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Model of Hydraulic Conductivity, Infiltration Rate, and Permeability at Gold Mine Waste Dump in North Sulawesi, Indonesia

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Abstract
The research area is a gold mine operating in North Sulawesi. The aim of the study was to analyze and calculate hydrological parameters, namely: hydraulic conductivity, infiltration rate, and permeability to find out how strong the soil cover is at one level of waste disposal. The method used is the Measurement of hydraulic conductivity, infiltration rate, and permeability in the field, analysis, and calculation of hydraulic conductivity, infiltration rate, and permeability based on field data. In the designated regions of the waste dump, specifically areas 1a, b, and c, we observed certain hydrological patterns that are worth noting. Firstly, the hydraulic conductivity in these areas, which is a crucial determinant of the rate at which water can move through the soil, consistently showcased low average values. This is further supported by the similarly slow infiltration rate identified in the same zones. The ability of the soil to transmit water, i.e., its permeability, also followed this trend, with values leaning towards the lower end of the scale, indicating very slow permeability. One major contributory factor to these patterns appears to be the soil's composition. Predominantly made up of sandy loam, the soil in these areas exhibits high water retention capabilities. Sandy loam, by its nature, binds and retains water effectively, which could potentially explain the observed hydrological behaviors in waste dump areas 1a, b, and c.

1. Introduction

The research area is a gold mine operating in North Sulawesi. The mining industry is one of the important sectors for providing electrical power for public and personal interests, regional development, as well as for industrial fuel [1]. Water is a very important resource for the life of living creatures. The existence of water on earth is closely related to the hydrological cycle. Infiltration is part of the hydrological cycle. Disturbed infiltration in an area will affect the existing hydrological cycle and make the natural balance unfulfilled. Some of the rainwater that falls to the surface of the earth will be stored or left on the surface of leaves or plant stems and some will reach the surface of the ground. The amount of water absorbed by the soil is largely determined by the speed of infiltration, the intensity and duration of rain and the depth of the soil layer that is able to store water [2]. Water entering the mining location can disrupt mining activities and result in production delays for the company in achieving the set production targets, so that if this happens the company will experience losses both materially and in time [3]The parameter or measure that can describe the ability of the soil to pass water is called hydraulic conductivity [4]. The hydraulic conductivity of the soil is influenced by the pore geometry of the soil and the fluid properties in the soil. Soil texture and structure are the main determining factors in soil pore geometry, while the fluid properties that directly affect soil hydraulic conductivity are viscosity and density [4]. The availability of water in the soil is inseparable from the role of the infiltration rate. The movement of water that falls to the ground surface will be forwarded in two directions, namely runoff water and water that moves vertically which is called infiltration water. The infiltration process is one of the important processes in the hydrological cycle because infiltration determines the amount of rainwater that seeps and enters the soil directly. An understanding of infiltration and infiltration rate data is very useful as a reference for planning irrigation activities, land use planning, and hydrotechnical modeling. Land use is a way of using land that is carried out by humans and is intended for human needs [5]. Usually in utilizing the land, to increase agricultural production, soil processing measures are carried out with certain methods. Until now, reports on the results of research on the effect of soil use and tillage on water infiltration have not been consistent because the factors of soil, slope, climate, and time have not been included as influencing factors. [6] and [7] reported that water infiltration in untreated soil was higher than in cultivated soil [8] reported that water infiltration in untreated soil was lower than in cultivated soil. Showed no significant difference in water infiltration in treated and untreated soils [9]. Found that vegetation type, slope, and time of day influence water infiltration [10] and [11]. Soil permeability is also an entity that includes soil infiltration and is useful as an ease in tillage. Soils with high permeability can increase the infiltration rate thereby reducing the runoff rate [12]. In mining activities, the company must move the material overburden (overburden removal) and stockpiling materials overburden in a safe and efficient location which is usually referred to as disposal or waste dump. It is planned to calculate hydrological parameters, namely: hydraulic conductivity, infiltration rate, permeability to find out how strong the covering material is (overburdened) in one step waste dump. A parameter or measure of a material's capacity to transmit water, it is defined as a constant of proportionality with respect to the specific discharge of a porous medium referred to as hydraulic conductivity (hydraulic conductivity [4]. The level of soil ability to pass water is strongly influenced by soil water content. Soil hydraulic conductivity is divided into 2, namely hydraulic conductivity in an unsaturated state, and in a saturated state. In this study discussed hydraulic conductivity in a saturated state.

2. Methodology

Measurements of hydraulic conductivity, infiltration rate, and permeability will be carried out twice at the same depth and the same hole at each measurement point of the Guelph Permeameter tool. measurements taken, namely: (1) Make a hole in the ground as deep as 43 cm by using a drill with a diameter of 8 cm. (2). Place the Guelph Permeameter in an upright position right above the hole then fill the water in the reservoir hole. (3) Setting the reservoir valve in the direction above for using the combined reservoir method, and adjusting the reservoir tube air inlet to determine the height of the inundation, this study uses an inundation height of 5 cm for the first test and 10 cm for the second test. (4) The hydraulic conductivity measurement time is 30 minutes, and the infiltration rate and permeability measurement time is 30 minutes. (5) After completing the measurement of the air inlet cap, so that when lifting the Guelph Permeameter tool and measuring the depth of water in the ground hole it does not increase. (5) Read and record the difference in the change in water level in the reservoir tube to a constant state. Hydraulic full of water determined from the field measurement data used to determine the conductivity of hydraulic water saturation using the two-head, combined reservoir method with the equation of [13];[14]. Determination of infiltration rate and permeability from the results of field measurements used to determine the rate of infiltration and permeability. Determination of the amount of water infiltration rate will be calculated based on the equation [15].

3. Results and discussions

3.1. Saturated Hydraulic Conductivity of Water Waste Dump 1a

Conductivity measurement results in hydraulic water saturation at gold mine waste dump 1a shows that on the first transect measurement point, 1 to measurement point 5 produces a hydraulic conductivity model (Figure 1) with the distance between 2 measurement points 1 to 5 meters, rate-rate conductivity hydraulic water saturation, that is:1,3 x 10-2 cm/sec the depth of the measurement point of 43 cm is classified as very slow [16]. Identifying the dominant texture in the area, waste dump 1a is sandy clay material with the ability of soil material to absorb high water, supported by a high average infiltration rate. Visually land on waste dump 1a is still open, uncovered, and not yet fully overgrown with grass vegetation.

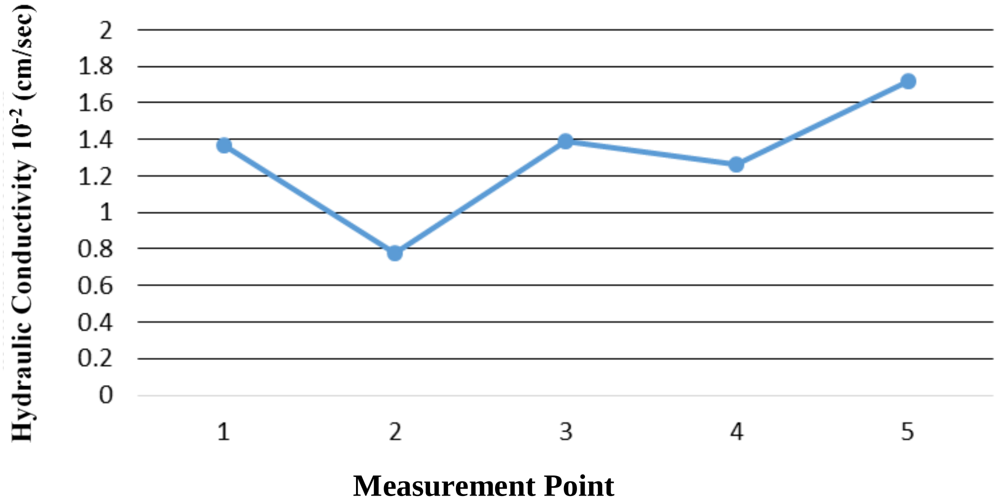

Figure 1. Hydraulic conductivity model at waste dump 1a

Conductivity hydraulic water saturation on waste dump 1a shows based on the measuring point in frequency 2 with the conductivity value hydraulic lowest water saturation, namely: 7,79 x 10^{-3} cm/sec which is classified as very high slow [16]. While conductivity hydraulic water saturation on waste dump 1a shows based on 5 measurement points with conductivity values hydraulic the highest water saturation, namely cm/s, is classified as very slow [16]. The low value of water hydraulic conductivity identified the dominant type of material with a sandy loam texture that has large particle sizes and large pores. The high value of hydraulic conductivity is identified as having a texture of fine sand material, due to the material's ability to absorb water and has a small porosity. According to [17] soil with high hydraulic conductivity will be easily infiltrated by water, so it dries quickly. Thus, dissolved materials contained in groundwater will easily move in the soil along with the movement of water in the soil. On the other hand, soils with low hydraulic conductivity will be relatively easily flooded.

3.2. Saturated Hydraulic Conductivity of Water Waste Dump 1b

Conductivity measurement results in hydraulic water saturation at gold mine waste dump 1b shows that on the transect the two measurement points 1 - 32 produce a hydraulic conductivity model (Figure 2) with a distance between the 2 measurement points of 1 to 5 meters. Average value conductivity hydraulic water saturation, namely: 8.19 x 10^{-3} cm/sec at a depth of 43 cm measuring point is classified as very slow [16].

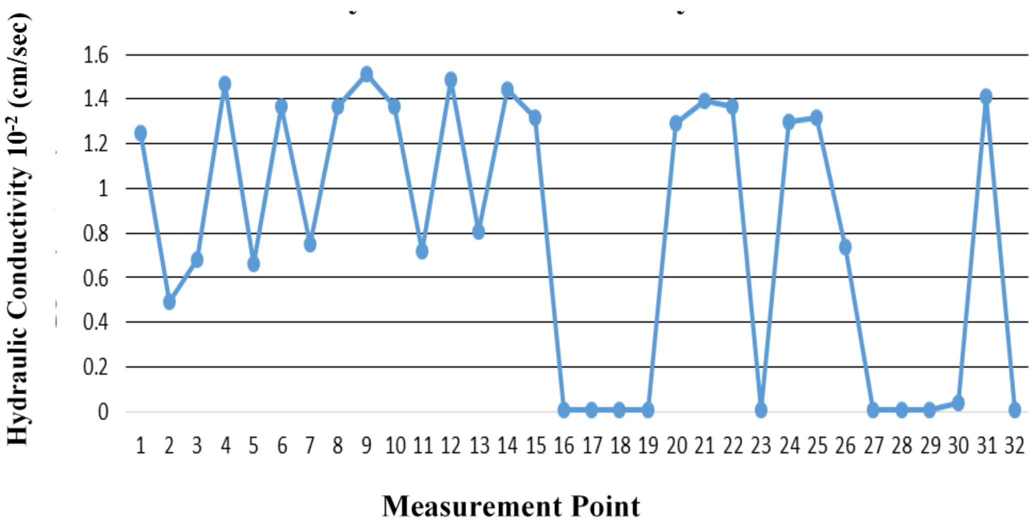

Figure 2. Hydraulic conductivity model at waste dump 1b

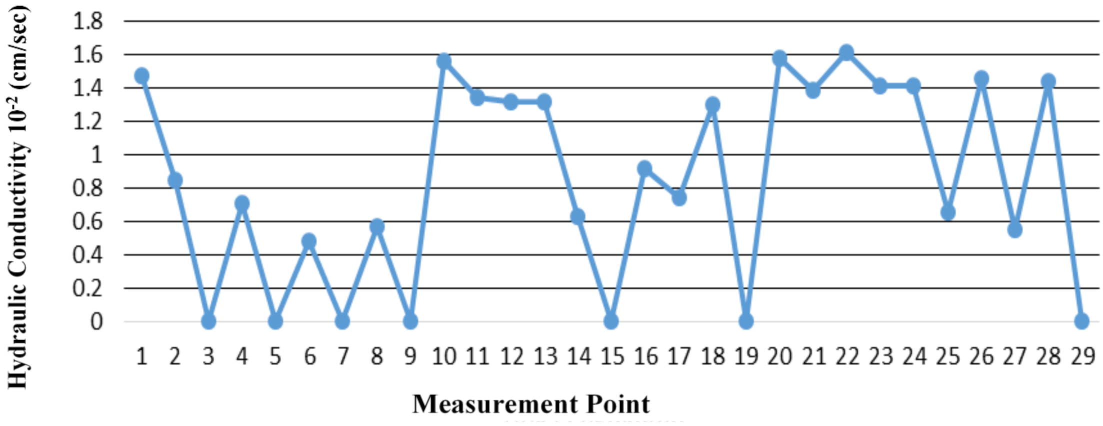

Figure 3. Hydraulic conductivity model at waste dump 1c

Conductivity hydraulic water saturation in waste dump 1b shows based on measurement points 16, 17, 18, 19, 23, 27, 28, 29, 32 with conductivity values hydraulic lowest water saturation, namely: 8.4 x 10^{-5} cm/sec which is classified as very slow. At 9 measurement points with a conductivity value hydraulic highest water saturation, namely: 1.15 x 10^{-2} cm/sec classified as very slow [16]. The low value of hydraulic conductivity identified the type of material with sandy loam texture having low water-saturated hydraulic conductivity. The possible cause is that heavy equipment is often traversed when stockpiling soil material which causes the soil to become compacted. The high value of hydraulic conductivity identified the type of material that has a sandy loam texture because of the material's ability to absorb large amounts of water, because it has small porosity. Visually, the second transect area has a dominant texture of sandy loam with stable granular (grain) aggregation, supported by a low average infiltration rate, and the condition of the land cover where there is no vegetation growing in the area. waste dump 1b.

3.3. Saturated Hydraulic Conductivity of Water Waste Dump 1c

Conductivity measurement results hydraulic water saturation at gold mine waste dump 1c shows that on the third transect measurement points 1 - 29 produce a model conductivity hydraulics (Figure 3) with a distance between 2 measuring points of 1 to 5 meters, average conductivity hydraulic water saturation, namely: 8.5 x 10^{-3} cm/sec the depth of the measurement point of 43 cm is classified as very slow [16].

Conductivity hydraulic water saturation on waste dump 1c shows based on measuring points 3, 5, 7, 9, 15, 19, 29 with conductivity values hydraulic lowest water saturation, namely: 8.4 x 10^{-5} cm/sec which is classified as very slow [16]. At 22 measurement points with a conductivity value hydraulic the highest water saturation, namely: 1.6 x 10^{-2} cm/sec is classified as very slow [16]. Low value conductivity hydraulic water saturation identified that the type of material in waste dump 1c has a sandy loam texture, with dry soil surface conditions. Possible cause because it is close to subsidence. High conductivity value hydraulic water saturation identified that the type of material in waste dump 3 sandy loam textured, moist soil surface conditions.

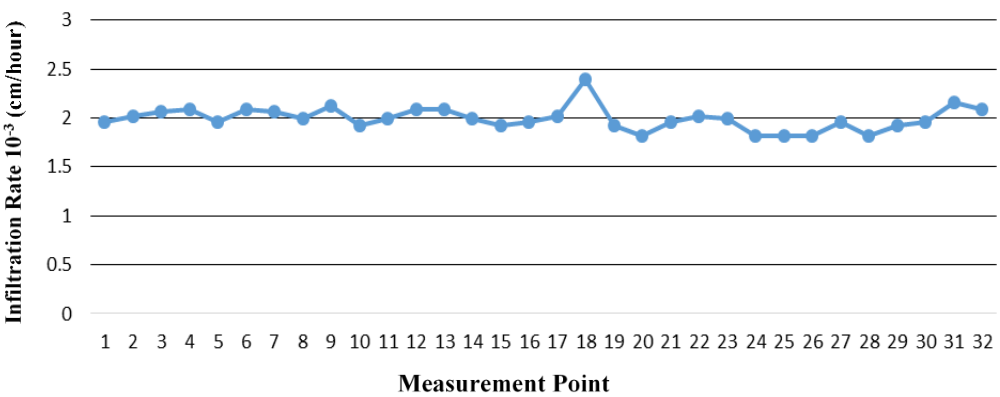

Figure 4. Infiltration rate model in waste dump 1a

Figure 5. Field condition of water runoff flow in waste dump 1a

3.4. Infiltration Rate 1a

Results of measurements of infiltration rate at gold mine waste dump 1a shows that on the first transect measurement point 1 to measurement point 5 produces an infiltration rate model (Figure 4) with a distance between 2 points 1 to 5 meters, the average infiltration rate is: 3.38×10^{-3} cm/hour depth the measurement point of 43 cm is classified as very slow [18].

Visually land at waste dump 1a is still open, uncovered, not yet fully overgrown with grass vegetation (Figure 5), the small number of plants as a ground cover may not be able to protect the soil from the blows of rocks which when the rain crashes so the soil is easily eroded. In (Figure 6) shows the scour caused by the runoff flow of water carrying rocks from above. According to [19] soil cover by plants will absorb raindrops that crash effectively in maintaining infiltration.

Figure 6. Conditions scraping in waste dump 1a

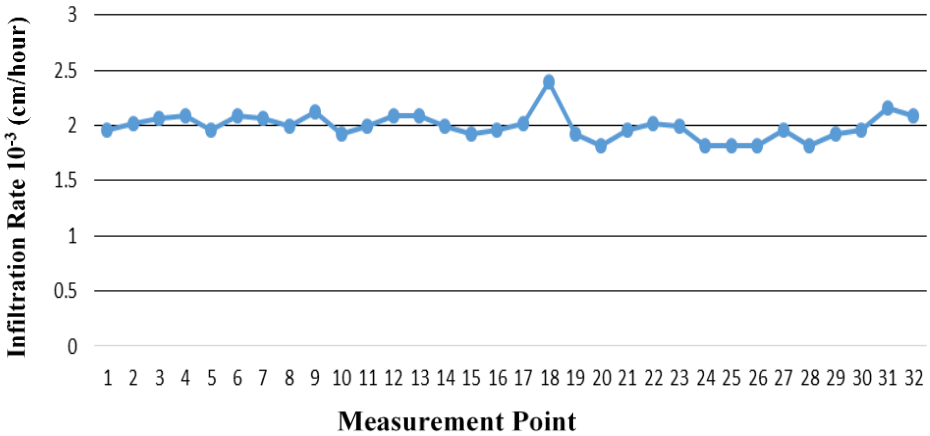

Figure 7. Infiltration rate model in waste dump 1b

Infiltration rate at waste dump 1a shows based on measurement point 2 with the lowest infiltration rate value of cm/hour which is classified as very slow [18]. While at measurement point 5 it has the highest infiltration rate value of cm/hour which is classified as very slow [18]. Visually, the low infiltration at measurement point 2 is supported by the moist soil surface, crumbly soil structure and soil texture of 22 cm of brown sandy loam, 21 cm of gray sandy loam, there is little grass vegetation, and the possible causes are because it is often passed by heavy equipment. when stockpiling material so that the soil is dense. Visually, the high infiltration at measurement point 5 has a fine sandy soil texture, no grass vegetation around the test, and has a fast permeability value.

3.5. Infiltration Rate 1b

Results of infiltration rate measurements at the transect gold mine waste dump 1b measurement points 1 to 32 measurement points produce an infiltration rate model (Figure 7) with a distance between 2 points 1 to 5 meters, the average infiltration rate is: 1.99 x 10^{-3} cm/hour the depth of the measurement point is 43 cm classified as very slowly [18].

Soil structure in waste dump 1b which is dominantly sandy loam, moist soil texture that has reached maximum water saturation. Visually land on waste dump 1b still open, uncovered, no grass growing, no plants as a ground cover, possibly unable to protect the soil from the blows of raindrops that crash so that the soil is easily destroyed. The flow of water runoff carrying small to medium sized rock grains. The material's ability to not hold water runoff when it rains which carries rocks can cause scour (Figure 8). In (Figure 9) erosion caused by rainwater transporting rocks towards waste dump 1b results in the erosion of soil material causing the ability of the material which is no longer able to hold the water content plus the material being transported with steep slopes resulting in scour that can occur.

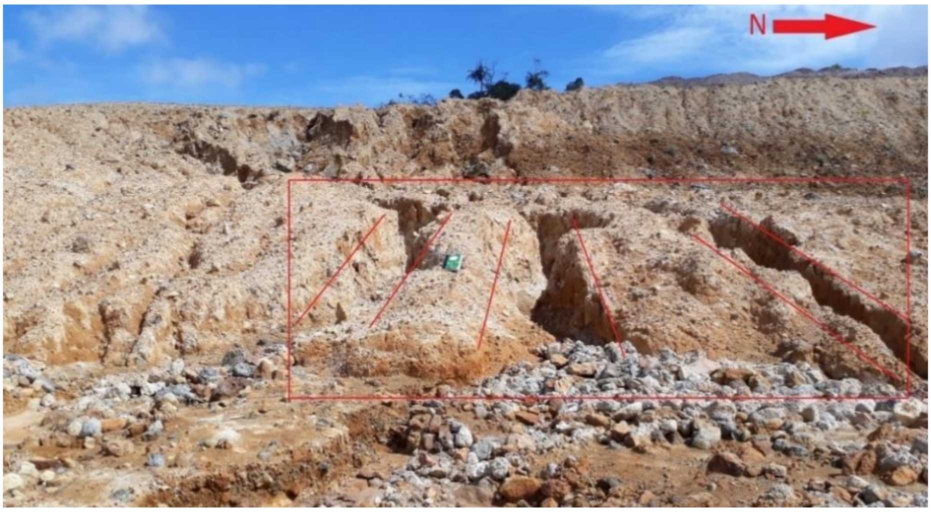

Figure 8. Field condition of water runoff flow in waste dump 1b

Figure 9. Conditions scraping in waste dump 1b

Infiltration rate at waste dump 1b shows that the measurement points 20, 24, 25, 26 and 28 are the points with the lowest infiltration rate, namely: 1.82 x 10^{-3} cm/hour which is classified as very slow [18]. Infiltration rate at waste dump 1b shows that measurement point 18 is the highest infiltration rate, namely: 2.39 x 10^{-3} cm/hour which is classified as very slow [18]. The low value of the infiltration rate is identified by conditions of moist soil, high soil water content, and clay texture. Visually, the high infiltration is supported because the top layer of soil is sand, loamy soil is not dense, and the structure is crumbly and the texture of sandy loam, and beside the measurement point there is subsidence. This is in accordance with the opinion of [20], which states that the higher the soil water content, the less infiltration rate, and will reach a constant minimum rate.

3.6. Infiltration Rate 1c

Results of infiltration measurements at the transect gold mine waste dump 1c measuring points 1 to 29 measuring points on site waste dump 1c generates an infiltration rate model (Figure 10) with a distance between 2 points 1 to 5 meters, the average value of the infiltration rate is: 2 x 10^{-3} cm/hour depth of point measurement 43 cm is classified as very slow [18].

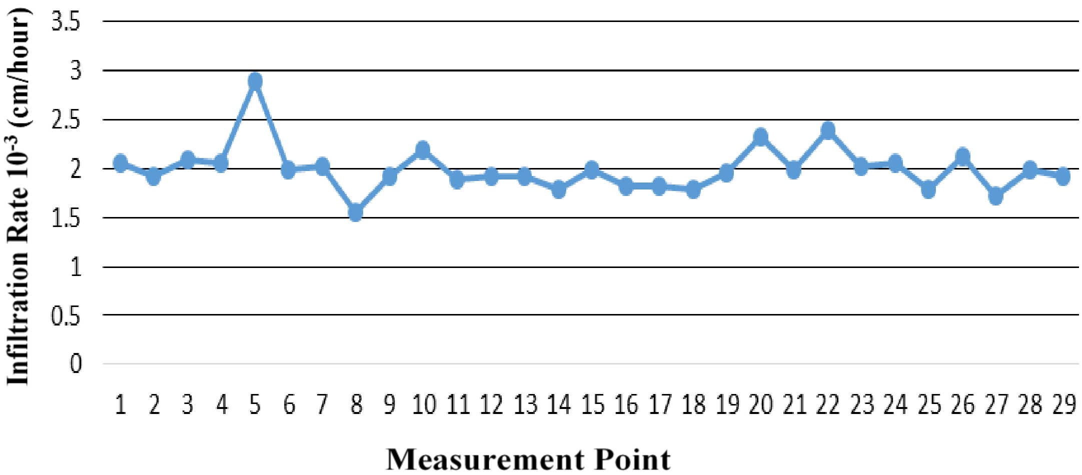

Figure 10. Infiltration rate model in waste dump 1c

Figure 11. Field condition of water runoff flow in waste dump 1c

Soil structure in waste dump 1c which is predominantly sandy loam, with a moist soil texture. Visually land at waste dump 1c is still open, uncovered, no grass growing (Figure 11). In (Figure 12) shows the flow of water runoff caused by rainwater transporting small to medium-sized rocks. The erosion of soil material causes the ability of materials that are no longer able to hold water content plus materials that are transported with steep slopes causing scour to occur. Supported by no vegetation that causes scouring to occur.

Infiltration rate at waste dump 1c shows that measurement point 8 is the point with the lowest infiltration rate, namely: 1.59×10^{-3} cm/hour which is classified as very slow [18]. At measurement point 5 is the point with the highest infiltration rate value, namely: 2.89×10^{-3} cm/hour which is classified as very slow [18]. Low infiltration rate values are identified in wet soil surface conditions and are the top surface layer of sandy soil, there are runoff flow paths, visually visible growth of vegetation in measurement point, sandy clay loam texture and no structure. The high value of the infiltration rate is identified on dry and present surface conditions mud cracks on the surface of the measurement point with a sandy clay texture.

Figure 12. Conditions scraping in waste dump 1c

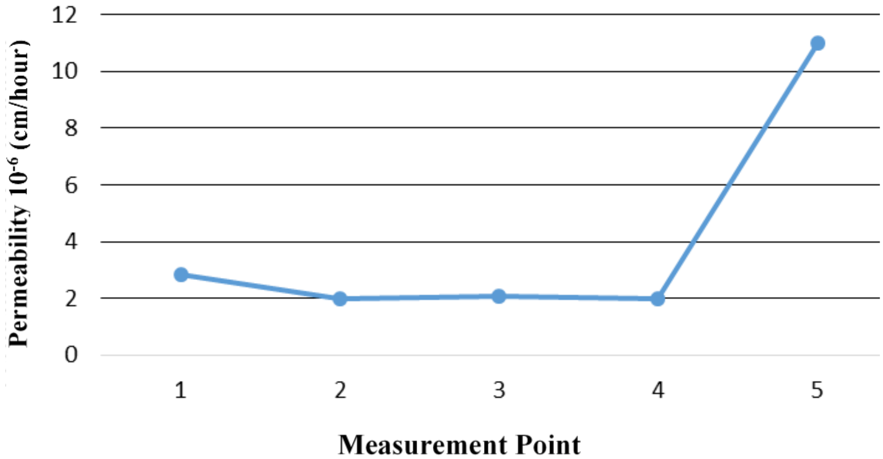

Figure 13. Soil permeability model waste dump 1a

3.7. Soil Permeability Waste Dump 1a

Results of soil permeability measurements at gold mine waste dump 1a shows that on the first transect measurement points 1 to 5 measurement points produce a soil permeability model (Figure 13), the average soil permeability is, namely: 3.97 x 10^{-6} cm/hour with a measurement depth of 43 cm and a distance between 2 measurement point of 1 meter to 5 meters is classified as very slow [21].

The first transect soil permeability shows that at measurement point 2 is the permeability with the lowest value, namely: 1,97 x 10^{-6} cm/hour classified as very slow [21]. At measurement point 5 is permeability with the highest value, namely: 1,1 x 10^{-5} cm/hour relatively fast [18]. The low permeability value of measurement point 2 is probably due to the top surface layer of brown sandy clay with a depth of 22 cm, gray sandy clay, moist soil conditions. The high permeability value of measurement point 5 is probably caused by a layer of fine sand soil up to a depth of 43 cm. The ability of soil material with a clay texture is very difficult for the material to pass water because it has very small grain size particles and small pores, and has a low infiltration rate. Meanwhile, the ability of soil material with a sand structure is very easy for the material to pass water because it has large grain size particles and large pores, and has a high infiltration rate value as well. Sand dominated soil will have many macro pores, dust-dominated soil will have many medium pores, while clay-dominated soil will have micro pores [22].

3.8. Soil Permeability Waste Dump 1b

The results of soil permeability measurements at gold mine waste dump 1b shows that on the transect of the two measurement points 1 - 32 measurement points produce a soil permeability model (Figure 14), the average soil permeability is: 2.35 x 10^{-6} cm/hour with a measurement depth of 43 cm and the distance between the 2 points measurement of 1 meter to 5 meters is classified as very slow [21].

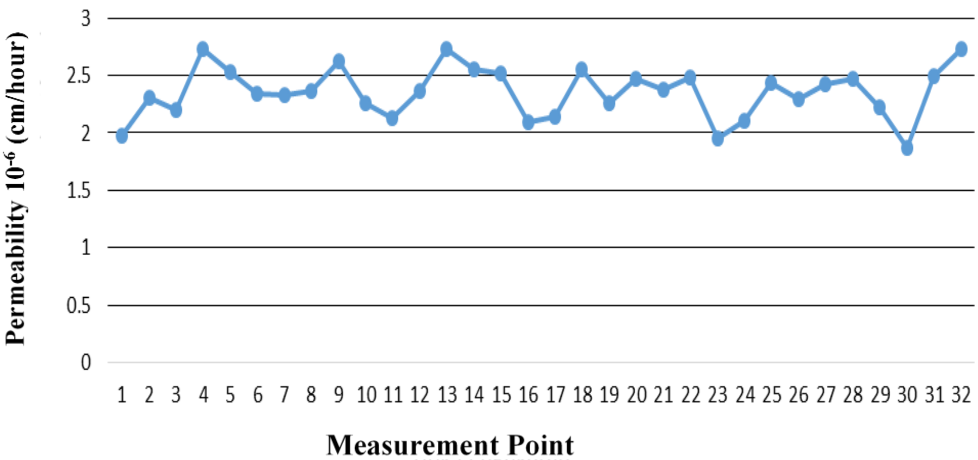

Figure 14. Soil permeability model waste dump 1b

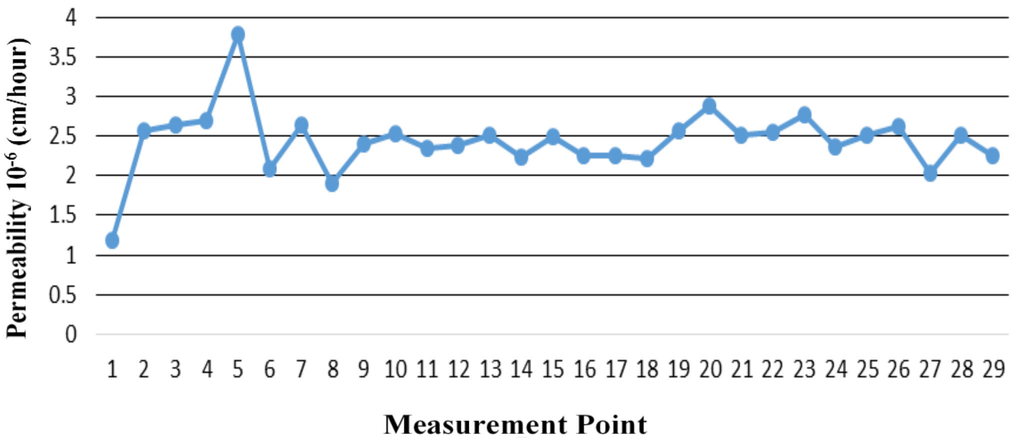

Figure 15. Soil permeability model waste dump 1c

Waste dump 1b has a condition of varying permeability values along the transect. The average permeability on this transect is slow, this is closely related to the condition of the soil which is compact, moist, dense, and possibly during the compaction of material stockpiling, which in this area is land with no tree vegetation. The second transect soil permeability shows that at measurement point 30 is permeability with the lowest value, is: 1.87 x 10^{-6} cm/hour, classified as very slow [21]. At measurement points 4, 13 and measurement points 32 are permeability with the same highest value, namely: 2.73 x 10^{-6} cm/hour, classified as very slow [21]. The very slow permeability value of the 30measurement point was identified because it has a sandy loam texture and is not structured to a depth of 43 cm. The ability of soil material with a sandy loam texture is very difficult for the material to pass water because it has very small grain size particles and small pores. It is supported that there is subsidence in the area of measurement point 30, because the material which is already saturated with water is not able to pass the collected water under rainy conditions resulting in subsidence. The soil permeability of the second transect shows that the high permeability values of measurement points 4, 13, and 32 are identified because the texture of the soil is sandy loam, and is supported by canals filled with water. Sandy soil has a large particle size so it has good porosity.

3.9. Soil Permeability Waste Dump 1c

Results of soil permeability measurements at gold mine waste dump 1c shows that on the transect of the three measurement points 1 to 29 measurement points produce a soil permeability model (Figure 15), the average soil permeability is: 2.44 x 10^{-6} cm/hour with a measurement depth of 43 cm and the distance between the 2 measurement points 1 meter to 5 meters is classified as very slow [21].

Waste dump 1c has a condition of varying permeability values along the transect. Possible identified material contained in waste dump 1c is dominated by sandy loam texture, visually the condition of the area waste dump 1c has not yet grown plant vegetation, and there is material carried by rainwater from waste dump 1c is supported by the presence of small to large rocks that are deposited waste dump 1c. The third transect soil permeability shows that at measurement point 8 with a depth of 43 cm is the lowest permeability value, namely: 1.91 x 10^{-6} cm/hour which is classified as very slow [21]. At measurement point 5 with a depth of 43 cm is the permeability with the highest value, namely: 3.78 x 10^{-6} cm/hour which is classified as very slow [21]. The very slow permeability value of measurement point 8 was identified, possibly because it has a clay loam texture and a lumpy structure, because at this measurement point there is a canal filled with water and the soil surface is wet. Supported by the presence of subsidence that is perpendicular to the measurement point. This is probably due to the fact that the clay-textured material which is already saturated with water is very difficult pass water for a very long time when it rains which causes subsidence. The permeability of the soil at measurement point 5 was identified as possibly due to having a sandy loam texture and crumb structure, and dry surface conditions. Supported by availability mud cracks at the ground surface of the measuring point. Materials with a sandy loam texture have the ability to easily allow water to pass through because they have large grain size particles and large pores. Soils that have large particle sizes and large pores have high permeability [23].

4. Conclusion

In the designated regions of the waste dump, specifically areas 1a, b, and c, we observed certain hydrological patterns that are worth noting. Firstly, the hydraulic conductivity in these areas, which is a crucial determinant of the rate at which water can move through soil, consistently showcased low average values. This is further supported by the similarly slow infiltration rate identified in the same zones. The ability of the soil to transmit water, i.e., its permeability, also followed this trend, with values leaning towards the lower end of the scale, indicating very slow permeability. One major contributory factor to these patterns appears to be the soil's composition. Predominantly made up of sandy loam, the soil in these areas exhibits high water retention capabilities. Sandy loam, by its nature, binds and retains water effectively, which could potentially explain the observed hydrological behaviors in waste dump areas 1a, b, and c.

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