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# Impact of Gold Mining on Physical Properties of Inceptisols in Muaro Sijunjung, West Sumatra Indonesia

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# Impact of Gold Mining on Physical Properties of Inceptisols in Muaro Sijunjung, West Sumatra Indonesia

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**Abstract.** Open mining causes some problems to the soil properties both *in situ* and *ex situ* or in the environment. A research on the effect of gold mining on physical properties of Inceptisols was conducted in Nagari Muaro, District of Sijunjung West Sumatra Indonesia. The disturbed and undisturbed soil was sampled at the ex gold mining, and at the previous land use, especially rubber plantation and grassland. Parameters analysed were soil texture, bulk density (BD), hydraulic conductivity (HC), soil organic matter (SOM), soil aggregate stability (SAS), and water content. Based on laboratory analyses, it was found that gold mining process changed soil physical properties at the top 0-40 cm soil in Muaro Sijunjung. It decreased SOM content, soil HC, SAS index, TP, and increased soil BD or hardness compared to the previous land use. The soil must be rehabilitated to increase its productivity and to anticipate environmental pollution.
**Keywords:** Ex-Gold Mining, Inceptisols, Land Use, Muaro Sijunjung, Soil Physical Properties

## 1. Introduction

Mining activity especially open mining degrades the soil properties as well as the environment. This is due to the activity of land clearance and soil excavation into deeper depth in the profile. The soil, in general method, is just piled up in one area without separating between the fertile top soil and the subsoil or even with the parent materials. This process degrades soil properties, especially the physical properties. Furthermore, ex mining land without vegetation also zeroes $CO_2$ capture from the atmosphere. Since the area of ex mining increases by time, the concentration of $CO_2$ in the atmosphere keeps accumulating causing global warming.

Soil physical degradation due to open mining primarily causes erosion during heavy rainfall, especially in sloping areas. Erosion does not only have impact soil *in situ*, but it also influences environment due to the toxic elements and the sedimentation in water bodies.

Exposing mining soil, especially, deeper soil materials having toxic elements to soil surface have become a big problem, either for plant growth or for other living organisms, including human beings. Besides derived from the soil material itself, the toxic elements could be also abundant due to chemical reagents used by people for gold processing during mining. One of the chemical used in gold processing is mercury (Hg).

Mercury as one of heavy metal affects plant growth. Mondal *et al* [1] reported that 0.5-1.0 ppm Hg within salt solution suppressed shoot, root, and nodulation growth of *Vigna radiata* L. At higher level (1.0-1.5 ppm), mercury was accumulated within shoot > root > leaf > nodule of the *Vigna radiata* L. Furthermore, Patra and Sharma [2] suggested that the possible causes of mercury toxicity are due to the permeability alteration of the cell membrane, reactions of sulphydryl (-SH) groups with cations, affinity for reacting with phosphate and active groups of ADP or ATP, and replacement of essential ions, especially major cations.

Injured cereal seeds due to organic mercury materials caused abnormal germination and hypertrophy of the roots and coleoptile [2]. Ling *et al* [3] found that seed germination, root and coleoptile growth of the vegetable species were significantly reduced by mercury. Among the species treated, *Brassica oleracea* was the most sensitive, while *B. campestris* was the most resist plants to mercury pollution. Mercury stress more affected the coleoptiles growth and root elongation. However, all the treated species were significantly suppressed when the $Hg^{2+}$ concentration increased to 0.8 mM.

Furthermore, mercury as a heavy metal has high particle density that is (13.55 $gcm^{-3}$). If it is mixed with soil materials, it will increase soil bulk density, since soil material only has particle density 2.65 g $cm^{-3}$in average. Therefore, high Hg concentration in soil will affect the bulk density. The higher the Hg concentration in soil is the bigger the soil BD or the soil is more compacted. Bulk density affects soil total pore. Total pore inversely correlates to the soil bulk density. Less percentage of soil total porosity impacted on decrease of the soil hydraulic conductivity. Compact soil inhibits root growth and development which is due to unbalance water-air availability.

Since the soil was turned into upside down, the texture of the soil generally is not as it is expected for plant growth. It often turns into coarser, because the material is excavated far below the solum of the soil. In addition, more gravels and stones on soil surface becomes barrier for soil cultivation. The materials are not only cause the soil to be hard to till, but they also inhibit seed germination, root growth and development. It means that physical properties of ex gold mining needs to evaluate in order to find out the best way in conducting the reclamation process.

## 2. Methods

### *2.1 Research Site*

This research was conducted in Muaro Sijunjung, West Sumatra Indonesia (0°18'43'-1°41'46' S and 100°46'50"-101°53'50" E), on which people did gold mining illegally (Figure 1). This area is located between 109 and 1,200 m above sea level (*asl*), with annual rainfall was > 2,000 mm, and monthly average was > 100 mm.

Gold mining in the area was still semi-traditional. They just bought pieces of land from the local people and excavated it without concerning conservation or standard rule for mining. The mining type used was mostly open mining. Pasca mining, the miners just left the land without any treatment to recover the degraded land.

### *2.2 Soil Sampling*

There were 4 different types of land use found, those were grassland, the mined grassland, rubber plantation, the mined rubber plantation. These area is wide enough, therefore they are quite representative to be sampled. The method of this research employed was purposive sampling, in which soil was sampled randomly at each of the four types of land use. Site selection was based on land use and soil order. In each land use (site), soil was sampled from original and the ex.mining land use. Two soil depths (0-20 and 20-40 cm) were sampled for disturbed, undisturbed, as well as undisturbed aggregate soils with three replications for each land unit. Undisturbed soil samples were taken using metal rings sizing 7 cm in diameter and 4 cm in height. Soil order selected for sampling was Inceptisols.

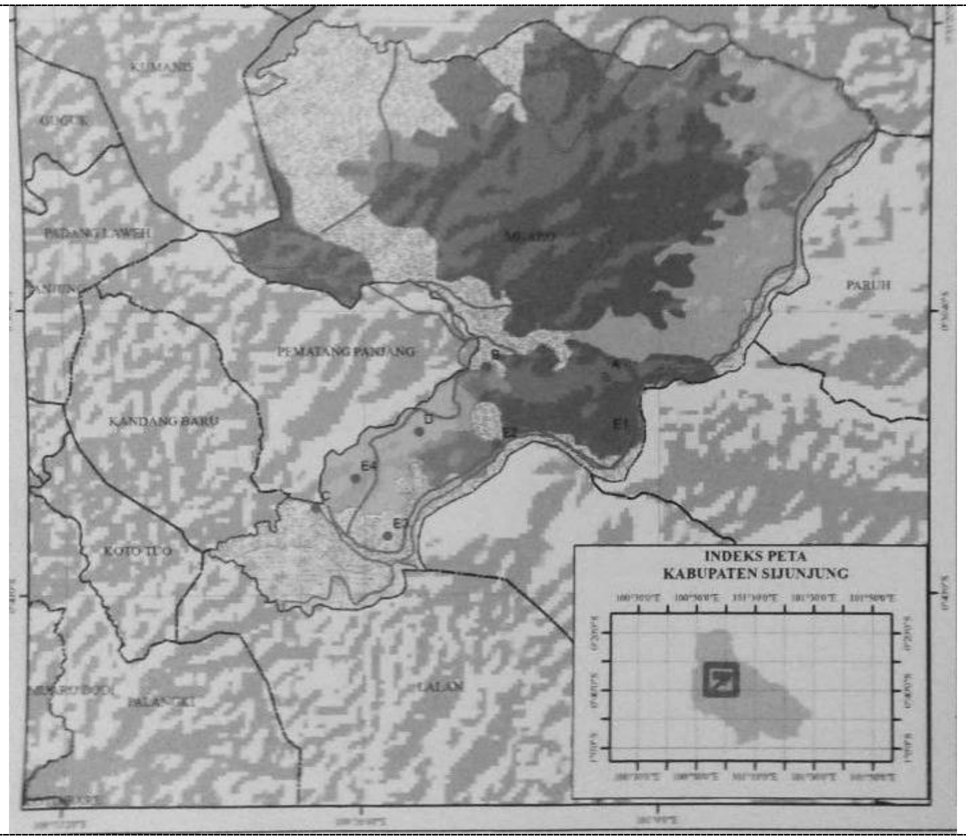



**Figure 1**. Map of soil sampling in Muaro Sijunjung, West Sumatra, Indonesia

Soil samples were brought and processed in soil laboratory, Agriculture Faculty, Universitas Andalas Padang. Disturbed soil samples were air-dried, and then ground before being sieved using 2 mm sieve for texture and 0.5 mm for organic carbon analyses. Undisturbed aggregated soil samples were air dried before they were analysed.

*2.3 Soil Analysis*
Undisturbed soil samples were for bulk density (BD) and total pore analyses (using gravimetric method) as well as for hydraulic conductivity (using constant head permeameter method based on Darcy's Law). Soil bulk density ($\rho_b$) was measured by using gravimetric method, and the data was calculated using the formula (1). Soil particle size analyses was conducted using sieve and pipette method [4] and the texture class was determine using textural triangle. Soil aggregate stability was analysed using dry and wet sieving method [5]. Soil organic carbon content was analysed using wet oxidation method [6] and calculated by using formula (2). Then, SOM content was conversed into the amount (Mg) within 40 cm soil depth per hectare (ha) by using formula (3).

$$\rho b\ (Mg\ m^{-3}) = \frac{DW}{Vt} \tag{1}$$

Where, $\rho b$ is soil bulk density ($Mg\ m^{-3}$), DW is soildry weight (Mg), and Vt is total volume of soil ($m^3$).

$$\% SOM = 1.72 \; x \; \% SOC \tag{2}$$

Where, SOM is sol organic matte and SOC is soil organic carbon.

$$SOM\ Stock\ (Mg\ Ha^{-1}) = \frac{\%\ SOM}{100} * \rho b * \ d * \frac{10{,}000}{Ha} \tag{3}$$

Where, SOM is sol organic matter (%), $\rho b$ is soil bulk density(Mg m$^{-3}$), d is depth from soil surface (m), and Ha is area 10,000 m$^2$.

Data resulted were analyzed statistically using t-test, by comparing between original and the ex-mining site within land use. The general formula of the T-test with a separate sample is as follows:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{\sum\left(x_1 - \bar{x}_1\right)^2 + \sum\left(x_2 - \bar{x}_2\right)^2}{n_1 + n_2 - 2}\left(\frac{n_1 + n_2}{n_1 . n_2}\right)}} \tag{4}$$

## 3. Results and Discussion

Mining activities left some problems to the soil in the mining land as well as to the environment. Among the soil problem, especially soil physical properties, found was soil texture or particle sizedistribution, soil organic matter (SOM) content and stock, soil bulk density, soil total pore, aggregate stability and soil hydraulic conductivity.

### *3.1 Soil Particle Size Distribution and Texture Class*

Based on Table 1 it is seen that mining conducted either at rubber plantation or at grassland in Muaro Sijunjung changed the soil particle size distribution. Mining activity increased sand content either at 0-20 cm or at 20-40 cm depth for both types of land use. However, compared to the secondary forest land use, the sand content of the soil at forest was much higher either at the top 0-20 cm or at the 20-40 cm depth. A soil with high sand percentage means that the soil has low soil water retention, and therefore plant available water. Water is a basic need for plant growth. Low plant available water in a soil causes the crop growing on it will suffer from water stress. It seemed that the secondary forest type in the research site was the land being abandon due to problematic soil.

Open mining activities mixed soil layer between the top and the subsoil. The subsoil and soil parent materials appeared on the soil surface, while some of the top soil was buried. Therefore, the sand particles increased on the top soil. Even, in the ex. mining land top soil was mixed with gravels and stones. However, while during texture analyses, the particles ≥ 2 mm were discarded, because they are not considered as soil.

Soil texture was dominated by finer particles, silt and clay, particles for all types of land use. Since texture is a soil property which is relatively stable, high sand particles in the unmined land seems to be the intrinsic property of the land. As the soil was classified into Inceptisol or developing soil, it still had high coarse particles. Based on texture triangle, the soil texture belonged to silty clay at the top 20 cm soil depth for all types of land use and then varied at the deeper (20-40 cm) soil depth.

**Table 1.** Particle size distribution of soil under several land use at 0-20 cm and 20-40 cm depths

| Land Use | Soil Particle Size Distribution | | | Texture Class |
|---|---|---|---|---|
| | Sand (%) | Silt (%) | Clay (%) | |
| 0-20 cm depth | | | | |
| Forest | 43.00 (±3.47) | 35.55 (±2.59) | 21.51 (±1.87) | Clay Loam |
| Rubber Plantation | 10.20 (±2.07) | 48.20 (±4.74) | 41.60 (±2.25) | Silty Clay |
| Mined Rubber Plantation | 12.46 (±0.86) | 46.26 (±2.92) | 41.26 (±2.15) | Silty Clay |
| Grass Land | 3.00 (±0.67) | 51.40 (±1.77) | 45.60 (±2.31) | Silty Clay |
| Mined Grass Land | 13.43 (±1.15) | 43.83 (±2.26) | 47.63 (±3.19) | Silty Clay |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 20-40 cm depth | | | | | | | |
| Forest | 42.6 | (±3.08) | 28.32 | (±1.76) | 33.36 | (±2.18) | Clay Loam |
| Rubber Plantation | 8.26 | (±1.19) | 56.33 | (±2.14) | 35.40 | (±1.10) | Silty Clay Loam |
| Mined Rubber Plantation | 12.23 | (±1.35) | 37.80 | (±4.27) | 49.96 | (±3.35) | Clay |
| Grass Land | 3.20 | (±0.89) | 44.40 | (±2.72) | 52.40 | (±3.25) | Silty Clay |
| Mined Grass Land | 21.60 | (±1.24) | 39.20 | (±2.80) | 39.20 | (±3.81) | Clay Loam |

Soils under rubber plantation and grassland were dominated by silt and clay particles. However, mining activities caused higher sand content of the soil for both mining sites. This was due to mixing process between top and sub soil even with parent materials of the soils. As reported by Wiskandar [7] that soil texture of ex. coal mining in Jambi was dominated by sand (38%) at the top 20 cm soil depth. The texture was classified into coarse texture soil, loam.

Texture is a soil property affecting soil characteristics. It especially influences other soil physical properties such as soil bulk density and total pore besides affecting soil chemical and biological properties. Soil BD (Fig. 2a) tended to linearly increase ($R^2$=0.45) and total pore (Fig. 2b) linearly decrease ($R^2$=0.46) as the sand percentage increased.

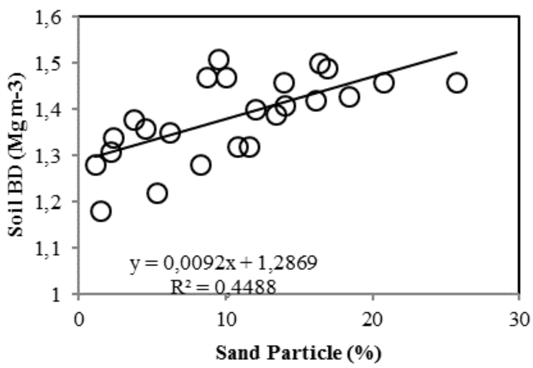



**Figure 2.** Relationship between sand particle percentage and BD of soil under several types of land use at 0-20 cm and 20-40 cm depth in Muaro Sijunjung

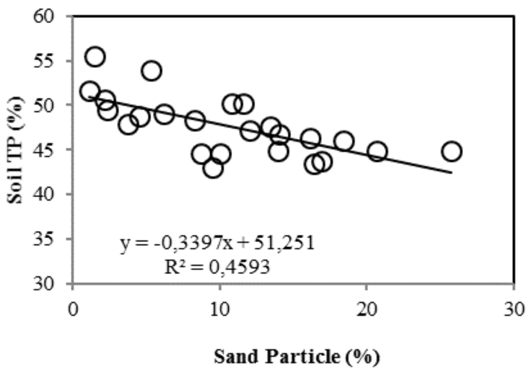



**Figure 2.** Relationship between sand particle percentage and TP of soil under several types of land use at 0-20 cm and 20-40 cm depth in Muaro Sijunjung

High coarse soil particles have high soil bulk density and less soil pores. As the more the solid materials, the higher the soil weight within a specific volume unit of the soil. Therefore, the bulk density becomes higher. As bulk density inversely relates to soil pores, high bulk density causes low soil total pores [8,9].

### *3.2 Soil Bulk Density (BD) and Total Pore (TP)*

Based on Fig. 3a it is seen that soil bulk density tended to increase as rubber plantation and grassland were mined. It followed the tendency of coarse (especially sand) particles in both of the *ex*mining sites. Higher sand particle percentage led to increase in soil BD. Coarse particles had low percentage of total pores, therefore it has higher weight at a certain unit volume than those at unmined sites.

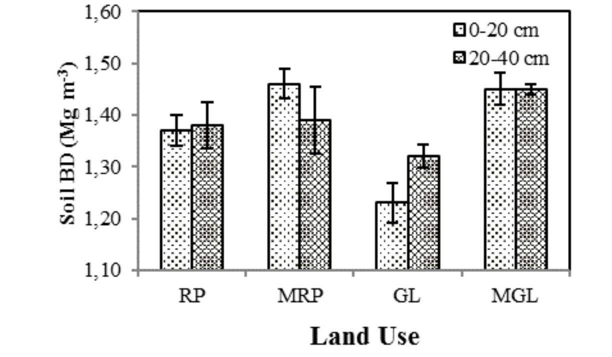



**Figure 3.** (a) Bulk density and total pore of land use at 0-20 cm and 20-40 cm depth in Muaro Sijunjung

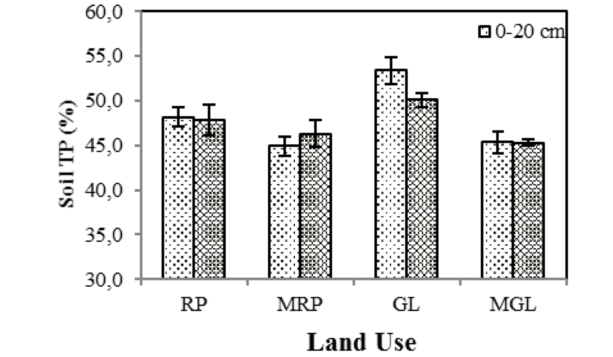



**Figure 3.** (b) Bulk density of soil under several types of land use at 0-20 cm and 20-40 cm depth in Muaro Sijunjung

Soil bulk density only increased by 7% at the top 20 cm and 1% at 20-40 cm soil depth as the rubber plantation was mined and then abandoned. The same tendency was also found under grassland. The soil BD at grassland was significantly higher for both depths compared to that at rubber plantation. Under normal condition, bulk density of soil under rubber plantation was higher, especially at the top 20 cm soil, than that at grassland. This was found to be true since soil surface under rubber plantation was routinely passed by farmers when extracting the rubber solution (latex). Additionally, dispersed latex during collecting it into soil also affects in solidifying process of the soil particles.

Soil BD increased by 7% as the rubber plantation and grassland were mined. If it is compared to forest land use, the soil BD increased by 32 and 31% at original and by 42 and 41% at mined sites, respectively at rubber plantation and grassland, on the top 20 cm soil depth. While at soil depth 20-40 cm, the soil BD between original and mined sites were not significantly different, but it increased by 28% as forest land use was changed into rubber plantation either for the original or for the mined site. At grassland, the soil BD increased by 26% and 33% as the forest land use was changed into grassland and mined grassland, respectively.

On the other hand, soil TP decreased by land use change from rubber plantation and grassland at both soil depths as they were mined (Fig. 3b). Under rubber plantation, soil TP decreased by 6.7% at top 20 cm and by 3% at 20-40 cm soil depth, while under grassland the TP decreased by 3% and 10% for 0-20 and 20-40 cm soil depth respectively at the mined sites. It seems that soil TP as well as the BD under both mining sites were not significantly different even though they came from different types of land use having different BD and TP values.

Compared to forest, soil total pore decreased by 21 and 12% at rubber plantation and grassland, and then decreased again by 26 and 25% as both types of land use was mined, respectively at the top 20 cm soil depth. Furthermore, at the 20-40 cm soil depth, the soil TP decreased by 20 and 15%as the forest was converted into rubber plantation and grassland, then further decreased by 21 and 23% as both types of land use were mined, respectively.

### *3.3 Soil Organic Matter Content and Stock*

SOM stock at the top 40 cm soil profile under mining sites decreased by 35 % and 47% from previous rubber plantation and grassland, respectively. If compared to forest land use, mining caused SOM stock decreased by 44% and 56% respectively for mined rubber plantation and mined grassland. As rubber plantation and grassland were mined, the SOM content decreased by 62% and 74% at 0-20 cm depth and by 53% and 60% at 20-40cm depth, respectively, compared to forest land use.

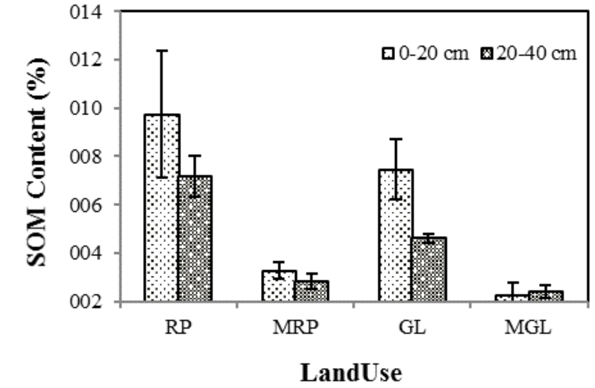



**Figure 4.** (a) Soil organic matter content and stock of land use at 0-20 and 20-40 cm soil depth in Muaro Sijunjung

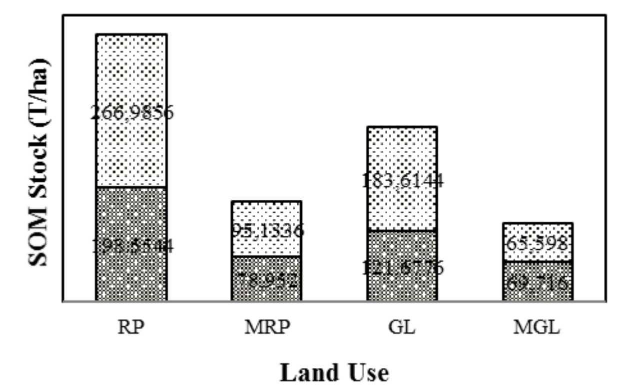



**Figure 4.** (b) Soil organic matter content under several types of land use at 0-20 and 20-40 cm soil depth in Muaro Sijunjung

However, it just decreased by 39% and 56% at 0-20 cm and by 35% and 43% at 20-40 cm depth, respectively from previous land use. The highest SOM stock within 40 cm depth of soil profile was found under forest and then followed by rubber plantation and grassland types land use.

Soil organic matter content under mining sites was much lower than those in the previous land use, rubber plantation and grassland, at both depths (Fig. 4a). However, the concentration at both sites was not significantly different. This was due to the fact that the physical condition of the soil after being mined in which the soil surface having higher SOM content was buried or mixed with the subsoil having lower SOM content.

At unmined sites, SOM content at the top 20 cm soil was much higher than that at the 20-40 cm soil depth. Soil OM content at 20-40 cm soil depth was approximately 74 % at rubber plantation and 62 % at grassland of that at the top (0-20 cm) soil depth. Higher SOM content at the top soil was found to be true since SOM source derived from the above ground, especially litter from vegetation and animal residue, was much higher than that from the below ground. The SOM source below ground was only derived from root death, root exudatess, and soil organisms. The percentage was much lower than that above ground SOM source. As reported that higher SOM content was found at top soil than the deeper layer [10].

Soil organic matter content at mining site was influenced by the SOM content of the previous sites. As the rubber plantation had higher SOM content than the grassland, the mining site also had higher SOM than the grassland mining site. Land use change from forest to rubber plantation and grassland decreased the SOM stock by 38-28%, 41-30%, respectively at 0-20 and 20-40 cm soil depth. As rubber plantation and grassland were mined, the SOM stock decreased by 62% and 74% at 0-20 cm depth and by 53% and 60% at 20-40cm depth, respectively, compared to the forest land use.

As the SOM content was conversed into the weight in a unit volume, it was found that the amount of SOM stock at the top 40 cm soil profile of those 4 types of land use was presented in Fig. 4b. The amount of SOM stock was much lower (<50%) at the mining sites than that at the previous sites. Total SOM at rubber plantation was 465.54 T/ha in the top 40 cm soil depth. This value was much higher than that at grassland (305.29 T/ha) > mined rubber plantation (174.09 T/ha) > mined grassland (135.31 T/ha).

Lower SOM stock recovered on the top 40 cm soil of mined sites was due to the fact that the depth soil being excavated was much deeper than 40 cm. Therefore, some of the SOM moved to the soil below 40cm.

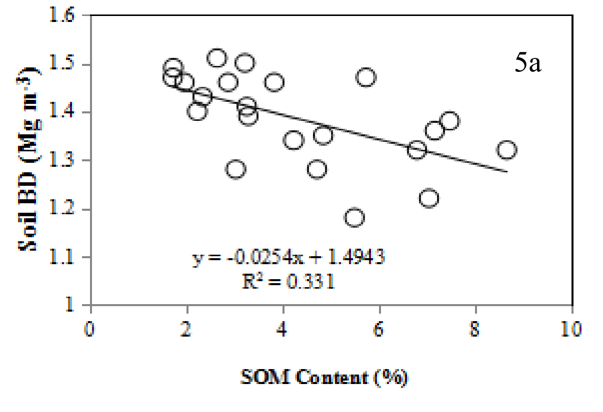



**Figure 5**. (a) Relationship between SOM content and BD as well as TP of land use at 0-20 cm and 20-40 cm depth in Muaro Sijunjung

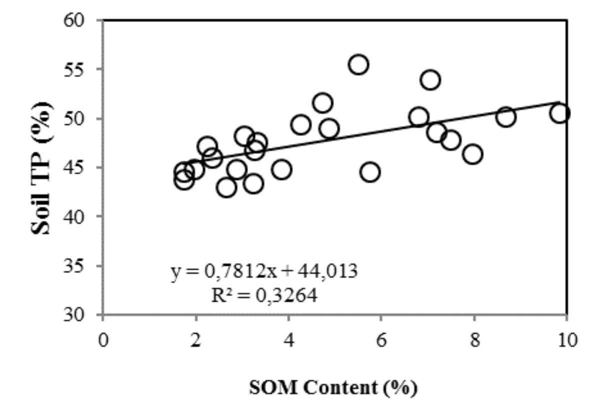



**Figure 5**. (b) Relationship between SOM content and BD of soil under several types of land use at 0-20 cm and 20-40 cm depth in Muaro Sijunjung

The SOM stock decreased by 72.61% as the rubber plantation was mined, while it decreased by 55.68% at the grassland. The decrease in SOM stock was mainly due to mixing soil materials from the top and the deeper soil depth during mining process. This was due to the mining activity conducted by people was generally illegal. There was no rule they had to follow.

The highest SOM stock within 40 cm depth of soil profile was found under forest and then followed by rubber plantation and grassland type of land use. SOM stock at the top 40 cm soil profile under mining sites decreased by 35 % and 47% from previous rubber plantation and grassland, respectively. If compared to forest land use, mining caused SOM stock decreased by 44% and 56% respectively for mined rubber plantation and mined grassland.

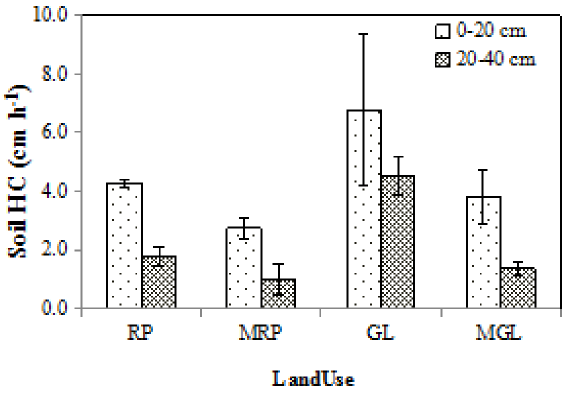
However, the SOM stock at mined sites just decreased by 39% and 56% at 0-20 cm and by 35% and 43% at 20-40 cm depth, respectively from both rubber plantation and grassland types of land use. Decrease in SOM had decreased soil aggregate stability and increased soil bulk density.

Open mining without following the rules will cause soil degradation such as environmental pollution either in situ or ex situ. Erosion is the highest change to happen since the location has high annual rainfall. Based on BMKG data, it was found that the site area had 2299 mm annually and > 100 mm monthly rainfall in average during the last 10 years (2007-2016). The highest rainfall reached 794 mm and the lowest was 15 mm in a month. This condition was highly dangerous for the area around the mining sites.

### *3.4 Hydraulic Conductivity and Soil Aggregate Stability*

Soil hydraulic conductivity between rubber plantation and grassland was significantly different. Grassland having lower SOM but lower or better BD than those at rubber plantation, therefore the grassland soil was easier to transmit or to pass water. The rate of the HC was higher on the top (0-20 cm) than that on the lower (20-40 cm) depth for each types of land use (Fig. 6a).

At both mining sites, the soil hydraulic conductivity rate was lower than the previous sites. This mostly due to the effect of low soil aggregate stability index, the soil was easily degraded and dispersed. The dispersed particles were blocked the pores resulting in lower soil HC rate.



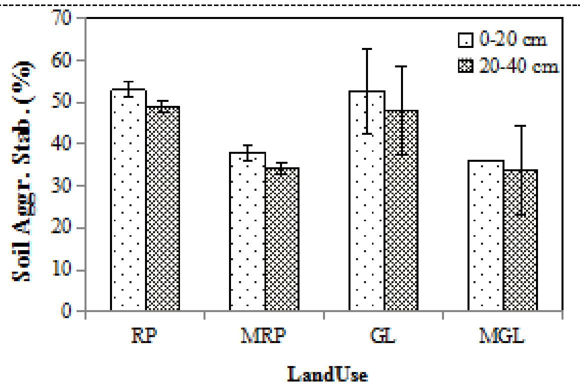




**Figure 6.** (a) Soil hydraulic conductivity and aggregate stability at 0-20 cm and 20-40 cm depth in Muaro, Sijunjung Regency

**Figure 6.** (b) Soil hydraulic conductivity under selected land use at 0-20 cm and 20-40 cm depth in Muaro, Sijunjung Regency

Soil hydraulic conductivity rate was much higher on the top 20 cm soil then that on the 20-40 cm soil depth. Soil HC at forest land was the highest and significantly different from the others. However, at the lower depth it did not show significant difference among them. This is probably due to the effect of sand dominated soil texture and high SOM content at the forest land. Coarse particles having high percentage of macro pore easily transmit water.

Then, high SOM content at forest land helped stabilizing soil aggregates (Fig. 6b). Therefore, the soil structures was not easily degraded, in other words, it keeps transmitting water well. As reported earlier that soil having high SOM content had stabile aggregates [8]. The highest the SOM content the highest the rate of hydraulic conductivity of Ultisol in tropical area [11]. Soil HC rate decreased by 38%, 40%, 60%, and 45%, respectively at rubber plantation, grassland, mined rubber plantation, and mined grassland compared to that at forest land use. As mining sites had higher sand particle content (Table 1) having no ability to floccule as well as lower SOM content (Fig.4) functioning in creating and stabilizing soil aggregates, the aggregate stability index become low.

Soil aggregate stability decreased by 19%, 19-21% as forest was converted into rubber plantation and grassland, respectively at 0-20 and 20-40cm soil depth. As rubber plantation and grassland were mined, the SAS decreased by 45% at 0-20 cm depth and by 38% and 36% at 20-40 cm depth compared to the original types of land use, rubber plantation and grassland, respectively.

## 4. Conclusion

Based on data resulted it could be concluded that the soil physical properties in ex gold mine sites were worse than theose of the original (unmined) types of land use. Mining activity had increased sand particles and bulk density (± 7%), decreased total pores (± 3-7%), SOM (± 53-74%), soil hydraulic conductivity (38-60%), and soil aggregate stability (36-45%) for both (0-20 and 20-40 cm) soil depths compared to the original types of land use. Compared to the forest type of land use, these sol physical properties were quite worse.

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