STUDY OF PHYSICAL SOIL QUALITY ON PT COAL MINE RECLAMATION LAND SUMBER BARA ABADI, KUTAI KARTANEGARA REGENCY

ABSTRACT

Evaluation of the physical quality of soil on coal mine reclaimed land is needed to monitor and evaluate reclamation activities aimed at restoring and improving soil quality. The results of the evaluation of the quality of the physical properties of the soil are presented as an index of the physical quality of the soil which can be used as input for taking further soil management actions. This research aims to determine the characteristics of the physical properties of the soil and assess the physical quality of the soil on coal mine reclaimed land as outlined in the soil physical quality index (IKFT). This research was carried out from August to November 2022 on the reclaimed coal mine land of PT. Sumber Bara Abadi, Sumber Sari Village, Sebulu District, Kutai Kartanegara Regency, East Kalimantan, Indonesia. The method used in this research was a survey. Determining the location of soil samples was carried out using a purposive method based on reclaimed land cover, reclamation age, and slope. Data analysis was carried out directly in the field and soil analysis in the soil laboratory of the Faculty of Agriculture, Mulawarman University. The assessment of the soil physical quality index (IKFT) is carried out after the analysis of the physical characteristics of the soil has been determined. The soil physical quality index (IKFT) is measured by following a three-step procedure, namely identification of indicator data sets, interpretation of indicators, and integration of all indicator scores into one overall IKFT value. The research results show that (1) the physical characteristics of the soil are: soil texture varies between clay, clay loam, and sandy clay loam; Soil porosity is classified as poor and good; stability is classified as less stable aggregate to very stable; Soil permeability is relatively slow and moderate; bulk density is classified as medium and slightly dense; surface rocks are abundant; the depth of the solum is classified as shallow and medium; and (2) the physical quality of the soil on reclaimed coal mine land is classified as rather low and moderate with limiting factors including a large amount of surface rock, large bulk density, low solum depth, and low aggregate stability.

Keywords: Quality of soil physical, Land of Coal Mine Reclamation

1. INTRODUCTION

Indonesia is a country that has diverse energy and mineral resources, such as oil, gas, copper, nickel, coal, and others. One type of mining material that is well-known outside of oil and gas is coal. To explore these resources, mining activities are carried out, both underground mining and open pit mining.

Open pit mining activities are carried out by digging the ground to a depth of tens of meters to extract the desired mineral materials. As a result, coarse material (overburden) is mixed with topsoil, resulting in soil that has low organic matter content, low water, and nutrient retention, as well as a high content of toxic elements and is unstructured. Ex-coal mining areas generally consist of very heterogeneous soil, low soil porosity, large amounts of surface rock, and high soil density, which affects plant root penetration and poor water and nutrient retention capabilities.

To overcome the negative impacts left by coal mining activities, environmental conservation efforts are needed through reclamation methods. Reclamation activities aim to manage, restore, and improve the quality of the environment and ecosystem in all mining businesses, both in ex-mining areas and outside ex-mining areas. Reclamation is carried out to prevent further soil damage.

Uncontrolled environmental changes can cause a decrease in the physical quality of the soil which will affect the level of soil fertility. Soil physical properties are very important because they have a major influence on plant growth and production, root penetration in the soil, water retention, drainage, aeration, and plant nutrition. Broadly speaking, the physical properties of soil can be divided into three main aspects: 1) as a physical medium that stores nutrients, air, and water needed by plants and becomes a place for plant roots to grow, 2) as a control of the supply of water available to plants, 3) controlling the process of supplying air or gas needed by plants.

To understand the current physical condition of the land which is influenced by mining activities, an evaluation of the physical characteristics of the soil is carried out. This evaluation is necessary because improving the physical properties of the soil takes quite a long time. The results of the evaluation of soil physical characteristics are presented in a soil physical quality index which can be used as input in the subsequent soil management process. The study of the quality and physical characteristics of soil that influence plant growth and production is very important to consider before taking soil management actions on coal mine reclaimed land.

This research aims to determine the characteristics of the physical properties of the soil and assess the physical quality of the soil on coal mine reclaimed land as outlined in the soil physical quality index (IKFT).

2. MATERIALS AND METHODS

2.1 Time and Location

This research was carried out from August to November 2022 on the reclaimed coal mine land of PT. Sumber Bara Abadi, Sumber Sari Village, Sebulu District, Kutai Kartanegara Regency, East Kalimantan, Indonesia.

2.2 Tools and Materials

Some of the tools used in this research include a soil drill, sample ring, field knife, measuring tape, labels, plastic samples, stationery, GPS to determine soil sampling coordinates, as well as laboratory analysis tools, and ArcGIS 10.8 software. The materials used are examples of field soil, distilled water, Calgon, and water.

2.3 Stages of Study

2.3.1 Data collection

The method used in this research was a survey. Determining the location of soil samples was carried out using a purposive method based on reclaimed land cover, reclamation age, and slope.

2.3.2 Data Analysis Method

Data analysis was carried out using direct field analysis and analysis in the soil laboratory of the Faculty of Agriculture, Mulawarman University.

2.3.3 Assessment of Soil Physical Quality Index

The assessment of the soil physical quality index (IKFT) is carried out after the analysis of the physical characteristics of the soil has been determined.

2.4 Analysis Method

Data analysis uses minimum weighting of the data set by paying attention to the selection of key indicators determining the physical quality of the soil, then determining the weighting coefficient by considering the function and relationship with other key indicators. Soil physical quality index (IKFT) is measured following a three-step procedure: (a) identification of indicator data sets, (b) interpretation of indicators, and (c) integration of all indicator scores into one overall IKFT value (Grzywna & Ciosmak, 2021) as presented in Table 1.

Table 1. Key parameters for assessing soil physical quality index and weight coefficient

Aspect	Determinant Factors for Fulfilling Soil Functions	Representation of physical properties of soil	**Code**	Influence on Other Key Parameters	**Value**
The physical medium where nutrients, water, and gas exist, as well as the rooting medium	- Volume or depth of soil - Soil density conditions so that the root system can penetrate - Soil's ability to absorb and bind nutrients and water	Solum Depth	S	• -	0.1250
		Aggregate Stability	A	• Porosity	0.1250
		Soil Texture	T	• Porosity • Permeability • Aggregate Stability	0.2500
		Bulk Density	B	• Permeability • Porosity	0.1875
		Surface Rock	R	• -	0.0625
Provides water available to plants	- The capacity of the soil to absorb, hold, bind, and supply water to plants and release water	Permeability	K	• -	0.0625

Fulfillment of the gas needed by plants	- Soil aeration to ensure good air circulation for the soil	Porositas	P	• Permeabilitas • Bobot isi	0.1875

Source : (Feng et al., 2019; Partoyo, 2005; L. M. Rachman, 2019)

The next step is to give a score of 1 to 5 for each parameter according to its conditions and performance as presented in Table 2.

Table 2. Score criteria for each parameter

Key Parameters	**Unit**	**Parameter Score**					
	N	**0**	**1**	**2**	**3**	**4**	**5**
Solumn Depth	Cm	<10	10-20	20-40	40-60	60-80	>80
Soil Texture		P, Li	PL, LiD, LiP	LLi, LP, LLiP	D, LD, LLiD		L
Bulk Density	g/cm^3	>1.6	1.4-1.6	1.2-1.4	1.0-1.2	0.8-1.0	< 0.8
Porosity	%	<30	40-30	50-40	60-50	80-60	100%
Permeability	cm/jam	<0.025	0.025-0.125	0.125-0.50	0.5-2.0 and >25.0	2.0-6.25 and 12.5-25.0	6,26-12.50
Aggregate Stability	%	<40	40-50	50-66	66-80	80-200	>200
Surface Rock	%	>60	35-60	15-35	3-15	0-3	0

Source : (Abdurachman & Rachman, 2006; Chairani et al., 2015; Grzywna & Ciosmak, 2021; Mulyono et al., 2019; Nakajima et al., 2016; L. M. Rachman, 2019; Tarigan et al., 2015)

Commented [SA1]: These symbol represent for what kind of soil texture?

Calculation of the physical quality index score by adding up the scores obtained for each parameter; namely :

$$TSoPi = Pi.SoPi$$

$$TSoSQI = \sum_{i}^{n} Pi.SoPi$$

Information:
TSoPi = total score of soil physical properties parameters I,
Pi = proportion (weight coefficient) of soil physical properties parameters I, SoPi = score of soil parameters I,
n = number of soil parameters, and TSoSQI = total score of Soil Physical Quality Index or Soil Physical Quality Index.

To determine the soil physical quality index score, the total score of each soil parameter is calculated by multiplying the proportion called the weighting coefficient and the score of each parameter (scale 1 to 5). Thus, the total Soil Quality Index score varies from 0 to 5, such as 3.06, 4.89, 2.45, and so on. Then, the soil physical quality index score is categorized into 5 groups based on a predetermined Table 3.

Table 3. Soil physical quality index categories

Category	**Score**
Low	≤1.0

Somewhat Low	1.0<X≤2.0
Medium	2.0<X≤3.0
Somewhat High	3.0<X≤4.0
High	4.0<X≤5.0

Source: Modification by L. M. Rachman, 2019.

Determining the soil physical quality index, the total score of each soil parameter is calculated by multiplying the proportion (weighting coefficient) and the score of each parameter (scale 1 to 5). This total score is then categorized into five categories, with the symbol of the main parameter which the limiting factor (parameters that have a value equal to or less than 2 (≤ 2.00) in the low category) followed behind the soil physical quality index number (L. M. Rachman, 2019).

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3. RESULTS AND DISCUSSION

3.1 Result of Study

3.1.1 General conditions of the study location

In this research, six locations were selected, each of which took soil samples using undisturbed, disturbed, and whole aggregate methods.

a. Ex Pit H Seam C&D Location 1 (PitHL1)

PitHL1 is land with a reclamation year of 2022, geographically the research location is located at 0°11'13,292" South Latitude and 116°57'25,961" East Longitude. PitHL1 is the location of the top of the terrace on the Pit H Seam C&D reclamation land. It has a flat area (slope) shape with terrace topography. Altitude 159 m above sea level has a slope percentage of 10%, measuring direction 132 m and slope direction 90ºT. PitHL1 has sapling class pioneer plant vegetation of the *Paraserianthes falcataria* type, namely young trees with a minimum height of 1.5 m and a trunk diameter of less than 10 cm. Pioneer plants in PitHL 1 have a planting distance of 5 m x 5 m with a crown diameter of 1-1.5 m. Vegetation other than pioneer plants in PitHL1 is grass (graminae) with a dense canopy cover category. PitHL1 has a land area of 1.67 Ha.

b. Ex Pit H Seam C&D Location 2 (PitHL2)

PitHL2 is land with the reclamation year of 2022, geographically the research location is located at 0°11'15.291" South Latitude and 116°57'27.193" East Longitude. PitHL2 is the middle location of the terrace on the Pit H Seam C&D reclamation land. It has a regional shape (slope) with terrace topography. Altitude 155 meters above sea level has a slope percentage of 15%, measuring direction 61m and slope direction 104ºT. PitHL2 has sapling class pioneer plant vegetation of the *Paraserianthes falcataria* type, namely young trees with a minimum height of 1.5 m and a trunk diameter of less than 10cm. Pioneer plants in PitHL2 have a planting distance of 5 m x 5 m with a crown diameter of 0.8-1.2 m. Vegetation other than pioneer plants in PitHL2 is grass (graminae) with a dense canopy cover category. PitHL2 has a land area of 2.06 Ha.

c. Ex Pit H Seam C&D Location 3 (PitHL3)

PitHL3 is land with the reclamation year of 2022, geographically the research location is located at 0°11'12,844" South Latitude and 116°57'31,097" East Longitude. PitHL3 is the basic location of the terrace on the Pit H Seam C&D land. It has the shape of a convex area (slope) with terrace topography. Altitude 152 m above sea level has a slope percentage of 17%, measuring direction 41 m and slope direction 104ºT. PitHL3 has the pioneer plant vegetation of the *Paraserianthes falcataria* in the seedling class, namely saplings or young plants with a height of less than 1.5 m. Pioneer plants in PitHL3 have a planting distance of 5m x 5m with a crown diameter of 0.5-0.8 m. Vegetation other than pioneer plants in PitHL3 is grass (graminae) with a sparse canopy cover category. PitHL3 has a land area of 3.29 Ha.

d. Ex Pit H Seam C&D Location 4 (PitHL4)

PitHL4 is land with the reclamation year of 2022, geographically the research location is located at 0°11'2,532" South Latitude and 116°57'33,272" East Longitude. PitHL4 is a location north of the Pit H Seam C&D land. It has the shape of a convex area (slope) and has no terraces. Altitude 155 m above sea level has a slope percentage of 12%, measuring direction 70 m and slope direction 309ºBL. PitHL4 has the pioneer plant vegetation of the *Paraserianthes falcataria* in the seedling class, namely saplings or young plants that are less than 1.5 m high. Pioneer plants in PitHL4 have a planting distance of 5 m x 5 m with a crown diameter of 0.5-0.8 m. Vegetation other than pioneer plants in PitHL4 is grass (graminae) with a sparse canopy cover category. PitHL4 has a land area of 1.26 Ha.

e. 2020 Reclamation Location 1 (2020L1)

2020L1 is land with a reclamation year of 2020, geographically the research location is located at 0°11'23,742" South Latitude and 116°57'6,633" East Longitude. 2020L1 is location one on the 2020 reclamation land. It has a concave area (slope) shape with peak topography. Altitude 185.02 m above sea level has a slope percentage of 9%, measuring direction 214 m and slope direction 46ºTL. 2020L1 has the vegetation of the pioneer plant type *Paraserianthes falcataria* pole class, namely trees with a diameter of between 10-20 cm. Pioneer plants in 2020L1 have a planting distance of 5 m x 5 m with a crown diameter of 2-3 m. Vegetation other than pioneer plants in 2020L1 is grass (graminae) with a dense canopy cover category. 202L1 has a land area of 1.62 Ha.

f. 2018 Reclamation Location 1 (2018L1)

2018L1 is land with a reclamation year of 2018, geographically the research location is located at 0°11'34.905" South Latitude and 116°57'40.136" East Longitude. 2018L1 is location one on the land reclamation in 2018. It has the shape of a peak area (slope). Altitude 182 m above sea level has a slope percentage of 31% in a measuring direction of 70 m and a slope direction of 304oBL. 2018L1 has tree-class vegetation of pioneer (*Paraserianthes falcataria*), namely plants with a diameter of more than or equal to 20 cm. Pioneer plants in 2018L1 had a planting distance of 5 m x 5 m with a canopy diameter of more than 3 m, however at several sampling points no similar vegetation was found and only used legume cover crops (Leguminosae), with a dense canopy cover category. Location 2018L1 has a land area of 2.29 Ha.

3.1.2 Results of analysis of soil physical characteristics

This research uses seven indicators of soil physical properties that are observed and analyzed, namely texture, porosity, intact aggregate, permeability, unit weight, surface rock, and solum depth. Sampling was carried out using three methods by the nature and objectives of the soil analysis. The results of the analysis of soil physical properties are presented in Table 4.

Table 4. Results of field observations and analysis of physical quality indicators

Symbol	Parameters	Unit	Research sites					
			Pit H L1	**Pit H L2**	**Pit H L3**	**Pit H L4**	**2020 L1**	**2018 L1**
t	Texture		C	CL	SCL	C	SCL	C
	Silt	%	22.70	18.75	17.55	26.04	19.70	32.41
	Clay	%	41.41	36.75	34.06	41.34	34.53	55.36
	Sand	%	35.89	44.50	48.39	32.61	45.77	12.22
p	Porosity	%	51.10	54.52	53.10	53.27	54.65	49.01
a	Undisturbed aggregate	%	109.81	43.90	61.19	57.43	77.68	291.25
k	Permeability	cm/jam	0.69	0.64	0.59	0.23	1.50	0.15
b	Bulk Density	g/cm3	1.30	1.17	1.22	1.09	1.19	1.34
r	Surface Rock	%	34.50	43.00	36.00	28.00	15.50	46.00
e	Solum Depth	cm	68.00	31.67	32.00	45.00	33.33	50.00

Source: Research data processed (2022)

3.1.3 Soil physical quality index scores and criteria

The soil physical quality index score is calculated by multiplying the proportion of each soil physical property parameter by the soil parameter score and then adding up the resulting scores. Soil physical quality index scores are categorized in Table 5. After calculation, the physical quality index number is given a limiting parameter symbol with a value equal to or less than 2 (≤ 2.00) in the low category. The results of assessing physical parameters and assessing physical quality indices are presented in Table 5.

Table 5. Soil physical quality index scores and criteria

Location	Score							Final Score
	T	P	A	K	B	R	S	
PitHL1	0	3	4	3	2	2	4	2.25_{tbr}
PitHL2	2	3	1	3	3	1	2	2.25_{tars}
PitHL3	2	3	2	3	2	1	2	2.19_{tabrs}
PitHL4	0	3	2	2	3	2	3	2.00_{takr}
2020L1	2	3	3	3	3	2	2	2.56_{trs}
2018L1	0	2	5	2	2	1	3	1.94_{tpkbr}

Source: Research data processed (2022)

Description: T= texture; P= porosity; A= aggregate stability; K= permeability (hydraulic conductivity); B= bulk weight; R= surface rockiness; S: solum depth; The code next to the final score is a limiting factor for physical quality with a value of ≤2.00

3.2 Discussion

3.2.1 Characteristics of soil physical properties

a. Soil texture

The soil texture at the PitHL1 location is clay (C), at the PitHL2 location it is clay loam (CL), at the PitHL3 location it is sandy clay loam (SCL), at the PitHL4 location it is clay (C), and at location 2020L1 it is sandy clay loam (SCL). Meanwhile, location 2018L1 is dominated by a clay percentage of 55% and has a clay texture (C).

The results of the analysis show that the soil texture in the reclamation area varies, namely clay, clayey clay, and sandy clay. Soil that contains too much clay can store large amounts of water but the water does not easily seep into the soil because the water flows on the surface of the soil and causes erosion. Soil that has a high sand content will be very easily absorbed but cannot store water for a long time due to infiltration into the lower layers. An ideal soil is a soil that has a relatively balanced texture of clay, sand, and dust, which is usually called loam (Holilullah et al., 2015). Soil with a clay texture has a large surface area so it can hold water and provide higher levels of nutrients (Sinaga et al., 2014). Low clay content can affect the soil's ability to bind or absorb water, causing problems with soil moisture and susceptibility to drought (Hartanto et al., 2022). Clay-textured soil also has a higher available water capacity than clay-textured soil, because clay-textured soil generally has more micropores so the amount of water that can be held is greater and the available water capacity is higher. Fine soil texture can increase available water capacity (Intara et al., 2011).

Clay loam soil texture can absorb more water, but the water in the soil is not necessarily available to plants. Research comparing the texture capabilities of clayey and sandy clay soils shows that plant height in sandy clay textures is higher than in soils with clayey clay textures because roots penetrate more easily in soil with larger pores in sandy soils than in clayey soils. with smaller pores. The condition of the physical properties of the soil greatly influences plant root penetration because the roots of a plant are used to absorb water and nutrients for plant growth and development. Many mine soils have a high proportion of coarse materials and high surface rock such as sand, clay, and sandy loam which causes faster water and nutrient loss. The texture of mine soil was found to be similar to natural soil 25 to 100 years after the coarse material and surface rock were separated (Feng et al., 2019).

b. Soil porosity

The results of the analysis show that the porosity at each research point shows variations, between 49% and 55%. The role of this pore distribution is to provide water and air to the soil. In general, porosity characteristics have poor and good status. The 2020L1 research location is known to have a sandy clay loam texture class which allows the soil to have better macro pore conditions. This causes roots to penetrate more easily in soil with larger pores in sandy soil than in clay soil with smaller pores.

Soil porosity tends to be positive towards organic matter, so the higher the organic matter content in the soil, the greater the soil porosity. This causes roots to penetrate more easily in soil with larger pores in sandy soil than in clay soil with smaller pores. With better root development, the development of the top of the plant will also be better. The condition of the physical properties of the soil greatly influences plant root penetration, because the roots of a plant are used to absorb water and nutrients for plant growth and development. Soil porosity also reflects the level of the soil's ability to pass water masses (permeability) or the speed of water flow through the soil mass (percolation). The greater the porosity value, the greater the maximum water storage capacity (Juarti, 2016).

Improvement of soil pore structure and aggregate formation takes a long time which is influenced by the movement of clay fractions, chemical elements, organic materials, and various mechanisms between the physical, chemical, and biological properties of the soil. If reclaimed soil becomes compacted due to the use of heavy equipment, the air and water in the soil will be blocked, resulting in extensive, long-lasting, and sometimes irreversible damage, negatively affecting soil productivity and ecosystem function (Feng et al., 2019). The condition of the physical properties of the soil greatly influences plant root penetration because the roots of a plant are used to absorb water and nutrients for plant growth and development (Ch Salawangi, Lengkong Jeanne, et al., 2020).

c. Aggregate stability

The analysis results show that the soil aggregate stability value at location 2018L1 (291.25) is the highest, while the lowest value is at location PitHL2 (43.90). Soil aggregate stability values vary from very stable to less stable. The low soil aggregate stability at the PitHL1 location is caused by the influence of the value of organic matter content on the land surface, especially the influence of the LCC above it in 2018L1 which provides a large input of organic matter to the soil.

Aggregate stability has a strong relationship with soil porosity. Soil that is easily dispersed or unstable aggregates can cause soil pores to be easily damaged or blocked/clogged by clay or dust (internal erosion), resulting in lower porosity. Aggregate stability is also influenced by several factors, one of which is the soil organic matter content. The higher the organic material content, the higher the aggregate stability (Adeli et al., 2013). At the 2018L1 research location, the dominant clay fraction content (55%) causes the soil texture to be classified as clay and increases aggregate stability. In addition, low clay fraction content can cause low aggregate stability, so the soil often loses nutrients due to leaching and the risk of erosion. According to Hanifah, another factor that influences aggregate stability is soil texture (Hanifah & Listyarini, 2020). Adverse conditions of reclamation, such as soil compaction and lack of vegetation, cause a shortage of organic matter, leading to a vicious cyclic cycle (Feng et al., 2019)

d. Soil permeability

Permeability at each research point shows variations, between 0.15 to 1.50, optimal permeability if the permeability value is close to 6.26-12.50, it is known that the permeability value can be classified as slightly slow and moderate. The porosity value at location 2020L1 is the highest among other locations, with a sandy clay texture content that allows the soil to have many macro pores.

High soil permeability occurs in soil that has good porosity and texture. Soil with high porosity has a good ability to hold water so that water easily seeps into the soil. Meanwhile, soil with a rough texture has large pores, so water can seep quickly into the soil. However, soil with a fine texture has small pores so it is difficult for water to seep into the soil.

The results of the analysis show that location 2020L1 has the highest permeability value (1.50 cm hour-1) and has a sandy clay loam texture, so it has a good ability to hold water. The large soil porosity that forms on the land is caused by the root activity of the vegetation on the land, which causes high water flow. This shows that vegetation growth on land influences soil porosity and water flow on the land (Tambunan et al., 2018). Meanwhile, location 2018L1 has the lowest permeability value (0.15 cm hour-1) and has a clay texture, so it has a low ability to hold water. This is caused by the pore size in clay-textured soils which have small pore spaces. The size of the pores and the relationship between the pores determines whether the soil has low or high permeability, where permeability may also be close to zero if the soil pores are very small, such as in clay soil (Mulyono et al., 2019).

e. Bulk density of soil (BD)

The results of the analysis show that the bulk density can be classified as medium and somewhat dense. Soil of bulk density is useful for evaluating the ability of plant roots to penetrate the soil. In addition, an increase in soil bulk density is also associated with a decrease in water content in denser soil and higher compaction. The high bulk density of soil in ex-mining land may be caused by the use of heavy equipment for a long time during mining activities, which causes soil porosity to decrease. The activity of using heavy equipment on ex-mining land causes the soil to become compact, the mass density (BD) value is high, the soil porosity and drainage are low, and air exchange in the soil is hampered. This affects the availability of water in the soil and ground surface flow when it rains. High bulk density of soil is also caused by tillage using heavy equipment for a long time and heavy equipment activity during topsoil placement (Hamid et al., 2017; Liu et al., 2014).

Bulk density (BD) is the weight of soil per volume which can be used to evaluate the possibility of roots penetrating the soil. The ideal BD usually ranges from 1.30 - 1.35 g cm^{-3}. However, BD in soil can vary depending on the type and degree of aggregation, texture, soil organic matter, and other factors such as tillage, organic matter, compaction by agricultural equipment, structure, and soil water content. Research (Zulkarnain, 2014) shows that the bulk of the soil on reclaimed land is mixed with residual coal, crushed stone, and soil conglomerate. Therefore, the low density of the soil mass at the reclamation site is not caused by a high organic material content, so it does not provide benefits for plant growth.

f. Surface rockiness

Soil surface rockiness is the number of rocks visible on the ground surface within a certain area. The percentage of gravel or rock in the field is measured by calculating the number and distance between coarse particles in the land area. Based on field observation data, the 2018L1 location has the highest percentage of rocks with 46%, while the other locations range between 15.50-43%, in the many categories. A high percentage of surface rock can inhibit plant root penetration and reduce the freedom of roots to penetrate the soil layers below the surface.

Rock fragments found on the ground surface or exposed on the ground surface can influence land use and management (Sukarman et al., 2017). If the land surface is dominated by rock, then the area may have experienced erosion or a high rate of formation, which can cause the soil volume in the area to be small. This can reduce the ability of the soil as a medium for biomass production. Apart from that, rock fragments contained in the soil can also affect the freedom of plant roots to penetrate layers below the soil surface (Abdulkarim et al., 2015).

g. Solum depth

Solum depth is the vertical distance from the soil surface to the layer that limits the freedom of development of the root system. The depth of the solum is measured by drilling on each surface of the soil until you get a hard layer beneath it. Each location was drilled three times and the average value was sought based on the six different fields, with an average depth of 3.67-68.00 cm.

The condition of the solum depth in this study can be categorized as moderate-shallow. PitHL2 has a low depth, perhaps caused by PitHL2 which is the middle location of the terrace on the Pit H Seam C&D reclaimed land with a sloped landform and terrace topography. Effective depth shows the average value of root depth and its effect on the slope. The steeper the slope, the soil has a smaller root solum depth. The depth of the solum can also be influenced by the land cover above it. The effective soil depth in vegetated land has a higher soil depth value compared to land with bushland cover. This is because land cover is a factor in soil formation or soil pedogenesis. Soil-filling technology is used to determine the development of reconstructed soil horizons. Young mine soils develop through interactions between climate, living organisms, and the soil surface, over time. Due to the complexity of the nature of mining soils, the formation of new subsurface soil horizons is found in mine soils of different ages, ranging from several years to several decades (Alfiyah et al., 2020).

3.2.2 Soil Physical Quality Index

The trend of improving soil quality on ex-mining land is an important indicator of the success of reclamation efforts undertaken. Soil quality index calculations can be used to measure the impact of post-mining reclamation on soil quality. By calculating the soil quality index, we can find out how well the reclamation efforts are being carried out and whether additional action is needed to improve the quality of the soil (A. Rachman et al., 2020). Soil quality is the ability of the soil to maintain plant productivity, ensure water availability, and support human activities. Soil quality cannot be measured directly, so it is necessary to determine physical, chemical, and biological indicators that together indicate the condition of soil quality. High soil quality can be characterized by high soil fertility. The results of the post-mining soil physical quality index analysis are presented in Table 6

Table 6. Physical quality index of post-mining soil

No.	**Site**	**Final Score**	**Category**	Limiting Factors of

1.	PitHL1	2.250	Medium	• Texture • Bulk density • Surface rock
2.	PitHL2	2.250	Medium	• Texture • Aggregate stability • Surface rock • Solum depth
3.	PitHL3	2.188	Medium	• Texture • Aggregate stability • Bulk density • Surface rock • Solum depth
4.	PitHL4	2.000	Medium	• Texture • Aggregate stability • Permeability • Surface rock
5.	2020L1	2.563	Medium	• Texture • Surface rock • Solum depth
6.	2018L1	1.938	Somewhat Low	• Texture • Porosity • Permeability • Surface rock • Bulk density

Source: Research data processed (2022)

Good quality can help soil function as a medium for plant growth, regulate and save water, and support a healthy environment. Good soil quality is a soil condition that has good physical, chemical, and biological properties as well as high and sustainable productivity. To illustrate the condition of soil quality on post-mining reclamation land, the following is a graph of the results of calculating the soil physical quality index (Figure 1)

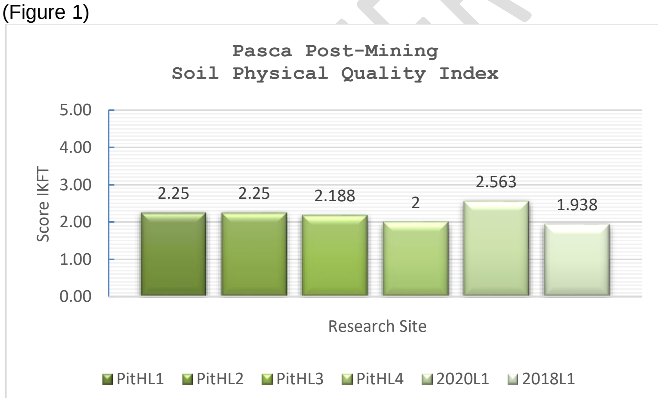

Figure 1. Soil Physical Quality Index Graph

Soil quality assessment is a way to evaluate how well soil meets certain standards. Soil quality is an important element of sustainable agriculture. Soil management systems can only survive if they can improve or maintain soil quality. Soil quality can be used as a tool to evaluate land and natural resource management practices on a trial basis. The sustainability of agricultural practices and other land uses can be measured quantitatively to evaluate the level of land degradation that occurs (Heryani & Sutrisno, 2013). Mining can affect the physical properties of soil, such as its function as a rooting medium and determining water availability. Several soil physical properties can be used as indicators of soil physical quality that are relevant and sensitive to changes in land management, including effective soil depth, soil texture, aggregate stability, surface rock, unit weight, porosity, and permeability.

Quality index of physical properties on coal mine reclaimed land, especially in this study, the physical properties of soil on coal mine reclaimed land have a moderate to quite high physical quality index. However, some parameters have low values (≤2). Slightly high soil quality is found at research locations PitHL2, PtHL3, and 2020L1, while moderate soil quality is found at locations PithL1, PitHL4, and 2018L1. The total area of reclaimed land is 12.18 Ha, with the area of land with rather high soil quality being 6.97 Ha or 57% of the total land area, and the area of land with moderate soil quality being 5.22 Ha or 43% of the total land area which is the subject of research. The factors that influence the soil physical quality index will be explained further, namely :

a. Pit H Seam C&D Location 1 (PitHL1)

PitHL1 is land reclamation in 2022 with a peak terrace location on the Pit H Seam C&D land. The shape of the area is flat with terrace topography and has a land area of 1.67 Ha. PitHL1 has a high bulk density or soil density with a value of 1.30 g cm-3 and a high percentage of surface rock with a value of 34.5%. These two parameters greatly influence the function of the soil as a rooting medium and water storage medium.

b. Pit H Seam C&D Location 2 (PitHL2)

PitHL2 is a reclamation location in 2022 which is located in the middle of the terrace on the Pit H Seam C&D land. The slopes have terrace topography and have a land area of 2.06 Ha. The aggregate stability in PitHL2 is less strong with a value of 43.9%, the surface rock percentage is 43.00%, and the solum depth is 31.67 cm. Aggregate stability, surface rock percentage, and solum depth greatly influence the storage media for water, nutrients, and pore space in the soil. Poor aggregate can cause internal erosion between pore spaces in the soil. The depth of the solum and the percentage of surface rock also influence plant root development.

c. Pit H Seam C&D Location 3 (PitHL3)

PitHL3 is land with a reclamation year of 2022. PitHL3 is the basic location of the terrace on the Pit H Seam C&D land. It has a convex slope (slope) shape with terrace topography, with a land area of 3.29 Ha. PitHL3 has several factors inhibiting the physical quality index, including aggregate stability with a value of 61.19%, bulk density with a value of 1.22 g cm-3, surface rock percentage with a value of 36.00%, and solum depth with a value of 32.00 cm. Aggregate stability, unit weight, surface rock, and solum depth influence the function of the soil, the physical medium in which nutrients, water, and gas exist, as well as the rooting medium and the fulfillment of the gas needed by plants.

d. Pit H Seam C&D Location 4 (PitHL4)

PitHL4 on the 2022 reclaimed land in the north of the Pit H Seam C&D land has a convex slope shape and does not have a terrace with a land area of 1.26 Ha. PitHL4 has several factors that influence the soil physical quality index, such as less stable aggregate stability (57.43%), permeability with a value of 0.23 cm hour-1, and shallow solum depth with a value of 45 cm. These factors influence the function of the soil as a medium that provides available water for plants, fulfills the gas needed by plants, as well as a place for nutrients, water, and gas, and as a rooting medium.

e. Reclamation in 2020 Location 1 (2020L1)

2020L1 is land that was reclaimed in 2020. 2020L1 is the location of one of the 2020 reclaimed lands. This land has a concave area shape with peak topography, with a land area of 1.62 Ha. Several factors hinder the soil physical quality index in 2020L1, namely the surface rock percentage of 15.50% and solum depth of 33.33 cm. The percentage of surface rock and the depth of the solum influence the function of the soil as a medium for the presence of nutrients, water, and gas, as well as a rooting medium for plants. 2018 Reclamation Location 1 (2018L1)

f. 2018L1 is land with a reclamation year of 2018.

2018L1 is the first location on land that was reclaimed in 2018. It has a steep landform at the top of the slope and has a land area of 2.29 Ha. 2018L1 has several soil physical properties that hinder the physical quality index, such as porosity, permeability, unit weight, and surface rock. Porosity at location 2018L1 has a value of 49.01% with porous criteria, followed by a slow permeability value with a value of 0.15 cm hour-1. The weight of the contents at this location is classified as solid with a value of 1.34 g cm-3. The percentage of surface rock was also identified as 46.00% in the many categories. Porosity, bulk density, and permeability greatly influence the function of the soil as a source of water available for plants and provide the gases needed by plants, while a large percentage of surface rock can influence the function of the soil as a rooting medium.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusion

a. The physical characteristics of the soil are: soil texture varies between clay, clay loam, and sandy clay loam; Soil porosity is classified as poor and good; aggregate stability is classified as less stable to very stable; Soil permeability is relatively slow and moderate; bulk density is classified as medium and slightly dense; surface rocks are abundant; the depth of the solum is classified as shallow and medium.

b. The physical quality of the soil on reclaimed coal mine land is classified as rather low and moderate with limiting factors including a large amount of surface rock, large bulk density, low solum depth, and low aggregate stability.

4.2 Suggestions

The soil at the research location, which is reclaimed coal mine land, has relatively low to medium physical quality, along with the limiting factors at the location that can influence a good growing medium for plants. Therefore, there needs to be soil management measures such as backfilling topsoil and adding organic inputs to maintain, restore, and improve the physical quality of the soil.

Commented [SA4]: Please recommend this evaluate methodology work? And about further work should to do

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