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Full Length Research

Rehabilitation of artisanal gold mining land in West Lombok, Indonesia: Characterization of overburden and the surrounding soils

B. Siswanto[1], B. D. Krisnayani[2], W. H. Utomo[1]*, C. W. N. Anderson[3]

[1]International Centre for Degraded and mine Land Management, Brawijaya University, Malang, Indonesia.
[2]Mataram University, Mataram, Indonesia.
[3]Institute of Natural Resources, Massey University Palmerston North, New Zealand.

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This study was carried out to characterize the overburden materials and soil properties of artisanal mining at Sekotong, West Lombok, Indonesia to suggest an appropriate rehabilitation technology. The results of the study showed that the properties of overburden materials from Sekotong artisanal mining has a relative neutral acidity (pH about 6.4), however, with time together with the formation of sulfate compounds, such as Cu-sulfate, the pH decrease to more acid condition. The overburden materials have a low water holding capacity, low in N, P and K, but rich in Ca, Mg. Landform of the area varies from undulating to hilly with land slope of 30 to 45%, and the soil have a shallow effective depth with sandy clay loam to clay loam.

Key words: Artisanal mining, gold, overburden, rehabilitation, reclamation, Indonesia.

INTRODUCTION

Artisanal mining is defined as an informal and unregulated system of small-scale mining and in the context of gold mining; it is also termed as artisanal and small-scale gold mining (ASGM). ASGM is practiced in the developing nations of Africa, Asia and South and Central America. Artisanal operations are often illegal and/or poorly regulated. Miners may have no title to the land they are working and therefore, there is no incentive for sustainable land management. Indonesia is regarded as a major location for ASGM activities. However, few monitoring or new-technology demonstration projects appear to have been conducted in Indonesia: CASM (Communities and Small Scale Mining) does not appear to be active in the country. A report entitled 'Small-scale Mining in Indonesia' was published by the Mining, Minerals and Sustainable Development project of the International Institute for Environment and Development in 2001 (Aspinal, 2001). The report shows the number of locations of illegal small-scale mining to 713 throughout Sumatra, Java, Kalimantan and Sulawesi, with majority of them ASGM.

Different from modern mining, the aartisanal mining employ very simple technologies both in the mining and processing of the metal ore. In addition, usually there is no planning for rehabilitation after the closure of the mining activities. Environmental destruction is the most visible outcome of artisanal mining. Problems include acid mine drainage, deforestation, soil erosion, river silting and the pollution of soil and water with toxic compounds. Degradation on mined land include landscape changes, physical, chemicals and biological properties of soils, microclimate, flora and fauna changes.

The mining industry produces a large amount of waste rock and overburden material, ranging from tens to hundreds of million tons that damage environmental conditions (Izquierdo et al., 2005). In this instance, overburden and waste rock are removed from the site in order to access and extract the ore (Misra and Dwivedi, 2004). Waste rock is defined as the material that is removed from above or adjacent to the ore. This material

*Corresponding author. E-mail: hadi_utomo@hotmail.com. Tel: +64341553623.

contains both non-mineralized and low-grade mineralized rock that is usually piled up close to the mine. Potentially these materials can impact surface and ground water quality, due to the nature and level of mineralization of the waste rock, prevailing climatic conditions, and the buffering capacity of the waste rock pile.

Despite the negativity, artisanal mining plays an essential role in developing societies. Small mines can be a major source of revenue for rural communities, and can provide income for investment. Artisanal miners can exploit a mineral deposit considered uneconomic by modern industry. Every $1 generated through artisanal mining generates about $ 3 in non-mining jobs. In Indonesia, artisanal mining is very useful as a means of livelihood for poor people and had proven played as a safety net in time of economic distress, especially during economic crisis which occurred in 1998 which prolonged for about 10 years (Limbong et al., 2002). In the words of Sir Mark Moody Stewart, the President of the Geological Society of London during a November 2003 conference on sustainable mining in London, “Artisanal mining should be encouraged; however, the associated poor health, safety and environmental conditions must be improved.”

To improve the environmental condition of artisanal mining, the rehabilitation of the land post mine operation is absolutely important. The most appropriate technologies which can be suggested for this purpose is re-vegetation. However, due to improper mining technology and overburden materials, land condition post artisanal mining is usually so degraded that any plant species hardly could grow.

Generally, mine wastes are coarse and open textured, and therefore, it is subject to erosion due to unstable materials. Overburden materials are usually characterized by a high rock fragment content (35 to >70 %), low clay content, low moisture retention capacity, and high bulk density (Maiti, 2007). Overburden will often have very poor water holding capacity that will lead to surface drought. In Sekotong, West of Lombok, the condition becomes worst and the soil in which artisanal mining is done has a very shallow lithic contact of 5 to 10 cm with steep land slope.

Chemically Most overburden material is low in nutrients, pH, but elevated in metal concentrations (Maiti, 2007). In mining sites, the total sulfur level (often present as pyritic mineral) causes acidity in overburden (Hosner, 1988). The presence of aluminum (Al) and/or iron (Fe) sulfates as well as, hydroxysulfates release more hydrogen ions and cause the substrates to become strongly acidic (Seone and Leiros, 1997). In addition to the acidity issue, overburden material is often characterized by high salinity, which is derived from the parent rock characterized by the presence of soluble salts in water or soil (Shaw, 2005), which can cause a decrease in the relative growth rate and water uptake in shoots and roots (Misra and Dwivedi, 2004; Shaw, 2005; Nathawar et al., 2007). Furthermore, saline conditions affects nitrogen (N) metabolism such as N uptake. These conditions can also significantly decrease dry matter production; the concentration of potassium (K+), calcium (Ca^{2+}) in leaves; and increase the sodium (Na^+) and chloride (Cl^-) content in leaves (Nathawar et al., 2007).

Looking at those conditions, using overburden as a growth medium requires a high degree of improvement and maintenance. Basically, an improvement of fertility status of overburden material is done by developing a pool of organic and inorganic nutrients in the raw material (Hosner, 1988), and there are two major strategies that can be used; (1) based on man-modified succession processes (using time, the natural accumulation of nutrients, N fixation, fertilizer); (2) accumulating organic matter and nutrients from other resources (using topsoil, sewage sludge, green manures, etc). However, overburden has different characteristics in different areas, due to the type of material being mined and the geology of the associated strata. Types of overburden minerals can range from weathered sub soils or deeper un-weathered overburdens and varies a lot in physical and chemical properties. Since any technology is usually only work well in specific conditions, a specific technology should be developed suitable for these environmental conditions.

The work described here was aimed to study the properties of soil and overburden in artisanal mining in Sekotong, West Lombok, Indonesia. The data is necessary to develop rehabilitation technique suitable for this location.

MATERIALS AND METHODS

Study location

The study was carried at Sekotong sub district, West Lombok, Indonesia (Figure 1). It is estimated that the area have gold reserve of about 1.4 millions ounces. Actually, the mining activity had been closed in 2006, although still illegal, the mining activity was re-opened in 2009

Sample collection

About 500 g for overburden materials collected from 10 active artisanal mining pits at Pelanggan and Mencanggah village. The samples were mixtures, and about 500 g sub-sample was then air dried in a drying cabinet with the temperature at 60°C for 96 h. The air dried samples were ground manually to pass through a 2 mm sieve, and then prepared for laboratory analysis. A soil profile was observed adjacent to the location of overburden sampling, and then soil sample from each horizon was collected for laboratory analysis.

Laboratory analysis

To analyse particle size distribution of waste rocks, about 2 kg waste rock was collected and then sieved through a series of sieve with diameter of 8.0, 4.0 and 2.0 mm diameter. For waste rock having diameter more than 8.0 mm was measured individually by a

Figure 1. Map study location at Lombok, Indonesia.

rule. The result was presented as percent weight. Soil particle size analysis was performed by the pipette method (Soil Survey Laboratory Staff, 1992). Soil pH was measured in 1: 2.5 ratio soil solutions (with de-ionized water) with a pH meter (Jenway, 3305).

The Walkley and Black wet oxidation method was used to determine organic C content (Soil Survey Laboratory Staff, 1992). Total N content, NH_4^+N and NO_3^-N were measured by the Kjeldhal method (Bremner and Mulvaney, 1982). The cation exchange capacity (CEC) was extracted with 1M NH_4Oac (buffered at pH 7.0), and exchangeable base concentrations were measured using AAS (Shimatzu).

The heavy metals iron (Fe), zinc (Zn), copper (Cu), nickel (Ni), cadmium (Cd), and arsenic (As) were extracted by 0.1 N HCl (Jones, 1984) and the concentration of these metals in the substrate was measured with AAS (Shimatzu).

RESULTS

Landform, geology, and soil

The area of artisanal mining at Sekotong has an undulating to hilly landform with slopes varies from 30 to 45%. The soil developed from volcano stone rich in some minerals such as Calcite, Dasite, and Silicates.

Based on field soil observation (Figure 2) and the result

A: Light brown (7.5 YR 6/4)
0 – 6 cm: moist, sandy clay loam on gravels (1-2 cm) 10%, medium to moderate granular structure, friable, slightly sticky and slightly plastic; very slightly acid; many fine and medium roots; many fine, medium and coarse pores; gradually boundary
B: Brown (7.5 YR 5/5)
6-19 cm: moist; sandy clay on hard feeling with gravels (1 – 2 cm) > 35 % and stone; medium weak angular block structure; friable, sticky and plastic, neutral acid, few fine roots, many fine and medium pores; clear and smooth boundary.
BC: Brown (7.5 YR 5/5)
19-30 cm: moist, sandy clay loam; gravels (1-2 cm) 10% stone >35 % medium to moderate sub-angular blocky structure, friable, slightly sticky and slightly plastic; very slightly acid; many fine and medium roots; many fine, medium and coarse pores; gradually boundary
C : rock
> 30 cm

A : very dark brown (10 YR 3/2)
0-9 cm: moist; sandy clay loam on hard feeling with gravels (1-2 cm) 10%, medium to moderate granular structure, friable, slightly sticky and slightly plastic; very slightly acid; many fine and medium roots; many fine, medium and coarse pores; gradually boundary
B : Dark brown (10 YR 3/3)
9-24 cm: moist; sandy clay on hard feeling with gravels (1 – 2 cm) > 35 % and stone; medium weak angular blocky structure; friable, sticky and plastic, neutral acid, few fine roots, many fine and medium pores; clear and smooth boundary.
BC : Dark yellowish brown (10 YR 4/4)
24-32 cm: moist, sandy clay loam; gravels (1-2 cm) 10% stone > 35%; medium to moderate sub-angular blocky structure, friable, slightly sticky and slightly plastic; very slightly acid; many fine and medium roots; many fine, medium and coarse pores; gradually boundary
C : rock
> 32 cm

Figure 2. Detail profile description of Mencangah (above) and Pelanggan (below).

of the laboratory analysis (Table 1) the soil in artisanal mining area of Sekotong, West Lombok, is classified as yellowish brown Mediterranean and greyish brown Mediterranean (Central Soil Research, 1991) or Lithic Dystropept (Soil Survey Staff, 1992). The soils have an effective depth of 5 to 15 cm, although in some location, especially that of in cavity area, the effective depth could be as deep as 30cm. The soil is slightly acid with pH of 6.4. The soil has low of organic matter, low in nitrogen and phosphorus, but high in potassium content. The cation exchange capaeity (CEC) of Mecanggah soil is relatively lower as compared to that of Pelanggan soil.

Soil texture varies from sandy clay loam to clay loam; the clay content increases with depth, but again decreases in the C horizon. The soils have a slightly friable to hard consistency and soil structure of blocky to sub-angular blocky. Gravel is dominant in B horizon with gravel content varying from 15 to 30%.

Overburden

Field observation showed that the overburden materials of Mecanggah site quite different with that of Pelanggan site (Figure 3). At Mecanggah site the overburden materials are dominated by volcanic rocks, but the overburden materials at Pelanggan are dominated by calcite materials. With time, the colour of overburden

Table 1. Some physical and chemical properties of soil at Sekotong artisanal mining area.

Soil	Horizon A		Horicon B		Horizon B/C		Horizon C	
	M1)	P	M	P	M	P	M	P
Clay (%)	23	26	27	31	8	10	-	-
Sand (%)	31	29	28	22	34	31	-	-
pH	6.4	6.6	6.7	6.6	6.8	6.2	-	-
C (%)	0.84	2.52	0.3	1.05	0.18	1	-	-
N (%)	0.21	0.52	0.01	0.02	-	-	-	-
P (mg kg^{-1})	0.17	0.21	0.23	0.32	0.24	0.28	-	-
CEC (cmol kg^{-1})	15.57	25.87	12.71	21.66	19.66	25.14	-	-
K (cmol kg^{-1})	2.99	1.11	1.94	1.05	3.35	4.84	-	-
Ca (cmol kg^{-1})	0.16	0.16	0.18	0.21	0.32	0.35	-	-
Mg (cmol kg^{-1})	0.24	0.26	0.32	0.28	0.31	0.34	-	-
Na (cmol kg^{-1})	1.39	1.5	1.33	1.49	2.1	1.66	-	-

1) M: Mecanggah; P; Pelanggan.

a.

b.

Figure 3. Visual figure of 2009 overburden materials from Mecanggah (a) and Pelanggan (b) artisanal mining.

from Pellanggan site changes from white colour to blue colour. This indicates that there was a Cupric-sulphate formation

Particle size distribution of the overburden artisanal mining at Sekotong is presented in Figure 4. The overburden from Mecanggah is dominated by large particles with diameter of more than 40 mm. The overburden from Pelanggan, on the other hand, is dominated by small particles, with diameter of less than 40 mm. The result in Figure 3 also shows that there is only a little change in particle size distribution of overburden materials with time. This phenomenon indicates that, under climatic conditions of Sekotong, the materials of overburden are relatively resistant to weathering. The overburden materials have an acid reaction with pH of around 4.6 (Table 2). The CEC is very low (2.32 cmol kg^{-1} for Mecanggah's overburden and 1.98 cmol kg^{-1} for Pelanggan's overburden). The low CEC of these materials is reasonable because the materials dominated by the coarse fraction (Figure 3). The overburden has relatively high S, but low in nitrogen N content. Except Cu, the other heavy metals were not detected on both Pelanggan and Mecanggah overburden materials.

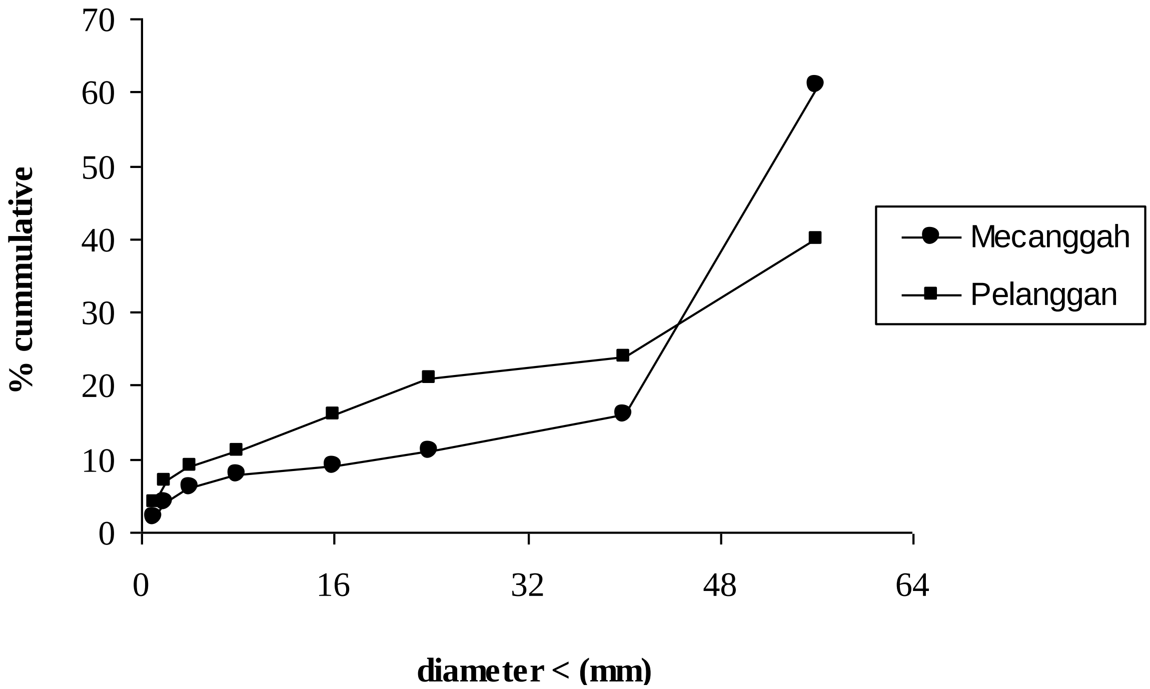

Figure 4. Particle size distribution of Mecanggah and Pelanggan materials.

Table 2. The properties of overburden materials from Sekotong artisanal mining.

Overburden properties	Mecanggah		Pelanggan	
	2009	2004	2009	2004
pH	5.2	4.7	4.9	4.6
NH4+-N (mg kg^{-1})	0.01	0.01	0.01	0.01
NO3- -N (mg kg^{-1})	0.01	0.01	0.02	0.01
P (mg kg^{-1})	0.15	0.16	0.18	0.15
S (mg kg^{-1})	12.73	14.56	11.01	16.72
CEC (cmol kg^{-1})	2.32	3.92	1.98	2.14
K (cmol kg^{-1})	0.05	0.001	0.12	0.04
Ca (cmol kg^{-1})	0.24	0.16	0.18	0.08
Mg (cmol kg^{-1})	0.28	0.18	0.23	0.09
Na (cmol kg^{-1})	0.08	0.03	0.03	0.01
Cu ((µg kg^{-1})	0.01	0.01	0.01	0.01
Al, Fe, Zn , Ni, Pb	ud	ud	ud	ud

ud) undetected.

DISCUSSION

Mine land rehabilitation technologies can be grouped into two broad groups, that is, (i) off site technology, which is usually done by removal of the contaminated materials for treatments, (ii) and on site technology, which treats the contaminated materials without excavation of the contaminated materials. Off site technology, especially for over burden materials will be very expensive. In addition , off site technology actually does not resolve the problems. It only shifts the problem to another location, and there is an environmental risk during transportation of the materials. Therefore, on site treatment is favourable. Due to its cost effective and low environmental impact, phytoremediation, the use of plant for remediation or rehabilitation of degraded land is now becoming more important. However, both the soil and overburden of artisanal gold mining at Sekotong have a very low plant nutrient availability (Tables 1 and 2). In addition, the overburden materials have significant of copper (Cu) metals (Table 2), and with time, these materials going to be acid.

In contrast, the overburden also demonstrates its potential as a source of soil nutrients, but these are contained in the primary minerals. Therefore, pre-treatment of overburden and waste rocks is very important to ensure the success of phytoremediation.

One of them promotes the weathering of these materials. Altering the water regime status and adding organic and inorganic amendments may as well accelerate the weathering processes. Weathering will break down the primary minerals, and release cations, which will contribute to the nutrient status of the overburden and thus support re-vegetation processes.

The disturbance of soil will change the abundance and diversity of the mycorrhizal fungal population; even diminish the population of some soil microbe (Prasetyo et al., 2010). On the other hand, the occurrence of soil microorganism is one of the success keys for phytoremediation. It has been widely known that mycorrhizal fungi are capable of improving soil properties, and increasing plant access to relatively immobile mineral nutrients (Gaur and Adholeya, 2004). In addition it is believed that mycorrhizal fungi are also able to bind heavy metals into roots thus restricting their translocation into shoot tissues, and hence minimize toxicity effect to plants (Gaur and Adholeya, 2004). Therefore, inoculation of soil microbe, such as mycorrhizal fungi is very important. The use of local indigenous species is the most appropriate inoculant.

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