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# Technical Blasting And Ripping Of Overburden To Reduce The Effect Of Ground Vibration On Slope Stability And Residence Around Coal Mine

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***Abstract***— **The coal mining method at the West Banko Pit 1 North is carried out in an open pit using a shovel-dump truck system. Overburden consists of top soil and claystone with a strength of 0.2 – 3 MPa. The digging force of the Komatsu PC 2000 excavator is 0.697 MPa, so to optimize the productivity of the excavator, it must be carried out using a Komatsu D375A ripper and blasting. Considering that the pit limit in the West is close to residential buildings, it is necessary to design the mining area to be ripping and the area to be blasted as well as blasting technical design to reduce the impact of ground vibration on slope stability and damage to buildings in residential areas around the mine. Based on the results of the analysis of overburden blasting at the West Banko Pit 1 North on the stability of static and pseudostatic slopes with the simulation of the optimal berm, the maximum berm is 12 m with a safety factor (SF) of 1.5, while the overburden blasting was based on research at West Banko pit 2 because the material conditions were relatively the same. The amount of safe explosives for predicting the Peak Vector Sump (PVS) value 3.5 mm/second is 50 Kg/ Delay with a minimum distance of 500 m from residential areas. The results of the analysis of the area to be blast are 112.59 Ha and the area that remains ripped is 134.04 Ha.**

***Keywords***— **blasting; ground vibration; pseudo-static slope stability; PPV; PPA.**

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## I. INTRODUCTION

The coal mining system at the West Banko Pit 1 North is strip mining using a shovel-dump truck system. Mining activities include land clearing, stripping and transportation of top soil and overburden, excavating and transporting coal, and mine reclamation / revegetation. In overburden excavation, the Komatsu PC 2000 backhoe excavator was used with a digging force of 626 kN = 0.626 MPa, while the overburden material in the form of claystone with compressive strength values ranging from 0.2 to 3.0 MPa was classified as extremely low strength rock (0.4-1 MPa). and very low strength rock (2-20 MPa) according to Bienawski [1] so that it cannot be excavated directly by an excavator. To support the excavator's performance, the overburden removal is carried out using the Komatsu D375A-5 ripper. The excavation of overburden on the material that has been milled is not optimal because the specifications of the Komatsu PC 2000 excavator and the Komatsu D375A-5 ripper used are not yet optimal [2]–[4]. To increase the productivity of the shovel-dump truck system, it is necessary to carry out blasting activities to deliver the material [5]–[8]. The West and Southwest sections of the pit limit of the West Banko Pit 1 North coal mine are close to residential areas (Fig. 2). In order to increase the efficiency of overburden excavation and overcome ground vibrations due to blasting and to increase slope stability, it is necessary to design blasting geometry, use of explosives, and delay systems [9]–[11].

Soil vibrations caused by blasting activities if it has exceeded a certain level can cause disturbance to slope stability and damage to the environment around the mine. Ground vibrations are usually expressed in terms of peak particle velocity (PPV), peak particle acceleration (PPA), displacement and acceleration which are strongly influenced by the maximum amount of explosives per delay and the distance from the measurement point to the blast site [12]–[15].

The purpose of this study will discuss the design of blasting geometry, use of explosives, and delay systems to reduce ground vibrations in residential areas where PPV values are below the quality standard threshold value based on SNI 7571: 2010 [16].

The results of this study are expected to be able to determine the minimum limit of material blasting by blasting and using ripping.

### *A. Geological Conditions*

Conditions West Banko Pit 1 North area is situated with hilly morphology. The highest elevation of the hill at ev +135 masl and the lowest elevation of the valley at ev +55 masl. The geological structure condition of the surrounding area is influenced by igneous andesite intrusion in the eastern part of the existing pit. The contour of the layering structure of the West Banko Pit 1 North area tends to follow the intrusion zone to form a dome with the intrusion zone as the central point. So that the direction of the sediment continues to the south then slides to the east following the intrusion zone. Fault structures tend to be found in areas bordering the andesite intrusion zone.

The existing pit West Banko Pit 1 North (Fig. 3) has an area of 120 hectares, extending following the direction of coal strike from north to south with a dip to west. The northern part is bordered by coal cropline boundaries, the eastern part is bordered by settlements, the western part is limited by the andesite intrusion zone, the southern part is the direction of the pit continuity.

The stratigraphy of the West Banko Pit 1 North area was obtained from the correlation of the drill data of PT Bukit Asam Tbk in the West Banko Pit 1 North area. The stratigraphy of West Banko Pit 1 North (Fig. 3) is as follows.

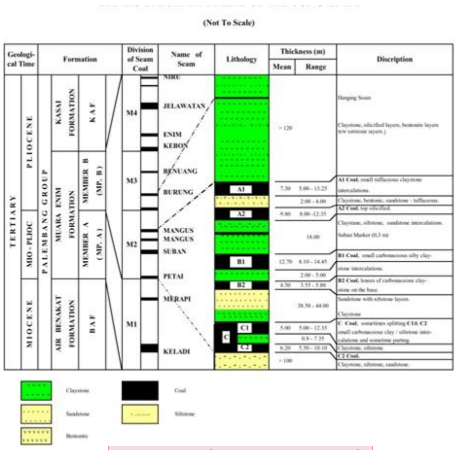


Fig. 1 Stratigraphy Area Pit 1 West Banko

### *B. Geotechnical Conditions*

The layer of material in the West Banko Pit 1 North area is divided into layers of overburden, coal seam, and interburden between seams. The dominant overburden layer is silty claystone. The coal seams consist of A1, A2, B1, B2 and C seams. The interburden layer consists of sandy silty claystone, silty claystone, and sandy siltstone types.

The geotechnical parameters used in this study were data on density, cohesion, and shear angle in the water-saturated material (Table I). Geotechnical parameter data was obtained

TABLE I
GEOTECHNICAL PARAMETER PIT 1 WEST

| No | Material | D (ton/m3) | | UCS | τ | C | Ø |
|---|---|---|---|---|---|---|---|
| | | In-Situ | Bulk | (MPa) | (MPa) | (KPa) | (°) |
| 1 | Top Soil | 1,005 - 1,63 | 1,53 - 1,88 | 0,066 - 0,199 | - | 32.81 | 11,2 - 24,36 |
| 2 | OB A1 | 1,13 - 2,03 | 1,35 - 2,27 | 1.32 | 0.47 | 77.14 | 3,24 - 27,16 |
| 3 | Seam A1 | 0,83 - 0,90 | 1,18 - 1,28 | 7.46 | 0.18 | 176.14 | 15,38 - 44,18 |
| 4 | IB A1-A2 | 1,34 - 2,001 | 1,76 - 2,17 | 5.75 | 0.17 | 142.41 | 6,1 - 30,77 |
| 5 | Seam A2 | 0,89 - 1,10 | 1,15 - 1,35 | 9.1 | 0.26 | 229.86 | 7,64 - 40,45 |
| 6 | IB A2-B1 | 0,98 - 1,92 | 1,59 - 2,16 | 2.02 | 0.28 | 107.23 | 5,6 - 30 |
| 7 | Seam B1 | 0,80 - 1,01 | 1,13 - 1,32 | 10.2 | 0.29 | 203.07 | 11,31 - 38,85 |
| 8 | IB B1-B2 | 1,65 - 2,24 | 1,94 - 2,42 | 0.4 | 0.14 | 126.84 | 7,64 - 25,9 |
| 9 | Seam B2 | 0,84 - 1,03 | 1,17 - 1,42 | 7.23 | 0.23 | 254.77 | 15,37 - 29,64 |
| 10 | IB B2-C | 0,93 - 2,30 | 1,2 - 2,46 | 3.29 | 0.25 | 118.2 | 2,86 - 127,4 |
| 11 | Seam C | 0,83 - 1,89 | 1,15 - 2,14 | 4.64 | 0.16 | 201.43 | 22,79 - 37,11 |
| 12 | Lower C | 1,70 - 2,08 | 1,96 - 2,27 | 2.66 | 1.27 | 139.59 | 9,1 - 24,39 |

### *C. Hydrogeological Conditions*

Groundwater around the West Banko Pit 1 North area is assumed to come from surface infiltration water. Ground water sources were not found in the pit openings. The groundwater flow in the West Banko Pit 1 North area is assumed to only follow the layer of the top soil layer. Top soil types tend to be loose material with a thickness of 1 - 3 m. The next layer has a type of silty claystone material which is more impermeable. Hence the water level effect was not considered in the analysis. It can be seen based on the state of rainfall in the area in Table 2.

TABLE II
WEST BANKO RAINFALL DATA 2019

| Month | Rainfall (mm) | Rainy Time (Jam) | Rainy Day | Rain Frequency |
|---|---|---|---|---|
| January | 491,8 | 52,5 | 27 | 69 |
| February | 445,2 | 78 | 27 | 69 |
| March | 257,8 | 27,6 | 21 | 40 |
| April | 404,8 | 47,2 | 23 | 57 |
| Mey | 110,9 | 18,2 | 15 | 31 |
| June | 61,1 | 13 | 18 | 29 |
| July | 90,8 | 7,4 | 11 | 19 |
| August | 117,4 | 10,6 | 2 | 9 |
| September | 19,3 | 1,5 | 4 | 6 |
| October | 47,4 | 4,4 | 9 | 12 |
| November | 158,3 | 20 | 16 | 30 |
| December | 326,5 | 58,1 | 18 | 64 |
| Total | 2531,1 | 338,5 | 191 | 433 |

## II. MATERIAL AND METHOD

The location of this research is the coal mining company PT Bukit Asam Tbk which is located in Tanjung Enim, Muara Enim Regency, South Sumatra Province. The

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**Commented [H3]:** Pemisahan decimal menggunakan tanda baca titik ( . )

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Cukup 3-4 gambar

Perbaiki juga gambar dengan proporsionalitas yang tepat, ukuran yang dapat dibaca, dan kualitas gambar yang baik (300 dpi) location of measurements and observations is in the coal mining area of the West Banko Pit 1 North.

The stages in this research started from the stage of literature study, field observation, data processing and analysis, as well as conclusions and suggestions.

Literature study is carried out to obtain a theoretical basis. The theoretical basis used in the static and pseudo-static slope stability analysis is to take into account the ground vibration variables due to overburden blasting systems [17]–[19]. In each section, the forces acting in the arc avalanche plane are as illustrated in Fig. 3.

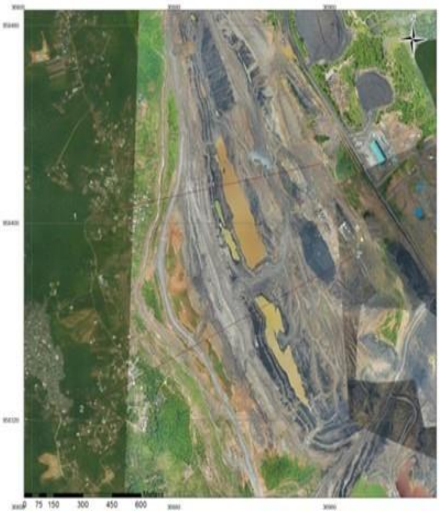

Fig. 2 Map of Orthophoto Pit 1 West Banko

To calculate the safety factor (SF) of pseudo-static slope stability, a seismic coefficient or horizontal earthquake coefficient (Kh) is required.

$$SF = \frac{\sum_{n=1}^{p}(c.B_n.Sec\,\alpha + W_n\cos\alpha_n\tan\varphi)}{\sum_{n=1}^{p}[W_n\,Sin\,\alpha_n + k_h W_n\left(\frac{L_n}{R}\right)]} \qquad (1)$$

Where: SF = Safety factor, Kh = horizontal earthquake coefficient; W = area of each slice; c = cohesion; R = landslide radius; h = average height of the slices; b = width of the slice; x = the horizontal distance from the center of mass of the slice to the center of the moment; α = angle of inclination of the slope.

The seismic coefficient is obtained from measuring ground vibrations using a blastmate. This horizontal vibration will control the pseudo-static force acting on the slope. Seismic acceleration (Kh) is equal to 50% of peak ground acceleration (PGA) (ie Kh = 0.5 x a max / g) [20]. The seismic coefficient (Kh) is obtained by the following equation:
Where: Kh = horizontal seismic coefficient;
ad = seismic acceleration corrected (gal); g = gal

The result of the correlation between the value of the calculation of the minimum distance of the rock that is safe from rock damage with the graph of the speed of propagation of the blasting wave, it is known that the PPV value that causes rock damage is 17.20 mm / second (PT. KJA), 18.41 mm / second (PTBA), 16.70 mm / sec (PT. BBE) and 16.80 mm / sec (PT. MSJ) [21].

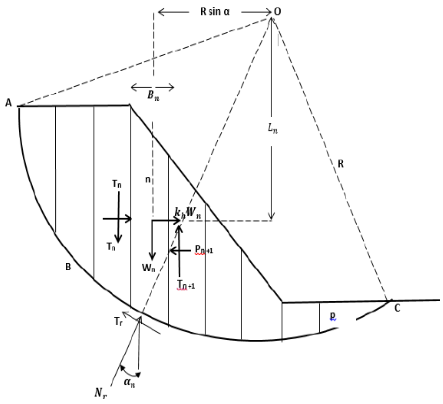

Fig. 3 Slope Model With Surface Sliding

The second stage of the field study was collecting primary data as well as secondary data as follows: Primary data includes direct measurement of ground vibrations (during blasting activities at a certain distance, data collection on the delay system pattern applied, and the amount of explosives used); blasting geometry measurements; observe geological structures. Secondary data required include maps of research locations, as well as geological data; geotechnical (physical characteristics and mechanical characteristics) of rocks at the study site; previous data on ground vibrations (including PPV, PPA, seismic acceleration, distance, number of holes, and number of explosives); map of the mining block sequence plan.

The third stage is processing and analyzing data. The analysis used to determine the effect of ground vibrations due to blasting of overburden on slope stability is to use the pseudo-static analysis method with the help of Slide version 6 and Geostudio 2012 software. By inputting data on geological, geotechnical, geohydrological / hydrological conditions, and acceleration of ground vibration safety factor for mine slopes (single slope, intermediate slope, and overall slope [1]. The results of the pseudo-static slope stability analysis by performing a berm simulation on the final slope to determine the final slope stability conditions of the three simulations. Slope stability analysis is discussed for five sections which are critical and safe slope conditions. Also discussed how to technically minimize ground vibration from overburden blasting effect.

The conclusions and suggestions are to know the results of the berm simulation on the stability of the final slope as a company reference in optimizing the overall slope of the final slope. In addition, technical recommendations for blasting to reduce ground vibrations (system delay, use of explosives, and application of controlled blasting methods) in order to improve slope stability [14], [15].

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Flow chart of research as shown in figure 4.

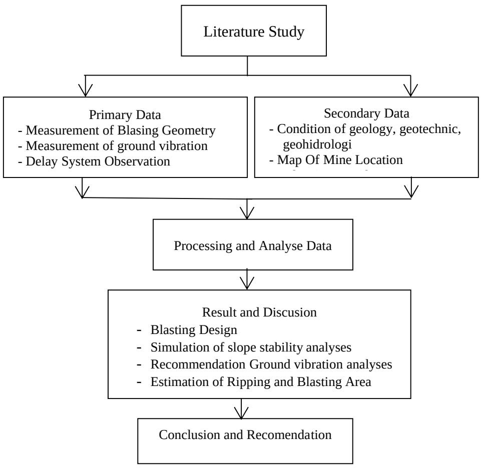


Fig. 4 Flow Chart of Research

## III. Results and Discussion

### A. Blasting Activity

The overburden blasting system at West Banko Pit 1 North uses a non-electric detonator (nonel) combined with an initiation system using a poweradet electric detonator which is connected to a blasting machine using a lead wire. Blasting geometry Diameter 6.75 inch (200 mm), Burden 8 meters, Space 9 meters, Depth 8 meters. The explosives used by ANFO consisted of 50 kg of Ammonium Nitrate (AN) and 3 liters of Fuel Oil (FO) for each blast hole, a loading density of 26.5 kg / m and a blasting powder factor of 53 kg / 576 bcm of 0 , 09 Kg / bcm. The geometry used at the pit 1 location is the same as the blasting geometry for pit 2 for detonating the overburden (Table 3). As well as the reference to the use of explosives in pit 1 will follow the reference to the use of explosives in West Banko pit 2, both non-air deck and air deck blasting.

The blasting delay system is divided into 5 groups, where 4 groups consist of 20 holes, and 1 group consists of 17 holes with a delay system for each group using a detonator delay of 0 ms, 42 ms, 67 ms, 109 ms, 3000 ms, and inhole. detonator 500 ms (Fig. 5). If the type of blasting is double deck, it uses a 500 ms inhole detonator and a 6000 ms inhole detonator to minimize the impact of blasting in the form of vibrations generated in the blasting.

TABLE III
Blasting Geometry

| S (m) | B (m) | PC (m) | T (m) | H (m) | PPV (mm/s) | | | PVS (mm/s) |
|---|---|---|---|---|---|---|---|---|
| | | | | | Tran | Vert | Long | |
| 9,23 | 8,12 | 1,89 | 6,41 | 8,50 | 7,62 | 5,84 | 4,57 | 7,81 |
| 9,01 | 8,20 | 1,89 | 6,22 | 8,41 | 1,14 | 0,889 | 1,4 | 2,01 |
| 9,14 | 8,03 | 1,89 | 6,15 | 8,44 | 4,70 | 7,49 | 2,54 | 7,63 |
| 9,05 | 8,17 | 1,89 | 6,31 | 8,52 | 1,78 | 1,02 | 1,4 | 2,13 |

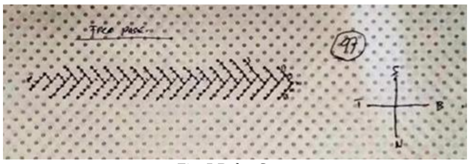

Fig. 5 Delay System

The results of measuring ground vibrations based on the amount of explosives and the delay system applied to the distance function obtained the largest PPV, PVS, and Seismic Acceleration as shown in Table 4.

TABLE IV
Ground Vibration Data

| NO | PPV (mm/s) | PVS (mm/s) | Acc (g) | Distance (m) | Holes (n) | Explosive (Kg) |
|---|---|---|---|---|---|---|
| 1 | 7,990 | 7,990 | 0,058 | 200 | 117 | 31,75 |
| 2 | 0,434 | 0.629 | 0,040 | 1700 | 43 | 25,40 |
| 3 | 4,190 | 6,110 | 0,106 | 300 | 120 | 25,40 |
| 4 | 2,410 | 2,680 | 0,106 | 480 | 140 | 31,75 |
| 5 | 2,160 | 3,340 | 0,106 | 400 | 122 | 31,75 |

The seismic coefficient (Kh) used for the calculation of the safety factor based on the pseudo-static slope stability analysis used the data assumption where the seismic acceleration was

0.106 g and PVS 6.110 mm / s at a distance of 300 m, then: Kh = 0.50 x acceleration (g)

Kh = 0.50 x 0.11 g = 0.055 g

When the blasting area approaches the final slope, it is necessary to reduce the number of explosives (number of explosive holes) per group delay and it is advisable to apply the blasting control system of line drilling [14].

### B. Analysis of Effect of Ground Vibration

#### 1) Analysis Stability of Final Slope

Static slope stability is determined by equilibrium limit analysis or pressure deformation analysis. In the analysis of the limit of the force equilibrium and or the moment of equilibrium for the soil mass above the potential landslide plane, it is considered and the soil mass above the plane is assumed to be in rigid conditions. The shear force is assumed to shift along the landslide surface, which results in a safety factor along the surface.

The effect of mine blasting vibrations spreads through the surrounding slopes causing dynamic shear forces that have the potential to cause slope landslides. The dynamic response of blasting activities needs to be known to determine the seismic acceleration which affects the dynamic shear force. The value of seismic acceleration is determined by selecting the greatest value of the peak acceleration of blasting activities around West Banko Pit 1 North. Seismic slope stability analysis can be determined using the pseudo-static method approach.

Potential factors causing mine slope landslides include slope geometric parameters, geotechnical parameters (physical and mechanical characteristics of slope forming materials), geological parameters (lithology and geological

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structures), hydrogeological parameters, ground vibration parameters (due to mining blasting and earthquake activities), stress parameters regional and time parameters. These parameters must be known in analyzing the stability of the final slope.

The geometry of the slope of the existing West Banko Pit 1 North is still in the process of expanding the pit. Mining slopes are still active working slopes with a width of 30 m, a height of 8 m, and a slope angle of 45 °. Especially in the North Low Wall area, the geometry used is single slope following the bottom seam coal floor. The analysis is carried out by simulating the final level geometry of the existing pit, assuming the deepening of the pit is carried out to the lowest floor seam layer (floor seam B2).

The geometry parameters of the final stage follow the parameters of the existing pit with a height of 8 m, and a single slope angle of 45 ° and a diameter of 15 m. Optimization of the overall slope pit limit will be simulated with 10 m, 12 m, and 15 m (Table 5).

The location of the cross section for the berm simulation analysis is chosen in an area that has been determined by the mining boundary (pit limit) by the company, namely the Low Wall section 1 and Low Wall section 2. The highwall area will be made a single slope. Sections created with the help of Minescape 5.7 software. There are two cross sections for the Low Wall area, namely section 1 and section 2 (Fig 6).

TABLE V
FINAL SLOPE GEOMETRY SIMULATION

| Geometry | | |
|---|---|---|
| Width (m) | Height (m) | Slope Angle (°) |
| 10 | 8 | 45 |
| 12 | 8 | 45 |
| 15 | 8 | 45 |

Slopes of section 1 and 2 are simulated against tiered slopes (overall slope, intermediate slope and single slope) following floor seam B2. Based on the simulation of each variable, level geometry, stratigraphic and geotechnical data and hydrogeological data were used to analyze the slope stability of the static method.

Overburden material removal activities at the West Banko Pit 1 North were renewed using a ripper and to optimize the removal activities, blasting activities were carried out against the overburden. The distribution of blasting vibrations that propagate on the walls of the mining slope causes seismic acceleration in the coating area. These factors have the potential to cause mining slope instability. The value of slope stability due to blasting activities can be determined by using the pseudo-static method approach. The pseudo-static method of slope stability analysis was performed with predetermined berm simulations.

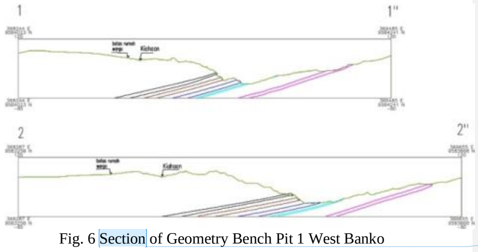

Fig. 6 Section of Geometry Bench Pit 1 West Banko

The seismic acceleration value (Seismic coefficient) of blasting activity at pit 1 West Banko is determined by selecting the peak acceleration (g) which has the highest effect. The seismic acceleration data for West Banko Pit 1 North consist of transverse, vertical, and longitudinal accelerations. In the analysis, the transverse and vertical accelerations are assumed to have no major effect on slope instability. The value of the greatest longitudinal acceleration with the highest PVS value is determined as the seismic acceleration of the slope simulation. The seismic acceleration values used in the analysis are the highest ground vibrations, namely the blasting in June with a longitudinal acceleration of 0.106 g and a PVS of 6.110 mm / s with a distance of 300 m (Table 1), so the Kh value used in calculating the safety factor of pseudo-static slope stability is Kh = 0.50 x 0.11 = 0.055 g.

Slope stability in static conditions is influenced by geometric slope parameters, material geotechnical parameters and hydrogeological parameters. Based on the blasting activity plan at the West Banko Pit 1 North, it adds to the effect of seismic acceleration on slope stability. Slope stability analysis was conducted to determine the effect of these factors on the slope safety factor. Approach is done by using the static arc and pseudo static equilibrium limit method.

The analysis stage was carried out by testing the slope safety factor (SF) on slope simulations in static and pseudo-static conditions. Slope modeling was made with 10 m, 12 m, and 15 m m variables. The geotechnical parameters of the slope constituent materials are assumed to be saturated with water because the hydrological parameters have a big influence in the slope stability analysis. The seismic acceleration value used in the pseudo-static slope stability analysis is the largest historical longitudinal acceleration, namely 0.055 g.

The areas analyzed were Low Wall section 1 and Low Wall section 2. The safety factor (SF) testing was carried out on the overall slope, intermediate slope, and single slope. Slope stability analysis used rocscience slide v 6.0 software with the bishop arc equilibrium limit method.

Slope stability simulation is carried out on modeling with variable berms of 10 m, 12 m, 15 m. The results of slope stability analysis under static and pseudo-static.

TABLE VI
SECTION FS OVERALL SLOPE 1

| Overall Slope | | | | | |
|---|---|---|---|---|---|
| Single Berm (m) | Width (m) | Height (m) | Slope Angle (*) | FS Static | FS Pseudostatic |

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| | | | | | |
|---|---|---|---|---|---|
| 10 | 296 | 132 | 24 | 1712 | 1517 |
| 12 | 308 | 128 | 23 | 1842 | 1615 |
| 15 | 353 | 128 | 19 | 2102 | 1813 |

TABLE VII
FS OVERALL SLOPE SECTION 2

| Overall Slope | | | | | |
|---|---|---|---|---|---|
| Single Berm (m) | Width (m) | Height (m) | Slope Angle (*) | FS Static | FS Pseudostatic |
| 10 | 296 | 136 | 25 | 1608 | 1428 |
| 12 | 326 | 134 | 22 | 1693 | 1481 |
| 15 | 376 | 136 | 20 | 1908 | 1646 |

TABLE 8
FS OVERALL SLOPE AT LOW WALL

| Overall Slope | | | | | |
|---|---|---|---|---|---|
| Single Berm (m) | Width (m) | Height (m) | Slope Angle (*) | FS Static | FS Pseudostatic |
| Lowwall 1 | 484 | 143 | 17 | 2.585 | 2.213 |
| Lowwall 2 | 425 | 132 | 17 | 2.631 | 2.247 |

Based on the results shown in Tables 6, 7 and 8 (Fig. 7,8,9) the value of the safety factor increases directly proportional to the increase in berm, either in static or pseudo- static conditions. In addition, it can be observed that in sections with the same diameter, there is a decrease in the safety factor (SF) between the slopes with static and pseudo- static conditions. As in section 2 with a 10 m diameter SF value of 1.428 in a pseudo-static slope condition shows a much smaller safety factor compared to 1.5 which is the standard of safety factors that have been set in the pseudo- static condition. Whereas with a 12 m diameter, the SF result in a static condition = 1.693 (Table 4.10), while the SF result in a pseudo-static condition = 1.481 (Table 4.10) with a decrease of about 12.5%. The decrease in SF in pseudo-static conditions is influenced by the value of the longitudinal seismic acceleration of 0.055 g due to blasting activities. For 15 m with static SF conditions and pseudo-static SF, the safety factor is far more than 1.5. Therefore, the optimal safety factor is with a diameter of 12 m which is closest to the SF of 1.5. Therefore, the optimal slope modeling is used based on safety both in static conditions and in pseudo static conditions, namely by using a diameter of 12 m.

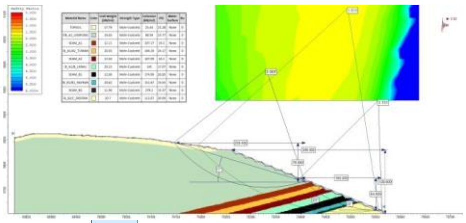

Fig. 7 Pseudo - Static Analysis FS HW Section 1 Berm 12 m

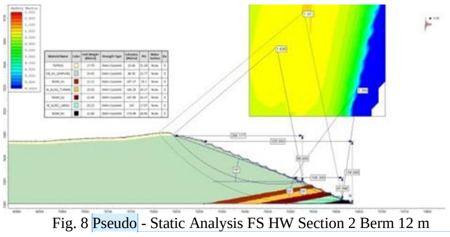

Fig. 8 Pseudo - Static Analysis FS HW Section 2 Berm 12 m

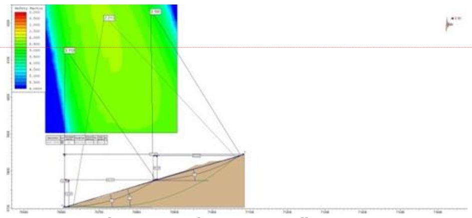

Fig. 9 Pseudo - Static Analysis FS Low wall Section 1 Berm 12 m

Slope instability also has the potential for intermediate slopes. This is influenced by the geotechnical conditions of the material composition (stratigraphy). The value of slope stability is determined in the same way as before. The Safety Factor scope of the final slopes is divided into two, the upper intermediate and the lower intermediate.

The results shown in show the Safety Factor results on the final slope, both the upper intermediate and the lower intermediate, indicating that the safety factor has far exceeded the predetermined safety standards. So that the cause of disturbance in slope stability is very small, both in static conditions and in pseudo static conditions. This is due to the material on the slope.

The upper intermediate Safety Factor had a smaller Safety Factor when compared to the lower intermediate Safety Factor. It is also influenced by the forming material. The upper intermediate is formed by the type of sandy siltstone material, while the lower intermediate material is formed from several types of harder materials, namely Sandy silty claystone, coal, and sandy siltstone. This is what causes the lower intermediate Safety Factor to be much higher.

To apply slope stability, both in section 1 and section 2, the optimal berm is determined, namely the overall slope, upper intermediate and lower intermediate 12 m. With a depth of 12 m, the slope will be safe in both static and pseudo-static conditions. By applying a berm of 12 m, it will be safe to do blasting without worrying about the impact of the disturbance on the slope stability of the West Banko Pit 1 North.

*2) Analysis of the Blast Effect on Residential Buildings*

Scaled distance (SD) is a factor that affects ground vibrations, namely the measurement distance divided by the root of the amount of explosives per time delay, the scaled distance affects the peak vector sum (PVS) value of ground vibrations produced by an explosion. This will affect the effect of ground vibrations on those caused by blasting activities. Efforts to minimize the effects of ground vibrations need to be taken measures to control ground vibrations so as

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**Commented [H10]:** Tulisan dalam gambar tdk terbaca not to cause danger to residential buildings at a certain distance. Therefore, it is necessary to measure the ground scraping and the activation of explosives to be carried out so that it can predict the safe distance to carry out blasting activities at West Banko Pit 1 North. The PPV or PVS threshold value for residential buildings around the mine is ⩽ 5 mm / second considering the building class, in the form of buildings with foundations, masonry and cement mortar and tied with concrete slopes (SNI 7571: 2010).

The results of the measurement of the Peak Vector Sum (PVS) vs Scaled Distance vibration above can be seen that at the PVS value of 7.81 with a distance of 700 meters with a hole charge of 50 kg per hole, the scaled distance is 98.994 (Table 9), while showing a PVS value of 0 , 57 with a distance of 1935 meters with a hole charge of 52.91 kg per hole obtained a scaled distance of 266.02 (Table 10). So it can be concluded also that the distance affects the level of ground vibrations, the farther the distance from the blasting area, the smaller the level of vibration that occurs and vice versa.

The value of ground vibrations that will occur in the next detonation can be predicted in a non-linear regression equation. The equation is obtained from the analysis of the value of the scaled distance and peak vector sum. Based on Table 9 and Table 10, a graph of the relationship between scaled distance and peak vector sum is obtained (Fig. 10). The results of the analysis of the relationship between the scaled distance and the actual PVS obtained from the results of measuring ground vibrations in the field show that there is a strong relationship between the scaled distance (SD) and the actual ground vibration (PVS), that is, each decrease in the scaled distance value is followed by an increase in the actual PVS value and conversely, any increase in the scaled distance value is followed by a decrease in the actual PVS value.

TABLE IX
SCALE DISTANCE AND PEAK VECTOR SUM (PVS) ELEKTRIC BLASTING

| Distance (m) | Charge/ Delay (kg) | Scaled Distance (m/kg^0,5) | PPV (mm/s) | | | PVS (mm/s) |
|---|---|---|---|---|---|---|
| | | | Tran | Vert | Long | |
| 700 | 150 | 98,9949494 | 7,62 | 5,84 | 4,57 | 7,81 |
| 500 | 50 | 70,7106781 | 1,14 | 0,889 | 1,4 | 2,01 |
| 500 | 150 | 70,7106781 | 4,70 | 7,49 | 2,54 | 7,63 |
| 1160 | 50 | 164,048773 | 1,78 | 1,02 | 1,4 | 2,13 |

TABLE X
ANALYSIS SCALE DISTANCE AND PEAK VECTOR SUM (PVS)

| Distance (m) | PPV (mm/s) | Charge/ hole (kg) | Scaled Distance (m/kg^0.5) |
|---|---|---|---|
| 1935 | 0,570 | 52,91 | 266,02 |
| 1876 | 0,413 | 58,20 | 245,91 |
| 1944 | 0,361 | 58,20 | 254,82 |
| 1750 | 0,421 | 52,91 | 240,59 |
| 1800 | 0,370 | 52,91 | 247,46 |
| 1400 | 0,808 | 58,20 | 183,51 |
| 1600 | 0,407 | 58,20 | 209,73 |
| 1800 | 0,241 | 52,91 | 247,46 |
| 1500 | 0,473 | 57,14 | 198,43 |
| 1800 | 0,262 | 42,33 | 276,67 |
| 1500 | 0,609 | 52,91 | 206,22 |

Fig. 10. Relationship Peak Vector Sum and Scaled Distance

The coefficient of determination (R2) from the data analysis shows that the R2 value is 0.4505, this indicates that the actual PVS is influenced by the scaled distance of 45.05%, while the rest is influenced by other factors such as physical and mechanical characteristics of the rock, lithology / rock bedding. , the geological structure / discontinuity area in the form of a joint of the lining in the mine area, the influence of groundwater content and others. The constants obtained in the equation to find the predictive PVS value are K = 7282.2 and M = -1.79. The constant values K and M are used to make calculations in predicting the peak vector sum amount at a certain scaled distance, to determine the blasting design simulation so that it can determine the safe vibration of an explosion based on explosives that can be used at certain distance (Table 11). So that we get the following equation.

$$PVS = 7282{,}2 \times SD^{-1{,}79} \quad (2)$$

*3) Ground Vibration Control*

Based on the blasting analysis that has been carried out, it is found that the more charge weight is used over a certain distance, the greater the value of the resulting ground vibration. The resulting ground vibrations can be controlled by changing the load weight / delay and determining the appropriate circuit pattern according to the conditions of the blasting location. PT. Bukit Asam, Tbk.

Recommended range for getting PVS = 3.5 mm / s With a distance of 300 - 1500 m by using the equations that have been obtained from simple linear regression analysis, predictions can be made by adjusting the fill in the scaled distance formula so that the optimum charge is obtained for one blasting hole. (Table 11).

TABLE XI
NUMBER OF SAFE USE OF EXPLOSIVES

| PVS (mm/s) | Distance (m) | Scaled Distance (m/kg^0.5) | Charge/ hole (kg) |
|---|---|---|---|
| 3 | 300 | 71,41 | 17,65 |
| 3 | 400 | 71,41 | 31,38 |
| 3 | 500 | 71,41 | 49,03 |
| 3 | 600 | 71,41 | 70,60 |
| 3 | 700 | 71,41 | 96,09 |
| 3 | 800 | 71,41 | 125,51 |
| 3 | 900 | 71,41 | 158,84 |
| 3 | 1000 | 71,41 | 196,10 |
| 3 | 1100 | 71,41 | 237,28 |
| 3 | 1200 | 71,41 | 282,39 |
| 3 | 1300 | 71,41 | 331,41 |
| 3 | 1400 | 71,41 | 384,36 |
| 3 | 1500 | 71,41 | 441,23 |

Based on Table 11, it can be seen that at a distance of 300 m and 400 m the fill / hole that can be filled is 17.65 kg and 31.5 kg, respectively, which indicates that the charge cannot fill the explosive material with a diameter of 200 mm and a depth of 8 m. therefore blasting activities are not recommended at this distance. Meanwhile, at a distance of 500 m, the blast hole charge of 49.03 kg is able to fulfill the charge in the blasting plan, as well as the vibrations generated by the safe blasting effect on the surrounding settlements,

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namely 3.5 mm / s With these provisions, at West Banko Pit 1 North blasting activities can be carried out with a minimum distance of 500 from residential areas.

### *C. Analysis of the planned area to be blown up*

By carrying out blasting activities in West Banko Pit 1 North, it is necessary to plan an area that can be blown up. It is necessary to consider the blasting activities that will be carried out because the effects of the vibrations caused can have an impact on residential areas. So it is necessary to control blasting in a predetermined area so that the impact of blasting vibrations can be minimized and can also narrow the safe distance that can be detonated.

Based on the results of the planned feed area carried out at West Banko Pit 1 North, it has been determined that the delivery area is divided into two areas, based on the treatment to be carried out, namely the ripping area and the blasting area (Fig. 11). The ripping area and the blasting area are 246.63 hectares.

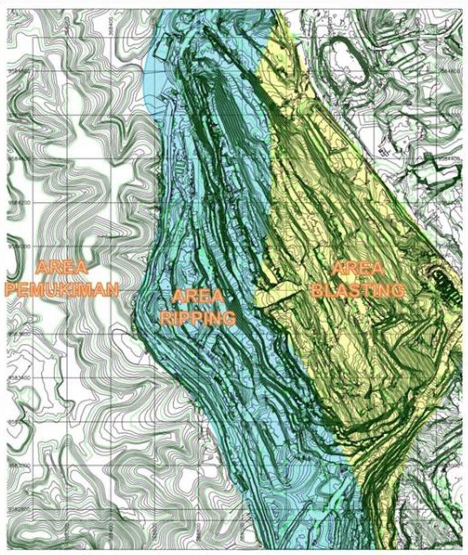


Fig. 11. Ripping - Blasting Overburden Area

The ripping area shows the areas that are blue. The area has a distance from the settlement of less than 500 m so the use of blasting is not recommended in that area. The ripping area is located in the West highwall area with an area of 134.04 Ha to be ripped. Whereas the yellow area is an area where the reporting activities carried out in that area are carried out using the blasting method. The area is more than 500 m from the residential area so that blasting activities can be carried out by adjusting the delay when blasting is carried out so that it can minimize ground vibrations which can have a bad impact on residential buildings if the vibration effect exceeds the predetermined standard. The blasting area in the low wall area of the East is 112.59 hectares. With this arrangement, it will be safe to carry out activities without disturbing residential areas.

## IV. Conclusion

The Blasting Design will apply the blasting technique applied to the West Banko Pit 1 North because the lithology of the coal deposition material is relatively the same and the location is adjacent to the West Banko Pit 2, the blasting geometry used is 200 mm in diameter, 8 m Burden, 9 m space, Depth 8 m, loading density 26.5 kg / m.

Simulations with 10 m, 12 m and 15 m for analysis of static and pseudo static slope stability on the overall slope and intermediate slope, the wider the Berm, the higher the value of the slope safety factor and the sloping the overall slope and the greater the striping ratio. The optimum Berm condition is 12 m with a pseudo-static safety factor of at least 1.50, the selection of the 12 m berm is taken based on the value of the safety factor in section 2 almost close to 1.5 (long term) in accordance with the Ministerial Decree 1827 of 2018.

Recommendation ground vibrations with blasting effects are planned for the scale distance for the PVS value set at $\leqslant$ 3.5 mm / s with the explosive charge per delay having an optimum value of 50 kg with a minimum distance of 500 m.

The area to be blast is 112.59 Ha, while the area to be ripped in the western pit limit area near residential areas with a radius of 500 m is 134.04 Ha.

## Acknowledgment

On this occasion, we would like to express our gratitude to the Management and Employee of the Department of Mines PT Bukit Asam, Tbk for the opportunity to conduct field research and supporting data.

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3. Round 3 (24-02-2022)

## Round 3

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# Hasil review pada round ke-3 (08 April 2022)

# Potential Economic Value of Water Resource Sustainability for Sustainable Environment: A Case Study in South Sumatra, Indonesia

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***Abstract***— **Erosion in coal mining land causes depletion in water quantity and quality, as well as inadequate drinking water resources for surrounding communities, making water resources unsustainable. Meanwhile, reclamation reduces erosion but is unable to restore water depletion optimally; thus, these resources remain unsustainable. These resources remain unsustainable. The objectives of this study were to develop a water resource sustainability concept for a sustainable environment by analyzing the potential economic value and, secondly, to calculate the water resource value due to erosion, reclamation, and domestic and economic importance of recycling efforts. The method used in this study was the Extended NPV. Furthermore, the total potential economic value of water resources loss resulting in water resource unsustainability was IDR 1,137,621,671,375 or IDR 1.14 trillion, while the potential economic value of depleted water utilization for drinking was IDR 2,298,339,797,000 or IDR 2.3 trillion. Therefore, this utilization provides potential economic value worth IDR 1.16 trillion for the resources' sustainability in the TAL area of PTBA. The study's results found and recommended depleted water utilization for drinking as a suitable method to replace water resources lost due to erosion, community drinking water resource loss, and to discover a sustainable environment's water resources sustainability concept. In addition, the study formulates environmental economics as a new mining science related to natural resource economics as well as mining for sustainable water resources and the mining environment.**

***Keywords***— **Water resource sustainability; Extended cost-benefit analysis; Erosion value; Domestic water value; Raw water value.**

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## I. INTRODUCTION

Sustainability appears as the most important consideration of natural resource management policy in mining as well as forms the basic principle of environmental science. Therefore, there is a great need to preserve this water resource sustainability for a balanced environment [1], [2]. Also, there is no denying the mining of natural supplies tends to enhance economic development substantially, generate extensive foreign exchange [3]–[9], create jobs, increase income, and serve as a potential income source for communities [3], [10]–[15]. Moreover, mining provides raw materials to build infrastructure and serve other industries and generates large energy quantities and other products [13], [16]. However, the sector is one of the major contributors to environmental degradation [3], [5], [7], [17]–[19], and therefore, resulting in deficient water resources and ecosystems.

Forest clearing is responsible for erosion, river sedimentation, silting, and turbidity [7], [20]–[23], with a significant impact on surface and groundwater supplies [24], [25]. This activity also influences downstream regions, resulting in a decreased marine quality [26], and in addition, eliminates water resource ecosystem services for mining communities [23], [27]–[29][23], [27]–[29], alongside instigating scarcity [30]. The limited freshwater availability implies less consumption [28], [31], [32]. Water resources are very important in sustaining economic development [33], and the entire mining operations require extensive supplies directly or indirectly [32]. This situation illustrates the importance of water for the overall survival of humans and living organisms [34]. Furthermore, mining impact potentially instigates deficient hydrological function of the forest as a catchment area, leading to a significant loss of water resource economic value [13], [21]. Therefore, a collaborative approach between hydrologists and economists is required to optimize the water value instruments [27] and mining resource analysis due to these shortfalls [32].

As a consequence, environmental damage is potentially repaired by reclamation [5]. This process can also reduce erosion and protect soil degradation [35]. However, the possible occurrence is greatly decreased by cultivating legium cover crops (LCC) in early vegetation stages [36]–[41]. Based on this study, mine reclamation demonstrated the robust capacity to restore environmental degradation but was unable to reform the depleted water resources completely. Therefore, recycling appears as a crucial necessity and also aids the improvement of water efficiency [42]. Furthermore, economic valuation is highly demanded as natural resources and the environment continue to diminish in monetary value [13], [29], [43]. In addition, cost-benefit analysis (BCA) serves as a comprehensive approach to assess the net impact on social, economic, and environmental aspects, as well as an effort to protect natural resources and communities [13], [44]–[47]. Also, BCA is used to engage water resource assessments for domestic purposes [29].

However, by evaluating the potential economic value, sustainability is easily analyzed, and with these provisions, environmental continuity and potable water supplies are adequately conserved. This circumstance agrees with the natural resource management policy, where natural mining resources are conducted while maintaining sustainability and environmental balance [2].

This study aims to develop a water resource sustainability concept for a sustainable environment by analyzing the potential economic value of lost and recovered water supplies in mining areas, surrounding communities, and possible domestic use. In addition, the potential is evaluated by the extended NPV. Therefore, the water resources and coal mining environment are expected to remain potable and also sustainable.

## II. The Materials and Method

### A. Study Area

This study was directly carried out in the coal mining of Tambang Air Laya (TAL) at PT Bukit Asam Persero Tbk, Muara Enim Regency, South Sumatra Province (Fig. 1).

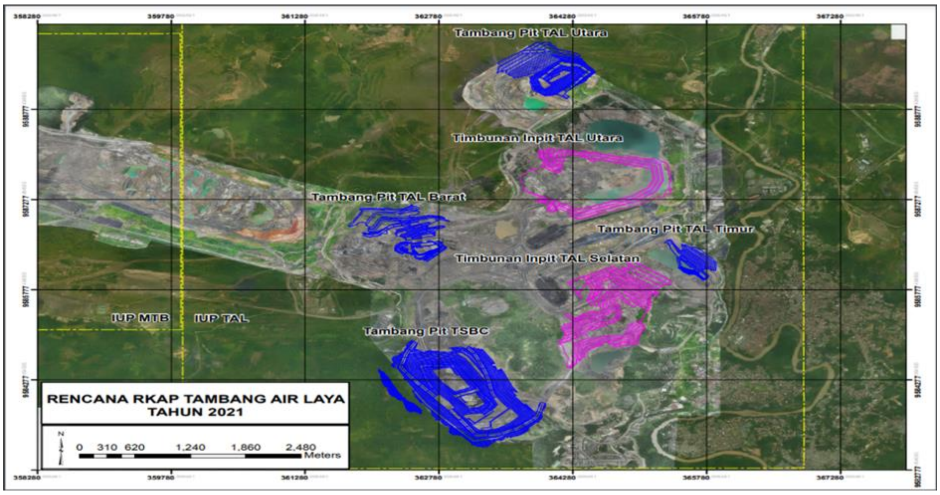


Fig. 1 Research Location

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### B. Cleared and reclaimed land, depleted water volume

The cleared and reclaimed land, as well as depleted water volume, were 3,106.59 ha, 1,374.5 ha and 48,738,366 $m^3$, respectively.

### C. Methods

This exploratory research employed the extended net present value (NPV) development, model. The approach is useful in conducting economic valuation in order to determine the economic value of water resource sustainability in coal mining. Quantitative techniques were applied to calculate the NPV of benefits and external costs of open coal mining on the value of water resources ecosystem services by these assessments.

### D. Economic valuation using the Extended NPV method

#### 1) Erosion value (potential economic value of water resources lost due to erosion)

The erosion value was possibly calculated using the extended cost-benefit analysis (extended NPV) developed by [48].

$$Extended\ NPV_{ne} = \sum_{t=0}^{n} \frac{B_{npe} - C_{npe}}{(1+r)^t}$$

where:

$NPV_{ne}$ = Net Present Value

= The erosion value is derived from the

erosion recovery value and the erosion-resisting value (IDR)

$B_{npe}$ = The erosion recovery value is an external the benefit of ex-mining land revegetation (IDR).

$C_{npe}$ = The erosion-resisting value is an external cost of the mining clearing impact (IDR)

n = Mine life (production and post production)

r = Discount rate = 1, 2,….n

t = Interest rate

*2) The domestic water value (the potential economic value for the loss of drinking water resources for the community)*

Domestic water value was also evaluated using the extended NPV method. The above equation was derived from the extended benefit and cost mathematical analysis model by [48].

$$Extended\ NPV_{cad,T} = \sum_{t=0}^{n} \frac{C_{adr,T} - M_{pa}}{(1+r)^t}$$

Where:

$NPV_{cad}$ = Net Present Value

= Domestic water cost value of the community (IDR)

$C_{adr}$ = Average domestic water cost per respondent (IDR)

$M_{pa}$ = The number of people buying water around TAL PTBA

n = Mine life (production and post mining)

r = 1,2, …. n

t = Interest rate

T = Research year

*3) The raw water value (potential economic value of water resources from utilizing (recycling) depleted water)*

The raw water value was determined using the developed method by a previous study [47].

$$Extended\ NPV_{nab} = \sum_{t=0}^{n} \frac{B_{ab} - C_{ab}}{(1+r)^t}$$

Where:

$NPV_{nab}$ = Net Present Value

= The raw water value originates from the benefit and cost estimates (IDR)

$B_{ab}$ = The raw water benefit from recycling (IDR)

$C_{ab}$ = The raw water cost from recycling (IDR)

n = Mine life (production and post-mining)

r = 1,2, …. n

t = Interest rate

## III. Result and Discussion

### *A. Impact of mining on water resources and community*

Figure 2 represents the occurrence of soil erosion and water depletion due to mining.

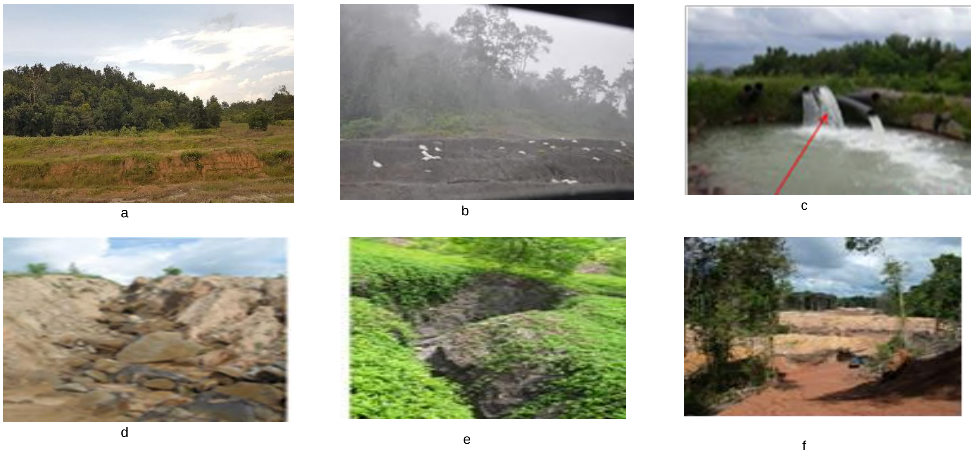


Fig. 2 Land erosion and water depletion

The above illustration showed the erosion occurrence on the ground/open land in Indonesian coal mining (a, b), and water depletion(c) due to pumped outlet at TAL PT Bukit Asam Persero Tbk, Kutai site (d), Suriname Artisanal Gold Mining (e).

Deforestation also instigated certain changes in water consumption, resulting in an erosion, where loss of hydrological function in forest, as a catchment area, possibly occurred. This event contributed to unsustainable outcome of water resources in terms of quantity, quality, and loss of plant economic value [13], [21]. The situation also eliminated water ecosystem services as a resource provider [18], [47], allowed sufficient space for environmental degradation [3], as well as initiated chemical, physical, and biological environmental changes [17], [49]. Furthermore, erosion is known to decrease surface water level, remove land cover, increase deforestation rate[25], [48], lower the water level, e.g in Baganuur mine, Mongolia, decline soil fertility, as well as trigger surface and groundwater pollution [5]. In addition, increased surface water runoff and sedimentation, decreased water quality, disrupted land and river transportation were observed [50]. However, an erosion of mine waste disposal, contamination of surface water, groundwater, and soil by released chemicals from the mining process, and extinction of certain species [24]. Soil erosion also occurred in open land of mining areas and river sediments [21], [23], [49], causing significant damages to flora, fauna, hydrological relationships, and soil [22]. Previous studies have reported the incident as a major challenge in coal mining [51]. Also, sedimentation results in river silting and turbidity [18], [23], [51]. However, turbidity is probably responsible in declining water quality as well as poses a major environmental problem. This condition is triggered by suspended particles, specifically sediment and soil particles from various erosion processes, as a result of human activities, e.g. mining [7]. Moreover, water quality decrease due to extensive mining presents a great risk of domestic water scarcity [30], and the impact in the downstream area in form of sediment transfer tends to lower marine quality [26]. For instance, mining in Sri Lanka is perceived to be seriously challenging, as a result of substantial degrading water resources [23]. This results in the loss of ecosystem services in providing free water for daily community consumption [23], [28], [29][23], [28], [29]. These distributions require utmost priorities in measuring the trade-offs between economic water benefits, in terms of mining and usage [27]. Therefore, water resources necessitates protection to enable proper and general utilization, as a natural resource for society and living organisms. Furthermore, limited fresh water and groundwater by barely 3 and 30%, respectively causes less consumption [28], [31]. Water resources are also very essential in maintaining economic development [33].

The above points showed the importance of water to humans and entire living organisms [34]. Therefore, a collaborative approach between hydrologists and economists appears as a great necessity in optimizing the value of water instruments [27]. The analysis of water resources in mining sector is very significant as the overall mining operations require water directly or indirectly. These activities demonstrated a substantial ecological impact [32].

The above illustration showed the erosion occurrence on the ground/open land in Indonesian coal mining (a, b), and water depletion(c) due to pumped outlet at TAL PT Bukit Asam Persero Tbk, Kutai site (d), Suriname Artisanal Gold Mining (e).

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*B. Mine Reclamation to Restore erosion*

Reclamation in TAL PT Bukit Asam Persero Tbk (Fig. 3).

a b

Fig. 3 Reclamation of TAL PTBA

The conversion of land to forest by reverting to a tree-covered landscape or establishing a commercial forestry program is a major mine reclamation alternative (Figure 3). A typical example is the recovery of entire former Appalachian mines to become one of the most beautiful forests in the world [53]. This process is highly needed to restore the forest structure and function [50] as erosion barrier [17], [21], [53]. Therefore, the reclamation process is believed to reduce erosion, prevent soil degradation [35], decline runoff rates, and increase porosity, permeability, and infiltration [54]. Moreover, erosion is possibly minimized by planting legium cover crops in early vegetation stages. Figure 4 represents the LCC cultivation in TAL PTBA reclamation zone.

a b

Fig. 4 Planting of legume cover crops at PTBA Tambang Air Laya

Furthermore, the introduction of LCC tends to prevent and control soil erosion, enrich and protect soil, increase water availability, and also serves as an environment preservation technique [55]. The improvement of soil's physical, chemical, and biological properties is achieved by increasing aggregate stability and reducing erosion. This provides various benefits for the agro-ecosystem, including erosion and weed control, as well as nutrient management [39]. Consequently, the improvement also prevents soil erosion, nutrient leakage [36], and provides ecosystem services, including erosion control, water quality regulation, soil moisture retention, accumulation of soil organic matter and microbial biomass, weed and pest control, as well as subsequent commercial crop yields. In addition, there is a possibility to regulate climate, soil, water as well as control erosion, clean water, and weed [38]. However, mitigating soil degradation functions as a shield from raindrops and surface runoff as well as increases the organic matter [41].

The reclamation of Hanjiawan coal mine region provided certain benefits for ecological development by enhancing soil quality, fertility, forest cover, and reducing soil/water loss, while serving an important role in economic and social aspects [25]. Similar recovery in the western zone of China mine targeted ecological restoration, environmental protection, and soil erosion control. This process is potentially a significant section of the coal industry [56]. Moreover, effective reclamation offers long-term success and high mining profitability for future economic benefits. According to [5], PTBA's coal mining land reclamation was not barely for environmental improvement through conservation and protection, but also served as an economic investment activity to create harmony and social benefits for local industry, agriculture, forestry, livestock and eucalyptus plants. Furthermore, PTBA reclamation to mine closure in NPV by 2043 reported a potential economic value of USD 91,295,530 (1 USD = IDR 13,329). Meanwhile, Appalachia Kentucky instance was estimated at a total ecosystem value of $ 456,428,682 [57].

The results of this study demonstrated the inability of mine reclamation to restore pumped water depletion from the outlets entirely, but was possible to repair erosion. This circumstance was due to a more effective water absorption and storage in forest land, compared to reclaimed regions. Forest land exhibited sufficient porosity and very rapid permeability. The extensive soil porosity tends to prevent surface runoff, and therefore, resulted in an increasing water infiltration to a certain capacity, prior to saturation. Moreover, forest land showed great ability to restrain erosion, compared to reclaimed portions. In addition, excessive infiltration rate was due to higher biodiversity (understory, shrubs, and trees), litter production, porosity and permeability, as well as decreased bulk density, and therefore, preventing erosion. The vegetation diversity (biodiversity) is effective in reducing rain energy and inhibiting surface runoff velocity [54].

Consequently, in order to increase water efficiency, recycling offers a paramount alternative [42]. This approach was adopted in TAL PTBA mine outlet as a solution in restoring water resource lost, due to depletion, and subsequently in upholding sustainability, in terms of quality and quantity. The provision was in line with natural resource management policies, where the use of natural coal resource is to needed to maintain water resource sustainability for a balanced environment [2].

### *C. Economic valuation of the water resource sustainability for a sustainable environment using the extended cost-benefit analysis (Extended NPV) model*

Resources, economy, and environment are interdependent systems for an economic valuation [57]. This process was aimed at providing a monetary assessment for natural resource loss and environmental degradation impact on humans [43]. Economic valuation is very important as natural resources and the environment showed no monetary value [13]. The effort aims to provide environmental protection as the ecosystem is responsible for free natural water resource availability [47]. In addition, the instance for Spain's Urdaibai Biosphere reserve in Spain was performed, using the framework of conservation and management policies to maximize social welfare. Furthermore, economic valuation was also conducted on the quality of water bodies, agricultural production, native forest protection, biodiversity, and recreation, where the local population were willing to support the management plan [45] financially. Cost-benefit analysis (CBA) serves as a comprehensive economic valuation method for net impact assessment on social, economic and environmental aspects [13], [27], [42], [44], [45]. This process was used to provide a potable water resource assessment. Previous studies stated the provisions of benefits and costs directly (financially) and indirectly (externalities) in economic, social, and environmental aspects, by the open coal mining [5], [8], [27], [46], [47], [58]–[62]. Economic valuation in this study was performed on erosion, domestic water, and raw water values of TAL PTBA, using extended benefit and cost analysis model.

1. Erosion value

Based on calculations, (Formula 1), the erosion value (Extended NPVne) between 1997-2023 was specified as IDR 716,328,638,488,- or 716 billion rupiahs, with an erosion-resisting estimate ($C_{npe}$) of IDR 736,436,108,129,- or 738 billion rupiahs, and an erosion recovery ($B_{npe}$) of IDR 20,107,469,641,- or 20 billion. These results indicated the clearing of the forest by TAL PTBA coal mining triggered an erosion and therefore, eliminated the ecosystem service value, leading to an unsustainable supply by 716 billion rupiahs. This shortfall was due to the loss of forest ecosystem services as an erosion barrier, causing unsustainable water resources by 736 billion rupiahs. Furthermore, reclamation tends to reduce erosion as well as restore forest ecosystem services and sustainable water resources by 20 billion. The results of this study were in accordance with [54], where ex-coal mine recovery showed a positive influence on diminishing erosion. However, reclamation possibly obtained a water resource sustainability value of 20 billion, but the lost water resources (716 billion rupiahs) were not completely restored. The calculation of erosion-resisting and recovery values employed benefit transfer similar to previous studies, including the use of flood control estimates, based on tropical forest types in Brazilian Amazon, with resemblance to Indonesian forests [63].

2. Domestic water value

The sample water emanated from Enim river in TAL PTBA. Figure 5 shows the river conditions of Enim and Artisanal gold mining site in Suriname (c) [49].

a b c

Fig. 5 The condition of PTBA Enim river (a, b), and China's coal industry polluting the Yellow River basin (c) Green Peace, 2014

Based on the above figure, Enim river was known to be highly turbid and degraded. This condition matched previous reports, where the rivers formed a component of the degradable freshwater ecosystem [64]. The result was also in accordance with questionnaire data, where 43.07% of respondents did not utilize Enim water for drinking or cooking, based on bad smell and high turbidity. This showed the sample had declined in quality. Furthermore, the present study results were supported by Enim water quality test from Muara Enim Regional Environmental Agency (2020), where the unsuitability for bathing and consumption conformed with Minister of Health Regulation No.492/MENKES/PER/IV/2010 on Requirements for Drinking Water Quality, and the Minister of Health Regulation No. 416/MENKES/PER/IX/1990 on Clean Water. However, both guidelines require a maximum turbidity value of 5 and odorless state. Meanwhile, the turbidity for Enim River at all monitoring points reflected a value above 5, but was very stinky. A previous study also observed similar conditions unfit for consumption (Ijazah, 2016). Moreover, water availability as an income source was urgently needed by surrounding communities for bathing and washing [65].

Erosion instigates the accumulation of sediments containing chemical toxins, responsible for groundwater pollution and changes in drinking water taste [3]. The water appears turbid, due to the total dissolved solids (TDS) content from dispersed colloidal particles. Consequently, turbidity is known to influence water color significantly, and the suspended material adversely affects the quality. Excessive TDS tends to increase the turbidity and alters the transparency, while high water hardness triggers a bad taste [66]. During mining, runoff sediment quantity increased and the total suspended solids (TSS) in the form of soil surface layer were removed by rainwater flow. This deposit emanated from the degraded forest land [67]. The TSS as a pollutant accesses the hydrosphere and lithosphere through surface runoffs, causing water and soil pollution. Also, the suspended materials showed an adverse impact on water quality as sun penetration reduced.

However, water turbidity increased due to a decrease in the photosynthetic process, where growth disturbances for the producing organisms were observed [66]. Another TSS impact exceeding water quality standard was unable to support fishing activities [19]. Coal mining in India causes unsuitable water resources for surrounding communities [3]. Furthermore, placer gold mining was also responsible for high turbidity in Tuul river [7] and Aristasal Suriname [49].

Deforestation as a result of mining revealed a significant impact on the downstream area in the form of sediment transfer [26]. It instigated water pollution in terms of quality and quantity [33], inadequate clean water availability [52], and river silting, due to elevated sedimentation responsible for reducing water depth [18], [23], [51][23], [49], [68]. The impact of coal mining on water resources triggers (1) surface water runoff and changing conditions in the catchment area, 2) destruction of aquifer structure, 3) damaging water circulation and balance conditions, and 4) water resource contamination. Furthermore, Gujiao coal mining activities played an important role in declining river runoff, while for one-tonne coal, a decrease in the river, surface, and base flows, with an estimation of 2.87, 0.24, and 2.63 $m^3$ were observed, respectively [6]. This condition significantly influenced water resource availability as a free ecosystem service [23], [27]–[29]. The questionnaire data indicated the elimination of ecosystem services of Enim river as a free portable water source by TAL PTBA coal mining. This impact causes the inability of the community to enjoy free supply and therefore requires payment. The charges are used to purchase water from neighbours in the form of gallons and PAM water, although the costs gradually become higher. In this study, domestic water value was calculated using contingent valuation/willingness to pay approach and a mathematical model developed from a previous study by the reclamation percentage method from time horizon [48]. Based on equation two calculations, the domestic water value of the surrounding community in TAL PTBA between 1997-2023 was specified as IDR 421,293,032,887 or 421.3 billion rupiahs. These findings indicate TAL PTBA coal mining was responsible for the loss of environmental benefits to the community, devoid of ecosystem services. As a consequence, potable water resources were reportedly unsustainable at 421.3 billion rupiahs.

Therefore, the overall loss of water resource economic value in similar mines was estimated at IDR 1,137,621,671,374,- or 1.14 trillion rupiahs. This estimation was derived from the erosion and domestic water values of IDR 716,328,638,488,- or 716 billion and IDR 421,293,032,887,- or 421.3 billion rupiahs, respectively. Based on these results, a significant loss was observed in water resources as an ecosystem service, resulting in unsustainable water resources by 1.14 trillion rupiahs. However, recycling provides a potential solution to rebuilding the actual state.

*D. The raw water value from utilizing (recycling) TAL PTBA depleted water for drinking water*

Increasing water efficiency was conducted by adopting new technologies, more efficient processes, combining reuse, recycling, and finding alternative water sources [42]. The recycling of discharged water from the mine appears very useful to the native population as a domestic water source, reduces the potential for land subsidence, and conserves valuable water resources for sustainable local environmental management. In Indonesia, PT Adaro Indonesia had recycled (utilized) mine water using water treatment plant 300 technology [47]. Subsequently, the processed potable water becomes safe for immediate consumption (Fig. 6).

Fig. 6 The processed mine void wastewater of PT Adaro Indonesia that can be consumed directly

Water from the Eastern Kentucky underground coal mine was supplied for municipal, industrial, agricultural, or household purposes. A similar circumstance was also observed in the former West Virginia coal mine, where recycling tends to meet the local water supply needs. Baganuur, Mongolia, mine water served as a community and agricultural, domestic source. Furthermore, the use of Greenwood Arkansas coal mine water for drinking purposes generated economic benefits in excess of twenty million dollars. This utilization provided the benefit values for lost water resources and economics. A previous study showed the use of PT Adaro Indonesia's coal mine void water for drinking provided economic benefits of IDR 4,438,400,888,338 (± USD 369, 866, 740) or 4.4 trillion rupiahs [47].

The raw water value (Extended $NPV_{av}$) in this study was obtained by recycling the depleted water in TAL PTBA. This estimate originated from the raw water benefit value (Bav) and raw water cost value ($C_{av}$). Based on equation 3 results, $B_{av}$ and $C_{av}$ were evaluated as IDR 5,458,557,017,875,- or 5.5 trillion rupiahs, and 3,160,217,220,875,- or 3.2 trillion rupiahs, respectively. In addition, the raw water value (Extended $NPV_{ba}$) from the use of mine water was obtained as IDR 2,298,339,797,000,- or 2.3 trillion rupiahs. These calculations indicate the recycling approach generated a water resource sustainability value of 2.3 trillion rupiahs. Therefore, the results of this study confirmed the depleted water in TAL PTBA was used for drinking purposes to provide potential economic value as well as replace the water resources. Consequently, the utilization provided economic, social, and ecological benefits for the sustainability of water resources for a sustainable environment and the maintenance of potable supplies to the community.

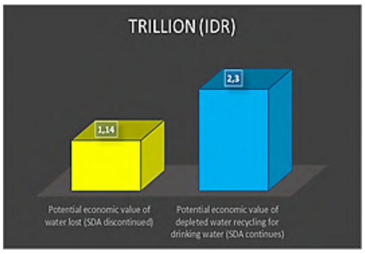


Fig. 7 Potential economic value of water resources

Table 1 generally represents the economic valuation results of benefit and cost values for the impact of TAL PTBA coal mining on the water resource sustainability for a sustainable environment.

TABLE I
THE ECONOMIC VALUATION RESULTS IN BENEFIT AND COST VALUES FOR THE IMPACT OF TAL PTBA COAL MINING ON THE WATER RESOURCE SUSTAINABILITY FOR A SUSTAINABLE ENVIRONMENT

| Benefits and costs components | Benefit and cost value | Unit (IDR) | Description |
|---|---|---|---|
| NPVne = Net Present Value (Project time 32 years) | Net erosion value | 716.328.638.488 | The erosion value was derived from the erosion recovery value and the erosion-resisting value |
| Bnpe | Erosion recovery benefit value | 20.107.469.641 | The erosion recovery value is an external benefit of ex-mining revegetation |
| Cnpe | Erosion-resisting cost value | 716.328.638.488 | The erosion-resisting value is an external cost of the impact of forest clearing by mining |
| NPVad = Net Present Value | Net domestic water value | 421.293.032.887 | The communal domestic water cost value was derived from the average domestic water cost value per respondent with the number of people buying water around TAL PTBA |
| Cadr | Average domestic water cost value per respondent | 36.931. | Average domestic water cost per respondent |
| Mpa | | 1.077.338.068. | The number of people buying water around TAL PTBA |
| NPVnab = Net Present Value | Net raw water value | 2.298.339.797.000 | The net raw water value originated from the raw water benefit value from recycling depleted water for drinking water with the cost of recycling depleted water for drinking water |
| Bab | Raw water benefit value | 5.458.557.017.875 | Raw water benefits from recycling depleted water for drinking water |
| Cab | Raw water cost value | 3.160.217.220.875 | Raw water cost from depleted water recycling for drinking water |

*E. The concept of water resource sustainability for a sustainable environment in the mining sector*

The background in the basic principles of environmental science comprises natural, man-made, and social [1], while sustainability deeply emphasizes the priority elements. Therefore, effective utilization and management of natural resources are greatly focused on environmental and natural resource sustainability. Based on the above principle, this study obtained the concept of water resource sustainability for a sustainable environment in the mining sector (Fig. 8). This view was developed from a previous study [1].

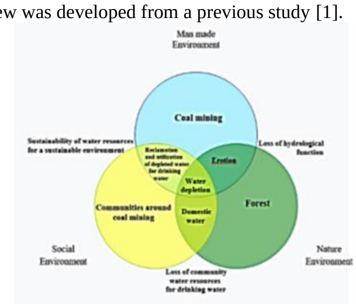


Fig. 8 The concept of water resource sustainability for a sustainable environment in the mining sector

Coal mining with the ability to clear forests causes erosion, as the plants tend to lose the hydrological barrier function. Also, erosion is responsible for water depletion, as the forests no longer behave as a catchment area and decline the water quality, resulting in the loss of clean water resources for surrounding communities. However, to restore the hydrological barrier role and lost resources, reclamation and utilization of depleted water for domestic use are possibly employed. This process provides economic benefits for water resource sustainability for a balanced environment. Based on the above concept, the analysis of potential economic value showed water depletion was instigated by erosion. Also, the loss of drinking water resources for the proximate communities in TAL PTBA mining generated unsustainable water resources of 1.14 trillion rupiahs. Mine water utilisation (recycling) provided water resource sustainability by 2.3 trillion rupiahs. This utilization generated sustainability benefits of 1.16 trillion rupiahs.

Furthermore, the recycling of depleted water due to TAL PTBA coal mining obtained a potential economic value for water resource sustainability of 1.16 trillion rupiahs (see Figure 7). Therefore, the water resources in the TAL PTBA and the environment tend to remain sustainable and the surrounding communities.

## IV. CONCLUSIONS

The coal mining of Tambang Air Laya (TAL) PT Bukit Asam Tbk, South Sumatra province, Indonesia instigated an environmental impact, with the loss of forest area's function as an erosion barrier. In addition, a significant loss of Enim river's role as a clean water source for the surrounding communities was also reported. These circumstances resulted in unsustainable water resources at the sample location. However, mine reclamation was possible to reduce erosion but unable to completely restore lost water resources. The recycling or utilization of depleted water for drinking purposes was not able to initiate a certain degree of replacement but also obtained potential economic value for the water resource sustainability in the site area by 1.2 trillion rupiahs. Therefore, water resources remained sustainable, and the sustainability of the environment and clean water resources for surrounding TAL PTBA communities appeared effectively maintained.

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4. Round 4 (21-04-2022)

## Round 4

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# Hasil review oleh reviewer pada round 4 (05 Juni 2022)

# Potential Economic Value of Water Resource Sustainability for Sustainable Environment: A Case Study in South Sumatra, Indonesia

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***Abstract*— Erosion in coal mining land causes depletion in water quantity and quality, as well as inadequate drinking water resources for surrounding communities, making water resources unsustainable. Meanwhile, reclamation reduces erosion, but is unable to restore water depletion optimally, thus, these resources remain unsustainable. these resources remain unsustainable. The objectives of this study were to develop water resource sustainability concept for a sustainable environment by analyzing the potential economic value and secondly, calculate the water resource value due to erosion, reclamation, domestic and economic importance, by recycling efforts. The method used in this study was the Extended NPV. Furthermore, the total potential economic value of water resources loss resulting in water resource unsustainability was IDR 1,137,621,671,375 or IDR 1.14 trillion, while the potential economic value of depleted water utilization for drinking was IDR 2,298,339,797,000 or IDR 2.3 trillion. Therefore, this utilization provides potential economic value worth IDR 1.16 trillion, for the resources' sustainability in the TAL area of PTBA. The study's results found and recommended depleted water utilization for drinking as a suitable method to replace water resources lost due to erosion, community drinking water resource loss, and to discover a sustainable environment's water resources sustainability concept. In addition, the study formulates environmental economics as a new mining science related to natural resource economics as well as mining, for sustainable water resources and mining environment.**

***Keywords*— Water resource sustainability; Extended cost-benefit analysis; Erosion value; Domestic water value; Raw water value.**

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## I. Introduction

Sustainability appears as the most important consideration of natural resource management policy in mining as well as forms the basic principle of environmental science. Therefore, there is a great need to preserve this water resource sustainability for a balanced environment [1], [2]. Also, there is no denial the mining of natural supplies tends to substantially enhance economy development, generate extensive foreign exchange [3]–[9], create jobs, increase income, and serve as a potential income source for communities [3], [10]–[15]. Moreover, mining provides raw materials to build infrastructure and serve other industries, as well as generates large energy quantity, and others products [13], [16]. However, the sector is one of the major contributors to environmental degradation [3], [5], [7], [17]–[19], and therefore, resulting to deficient water resources and ecosystems.

Forest clearing is responsible for erosion, river sedimentation, silting and turbidity [7], [20]–[23] with significant impact on surface and groundwater supplies [24], [25]. This activity also influences downstream regions, resulting in a decreased marine quality [26], and in addition, eliminates water resource ecosystem services for mining communities [23], [27]–[29][23], [27]–[29], alongside instigating scarcity [30]. The limited fresh water availability implies less consumption [28], [31], [32]. Water resources are very important in sustaining economic development [33] and the entire mining operations require extensive supplies directly or indirectly [32]. This situation illustrates the importance of water for the overall survival of humans and living organisms [34]. Furthermore, mining impact potentially instigates deficient hydrological function of forest as a catchment area, leading to a significant loss of water resource economic value [13], [21]. Therefore, collaborative approach is required between hydrologists and economists to optimize the water value instruments [27] and mining resource analysis, due to these shortfalls [32] .

As a consequence, environmental damage is potentially repaired by reclamation [5]. This process is also capable of reducing erosion and protecting soil degradation [35]. However, possible occurrence is greatly decreased by cultivating legium cover crops (LCC) in early vegetation stages [36]–[41]. Based on this study, mine reclamation demonstrated the robust capacity to restore environmental degradation, but was unable to completely reform the depleted water resources. Therefore, recycling appears as a crucial necessity, and also aids the improvement of water efficiency [42]. Furthermore, economic valuation is highly demanded as natural resources and environment continue to diminish in monetary value [13], [29], [43]. In addition, cost-benefit analysis (BCA) serves as a comprehensive approach to assess the net impact on social, economic, and environmental aspects, as well as an effort to protect natural resources and communities [13], [44]–[47]. Also, BCA is used to engage water resource assessments for domestic purposes [29]. However, by evaluating the potential economic value, sustainability is easily analyzed, and with these provisions, environmental continuity and potable water supplies is adequately conserved. This circumstance agrees with the natural resource management policy, where mining natural resources is conducted while maintaining sustainability and environmental balance [2].

The purpose of this study is to develop water resource sustainability concept for a sustainable environment by analyzing the potential economic value of lost and recovered water supplies in mining areas, surrounding communities, and possible domestic use. In addition, the potential is evaluated by the extended NPV. Therefore, the water resources and coal mining environment are expected to remain potable and also sustainable.

## II. The Materials and Method

### A. Study Area

This study was directly carried out in the coal mining of Tambang Air Laya (TAL) at PT Bukit Asam Persero Tbk, Muara Enim Regency, South Sumatra Province (Fig. 1).

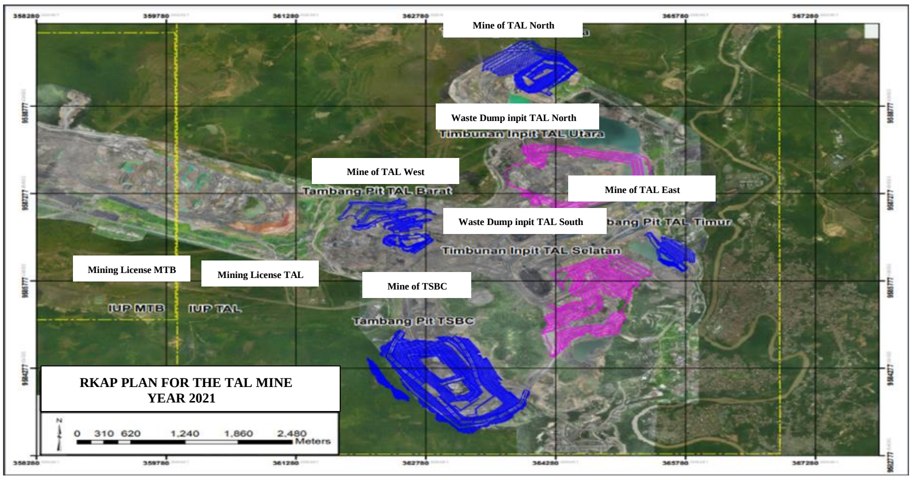


Fig. 1 Research Location

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### B. Cleared and reclaimed land, depleted water volume

The cleared and reclaimed land, as well as depleted water volume were 3,106.59 ha, 1,374.5 ha and 48,738,366 $m^3$, respectively.

### C. Methods

This exploratory research employed the extended net present value (NPV) development model. The approach is useful in conducting economic valuation, in order to determine the economic value of water resource sustainability in coal mining. Quantitative techniques were applied to calculate the NPV of benefits and external costs of open coal mining on the value of water resources ecosystem services by these assessments.

### D. Economic valuation using the Extended NPV method

1) *Erosion value (potential economic value of water resources lost due to erosion)*

The erosion value was possibly calculated using the extended cost-benefit analysis (extended NPV), developed by [48].

$$Extended\ NPV_{ne} = \sum_{t=0}^{n} \frac{B_{npe} - C_{npe}}{(1+r)^t}$$

where:

$NPV_{ne}$ = Net Present Value

= The erosion value is derived from the erosion recovery value and the erosion-resisting value (IDR)

$B_{npe}$ = The erosion recovery value is an external benefit of ex-mining land revegetation (IDR).

$C_{npe}$ = The erosion-resisting value is an external cost of the mining clearing impact (IDR)

n = Mine life (production and post production)

r = Discount rate = 1, 2,….n

t = Interest rate

*2) The domestic water value (potential economic value for the loss of drinking water resources for the community)*

Domestic water value was also evaluated using the extended NPV method. The above equation was derived from the extended benefit and cost analysis mathematical model by [48].

$$Extended\ NPV_{cad,T} = \sum_{t=0}^{n} \frac{C_{adr,T} - M_{pa}}{(1+r)^t}$$

Where:

$NPV_{cad}$ = Net Present Value

= Domestic water cost value of the community (IDR)

$C_{adr}$ = Average domestic water cost per respondent (IDR)

$M_{pa}$ = The number of people buying water around TAL PTBA

n = Mine life (production and post mining)

r = 1,2, …. n

t = Interest rate

T = Research year

*3) The raw water value (potential economic value of water resources from utilizing (recycling) depleted water)*

The raw water value was determined, using the developed method by a previous study [47].

$$Extended\ NPV_{nab} = \sum_{t=0}^{n} \frac{B_{ab} - C_{ab}}{(1+r)^t}$$

Where:

$NPV_{nab}$ = Net Present Value

= The raw water value originates from the benefit and cost estimates (IDR)

$B_{ab}$ = The raw water benefit from recycling (IDR)

$C_{ab}$ = The raw water cost from recycling (IDR)

n = Mine life (production and post mining)

r = 1,2, …. n

t = Interest rate

## III. Result and Discussion

### *A. Impact of mining on water resources and community*

Figure 2 represents the occurrence of soil erosion and water depletion, due to mining.

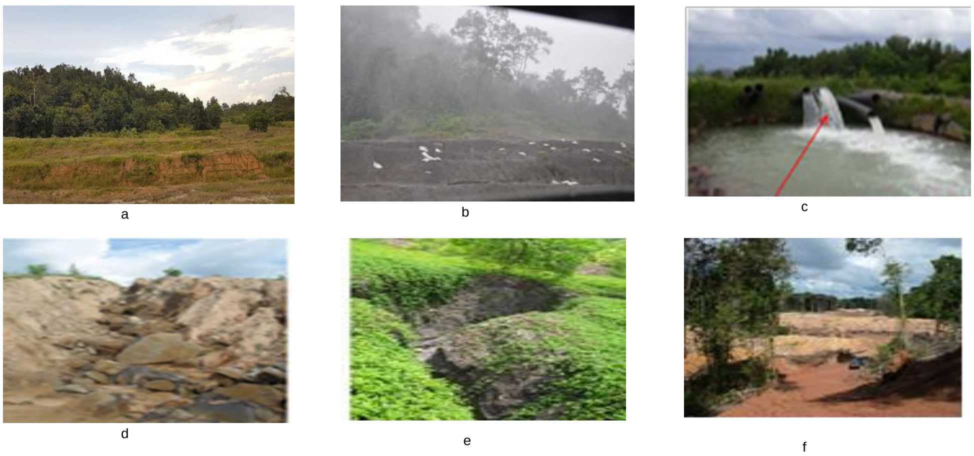


Fig. 2 Land erosion and water depletion

The above illustration showed the erosion occurrence on the ground/open land in Indonesian coal mining (a, b), and water depletion(c) due to pumped outlet at TAL PT Bukit Asam Persero Tbk, Kutai site (d), Suriname Artisanal Gold Mining (e).

Deforestation also instigated certain changes in water consumption, resulting in an erosion, where loss of hydrological function in forest, as a catchment area, possibly occurred. This event contributed to unsustainable outcome of water resources in terms of quantity, quality, and loss of plant economic value [13], [21]. The situation also eliminated water ecosystem services as a resource provider [18], [47], allowed sufficient space for environmental degradation [3], as well as initiated chemical, physical, and biological environmental changes [17], [49]. Furthermore, erosion is known to decrease surface water level, remove land cover, increase deforestation rate[25], [48], lower the water level, e.g in Baganuur mine, Mongolia, decline soil fertility, as well as trigger surface and groundwater pollution [5]. In addition, increased surface water runoff and sedimentation, decreased water quality, disrupted land and river transportation were observed [50]. However, an erosion of mine waste disposal, contamination of surface water, groundwater, and soil by released chemicals from the mining process, and extinction of certain species [24]. Soil erosion also occurred in open land of mining areas and river sediments [21], [23], [49], causing significant damages to flora, fauna, hydrological relationships, and soil [22]. Previous studies have reported the incident as a major challenge in coal mining [51]. Also, sedimentation results in river silting and turbidity [18], [23], [51]. However, turbidity is probably responsible in declining water quality as well as poses a major environmental problem. This condition is triggered by suspended particles, specifically sediment and soil particles from various erosion processes, as a result of human activities, e.g. mining [7]. Moreover, water quality decrease due to extensive mining presents a great risk of domestic water scarcity [30], and the impact in the downstream area in form of sediment transfer tends to lower marine quality [26]. For instance, mining in Sri Lanka is perceived to be seriously challenging, as a result of substantial degrading water resources [23]. This results in the loss of ecosystem services in providing free water for daily community consumption [23], [28], [29][23], [28], [29]. These distributions require utmost priorities in measuring the trade-offs between economic water benefits, in terms of mining and usage [27]. Therefore, water resources necessitates protection to enable proper and general utilization, as a natural resource for society and living organisms. Furthermore, limited fresh water and groundwater by barely 3 and 30%, respectively causes less consumption [28], [31]. Water resources are also very essential in maintaining economic development [33].

The above points showed the importance of water to humans and entire living organisms [34]. Therefore, a collaborative approach between hydrologists and economists appears as a great necessity in optimizing the value of water instruments [27]. The analysis of water resources in mining sector is very significant as the overall mining operations require water directly or indirectly. These activities demonstrated a substantial ecological impact [32].

The above illustration showed the erosion occurrence on the ground/open land in Indonesian coal mining (a, b), and water depletion(c) due to pumped outlet at TAL PT Bukit Asam Persero Tbk, Kutai site (d), Suriname Artisanal Gold Mining (e).

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*B. Mine Reclamation to Restore erosion*

Reclamation in the coal mining area of TAL PT Bukit Asam Persero Tbk (Fig. 3).

a

b

Fig. 3 Reclamation of TAL PTBA

The conversion of land to forest by reverting to a tree-covered landscape or establishing a commercial forestry program is a major mine reclamation alternative (Figure 3). A typical example is the recovery of entire former Appalachian mines to become one of the most beautiful forests in the world [53]. This process is highly needed to restore the forest structure and function [50] as erosion barrier [17], [21], [53]. Therefore, reclamation process is believed to reduce erosion, prevent soil degradation [35], decline runoff rates, as well as increase porosity, permeability, and infiltration [54]. Moreover, erosion is possibly minimized by planting legium cover crops in early vegetation stages. Figure 4 represents the LCC cultivation in TAL PTBA reclamation zone.

a

b

Fig. 4 Planting of legume cover crops at PTBA Tambang Air Laya

Furthermore, the introduction of LCC tends to prevent and control soil erosion, enrich and protect soil, increase water availability, and also serves as an environment preservation technique [55]. The improvement of soil's physical, chemical, and biological properties is achieved by increasing aggregate stability and reducing erosion. This provides various benefits for the agro-ecosystem, including erosion and weed control, as well as nutrient management [39]. Consequently, the improvement also prevents soil erosion, nutrient leakage [36], and provides ecosystem services, including erosion control, water quality regulation, soil moisture retention, accumulation of soil organic matter and microbial biomass, weed and pest control, as well as subsequent commercial crop yields. In addition, there is a possibility to regulate climate, soil, water as well as control erosion, clean water, and weed [38]. However, mitigating soil degradation functions as a shield from raindrops and surface runoff as well as increases the organic matter [41].

The reclamation of Hanjiawan coal mine region provided certain benefits for ecological development by enhancing soil quality, fertility, forest cover, and reducing soil/water loss, while serving an important role in economic and social aspects [25]. Similar recovery in the western zone of China mine targeted ecological restoration, environmental protection, and soil erosion control. This process is potentially a significant section of the coal industry [56]. Moreover, effective reclamation offers long-term success and high mining profitability for future economic benefits. According to [5], PTBA's coal mining land reclamation was not barely for environmental improvement through conservation and protection, but also served as an economic investment activity to create harmony and social benefits for local industry, agriculture, forestry, livestock and eucalyptus plants. Furthermore, PTBA reclamation to mine closure in NPV by 2043 reported a potential economic value of USD 91,295,530 (1 USD = IDR 13,329). Meanwhile, Appalachia Kentucky instance was estimated at a total ecosystem value of $ 456,428,682 [57].

The results of this study demonstrated the inability of mine reclamation to entirely restore pumped water depletion from the outlets, but was possible to repair erosion. This circumstance was due to a more effective water absorption and storage in forest land, compared to reclaimed regions. Forest land exhibited sufficient porosity and very rapid permeability. The extensive soil porosity tends to prevent surface runoff, and therefore, resulted in an increasing water infiltration to a certain capacity, prior to saturation. Moreover, forest land showed great ability to restrain erosion, compared to reclaimed portions. In addition, excessive infiltration rate was due to higher biodiversity (understory, shrubs, and trees), litter production, porosity and permeability, as well as decreased bulk density, and therefore, preventing erosion. The vegetation diversity (biodiversity) is effective in reducing rain energy and inhibiting surface runoff velocity [54].

Consequently, in order to increase water efficiency, recycling offers a paramount alternative [42]. This approach was adopted in TAL PTBA mine outlet as a solution in restoring water resource lost, due to depletion, and subsequently in upholding sustainability, in terms of quality and quantity. The provision was in line with natural resource management policies, where the use of natural coal resource is to needed to maintain water resource sustainability for a balanced environment [2].

### *C. Economic valuation of the water resource sustainability for a sustainable environment using the extended cost-benefit analysis (Extended NPV) model*

Resources, economy, and environment are interdependent systems for an economic valuation [57]. This process was aimed at providing a monetary assessment for natural resource loss and environmental degradation impact on humans [43]. Economic valuation is very important as natural resources and the environment showed no monetary value [13]. The effort aims to provide environmental protection as the ecosystem is responsible for free natural water resource availability [47]. In addition, the instance for Spain's Urdaibai Biosphere reserve in Spain was performed, using the framework of conservation and management policies to maximize social welfare. Furthermore, economic valuation was also conducted on the quality of water bodies, agricultural production, native forest protection, biodiversity, and recreation, where the local population were willing to financially support the management plan [45]. Cost-benefit analysis (CBA) serves as a comprehensive economic valuation method for net impact assessment on social, economic and environmental aspects [13], [27], [42], [44], [45]. This process was used to provide a potable water resource assessment. Previous studies stated the provisions of benefits and costs directly (financially) and indirectly (externalities) in economic, social, and environmental aspects, by the open coal mining [5], [8], [27], [46], [47], [58]–[62]. Economic valuation in this study was performed on erosion, domestic water, and raw water values of TAL PTBA, using extended benefit and cost analysis model.

1. Erosion value

Based on calculations, (Formula 1), the erosion value (Extended NPVne) between 1997-2023 was specified as IDR 716,328,638,488,- or 716 billion rupiahs, with an erosion-resisting estimate ($C_{npe}$) of IDR 736,436,108,129,- or 738 billion rupiahs, and an erosion recovery ($B_{npe}$) of IDR 20,107,469,641,- or 20 billion. These results indicated the clearing of the forest by TAL PTBA coal mining triggered an erosion and therefore, eliminated the ecosystem service value, leading to an unsustainable supply by 716 billion rupiahs. This shortfall was due to the loss of forest ecosystem services as an erosion barrier, causing unsustainable water resources by 736 billion rupiahs. Furthermore, reclamation tends to reduce erosion as well as restore forest ecosystem services and sustainable water resources by 20 billion. The results of this study were in accordance with [54], where ex-coal mine recovery showed a positive influence on diminishing erosion. However, reclamation possibly obtained a water resource sustainability value of 20 billion, but the lost water resources (716 billion rupiahs) were not completely restored. The calculation of erosion-resisting and recovery values employed benefit transfer similar to previous studies, including the use of flood control estimates, based on tropical forest types in Brazilian Amazon, with resemblance to Indonesian forests [63].

2. Domestic water value

The sample water emanated from Enim river in TAL PTBA. Figure 5 shows the river conditions of Enim and Artisanal gold mining site in Suriname (c) [49].

a b c

Fig. 5 The condition of PTBA Enim river (a, b), and China's coal industry polluting the Yellow River basin (c) Green Peace, 2014

Based on the above figure, Enim river was known to be highly turbid and degraded. This condition matched previous reports, where the rivers formed a component of the degradable freshwater ecosystem [64]. The result was also in accordance with questionnaire data, where 43.07% of respondents did not utilize Enim water for drinking or cooking, based on bad smell and high turbidity. This showed the sample had declined in quality. Furthermore, the present study results were supported by Enim water quality test from Muara Enim Regional Environmental Agency (2020), where the unsuitability for bathing and consumption conformed with Minister of Health Regulation No.492/MENKES/PER/IV/2010 on Requirements for Drinking Water Quality, and the Minister of Health Regulation No. 416/MENKES/PER/IX/1990 on Clean Water. However, both guidelines require a maximum turbidity value of 5 and odorless state. Meanwhile, the turbidity for Enim River at all monitoring points reflected a value above 5, but was very stinky. A previous study also observed similar conditions unfit for consumption (Ijazah, 2016). Moreover, water availability as an income source was urgently needed by surrounding communities for bathing and washing [65].

Erosion instigates the accumulation of sediments containing chemical toxins, responsible for groundwater pollution and changes in drinking water taste [3]. The water appears turbid, due to the total dissolved solids (TDS) content from dispersed colloidal particles. Consequently, turbidity is known to significantly influence water color, and the suspended material adversely affects the quality. Excessive TDS tends to increase the turbidity and alters the transparency, while high water hardness triggers a bad taste [66]. During mining, runoff sediment quantity increased and the total suspended solids (TSS) in the form of soil surface layer were removed by rainwater flow. This deposit emanated from the degraded forest land [67]. The TSS as a pollutant accesses the hydrosphere and lithosphere through surface runoffs, causing water and soil pollution. Also, the suspended materials showed an adverse impact on water quality as sun penetration reduced. However, water turbidity increased due to a decrease in the photosynthetic process, where growth disturbances for the producing organisms were observed [66]. Another TSS impact exceeding water quality standard was unable to support fishing activities [19]. Coal mining in India causes unsuitable water resources for surrounding communities [3]. Furthermore, placer gold mining was also responsible for high turbidity in Tuul river [7], as well as in Aristasal Suriname [49].

Deforestation as a result of mining revealed a significant impact on the downstream area in the form of sediment transfer [26], and instigated water pollution in terms of quality and quantity [33], inadequate clean water availability [52], and river silting, due to elevated sedimentation responsible for reducing water depth [18], [23], [51][23], [49], [68]. The impact of coal mining on water resources triggers (1) surface water runoff and changing conditions in the catchment area, 2) destruction of aquifer structure, 3) damaging water circulation and balance conditions, and 4) water resource contamination. Furthermore, Gujiao coal mining activities played an important role in declining river runoff, while for one-tonne coal, a decrease in river, surface, and base flows, with an estimation of 2.87, 0.24, and 2.63 $m^3$ were observed, respectively [6]. This condition significantly influenced water resource availability as a free ecosystem service [23], [27]–[29]. The questionnaire data indicated the elimination of ecosystem services of Enim river as a free portable water source by TAL PTBA coal mining. This impact causes the inability of the community to enjoy free supply and therefore requires payment. The charges are used to purchase water from neighbors, in form of gallon and PAM water, although the costs gradually becomes higher. In this study, domestic water value was calculated, using contingent valuation/willingness to pay approach, and a mathematical model developed from previous study by the reclamation percentage method from time horizon [48]. Based on equation 2 calculations, the domestic water value of surrounding community in TAL PTBA between 1997-2023 was specified as IDR 421,293,032,887 or 421.3 billion rupiahs. These findings indicate TAL PTBA coal mining was responsible for the loss of environmental benefits to the community, devoid of ecosystem services. As a consequence, potable water resources were reportedly unsustainable at 421.3 billion rupiahs.

Therefore, the overall loss of water resource economic value in similar mines was estimated at IDR 1,137,621,671,374,- or 1.14 trillion rupiahs. This estimation was derived from the erosion and domestic water values of IDR 716,328,638,488,- or 716 billion and IDR 421,293,032,887,- or 421.3 billion rupiahs, respectively. Based on these results, significant loss was observed in water resources as an ecosystem service, resulting in an unsustainable water resources by 1.14 trillion rupiahs. However, recycling provides a potential solution in rebuilding the actual state.

*D. The raw water value from utilizing (recycling) TAL PTBA depleted water for drinking water*

Increasing water efficiency was conducted by adopting new technologies, more efficient processes, combining reuse, recycling, and finding alternative water sources [42]. The recycling of discharged water from the mine appears very useful to the native population as a domestic water source, reduces the potential for land subsidence, and conserves valuable water resources for sustainable local environmental management. In Indonesia, PT Adaro Indonesia had recycled (utilized) mine water, using water treatment plant 300 technology [47]. Subsequently, the processed potable water becomes safe for immediate consumption (Fig. 6).

Fig. 6 The processed mine void wastewater of PT Adaro Indonesia that can be consumed directly

Water from Eastern Kentucky underground coal mine was supplied for municipal, industrial, agricultural, or household purposes. Similar circumstance was also observed in the former West Virginia coal mine, where recycling tends to meet the local water supply needs. Baganuur, Mongolia mine water served as community and agricultural domestic sources. Furthermore, the use of Greenwood Arkansas coal mine water for drinking purposes generated economic benefits in excess of twenty million dollars. This utilization provided the benefit values for lost water resources and economics. Previous study showed the use of PT Adaro Indonesia's coal mine void water for drinking provided economic benefits of IDR 4,438,400,888,338 (± USD 369, 866, 740) or 4.4 trillion rupiahs [47].

The raw water value (Extended $NPV_{av}$) in this study was obtained by recycling the depleted water in TAL PTBA. This estimate originated from the raw water benefit value (Bav) and raw water cost value ($C_{av}$). Based on equation 3 results, $B_{av}$ and $C_{av}$ were evaluated as IDR 5,458,557,017,875,- or 5.5 trillion rupiahs, and 3,160,217,220,875,- or 3.2 trillion rupiahs, respectively. In addition, the raw water value (Extended $NPV_{ba}$) from the use of mine water was obtained as IDR 2,298,339,797,000,- or 2.3 trillion rupiahs. These calculations indicate the recycling approach generated a water resource sustainability value of 2.3 trillion rupiahs. Therefore, the results of this study confirmed the depleted water in TAL PTBA was used for drinking purpose to provide potential economic value as well as replace the water resources. Consequently, the utilization provided economic, social, and ecological benefits for the sustainability of water resources for a sustainable environment and the maintenance of potable supplies to the community.

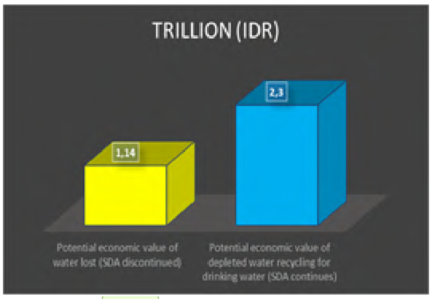


Fig. 7 Potential economic value of water resources

Table 1 generally represents the economic valuation results of benefit and cost values for the impact of TAL PTBA coal mining on the water resource sustainability for a sustainable environment.

TABLE I
THE ECONOMIC VALUATION RESULTS OF BENEFIT AND COST VALUES FOR THE IMPACT OF TAL PTBA COAL MINING ON THE WATER RESOURCE SUSTAINABILITY FOR A SUSTAINABLE ENVIRONMENT

| Benefits and costs components | Benefit and cost value | Unit (IDR) | Description |
|---|---|---|---|
| NPVne = Net Present Value (Project time 32 year) | Net erosion value | 716.328.638.488 | The erosion value was derived from the erosion recovery value and the erosion-resisting value |
| Bnpe | Erosion recovery benefit value | 20.107.469.641 | The erosion recovery value is an external benefit of ex-mining revegetation |
| Cnpe | Erosion-resisting cost value | 716.328.638.488 | The erosion-resisting value is an external cost of the impact of forest clearing by mining |
| NPVad = Net Present Value | Net domestic water value | 421.293.032.887 | The communal domestic water cost value was derived from the average domestic water cost value per respondent with the number of people buying water around TAL PTBA |
| Cadr | Average domestic water cost value per respondent | 36.931. | Average domestic water cost per respondent |
| Mpa | | 1.077.338.068. | The number of people buying water around TAL PTBA |
| NPVnab = Net Present Value | Net raw water value | 2.298.339.797.000 | The net raw water value originated from the raw water benefit value from recycling depleted water for drinking water with the cost of recycling depleted water for drinking water |
| Bab | Raw water benefit value | 5.458.557.017.875 | Raw water benefits from recycling depleted water for drinking water |
| Cab | Raw water cost value | 3.160.217.220.875 | Raw water cost from depleted water recycling for drinking water |

*E. The concept of water resource sustainability for sustainable environment in mining sector*

The background in the basic principles of environmental science comprises natural, man-made, and social [1], while sustainability deeply emphasizes the priority elements. Therefore, effective utilization and management of natural resources are greatly focused on environmental and natural resource sustainability. Based on the above principle, this study obtained the concept of water resource sustainability for a sustainable environment in the mining sector (Fig. 8). This view was developed from a previous study [1].

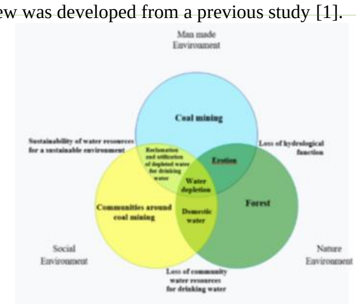


Fig. 8 The concept of water resource sustainability for sustainable environment in the mining sector

Coal mining with the ability to clear forests causes erosion, as the plants tends to lose the hydrological barrier function. Also, erosion is responsible for water depletion, as the forests no longer behave as a catchment area, and decline the water quality, resulting in loss of clean water resources for surrounding communities. However, to restore the hydrological barrier role and lost resources, reclamation and utilization of depleted water for domestic use are possibly employed. This process provides economic benefits for water resource sustainability for a balanced environment. The analysis of potential economic value, based on the above concept, showed water depletion was instigated by erosion. Also, loss of drinking water resources for the proximate communities in TAL PTBA mining generated unsustainable water resources by 1.14 trillion rupiahs. Utilization (recycling) of mine water provided water resource sustainability by 2.3 trillion rupiahs. This utilization generated sustainability benefits by 1.16 trillion rupiahs.

Furthermore, the recycling of depleted water due to TAL PTBA coal mining obtained a potential economic value for water resource sustainability by 1.16 trillion rupiahs (see Figure 7). Therefore, the water resources in the TAL PTBA and the environment tends to remain sustainable, as well as the surrounding communities.

## IV. CONCLUSIONS

The coal mining of Tambang Air Laya (TAL) PT Bukit Asam Tbk, South Sumatra province, Indonesia instigated an

**Commented [NH2]:** The texts (in the figure are not clear and readable environmental impact, with the loss of forest area's function as an erosion barrier. In addition, a significant loss of Enim river's role as a clean water source for the surrounding communities was also reported. These circumstances resulted in unsustainable water resources at the sample location. However, mine reclamation was possible to reduce erosion, but unable to completely restore lost water resources. The recycling or utilization of depleted water for drinking purposes was not barely able to initiate a certain degree of replacement, but also obtained potential economic value for the water resource sustainability in the site area by 1.2 trillion rupiahs. Therefore, water resources remained sustainable and the sustainability of the environment and clean water resources for surrounding TAL PTBA communities appeared effectively maintained.

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5. Round 5 (07-06-2022)

## Round 5

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**Hasil review round 5, dimana tidak ada lagi perbaikan (27 Agustus 2022)**

# Potential Economic Value of Water Resource Sustainability for Sustainable Environment: A Case Study in South Sumatra, Indonesia

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***Abstract*— Erosion in coal mining land causes depletion in water quantity and quality, as well as inadequate drinking water resources for surrounding communities, making water resources unsustainable. Meanwhile, reclamation reduces erosion, but is unable to restore water depletion optimally, thus, these resources remain unsustainable. these resources remain unsustainable. The objectives of this study were to develop water resource sustainability concept for a sustainable environment by analyzing the potential economic value and secondly, calculate the water resource value due to erosion, reclamation, domestic and economic importance, by recycling efforts. The method used in this study was the Extended NPV. Furthermore, the total potential economic value of water resources loss resulting in water resource unsustainability was IDR 1,137,621,671,375 or IDR 1.14 trillion, while the potential economic value of depleted water utilization for drinking was IDR 2,298,339,797,000 or IDR 2.3 trillion. Therefore, this utilization provides potential economic value worth IDR 1.16 trillion, for the resources' sustainability in the TAL area of PTBA. The study's results found and recommended depleted water utilization for drinking as a suitable method to replace water resources lost due to erosion, community drinking water resource loss, and to discover a sustainable environment's water resources sustainability concept. In addition, the study formulates environmental economics as a new mining science related to natural resource economics as well as mining, for sustainable water resources and mining environment.**

***Keywords*— Water resource sustainability; Extended cost-benefit analysis; Erosion value; Domestic water value; Raw water value.**

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## I. INTRODUCTION

Sustainability appears as the most important consideration of natural resource management policy in mining as well as forms the basic principle of environmental science. Therefore, there is a great need to preserve this water resource sustainability for a balanced environment [1]. Also, there is no denial the mining of natural supplies tends to substantially enhance economy development, generate extensive foreign exchange [2]–[4] create jobs, increase income, and serve as a potential income source for communities [5], [6]. The mining industry is a major contributor to the Australian economy [7].

However, the sector is one of the major contributors to environmental degradation [2], [8] and therefore, resulting to deficient water resources and ecosystems.

Forest clearing is responsible for erosion, river sedimentation, silting and turbidity [9] with significant impact on surface and groundwater supplies [10], [11]. This activity also influences downstream regions, resulting in a decreased marine quality and in addition, eliminates water resource ecosystem services for mining communities [12]. The limited fresh water availability implies less consumption [13]. Water resources are very important in sustaining economic development [14]. This situation illustrates the importance of water for the overall survival of humans and living organisms [15]. Furthermore, mining impact potentially instigates deficient hydrological function of forest as a catchment area, leading to a significant loss of water resource economic value [9]. Therefore, collaborative approach is required between hydrologists and economists to optimize the water value instruments [12]. Post-mining closure must adapt to local community expectations [16].

As a consequence, environmental damage is potentially repaired by reclamation [2], [3]. This process is also capable of reducing erosion and protecting soil degradation [17]. However, possible occurrence is greatly decreased by cultivating legium cover crops (LCC) in early vegetation stages [18]–[21]. Based on this study, mine reclamation demonstrated the robust capacity to restore environmental degradation, but was unable to completely reform the depleted water resources. Therefore, recycling appears as a crucial necessity, and also aids the improvement of water efficiency [22]. Furthermore, economic valuation is highly demanded as natural resources and environment continue to diminish in monetary value [23]–[25] In addition, cost-benefit analysis (BCA) serves as a comprehensive approach to assess the net impact on social, economic, and environmental aspects, as well as an effort to protect natural resources and communities  Also, BCA is used to engage water resource assessments for domestic purposes [26]–[28].  However, by evaluating the potential economic value, sustainability is easily analyzed, and with these provisions, environmental continuity and potable water supplies is adequately conserved. This circumstance agrees with the natural resource management policy, where mining natural resources is conducted while maintaining sustainability and environmental balance [1].

The purpose of this study is to develop water resource sustainability concept for a sustainable environment by analyzing the potential economic value of lost and recovered water supplies in mining areas, surrounding communities, and possible domestic use. In addition, the potential is evaluated by the extended NPV. Therefore, the water resources and coal mining environment are expected to remain potable and  also sustainable.

## II. The Materials and Method

### *A. Study Area*

This study was directly carried out in the coal mining of Tambang Air Laya (TAL) at PT Bukit Asam Persero Tbk, Muara Enim Regency, South Sumatra Province (Fig. 1).

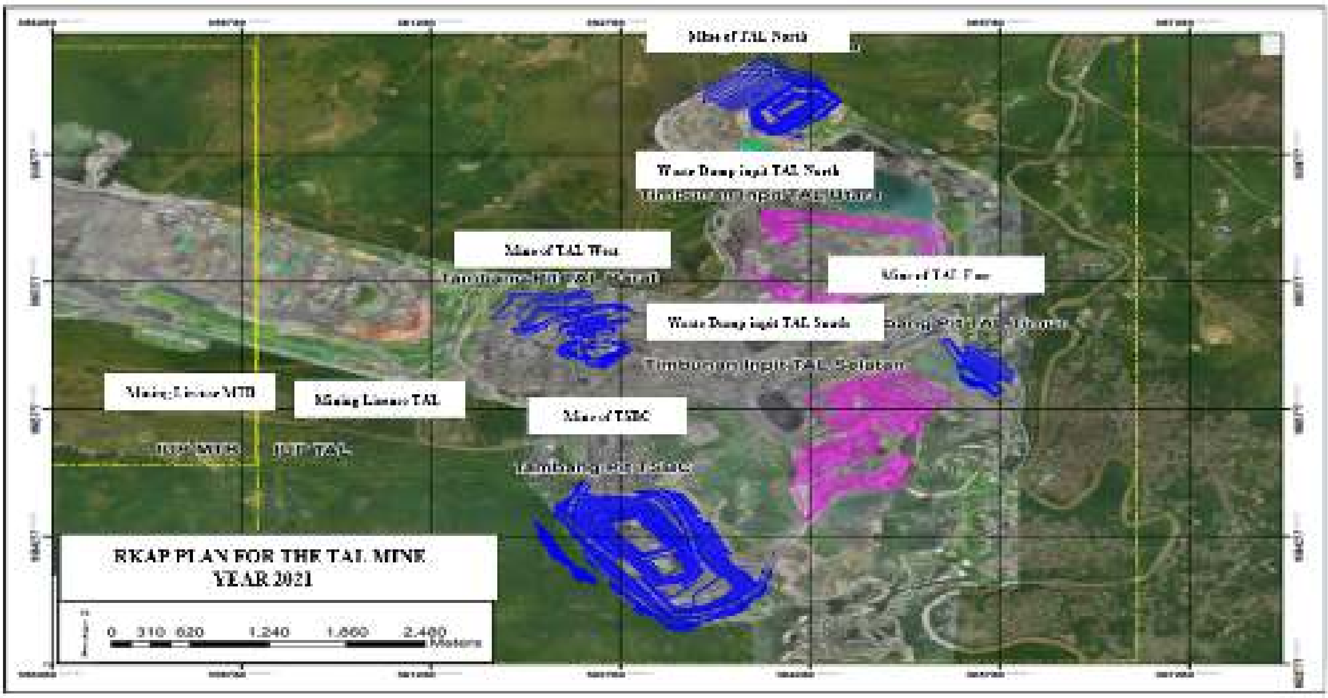


Fig. 1  Research Location

### *B. Cleared and reclaimed land, depleted water volume*

The cleared and reclaimed land, as well as depleted water volume were 3,106.59 ha, 1,374.5 ha and 48,738,366 $m^3$, respectively.

### *C. Methods*

This exploratory research employed the extended net present value (NPV) development model. The approach is useful in conducting economic valuation, in order to determine the economic value of water resource sustainability in coal mining. Quantitative techniques were applied to calculate the NPV of benefits and external costs of open coal mining on the value of water resources ecosystem services by these assessments.

### *D. Economic valuation using the Extended NPV method*

#### *1) Erosion value (potential economic value of water resources lost due to erosion)*

The erosion value was possibly calculated using the extended cost-benefit analysis (extended NPV), developed by [27].

$$Extended\ NPV_{ne} = \sum_{t=0}^{n} \frac{B_{npe} - C_{npe}}{(1+r)^t}$$

where:

$NPV_{ne}$ = Net Present Value

= The erosion value is derived from the

erosion recovery value and the erosion-resisting value (IDR)

$B_{npe}$ = The erosion recovery value is an external benefit of ex-mining land revegetation (IDR).

$C_{npe}$ = The erosion-resisting value is an external cost of the mining clearing impact (IDR)

n = Mine life (production and post production)

r = Discount rate = 1, 2,….n

t = Interest rate

2) *The domestic water value (potential economic value for the loss of drinking water resources for the community)*

Domestic water value was also evaluated using the extended NPV method. The above equation was derived from the extended benefit and cost analysis mathematical model by [27].

$$Extended\ NPV_{cad,T} = \sum_{t=0}^{n} \frac{C_{adr,T} - M_{pa}}{(1+r)^t}$$

Where:

$NPV_{cad}$ = Net Present Value

= Domestic water cost value of the community (IDR)

$C_{adr}$ = Average domestic water cost per respondent (IDR)

$M_{pa}$ = The number of people buying water around TAL PTBA

n = Mine life (production and post mining)

r = 1,2, …. n

t = Interest rate

T = Research year

3) *The raw water value (potential economic value of water resources from utilizing (recycling) depleted water)*

The raw water value was determined, using the developed method by a previous study [27].

$$Extended\ NPV_{nab} = \sum_{t=0}^{n} \frac{B_{ab} - C_{ab}}{(1+r)^t}$$

Where:

$NPV_{nab}$ = Net Present Value

= The raw water value originates from the benefit and cost estimates (IDR)

$B_{ab}$ = The raw water benefit from recycling (IDR)

$C_{ab}$ = The raw water cost from recycling (IDR)

n = Mine life (production and post mining)

r = 1,2, …. n

t = Interest rate

## III. Result and Discussion

### A. *Impact of mining on water resources and community*

Figure 2 represents the occurrence of soil erosion and water depletion, due to mining.

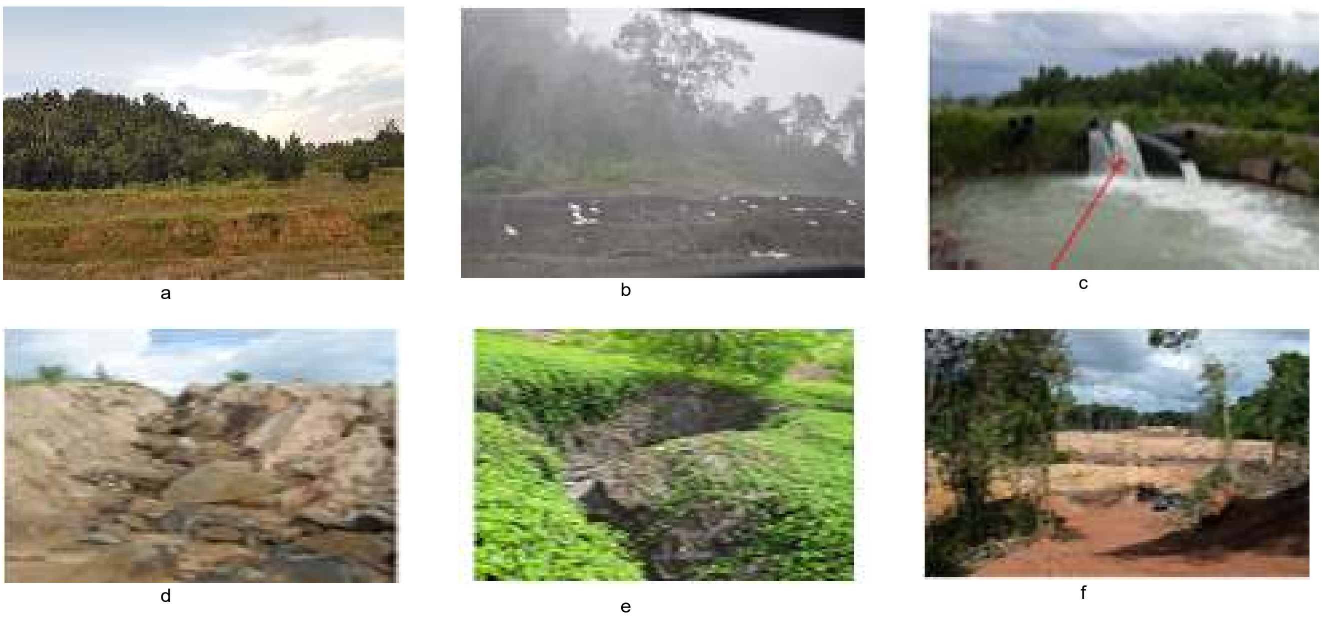


Fig. 2 Land erosion and water depletion

The above illustration showed the erosion occurrence on the ground/open land in Indonesian coal mining (a, b), and water depletion(c) due to pumped outlet at TAL PT Bukit Asam Persero Tbk, Kutai site (d), Suriname Artisanal Gold Mining (e).

Deforestation also instigated certain changes in water consumption, resulting in an erosion, where loss of hydrological function in forest, as a catchment area, possibly occurred. This event contributed to unsustainable outcome of water resources in terms of quantity, quality, and loss of plant economic value [9]. The situation also eliminated water ecosystem services as a resource provider [14], allowed sufficient space for environmental degradation as well as initiated chemical, physical, and biological environmental changes [8]. Furthermore, erosion is known to decrease surface water level, remove land cover, increase deforestation rate[11], [27], lower the water level, e.g in Baganuur mine, Mongolia, decline soil fertility, as well as trigger surface and groundwater pollution [3]. In addition, increased surface water runoff and sedimentation, decreased water quality, disrupted land and river transportation were observed [29]. However, an erosion of mine waste disposal, contamination of surface water, groundwater, and soil by released chemicals from the mining process, and extinction of certain species [10]. Soil erosion also occurred in open land of mining areas and river sediments [9], causing significant damages to flora, fauna, hydrological relationships, and soil. Previous studies have reported the incident as a major challenge in coal mining. Also, sedimentation results in river silting and turbidity [30]. However, turbidity is probably responsible in declining water quality as well as poses a major environmental problem. This condition is triggered by suspended particles, specifically sediment and soil particles from various erosion processes, as a result of human activities, e.g. mining [31]. These distributions require utmost priorities in measuring the trade-offs between economic water benefits, in terms of mining and usage [12]. Therefore, water resources necessitates protection to enable proper and general utilization, as a natural resource for society and living organisms. Furthermore, limited fresh water and groundwater by barely 3 and 30%, respectively causes less consumption [13].

The above points showed the importance of water to humans and entire living organisms [15]. Therefore, a collaborative approach between hydrologists and economists appears as a great necessity in optimizing the value of water instruments [12].

The above illustration showed the erosion occurrence on the ground/open land in Indonesian coal mining (a, b), and water depletion(c) due to pumped outlet at TAL PT Bukit Asam Persero Tbk, Kutai site (d), Suriname Artisanal Gold Mining (e).

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Mine Reclamation to Restore erosion

Reclamation in the coal mining area of TAL PT Bukit Asam Persero Tbk (Fig. 3).

a

b

Fig. 3 Reclamation of TAL PTBA

The conversion of land to forest by reverting to a tree-covered landscape or establishing a commercial forestry program is a major mine reclamation alternative (Figure 3). A typical example is the recovery of entire former Appalachian mines to become one of the most beautiful forests in the world. This process is highly needed to restore the forest structure and function [29] as erosion barrier [8], [9]. Therefore, reclamation process is believed to reduce erosion, prevent soil degradation, decline runoff rates, as well as increase porosity, permeability, and infiltration [17]. Moreover, erosion is possibly minimized by planting legium cover crops in early vegetation stages. Figure 4 represents the LCC cultivation in TAL PTBA reclamation zone.

a

b

Fig. 4 Planting of legume cover crops at PTBA Tambang Air Laya

Furthermore, the introduction of LCC tends to prevent and control soil erosion, enrich and protect soil, increase water availability, and also serves as an environment preservation technique. The improvement of soil's physical, chemical, and biological properties is achieved by increasing aggregate stability and reducing erosion. This provides various benefits for the agro-ecosystem, including erosion and weed control, as well as nutrient management [20]. Consequently, the improvement also prevents soil erosion, nutrient leakage, and provides ecosystem services, including erosion control, water quality regulation, soil moisture retention, accumulation of soil organic matter and microbial biomass, weed and pest control, as well as subsequent commercial crop yields. In addition, there is a possibility to regulate climate, soil, water as well as control erosion, clean water, and weed [32]. However, mitigating soil degradation functions as a shield from raindrops and surface runoff as well as increases the organic matter.

The reclamation of Hanjiawan coal mine region provided certain benefits for ecological development by enhancing soil quality, fertility, forest cover, and reducing soil/water loss, while serving an important role in economic and social aspects [11]. Moreover, effective reclamation offers long-term success and high mining profitability for future economic benefits. According to [3], PTBA's coal mining land reclamation was not barely for environmental improvement through conservation and protection, but also served as an economic investment activity to create harmony and social benefits for local industry, agriculture, forestry, livestock and eucalyptus plants. Furthermore, PTBA reclamation to mine closure in NPV by 2043 reported a potential economic value of USD 91,295,530 (1 USD = IDR 13,329). Meanwhile, Appalachia Kentucky instance was estimated at a total ecosystem value of $ 456,428,682 [33].

The results of this study demonstrated the inability of mine reclamation to entirely restore pumped water depletion from the outlets, but was possible to repair erosion. This circumstance was due to a more effective water absorption and storage in forest land, compared to reclaimed regions. Forest land exhibited sufficient porosity and very rapid permeability. The extensive soil porosity tends to prevent surface runoff, and therefore, resulted in an increasing water infiltration to a certain capacity, prior to saturation. Moreover, forest land showed great ability to restrain erosion, compared to reclaimed portions. In addition, excessive infiltration rate was due to higher biodiversity (understory, shrubs, and trees), litter production, porosity and permeability, as well as decreased bulk density, and therefore, preventing erosion. The vegetation diversity (biodiversity) is effective in reducing rain energy and inhibiting surface runoff velocity.

Consequently, in order to increase water efficiency, recycling offers a paramount alternative [22]. This approach was adopted in TAL PTBA mine outlet as a solution in restoring water resource lost, due to depletion, and subsequently in upholding sustainability, in terms of quality and quantity. The provision was in line with natural resource management policies, where the use of natural coal resource is to needed to maintain water resource sustainability for a balanced environment [1].

### B. *Economic valuation of the water resource sustainability for a sustainable environment using the extended cost-benefit analysis (Extended NPV) model*

Resources, economy, and environment are interdependent systems for an economic valuation [33]. This process was aimed at providing a monetary assessment for natural resource loss and environmental degradation impact on humans [25]. Economic valuation is very important as natural resources and the environment showed no monetary value The effort aims to provide environmental protection as the ecosystem is responsible for free natural water resource availability. In addition, the instance for Spain's Urdaibai Biosphere reserve in Spain was performed, using the framework of conservation and management policies to maximize social welfare. Furthermore, economic valuation was also conducted on the quality of water bodies, agricultural production, native forest protection, biodiversity, and recreation, where the local population were willing to financially support the management plan [26]. Cost-benefit analysis (CBA) serves as a comprehensive economic valuation method for net impact assessment on social, economic and environmental aspects [26], [27]. This process was used to provide a potable water resource assessment. Previous studies stated the provisions of benefits and costs directly (financially) and indirectly (externalities) in economic, social, and environmental aspects, by the open coal mining [3], [12], [33], [34]. Economic valuation in this study was performed on erosion, domestic water, and raw water values of TAL PTBA, using extended benefit and cost analysis model.

1. Erosion value

Based on calculations, (Formula 1), the erosion value (Extended NPVne) between 1997-2023 was specified as IDR 716,328,638,488,- or 716 billion rupiahs, with an erosion-resisting estimate ($C_{npe}$) of IDR 736,436,108,129,- or 738 billion rupiahs, and an erosion recovery ($B_{npe}$) of IDR 20,107,469,641,- or 20 billion. These results indicated the clearing of the forest by TAL PTBA coal mining triggered an erosion and therefore, eliminated the ecosystem service value, leading to an unsustainable supply by 716 billion rupiahs. This shortfall was due to the loss of forest ecosystem services as an erosion barrier, causing unsustainable water resources by 736 billion rupiahs. Furthermore, reclamation tends to reduce erosion as well as restore forest ecosystem services and sustainable water resources by 20 billion. However, reclamation possibly obtained a water resource sustainability value of 20 billion, but the lost water resources (716 billion rupiahs) were not completely restored. The calculation of erosion-resisting and recovery values employed benefit transfer similar to previous studies, including the use of flood control estimates, based on tropical forest types in Brazilian Amazon, with resemblance to Indonesian forests [27].

2. Domestic water value

The sample water emanated from Enim river in TAL PTBA. Figure 5 shows the river conditions of Enim and Artisanal gold mining site in Suriname (c).

a b c

Fig. 5 The condition of PTBA Enim river (a, b), and China's coal industry polluting the Yellow River basin (c) Green Peace, 2014

Based on the above figure, Enim river was known to be highly turbid and degraded. This condition matched previous reports, where the rivers formed a component of the degradable freshwater ecosystem [35]. The result was also in accordance with questionnaire data, where 43.07% of respondents did not utilize Enim water for drinking or cooking, based on bad smell and high turbidity. This showed the sample had declined in quality. Furthermore, the present study results were supported by Enim water quality test from Muara Enim Regional Environmental Agency (2020), where the unsuitability for bathing and consumption conformed with Minister of Health Regulation No.492/MENKES/PER/IV/2010 on Requirements for Drinking Water Quality, and the Minister of Health Regulation No. 416/MENKES/PER/IX/1990 on Clean Water. However, both guidelines require a maximum turbidity value of 5 and odorless state. Meanwhile, the turbidity for Enim River at all monitoring points reflected a value above 5, but was very stinky.

Erosion instigates the accumulation of sediments containing chemical toxins, responsible for groundwater pollution and changes in drinking water taste. The water appears turbid, due to the total dissolved solids (TDS) content from dispersed colloidal particles. Consequently, turbidity is known to significantly influence water color, and the suspended material adversely affects the quality. Excessive TDS tends to increase the turbidity and alters the transparency, while high water hardness triggers a bad taste During mining, runoff sediment quantity increased and the total suspended solids (TSS) in the form of soil surface layer were removed by rainwater flow. This deposit emanated from the degraded forest land [36]. The TSS as a pollutant accesses the hydrosphere and lithosphere through surface runoffs, causing water and soil pollution. Also, the suspended materials showed an adverse impact on water quality as sun penetration reduced. However, water turbidity increased due to a decrease in the photosynthetic process, where growth disturbances for the producing organisms were observed. Another TSS impact exceeding water quality standard was unable to support fishing activities.

Deforestation as a result of mining revealed a significant impact on the downstream area in the form of sediment transfer and instigated water pollution in terms of quality and quantity, inadequate clean water availability and river silting, due to elevated sedimentation responsible for reducing water depth [30]. The impact of coal mining on water resources triggers (1) surface water runoff and changing conditions in the catchment area, 2) destruction of aquifer structure, 3) damaging water circulation and balance conditions, and 4) water resource contamination. Furthermore, Gujiao coal mining activities played an important role in declining river runoff, while for one-tonne coal, a decrease in river, surface, and base flows, with an estimation of 2.87, 0.24, and 2.63 $m^3$ were observed, respectively. This condition significantly influenced water resource availability as a free ecosystem service [12]. The questionnaire data indicated the elimination of ecosystem services of Enim river as a free portable water source by TAL PTBA coal mining. This impact causes the inability of the community to enjoy free supply and therefore requires payment. The charges are used to purchase water from neighbors, in form of gallon and PAM water, although the costs gradually becomes higher. In this study, domestic water value was calculated, using contingent valuation/willingness to pay approach, and a mathematical model developed from previous study by the reclamation percentage method from time horizon [27]. Based on equation 2 calculations, the domestic water value of surrounding community in TAL PTBA between 1997-2023 was specified as IDR 421,293,032,887 or 421.3 billion rupiahs. These findings indicate TAL PTBA coal mining was responsible for the loss of environmental benefits to the community, devoid of ecosystem services. As a consequence, potable water resources were reportedly unsustainable at 421.3 billion rupiahs.

Therefore, the overall loss of water resource economic value in similar mines was estimated at IDR 1,137,621,671,374,- or 1.14 trillion rupiahs. This estimation was derived from the erosion and domestic water values of IDR 716,328,638,488,- or 716 billion and IDR 421,293,032,887,- or 421.3 billion rupiahs, respectively. Based on these results, significant loss was observed in water resources as an ecosystem service, resulting in an unsustainable water resources by 1.14 trillion rupiahs. However, recycling provides a potential solution in rebuilding the actual state.

*C. The raw water value from utilizing (recycling) TAL PTBA depleted water for drinking water*

One the basic needs of the mining industry is water [37]. Increasing water efficiency was conducted by adopting new technologies, more efficient processes, combining reuse, recycling, and finding alternative water sources [22]. The recycling of discharged water from the mine appears very useful to the native population as a domestic water source, reduces the potential for land subsidence, and conserves valuable water resources for sustainable local environmental management. In Indonesia, PT Adaro Indonesia had recycled (utilized) mine water, using water treatment plant 300 technology [27][38]. Subsequently, the processed potable water becomes safe for immediate consumption (Fig. 6).

Fig. 6 The processed mine void wastewater of PT Adaro Indonesia that can be consumed directly

Water from Eastern Kentucky underground coal mine was supplied for municipal, industrial, agricultural, or household purposes. Similar circumstance was also observed in the former West Virginia coal mine, where recycling tends to meet the local water supply needs. Baganuur, Mongolia mine water served as community and agricultural domestic sources. Furthermore, the use of Greenwood Arkansas coal mine water for drinking purposes generated economic benefits in excess of twenty million dollars. This utilization provided the benefit values for lost water resources and economics. Previous study showed the use of PT Adaro Indonesia's coal mine void water for drinking provided economic benefits of IDR 4,438,400,888,338 (± USD 369, 866, 740) or 4.4 trillion rupiahs.

The raw water value (Extended $NPV_{av}$) in this study was obtained by recycling the depleted water in TAL PTBA. This estimate originated from the raw water benefit value (Bav) and raw water cost value ($C_{av}$). Based on equation 3 results, $B_{av}$ and $C_{av}$ were evaluated as IDR 5,458,557,017,875,- or 5.5 trillion rupiahs, and 3,160,217,220,875,- or 3.2 trillion rupiahs, respectively. In addition, the raw water value (Extended $NPV_{ba}$) from the use of mine water was obtained as IDR 2,298,339,797,000,- or 2.3 trillion rupiahs. These calculations indicate the recycling approach generated a water resource sustainability value of 2.3 trillion rupiahs. Therefore, the results of this study confirmed the depleted water in TAL PTBA was used for drinking purpose to provide potential economic value as well as replace the water resources. Consequently, the utilization provided economic, social, and ecological benefits for the sustainability of water resources for a sustainable environment and the maintenance of potable supplies to the community.

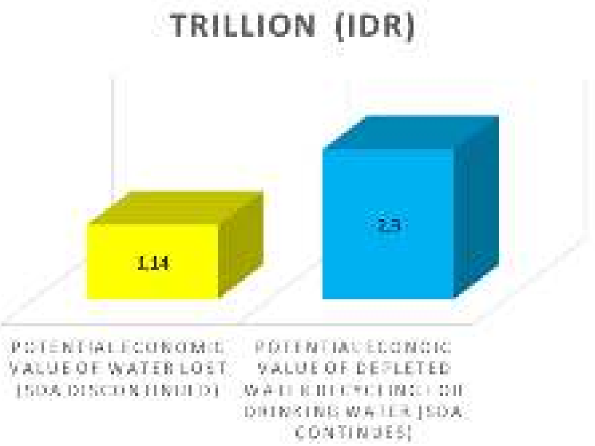


Fig. 7 Potential economic value of water resources

Table 1 generally represents the economic valuation results of benefit and cost values for the impact of TAL PTBA coal mining on the water resource sustainability for a sustainable environment.

TABLE I
THE ECONOMIC VALUATION RESULTS OF BENEFIT AND COST VALUES FOR THE IMPACT OF TAL PTBA COAL MINING ON THE WATER RESOURCE SUSTAINABILITY FOR A SUSTAINABLE ENVIRONMENT

| Benefits and costs components | Benefit and cost value | Unit (IDR) | Description |
|---|---|---|---|
| NPVne = Net Present Value (Project time 32 year) | Net erosion value | 716.328.638.488 | The erosion value was derived from the erosion recovery value and the erosion-resisting value |
| Bnpe | Erosion recovery benefit value | 20.107.469.641 | The erosion recovery value is an external benefit of ex-mining revegetation |
| Cnpe | Erosion-resisting cost value | 716.328.638.488 | The erosion-resisting value is an external cost of the impact of forest clearing by mining |
| NPVad = Net Present Value | Net domestic water value | 421.293.032.887 | The communal domestic water cost value was derived from the average domestic water cost value per respondent with the number of people buying water around TAL PTBA |
| Cadr | Average domestic water cost value per respondent | 36.931. | Average domestic water cost per respondent |
| Mpa | | 1.077.338.068. | The number of people buying water around TAL PTBA |
| NPVnab = Net Present Value | Net raw water value | 2.298.339.797.000 | The net raw water value originated from the raw water benefit value from recycling depleted water for drinking water with the cost of recycling depleted water for drinking water |
| Bab | Raw water benefit value | 5.458.557.017.875 | Raw water benefits from recycling depleted water for drinking water |
| Cab | Raw water cost value | 3.160.217.220.875 | Raw water cost from depleted water recycling for drinking water |

*D. The concept of water resource sustainability for sustainable environment in mining sector*

The background in the basic principles of environmental science comprises natural, man-made, and social [39], while sustainability deeply emphasizes the priority elements. Therefore, effective utilization and management of natural resources are greatly focused on environmental and natural resource sustainability. Based on the above principle, this study obtained the concept of water resource sustainability for a sustainable environment in the mining sector (Fig. 8). This view was developed from a previous study [27].

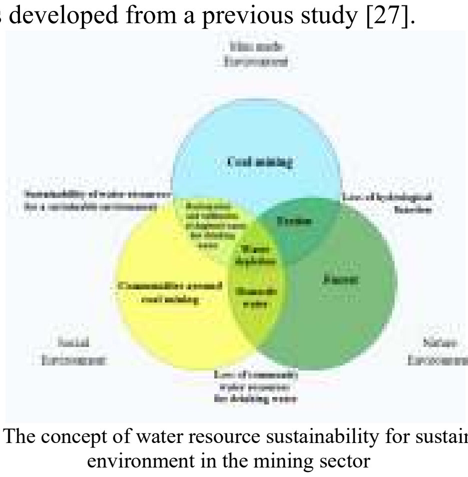


Fig. 8 The concept of water resource sustainability for sustainable environment in the mining sector

Coal mining with the ability to clear forests causes erosion, as the plants tends to lose the hydrological barrier function. Also, erosion is responsible for water depletion, as the forests no longer behave as a catchment area, and decline the water quality, resulting in loss of clean water resources for surrounding communities. However, to restore the hydrological barrier role and lost resources, reclamation and utilization of depleted water for domestic use are possibly employed. This process provides economic benefits for water resource sustainability for a balanced environment. The analysis of potential economic value, based on the above concept, showed water depletion was instigated by erosion. Also, loss of drinking water resources for the proximate communities in TAL PTBA mining generated unsustainable water resources by 1.14 trillion rupiahs. Utilization (recycling) of mine water provided water resource sustainability by 2.3 trillion rupiahs. This utilization generated sustainability benefits by 1.16 trillion rupiahs.

Furthermore, the recycling of depleted water due to TAL PTBA coal mining obtained a potential economic value for water resource sustainability by 1.16 trillion rupiahs (see Figure 7). Therefore, the water resources in the TAL PTBA and the environment tends to remain sustainable, as well as the surrounding communities.

## IV. Conclusions

The coal mining of Tambang Air Laya (TAL) PT Bukit Asam Tbk, South Sumatra province, Indonesia instigated an environmental impact, with the loss of forest area's function as an erosion barrier. In addition, a significant loss of Enim river's role as a clean water source for the surrounding communities was also reported. These circumstances resulted in unsustainable water resources at the sample location. However, mine reclamation was possible to reduce erosion, but unable to completely restore lost water resources. The recycling or utilization of depleted water for drinking purposes was not barely able to initiate a certain degree of replacement, but also obtained potential economic value for the water resource sustainability in the site area by 1.2 trillion rupiahs. Therefore, water resources remained sustainable and the sustainability of the environment and clean water resources for surrounding TAL PTBA communities appeared effectively maintained.

## Acknowledgment

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6. Editor decision (03-09-2022)

## Editor Decision

| | |
|---|---|
| Decision | Accept Submission 2022-09-03 |
| Notify Editor | Editor/Author Email Record 2022-06-05 |
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16th September 2021
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Dear **Restu Juniah**
Mining Engineering Faculty, Sriwijaya University, Palembang 30139, Indonesia
Coresponding Author : restu_juniah@yahoo.co.id

| | |
|---|---|
| Title: | Potential Economic Value of Water Resource Sustainability for Sustainable Environment: A Case Study in South Sumatra, Indonesia |
| Author(s): | Restu Juniah, M. Taufik Toha, Syaifudin Zakir, Hisni Rahmi |
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***The novelty:*** The concept of water resource sustainability in the context of a sustainable mining environment has been discovered through reclamation activities and the utilization of depleted mine void water for drinking. (1a)

**The Title:** The **title** summarizes the main idea or ideas of your study. A good **title contains** the fewest possible words that adequately describe the contents and/or purpose of your research paper. The **title** is without doubt the part of a paper that is read the most, and it is usually read first. The title of this paper is good and informative. The title of this paper has described the main idea with appropriate words and present the content of paper.

**The abstract**: has already explained, "What is the importance of research". [An abstract should be between 150-250 words.]. Abstract consists of 224 words (range between 150-250 words according to reviewer's input)

*Abstract—* **ABSTRACK**

Abstract –Erosion in coal mining land causes depletion in water quantity and quality, as well as inadequate drinking water resources for surrounding communities, making water resources unsustainable. Meanwhile, reclamation reduces erosion, but is unable to restore water depletion optimally, thus, these resources remain unsustainable. these resources remain unsustainable. The objectives of this study were to develop water resource sustainability concept for a sustainable environment by analyzing the potential economic value and secondly, calculate the water resource value due to erosion, reclamation, domestic and economic importance, by recycling efforts. The method used in this study was the Extended NPV. Furthermore, the total potential economic value of water resources loss resulting in water resource unsustainability was IDR 1,137,621,671,375 or IDR 1.14 trillion, while the potential economic value of depleted water utilization for drinking was IDR 2,298,339,797,000 or IDR 2.3 trillion. Therefore, this utilization provides potential economic value worth IDR 1.16 trillion, for the resources' sustainability in the TAL area of PTBA. The study's results found and recommended depleted water utilization for drinking as a suitable method to replace water resources lost due to erosion, community drinking water resource loss, and to discover a sustainable environment's water resources sustainability concept. In addition, the study formulates environmental economics as a new mining science related to natural resource economics as well as mining, for sustainable water resources and mining environment. **(224 words)**

Keywords—Water resource sustainability; extended cost-benefit analysis; erosion value; domestic and raw water value.

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**The Introduction** The results of this study are presented with the aim of introducing oneself to readers and attracting their attention. The attractiveness, clarity, fun and analytical capacity of the presentation will encourage the reader to read the article. The Introduction typically occupies 10-15% of the paper. The introduction should consists of two parts: It should include a few general statements about the subject to provide a background to your paper and to attract the reader's attention. It should try to explain why you are writing the paper. The introduction section has included a general introduction, problem definition, problem solution, study motivation, aims and objectives, gaps in the literature.

Noted: Please add some recent literature to further support the need for this research to be conducted.

Comment: Some recent literature to support the need for this research to be conducted have added.

### The Introduction (before the reviewer's revision)

Forest clearing is responsible for erosion, river sedimentation, silting and turbidity [7], [20]–[23] with significant impact on surface and groundwater supplies [24], [25]. This activity also influences downstream regions, resulting in a decreased marine quality [26], and in addition, eliminates water resource ecosystem services for mining communities [23], [27]–[29][23], [27]–[29], alongside instigating scarcity [30]. The limited fresh water availability implies less consumption [28], [31], [32]. Water resources are very important in sustaining economic development [33] and the entire mining operations require extensive supplies directly or indirectly [32]. This situation illustrates the importance of water for the overall survival of humans and living organisms [34]. Furthermore, mining impact potentially instigates deficient hydrological function of forest as a catchment area, leading to a significant loss of water resource economic value [13], [21]. Therefore, collaborative approach is required between hydrologists and economists to optimize the water value instruments [27] and mining resource analysis, due to these shortfalls [32] .

As a consequence, environmental damage is potentially repaired by reclamation [5]. This process is also capable of reducing erosion and protecting soil degradation [35]. However, possible occurrence is greatly decreased by cultivating legium cover crops (LCC) in early vegetation stages [36]–[41]. Based on this study, mine reclamation demonstrated the robust capacity to restore environmental degradation, but was unable to completely reform the depleted water resources. Therefore, recycling appears as a crucial necessity, and also aids the improvement of water efficiency [42]. Furthermore, economic valuation is highly demanded as natural resources and environment continue to diminish in monetary value [13], [29], [43]. In addition, cost-benefit analysis (BCA) serves as a comprehensive approach to assess the net impact on social, economic, and environmental aspects, as well as an effort to protect natural resources and communities [13], [44]–[47]. Also, BCA is used to engage water resource assessments for domestic purposes [29]. However, by evaluating the potential economic value, sustainability is easily analyzed, and with these provisions, environmental continuity and potable water supplies is adequately conserved. This circumstance agrees with the natural resource management policy, where mining natural resources is conducted while maintaining sustainability and environmental balance [2].

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The purpose of this study is to develop water resource sustainability concept for a sustainable environment by analyzing the potential economic value of lost and recovered water supplies in mining areas, surrounding communities, and possible domestic use. In addition, the potential is evaluated by the extended NPV. Therefore, the water resources and coal mining environment are expected to remain potable and also sustainable.

## The Introduction (After revision from the reviewer)

Sustainability appears as the most important consideration of natural resource management policy in mining as well as forms the basic principle of environmental science. Therefore, there is a great need to preserve this water resource sustainability for a balanced environment [1], [2]. Also, there is no denial the mining of natural supplies tends to substantially enhance economy development, generate extensive foreign exchange [3]–[9], create jobs, increase income, and serve as a potential income source for communities [3], [10]–[15]. Moreover, mining provides raw materials to build infrastructure and serve other industries, as well as generates large energy quantity, and others products [13], [16]. However, the sector is one of the major contributors to environmental degradation [3], [5], [7], [17]–[19], and therefore, resulting to deficient water resources and ecosystems.

Forest clearing is responsible for erosion, river sedimentation, silting and turbidity [7], [20]–[23] with significant impact on surface and groundwater supplies [24], [25]. This activity also influences downstream regions, resulting in a decreased marine quality [26], and in addition, eliminates water resource ecosystem services for mining communities [23], [27]–[29][23], [27]–[29], alongside instigating scarcity [30]. The limited fresh water availability implies less consumption [28], [31], [32]. Water resources are very important in sustaining economic development [33] and the entire mining operations require extensive supplies directly or indirectly [32]. This situation illustrates the importance of water for the overall survival of humans and living organisms [34]. Furthermore, mining impact potentially instigates deficient hydrological function of forest as a catchment area, leading to a significant loss of water resource economic value [13], [21]. Therefore, collaborative approach is required between hydrologists and economists to optimize the water value instruments [27] and mining resource analysis, due to these shortfalls [32] .

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**The Materials and methodology** The methods have described how the research question was answered, explain how the results were analysed.

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This study utilized direct observations of the opened and reclaimed land, as well as the declining water volume in the coal mining area of Bukit Asam Persero Company, situated in Muara Enim Regency, South Sumatra Province, Indonesia. The developed model, known as Extended Net Present Value (Extended NPV), was employed to assess the benefits and external costs associated with the impact of coal mining on the value of ecosystem services provided by water resources. The model enabled the determination of the erosion value, representing the economic potential of water resources lost due to erosion, as well as the domestic water value, indicating the economic potential resulting from the loss of drinking water resources for communities.

**Results and Discussion** have included findings, comparison with prior studies, causal arguments, and deductive arguments.

Noted: The research findings have adequately described and discussed. However, it would be better if the authors elaborate the implications of the findings and provide recommendations related to consumption of water, food and energy in the future. The discussion also needs to be supplemented with supporting literature to strengthen the research findings.

Land clearing activities associated with forest opening have significant implications for erosion and water depletion. Erosion disrupts the hydrological function of forests as catchment areas, leading to unsustainable water resources. It triggers surface water runoff, lowers water table levels, increases water turbidity due to sedimentation, contaminates surface and groundwater, degrades water resources, and poses risks of domestic water scarcity. Additionally, the loss of ecosystem services that provide free water for daily needs exacerbates these issues. The damage to flora and fauna, soil fertility loss, and diminishing economic value of forests further contribute to the decline in water quality and quantity. Water resources are crucial for sustaining economic development and supporting all living organisms, highlighting their vital role in maintaining life. In the mining sector, water resources are particularly essential as they are directly and indirectly required for mining operations, leading to ecological impacts. Therefore, it is important to protect water resources through appropriate utilization that benefits society and the environment [9], [14], [8], [11], [27], [3], [29]. Examples of erosion and water depletion can be observed in coal mines such as Bukit Asam Persero Company in Kutai East Kalimantan and artisanal gold mining in Suriname. Semen Baturaja Persero Company represents an instance of water depletion [27]. Reclamation activities, such as planting legume cover crops (LCC) like beans and sengon, can effectively reduce erosion, prevent soil degradation, decrease runoff levels, and improve porosity, permeability, and infiltration.

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This process is crucial for restoring forest structure and controlling erosion. Successful reclamation offers long-term benefits and profitability, ensuring future economic advantages in mining. In the case of Bukit Asam Persero Company's coal mining, land reclamation not only contributes to environmental improvement through soil conservation but also serves as an economic investment that fosters harmony and social benefits for local industries, agriculture, forestry, livestock, and essential oil plants. The potential economic value of reclamation activities until mine closure is estimated at USD 91,295,530 (1 USD = IDR 13,329). Similarly, in Appalachia Kentucky, the total value of the ecosystem is estimated to be $456,428,682. Reclamation activities can restore depleted water resources due to water scarcity, ensuring sustainable water resources in terms of quality and quantity [10], [9], [30], [31], [12]. Similarly, the utilization of depleted mine void water for drinking purposes can contribute to sustainable water resources. This aligns with the policy of natural resource management that the utilization of coal resources must ensure the sustainability of water resources for economically, socially, and ecologically sustainable mining operations [20], [32], [11], [33], [22].

**Conclusion:** This section shows how the work advances the field from the present state of knowledge. In some journals, it's a separate section; in others, it's the last paragraph of the Discussion section. Whatever the case, without a clear conclusion section, reviewers and readers will find it difficult to judge your work and whether it merits publication in the journal. A common error in this section is repeating the abstract, or just listing experimental results. Trivial statements of your results are unacceptable in this section.

Noted: Conclusions are well presented and described. However, the implications of the research findings need to be added as well as the recommendations for Indonesia regarding to optimize the function of the dams.

The coal mining operation conducted by Bukit Asam Company in Tambang Air Laya (TAL), South Sumatra Province, Indonesia, has had significant environmental impacts, particularly the loss of forest areas' erosion control function. As a result, the contamination of the Enim River due to sedimentation from the erosion process has adversely affected water resources in the study area, leading to their unsustainability. Although mine reclamation can reduce erosion, it cannot fully restore the lost water resources. Therefore, it is essential to consider the utilization of depleted mine void water as a viable solution. The potential economic value of utilizing the depleted mine void water for drinking water purposes and ensuring the sustainability of water resources in the study area amounts to IDR. 1.6 trillion. This approach not only provides economic benefits but also contributes to the maintenance of water resource sustainability and the overall well-being of the mining environment. It plays a crucial role in addressing the scarcity and loss of drinking water resources faced by the communities residing near the TAL PTBA coal mine, which have been affected by water resource pollution resulting from coal mining activities. This study strongly recommend the utilization of depleted coal mine void water for drinking water as an effective measure to alleviate the scarcity and loss of drinking water resources in the communities residing near the coal mine. This approach not only addresses the environmental challenges but also offers significant economic benefits, while ensuring the sustainability of water resources and the mining environment.

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**Reference:**
The author has added references to the publication, which has been published for the past three years, according to the reviewer's advice. **Please make sure that the format of "Index Terms" is correct.**

Comment: In general, the references used are appropriate and related to the research topic. For some references it would be better if the author updated to the latest edition. Several references have been updated to the latest edition according to reviewer input.

**Decision:** As a result of research with an appropriate methodology, **this paper is ACCEPTED for publication with minor revision.**

**Additional Comments:**

There are some grammatic mistakes and some mistakes in Punctuation. Please revise the Table numbers

**D. Recommendation** (Tick one)

1. Accepted without modifications. ☐
2. Accepted with minor corrections. ■
3. Accepted with major modification. ☐
4. Rejected. ☐

**E. Comments to the editors** (These comments will not be sent to the authors)

Please makes sure that all reviewers comment already answered by the author and fixed it in the manuscript.

Sincerely,

Regards,

**Rahmat Hidayat**

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## REVIEW FORM

8th February 2022
Ref. No. 5/ReV/IJASEIT/II/2022

Dear **Restu Juniah**
Mining Engineering Faculty, Sriwijaya University, Palembang 30139, Indonesia
Coresponding Author : restu_juniah@yahoo.co.id

| | |
|---|---|
| Title: | Potential Economic Value of Water Resource Sustainability for Sustainable Environment: A Case Study in South Sumatra, Indonesia |
| Author(s): | Restu Juniah, M. Taufik Toha, Syaifudin Zakir, Hisni Rahmi |
| Paper-ID | 16223 |

### A. Technical aspects

| | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1. The paper is within the scope of the Journal. | □ | □ | □ | □ | ■ | □ |
| 2. The paper is original. | □ | □ | □ | □ | □ | ■ |
| 3. The paper is free of technical errors. | □ | □ | □ | □ | ■ | □ |

### B. Communications aspects

| | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1. The paper is clearly readable. | □ | □ | □ | □ | ■ | □ |
| 2. The figures are clear & do clearly convey the intended message. | □ | □ | □ | □ | □ | ■ |
| 3. The length of the paper is appropriate. | □ | □ | □ | □ | ■ | □ |

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**C. Comments to the authors** (You may use another sheet of paper.)

Thank you very much for the submission through the online system. The manuscript has been reviewed. Please look into this and resubmission your manuscript after revision. Please find the revision in the attachment!

***The novelty:*** The concept of water resource sustainability in the context of a sustainable mining environment has been discovered through reclamation activities and the utilization of depleted mine void water for drinking (1a). The results recommended the use of depleted mine void water in Bukit Asam Persero Company's coal mining operations as a source of drinking water (2a).

**The Title:** The **title** summarizes the main idea or ideas of your study. A good **title contains** the fewest possible words that adequately describe the contents and/or purpose of your research paper. The **title** is without doubt the part of a paper that is read the most, and it is usually read first. The title of this paper is good and informative. The title of this paper has described the main idea with appropriate words and present the content of paper.

**The abstract**: There are no changes in the abstract/nothing to revise in the abstract. The manuscript has been read and translated by a reading professional.

*Abstract*— **ABSTRACK**

Abstract –Erosion in coal mining land causes depletion in water quantity and quality, as well as inadequate drinking water resources for surrounding communities, making water resources unsustainable. Meanwhile, reclamation reduces erosion, but is unable to restore water depletion optimally, thus, these resources remain unsustainable. these resources remain unsustainable. The objectives of this study were to develop water resource sustainability concept for a sustainable environment by analyzing the potential economic value and secondly, calculate the water resource value due to erosion, reclamation, domestic and economic importance, by recycling efforts. The method used in this study was the Extended NPV. Furthermore, the total potential economic value of water resources loss resulting in water resource unsustainability was IDR 1,137,621,671,375 or IDR 1.14 trillion, while the potential economic value of depleted water utilization for drinking was IDR 2,298,339,797,000 or IDR 2.3 trillion. Therefore, this utilization provides potential economic value worth IDR 1.16 trillion, for the resources' sustainability in the TAL area of PTBA. The study's results found and recommended depleted water utilization for drinking as a suitable method to replace water resources lost due to erosion, community drinking water resource loss, and to discover a sustainable environment's water resources sustainability concept. In addition, the study formulates environmental economics as a new mining science related to natural resource economics as well as mining, for sustainable water resources and mining environment. **(224 words)**

Keywords—Water resource sustainability; extended cost-benefit analysis; erosion value; domestic and raw water value.

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**The Introduction** The results of this study are presented with the aim of introducing oneself to readers and attracting their attention. The attractiveness, clarity, fun and analytical capacity of the presentation will encourage the reader to read the article. The Introduction typically occupies 10-15% of the paper. The introduction should consists of two parts: It should include a few general statements about the subject to provide a background to your paper and to attract the reader's attention. It should try to explain why you are writing the paper. The introduction section has included a general introduction, problem definition, problem solution, study motivation, aims and objectives, gaps in the literature.

Noted: Some recent literature to support the need for this research to be conducted have added.

**The Materials and methodology** The methods have described how the research question was answered, explain how the results were analysed.

Comment: The material and method section has revised and improved.

This study utilized direct observations of the opened and reclaimed land, as well as the declining water volume in the coal mining area of Bukit Asam Persero Company, situated in Muara Enim Regency, South Sumatra Province, Indonesia. The developed model, known as Extended Net Present Value (Extended NPV), was employed to assess the benefits and external costs associated with the impact of coal mining on the value of ecosystem services provided by water resources. The model enabled the determination of the erosion value, representing the economic potential of water resources lost due to erosion, as well as the domestic water value, indicating the economic potential resulting from the loss of drinking water resources for communities. (1a). The erosion value can be calculated by evaluating the erosion recovery value and the erosion-restraining value (Rp), along with the costs associated with the community's domestic water (Rp) throughout the lifespan of the mining operation, including both the production and post-production periods. (2a)

**Results and Discussion** have included findings, comparison with prior studies, causal arguments, and deductive arguments.

Noted: The research findings have revised and improved. However, it would be better if the authors elaborate more the implications of the research findings. The recommendations should be based on the findings.

Land clearing activities associated with forest opening have significant implications for erosion and water depletion. Erosion disrupts the hydrological function of forests as catchment areas, leading to unsustainable water resources.

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It triggers surface water runoff, lowers water table levels, increases water turbidity due to sedimentation, contaminates surface and groundwater, degrades water resources, and poses risks of domestic water scarcity. Additionally, the loss of ecosystem services that provide free water for daily needs exacerbates these issues. The damage to flora and fauna, soil fertility loss, and diminishing economic value of forests further contribute to the decline in water quality and quantity. Water resources are crucial for sustaining economic development and supporting all living organisms, highlighting their vital role in maintaining life. In the mining sector, water resources are particularly essential as they are directly and indirectly required for mining operations, leading to ecological impacts. Therefore, it is important to protect water resources through appropriate utilization that benefits society and the environment [9], [14], [8], [11], [27], [3], [29]. Examples of erosion and water depletion can be observed in coal mines such as Bukit Asam Persero Company in Kutai East Kalimantan and artisanal gold mining in Suriname. Semen Baturaja Persero Company represents an instance of water depletion [27]. Reclamation activities, such as planting legume cover crops (LCC) like beans and sengon, can effectively reduce erosion, prevent soil degradation, decrease runoff levels, and improve porosity, permeability, and infiltration. This process is crucial for restoring forest structure and controlling erosion. Successful reclamation offers long-term benefits and profitability, ensuring future economic advantages in mining. In the case of Bukit Asam Persero Company's coal mining, land reclamation not only contributes to environmental improvement through soil conservation but also serves as an economic investment that fosters harmony and social benefits for local industries, agriculture, forestry, livestock, and essential oil plants. The potential economic value of reclamation activities until mine closure is estimated at USD 91,295,530 (1 USD = IDR 13,329). Similarly, in Appalachia Kentucky, the total value of the ecosystem is estimated to be $456,428,682. Reclamation activities can restore depleted water resources due to water scarcity, ensuring sustainable water resources in terms of quality and quantity [10], [9], [30], [31], [12]. Similarly, the utilization of depleted mine void water for drinking purposes can contribute to sustainable water resources. This aligns with the policy of natural resource management that the utilization of coal resources must ensure the sustainability of water resources for economically, socially, and ecologically sustainable mining operations [20], [32], [11], [33], [22]. (1a)

The economic value of sustainable water resources for environmental sustainability is assessed using the Extended Net Present Value (Extended NPV) approach. This method recognizes the interconnectedness of resources, economics, and the environment in economic evaluations [33]. Its objective is to provide a monetary assessment of the loss of natural resources and the impact of environmental degradation on human well-being [25]. Economic valuation is crucial because natural resources and the environment do not have an inherent monetary value. By applying this technique, efforts can be made to protect the environment as an ecosystem that provides valuable natural resources. Cost-benefit analysis (CBA), a commonly used economic valuation tool, enables a comprehensive evaluation of the net impacts on the social, economic, and environmental aspects associated with the utilization of depleted mine void water for drinking purposes. This analysis captures both the direct (financial) and indirect (externalities) benefits and costs in the economic, social, and environmental dimensions of open coal mining impacts. (2a)

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**Conclusion:** This section shows how the work advances the field from the present state of knowledge. In some journals, it's a separate section; in others, it's the last paragraph of the Discussion section. Whatever the case, without a clear conclusion section, reviewers and readers will find it difficult to judge your work and whether it merits publication in the journal. A common error in this section is repeating the abstract, or just listing experimental results. Trivial statements of your results are unacceptable in this section.

Comment: The conclusions section has revised and improved.

The coal mining operation conducted by Bukit Asam Company in Tambang Air Laya (TAL), South Sumatra Province, Indonesia, has had significant environmental impacts, particularly the loss of forest areas' erosion control function. As a result, the contamination of the Enim River due to sedimentation from the erosion process has adversely affected water resources in the study area, leading to their unsustainability. Although mine reclamation can reduce erosion, it cannot fully restore the lost water resources. Therefore, it is essential to consider the utilization of depleted mine void water as a viable solution. The potential economic value of utilizing the depleted mine void water for drinking water purposes and ensuring the sustainability of water resources in the study area amounts to IDR. 1.6 trillion. This approach not only provides economic benefits but also contributes to the maintenance of water resource sustainability and the overall well-being of the mining environment. It plays a crucial role in addressing the scarcity and loss of drinking water resources faced by the communities residing near the TAL PTBA coal mine, which have been affected by water resource pollution resulting from coal mining activities. The findings of this study strongly recommend the utilization of depleted coal mine void water for drinking water as an effective measure to alleviate the scarcity and loss of drinking water resources in the communities residing near the coal mine. This approach not only addresses the environmental challenges but also offers significant economic benefits, while ensuring the sustainability of water resources and the mining environment.

**Reference:**
Please ensure that the citations and references are correct. Use Mendeley in writing quotes and references. The citation style used is IEEE, please follow this style in writing all citations and references.

Comment: Quotations and references are correct. Already using Mendeley in writing quotes and references. The citation style used is IEEE, in writing all citations and references. (2a).

**Decision: This paper is ACCEPTED for publication with minor revision.**

**Additional Comments:**

Please correct some grammatical errors.

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**D. Recommendation** (Tick one)

1. Accepted without modifications. ☐
2. Accepted with minor corrections. ■
3. Accepted with major modification. ☐
4. Rejected. ☐

**E. Comments to the editors** (These comments will not be sent to the authors)

Please makes sure that all reviewers comment already answered by the author and fixed it in the manuscript.

Sincerely,

Regards,

**Rahmat Hidayat**

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# REVIEW FORM

5th June 2022
Ref. No. 7/ReV/IJASEIT/VI/2022

Dear **Restu Juniah**
Mining Engineering Faculty, Sriwijaya University, Palembang 30139, Indonesia
Coresponding Author : restu_juniah@yahoo.co.id

| | |
|---|---|
| Title: | Potential Economic Value of Water Resource Sustainability for Sustainable Environment: A Case Study in South Sumatra, Indonesia |
| Author(s): | Restu Juniah, M. Taufik Toha, Syaifudin Zakir, Hisni Rahmi |
| Paper-ID | 16223 |

## A. Technical aspects

| | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1. The paper is within the scope of the Journal. | □ | □ | □ | □ | ■ | □ |
| 2. The paper is original. | □ | □ | □ | □ | □ | ■ |
| 3. The paper is free of technical errors. | □ | □ | □ | □ | ■ | □ |

## B. Communications aspects

| | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1. The paper is clearly readable. | □ | □ | □ | □ | ■ | □ |
| 2. The figures are clear & do clearly convey the intended message. | □ | □ | □ | □ | □ | ■ |
| 3. The length of the paper is appropriate. | □ | □ | □ | □ | ■ | □ |

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**C. Comments to the authors** (You may use another sheet of paper.)

Thank you very much for the submission through the online system. The manuscript has been reviewed. Please look into this and resubmission your manuscript after revision. Please find the revision in the attachment!

***The novelty:*** The concept of water resource sustainability in the context of a sustainable mining environment has been discovered through reclamation activities and the utilization of depleted mine void water for drinking. (1a). The results recommended the use of depleted mine void water in Bukit Asam Persero Company's coal mining operations as a source of drinking water. (2a). The utilization of depleted mine void water for drinking water offers an economic advantage, valued at 1.16 trillion rupiah, brings social benefits to the communities living in the vicinity of the coal mining area and provides ecological benefits. (3a)

**The Title:** The **title** summarizes the main idea or ideas of your study. A good **title contains** the fewest possible words that adequately describe the contents and/or purpose of your research paper. The **title** is without doubt the part of a paper that is read the most, and it is usually read first. The title of this paper is good and informative. The title of this paper has described the main idea with appropriate words and present the content of paper.

**The abstract**: There are no changes in the abstract/nothing to revise in the abstract. The manuscript has been read and translated by a reading professional.

*Abstract*— **ABSTRACK**

Abstract –Erosion in coal mining land causes depletion in water quantity and quality, as well as inadequate drinking water resources for surrounding communities, making water resources unsustainable. Meanwhile, reclamation reduces erosion, but is unable to restore water depletion optimally, thus, these resources remain unsustainable. these resources remain unsustainable. The objectives of this study were to develop water resource sustainability concept for a sustainable environment by analyzing the potential economic value and secondly, calculate the water resource value due to erosion, reclamation, domestic and economic importance, by recycling efforts. The method used in this study was the Extended NPV. Furthermore, the total potential economic value of water resources loss resulting in water resource unsustainability was IDR 1,137,621,671,375 or IDR 1.14 trillion, while the potential economic value of depleted water utilization for drinking was IDR 2,298,339,797,000 or IDR 2.3 trillion. Therefore, this utilization provides potential economic value worth IDR 1.16 trillion, for the resources' sustainability in the TAL area of PTBA. The study's results found and recommended depleted water utilization for drinking as a suitable method to replace water resources lost due to erosion, community drinking water resource loss, and to discover a sustainable environment's water resources sustainability concept. In addition, the study formulates environmental economics as a new mining science related to natural resource economics as well as mining, for sustainable water resources and mining environment. **(224 words)**

Keywords—Water resource sustainability; extended cost-benefit analysis; erosion value; domestic and raw water value.

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**The Introduction** The results of this study are presented with the aim of introducing oneself to readers and attracting their attention. The attractiveness, clarity, fun and analytical capacity of the presentation will encourage the reader to read the article. The Introduction typically occupies 10-15% of the paper. The introduction should consists of two parts: It should include a few general statements about the subject to provide a background to your paper and to attract the reader's attention. It should try to explain why you are writing the paper. The introduction section has included a general introduction, problem definition, problem solution, study motivation, aims and objectives, gaps in the literature.

Noted: Some recent literature to support the need for this research to be conducted have added.

**The Materials and methodology** The methods have described how the research question was answered, explain how the results were analysed.

Comment: The material and method section has revised and improved.

This study utilized direct observations of the opened and reclaimed land, as well as the declining water volume in the coal mining area of Bukit Asam Persero Company, situated in Muara Enim Regency, South Sumatra Province, Indonesia. The developed model, known as Extended Net Present Value (Extended NPV), was employed to assess the benefits and external costs associated with the impact of coal mining on the value of ecosystem services provided by water resources. The model enabled the determination of the erosion value, representing the economic potential of water resources lost due to erosion, as well as the domestic water value, indicating the economic potential resulting from the loss of drinking water resources for communities. (1a). The erosion value can be calculated by evaluating the erosion recovery value and the erosion-restraining value (Rp), along with the costs associated with the community's domestic water (Rp) throughout the lifespan of the mining operation, including both the production and post-production periods. (2a). The determination of this value is crucial in assessing the sustainability of water resources in the study area and ensuring the economic, social, and environmental sustainability of coal mining operations. This value is needed to determine the sustainability of water resources in the study area and and to ensure the economic, social, and environmental sustainability of coal mining operations. (3a).

**Results and Discussion** have included findings, comparison with prior studies, causal arguments, and deductive arguments.

Comment: The research findings have revised and improved. The discussions are also revised and improved.

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Land clearing activities associated with forest opening have significant implications for erosion and water depletion. Erosion disrupts the hydrological function of forests as catchment areas, leading to unsustainable water resources. It triggers surface water runoff, lowers water table levels, increases water turbidity due to sedimentation, contaminates surface and groundwater, degrades water resources, and poses risks of domestic water scarcity. Additionally, the loss of ecosystem services that provide free water for daily needs exacerbates these issues. The damage to flora and fauna, soil fertility loss, and diminishing economic value of forests further contribute to the decline in water quality and quantity. Water resources are crucial for sustaining economic development and supporting all living organisms, highlighting their vital role in maintaining life. In the mining sector, water resources are particularly essential as they are directly and indirectly required for mining operations, leading to ecological impacts. Therefore, it is important to protect water resources through appropriate utilization that benefits society and the environment [9], [14], [8], [11], [27], [3], [29]. Examples of erosion and water depletion can be observed in coal mines such as Bukit Asam Persero Company in Kutai East Kalimantan and artisanal gold mining in Suriname. Semen Baturaja Persero Company represents an instance of water depletion [27]. Reclamation activities, such as planting legume cover crops (LCC) like beans and sengon, can effectively reduce erosion, prevent soil degradation, decrease runoff levels, and improve porosity, permeability, and infiltration. This process is crucial for restoring forest structure and controlling erosion. Successful reclamation offers long-term benefits and profitability, ensuring future economic advantages in mining. In the case of Bukit Asam Persero Company's coal mining, land reclamation not only contributes to environmental improvement through soil conservation but also serves as an economic investment that fosters harmony and social benefits for local industries, agriculture, forestry, livestock, and essential oil plants. The potential economic value of reclamation activities until mine closure is estimated at USD 91,295,530 (1 USD = IDR 13,329). Similarly, in Appalachia Kentucky, the total value of the ecosystem is estimated to be $456,428,682. Reclamation activities can restore depleted water resources due to water scarcity, ensuring sustainable water resources in terms of quality and quantity [10], [9], [30], [31], [12]. Similarly, the utilization of depleted mine void water for drinking purposes can contribute to sustainable water resources. This aligns with the policy of natural resource management that the utilization of coal resources must ensure the sustainability of water resources for economically, socially, and ecologically sustainable mining operations [20], [32], [11], [33], [22]. (1a)

The economic value of sustainable water resources for environmental sustainability is assessed using the Extended Net Present Value (Extended NPV) approach. This method recognizes the interconnectedness of resources, economics, and the environment in economic evaluations [33]. Its objective is to provide a monetary assessment of the loss of natural resources and the impact of environmental degradation on human well-being [25]. Economic valuation is crucial because natural resources and the environment do not have an inherent monetary value. By applying this technique, efforts can be made to protect the environment as an ecosystem that provides valuable natural resources. Cost-benefit analysis (CBA), a commonly used economic valuation tool, enables a comprehensive evaluation of the net impacts on the social, economic, and environmental aspects associated with the utilization of depleted mine void water for drinking purposes.

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This analysis captures both the direct (financial) and indirect (externalities) benefits and costs in the economic, social, and environmental dimensions of open coal mining impacts. (2a). This study discovered the concept of sustainable water resources for environmentally sustainable mining by utilizing reclamation activities and depleted mine void water for drinking purposes. Based on this concept, the analysis of the potential economic value indicated that water depletion is triggered by erosion. Additionally, the loss of drinking water resources for communities residing near the TAL PTBA mining area results in an unsustainable water resource situation valued at IDR 1.14 trillion. Through the utilization (recycling) of depleted mine void water, water resource sustainability amounting to IDR 2.3 trillion can be achieved, yielding sustainability benefits worth IDR 1.16 trillion. This utilization of depleted water from TAL PTBA coal mining holds significant potential for water resource sustainability, amounting to IDR 1.16 trillion. As a result, the water resources in the TAL PTBA area and the surrounding environment will remain sustainable, ensuring the well-being of the communities residing near the mine. (3a)

**Conclusion:** This section shows how the work advances the field from the present state of knowledge. In some journals, it's a separate section; in others, it's the last paragraph of the Discussion section. Whatever the case, without a clear conclusion section, reviewers and readers will find it difficult to judge your work and whether it merits publication in the journal. A common error in this section is repeating the abstract, or just listing experimental results. Trivial statements of your results are unacceptable in this section.

Comment: The conclusions section has revised and improved.

The coal mining operation conducted by Bukit Asam Company in Tambang Air Laya (TAL), South Sumatra Province, Indonesia, has had significant environmental impacts, particularly the loss of forest areas' erosion control function. As a result, the contamination of the Enim River due to sedimentation from the erosion process has adversely affected water resources in the study area, leading to their unsustainability. Although mine reclamation can reduce erosion, it cannot fully restore the lost water resources. Therefore, it is essential to consider the utilization of depleted mine void water as a viable solution. The potential economic value of utilizing the depleted mine void water for drinking water purposes and ensuring the sustainability of water resources in the study area amounts to IDR. 1.6 trillion. This approach not only provides economic benefits but also contributes to the maintenance of water resource sustainability and the overall well-being of the mining environment. It plays a crucial role in addressing the scarcity and loss of drinking water resources faced by the communities residing near the TAL PTBA coal mine, which have been affected by water resource pollution resulting from coal mining activities. The findings of this study strongly recommend the utilization of depleted coal mine void water for drinking water as an effective measure to alleviate the scarcity and loss of drinking water resources in the communities residing near the coal mine. This approach not only addresses the environmental challenges but also offers significant economic benefits, while ensuring the sustainability of water resources and the mining environment.

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**Reference:**
The citations and references have corrected.

**Decision: This paper can be ACCEPTED for publication.**

**Additional Comments:**

Please correct some grammatical errors.

**D. Recommendation** (Tick one)

1. Accepted without modifications. ☐
2. Accepted with minor corrections. ■
3. Accepted with major modification. ☐
4. Rejected. ☐

**E. Comments to the editors** (These comments will not be sent to the authors)

Please makes sure that all reviewers comment already answered by the author and fixed it in the manuscript.

Sincerely,

Regards,

**Rahmat Hidayat**

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