EVALUATION OF THE SUCCESS OF FOREST RECLAMATION ON COAL MINING LAND IN THE IUP AIR LAYA MINING PT. BUKIT ASAM TBK, KAB. MUARA ENIM, SOUTH SUMATRA

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ABSTRACT

Coal mining activities can cause significant ecosystem changes. This needs to be remedied by reclamation. In reality, reclamation carried out in the field is not always successful, hence the need for monitoring This study integrates remote sensing technology in the form of aerial photo analysis and spatial mapping using the ArcGIS application, combined with biophysical assessments in the field. The purpose of this study is to quantitatively assess the success rate of post-mining land reclamation in the area of the Air Laya Mining IUP of PT. Bukit Asam Tbk and to identify factors that support or hinder the reclamation process. This study uses the Minister of Forestry Regulation No. P.60 of 2009 with parameters of land management, erosion and sedimentation control, and revegetation. Data was collected using reference study, survey, sampling, scoring and analysis. The revegetation plants used are revegetation with the age of 1 years, 2 years and 5 year. Revegetation assessment was conducted by purposive sampling, based on planting year and ease of access using sample plots. The number of sample plots was determined as 5% of the total reclamation area. The number of sample plots observed was 6 plots with a size of 40 x 25 m. The results showed that reclaimed land with revegetation aged 5 and 2 years fell into the good and successful category with evaluation scores of 81 and 85. Whereas on reclaimed land with 1 year old revegetation is included in the medium category and is acceptable but must be improved again with an evaluation value of 75.5. Inhibiting factors for the reclamation process include poor integration of drainage channels, very acidic soil pH, and lack of local plants.

Keywords: coal mining, forest reclamation, mining land, revegetation.

ABSTRAK

Kegiatan pertambangan batubara dapat menyebabkan perubahan ekosistem yang signifikan. Perlu dilakukan perbaikan dengan reklamasi. Pada kenyataannya reklamasi yang dilakukan di lapangan tidak selalu berhasil, maka dari itu perlu dilakukan pemantauan. Penelitian ini mengintegrasikan teknologi penginderaan jauh berupa analisis foto udara dan pemetaan spasial menggunakan aplikasi ArcGIS, yang dipadukan dengan penilaian biofisik di lapangan. Tujuan dari penelitian ini adalah untuk menilai secara kuantitatif tingkat keberhasilan reklamasi lahan pasca tambang di wilayah di IUP Tambang Air Laya PT. Bukit Asam Tbk dan untuk mengidentifikasi faktor yang mendukung atau menghambat proses reklamasi. Kajian ini menggunakan Permenhut Nomor P.60 Tahun 2009 dengan parameter penataan lahan, pengendalian erosi dan sedimentasi, serta revegetasi. Pengumpulan data menggunakan studi referensi, *survey,* *sampling*, *skoring* dan analisis. Tanaman revegetasi yang digunakan yaitu revegetasi dengan umur 1 tahun, 2 tahun dan 5 tahun. Penilaian revegetasi dilakukan dengan *purposive sampling,* berdasarkan tahun tanam dan kemudahan akses menggunakan plot contoh. Penentuan jumlah plot contoh yaitu 5% dari total luasan area reklamasi. Banyaknya plot contoh yang diamati sebanyak 6 plot dengan ukuran 40 x 25 m. Hasil penelitian menunjukkan bahwa pada lahan reklamasi dengan revegetasi berumur 5 dan 2 tahun termasuk dalam kategori baik dan berhasil dengan nilai evaluasi 81 dan 85. Sedangkan pada lahan reklamasi dengan revegetasi berumur 1 tahun termasuk dalam kategori sedang dan dapat diterima tapi harus ditingkatkan lagi dengan nilai evaluasi 75,5. Faktor penghambat proses reklamasi berupa integrasi saluran drainase yang belum baik, pH tanah yang sangat masam, kurangnya tanaman lokal.

Kata Kunci: lahan tambang, pertambangan batubara, reklamasi hutan, revegetasi.

INTRODUCTION

According to Kusnoto and Kusumodirdjo (1995, as cited in Azhar et al., 2023), mining activities pose a range of environmental impacts, including alterations in microclimate, declines in land productivity, disturbances to flora and fauna, ground movement, soil compaction, landslides, erosion and sedimentation, as well as risks to public health and safety. For this reason, mining operations must be accompanied by continuous efforts in environmental rehabilitation through reclamation activities.

Through reclamation actions such as landform renovation, land reconstruction, and revegetation (Feng et al., 2019), the stock of reclaimed soil nutrients (Guan et al., 2020), vegetation cover (Vidal-Macua et al., 2020), and the landscape function of damaged land ecosystems in mining areas are expected to develop in a healthy and orderly direction (Bai et al., 1995) in (Guan et al., 2022).

Previous research conducted by (Guan et al., 2022) stated that the reclaimed area recovered stably within a certain number of years after reclamation. Calculated based on the number of years required for the rehabilitated vegetation to reach a stable state. This goal certainly requires a long process of restoration and adaptation of the affected ecosystem to achieve a dynamic balance between restoration efforts and natural succession (Feng et al., 2011) in (Guan et al., 2022). The main purpose of monitoring and evaluating the impact of land reclamation is to identify and correct problems in the dynamic development process and summarize experiences and lessons learned (Manero et al., 2020) to provide a basis for optimizing the reclamation model and improving reclamation efficiency.

Reclaiming forested areas affected by mining operations requires meticulous planning, spanning from the initial stages of project development through the post-mining period, with the primary objective of restoring ecological function. In practice, however, reclamation efforts do not always succeed, particularly when the extent of land degradation caused by mining exceeds anticipated thresholds.Reclamation is generally divided into three components, namely reorganization of former mining land, erosion and sedimentation control, and revegetation.

This study focuses on post-mining forest areas within the Forest Area Borrow-Use Permit (PPKH) of the Air Laya Mining Permit Area (IUP) operated by PT. Bukit Asam in Muara Enim Regency, South Sumatra Province. Although this company has implemented a post-mining reclamation program in accordance with regulations, its effectiveness and success rate still need to be evaluated comprehensively and scientifically. This study integrates remote sensing technology in the form of aerial photo analysis and spatial mapping using the ArcGIS application, combined with biophysical assessments in the field. Evaluation of the success of reclamation is carried out based on indicators listed in the Regulation of the Minister of Forestry No. P.60/Menhut-II/2009, including land cover levels, plant growth, and erosion and sedimentation control. The purpose of this study is to quantitatively assess the success rate of post-mining land reclamation in the working area of PT Bukit Asam Tbk and to identify factors that support or hinder the reclamation process. The results of this study are expected to provide a scientific basis for improving adaptive reclamation strategies that are in accordance with government regulations.

MATERIALS AND METHODS

Data collection was conducted across reclaimed forest areas of the PT. Bukit Asam coal mining site (Air Laya IUP), specifically in the following locations: Disposal Suban (ID 71) with 1-year-old revegetation, Backfilling TAL Suban (ID 65–68) with 2-year-old revegetation, and Ex-Jalan Lingkar (ID 52) with 5-year-old revegetation. Therefore, forest reclamation assessment has been regulated in the Minister of Forestry Regulation Number P.60/Menhut-II/2009 concerning Guidelines for Forest Reclamation Assessment. This activity will be carried out for ± 2 months, calculated from April 22, 2024 to June 12, 2024. The location map of the sampling points is presented in **Figures 1, 2** and **3**.

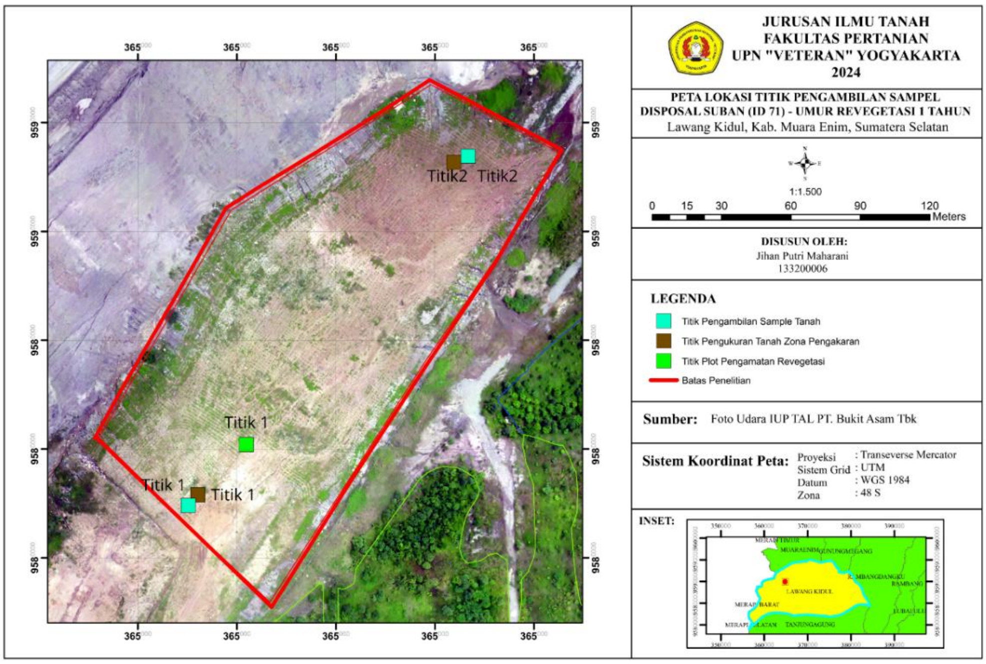

Figure 1. 1- Year Vegetation Sampling Point Location Map

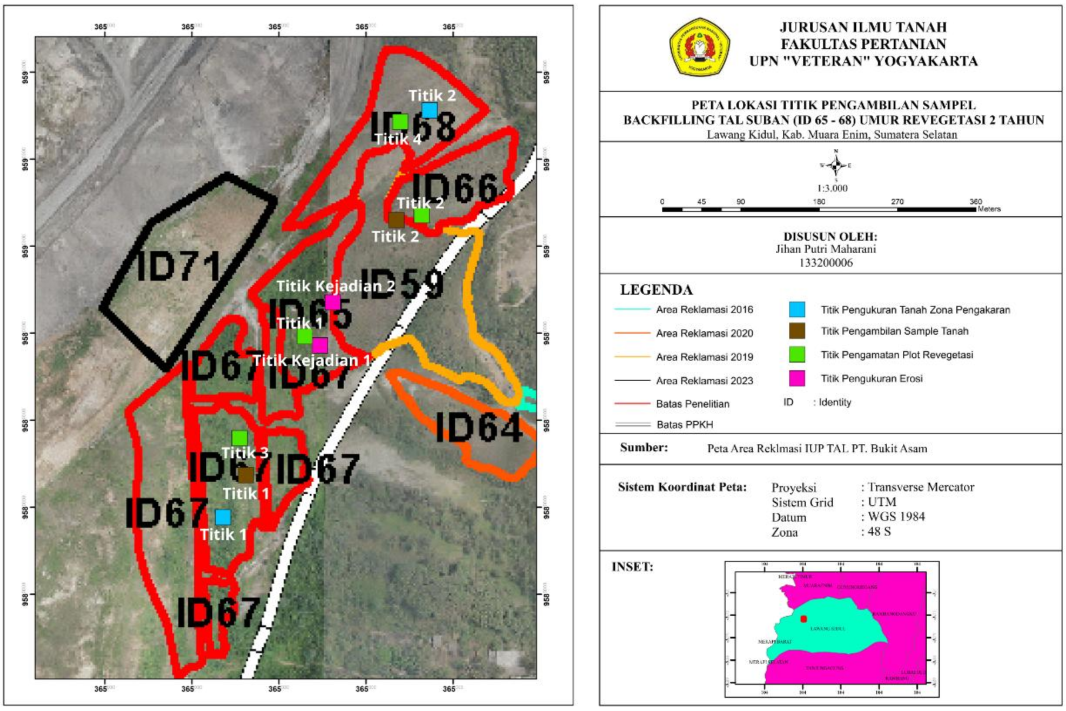

Figure 2. 2-Year Vegetation Sampling Point Location Map

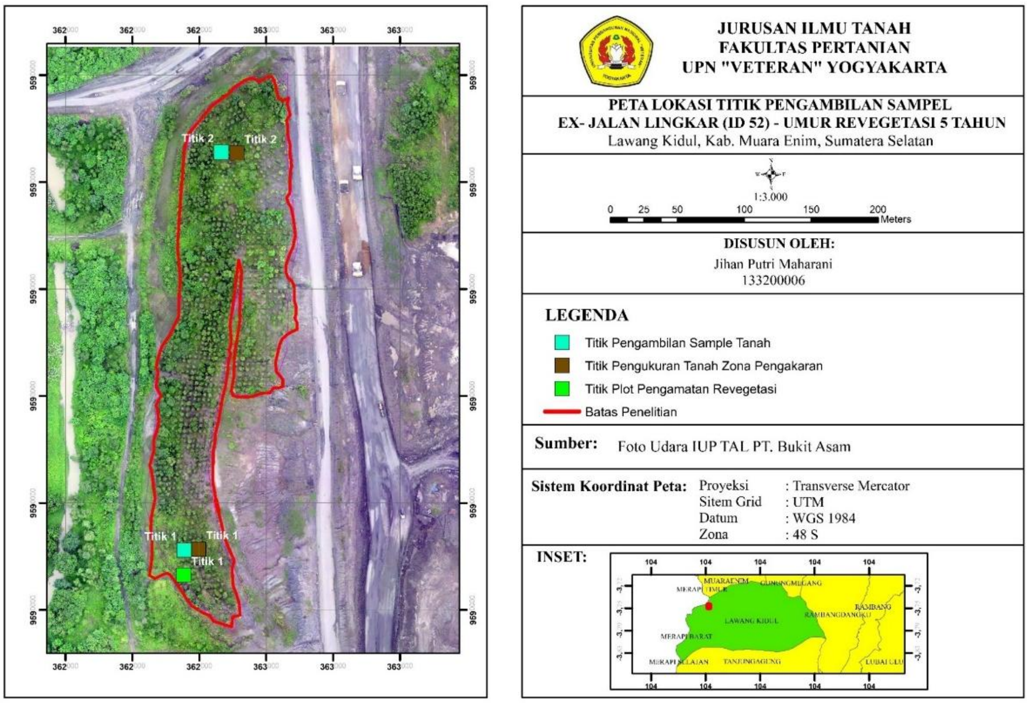

Figure 3. 5-Year Vegetation Sampling Point Location Map

Research Methods

The data collection process integrated literature review, field surveys, sampling, scoring, and data analysis. The research was conducted in four stages:

Literature Review, Administrative Preparations, and Secondary Data Collection

The secondary data prepared comes from PT. Bukit Asam Tbk in the form of the Air Laya Mining IUP Reclamation Plan Document for the 2019-2023 Period, Aerial Photos of the 2024 Air Laya Mining IUP reclamation location, Map of the Air Laya Mining IUP reclamation location for the 2013-2023 period, rainfall and there is also secondary data that does not come from the company, namely the Reclamation Success Evaluation Form sourced from Permenhut No. P.60 of 2009 and the Muara Enim Regency Administration Map.

Field Stage

This research was conducted using survey and sampling methods.

1) Land Use Management

The success rate of land management is determined by calculating the total area of land that has been managed compared to the area that should be managed. The parameters for refilling former mining holes and the area being arranged are assessed using aerial photographs and compared with the plan stated in the reclamation plan document.

$$\frac{Realization}{Plan} \times 100\%$$

Slope stability parameters can be determined by the presence or absence of landslides in the specified area. If a landslide occurs, determine the area of landslides in the reclamation area with meters. Then for the parameters of spreading the root zone soil, research is carried out by calculating its volume and comparing it with the spreading plan stated in the reclamation plan document. The formula used is:

Root-Zone Topsoil Volume (m^3) = The area being landscaped (m^2) x depth of root zone soil (m)

2) Erosion and Sedimentation Control

The parameters assessed are conservation buildings, cover crop planting, and erosion and sedimentation assessments. Assessment of land conservation buildings is carried out by reviewing the company's plans and realization reports, checking and recording the number and type as well as their conditions and suitability. Evaluation of the benefits of conservation buildings is determined by whether or not erosion and sedimentation occur, as well as the level of water turbidity in the drainage channels. While the physical volume is calculated by comparing the realization in the field with the plan in the reclamation document.

Cover crop planting, the assessment is based on data in the Air Laya Mining IUP Reclamation Plan Document for the 2019-2023 Period and compared with its realization through aerial photography and field verification. Erosion and sedimentation assessment requires direct observation of erosion events in the field. The area of land erosion is measured using a meter, and the results are calculated by comparing the area of erosion and the area of reclamation.

3) Revegetation

The assessment at this stage begins by making a rectangular measuring plot with dimensions of 40 m x 25 m or 0.1 Ha and the sample intensity is set at 5% (to meet the principle of representativeness) of the entire research area. Calculation of the number of measuring plots:

$$Number\ of\ Plots = \frac{Revegetation\ Area\ (Ha)}{Plot\ Size\ (Ha)} X5\%$$

Evaluation of revegetation plants was carried out through the utilization of a sampling approach with the Purposive Sampling method, based on the age of revegetation and ease of access. The parameters measured were the area of planting, percentage of plant growth, number of plants per hectare, composition of plant types and plant health.

The area of planting is calculated by comparing the realization and plan through observation with aerial photos and reclamation plan documents. Then the percentage parameter of plant growth in each measurement plot is calculated by comparing the actual number of plants in the plot being examined with the planned number of plants.

$$= (\sum hi / \sum Ni) x100\%$$

$$= \frac{hi + h2 + \cdots \ldots + hn}{(N1 + N2 + \cdots . Nn)x100} \%$$

Where:

T = Percentage (%) of plant growth

Hi = Number of live plants found in measuring plot i

Ni = The number of plants that should be in the i measurement plot

The number of plants per hectare is calculated by dividing the area of the measuring plot, which is 1000 m2, by the planting distance used, which is 4×4 m, resulting in 625 trees per hectare. Then the composition of plant species is assessed by comparing the number of local plants/MPTS with the total number of plants in the measuring plot. Furthermore, plant health is assessed based on leaf color, the presence of pests or diseases, and weeds. Observations of plant growth are classified into three different groups: healthy plants, unhealthy or moderate plants, and miserable plants. All assessments are recorded in a tally sheet in accordance with the Regulation of the Minister of Forestry Number P.60 of 2009.

Laboratory Stage

Testing of soil samples that have been taken in the field. The purpose of this stage is to determine the pH of the soil based on the soil of 5 years, 2 years and 1 year of revegetation age with two repetitions and the H_2O method.

Skoring

Then after collecting secondary and primary data, scoring is carried out based on P.60/Menhut-II/2009. The final results are divided into 3, namely:

>80 : Good (the results of the reclamation implementation are acceptable).

60-80 : Moderate (the results of the reclamation implementation are accepted with the note that improvements need to be made until a value of > 80 is achieved.)

<60 : Bad (reclamation results are unacceptable and intensive maintenance is needed). For the return of forest area use, if the permit has expired, then reclamation repair can use a maintenance period of 3 years, so that it can achieve an adequate value of > 80.

RESULTS AND DISCUSIONS

A. Land Contouring

Land contouring was assessed through both company documentation and direct field observations. The results are presented in **Table 1**.

Table 1. Land Contouring Assessment Results at Study Sites

Parameter	Revegetation age		
	1 year	2 years	5 years
Backfilling of Mining Voids	5	5	5
Area Contoured	5	5	5
Slope Stability	5	5	5
Placement of Root-Zone Topsoil	4	3	3
Total Score	**28,5**	**27**	**27**

1. Backfilling of Mining Voids

Karena area ini telah direklamasi dalam waktu yang cukup lama kurang lebih sejak tahun 2019, 2022 dan 2023 kondisi di dalam lingkungan reklamasi telah dihuni oleh vegetasi yang ditanam. The backfilled area included Backfilling TAL Suban (2-year-old revegetation), covering 8.17 hectares. Meanwhile, Disposal Suban (1-year) and Ex-Jalan Lingkar (5-year) sites did not require void backfilling, as they previously served as access roads and temporary disposal areas. The planned versus actual backfilling performance is shown in **Table 2**.

Table 2. Backfilling Assessment of Former Mining Voids

Revegetation Age	No. of Voids	Planned Area (Ha)*	Actual Area (Ha)	Completion (%)	Score
1 year	0	0	0	100	5
2 years	1	8.17	8.12	99	5
5 years	0	0	0	100	5

Sumber: PT. Bukit Asam Tbk, 2023*

In this reclamation area of the Suban TAL Backfilling, all of the basin-shaped land has been restored to its original state, reinforced by the fact that no open mining pits still exist near the reclamation area. In addition, the actual condition area was calculated using ArcGis application. Based on these results, it can be stated that the closure of ex-mining pits in the Suban TAL Bacfilling reclamation area with a revegetation age of 2 years is more than 90% because the closure has been carried out thoroughly and has a value of 5 per cent.

PT Bukit Asam carries out backfilling of former mining pits using the backfill method. To facilitate the backfilling process, PT Bukit Asam has built and developed a waste disposal or disposal area. This area functions as a temporary storage location for backfill material, including root zone soil and cover layers. The type of cover material that will be used in land use is Overburden (OB) which is dominated by claystone material and there is also siltstone and sandstone material. Then encapsulated with Fly Ash & Bottom Ash (FABA) material. Fly ash and bottom ash or more often abbreviated as FABA, are residual materials from the coal combustion process. The encapsulation technique means coating waste with inert (stable) material. The coating material is chemically stable, adheres to the waste, and is resistant to biodegradation.

2. **Area Contoured**

This parameter assesses the proportion of planned reclamation area that has been physically contoured. The results are presented in **Table 3**.

Table 3. Contoured Area Assessment Results

Revegetation Age	Planned Area (Ha)*	Actual Area (Ha)	Completion (%)	Score
1 Year	1.90	1.90	100	5
2 Years	8.17	8.12	99	5
5 Years	2.59	2.61	100.7	5

Sumber: PT. Bukit Asam Tbk, 2023*

The increase in the mining area is the reason for the change in the arrangement of the reclamation area. The size corresponds to the increase or size of the disturbed area. Changes in arrangement occur when the area of land designated for mining expands, resulting in larger disturbed areas that need to be closed. These three locations have a realisation percentage of >90% or are in accordance with the plan. Referring to Minister of Forestry Regulation No. P.60 of 2009, the area that has been regulated is ≥ 90% of the plan, receiving a score of 5 (Table 3).

3. **Slope stability**

The assessment for this parameter is carried out directly by reviewing the reclamation area. The arranged area has quite good embankment stability because there was only a landslide at the TAL Suban Backfilling location with a revegetation age of 2 years of 0.044% (table 4).

Table 4. Observations and Calculations of Erosion Occurrence

Revegetation Age	Area Size (m²)	Total Eroded Area (m²)	Erosion Occurrence (%)	Remarks
1 year	19,000	0	0.000	No erosion observed
2 years	81,700	36.45	0.044	Very light rill erosion identified
5 years	25,900	0	0.000	No erosion observed

Source: PT. Bukit Asam Tbk, 2023*

Based on Forestry Ministerial Regulation Number 60 of 2009, the slope stability assessment is 5, where there is no landslide to very light landslide < 5%. In addition, vegetation also affects landslides. In the area where the landslide was found, it was not covered by cover plants. These results are consistent with previous research by (Li et al., 2024), that soil surface erodibility can be reduced by vegetation cover, which reduces the risk of soil erosion.

Reclamation activities at the location where the landslide was found are still relatively new, namely 2 years, so that the vegetation has not grown large and dense. Plant roots can strengthen soil aggregates to be denser, making them more resistant to being easily broken by rainwater, while vegetation can function to break raindrops so that they do not fall directly to the ground. As concluded by (Chen et al., 2018), the forest canopy captures rainwater and reduces kinetic energy to protect the soil from erosion. Ground cover, such as grass and litter layers, also effectively control soil erosion from rainwater splashes.

4. Placement of Root-Zone Topsoil

In reclamation areas with a revegtation age of 1 year, 2 years and 5 years, root-zone topsoil sowing activities have been carried out for a long time. The following is data from measurements of the soil depth of the root zone (Table 5).

Table 5. Root-Zone Topsoil Depth

Revegetation Age	Root-Zone Topsoil Depth		Median
	Sample 1	Sample 2	
5 year	25 cm	45 cm	35 cm
2 year	30 cm	35 cm	32,5 cm
1 year	48 cm	27 cm	37,5 cm

Plant growth is influenced, among other things, by the depth of the root zone soil. According to the standards set by PT. Bukit Asam Tbk, the depth of sowing in the root zone is 45 cm – 50 cm or around 5,000 bcm per 1 Ha and 4,500 ccm if converted to solid form. Root zone soil originating from excavations is taken to a depth of 0.8 - 1 m and from embankments to a depth of 0.5 - 1 m. If the root-zone topsoil will not be used yet because it is waiting for the final land, then the root-zone topsoil will be collected to a certain place (top soil stockpile), then planted with LCC so that it is not eroded and damaged by the weather. The location of the root-zone topsoil stock is in the land that has been opened so that there is no additional stockpile location. The root zone soil material used for the planting medium is taken from the soil stockpile/disposal location. The root zone soil is then transported using a dump truck and leveled with a dozer. The land was formed using waste rock and root zone soil at the top. The arrangement and compaction are carried out in layers, so the arrangement is carried out in stages.

After measuring the depth of the root-zone yopsoil, a calculation of the realization of the root-zone topsoil sowing is carried out. The results of the assessment of the distribution of root zone soil are presented in Table 6 below.

Table 6. Root-Zone Topsoil Placement Assessment

Revegetation Age	Planned Volume (Ccm)*	Actual Volume (Ccm)	Completion (%)	Score
1 Year	8,550	7,125	83.3	4
2 Years	36,705	26,552.5	72	3
5 Years	11,655	9,065	78	3

Sumber: PT. Bukit Asam Tbk, 2023*

Based on the data presented in Table 6, the sowing of the root zone soil has not been able to reach the maximum value. The reclamation area of 5 years of revegetation age got a realization percentage of 78%, so it got a value of 3. Then the reclamation area of 2 years of revegetation age got a realization percentage of 72%, so it got a value of 3. Finally, the reclamation area of 1 year of revegetation age got a realization percentage of 83.3% and a value of 4.

According to (Tenriajeng, 2003), the process of earth moving causes material development (soil volume). Material development is a change in the form of adding or reducing the volume of material (soil) that is disturbed from its original form. The form of material is divided into 3 conditions, namely the original condition (bank condition), loose condition, and compact condition. The root zone soil that has been spread in the reclamation area is soil whose material condition is already solid, the change in volume occurs due to the shrinkage of the air cavity between the air particles. Therefore, the volume decreases while the weight remains the same. To calculate the volume of soil that has been disturbed from its original form, by digging and then compacting it, it needs to be multiplied by the conversion factor.

Erosion and weather factors also affect these parameters. The research location has high rainfall, which causes erosion and surface flow. This phenomenon is in accordance with research conducted by (Chen et al., 2018), where soil susceptibility to erosion increases with increasing rainfall intensity. This is coupled with the lack of integrated drainage channels in the reclamation area, reducing the volume and thickness of the root zone soil.

B. Erosion and Sedimentation Control

Mining companies are required to implement effective erosion and sedimentation control measures both during and after mining operations. These measures are essential to prevent land degradation, maintain soil stability, and reduce the downstream transport of sediment that can negatively impact aquatic ecosystems and local infrastructure.

Table 7. Evaluation Results of Erosion and Sedimentation Control

Parameter	Revegetation Age		
	1 Year	2 Years	5 Years
Number of Conservation Structures	5	5	5
Functionality of Structures	4	3	3
Cover Crop Area Coverage	5	5	5
Erosion and Sedimentation Control	5	5	5
Total Score	19	18	18

1. Soil Conservation Structures

The implementation of conservation buildings is very important to reduce and prevent soil erosion. Types of conservation buildings in reclamation areas include drainage channels, installation of stones on channels in the form of riprap, check dams and mud settling ponds (KPL).

In addition, erosion is prevented by installing rocks on check dams and drainage channels in the form of riprap (Figure 5). Riprap is a composition of rock blocks placed in drainage channels and check dams. This conservation structure functions as a protective layer to reduce the depth of local erosion and to protect the base soil downstream of the dam energy absorber. Riprap can be placed along the outer edge of the river bend, to eliminate the force of water against the river bank (Figure 5), and also near bridges along the embankment and adjacent to supports in water channels (Figure 4).

The next land conservation structure found in the research location is a check dam. A retaining embankment or check dam is a small dam with a simple construction (embankment of soil or rocks), made in a ravine or small river channel. The check dam functions to hold/control sediment and surface water flow from the catchment area in the upstream section. An illustration of the check dam at PT. Bukit Asam Tbk is presented in Figure 4 below.

Figure 4. Illustration of check dam and riprap (rock)

Figure 5. Illustration of Riprap (rock) in Drainage Channel

The effectiveness of soil and water conservation structures can be evaluated based on the presence or absence of erosion and sedimentation, as well as water turbidity levels in drainage channels. The check dams and sedimentation ponds observed at the study sites appeared to function effectively, successfully reducing surface runoff and sediment transport from upstream catchment areas. As a result, only 36.45 m^2 of erosion was recorded across a total reclaimed area of 81,700 m^2. Based on these outcomes, the conservation infrastructure parameter received a top score of 5 across all three sites. This reflects the physical adequacy of conservation structures constructed by PT. Bukit Asam Tbk, which include drainage channels, check dams, riprap linings, and sedimentation ponds (KPL).

The assessment of conservation structure performance was conducted by observing signs of erosion, sediment deposition, and water turbidity within and around these structures. The drainage channel system in the study area was found to be only partially effective. At the Disposal Suban site, with a revegetation age of one year, a score of 4 (effective) was assigned due to the absence of both standing water and visible erosion. However, the conservation structures were not well integrated, limiting their overall functionality. At the Backfilling TAL Suban site, with two years of revegetation, light rill erosion was still detected, accounting for 0.044% of the area (see Table 8), alongside the presence of turbid standing water. Consequently, this site was rated 3 (moderately effective). Similarly, at the Ex-Jalan Lingkar site with five years of revegetation, water with yellowish turbidity was observed stagnating in the drainage channel, warranting a score of 3 (moderately effective).

2. Cover Crop Establishment Area

The primary objective of cover crop planting is to protect and improve soil quality during periods between the cultivation of main crops or among tree and vine plantings (Ministry of Forestry Regulation, 2009). In the studied area, two species of leguminous cover crops (LCC) were planted: *Calopogonium mucunoides* (CM) and *Centrosema pubescens* (CP). Referring to research conducted by (Syofiani et al., 2020), the type of LCC used can affect the difference in increasing physical, chemical and biological properties of the soil. The results of the study (Ahmad, 2018), stated that the Calopogonium mucunoides (CM) type of LCC produces high biomass and will correlate with the return of nutrients to the soil in improving soil fertility.

In the study area, cover crop planting had been established for a substantial period prior to assessment. Consequently, evaluation of the cover crop planting parameter was based on available company records, particularly the reclamation plan and aerial imagery of cover crop establishment maintained by PT. Bukit Asam Tbk. Comprehensive cover crop planting was carried out in three distinct areas, covering 1.90 ha, 8.12 ha, and 2.61 ha, respectively. Based on the extent of vegetation cover—achieving at least 90% coverage—the cover crop planting parameter was assigned the maximum score of 5 (see Table 7).

3. Erosion and Sedimentation Monitoring

The evaluation of this criterion was conducted by assessing the presence of erosion within the reclaimed area. Field observations indicated the occurrence of erosion at several locations. The type of erosion identified on-site was rill erosion. The following presents the observed data on erosion magnitude in the field.

Table 8. Observations and Calculations of Erosion Occurrence

Revegetation Age	Area Size (m^2)	Total Eroded Area (m^2)	Erosion Occurrence (%)	Remarks
1 year	19,000	0	0.000	No erosion observed
2 years	81,700	36.45	0.044	Very light rill erosion identified
5 years	25,900	0	0.000	No erosion observed

Source: PT. Bukit Asam Tbk, 2023*

Erosion observed in the Backfilling TAL Suban area, which has undergone two years of revegetation, affected 36.45 m² of the total reclamation area, resulting in an erosion incidence of only 0.044%. As this value falls within the ≤5% threshold, it was assigned the highest evaluation score of 5 (Table 7). Similarly, no visible erosion was recorded in the Disposal Suban site (1-year revegetation) and the Ex–Jalan Lingkar site (5-year revegetation), both of which also received a score of 5 (Table 7).

The erosion occurring within these reclamation areas is classified as rill erosion, characterized by shallow channels formed on the soil surface. Most erosion incidents were observed in areas lacking vegetative ground cover. Several interrelated factors influence erosion processes, including rainfall intensity, soil type, drainage infrastructure, and vegetation cover.

Table 9. Rainfall Data for Muara Enim Regency for 10 years

Year	Number of Wet Months	Number of Humid Months	Number of Dry Months	Rainfall mm/year
2014	10	-	2	2850
2015	6	1	5	1951
2016	9	1	2	3608
2017	5	1	6	1667
2018	9	2	1	2812
2019	8	1	3	2420
2020	11	1	-	2994
2021	5	3	4	1696
2022	12	-	-	3251
2023	8	4	-	2217
Amount	**83**	**14**	**23**	**25466**
Median	**8,3**	**1,4**	**2,3**	**2546,6**

Source : PT. Bukit Asam Tbk, BPS Kab. Muara Enim, author's calculations 2024

Rainfall is a key driver of erosion in the study area, as raindrop impact exerts kinetic energy capable of detaching soil aggregates. With an average annual precipitation of 2,546.6 mm (see Table 9), the region is subject to significant erosion potential. This is in line with research conducted (Sitepu et al., 2017), that rainfall intensity has a directly proportional effect on erosion. High rainfall intensity will increase the rate of soil erosion. Soil type is another critical factor; the dominant soil in the study area is Ultisol, which, as noted by Sudaryono (2009), is inherently susceptible to erosion due to its low aeration porosity and weak structural stability, making it prone to both compaction and detachment.

Vegetative cover also plays a vital role in mitigating erosion. Most erosion events were recorded in areas with sparse or absent vegetation, highlighting the importance of plant canopies in intercepting rainfall before it impacts the soil surface. This finding aligns with the results of Sadewo et al. (2023), who demonstrated that bare, unprotected land surfaces are significantly more vulnerable to erosion due to the absence of physical barriers that could otherwise slow surface runoff and prevent soil displacement.

Drainage channels also affect the potential for erosion where the drainage channels themselves have the function of draining and accommodating rainwater so that the potential for erosion can be overcome, but in reality in the field, several drainage channels have not functioned optimally and have not been integrated properly so that the function of the drainage channels to accommodate and drain rainwater is also not optimal and results in the potential for erosion to be large.

C. Revegetation

The assessment of revegetation criteria was carried out by sampling using measurement plots made at several points in the reclamation area being studied. Parameters in the revegetation assessment include the area of planting, percentage of plants growing, number of plants per hectare and plant health **(Table 10**).

Table 10. Revegetation Indicator Assessment

Parameter	Revegetation Age		
	1 Year	**2 Years**	**5 Years**
Planting Area	5	5	5
Growth Percentage	1	3	4
Number of Plants	2	5	5
Type Composition	1	4	2
Plant Health	5	3	2
Calculation Score	**28**	**40**	**36**

1. Planting area

The planting area refers to the designated land for revegetation efforts within the reclamation zones. **Table 11.** presents a comparison between the planned and actual planted areas.

Table 11. Planned and Actual Planted Area for Revegetation Activities

Site	Revegetation Age	Planned Area (Ha)*	Actual Area (Ha)	Achievement (%)	Score
Suban Disposal Area	1 Year	1.90	1.90	100.0%	5
TAL Suban Backfilling Area	2 Years	8.17	8.12	99.0%	5
Ex-Jalan Lingkar	5 Years	2.59	2.61	100.7%	5

Source: PT. Bukit Asam Tbk, 2023*

The evaluation of this parameter focuses on the coverage of three vegetation types: ground cover crops, fast-growing species, and local multipurpose tree species (LDP/MPTS). The cover crops used in the study areas include *Calopogonium mucunoides* (CM) and *Centrosema pubescens* (CP). In terms of actual field conditions, the Backfilling TAL Suban site (2 years of revegetation) and the Ex–Jalan Lingkar site (5 years of revegetation) both exhibited well-established vegetation, including cover crops, fast-growing species, and local species. In contrast, the Disposal Suban site, with only one year of revegetation, had yet to be planted with local species, as efforts remain focused on establishing cover crops and fast-growing vegetation. Based on the percentage of area successfully revegetated—≥90% at all sites—the indicator score for this parameter was assigned the maximum value of 5.

2. Growing percentage

The calculation of plant survival rate is derived from the ratio between the number of surviving plants and the total number of plants originally planted within the observed sample plots. **Table 12** presents the data on plant survival percentages.

Table 12. Vegetation Growth Percentage by Site and Revegetation Age

Site	Revegetation Age	Growth Percentage (%)	Score
Suban Disposal Area	1 Year	36.8%	1
TAL Suban Backfilling Area	2 Years	73.4%	3
Ex-Jalan Lingkar Area	5 Years	84.0%	4

As shown by the average total plant survival rate (**Table 8**) across the study sites, the values suggest that, overall, plant species have not yet fully adapted to their respective growing environments. At the site with one year of revegetation, the plant survival rate was recorded at 36.8%, earning a score of 1. This low percentage is primarily attributed to the site's early-stage focus on establishing legume cover crops (LCC) and pioneer species, unlike the other two sites where local long-rotation species have already been introduced.

At the two-year revegetation site, several localized erosion events were observed. These erosion occurrences are linked to the inadequate integration of the drainage system. Erosion can disrupt the growth of revegetated species on reclaimed land, as unstable soil conditions may prevent proper root anchorage, resulting in plant lodging or mortality.

3. Number of plants

Plant density per hectare was calculated based on the total planted area divided by the planting distance. According to Regulation No. P.60 of 2009 by the Ministry of Forestry, the maximum planting distance for revegetation areas is 4 m × 4 m, corresponding to a minimum density of 625 plants per hectare. However, the actual planting pattern implemented in the study areas used a spacing of 4 m × 2 m, resulting in an expected plant density of 1,250 plants per hectare. The calculated plant density per hectare is summarized in **Table 13.**

Table 13. Plant Density by Site and Revegetation Age

Site	Revegetation Age	Plant Density (plants/Ha)	Score
Suban Disposal Area	1 Year	460	2
TAL Suban Backfilling Area	2 Years	917	5
Ex-Jalan Lingkar Area	5 Years	1,050	5

A significant variation in plant density per hectare was observed between the one-year revegetation site (Disposal Suban) and the two- and five-year revegetation sites (Backfilling TAL Suban and Ex-Jalan Lingkar, respectively). This discrepancy is primarily attributed to differences in planting years. At the Disposal Suban site, planted in 2023, only legume cover crops (LCC) and pioneer species have been established thus far, in contrast to the other two sites, which have already been supplemented with long-rotation local species.

4. Type composition

Given that the reclamation area is designated as part of a forest utilization permit zone (PPKH), species enrichment is essential to increase vegetation diversity and create a more heterogeneous ecosystem. Enrichment species may include locally valuable species, exotic plants, or multiple-purpose tree species (MPTS). In practice, cover crops and fast-growing species are planted concurrently in the early stages, followed by the introduction of local long-rotation species after 2–3 years of initial growth. This is because most local species are shade-tolerant or semi-tolerant, requiring canopy cover for optimal development. The results of the species composition assessment are presented in **Table 14.**

Tabel 14. Plant Species Composition by Site and Revegetation Age

Site	Revegetation Age	Species Composition (%)	Score
Suban Disposal Area	1 Year	0.0%	1
TAL Suban Backfilling Area	2 Years	30.6%	4
Ex-Jalan Lingkar Area	5 Years	17.14%	2

At the Disposal Suban site (1-year revegetation), the composition index scored 1, with a recorded species composition percentage of 0%. The absence of supplementary planting in this area is due to land conditions not yet conducive for the establishment of local species, as LCC and fast-growing species were only introduced in 2023. A 2–3 year waiting period is necessary before the introduction of long-rotation native species. Currently, the focus at the one-year revegetation site is on establishing ground cover and fast-growing species to accelerate land cover development and soil nutrient enrichment. Subsequent enrichment planting will involve the introduction of long-rotation native species.

Then at the location of the 2-year revegetation age (Backfilling TAL Suban) obtained a value of 4 with a percentage of species composition of 30.6%. Finally, the location of the 5-year revegetation age (Ex-Jalan Lingkar) obtained a value of 2 with a percentage of species composition of 17.14%. This is related to the suitability of the reclamation land with the type of supplementary plants, where not many supplementary plants can grow well on reclaimed land. Notable local and MPTS species identified in the study areas for future enrichment include *Adenanthera pavonina* (Saga) and *Hibiscus tiliaceus* (Waru).

5. Plant health

The percentage of plant health was determined by calculating the ratio of healthy plants to the total number of plants within the measurement plots. Plant health was classified into three categories: healthy, moderately healthy, and unhealthy. The observed percentages of plant health across the study sites are presented in **Table 15.**

Tabel 15. Plant Health Percentage by Site and Revegetation Age

Lokasi	Umur Revegetasi	Persentase	Nilai
Disposal Suban	1 tahun	97,82%	5
Backfilling TAL Suban	2 tahun	78,85%	3
Ex- Jalan Lingkar	5 tahun	60,95%	2

At the site with five years of revegetation (Ex-Jalan Lingkar), the percentage of healthy vegetation was 60.95%, resulting in a score of 2. The adaptation capacity of fast-growing species in both the two- and five-year revegetation sites has not yet reached optimal levels, as reflected in the relatively low health percentages. This limitation is largely attributed to the presence of erosion within some measurement plots, which disrupts plant development by depleting topsoil layers due to surface runoff. Additionally, the suboptimal function of soil conservation structures has contributed to standing water in some areas. This highlights the need for the company to improve drainage infrastructure, as poorly functioning drainage channels fail to direct runoff effectively, exacerbating surface water accumulation and erosion. Soil acidity is another critical factor influencing plant growth, as nutrient availability in the soil is closely tied to soil pH levels. Soil pH assessments for each site are summarized in **Table 16.**

Tabel 16. Soil pH Measurement by Site and Revegetation Age

Site	Revegetation Age	Sample 1	Sample 2	Average pH	Description
Suban Disposal Area	1 Year	4.96	4.90	4.93	Acidic
TAL Suban Backfilling Area	2 Years	2.68	2.30	2.49	Strongly acidic
Ex-Jalan Lingkar Area	5 Years	5.91	4.96	5.43	Acidic

According to the data, all three study locations exhibit acidic to highly acidic conditions. The Disposal Suban site (1-year revegetation) had an average pH of 4.93 (acidic), the Backfilling TAL Suban site (2-year revegetation) showed a strongly acidic pH of 2.49, while the Ex-Jalan Lingkar site (5-year revegetation) recorded an average pH of 5.43 (acidic). Optimal plant growth generally occurs under neutral pH conditions, which facilitate better nutrient absorption. In contrast, acidic soils can hinder nutrient uptake, as essential nutrients become bound to heavy metals, which are more soluble in acidic environments. This phenomenon is consistent with findings by Tampinongkol et al. (2021), who reported that nutrient availability significantly influences plant growth.

In addition to the fact that the reclaimed land has acidic soil due to the oxidation reaction between sulfide minerals or PAF (Potential Acid Forming) materials with air and air, the soil on this land is Ultisol soil which tends to have a high level of acidity. According to research (Suyono et al., 2023), the pH of Ultisol soil is classified as acidic to very acidic with low organic matter content.

Another factor that affects plant health in reclamation areas is the lack of maintenance carried out by the company. This is reinforced by the older the age of the revegetation, the smaller the percentage of its health. Therefore, companies need to pay more attention to revegetation areas that have been planted. Maintenance that can be carried out includes fertilizing plants that have been planted in the previous year, replanting dead plants.

D. Evaluation Results of Each Parameter

The evaluation of reclamation success was conducted through a weighted scoring of each criterion and success indicator, followed by a final assessment calculation based on forest reclamation policies as outlined in the Indonesian Ministry of Forestry Regulation No. P.60/2009. The results of this assessment are presented in **Table 17.**

Tabel 17. Evaluation of Post-Mining Rehabilitation Parameters

Site	Revegetation Age	Indicator	Weight	Score	Category
Suban Disposal Area	1 Year	Land Preparation	30	28.5	Moderate
		Erosion and Sedimentation Control	20	19	
		Revegetation	50	28	
		Total	**100**	**75.5**	**Moderate**
TAL Suban Backfilling Area	2 Years	Land Preparation	30	27	Good
		Erosion and Sedimentation Control	20	18	
		Revegetation	50	40	
		Total	**100**	**85**	**Good**
Ex-Jalan Lingkar Area	5 Years	Land Preparation	30	27	Good
		Erosion and Sedimentation Control	20	18	
		Revegetation	50	36	
		Total	**100**	**81**	**Good**

According to the table, the Backfilling TAL Suban site (2-year revegetation) received a score of 85, and the Ex-Jalan Lingkar site (5-year revegetation) scored 81. Both locations fall within the "good" category, with evaluation scores exceeding 80, indicating that reclamation efforts are deemed successful and acceptable. Conversely, the Disposal Suban site (1-year revegetation) scored 75.5, placing it in the "moderate" category (score range: 60–80). While reclamation outcomes at this site are considered acceptable, they require improvement and specific management recommendations—particularly for areas with only one year of revegetation. These recommendations involve both technical and institutional approaches aimed at minimizing environmental impacts.

CONCLUSIONS

Based on the research results of the Evaluation of the Success of Forest Reclamation on Coal Mining Land in the Air Laya Mining IUP of PT. Bukit Asam Tbk, Muara Enim Regency, South Sumatra which has been conducted, the following conclusions were obtained:

1. The reclamation area with a revegetation age of 1 year received a score of 75.5, so it is included in the medium category, with an evaluation result of 60 - 80, where the results of the reclamation implementation are accepted with a note that improvements need to be made until it reaches a score of > 80. Then the reclamation area with a revegetation age of 2 years received a score of 85 and the reclamation area with a revegetation age of 5 years received a score of 81. These

two areas fall into the good category, which is indicated by the magnitude of the evaluation value >80 so that the reclamation can be accepted and said to be successful.

2. Inhibiting factors for the reclamation process found in the field include poor integration of drainage channels, very acidic soil pH, and lack of composition of local plant species/MPTS planted.

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