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MORALITY BEFORE KNOWLEDGE

Soil erodibility results of revegetation using Bitti plant at various ages reclamation of quarry a limestone mine at PT. Semen Tonasa, Pangkep District, South Sulawesi

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ABSTRACT
Background: Limestone mine reclamation by Limited Liability Company (LLC)/Perseroan Terbatas (PT) Semen Tonasa is carried out periodically to restore land conditions sustainably. The reclamation was carried out through revegetation using endemic plants, namely the bitter plant (*Vitex colossus R.*), which grows significantly in the southern part of Sulawesi. This study aims to determine the erodibility of the soil in limestone mine reclamation land planted with bitti plants. **Methods:** The method used is the survey method by determining the location of soil samples using the purposive sampling method based on the reclamation age planted with bitti plants in 2019, 2015 and 2010 and determining the erodibility value using the formula according to Wischmerier and Smith (1978). The parameters used included soil texture, structure, organic matter, permeability, pH, and unit weight. **Findings:** The results of this study indicate that the erodibility of the soil in the limestone mine reclamation land planted with bitti plants is classified as high due to the high dust content, which is influenced by the parent material. The results of this study indicate that the erodibility value of the land reclamation in 2019 was classified as moderately low to moderately high, the land reclamation in 2015 was classified as moderate to moderately high, and the land reclamation in 2010 was classified as moderate to high. **Conclusion:** The factor affecting the erodibility of the soil in the reclamation area is the M value (percentage of very fine silt and sand). **Novelty/Originality of this Study:** This study's novelty lies in examining soil erodibility changes over different reclamation ages in a limestone mine using endemic bitti plants. This research highlights the unique relationship between reclamation age and soil properties, contributing valuable insights into effective land reclamation practices in tropical karst environments.

KEYWORDS: bitti plant, mine land reclamation, soil erodibility, revegetation

1. Introduction

Mining activities cause damage to the surrounding environment (Zibret et al., 2018). The impacts include the loss of forest vegetation, flora and fauna, and soil layers, so every mining company must reclaim the former mining land (Patiung et al., 2011). PT. Semen Tonasa is one of the companies engaged in limestone mining in Eastern Indonesia. It is located in Bungoro District, Pangkep Regency, South Sulawesi Province. The mining system applied in the limestone mine of PT. Semen Tonasa is an open pit mining system or quarry method. At the end of mining activities, it leaves ex-mining land that damages the

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surrounding environment (Pratiwi et al., 2021). Using natural resources without reclamation activities can cause erosion on the land, affecting the decline in soil productivity (Lal, 2012).

Erosion is a phenomenon that cannot be separated from the soil erodibility factor (Gao et al., 2020). Soil erodibility (K) indicates the level of soil sensitivity to erosion, namely the extent to which the soil is easily eroded or not (Khanchoul & Boubehziz, 2019). Soil erodibility is influenced by soil texture, structure, permeability, and organic matter content (Wischmeier & Mannering, 1969; Arsyad, 2010; Belasari et al., 2017). Understanding these factors is very important in the context of reclamation of ex-mining land, because post-mining soil characteristics are often very different from their natural conditions.

Limestone mine reclamation carried out by PT. Semen Tonasa is located in quarry A with an area of 85 Ha, and the reclaimed land area is 19.3 Ha since 2010. This scale of reclamation shows the complexity and challenges in restoring post-mining land, considering the vast area affected and the differences in the age of the existing reclamation. The reclamation process, which has been going on for more than a decade, provides a unique opportunity to observe changes in soil characteristics and erodibility levels over time.

Revegetation using bitti plants (*Vitex colossus R.*) is one of the reclamation efforts carried out by PT. Semen Tonasa inhibits the rate of erosion on the reclaimed land of quarry A, where this plant is an endemic plant that grows in South Sulawesi. The selection of endemic plants for revegetation shows an approach that considers ecological suitability and potential for long-term success. Endemic plants are usually more adaptive to local conditions, which can increase survival rates and effectiveness in controlling erosion.

Plant characteristics that affect erodibility are roots and leaf litter (Hao et al, 2020). The role of roots and leaf litter in these plants can reduce the dispersion force of rainwater, reduce the amount and speed of surface flow, and increase water infiltration into the soil to reduce soil erodibility (Dunkerley, 2020; Vannoppen et al., 2015; Zuazo & Pleguezuelo, 2009). A strong root system can increase soil stability, while leaf litter protects the soil surface from the direct impact of raindrops and increases soil organic matter content over time.

Periodic limestone quarry A reclamation can show varying soil erodibility values. This variation can be caused by differences in the reclamation techniques applied, differences in reclamation age, and differences in vegetation development and soil structure formation. The study of soil erodibility values in limestone quarry reclamation is very important in determining conservation and processing activities to maintain soil sustainability and productivity (Sheoran et al, 2010; Ruiz et al., 2020).

The importance of this study lies in several key aspects. First, a deeper understanding of soil erodibility allows for the design of more effective and targeted conservation strategies. This can include selecting appropriate tillage techniques, determining the type and pattern of vegetation planting, and implementing physical structures to control erosion if necessary. Second, information on changes in soil erodibility over time can help evaluate the success of reclamation efforts that have been carried out and identify areas that may require additional intervention.

In addition, such studies also contribute to a broader understanding of the dynamics of post-mining ecosystem recovery. By observing changes in soil erodibility and the factors that influence it, researchers and practitioners can gain valuable insights into the natural processes that occur during land restoration. This information is not only useful for current reclamation projects, but can also be used to improve future reclamation practices, both at the same site and at other sites with similar characteristics.

Furthermore, the study of soil erodibility in limestone mine reclamation areas has important implications for environmental and economic sustainability. Effective erosion control not only protects the reclaimed land itself, but also prevents negative impacts on the surrounding ecosystem, such as river sedimentation or degradation of downstream agricultural land. From an economic perspective, a good understanding and management of soil erodibility can reduce the long-term costs associated with maintaining reclaimed land and mitigating environmental impacts. Thus, research on soil erodibility in limestone mine reclamation areas not only contributes to scientific knowledge, but also has significant practical applications in post-mining land management and broader ecosystem restoration efforts.

2. Methods

The research was conducted in the field with the determination of sample location points Figure 1. based on the age of reclamation planted with bitti plants, namely three years (2019), seven years (2015), and 12 years (2010). Soil samples were collected at each reclamation age by making 10 x 10 m plant plots diagonally so that there were five soil samples at each reclamation age. Observations of soil structure were made in the field, while soil texture, permeability, and organic matter were determined through laboratory analysis (Rabot et al., 2018; de Andrade Bonetti et al., 2017).

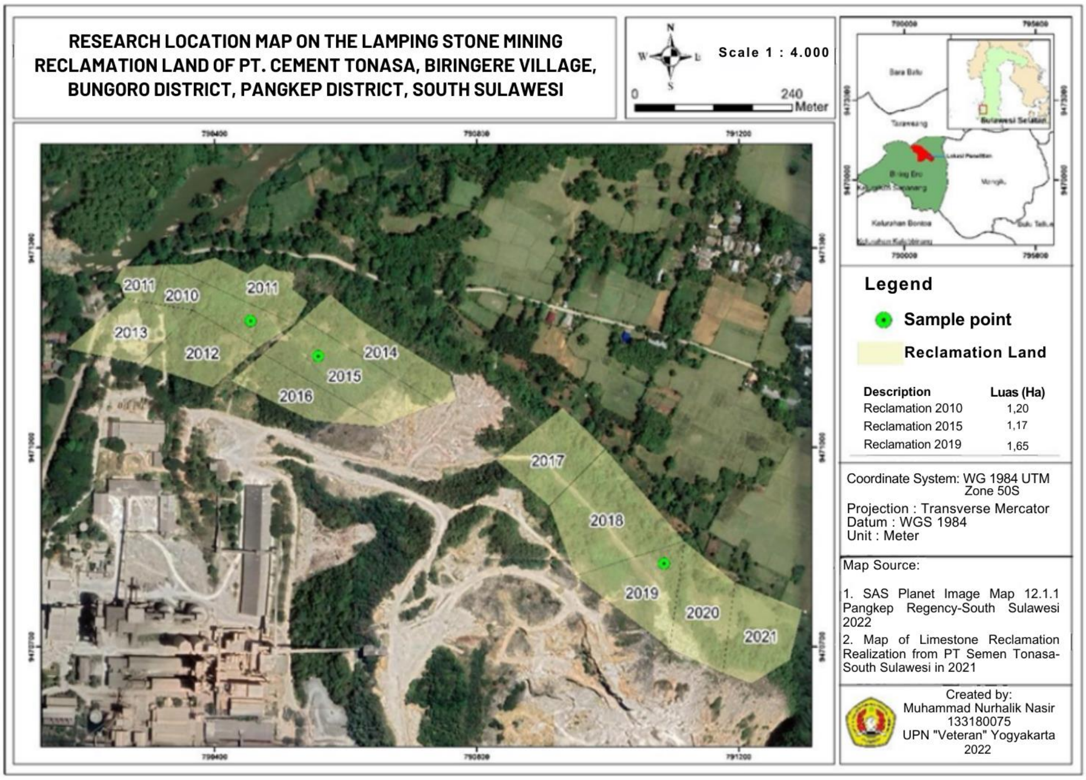

Fig. 1. Research Location

Soil texture used the pipette method, permeability used the constant head soil core method, and organic matter used the Walkley-black method—determination of erodibility value based on Wischmeier and Smith (1978) Equation 1 (Mwendwa, 2022; Elhakim, 2016; Bahadori & Tofighi, 2017; Kruk, 2021). In Equation 1, K is Soil Erodibility; M is Soil grain size parameter (% dust + % very fine sand) (100-% clay); a is % organic matter ; b is Soil structure class; and c is Soil permeability class.

$$100K= 1.292 [2.1M1.14 (10-4) (12-a) + (b-2) 3.25 + (c-3) 2.5] \qquad \text{(Eq. 1)}$$

The research location is in Biringere Village, Pangkep Regency, South Sulawesi Province. The limestone mining area of quarry A of PT Semen Tonasa has an area of 86.51 ha and has been reclaimed since 2010, covering an area of 15.53 ha. The reclamation location is located in the Maros-Pangkep karst cluster and is influenced by the Pangkajene River which has experienced meandering. The geology of the 2019 reclamation location is included in the Undak deposit, while the 2010 and 2015 reclamations are included in the Tonasa formation. The Undak deposit consists of gravel, sand, and clay. These geological characteristics play an important role in the reclamation and land restoration process, affecting the physical and chemical properties of the soil and the potential for vegetation growth in the area.

The Maros-Pangkep karst cluster is a unique area with a distinctive landscape in the form of limestone hills and caves. The presence of a mining area in this area poses a special challenge in reclamation efforts, given the sensitivity of the karst ecosystem to disturbance. The influence of the Pangkajene River, which has experienced meandering, also needs to be considered in the context of the hydrology of the area and its potential impact on the stability of the reclaimed land. River meandering can affect erosion and sedimentation patterns around the reclamation area, which in turn can affect the success of land restoration efforts.

Differences in geological formations between the 2019 reclamation location (Undak deposit) and the 2010 and 2015 reclamation locations (Tonasa formation) indicate variations in soil and bedrock characteristics in the study area. This can have an impact on the reclamation strategy implemented, including the selection of plant types for revegetation and the soil management techniques used. Undak deposits consisting of gravel, sand, and clay may require a different approach in terms of soil processing and plant selection compared to areas in the Tonasa formation.

The linear regression data analysis process was carried out using Carl Pearson correlation analysis (Sugiyono, 2019; Liu et al., 2017). This analysis aims to assess the strength of the relationship between soil erodibility and the factors that influence it, namely permeability, M value, and organic matter content (Ostovari et al., 2016; Ostovari et al., 2019; Efthimiou, 2020). The selection of this method allows researchers to quantify the extent to which each factor contributes to soil erodibility, which is very important in designing effective land management strategies to reduce erosion risks.

A t-test analysis was conducted to determine differences in soil erodibility values at various reclamation ages using Microsoft Excel 2016 software (Mukerji, 2020; Toisoul Laurent, 2022). The use of the t-test allows for a robust statistical comparison between soil erodibility values on reclaimed land of different ages. This can provide valuable insights into how soil erodibility changes over time after reclamation, which can help in planning long-term interventions and assessing the success of reclamation efforts.

This comprehensive data analysis approach allows for a thorough evaluation of the dynamics of soil erodibility in reclaimed land. By considering the various factors that influence soil erodibility, this study can provide a deeper understanding of the processes that occur during post-mining land recovery. This information is invaluable for optimizing future reclamation practices, not only in the study site but also in other mining areas with similar characteristics.

In addition, the use of robust statistical methods such as linear regression and t-tests increases the reliability of the study findings. This is important given the complexity of the interactions between the various factors that influence soil erodibility and the overall land recovery process. With a better understanding of the factors that influence soil erodibility and how these factors change over time, land managers and policy makers can make more informed decisions about the most effective reclamation strategies to implement at various stages of the land recovery process.

3. Results and Discussion

3.1 Soil Erodibility at Various Ages of Reclamation

The soil erodibility value is obtained by calculating influencing factors: soil texture, soil structure, soil permeability, and organic matter (Wischmeier & Mannering, 1969; Zhao et al., 2018). The results of soil erodibility calculations using the Wischmeier and Smith (1978) equation are presented in Table 1. Soil erodibility on the three reclaimed lands is predominantly relatively high; thus, there is potential for increased surface erosion.

Table 1. Soil Erodibility Values at Different Ages of Reclamation

Reclamation Age (Years)		3 Years (2019)	7 Years (2015)	12 Years (2010)
Texture (%)	Coarse Sand	6.6	32.4	27.8
	Very Fine Sand	2.8	13.8	12
	Dust	63	45.6	52.2
	Clay	27.6	7.8	8.2
	Class	*Silty Clay Loam*	*Loam*	*Sandy Loam*
	M	4809,4	5483,2	5897.4
BO (%)	C-organic	2.08	1.98	2.08
	A	3.58	3.41	3.58
	Level	Medium	Medium	Medium
Structure	Type	Fine Granular	Coarse Granular	Medium Granular
	B	2	3	3
Permeability	Value	4.63	6.01	5.06
	Class	Slow-Medium	Slow-Medium	Slow-Medium
	c	4	4	4
K		0.39	0.5	0.53
Dignity		Medium	Rather High	Rather High

One of the factors affecting surface erosion is derived from the kinetic water of rain that hits the ground and the force of the surface flow (Singh & Hartsch, 2019). This is supported by the dominance of the dust fraction on each reclaimed land. Dust is the most easily eroded soil fraction because it is relatively delicate and easily transported (Shahabinejad et al., 2019). This fraction also cannot form bonds (without the help of adhesive/binding materials) because it has no charge (Lal & Elliot, 2017; Dariah et al., 2004). Efforts to reduce the high soil erodibility include planting cover crops as part of land management practices (Haruna et al., 2020). Cover crops reduce the energy of surface runoff, increase surface roughness, thereby decreasing the velocity of surface flow, and consequently diminish the ability of surface runoff to detach and transport sediment particles. Additionally, the presence of cover crops is beneficial in improving soil structure, adding organic matter, and reducing the kinetic energy of raindrops before they reach the soil surface (Adetunji et al., 2020).

The 2019 reclamation land is 10 meters above sea level and is a long-term unprocessed limestone waste disposal area. This land is located 10 meters above sea level from below the sediment consisting of gravel, clay, and sand. The erodibility value of this land is the lowest among the other two lands because it is influenced by the dominance of dust and clay fractions. The dust fraction is a fraction that cannot form bonds, while the clay fraction has a charge that can form bonds. These characteristics provide better stability to the soil, reduce the risk of erosion and increase the soil's ability to retain water and nutrients.

The 2015 reclamation land is 25 meters above sea level and is a limestone mining location. This land is karst, part of the Tonasa Formation, where the constituent elements come from limestone. Land arrangement during reclamation is carried out by filling and leveling the land using topsoil and overburden materials. The increase in erodibility value on this land is influenced by the M value, which is based on the soil texture obtained, dominated by sand and dust fractions. This composition makes the soil more susceptible to erosion due to the lack of cohesion between soil particles. In addition, the dominance of sand and dust fractions can also affect the water retention capacity of the soil, which in turn can affect plant growth and overall land stability.

The 2010 reclamation land is located at an altitude of 25 meters above sea level and is a limestone mining location. This land is karst, part of the Tonasa Formation, where the constituent elements come from limestone. Land arrangement uses topsoil and overburden materials, and land leveling uses a bulldozer. Soil erodibility on this land has almost the same value as the reclaimed land planted with bitti plants in 2015, where the soil texture is dominated by high dust fractions and fine sand, which affects the increase in soil erodibility. However, with relatively the same soil conditions as the land in 2015, the soil structure on this land is medium granular.

This proves that as the reclamation age increases, the soil structure also improves due to the organic matter content in the soil (Liu et al., 2021; Noviyanto, 2017; Hamid, 2017; Liu et al., 2017). This improvement in soil structure has important implications for the long-term success of the reclamation project. Better soil structure increases water infiltration, reduces surface runoff, and supports better root growth. In addition, increasing organic matter content over time not only improves soil structure but also increases soil fertility, pH buffering capacity, and beneficial soil microbial activity.

A comparison of these three reclaimed lands shows the complex dynamics of the post-mining land recovery process. The 2019 reclaimed land, although it has the lowest erodibility value, still faces challenges because it is a limestone waste disposal area. This shows the importance of proper waste management in mining operations. The 2015 reclaimed land illustrates the intermediate stage in the recovery process, where land management has been carried out but the soil is still susceptible to erosion. The 2010 reclaimed land shows positive results from long-term reclamation efforts, with significant improvements in soil structure.

The difference in elevation between these lands (10m vs. 25m above sea level) can also affect erosion and land recovery processes. Higher land may be at greater risk of erosion due to gravity, but may also have better drainage. These factors need to be considered in planning and implementing future reclamation strategies. These findings emphasize the importance of a long-term approach to mined land reclamation, with particular consideration of soil composition, land-planning techniques, and plant selection for revegetation. In addition, further research into the interactions between factors such as topography, microclimate, and land management practices may provide valuable insights to improve the success of future reclamation efforts.

3.2 Factors affecting soil erodibility

3.2.1 M Value

Data analysis using simple linear regression analysis shows a unidirectional relationship or positive correlation between the M value (independent variable) and the soil erodibility value (dependent variable). This relationship is characterized by a correlation coefficient that shows the closeness of the relationship between the two variables. In this case, an increase in the M value has a direct effect on the increase in the soil erodibility value with a correlation coefficient reaching 0.94, which indicates that this relationship is very close.

The determination value or R^2 also provides important information, where a value of 0.89 indicates that 89% of changes in soil erodibility can be explained by the M value through the existing linear relationship. This means that the M value has a significant effect on increasing soil erodibility on reclaimed land in 2019. Thus, the M variable is a key factor in determining soil erodibility in the context of reclamation.

The results of the t-test calculation show that the t-count value of 10.31 is greater than the t-table value of 2.16. This indicates that there is a significant difference between the M value and soil erodibility on reclaimed land. In addition, the percentage of fine sand and dust also contributes to the high M value (Moon et al., 2020). The higher the percentage of fine sand and dust in the soil, the higher the M value obtained, which is then followed by an increase in the K value. Soil dominated by fine sand and dust textures tends to be more sensitive to erosion compared to soil with a dominant clay texture (Wade, 2020; Arsyad, 2010; Mumzaei et al., 2023). This shows that the physical characteristics of the soil, especially the texture composition, play an important role in the potential for soil erosion. In the context of reclamation, understanding these factors is very important for planning appropriate management strategies to improve soil stability and minimize the risk of erosion. This study is expected to provide deeper insight into the effect of soil characteristics on erodibility, so that it can support more effective and sustainable reclamation practices.

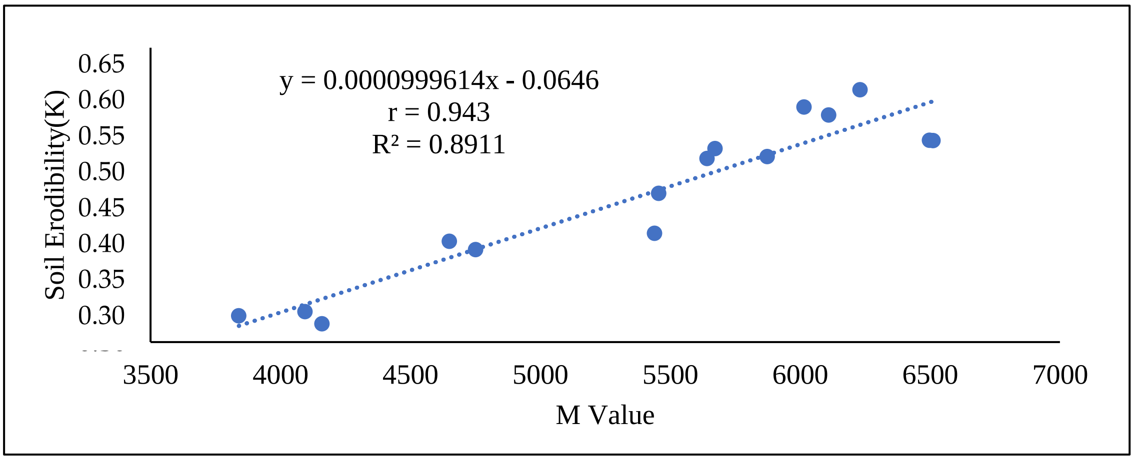

Fig. 2. M Value on Erodibility

3.2.2 Organic Material

Based on data analysis using simple linear regression analysis (Figure 3) shows an inverse relationship or negative correlation where the addition of organic matter (x) affects the decrease in soil erodibility value (y) on limestone mine reclamation land. The correlation coefficient that shows the relationship with the increase in organic matter affects the decrease in erodibility value where the correlation coefficient is 0.33, meaning that it has a small/not close relationship. The value of determination or R2 is obtained at 0.11, or organic matter content affects the increase in soil erodibility value by 11%.

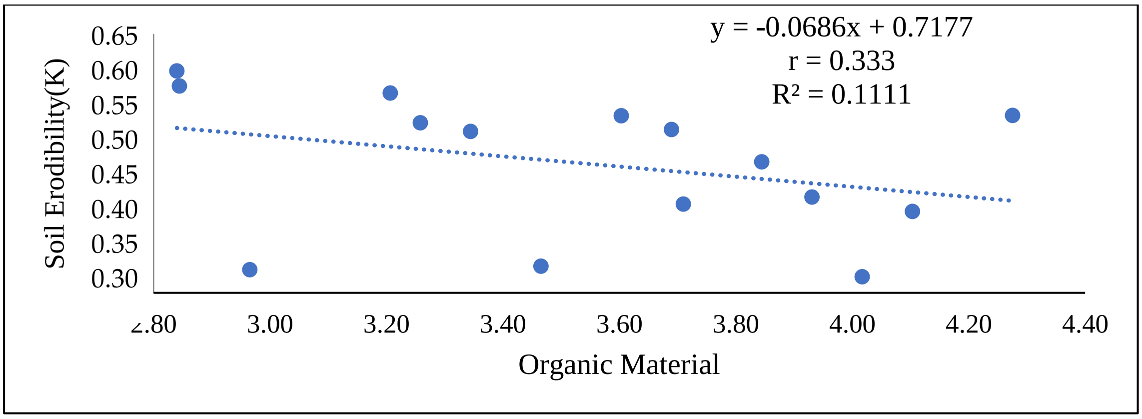

Fig. 3. Organic meter

Based on the calculation of the t-test, organic matter with soil erodibility obtained a count of 1.27, smaller than the t-table of 2.16 at a significance level of 5%, which means that there is no real difference between organic matter with soil erodibility value (Arunrat et al., 2022; Ayoubi, 2018). Based on the simple regression analysis followed by the t-test, the vegetation growing on the reclaimed land, especially the bitti plant, can contribute sufficient organic matter to the soil but has yet to be able to affect the soil erodibility value on the land (Liu et al., 2019; Feng et al., 2018; Carabassa & Alcaniz, 2018).

3.2.3 Soil Structure

Based on Table 2, observations of soil structure in the 2019 reclamation showed an acceptable type of granular structure. This is influenced by the high percentage of dust and clay fractions in the soil. In addition, the high organic matter content also contributes to the narrowing of the pore size, so that the soil structure becomes finer. The finer the size of the soil particles, the smaller the pore size in the soil, causing the distance between soil grains to be closer. This condition increases the potential for water runoff, because water that falls on the soil surface tends not to be absorbed properly due to the small pore size.

The inability of the soil to absorb this water can cause water accumulation on the surface, which has the potential to lead to soil erosion. Therefore, it is important to pay attention to the composition of soil fractions and organic content in reclamation efforts in order to achieve a good balance between infiltration capacity and soil stability. Further monitoring of changes in soil structure and implementation of appropriate management practices are needed to minimize the negative impacts that may arise from this condition.

Table 2. Soil Structure Classification

Reclamation Age (Years)	Type of Soil Structure	Structure Class
2019	Fine Granular	2
2015	Coarse Granular	3
2010	Medium Granular	3

Reclamation carried out in 2015 showed a coarse granular structure type. This is influenced by the high percentage of sand and parent material originating from the Tonasa Formation (Zacny, 2018). This coarse granular structure can contribute to increased soil permeability, which in turn affects its erodibility. Soil with a coarse structure tends to have larger pore spaces, allowing water to flow faster, but also increasing the risk of erosion if not managed properly.

On the other hand, reclamation carried out in 2010 showed a medium granular structure type. This difference can be attributed to the longer age of reclamation compared to the reclaimed land in 2015. According to Hamid (2017), as the age of reclamation increases, the soil structure also tends to improve (Yunanto, 2022; Lucas et al., 2022). This process includes the development of soil aggregates and increased soil stability which can increase its ability to retain water and reduce the risk of erosion.

This improvement in soil structure is important for improving ecosystem health, because soil with a good structure is better able to support vegetation growth. This also has a positive impact on the overall success of the reclamation project, where plants can grow well and contribute to soil stability. Further research is needed to explore how other factors, such as vegetation management and reclamation techniques, can affect the development of soil structure over time. A deeper understanding of these dynamics can help in formulating more effective and sustainable reclamation strategies in the future.

3.2.4 Soil Permeability

Data analysis using simple linear regression (Figure 5) shows a unidirectional relationship or positive correlation, where permeability (x) has a significant effect on soil erodibility (y). However, the correlation coefficient obtained shows that increasing permeability only contributes to increasing erodibility with a correlation coefficient of 0.22. This indicates that the relationship between the two variables is relatively small or not too close. The determination value or R^2 obtained is 0.04, which means that soil permeability only affects the increase in soil erodibility by 4%. These results indicate that other factors may have a more significant effect on soil erodibility in reclaimed land. Based on the t-test calculation, the calculated t-value of 0.81 is smaller than the t-table value of 2.16 at a significance level of 5%. This implies that there is no significant difference between the permeability value and the soil erodibility value on the reclaimed land. Further research is needed to identify other factors that may contribute to soil erodibility, so that more effective management strategies can be formulated.

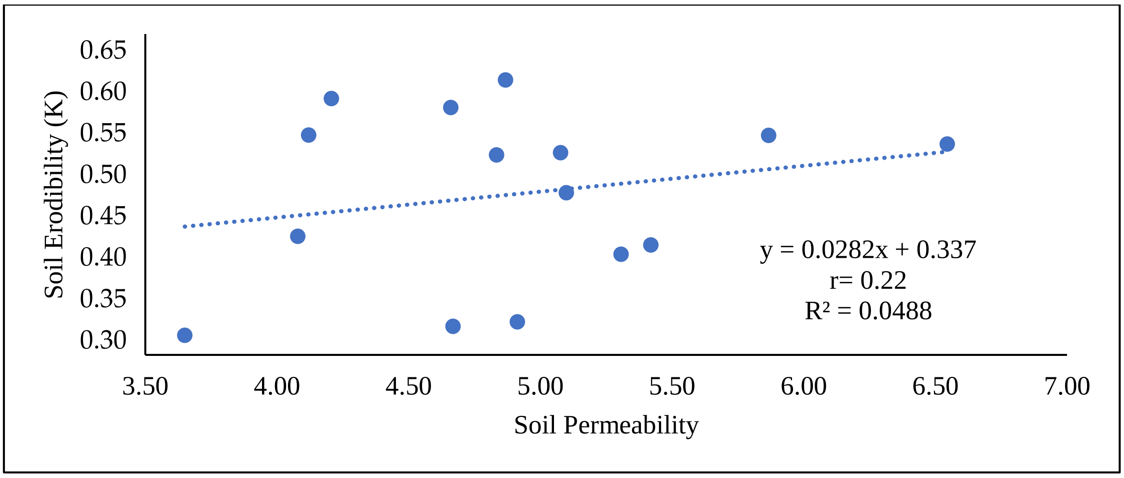

Fig. 5. Soil Permeability

The results of this study indicate that increasing soil permeability does not reduce soil erodibility, as stated by Taleshian (2018) and Yang et al. (2017). One factor that greatly affects erodibility is the soil volume weight, which in each type of land ranges from 1.20 to 1.39 g/cm^3. According to Saputra (2018), a soil volume weight exceeding 1.2 g/cm^3 indicates that the soil has undergone a compaction process. This compaction process is often caused by the use of heavy equipment during reclamation land management. When the soil is compacted, the soil pores will decrease, which has a direct impact on the soil's ability to absorb and drain water. Compacted soil tends to have smaller pores, reducing the efficiency of water infiltration. Under these conditions, compacted soil becomes less able to facilitate water infiltration, which causes increased surface runoff. This increased runoff ultimately contributes to increased erosion potential (Odey, 2018; Gabriels et al., 2020; Lamande et al., 2018).

The interplay between soil permeability, erodibility, and compaction demonstrates the complex relationship between soil properties and how soils respond to land management practices. Understanding these dynamics is critical to developing effective soil conservation strategies. With increasing pressure from human activities, including the use of heavy equipment on reclaimed land, it is important to find effective ways to minimize soil compaction. This will not only increase the infiltration capacity of the soil but also help maintain the sustainability of a healthy soil ecosystem.

One approach that can be implemented is to use more environmentally friendly agricultural technologies and soil management methods that can reduce the negative impacts of compaction. For example, agroforestry practices or planting cover crops can help reduce pressure on the soil and improve the overall soil structure. In addition, the use of heavy equipment designed to minimize pressure on the soil can also be a good alternative.

long-term nature, the implementation of sustainable agricultural practices and better reclamation techniques will contribute to more efficient management of natural resources. This is important to reduce the negative impacts of human activities on the environment, so that the land can continue to provide optimal benefits, both in terms of agriculture and ecosystems. Therefore, soil conservation efforts must be a priority in every land management program in order to create a healthier and more sustainable environment for future generations.

4. Conclusions

Based on the results of this study, it can be concluded that the age of limestone mine reclamation planted with bitti plants does not have a significant effect on soil erodibility. However, there are variations in soil erodibility values on reclaimed land with different ages, where the reclaimed land in 2019 (3 years old) shows relatively low to rather high erodibility, the land in 2015 (7 years old) shows moderate to high erodibility, and the land in 2010 (12 years old) shows relatively high to high erodibility. The main factor influencing the erodibility value on the three reclaimed lands is soil texture, especially the composition of fine sand and dust. Differences in geological characteristics between reclaimed lands, where the land in 2019 is dominated by dust and clay from the lower sediment, while the land in 2015 and 2010 is dominated by dust and sand from the Tonasa Formation, plays an important role in determining the level of erodibility. To overcome the risk of erosion on reclaimed land, it is recommended to arrange the land by adding ground cover plants that can help reduce the kinetic energy of rainwater and the strength of surface flow, thereby minimizing the sensitivity of the soil to erosion. Given the high erodibility value found in reclaimed land, further research is needed on the quality of limestone reclaimed soil and erosion hazards to develop more effective and sustainable reclamation strategies.

The implications of these findings are very important, especially in the context of post-mining land management. More integrated and sustainable reclamation policies need to be developed to improve soil quality and minimize the risk of erosion. In addition, the results of this study can be a reference for related parties in designing more effective rehabilitation programs, which not only consider the physical aspects of the soil, but also the interactions between vegetation, soil, and other environmental factors. Efforts to increase public knowledge about the importance of planting ground cover plants are also very crucial, in order to create awareness of the role of vegetation in maintaining soil stability and ecosystem sustainability. Thus, a holistic and sustainable approach to post-mining land reclamation will bring long-term benefits, both for the environment and the surrounding community.

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Author Contribution
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