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Research Article

The acid mine drainage (AMD) impact of tailings and non-tailings on the ecosystem changes in the ModADA sedimentation area, Timika

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Abstract: Tailings are the parent material residues resulted from a separation process of valuable minerals containing copper, gold and silver. This separation process is carried out mechanically by destroying copper, gold and silver rocks on the Grasberg plateau. However, in the production process of tailing materials from Wanagon and Aghawagon rivers, there was also non-tailing material mixed with tailing materials. This condition cannot be avoided due to high and intensive rainfall so that non-tailing material from an ex-mine excavation in the form of overburden can flow naturally through the river flow system from the highlands to the lowlands of ModADA. Acid Mine Drainage (AMD) is one of the important impacts of mining activities that must be managed because it has an impact on the aquatic environment or groundwater, and once it has been formed it will be difficult to stop unless one of the components runs out. The study was carried out from 2005 to 2014 at several representative locations in ModADA included inactive tailings at MP 27 and MP 21, as well as active tailings at WA 225, WA 185, and WA 160. The average heavy metal content in WA 225, WA 185, WA 160 included in the criteria of class C, namely As (> 33 mg/kg), Cu (> 150 mg/kg), Pb (> 130 mg/kg), and Zn (> 460 mg/kg). Another heavy metal categorized as class B was Cd (1-5 mg/kg), while class A consisted of Cr (<43 mg/kg), Hg (<0.2 mg/kg), and Ni (<23 mg/kg). At WA 185, The ANC/MPA ratio at WA 185 < 1.5 was 0.97 (0-20 cm) and increased slightly to 1.59 (20-40 cm). The ANC/MPA ratio < 1.5 shows a higher acid-forming ability (MPA) than the ability to neutralize acid (ANC). The average heavy metal content in MP 27 is lower in concentration, except Cu which included in class C (> 150 mg/kg) which is similar to the host rock mined and involved in the tailings flow from MP 74. The Cu concentration at MP 21 decreased drastically, except for As which included in class C (> 33 mg/kg). The ANC/MPA ratio at MP 21 was 1.92 (0-20 cm) and slightly increased to 2.22 (20-40 cm), while MP 21 has the ANC/MPA ratio at 12.61 (0- 20 cm), and decreased to 4.34 (20-40 cm).

Keywords: *acid mine drainage, heavy metals, ModADA tailings, overburden*

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Introduction

Tailings are the parent material residues resulted from a separation process of valuable minerals containing copper, gold and silver. This separation process is carried out mechanically by destroying copper, gold and silver rocks on the Grasberg plateau. The total tailings produced by PTFI are 230,000 tons/day, flowing from the highlands of 2800 m above sea level through the Aghawagon-Otomona-Ajkwa River system to the lowlands to be deposited in the West and East Embankments called Modified Ajkwa Deposition Areas (ModADA). The area of ModADA covers 45,000 ha consisting of 23,000 ha mainland, and the rest 22,000 ha is part of the estuary (PTFI 2006; 2007; Taberima et al., 2008).

In the production process of tailing materials from the highlands to the lowlands (ModDA), there are also non-tailing materials from the Wanagon and Aghawagon rivers mixed with tailings material. This condition cannot be avoided due to high and intensive rainfall in the Timika area so that non-tailing material from an ex-mine excavation in the form of overburden can flow naturally through the river from the highlands to the lowlands. Overburden is a layer of topsoil that in the mining industry usually excavated and moved to a specific area (disposal area) for extracting its valuable mineral (ore). Topsoil from this overburden will function again after post OB mining and can be used for reclamation and reforestation of the ex-mine land, contrary to the case of PT Freeport Indonesia's Grasberg mine operations that the OB of the excavated material is in the form of a parent material surface that has not undergone a weathering process into the soil layer.

The Acid Mine Drainage (AMD) or acid rock drainage (ARD) is acidic water with high acidity and is often characterized by a pH value < 5 as a result of oxidation of sulfide minerals with air or by presence water containing oxygen (O_2). The main activities of mining operations with the excavation of valuable parent (ore) minerals can accelerate the AMD formation process due to exposure of sulfide minerals to air, water and microorganisms (Kuyucak, 2002). The formation of AMD has a negative impact on the pollution of the aquatic environment because it directly produces high levels of acidity while indirectly increase the metal content in acidic water so that metals are easily soluble.

Prevention of the formation of AMD by identifying the rocks that potential to form acids is better than processing it because it guarantees for long-term and minimizes the risk. The formation of AMD is one of the main impacts of mining activities that must be managed, not only because of their impact on the aquatic environment or groundwater but also because once it has been formed, it will be difficult to stop, unless one of the components runs out. Moreover, AMD has a very long impact and surpasses the life of the mine even it can reach hundreds of years. The formation of AMD occurs because of the availability of sulfide minerals as a source of sulfur or acid, oxygen in the air as an oxidizer, and water as a result of oxidation washing (Anita Parbhakar-Fox et al., 2018). Therefore it is necessary to know the type of sulfur from easily oxidized rocks in the form of sulfide minerals, such as FeS_2 (pyrite), FeS_2 (marcasite), FexSx (pyrrhotite), Cu_2S (chalcocite), CuS (covellite), MoS_2 (molybdenite), $CuFeS_2$ (chalcopyrite), PbS (galena), ZnS (sphalerite), and FeAsS (arsenopyrite).

Valuable minerals (ore) from PTFI's mining operations daily produce concentrations of 3 – 4 % gold, silver and copper, while the remaining 96 - 97% is in the form of mine waste sand or tailings containing sulfide minerals, such as pyrite (FeS_2), $CuFeS_2$ (chalcopyrite), CuS (covellite), $CuFeS_4$ (bornite), and Cu_2S (chalcocite) (PTFI, 1997; PTFI, 2008). In addition, tailings also contain several metal elements, such as copper (Cu), arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg), cyanide (Cn), etc (Noviani & Gusrizal, 2004). These elements in high concentrations are dangerous and pollute the environment and aquatic biota that cause changes in the ecosystem (Mealey, 1999).

Several studies from 2005 to 2014 in the tailings reclamation area found a tendency of the increasing of some hazardous and toxic elements as a result of the subsequent non-tailing material mixed with tailings material in ModADA. This report is made based on a study of increased sedimentation (TSS) and the concentration of some hazardous metal elements which are suspected originate from non-tailing materials from overburden mixed tailings that have entered the ModADA area in the period 2007 - 2009.

Materials and Methods

The research was done on tailings ModADA in Timika, Papua. The tailings area is located in the lowlands of Timika and has a high rainfall from 3,500 - 4,000 mm/year, temperature from 25- 27 ^oC, and humidity > 90%. Research activities at ModADA have been carried out from 2005 to 2014. The location of the study in ModADA - Timika is presented in Figure 1. Samples of inactive tailings were taken at several representative sites in ModADA at two depths of 0-20 cm and 20-40 cm, including MP 27 and MP 21 from land reclaimed with agricultural plants. Samples of active tailings WA 225, WA 185, and WA 160 without plants were taken as the comparison. The monitoring samples from East Levee of ModADA was also taken at MP 36 from tailings sedimentation around the river. The study of heavy metal content and tailings geochemical was conducted by the analysis of samples at the Environmental Laboratory. The heavy metal content included As, Cd, Cr, Co, Cu, Hg, Pb, Ni, S, Zn. The analysis of geochemical properties included pH H_2O, EC H_2O, ANC, total S, NAG pH, MPA, NAP, and the ratio of ANC/MPA. Analysis of heavy metal content and tailings geochemical was carried out at Timika Environmental Laboratory (TEL), Timika. The criteria for heavy metal content refer to the Screening and Assessment of Contaminated Sediment (2014). Data collected from the study are presented in tables and graphics.

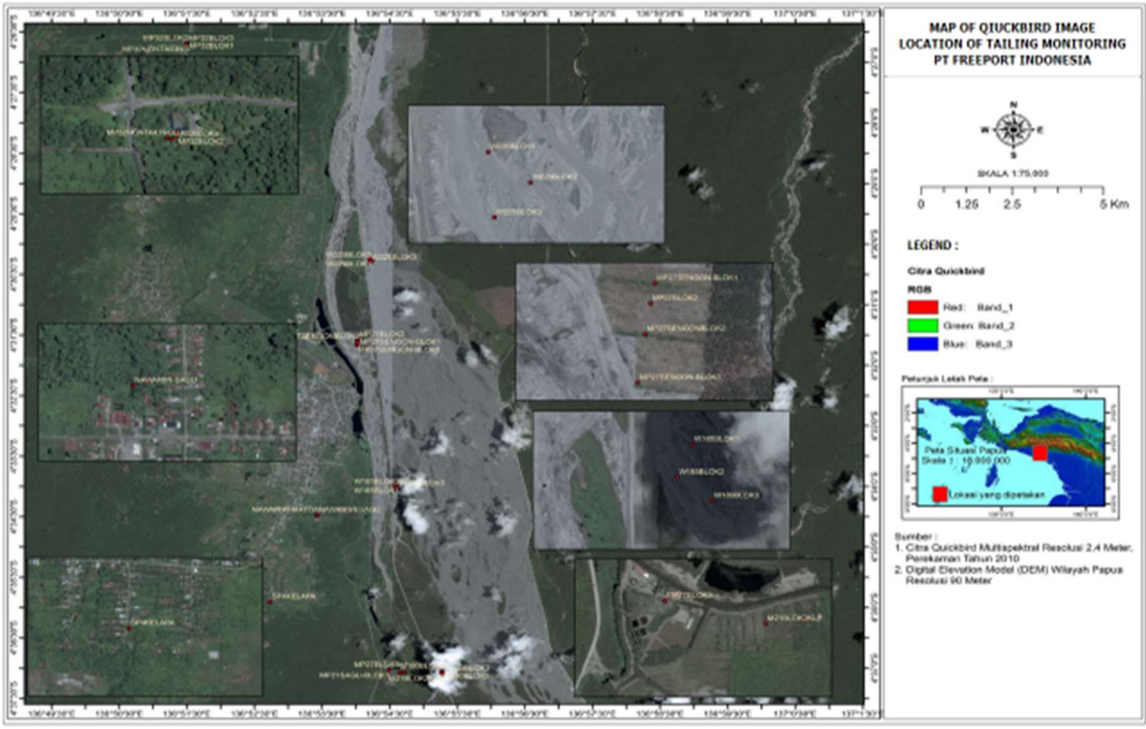

Figure 1. The Location of the study at ModADA – Timika.

Results and Discussion

The Acid Mine Drainage (AMD) formation

The Acid Mine Drainage (AMD) is one of the main impacts of mining activities that must be managed not only because of its impact on the aquatic environment or groundwater but also because once it has been formed it will be difficult to stop unless one component runs out. The formation of AMD can have a very long-lasting impact, even beyond the life of the mine and can last up to hundreds of years (Gautama, 2012). The main factors that determine the formation of AMD are pH, temperature, oxygen content of the gas phase with saturation < 100%, oxygen concentration in the water phase, saturation with water, Fe^{3+} chemical activity, exposed metal sulphide surface area, chemical activation energy, and bacteria activity (Akcil and Koldas, 2006). AMD is formed from oxidation of minerals containing iron-sulfur, such as pyrite (FeS_2) and Fe_xS_x (pyrrhotite) by oxidizers such as water, oxygen and carbon dioxide with the help of bacterial catalysts and other products as a result of these oxidation reactions (Fahruddin, 2010; Dold, 2014). The reaction can be stated in the following stages:

a. The sulfide mineral oxidation process may occur due to the presence of air and water with the help of *Thiobacillus ferooxidans* bacteria. The reaction formed is:

$$2\ FeS_{2\ (s)} + 7\ O_{2\ (aq)} + 2\ H_2O \rightarrow 2\ Fe^{2+} + 4\ SO_4^{2-} + 4\ H^+$$

Slightly acidic environmental conditions or low pH will trigger the development of the *Thiobacillus ferooxidans* bacteria that use inorganic compounds containing S and Fe as an energy source and result in the formation of pyrite.

b. *T. ferooxidans* speeds up the reaction rate of chemical oxidation of pyrite from 500,000 - 1,000,000 times. The Fe^{3+} ion is a very strong oxidant, so the reaction formed is:

$$FeS_{2\ (s)} + 14\ O_{2\ (aq)} + 8H_2O \rightarrow 15\ Fe^{2+} + 2\ SO_4^{2-} + 16\ H^+$$

c. The reaction causes the pH to drop dramatically, and the reaction formed is:

$$Fe^{2+} + O_2 + 4\ H^+ \rightarrow 4\ Fe^{3+} + H_2O$$

The resulting Fe^{3+} ion will be used by *T. ferooxidans* to form AMD repeatedly so that once the AMD appears, it cannot be stopped for hundreds of years (Fahruddin, 2010). From this reaction, the Fe metal will accumulate on the soil and water. Some other metals besides Fe, such as Mn, Zn, Cu, Ni. Pb, Cd, etc can be found. The speed of AMD formation is also influenced by several factors both internally and externally. Internal factors such as rock characteristics and sulfur form, while external factors are temperature, pH, and population of sulfur-oxidizing bacteria. Once the AMD has been formed, it cannot be stopped and it takes a very long time to hundreds of years to overcome it. Therefore it is very important to prevent or control the possibility of AMD formation.

Monitoring of tailings deposition areas at ModADA

Non-tailing material

There are two (2) types of mine waste as non-tailing materials, namely suspended sediment and basic sediment. Suspended sediment is a product of acid mine drainage (AMD) around the Grassberg area and overburden stockpiles which has been neutralized by limestone and erosion from the overburden stockpiles. The particle size of this sediment is 0.010 mm (50%), chemical characteristics colloidal, difficult to settle, with acid-neutralizing capacity (ANC), and concentrations of some heavy metals such as Pb, Zn, and As are higher than those contained in tailings. Basic sediment is an erosion product from the Grasberg area and OB stockpiles in West Grassberg and Wanagon that has a greater particle size than the particle size of the tailings. The two types of mine waste products flow to the Aghawagon and Wanagon rivers, which then mix with the tailings material through the Otomona river system which then settles in ModADA.

Tailing material and suspended sediment

The heavy fraction tailing material that has large particles flowing through the river system along with suspended sediment will settle at ModADA. When the erosion rates increase due to high rainfall, the overburden stockpiles in Wanagon tend to affect the tailings storage capacity, therefore area expansion at ModADA is needed. Sulfide mineral oxidation process from pyrite (FeS_2) as a negative impact is a phenomenon of the presence of non-tailings material in ModADA that potentially produce acid mine drainage (AMD) and leaching of sulfide minerals in decades, which results in the pollution of the surrounding environment of ModADA. The magnetite levels in the range of 4-10% is a positive impact of tailings and non-tailing waste that settles on ModADA (Leys, 2007). The chemical analysis of sediment deposition contains 6.14%-8.88% of Fe metal and 0.16%-0.25% of Cu. It consist also around magnetite (34.35%-59.85%), pyrite (18.3%-29.71%, quartz (15.31%-25.43%), garnet (1.73%-3%), rutile (0.46%), chalcopyrite (0.17%-1.46%), pyroxene (0.8%-2.35%), hematite (3.49%), and iron oxide (1.80%-4.81%) (Virman et al., 2010). Figure 2 shows the AMD seepage that passes the edge of the ModADA East embankment at MP 36 to Kopi river in 2007.

Impact of tailings and SS materials on sedimentation in the Ajkwa estuary

The monitoring of suspended sediment waste products types to the tailing material for suspended solid in Otomona, Kelapa Lima, and Pandan Lima found that the ANC values increased and the total sulfur value decreased. This phenomenon has a positive impact, which can reduce the potential for AMD to occur (Golder, 2010). In 2010, the average tailings production is about 222,349 tons, suspended sediment from the Wanagon river was 9900 mg/L, and the ANC ratio in Otomona to tailings material was 1.1, while Kelapa Lima and Pandan Lima had the similar ratio at 1.5 with TSS values of 4,700 and 7,600 mg/L, respectively. The monitoring in 2012 found that the average tailings production decreased to around 170,950 tons and suspended sediment from the Wanagon river increased to 39,500 mg/L, so that the ANC ratio in Kelapa Lima and Pandan Lima became 3.2 and 3.8, with TSS values respectively are 11,600 and 7600 mg/L.

The increase in the ANC ratio at Kelapa Lima and Pandan Lima due to the high contribution from the suspended sediment caused an increase in the levels of As, Pb, and Zn in the Ajkwa estuary and its surrounding area. While Cu content is relatively constant or even low, the Cu content contained in the suspended sediment is generally lower than the tailings material. The monitoring results of the levels of As, Pb, Zn, and Cu in sediments of the Ajkwa estuary (EM270) in the second term of 2010 are 17; 100; 233; and 869 mg/kg, respectively, while in the second term of 2012 the levels of As, Pb, and Zn respectively increased to 35; 311; and 574 mg/kg, but Cu decreased to 761 mg/kg. Monitoring of particle size and median obtained particle percentage of 0.002 mm at 10% increased to 18%, while median particle size of 0.015 mm decreased to 0.008 mm (KepMen Lingkungan Hidup No. 5 Tahun 2014).

The existence of the suspended sediment was found more significant than the tailings material, therefore, further serious management is needed in the ModADA area which is mixed with the non-tailing material. It is stated in the Minister of Finance Decree No. 431 in July 2008 that the value of TSS (total suspended solid) was 9000 mg/L at Kelapa Lima and Pandan Lima. This value was calculated based on the sum of the daily TSS divided by the number of days in a month and the number calculated by 50% of the actual measurement results with the allowed TSS value is 18,000 mg/L. The monitoring showed that the average percentage of tailings and non-tailing materials in the form of natural sediments from the East and West Otomona rivers on Otomona Bridge during the period 1998 - 2006 were 59% and 41%, respectively.

Figure 2. AMD seepage that passes the edge of the ModADA East embankment at MP 36 to Kopi river in 2007.

In 2009 a different TSS monitoring result was obtained that the percentage of non-tailing material from Grassberg and overburden from Wanagon which flowed to the Aghawagon and Wanagon rivers which also mixed with tailings material with a range of 29-67%. The difference results from previous periodic monitoring in 1998-2006 related to the high and intensive rainfall at the Wanagon highlands, resulting in erosion of overburden deposits, which then flowed through the Wanagon and Aghawagon rivers. Meanwhile, the results of monitoring to the percentage of natural sediments from the West and East Otomona rivers are only around 2% per year. This phenomenon shows that the percentage of TSS from the sedimentation process increases due to erosion of overburden deposits caused by high rainfall and intensive during the period of 2009.

Impact of sedimentation in the Ajkwa estuary on the aquatic biota

Determination of sediment quality standards is very important to protect ecosystems in waters. The sediment quality standards published by Screening and Assessment of Contaminated Sediment (2014) for salt water is a criterion of class C with the sediment criteria are highly contaminated and tend to pose a risk to aquatic life, with Pb levels > 220, Zn > 410, and Cu > 270 mg/kg. The levels of the three metal elements compared to those contained in sediments in the Ajkwa estuary in 2012 were higher, that are 311, 74 and 761 mg/kg, respectively. On the contrary, As is lower at 35 mg/kg, that is categorized to the class B criteria (8.2 - 70 mg/kg), with the sediment category slightly contaminated, so further testing is still needed to monitor the potential risks.

Heavy metal content in tailings active ModADA

The heavy metal contained inactive tailings in WA 225, WA 185, and WA 160 (North-South ModADA) are presented in Figure 2. There is a tendency for higher levels of heavy metals in the surface layer (0 - 20 cm) and a decrease in the lower layer (20-40 cm) for monitoring sites in the northern part of WA 225 and WA 185, except the southern part of WA 160 which has decreased. On the other hand, Pb and Zn increased significantly compared to the two previous locations in the North. The average heavy metal content of the sampling location with a depth of 0-20 cm and 20-40 cm at WA 225, WA 185, and WA 160 according to Screening and Assessment of Contaminated Sediment (2014) for fresh water, categorized in the criteria for class C with As (> 33 mg/kg), Cu (> 150 mg/kg), Pb (> 130 mg/kg), and Zn (> 460 mg/kg). Class C is a sediment that has a very high risk of contamination and tends to be at risk for water life. Some other heavy metals included in the class B criteria are Cd (1-5 mg/kg), while class A is Cr (< 43 mg/kg), Hg or mercury (< 0.2 mg/kg), and Ni (< 23 mg/kg) as presented in Table 1a-b. Table 1a shows that the deposition area of the active tailings in ModADA requires attention in handling the environment for some heavy metals (As, Cu, Pb, Zn) which are found in very high concentrations.

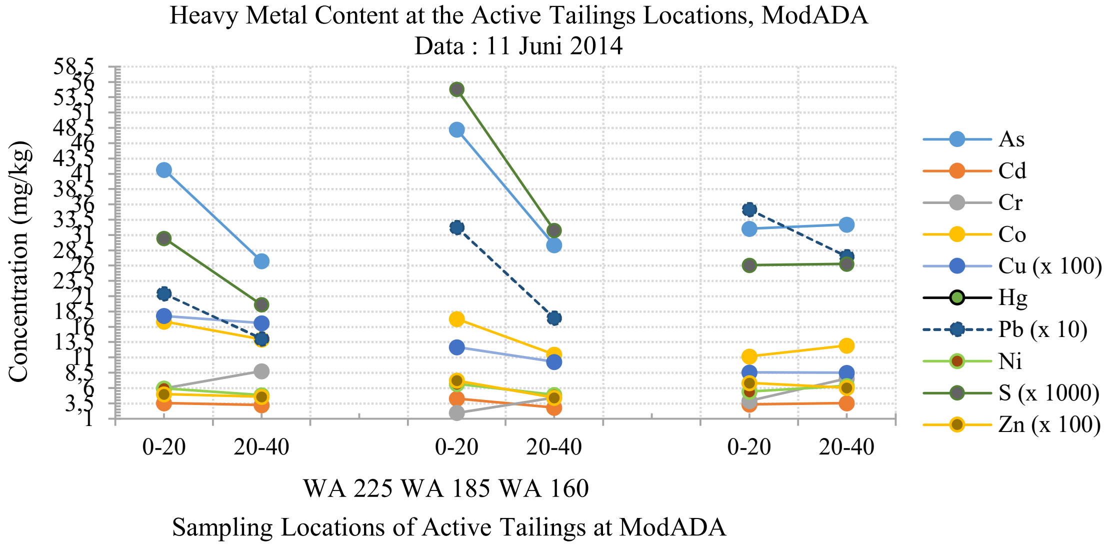

Figure 3. Heavy metal content at the active tailings locations, ModADA.

Table 1a. Average heavy metal content and class criteria of active tailings at ModADA.

Location (mg/kg)	As	Cd	Cr	Cu	Hg	Pb	Ni	Zn
WA 225	34.20	3.37	7.35	1720.00	0.01	177.33	5.40	479.67
WA 185	38.82	3.55	3.19	1146.33	0.00	248.33	5.78	583.33
WA 160	32.38	3.42	5.74	852.67	0.01	313.17	5.88	645.17
The average of Class	C	B	A	C	A	C	A	C

Note: Class A = Sediment has a low risk of contamination for water life; Class B = Sediments have a slight to moderate risk of contamination, and further testing is still needed to monitor the potential risks; Class C = Sediments have a high risk of contamination and tend to be at risk for water life.

The geochemical analysis of active tailings at ModADA as presented in Table 1b shows that the pH values are slightly alkaline (pH 7.6 - 8.5) to alkaline (pH > 8.5) at a depth of 0-20 cm and 20-40 cm. The total sulfur (S) is high in the surface layer and decrease in the layer below. The increasing of sulfur concentration in the surface layer due to the oxidation when in contact with oxygen from air or water. However, before entering ModADA, the tailings have been neutralized with $CaCO_3$ or CaO limestone, so that the pH of the tailings in ModADA is in the range of slightly alkaline to alkaline. The oxidation process tends to be intensive in the surface layers with coarse particle size (WA 225) and medium (WA 185) compared to fine particles (WA 160). Therefore some heavy metals are found in high concentrations but are not available.

Table 1b. Geochemical characteristics of active tailings at ModADA.

Location of Active Tailings		**WA 225**		**WA 185**		**WA 160**	
Parameter	Unit	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm
pH H_2O		8.68	8.63	7.94	8.47	7.94	7.90
EC H_2O	µS/cm	1478.33	2340	1886.67	1230	1426.67	1633.33
ANC	kg H_2SO_4/t	215	214	175.67	157	263.67	252.67
Total S	%	3.10	1.96	5.91	3.23	2.92	2.86
NAG pH		8.24	8.28	8.23	9.46	8.80	8.50
NAG pH 4.5	kg H_2SO_4/t	0.00	0.00	0.00	0.00	0.00	0.00
NAG pH 7.0	kg H_2SO_4/t	0.00	0.00	0.00	0.00	0.00	0.00
MPA		94.96	59.87	180.95	98.74	89.35	87.52
NAPP		-120.04	-154.13	5.28	-58.26	-174.31	-165.15
ANC/MPA		2.26	3.57	0.97	1.59	2.95	2.89

Note: Data Analysis issued by TEL-PTFI June 11, 2014; EC = electrolyte conductivity, NAG = net acid generating; NAPP = nett acid-producing potential; ANC = acid neutralizing capacity; MPA = maximum potential acidity.

If the ANC/MPA ratio is > 1.5, it is not potentially acidic, but the ratio at the sampling location WA 185 is < 1.5, which is equal to 0.97 (0-20 cm) in the surface layer and has a slight increase to 1.59 (20-40 cm) in the layer below. The ANC/MPA ratio < 1.5 indicates that the ability to form acid (MPA) is higher than the ability to neutralize acid (ANC). In this condition there is a tendency for AMD to be formed at WA 185, therefore, serious processing and periodic routine monitoring is needed.

Heavy metal content at inactive tailings of ModADA

The heavy metal contained in inactive tailings in MP 27 and MP 21 (North-South ModADA) is presented in Figure 4. It can be seen from the graph that heavy metals content in the northern part of MP 27 is low, except Cu which is categorized as class C (> 150 mg/kg) because it is originated from the source rock that mined and carried away by the tailings from MP 74. On the other hand, the Cu concentration in the southern part of MP 21 decreases drastically except for As which is in the C criteria class (> 33 mg/kg). The increasing of As concentration due to Sulfur (S) increased from 0.33% (0-20 cm) to 1.33% (20-40 cm) as a result of the oxidation process of sulfide minerals with air and water, resulting in a decrease of pH from 7.91 (0-20 cm) to pH 7.51 (20-40 cm), as shown in Table 2a-b. The geochemical analysis of inactive tailings at ModADA as presented in Table 2b shows an increase in pH value from 7.78 (slightly alkaline) at 0-20 cm to pH 8.56 (alkaline) at 20-40 cm in MP 27. While in MP 21 the pH value decreases from 7.91 (slightly alkaline) at 0-20 cm to 7.57 (slightly alkaline) at 20-40 cm. The total Sulfur (S) increases very significant from the concentration of 0.33% (0-20 cm) to 1.04% (20-40 cm) by decreasing the pH value of 7.91 to pH 7.57.

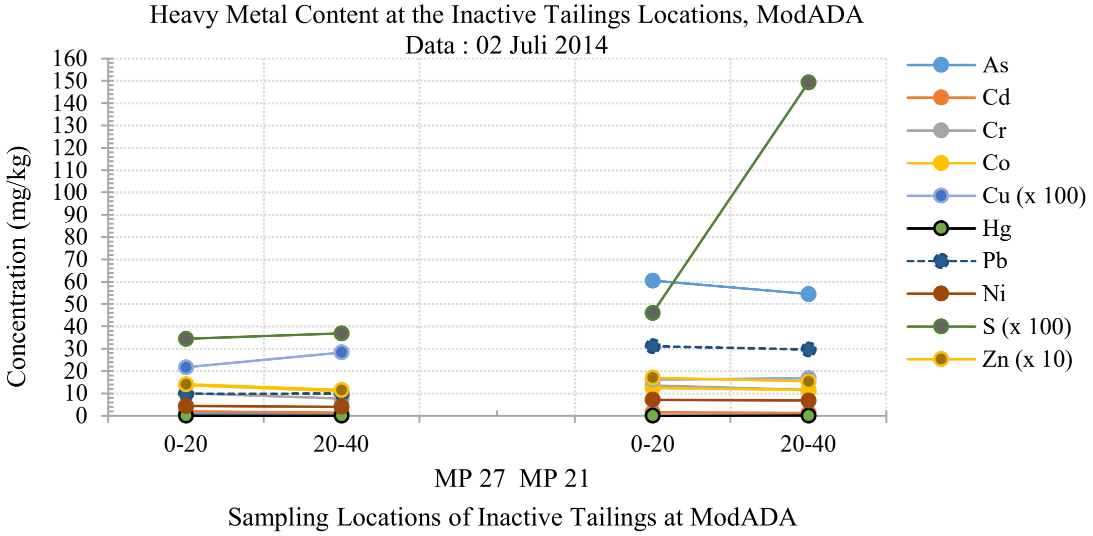

Figure 4. Heavy metal content of inactive tailings locations at ModADA.

Table 2a. Average heavy metal content and class criteria of inactive tailings at ModADA.

Location (mg/kg)	As	Cd	Cr	Cu	Hg	Pb	Ni	Zn
MP 27	0.92	1.73	8.91	2501.67	0.01	9.89	4.22	128.50
The average of Class	A	B	A	C	A	A	A	B
MP 21	57.50	1.43	12.52	16.55	0.02	30.43	6.96	16.25
The average of Class	C	B	A	A	A	A	A	A

Note: Class A = Sediment has a low risk of contamination for water life; Class B = Sediments have a slight to moderate risk of contamination, and further testing is still needed to monitor the potential risks; Class C = Sediments have a high risk of contamination and tend to be at risk for water life

The tailings material before entering ModADA has been neutralized with $CaCO_3$ or CaO limestone material so that the pH of the tailings can constant at slightly alkaline to alkaline. Unlike tailings material at MP 21 has been inactive since 1992/1993 and has functioned as a pilot reclamation area for agricultural and forestry, tailing at MP 27 which used as a reclamation area since 2001/2002 has more rough particles in the north than in the southern part of ModADA, therefore, the availability of essential macro nutrients is very low due to the ability to absorb nutrients very low.

Tailings have a limited buffer capacity to heavy metals and it is determined by several factors such as pH, organic matter content, and cation exchange capacity (Lepp, 1981). The CEC value in the surface layer of MP 27 tailings was 2.79 cmol/kg, and the lower layer was 3.07 cmol/kg, with criteria of very low CEC (< 5 cmol/kg). On the other hand, the CEC value in the surface layer of MP 21 was 13.21 cmol/kg, and the lower layer was 5.31 cmol/kg, with criteria of low or CEC 5-16 cmol/kg (Taberima et al, 2008). The increasing of CEC due to organic colloids content of tailing derived from organic matter from decomposed plant litter that has been cultivated on the reclamation area. The C-organic content at MP 21 is higher at 2.59% and 1.65% compared to MP 27 which is at 0.36 cmol/kg and 0.27 cmol/kg in layers 0-20 cm and 20-40 cm, respectively (Taberima and Sarwom, 2016).

Table 2b. Geochemical characteristics of inactive tailings at ModADA.

Location of Inactive Tailings		MP 27		MP 21	
Parameter	Unit	0-20 cm	20-40 cm	0-20 cm	20-40 cm
pH H_2O		7.78	8.56	7.91	7.57
EC H_2O	µS/cm	1523.33	1700.00	1119.00	1180.00
ANC	kg H_2SO_4/t	16.67	17.67	126.00	138
Total S	%	0.28	0.26	0.33	1.04
NAG pH		4.47	5.00	8.66	8.47
NAG pH 4.5	kg H_2SO_4/t	1.00	0.00	0.00	0.00
NAG pH 7.0	kg H_2SO_4/t	4.00	3.00	0.00	0.00
MPA		8.67	7.96	10.00	31.72
NAPP		-8.00	-9.71	-116.00	-105.94
ANC/MPA		1.92	2.22	12.61	4.34

Note: Data Analysis issued by TEL-PTFI June 11, 2014; EC = electrolyte conductivity, NAG = net acid generating, NAPP = nett acid-producing potential; ANC = acid neutralizing capacity, MPA = maximum potential acidity.

The ANC/MPA ratio at > 1.5 is not potentially acidic, but at the MP 27 sampling location, the ANC/MPA ratio is found at 1.92 (0-20 cm) and slightly increases to 2.22 (20-40 cm) in the layer below it. On the other hand, the sampling location at MP 21 had an ANC/MPA at 12.61 (0-20 cm) and decreased to 4.34 (20-40 cm). It is clear that the presence of Sulfur (S) is significantly related to the change of the ANC/MPA ratio. In conditions of total S < 1%, the ANC/MPA ratio tends to be stable, but the total of S that > 1% tends to cause a drastic change to the ANC/MPA ratio. Technically, before tailings enter ModADA, the neutralization process with lime material has been carried out. The S content of 1% in 1 ton of tailing material will produce sulfuric acid (H_2SO_4) of 30.62 kg so that it requires 31.25 kg of $CaCO_3$ to neutralize it. The existence of S of tailing material in the form of pyrite (FeS_2) will quantify the potential for acid formation due to the total sulfur content (Gautama, 2012).

Conclusion

The Acid Mine Drainage (AMD) is one of the important impacts of mining activities that must be managed not only because of its impact on the aquatic or groundwater environment but also sedimentation of tailings at ModADA after mining operation. The geochemical analysis of inactive tailings at ModADA showed that the ANC/MPA ratio at MP27 was 1.92 (0-20 cm), and slightly increased to 2.22 (20-40 cm), while MP 21 had ANC/MPA ratio at 12.61 (0-20 cm), and decreased to 4.34 (20-40 cm). The average heavy metals content at MP 27 was low except Cu which was categorized as class C (> 150 mg/kg) because it originated from source rock mined and follows tailings flow from MP 74. Except MP 21 had a drastically decrease of Cu concentration and As categorized in class C (> 33 mg/kg).

The geochemical analysis of active tailings at ModADA showed that the ANC/MPA ratio at WA 185 was < 1.5, which was equal to 0.97 (0-20 cm), and slightly increased to 1.59 (20-40 cm). The ANC/MPA ratio < 1.5 performed a higher acid-forming ability (MPA) than the ability to neutralize acid (ANC). The average heavy metal content of active tailings at WA 225, WA 185, and WA 160 which categorized in the criteria for C class were As (> 33 mg/kg), Cu (> 150 mg/kg), Pb (> 130 mg/kg), and Zn (> 460 mg/kg), while Cd (1-5 mg/kg) was categorized in class B, and Cr (< 43 mg/kg), Hg (< 0.2 mg/kg), as well as Ni (< 23 mg/kg) were categorized in class A. By knowing the value of ANC/MPA ratio from tailing sedimentation (inactive and active) at ModADA based on its tailing characteristics so that in the formation of a good prevention planning can be arranged before entering the post-mining.

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