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Research Article

Analysis of the Potential for Acid Mine Drainage of the Nickel Mining Area in the Ultramafic Formation

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Abstract

The phenomenon of acid mine drainage (AMD) is one of the serious environmental problems that is often encountered at a mine site. Controlling acid mine drainage is an important thing to do during mining activities and after mining activities end. This research aims to analyze the potential for rock and soil formation of acid mine drainage to the environment around the nickel mining area in Kabaena Timur District. Data obtained through the analysis of the laboratory of Limited Company of Narayana Lambale Selaras. The results showed that in open land the sulphure content range was 0.411-1.452 Kg H2SO4/ton. NAG values are in the equivalent range of 0-3.675 Kg H2SO4/ton. ANC ranges from 25.725-60.025 Kg H2SO4/ton. The range of MPA values is equivalent to 1.977-44.470 Kg H2SO4/ton. The NAPP values ranged from -40.526 to -3.839 and the NPR ranged from 1.116 to 3.776. Whereas in closed land the values for sulphure content, NAG, ANC, MPA, NAPP, and NPR were respectively = 0.418-1.364 Kg H2SO4/ton; 0-3.185 Kg H2SO4/ton; 25.725-57.575 Kg H2SO4/ton; 12.790-41.775 Kg H2SO4/ton; -36.846 to -1.276 and 1.037-3.927. Based on the criteria for NAPP and NPR values, shows that all rock and soil samples in the nickel mining area don't have the potential to form acid mine drainage because the NAPP value is < 0 and the NPR value > 1.

Keywords

Acid mine drainage, Nickel mine, Kabaena Timur

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Introduction

The phenomenon of Acid Mine Drainage (AMD) is a serious problem to the environment that is often found in mining sites that contain sulfides (Nasir, Ibrahim, & Arief, 2014). Acid mine drainage occurs in a mining environment when sulfide minerals oxidize. The formation of acid mine drainage is influenced by water, oxygen, and rocks containing sulfide minerals such as pyrite (Fe_2S), chalcopyrite ($CuFe_2S$), marcasite (FeS_2), sphalerite (ZnS), galena (PbS), millerite (NiS), arsenpirite (FeAsS), pyrhotite (FeO_8S) and contains dissolved heavy metals from rocks at the mining site. This is supported by (Kaharapenni & Noor, 2015). One of the causes of water quality pollution is the potential for acid mine drainage because generally, acid mine drainage contains sulfide minerals, namely pyrite (FeS_2), millerite (NiS), or others. Sulfide minerals have the potential to cause or form acid mine drainage, this is naturally found in rocks in the bowels of the earth. An indication of acid mine drainage is the appearance of a "yellow boy" at the mine site which is the result of the oxidation reaction of sulfide minerals which is known as a common reaction that produces acid mine drainage (Gautama, 2014). Acid mine drainage is one of the environmental impacts that occur due to reactions of sulfate compounds and metal ions such as iron, nickel, or others in potentially acidic rocks (Potential Acid Forming) (Yusmur, Ardiansyah, & Mansur, 2019). Rocks in the mining location are exposed on the surface as a result of land clearing or rock unloading during mining. The sulfide minerals contained in the rock will then be oxidized to form oxide compounds and when in contact with water (rainwater or mine water). If this acidic water is not neutralized, it will cause acid mine drainage to the surrounding environment and can cause environmental pollution. The process of sulfide mineral oxidation is often accelerated by the presence of microbiological activity (Wijaya, 2010), and the microorganisms also facilitate the formation of acid mine drainage (Hallberg, González-Toril, & Johnson, 2010). Apart from rock, acid mine drainage also occurs due to the oxidation process of pyrite (FeS_2) and other sulfide mineral materials such as millerite (NiS) which are exposed to the surface of the ground in the process of extracting mining minerals (Wahyudin, Widodo, & Nurwaskito, 2018). The impact of mining activities on areas that have the potential to produce acidic water must be managed not only because of its impact on the environment but because once formed it will be difficult to stop it and this can last for hundreds of years or even beyond the life of the mine so that even though the mine has been closed it still leaves the problem. The environmental impact caused by acid mine drainage can be minimized by preventing direct contact between sulfide minerals, oxygen, and water (MAHARANI, Purwanto, & Hidayat, 2019). The method of prevention is the most effective, but the formation of acid mine drainage is very difficult to prevent, especially in mining activities (Kasmiani, Widodo, & Bakri, 2018). Although the impact of mining activities in areas that have rocks that have the potential to form acidic water cannot be avoided, from the mining business actor's point of view, this must be managed properly. After all, it can impact the business actor as the person in charge and also have an impact on reclamation costs because it has to carry out excavation and backfilling at post-mining which also requires high costs to treat it (García et al., 2014; Park et al., 2014; Vitor et al., 2015; Wijaya, 2010; Wu et al., 2016; Zou et al., 2015). Controlling acid mine drainage is something that needs to be done during mining activities and after mining activities end because acid mine drainage can reduce the quality of surface water and groundwater, besides that if it is discharged into the river it will have an impact on the people who live along the river flow as well as will disturb the biota that lives on land as well as biota in the waters (Irawan et al., 2016). Wijaya (2010) researched about the neutralization of acid mine drainage with alkaline reagents, namely limestone (calcium carbonate), and the management of sulfide waste material by applying the encapsulation in-pit disposal model. Nasir et al. (2014) researched about neutralizing acid mine drainage by using a combination of processing tools, namely sand filters, ultrafiltration, and reverse osmosis. Yusmur et al. (2019) researched about neutralizing acid mine drainage by using artificial swamp forest. Wahyudin et al. (2018) researched about the effectiveness of acid mine water management in the settling pond. Kaharapenni and Noor (2015) researched about the quality of rivers due to acid mine drainage. From several studies of acid mine drainage in Indonesia that have been conducted before, as above, it is shown that many researchers have studied the acid mine drainage that has been formed, even studying its impact on the environment, so a way is needed to overcome it. Meanwhile, our research entitled "Analysis of the Potential for Acid Mine Drainage of the Nickel Mining Area in the Ultramafic Formation" tries to examine it from the aspect of prevention because the method of prevention is the most effective method of treating. Where planning to prevent the formation of acid mine drainage is important to know and calculate the amount of potential acid mine drainage that will be generated in the environment around the mine. So that our position in our research is an initial analysis stage to identify the potential for acid production from the layers of rock and soil around the mine site whether it is an acid producer, neutral, or alkalinity producer. The results of the preliminary analysis can then be used as a basis or recommendation for choosing an effective mining method, appropriate equipment, and efficient handling techniques for potential acid-forming materials by nickel mine managers in Kabaena Timur District, thereby minimizing the impact caused when mining operations are carried out and also impact on post-mining. Furthermore, the results of the analysis of the potential for acid-forming rocks and soils in the mining area become important guidelines for efficient, effective, and environmentally friendly mine management steps both during mining operations and at post-mining. The Company Performance Rating Program in Environmental Management is one of the supervisory controls carried out by the Ministry of Environment and the Environmental Agency in Indonesia, concerning controlling damage to the mining environment. One of the parameters of this program is an effort to study and handle rocks and soils that have the potential to form acid mine drainage and the potential impact of acid mine drainage on the water conditions around the mining site. The potential for nickel reserves in Bombana Regency reaches 28.2 billion Wet Metric Tons (WMT) (Energi & Mineral, 2015). The potential for nickel that is owned by Bombana Regency, one of which is located in the Kabaena Timur District at this time, has attracted the attention of mining companies to carry out exploration and exploitation activities of nickel mining. However, from these activities, accurate information is needed regarding the preliminary data on the potential for mapping of mineral and energy resources that have been determined by the Indonesian Minister of Environment before mining exploration and exploitation activities. This is due to the uneven nature of the presence of minerals on the earth's surface and its formation still requires a long geological time, so planning to prevent the formation of acid mine drainage needs to be done to determine and calculate the potential size of acid mine drainage that will be generated. Therefore, it is important to research the distribution of the potential for acid water formation in nickel mining areas in Kabaena Timur District in terms of environmental and ecosystem management aspects. The purpose of this research was to analyze the potential for rock and soil formation of acid mine drainage to the environment around the nickel mining area in Kabaena Timur District as well as the potential for acid mine drainage on the water conditions around the mining site. This research is useful as input for the improvement of technical environmental management plans that are environmentally friendly and assist in making decisions on environmental planning and management in activities to be carried out, especially the first steps in terms of preventing the negative impacts of mining activities.

Materials and methods

Analysis of the Potential of Acid Mine Drainage at Nickel Mining Locations in Kabaena Timur District to Realize Environmentally Friendly Mining Management is carried out in the Nickel mining area in Kabaena Timur District by analyzing the potential of rock and soil-forming acid mine drainage on the environment around the Nickel mining area. For potential rock analysis, it consists of 16 sample points. Rock samples were obtained in open land with a total of 8 sample points. While the rock samples obtained on closed land were 8 sample points. Soil potential analysis also consists of 16 sample points. Soil samples were obtained in open land with a total of 8 sample points. While the soil samples obtained on closed land were 8 sample points. More details on the map of the research location can be seen in **Figure 1**. While the characteristics of each sample of rock and soil areas presented in **Table 1** and **Table 2** below.

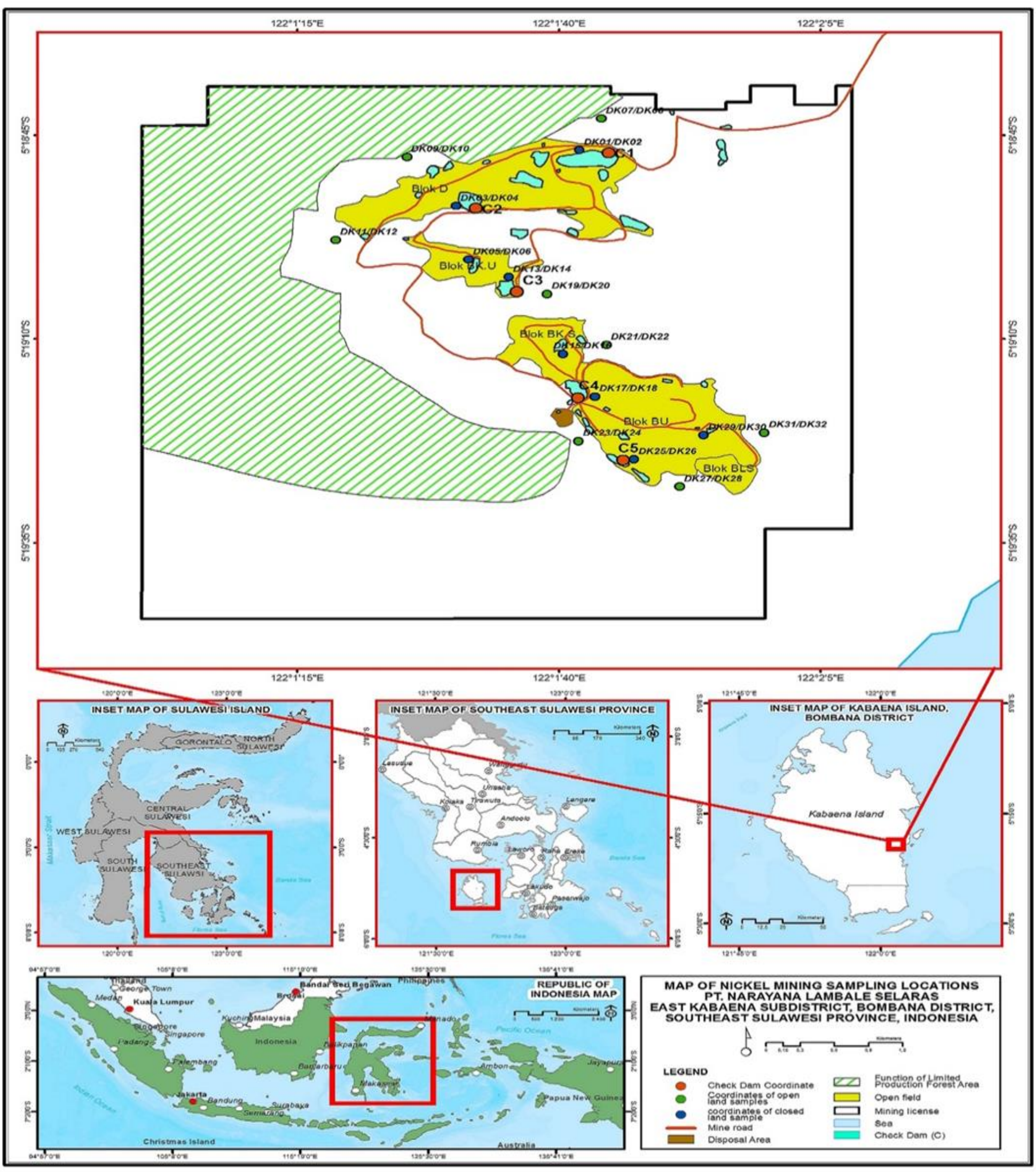

Figure 1 Map of research location.

Table 1.
The characteristics of each rock and soil sample on open land in the nickel mining area in Kabaena Timur District.

Sample Code	Information	Description	Documentation
DK01 DK02	Rock in Open Land Soil in Open Land	The land that has been mined is located in Block D close to Check Dam (C1), 128 meters above sea level (MASL)	
DK03 DK04	Rock in Open Land Soil in Open Land	The land that has been mined is located in the lower Block D near the Check Dam (C2) with a height of 112 meters above sea level (MASL)	
DK05 DK06	Rock in Open Land Soil in Open Land	The land that has been mined is located in the upper BK.U Block near the Check Dam, an altitude of 102 meters above sea level (MASL)	
DK13 DK14	Rock in Open Land Soil in Open Land	The land that has been mined is located in the lower BK.U Block near the Check Dam (C3) with a height of 95 meters above sea level (MASL)	
DK15 DK16	Rock in Open Land Soil in Open Land	The land that has been mined is located in the lower part of the BK.S Block near the Check Dam with a height of 90 meters above sea level (MASL)	
DK17 DK18	Rock in Open Land Soil in Open Land	The land that has been mined is located in the lower BU Block near the Check Dam (C4) with a height of 68 meters above sea level (MASL)	
DK25 DK26	Rock in Open Land Soil in Open Land	The land that has been mined is located in the side of the BU Block with Check Dam (C5) with a height of 24 meters above sea level (MASL)	
DK29 DK30	Rock in Open Land Soil in Open Land	The land that has been mined is located in the side of the BU Block with Check Dam with a height of 28 meters above sea level (MASL)	

Table 2.
The characteristics of each rock and soil sample on closed land in the nickel mining area in Kabaena Timur District.

Sample Code	Information	Description	Documentation
DK07	Rock in Closed Land	The land that has not been mined is located in Block D above close to Check Dam (C1), with an altitude of 132 meters above sea level (MASL)	
DK08	Soil in Closed Land		
DK09	Rock in Closed Land	The land that has not been mined is located in Block D above close to Check Dam (C1) with a height of 130 meters above sea level (MASL)	
DK10	Soil in Closed Land		
DK11	Rock in Closed Land	The land that has not been mined is located in the lower part of Block D with an altitude of 109 meters above sea level (MASL)	
DK12	Soil in Closed Land		
DK19	Rock in Closed Land	The land that has not been mined is located in Block BK.U on the right side close to Check Dam (C3) with an altitude of 82 m above sea level (MASL)	
DK20	Soil in Closed Land		
DK21	Rock in Closed Land	The land that has not been mined is located in the BK.S Block on the right side with a height of 92 meters above sea level (MASL)	
DK22	Soil in Closed Land		
DK23	Rock in Closed Land	The land that has not been mined is located on the side of the BU Block with Check Dam (C5) with a height of 27 meters above sea level (MASL)	
DK24	Soil in Closed Land		
DK27	Rock in Closed Land	The land that has not been mined is located at the bottom with an altitude of 22 meters above sea level (MASL)	
DK28	Soil in Closed Land		
DK31	Rock in Closed Land	The land that has not been mined is located	

DK32	Soil in Closed Land	in BU Block on the right side with Check Dam with a height of 27 meters above sea level (MASL)

Primary data in this research were obtained through the results of the laboratory analysis of Limited Company of Narayana Lambale Selaras. The specifications of the methods and materials used in this research can be seen in **Table 3**.

Table 3
Specifications of methods and materials used in the research.

Parameters	Method Specifications	Method Explanation	Information	Materials Used
Sulphure in Rock Samples Sulphure in Soil Samples	SNI 13-3481-1998	Sulphure analysis for rock and soil samples using the Eschka method based on the Indonesian National Standard.	Ex-Situ	100 mesh sieve, porcelain cup, muffle furnace, beaker glass (400 mL), bath, filter paper, desiccator, scale, oven, hotplate
Net Acid Generation (NAG) on Rock Net Acid Generation (NAG) on Soil	SNI 13-6599-2001	Analysis of the system for determining the net acid generation (NAG) based on the Indonesian National Standard.	Ex-Situ	Scale, 60 mesh sieve, beaker glass (150 mL), watch glass, fume hood, pH meter
Acid Neutralizing Capacity (ANC) on Rock Acid Neutralizing Capacity (ANC) on Soil	SNI 13-7170-2006	Analysis of determining the acid neutralizing capacity (ANC) for mining materials based on the Indonesian National Standard.	Ex-Situ	Scale, 60 mesh sieve, aluminum foil, erlenmeyer flask (250 mL), pH meter, burette, petri dishes, hotplate
Fe Content in Rocks MgO Content in Rocks CaO Content in Rocks Fe Content in Soil MgO Content in Soil CaO Content in Soil	X-Ray Diffraction (XRD)	One form of electromagnetic radiation which has an energy between 200 eV-1MeV. These rays are in the radiation between gamma and ultraviolet (UV) rays, so X-rays become a technique in structural analysis such as rock/soil mineral identity analysis.	Ex-Situ	100 mesh sieve, toledo mettler scale, jaw crusher, oven, rinmilk essa, spectrometer, philips analytical diffractometer PW1710 BASED

In this research, the data analysis used is descriptive quantitative analysis which is presented using graphs and tables which are sourced from the results of the analysis of the Limited Company of Narayana Lambale Selaras and the results of the calculation of the formula analysis are as follows:

Calculation for total sulphure content

The sulphure content can be calculated using the following equation:
Total sulphure content (% TS) = (13.74 (m2 - m3 + 0.0080)) / mL………………………………(1)
Information: m2 = Precipitated weight of $BaSO_4$ in the sample; m3 = Precipitated weight of $BaSO_4$ in the blanko; mL = Sample weight (gram).

Test calculation for net acid generation (NAG)

The net acid generation (NAG) can be calculated using the following equation:
NAG = (49 x V x M) / (Sample Weight (Gram))……………………………………(2)
Information: V = Volume of NaOH of the titration result (mL); M NAOH = Molarity of NaOH solution (mol/L); 49 = Weight equivalent to H_2SO_4.

Test calculation for acid neutralizing capacity (ANC)

The acid neutralizing capacity (ANC) can be calculated using the following equation:
ANC = ({(N.HCl x V.HCl) - (N.NaOH x V.NaOH)} x 49) / (Sample Weight (Gram))………………(3)
Information: ANC = Equivalent to Kg H_2SO_4/Ton; N.HCL = Normality of HCl solution (N); V.HCL = Volume of HCl solution (mL); N.NAOH = Normality of solution (NaOH) (N); V.NaOH = Volume of NaOH solution (mL); 49 = Weight equivalent to H_2SO_4.

Calculation for maximum potential acidity (MPA)

The maximum potential acidity (MPA) can be calculated using the following equation:
The MPA value is expressed by a formula = % TS x 30.625……………………(4)

Calculations for nett acid producing potential (NAPP)

The potential for nett acid producing potential (NAPP) can be calculated using the following equation:
The NAPP value is expressed by a formula = MPA – ANC…………………….(5)

Calculation for net potential ratio (NPR)

The net potential ratio (NPR) can be calculated using the following equation:
The NPR value is expressed by a formula = ANC / MPA………………………(6)

Based on the pH value of the NAG test and the value of NAPP, then the classification of rock and soil sample types can be carried out based on their geochemical properties, among others, as follows [18]:

– NAPP ≤ 0 ; NAG with pH ≥ 4.5 then it is classified as Non Acid Forming (NAF)
– NAPP > 0 ; NAG with pH < 4.5 then it is classified as Potentially Acid Forming (PAF)

The criteria for Potentially Acid Forming (PAF) by comparison NAPP and NPR that is:

– NAPP > 0; NPR < 1; pH NAG < 4.5
–

Calculation for rock sample level in open land, rock sample level in closed land, soil sample level in open land and soil sample level in closed land

Analysis of the type of sulfide minerals using the X-Ray Difraction (XRD) analysis technique through a diffractometer, where the XRD characterization results that are read will show the identity of the minerals contained in samples of nickel mining rock/soil in Kabaena Timur District. Where the content (w/W) is the weight of the rock and soil samples containing Fe, MgO and CaO levels to the total weight of the rock and soil samples.

Results and discussion

The problem of acid mine drainage is one of the potential impacts facing the mining world. Acid mine drainage is one of the environmental problems that can be found in mining sites such as nickel mining. The first step taken to manage acid mine drainage is to know the sources/locations that have the potential to form acid mine drainage. To determine the potential for acid mine drainage formation, several analyzes were carried out, namely analysis of sulphure content, net acid generation (NAG), acid neutralizing capacity (ANC), maximum potential acidity (MPA), nett acid producing potential (NAPP), net potential ratio (NPR), level of iron (Fe), level of magnesium oxide (MgO) and level of calcium oxide (CaO) in rocks and soils are based on methods following Indonesian National Standards.

Sulphure levels, net acid generation (NAG), acid neutralizing capacity (ANC)

The results of the analysis of sulphure levels, Net Acid Generation (NAG), Acid Neutralizing Capacity (ANC) on rock samples and soil samples obtained on open land and closed land at the nickel mining location in Kabaena Timur District are presented in **Figure 2**.

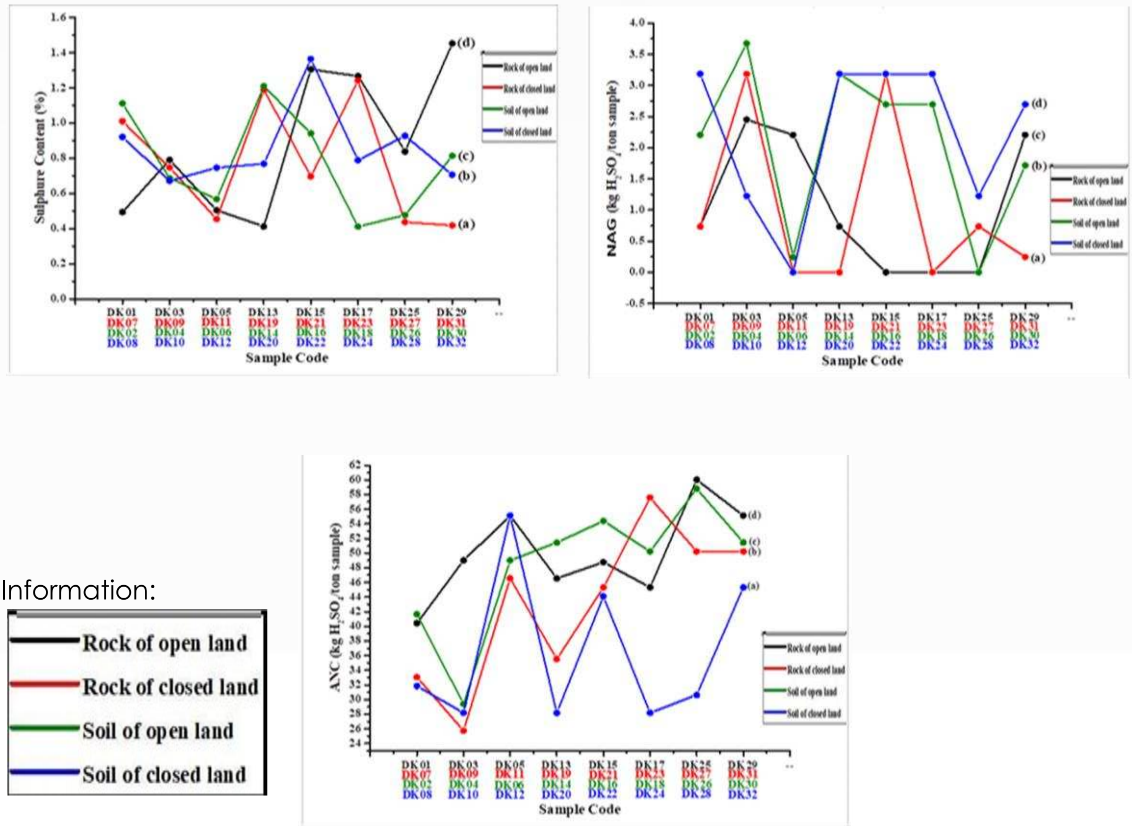

Figure 2 Graph of sulphure content, net acid generation (NAG), acid neutralizing capacity (ANC) on rock samples and soil samples in open land and closed land.

Maximum potential acidity (MPA), nett acid producing potential (NAPP), net potential ratio (NPR)

The results of the analysis of the maximum potential acidity (MPA), nett acid producing potential (NAPP), net potential ratio (NPR) of rock samples and soil samples obtained on open land and closed land at the nickel mining location in Kabaena Timur District are presented in **Figure 3**.

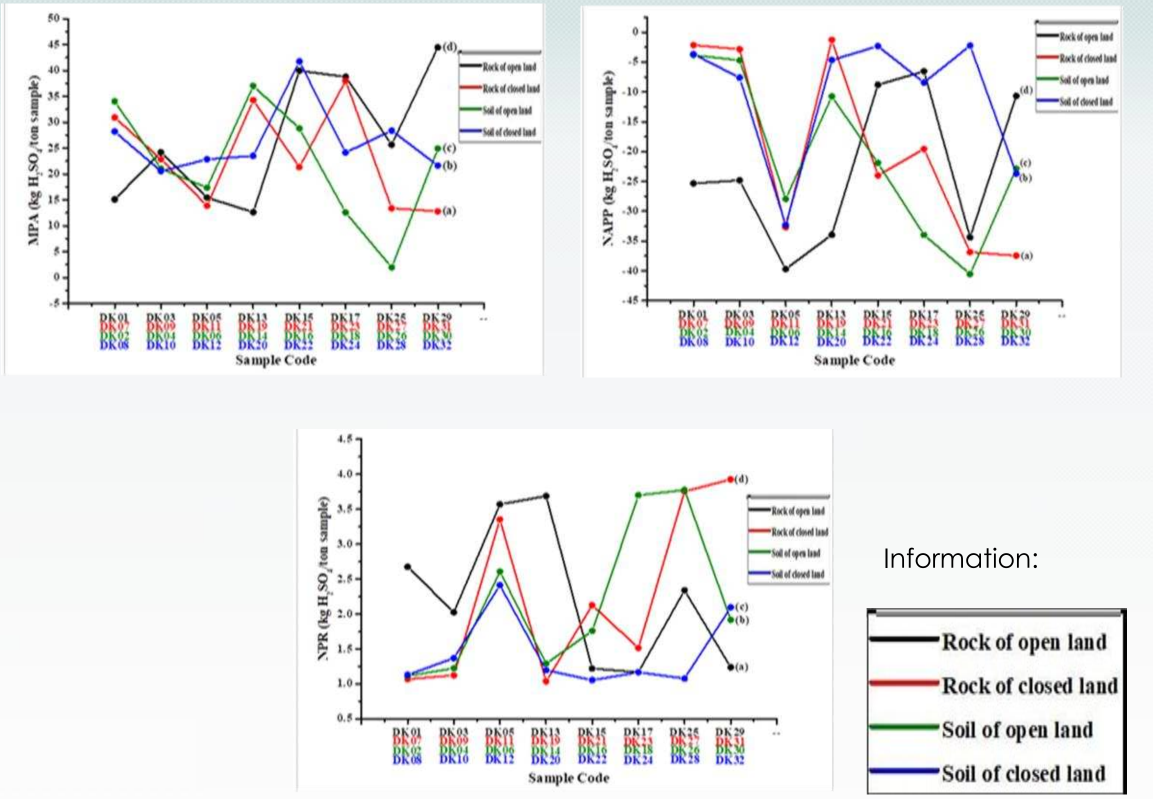

Figure 3 Graph of the maximum potential acidity (MPA), nett acid producing potential (NAPP), net potential ratio (NPR) on rock samples and soil samples in open land and closed land.

Rocks in open land

Based on the data in **Figure 2** above, it can be seen that rocks in open land have a sulphure content range of 0.412-1.452 Kg H_2SO_4/ton sample. The highest sulphure content value is a sample with code DK29 obtained from rocks in open land in BU block with a value of 1.452 Kg H_2SO_4/ton sample and the lowest sulphure content value with sample code DK13 on BK.U block with a value of 0.412 Kg H_2SO_4/ton sample. The value of net acid generation (NAG) was in the range of 0-2.029 Kg H_2SO_4/ton of sample. The highest Net Acid Generation (NAG) value was the sample with DK29 obtained from open land in the BU block. The value of acid neutralizing capacity (ANC) ranges from 40.425-60.025 Kg H_2SO_4/ton sample. The sample that had the highest acid neutralizing capacity (ANC) was the DK25 sample originating from open land rocks in the BU block. Acid mine drainage is formed when rock, usually containing pyrite (FeS_2) or others such as millerite (NiS), is exposed to oxygen, water, and/or oxidizing microorganisms, resulting in an oxidation process that dissolves iron and other elements such as nickel in the rock (Fernando et al., 2018). In nature, the reactions involved in the formation of acid-mining water occur slowly and water can buffer acidity and soluble metal ions. Mining activities amplify this reaction by exposing large surface areas of sulfidic rock resulting in the production of large volumes of acid mine drainage that exceed the natural buffering capacity of natural watercourses (Feris & Kotze, 2014; Ochieng, Seanego, & Nkwonta, 2010; Vyawahre & Rai, 2016). Acid mine drainage, typically characterized by a high sulfate content and low pH, is commonly known as "acid mine drainage" (AMD) or "acid rock drainage" (ARD) (Blowes & Jambor, 1990; Dold, 2017; Nordstrom, Blowes, & Ptacek, 2015). The quality and final pH of the mine effluent is largely determined by the dynamic balance between the ratio of acid-producing and acid-neutralizing minerals, chemical composition, availability of oxidizing agents, climatic conditions, and biological processes (Amos et al., 2015; Blowes & Ptacek, 1994; Blowes & Jambor, 1990; Eary, Runnells, & Esposito, 2003; Malmström, Berglund, & Jarsjö, 2008; Morin & Hutt, 1994). Abandoned and open mines release low-grade waste which creates large piles at the mining site. This waste is particularly rich in sulfides. Sulfides are the most common minerals that comprise most of the rock in most mines. Due to the unstable nature of sulfides, it reacts with oxygen and water releasing hydrogen and sulfide ions which lower the pH of the water. The pH of acid mine drainage can be lowered to 2-4 (Bhattacharya, Islam, & Cheong, 2006; Das et al., 2009). Typical acid mine drainage consists of various elements/ions, one of which is nickel. The walls of mine pits that are formed during open-pit mining may contain sulfide minerals that have the potential to form acid mine drainage. Formation occurs when the rock walls of the mine containing sulfide minerals are exposed to the air, that is, when the water in the mine holes is reduced or pumped out. When rain falls on the walls of the mine pit, acid mine drainage is formed and flows into the mine pit. If the walls of the hole are left open (not flooded), acid mine drainage will occur (Ali, 2017; Costa, Costa, & Martínez, 2020). These extractive mine waste materials often pose a serious threat to the environment due to their high concentrations of toxic metals/metalloids (eg. nickel) and minerals (eg. sulfides) which are chemically reactive after exposure to atmospheric conditions (Blowes et al., 2013; Nordstrom et al., 2015; Parbhakar-Fox & Lottermoser, 2015). This process is a direct or indirect result of the oxidation mechanism of sulfide minerals in the presence of oxygen and water in the atmosphere, and/or microbial activity that occurs in waste materials (Amos et al., 2015; Blowes & Ptacek, 1994; Gunsinger et al., 2006; Pabst et al., 2017; Singer & Stumm, 1970, Priambodo, 2021 #76). The pollution of acid mine drainage has received widespread attention in recent years (Chai et al., 2020; Rašidagić & Hesova, 2020). Discharge of acid water associated with sulfides, pyrites with other metals, or such as millerite from abandoned or active mines is a major cause of acid mine drainage in mining areas (Bomfim et al., 2020; Vermeulen et al., 2020). The fluids released from the mining sector often contain dangerous and toxic heavy metals such as nickel. Acid mine drainage, caused by weathering of sulfide-rich mine waste, is arguably the most critical environmental problem in the mining sector (Muniruzzaman et al., 2020). The best technique for managing acid mine drainage is to prevent its formation by minimizing contact between the sulfide ore and oxygen, water, and/or oxidizing bacteria (Chowdhury, Sarkar, & Datta, 2015; Moodley et al., 2018; Pozo-Antonio et al., 2014; Skousen, Ziemkiewicz, & McDonald, 2019; Suyasa, Hamdi, & Teguh, 2019). Data on the maximum potential acidity (MPA), nett acid producing potential (NAPP), and the net potential ratio (NPR) of samples in open land rocks are shown in **Figure 3** above. Based on the analysis results, it can be seen that the range of maximum potential acidity (MPA) is equivalent to 12.621-44.470 Kg H_2SO_4/ton sample. The range of nett acid producing potential (NAPP) values is -34.361 to -6.535 and the net potential ratio (NPR) ranges from 1.220-3.688. Based on the criteria for the value of nett acid producing potential (NAPP) and net potential ratio (NPR), it shows that all rock samples also do not have the potential to form acid mine drainage because the range of NAPP values < 0 and NPR values > 1.

Rocks in closed land

Based on the data in **Figure 2** above, it can be seen that rocks in closed land have a sulphure content range of 0.418-1.242 Kg H_2SO_4/ton sample. The highest sulphure content value is a sample with code DK23 obtained from rocks in closed land in BU block with a value of 1.242 Kg H_2SO_4/ton sample and the lowest sulphure content value comes from rocks in closed land in BU block with a value of 0.418 Kg H_2SO_4/ton sample. The value of net acid generation (NAG) was in the range of 0-3.185 Kg H_2SO_4/ton sample. The highest net acid generation (NAG) values were samples with DK9 and DK21 obtained from closed land in blocks D and BU. The value of acid neutralizing capacity (ANC) ranges from 25.725-57.575 Kg H_2SO_4/ton sample. The sample with the highest acid neutralizing capacity (ANC) was the DK23 sample from rocks in open land in the BU block. Acid mine drainage is prevalent in most mining areas due to active and closed mining activities (Bratkova et al., 2018; Feris & Kotze, 2014; Kumari, Udayabhanu, & Prasad, 2010). Mining activities expose rock containing sulfides to oxygen and water (Akcil & Koldas, 2006; Jamil & Clarke, 2013; Johnson & Hallberg, 2005; Ramla & Sheridan, 2015). The exposed sulfides are oxidized to sulfates in a chemical reaction which is greatly enhanced by bacterial activity (Berg, Botes, & Cloete, 2016; Bratkova et al., 2018; Hesketh et al., 2010; Hiibel et al., 2011; Schwarz et al., 2020). Ferrous sulfide (pyrite) or other types such as nickel sulfide (millerite) are major contributors to acid mine drainage. In the presence of oxygen and water, pyrite or millerite is oxidized to sulfate, metals are mobilized and acidity is formed (Chowdhury et al., 2015; Lukovic & Stankovic, 2012; Ramla & Sheridan, 2015). Pyrite oxidation or millerite oxidation is a multi-step process that involves an oxygen-free reaction and an oxygen-dependent reaction (Lukovic & Stankovic, 2012). One of the most important sources of trace elements in the environment is acid mine drainage produced by the oxidation of pyrite and other sulfides such as millerite which come into contact with the atmosphere (Nordstrom et al., 2015; Skousen et al., 2019). Acid mine drainage is characterized by a low pH and high content of sulfates, iron, and other metals such as nickel and metalloids (Nordstrom et al., 2015). A pile of crushed mineral ore into smaller (soft) mineral ore, coarse reject, has a similar condition to a waste rock pile. However, because the particles are more released, the oxygen is easier to enter and can cause the formation of acid mine drainage (Shokouhi, Williams, & Kho, 2014). Due to their fine particle size, tailings in mineral or metal mines, if they contain mineral sulfides, are more reactive with water and air and form acid mine drainage. Acid mine drainage from tailings can be in the form of leachate flow that seeps out of the weir or as leachate flowing water that flows into groundwater (Ali, 2017; Yun, 2020). The level of acidity, composition, and concentration of metals in acid mine drainage depends on the type and amount of sulfide minerals and the presence or absence of alkaline materials in the rock. The presence of alkaline materials can be acid-neutralizing agents, thereby reducing the amount of acid mine drainage that is formed (Skousen et al., 2002). For example, a rock containing 5% sulfide minerals may not produce acid due to the limestone content in the rock which can neutralize all of the acid produced. Conversely, rocks that contain only 2% sulfide minerals can produce a lot of acids if the rock does not contain alkaline material. If the rate of acid formation remains high and the neutralization potential in the rock is exhausted, the pH will drop below 3 and the acid mine drain becomes more severe (Ali, 2017). In the mining process, starting from the demolition and dredging of overburden and processing of mining materials and disposal of their waste, materials that have the potential to form acid mine drainage may be scattered and located in several locations in the mining environment. Knowledge of the presence of these materials is important in assessing the load caused by acidity and the metals contained in acid mine drainage and its management. Because the negative impacts of acid mine drainage can last a long time, long after the mine closure period, even hundreds of years or as long as sulfide minerals are still available and oxidized, and require large funds for their remediation (Ali, 2017; Mukama, 2020). Data on maximum potential acidity (MPA), nett acid producing potential (NAPP), and net potential ratio (NPR) in rock samples in closed land are shown in **Figure 3** above. Based on the results of the analysis, it can be seen that the range of values for the maximum potential acidity (MPA) is equivalent to 12.790-38.033 Kg H_2SO_4/ton sample. The Nett Acid Producing Potential (NAPP) values are -37.435 to -1.276 and the Net Potential Ratio (NPR) ranges from 1.037-3.927. Based on the criteria for the value of Net Acid Producing Potential (NAPP) and Net Potential Ratio (NPR), it shows that all rock samples also do not have the potential to form acid mine drainage because the range of NAPP values < 0 and NPR values > 1.

Soil in open land

Based on the data in **Figure 2** above, it can be seen that these samples have a sulphure content range of 0.412-1.452 Kg H_2SO_4/ton sample. The highest sulphure content value was the sample with code DK29 obtained from the open land in the BU block of 1.452 Kg H_2SO_4/ton sample. The lowest sulphure content value comes from the soil in open land in the BK.U block with sample code DK13 of 0.412 Kg H_2SO_4/ton sample. The net acid generation (NAG) ranged from 0-3.675 Kg H_2SO_4/ton sample. The highest net acid generation (NAG) value is the sample with code DK04 which is a sample of soil in open land in block D. The sample that has a value of NAG = 0 is sample DK26. The acid neutralizing capacity (ANC) ranges from 25.725-55.125 Kg H_2SO_4/ton sample. The sample with the highest acid neutralizing capacity (ANC) was the DK26 sample with an equivalent value of 55.125 Kg H_2SO_4/ton sample. The lowest value is a sample of DK04. Overburden spoil generated in mineral ore mining operations and waste rock from the metal mining process is usually piled on top of the ground within the mine site. During their time in the pile, physical and chemical weathering can cause environmental problems if they contain sulfide minerals, including the formation of acid mine drainage (Shokouhi et al., 2014), which can then seep out from the bottom of the pile or flow under the pile into groundwater. In open-pit mines, acid mine drainage is formed from the release of sulfide minerals contained in overburden or waste rock generated during excavation and stockpiling activities. The sulfide minerals then react with oxygen in the air and rainwater flows on the surface soil with the potential for acid formation (Abfertiawan et al., 2020). Metal ore mining and mineral processing produce large amounts of solid waste, which is usually stored in facility-specific conditions (such as waste rock piles or tailings stockpiling) above ground or below ground (Drainage, 2009; Price, 2009). Acid mine drainage is one of the serious environmental problems faced by the mining industry. Due to its high level of acidity and soluble metal concentrations, acid mine drainage can pollute terrestrial ecosystems, making the soil not conducive to the growth of plants and soil beneficial organisms. The negative impact due to acid mine drainage can last a long time, long after the mine closure period, even hundreds of years or as long as sulfide minerals are still available and oxidized, and require large funds for remediation (Ali, 2017). Soils affected by acid mine drainage become useless for agricultural activities because of their high acidity and high metal concentrations affecting animal and plant life (Moodley et al., 2018). If it is formed or passes through land (soil) ecosystems, acid mine drainage can contaminate and poison soil organisms, including vegetation. Therefore, efforts to prevent, reduce or inhibit the formation of acid mine drainage from materials that have the potential to produce acid (at-source) are very important, before acid mine drainage is spread to the wider environment. Likewise, the remediation of acid mine drainage that has been formed is very important to reduce the level of environmental damage (Ali, 2017). Therefore, preventive measures must be carefully planned to minimize the formation of acid mine drainage during the post-mining phase (Abfertiawan et al., 2020). In the process of reclamation (rehabilitation) of mine land, materials returned as backfill or used as soil material for revegetation often contain or are mixed with potentially acid-forming materials (PAF). As a result, acid mine drainage can form in the soil, which in turn can increase the acidity of the soil. In very acidic conditions, the minerals in the soil dissolve easily and can liberate metals such as nickel (Australia, 1997; Jennings, Neuman, & Blicker, 2008). In these conditions, the soil becomes a medium that is not suitable for the growth of plants and other important soil organisms. In addition, acid mine drainage that forms in the soil can flow with run-off, seepage, or leachate water, which then pollutes the soil (Ali, 2017). Concomitant laying of the land surface and revegetation is a method to reduce the acid load from mining sites that are still operating or that have already been completed. Covering material containing pyrite or millerite at a mining site with good soil material and planting vegetation on it has the main impact of reducing the concentration of acid in the water and reducing the amount of water flow from the mine area due to increased infiltration into the soil and evapotranspiration by the plant. The presence of cover vegetation drastically reduces the rate and amount of run-off, compared to the exposed land surface, thereby reducing the spread of acid mine drainage (Ali, 2017). Data on sulphure content, net acid generation, and acid neutralizing capacity were then used to classify the soil sample as having the potential to form acid or not. The classification is based on the calculation of the maximum potential acidity (MPA), nett acid producing potential (NAPP), and net potential ratio (NPR). The diagram of maximum potential acidity (MPA), nett acid producing potential (NAPP), and net potential ratio (NPR) in soil samples are shown in **Figure 3** above. The range of values for the maximum potential acidity (MPA) was equivalent to 1.977-34.036 Kg H_2SO_4/ton of soil samples. The value of the Nett Acid Producing Potential (NAPP) ranges from -40.526 to -3.839 and the Net Potential Ratio (NPR) ranges from 1.116-3.776. Based on the value criteria of Nett Acid Producing Potential (NAPP) and Net Potential Ratio (NPR), it shows that all soil samples are not potential to form acid mine drainage because the NAPP value < 0 and the NPR value > 1.

Soil in closed land

Based on the data in **Figure 2** above, it can be seen that these samples have a sulphure content range from 0.672 to 1.364 Kg H_2SO_4/ton of sample. The highest sulphure content value was a sample with code DK22 obtained from the soil in closed land in the BK.S block of 1.364 Kg H_2SO_4/ton sample. The lowest sulphure content value comes from the soil in closed land in the block with sample code DK10 in block D of 0.672 Kg H_2SO_4/ton sample. The net acid generation value (NAG) ranged from 0-3.185 Kg H_2SO_4/ton sample. The highest net acid generation (NAG) values were samples with the code DK08, DK20, DK22, and DK24 which were soil samples in closed land in block D, BK.U, BK.S, and BU. The sample that has a value of NAG = 0 is sample DK12. The acid neutralizing capacity (ANC) ranges from 28.175-55.125 Kg H_2SO_4/ton sample. The sample with the highest acid neutralizing capacity (ANC) was the DK12 sample with an equivalent value of 55.125 Kg H_2SO_4/ton of sample. The lowest value is the sample of DK24. Acid mine drainage can occur in underground mining activities. Generally, this situation occurs because the element sulphure contained in naturally oxidized rock is also supported by high rainfall which accelerates the change of sulfuric oxide to acid (Irawan et al., 2016). Acid mine drainage is formed from the release of sulfide minerals contained in the overburden produced during excavation and stockpiling activities. The sulfide minerals then react with oxygen in the air and rainwater flows over the surface soils with the potential for acid formation (Abfertiawan et al., 2020). Acid mine drainage can occur during excavation/mining activities in underground mines. In addition, it can also come from material hoarding activities and mining material processing activities. Problems such as what occurs in the waste dump are the oxidation process of sulfide minerals which causes the surrounding soil to become acidic and infertile. If this layer is exposed to rainwater, there will be a flow of acidic water (Wijaya, 2010). Acid mine drainage is environmental pollutant waste that occurs due to mining activities. This waste occurs due to the oxidation process of pyrite minerals (FeS_2) and other sulfide mineral materials such as millerite (NiS) which are exposed to the soil surface in the process of extracting mining minerals. The chemical and biological processes of these mineral materials produce sulfates with high acidity. Directly or indirectly, the high level of acidity affects the quality of the environment and the life of the organism (Yusron, 2009). One of the significant negative impacts is the contamination of acid mine drainage which can result in a decrease in the value of environmental functions and even damage the function of the environment and surrounding ecosystems such as water and soil components (Down & Stock, 1978). Acid mine drainage that seeps into the soil will result in loss of soil fertility and death in plants. Soil conditions with pH levels that are too acidic in post-mining land have disrupted plant growth (Widiyatmoko, Wasis, & Prasetyo, 2017). Acid mine drainage that seeps into the soil pores up to the groundwater level can have a serious impact on groundwater, especially aquifers (Wijaya, 2010). Data on sulphure content, net acid generation, and acid neutralizing capacity are then used to classify the rock and soil samples whether they have the potential to form acid or not. The classification is based on the calculation of maximum potential acidity (MPA), nett acid producing potential (NAPP), and net potential ratio (NPR). The diagram of maximum potential acidity (MPA), nett acid producing potential (NAPP), and net potential ratio (NPR) in soil samples are shown in **Figure 3** above. The range of values for the maximum potential acidity (MPA) was equivalent to 20.573-41.775 Kg H_2SO_4/ton of soil samples. The value of the Nett Acid Producing Potential (NAPP) ranges from -23.700 to -2.226 and the Net Potential Ratio (NPR) ranges from 1.056-2.413. Based on the criteria for the value of Nett Acid Producing Potential (NAPP) and Net Potential Ratio (NPR), it shows that all soil samples are not potential to form acid mine drainage because the NAPP value < 0 and the NPR value > 1. Based on the comparison of the results of the analysis, it can be seen that the mean order of the sulphure content of soil samples > rock samples, the mean of the acid neutralizing capacity (ANC) of rock samples > soil samples, the average of the maximum potential acidity (MPA) of rock samples > soil samples, and the mean of the net potential ratio (NPR) soil samples > rock samples. This condition is supported by soil pH data with a pH range of 5.24-7.76.

Levels of iron (Fe), levels of magnesium oxide (MgO) and levels of calcium oxide (CaO)

The results of the analysis of Fe, MgO and CaO levels on rock samples and soil samples obtained on open land and closed land at the nickel mining location in Kabaena Timur District are presented in **Figure 4**.

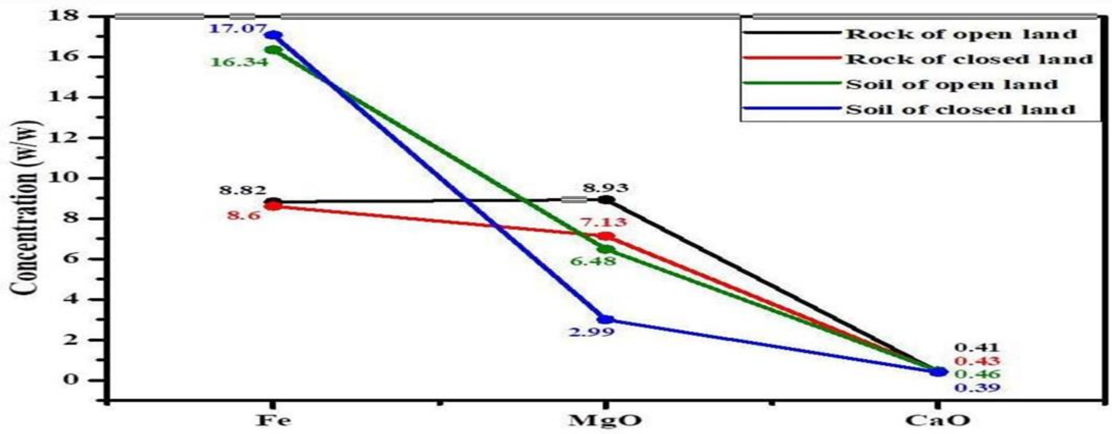

Figure 4 Graph of Fe, MgO and CaO levels on rock samples and soil samples in open land and closed land.

Data on metal content and metal oxides whose distribution varies in the soil in closed land and open land. The results of the analysis above are also supported by data on metal and oxide content in rock and soil, as shown in **Figure 4** above, especially the levels of iron (Fe), magnesium oxide (MgO), and calcium oxide (CaO). Based on the tendency of acidity in rocks and soils, the results of the analysis and their relationship with levels of magnesium oxide (MgO) and calcium oxide (CaO), in rocks and soils of ultramafic formations in the nickel mining area in Kabaena Timur District, have led to an assumption that acid mine drainage with a pH range of 5.24 experiencing neutralization naturally with varying levels of penetration until it reaches a pH of around 7.74. Calcium oxide (CaO) and magnesium oxide (MgO) play an important role which reacts with water and immediately neutralizes acids. After the metal hydroxide settles, what is left in the water is generally Ca and Mg, and bicarbonate. The neutralization process takes place following the physical-chemical conditions of the rock and soil in the mining area. If this acidic water is not neutralized, it will cause acid mine drainage to the surrounding environment and can cause environmental pollution. The level of acidity, composition, and concentration of metals in acid mine drainage depends on the type and amount of sulfide minerals and the presence or absence of alkaline materials in the rock. The presence of alkaline materials can be acid-neutralizing agents, thereby reducing the amount of acid mine drainage that is formed (Skousen et al., 2002). For example, a rock containing 5% sulfide minerals may not produce acid due to the limestone content in the rock which can neutralize all of the acid produced. Conversely, rocks that contain only 2% sulfide minerals can produce a lot of acids, if the rock does not contain alkaline material. If the rate of acid formation remains high and the neutralization potential in the rock is exhausted, the pH will drop below 3 and the acid mine drain becomes more severe (Ali, 2017). The quality and final pH of the mine effluent is largely determined by the dynamic balance between the ratio of acid-producing and acid-neutralizing minerals, chemical composition, availability of oxidizing agents, climatic conditions, and biological processes (Amos et al., 2015; Blowes & Ptacek, 1994; Blowes & Jambor, 1990; Eary et al., 2003; Malmström et al., 2008; Morin & Hutt, 1994).

Conclusions

Based on the results of the research that has been done, it is concluded that for rock samples and soil samples in the mining area in open land the sulphure content range is 0.411-1.452 Kg H_2SO_4/ton sample. The value of net acid generation (NAG) was in the range of 0-3.675 Kg H_2SO_4/ton sample. The acid neutralizing capacity (ANC) ranges from the equivalent of 25.725-60.025 Kg H_2SO_4/ton sample. The range of values for the maximum potential acidity (MPA) was equivalent to 1.977-44.470 Kg H_2SO_4/ton sample. The value of the nett acid producing potential (NAPP) ranges from -40.526 to -3.839 and the net potential ratio (NPR) ranges from 1.116 to 3.776. As for samples in closed land, values for sulphure content, NAG, ANC, MPA, NAPP, and NPR were respectively = 0.418-1.364 Kg H_2SO_4/ton sample; 0-3.185 Kg H_2SO_4/ton sample; 25.725-57.575 Kg H_2SO_4/ton sample; 12.790-41.775 Kg H_2SO_4/ton sample; -36.846 to -1.276 and 1.037-3.927. Based on the criteria for the value of nett acid producing potential (NAPP) and net potential ratio (NPR), it shows that all rock samples and soil samples in the nickel mining area in Kabaena Timur District have no potential to form acid mine drainage because the NAPP value < 0 and the NPR value > 1.

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