerals used for construction. The demand for sand increases along with the increase in infrastructure and buildings (Padmalal et al., 2008; Sreebha and Padmalal, 2011; Saviour, 2012). Although most people are aware of the importance of sand in the construction sector, they may not be aware of the harmful effects of over-mining of sand on ecosystems (Moran et al., 2014; Aitken et al., 2016), soil characteristics (Gavriletea, 2017), and food security (Farahani and Bayazidi, 2018).

The problem of land degradation due to sand mining activities is increasingly observed in both developed and developing countries (Ako et al., 2014; Gavriletea, 2017). Sand mining activities can result in erosion of soil humus, which is the top layer of the soil surface (topsoil) that contains organic matter. Land degradation is caused by two factors (Le et al., 2012; Vu et al., 2012). First, it is caused by human activities (anthropogenic), like land use that does not pay attention to conservation principles. Second, caused by natural phenomena, such as topographical factors of the areas with wavy and hilly topography with steep to very steep slopes. Besides topography, another natural phenomenon is climatic factors. Land degradation has led to a decrease in environmental quality, ecosystem services (Schröter et al., 2005; Vogt et al., 2011; Andrade et al., 2015) and the loss of the main source of livelihood for local communities as a result of excessive mining activities (Musah and Barkarson, 2009; Ashraf et al., 2011). Moreover, the business of selling sand has caused significant road damage and conflicts between local residents (Pearson, 2013; Khan and Sugie, 2015; Purnomo et al., 2021). Also, Ayenagbo et al. (2011) argue that social inequality in the community around the mining area is caused by profitable sand mining activities.

Sand mining in developing countries requires special attention regarding the problem of illegal sand mining. There are several countries that carry out illegal sand mining activities: India (Bagchi, 2010; Martinez-Alier et al., 2015), Malaysia (Ministry of Natural Resources and Environment Malaysia, 2009; Ashraf et al., 2011), Sri Lanka (Piyadasa, 2011; Ratnayake, 2013; Padmalal and Maya, 2014), Nepal (Sayami and Tamrakar, 2007), Bangladesh (Khan and Sugie, 2015), South Africa (Green, 2012; Chevallier, 2014), Tanzania (Masalu, 2002), Botswana (Madyise, 2013), Philippines (Chaussard and Kerosky, 2016). This phenomenon not only has an impact on the community's social and economic situations, but it also causes environmental damage on a local and large scale. (Ashraf et al., 2011). Thus, when mining is in progress and has taken place, especially the topsoil, it must be preserved because it has an important source of nutrients for plants to live and serves as a root stimulant to propagate to the lower layers. The main problem in natural resource management is the increasing intensity of utilization without proper and effective management so as not to damage the environment. Proper management of natural resources will help preserve the environment so that natural resources will be sustainable and continue to provide benefits for future generations. Environmental impact assessment is a method for predicting the possible effects on the environment caused by the implementation of development projects (Dent et al., 2002). The purpose of the environmental impact analysis is to produce the information needed for the decision-making process as well as to choose the best technique in the environmental reclamation process. Therefore, environmental impact assessment studies seek to minimize or reduce negative environmental impacts while maximizing positive impacts (Macfarlane and Mitchell, 2003).

A large number of mining activities, especially sand excavations, has resulted in environmental impacts. That is why if the mining activities have been completed, the sand mine land should be reclaimed. Recovery efforts to restore the condition of former mining land are often referred to as reclamation (Ministry of Energy and Mineral Resources Regulation Number 07 of 2014). In terms of land reclamation, it takes a long time and a high cost to restore it according to its initial function (Rovira et al., 2005; Dariah et al., 2010; Fauzi, 2010). Reclamation activities and the use of former mining land involve various disciplines, including: technical, social, and economic (Sukarman and Gani, 2020). The type determination of the utilization of former mining land, whether it is used for food crops, plantations, fisheries, agro-tourism, or other needs, should be based on the ownership status and biophysical conditions of the land, as well as the needs of the community or local government. The results of research conducted by Erfandi et al. (2019) showed that former mining land can be reused into productive agricultural land with a touch of technology that is under the characteristics of the land. Some food crop commodities that can develop well are peanuts, corn, sweet potatoes, and cassava (Suastika and Haryati, 2019).

The study aimed to evaluate changes in soil characteristics at various ages of sand mining and the cost of reclamation of environmental degradation due to sand mining activities. Therefore, to answer the main objective of this research, two critical questions must be answered: first, how is the impact of sand mining activities on soil characteristics, i.e., soil organic C, soil bulk density, soil particle density, and soil porosity based on the age of the mine? Second, how much does it cost to restore environmental damage due to mining activities?

Materials and Methods

This study was conducted in Sumberbulu Micro Watershed (112° 44' 39.79"-112° 49' 58.30" E and 8° 06' 56.11"- 8° 09' 02.01" S), especially located in

Bambang Village, Wajak Sub-District, Malang Regency (Figure 1). Determination of the research location was done by a purposive sampling method. This location was chosen due to the consideration that the area of Bambang Village is included as a place for material deposits of Mount Semeru. Bambang Village is a critical land in Malang district due to sand mining on agricultural land. Soil analysis was carried out in the Department of Soil Science laboratory, Faculty of Agriculture, Brawijaya University, and in the Department of Agrotechnology laboratory, Faculty of Agriculture and Animal Husbandry, University of Muhammadiyah Malang.

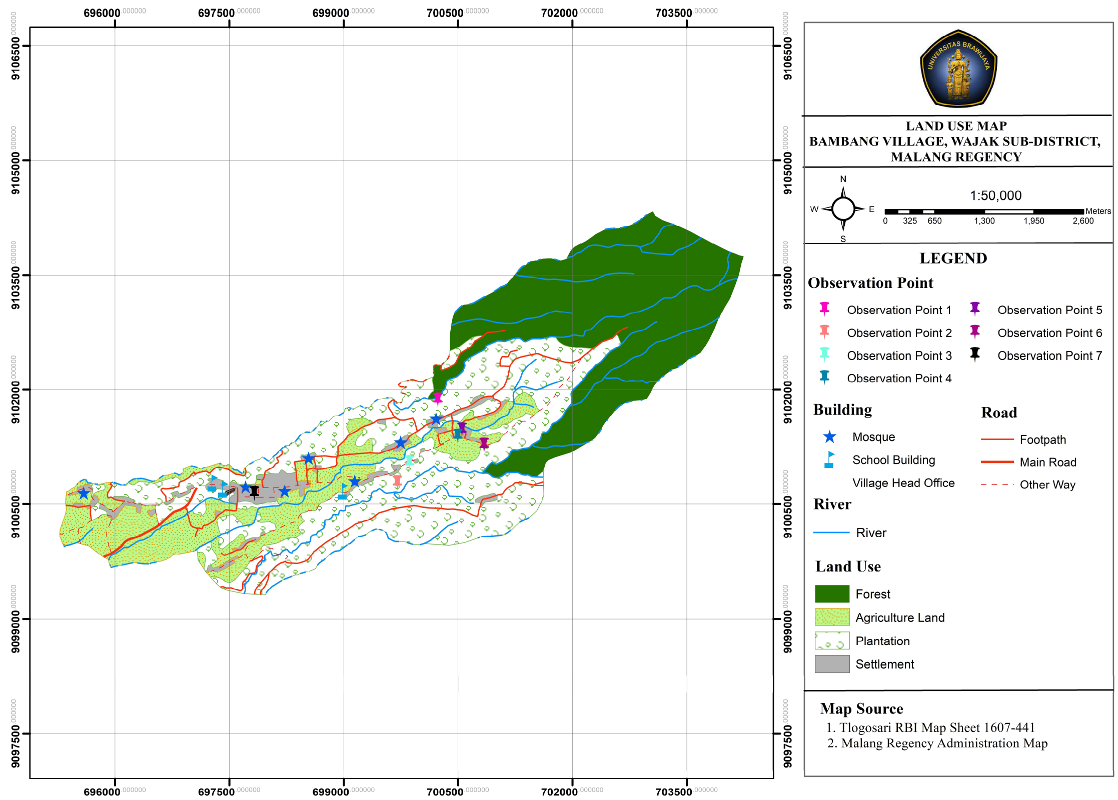

Figure 1. Location of the study area in Bambang Village within Sumberbulu micro watershed.

Soil samples were taken at 2 soil depths, that was: 0-20 cm and 20-40 cm with 3 replications at 7 different locations. The locations are distinguished based on the age of land use. Location 1 is a location that has never been mined (referred to as "initial or before") and is located at coordinates 112° 49' 2.25" E and 8° 7' 16.04" S. Location 2 is a 2-year-old mine site located at coordinates 112° 48' 45.05" E and 8° 7' 51.33" S. Location 3 is a 3-year-old mine located at coordinates 112° 48 '50.16" E and 8° 7 '42.76" S. Location 4 is a 4-year mining site. Location 5 is a 5-year-old mining site at 112° 49' 12.63" E and 8° 7' 28.78" S. Location 6 is a 6-year-old mining site at 112° 49' 22.13"E and 8° 7' 35.16" S. Location 7 is a former sand mining area at 112° 47' 43.77" E and 8° 7' 56.18" S (Figure 1). Thus, the total samples to be analyzed in the laboratory were 42 samples. The initial or un-mined location was determined in plantation areas that were planted by sengon (*Paraserianthes falcataria*), whereas the location of post-mined was located in agricultural lands and dominantly planted by local farmers with maize and chilies.

Soil analysis

The analysis of the soil physical properties included: bulk density, the method for determining the bulk density of the soil used was the gravimetric method by taking intact soil samples using a ring sample with a soil sample weight of approximately 100 g (Blake and Hartge, 1986; Chaudhari et al., 2013). Particle density was calculated based on the measurement of mass and volume of soil particles. The mass of soil solids was determined by weighing a dry soil sample that had been oven-dried at 105°C for 24 hours. The method used to determine the particle density of the soil was the pycnometer method through the separation between the volume of particles that have been calculated from the mass and the particle density of the liquid (Blake and Hartge, 1986; Chaudhari et al., 2013). According to (Hillel, 1982; Hao et al., 2008;

Chaudhari et al., 2013), total soil porosity (s_t) can be calculated by mathematical calculations using bulk density data and particle density data as follows:

$$\text{Total soil porosity} = 1 - \frac{D_b}{D_p} \ (1)$$

A soil biological property analyzed in this study was only soil organic C that was determined by the Walkley and Black method (Walkley and Black, 1934; Bulluck-Lii et al., 2002; Gelman et al., 2012). Prior to statistical analysis, the data from the analysis carried out in the laboratory were tested for normality using Shapiro Wilk's test. Then, analysis of variance (ANOVA) was performed at a level of 5% to determine the significance of the difference to the soil characteristics at each soil depth (0-20 and 20-40 cm), followed by the Least Significant Difference (LSD) test. All statistical analysis was conducted using R statistics software.

The estimated value of the environmental damage and the cost of reclamation

The conceptual basis for using Resource Equivalency Analysis (REA) in assessing damage to natural resources has been developed by several previous studies (Quétier and Lavorel, 2011; Carson, 2012). Resource Equivalency Analysis (REA) is also often referred to as Habitat Equivalency Analysis (HEA), where the unit of environmental damage and restoration is expressed in hectares of damaged land, hectares of damaged coral reefs, and so on. These two terms are often used in the same context with the same interpretation, so they can be used simultaneously. REA is used to calculate the magnitude (scale) of damage and calculate the scale and cost of reclamation to restore environmental resource services to their original state. (Roach and Wade, 2006; Fauzi, 2014). The estimated time for reclamation in this study is 4 years, and the interest rate used is the Bank Indonesia interest rate in the second quarter of 2021, which is 3.50%. The REA analysis has three main steps (Dunford et al., 2004; Barbier, 2013; Fauzi, 2014; Desvousges et al., 2018): The first step is to calculate the temporary loss of natural resource services affected by natural resource damage (discharge). In this study, the lost resource is agricultural land. Calculation of the total present value of the debit was calculated using the formula:

$$\text{PVD} = \sum_{t=0}^{T} L_t \, (1 + r)^{P-t} \ (2)$$

The second step, estimating the reclamation activities required to find lost natural resource services (credits), includes identification of the type of reclamation, identification of the time required, and identification of credits generated from the recording. The calculation of the total present value of credit was calculated using almost the same formula, namely:

$$\text{PVC} = \sum_{t=0}^{T} R_s \, (1 + r)^{P-t} \ (3)$$

The last step is to calculate the amount (scale) of reclamation required after calculating the discounted debit and discounted credit. The amount and costs required for reclamation were obtained from the distribution of present value debit and present value credit, namely:

$$S = \frac{\sum_{t=0}^{T} \text{PVD}_t}{\sum_{s=0}^{s} \text{PVC}_t} \ (4)$$

Note:

L_t	=	The amount of intermediate loss
R_s	=	The amount of credit recovered
r	=	Discount Rate
t	=	Time
P	=	Time of occurrence
t1	=	End time of loss or service lost
t0	=	Initial time of loss or service lost
s1	=	Service end time obtained
s0	=	Service start time obtained

For the estimation of the cost of reclamation, this study assumed that reclamation activities are carried out by returning the soil back to agricultural land and planting seasonal crops. This is due to the fact that the initial land use prior to mining was agricultural land dominated by maize. Because the plant has a short lifespan, it is easy to cultivate, and it has good economic value. The selection of maize as a commodity for land reclamation was also based on the interviews with local farmers, especially the most selected plant that can be cultivated on the reclamation land. Thus, the reclamation cost per hectare was estimated when the sand mining land was converted to maize cultivation, including land preparation costs, planting costs, maintenance costs, and harvest costs.

Results dan Discussion

Changes in soil organic C and physical properties before, during, and after sand mining

Sand mining activities carried out on agricultural land have affected the condition of the existing total organic C and the physical properties of the soil. The results of statistical analysis showed that sand mining activities significantly decreased ($p < 0.05$) soil organic C content at depths of 0-20 cm and 20-40 cm (Figures 2 and 3). This is shown by the lowest soil organic C content at the 6-year-old mine (location 6) and the post-mined lands as compared to those in the initial or un-mined land. These findings corresponded to the results of Qin et al. (2020), who reported that soil organic C at 0–40 cm soil depth in the sand mining area was lower than that of forest land and farmland. In addition, the differences in soil organic C at 0–20 cm and 20–40 cm soil depths were also detected among sand mining ages. The increases in sand mining age (6-year mining activities) resulted in lower soil organic C than all the other sand mining activities (2, 3, 4, and 5-year sand mining age), probably due to the high soil loss through removal of topsoil from the area of sand mining operation, runoff, and soil erosion.

Asiedu (2013) and Kuffour et al. (2018) reported that surface mining activities invariably removed the soil top layer, which contained a large amount of organic C, from the mining area and accumulated it into heaps elsewhere. In addition, sand mining activities that cleared up the surface vegetation caused the loss of organic C input and resulted in the decreases in soil organic C. Further, the loss of organic C in the sand mining land is caused by runoff and soil erosion because the surface soil in the sand mining land is open, as consequently, the soil is susceptible to runoff and erosion. Asabonga et al. (2017) reported that sand mining activities (i.e., land clearing) contributed to the loss of soil through soil erosion. In contrast, the higher soil organic C in the un-mined land (location 1) was due to the decayed plant litter, which affects the organic matter content of the soil (Cotrufo et al., 2013; Cotrufo et al., 2015). The un-mined land was dominated by "sengon" (*Paraserianthes falcataria*), and accordingly had more litter input and root mass as a source of organic C to the soil, as compared to those of mining lands (no vegetation) and post-mined lands planted with corn and chilies.

Following the statement of Foth (1994), decomposed plant litter can provide raw materials for the microbial decomposition process of roots containing 50% C. Soil organic C is part of complex and dynamic soil organic matter. The main source of soil organic C comes from the decomposition and sequestration of soil organic matter (Tarnocai et al., 2009; Nurida and Jubaedah, 2014). Soil organic C has a very important function and role in determining soil productivity and fertility on soil physical, chemical and biological properties (Jackson et al., 2017; Sanchez, 2019). Differ from soil organic C, the significant ($p<0.05$) impact of sand mining activities on soil physical changes such as bulk density, particle density, and soil porosity were found at 20-40 cm depth of soil (Figures 2 and 3).

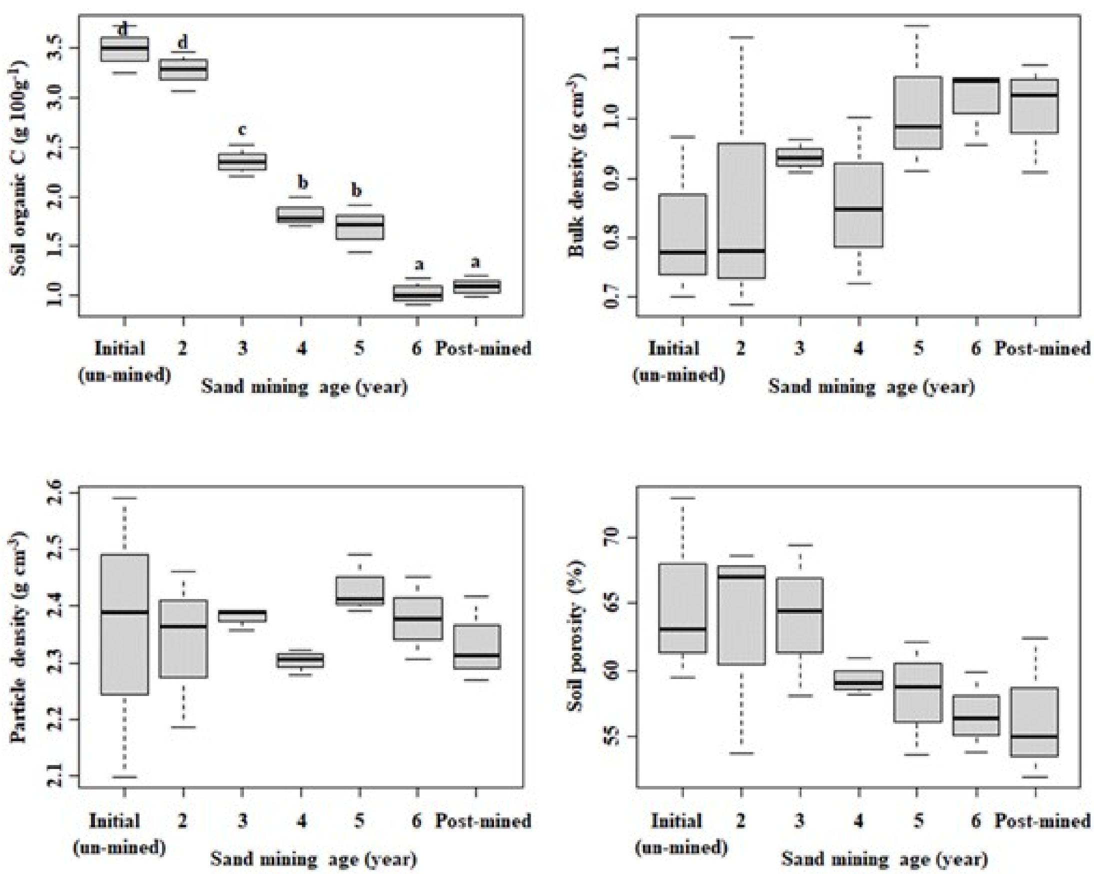

Figure 2. Changes in soil organic C and soil physical properties (weight, density, porosity) before, during mining (age 2, 3, 4, 5, and 6 years) and after sand mining at a depth of 0-20 cm in the Sumberbulu micro watershed, Bambang Village, Wajak Sub-District, Malang Regency.

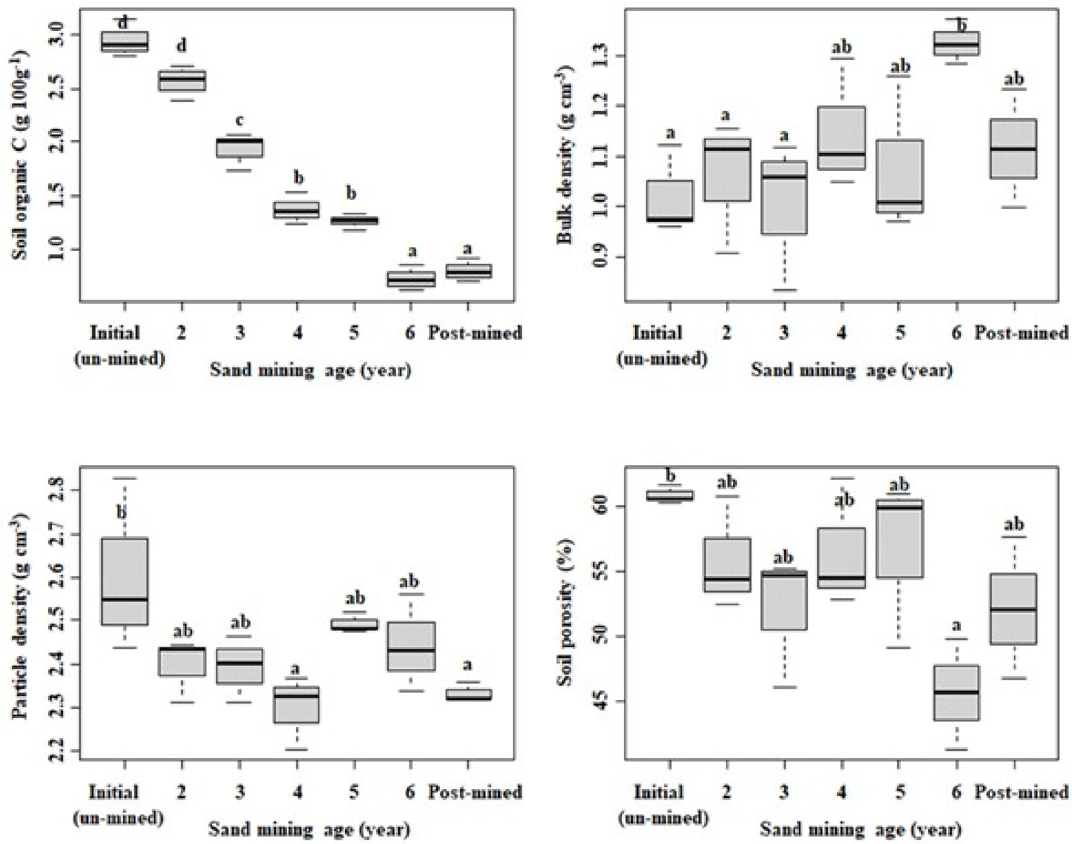

Figure 3. Changes in soil organic C and soil physical properties (weight, density, porosity) before, during mining (age 2, 3, 4, 5, and 6 years) and after sand mining at a depth of 20-40 cm in the Sumberbulu micro watershed, Bambang Village, Wajak Sub-District, Malang Regency.

Comparing among sand-mining age land, the study was unable to detect differences in soil physical properties except for soil bulk density at 20-40 cm where the bulk density of soil in the locations 2 and 3 (2 and 3 years old of sand mining) were lower than those in the location 6 (a 6 years old sand mining land; Figure 3). Consequently, the soil layer at 20–40 cm soil depth at location 6 (6-year-old sand mining) has a lower porosity than those at location 1 (un-mined). This was presumably due to soil compaction, which caused the increases in soil bulk density and the decreases in soil porosity. Soil compaction occurred in the following years of sand mining operations, and it may be attributed to decreases in soil organic C (Pearson correlation test $r = -0.51$, p-value = 0.02) and sand mining activities by using truck traffic carrying mining products. Saviour and Stalin (2012) reported that soil bulk density was increased gradually with increasing sand mining age. In addition, the higher the density of the soil, the lower the porosity of the soil. In accordance with the statements of Hillel (1982) and Hairiah et al. (2020), if the density of the soil increases, the porosity of the soil will decrease, which makes the soil difficult to distribute water or difficult to penetrate by plant roots. Vice versa, if the density of the soil decreases, the porosity of the soil will increase (Hardjowigeno, 2007).

Environmental degradation assessment and cost estimation of former mining land reclamation activities

The consequences of mining activities will cause landscape changes, either temporary or permanent (Figure 4). The total area of agricultural land damaged by sand mining activities is 16.8 ha. The existence of sand mining activities causes a decrease in the quality of the topsoil, which results in disturbed ecosystems (Saviour, 2012; Li et al., 2014; Wang, 2017). Land reclamation after mining activities is a social, economic, and environmental topic because it is related to the function of land in providing agricultural land (Irawan and Nurida, 2014). The selection of interest rates is very important for environmental reclamation budget planning (Kiker et al., 2005; Fauzi, 2014). Officially, the United States government has set the interest rate for economic valuation and assessment of damage to natural resources and the environment at

3–7% (Fauzi, 2014). Unlike the case in Indonesia, things such as setting interest rates for economic valuations and assessing damage to natural resources and the environment are not found. So those various variations in determining interest rates are often found in various studies related to economic valuation. This is done to see the effect of interest rates on the size of the former mining land that must be compensated for due to injury. Compensation for the area of former mining land due to an injury can be estimated if the extent of land damage and the period of time the damage occurred are known (Table 1).


(A) (B)

Figure 4. Excavated stockpile and mining waste (A) loss of biodiversity (B).

Table 1. Visual_HEA analysis results.

No	Description	Value (ha)
1	Total Discounted Service Unit Years (DSUYs) lost	593,015
2	Total Discounted Service Unit Years (DSUYs) gained	463,649
3	Discounted SUYs gained per unit	27,598
4	Replacement habitat size (ha)	21,487

The results of statistical analysis using Visual_HEA 2.61 (Table 1) indicated the Total Value of the Discounted Service Unit Years (DSUYs) lost by 593,015 ha, which means the total amount of service is lost if the damage caused by sand mining activities continues until the Discount Factor reaches 0.000. Likewise, the Total Value of Discounted Service Unit Years (DSUYs) gained 463,649 ha, which means the total number of services received if the compensation is carried out continuously until the Discount Factor reaches 0.000. The amount of land area (ha) that must be compensated requires the value of Discounted SUYs gained per unit by dividing the value of Total Discounted Service Unit Years (DSUYs) gained by the area of damaged land, which is 16.8 ha. Thus, the result of Discounted SUYs gained per unit is 27,598 ha. So that it can be obtained the area of habitat that must be reclaimed is 2,487 ha. The estimated cost of land reclamation (per ha) from ex-sand mining on agricultural land is presented in Table 2. From a technical point of view, the former mining area can be used for agricultural cultivation if land reclamation has been carried out (Dariah et al., 2010). The use of former mining land should lead to sustainability for the regional economy, especially the surrounding community, without neglecting environmental functions. The form of land reclamation in this study is revegetation (for example, with corn plants because the plant is commonly cultivated in the post-mined area and has a high economic benefit for local farmers), which is expected to be able to restore the function of lost environmental services and benefit the community. The total cost to reclaim the ex-sand mining area is 790,023,273 IDR if the cost is assumed to be 36,767,500 IDR ha^{-1} (Table 2).

Conclusion

Sand mining activities were significantly decreased soil organic C, as a consequence, increased soil bulk density and decreased soil porosity. Reclamation activities are post-mining activities that must be carried out by every mining business actor. Based on the findings of this study, the estimated total cost of reclamation of ex-sand mining land in Bambang Village with an area of 21,487 ha is 790,023,273 IDR. Therefore, this study suggests to policymakers to promote reclamation of ex-mining land, especially to mining business actors in order to reduce natural disasters due to environmental damage and improve the function of environmental services. Future research may be improved by incorporating other soil characteristics such as soil nutrient and two interest rates, like the average loan interest rate and the average deposit rate, to determine the scheme of using interest rates to support the findings of this study.

Table. 2 Calculation result of reclamation cost estimation (per ha) due to Sand Mining.

Estimated Cost of Land Reclamation After Sand Mining on Agricultural Land					
No	**Activity**	**Quantity**	**Unit**	**Price (IDR)**	**Cost (IDR)**
1	Land Preparation from Mining Land to Agricultural Land				
	• Excavator rent	1	unit	10,000,000	10,000,000
2	Provision of Organic Fertilizer	20,000	kg ha^{-1}	800	16,000,000
3	Corn Seed needs	30	kg ha^{-1}	85,000	2,550,000
4	Fertilizer needs				
	• Urea Fertilizer Needs	300	kg ha^{-1}	2,250	675,000
	• NPK Fertilizer Needs	450	kg ha^{-1}	2,300	1,035,000
5	Pesticide need				
	• Pesticide requirement (stem borer)	1.5	L ha^{-1}	75,000	112,500
	• Pesticide requirement (cob borer)	2	L ha^{-1}	75,000	150,000
	• Pesticide requirement (downy mildew)	2.5	L ha^{-1}	50,000	125,000
6	Labor requirements:				
	• Tillage: 5 workers on 7 days	42	Working Labor Day	60,000	2,520,000
	• Planting and embroidery: 4 workers on 4 days	20	Working Labor Day	60,000	1,200,000
	• Maintenance or weeding: 4 workers on 5 days	25	Working Labor Day	60,000	1,500,000
	• Harvest: 4 workers on 3 days	15	Working Labor Day	60,000	900,000
Total					36,767,500

Remarks: *Price of Fertilizer in accordance with Article 12 of the Regulation of the Minister of Agriculture of the Republic of Indonesia Number 49 of 2020. *The area of land that must be reclaimed is 21,487 ha, with a total cost of 790,023,273 IDR.

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