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

Restu Juniah (✉ restu_juniah@yahoo.co.id)
sriwijaya university
Muhammad Taufik Toha
Sriwijaya University: Universitas Sriwijaya
Syaifudin Zakir
Sriwijaya University: Universitas Sriwijaya
Hisni Rahmi
STTIND: Sekolah Tinggi Teknologi Industri Padang

Research

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Abstract

Effective water resource management offers a very significant value across social, economic, commercial and environmental application. For this fundamental reason, adequate sustainability becomes equally crucial. Therefore, activities geared towards the depletion in quantity, quality, and loss of potable water resources, particularly for communities, demand urgent reconsiderations. 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. However, recycling depleted water utilization for drinking provides economic value for the environment, as well as the community's drinking water resources' availability and sustainability. 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.

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, 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], 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.

Material And Methods

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).

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.

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.

Economic valuation using the Extended NPV method

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:

NPVne = Net Present Value

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

Bnpe = The erosion recovery value is an external benefit of ex-mining land revegetation (IDR).

Cnpe = 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

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:

NPVcad = Net Present Value

= Domestic water cost value of the community (IDR)

Cadr = Average domestic water cost per respondent (IDR)

Mpa = 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

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:

NPVnab = Net Present Value

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

Bab = The raw water benefit from recycling (IDR)

Cab = The raw water cost from recycling (IDR)

n = Mine life (production and post mining)

r = 1,2, …. n

t = Interest rate

Results And Discussion

Impact of mining on water resources and community

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

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, 18]. 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 [19], [21, 23], 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]. 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].

Mine Reclamation to Restore erosion

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

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 (Fig. 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 [55]. 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.

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 [56]. 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 [57]. 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 [58].

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 [55].

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].

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 [58]. 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, 27, 44, 45, 57–62]. 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.

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 (Cnpe) of IDR 736,436,108,129,- or 738 billion rupiahs, and an erosion recovery (Bnpe) 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 [55], 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 [64].

Domestic water value

a. Domestic water quality

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) [19].

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 [65]. 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 [66].

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 [67]. 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 [68]. 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 [67]. Another TSS impact exceeding water quality standard was unable to support fishing activities [69]. 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 [19].

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 [49], and river silting, due to elevated sedimentation responsible for reducing water depth [18, 23, 51]. 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 m3 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 Eq. 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.

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).

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 NPVav) 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 (Cav). Based on Eq. 3 results, Bav and Cav 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 NPVba) 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.

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 1
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

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].

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 Fig. 7). Therefore, the water resources in the TAL PTBA and the environment tends to remain sustainable, as well as the surrounding communities.

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.

Declarations

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Authors’ contributions

RJ prepared and revised draft manuscripts, and also involved in methodology development, formal analysis and data presentation. MTT contributes to the concept of mine reclamation. SZ contributes to socio-economic analysis. HR contributed to the presentation of the manuscript data. All authors reviewed and approved the final manuscript.

Availability of data and materials

The data used to support the findings of this study are available from the corresponding author upon request.

Competing interests

The authors declare they have no competing interests.

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Figures

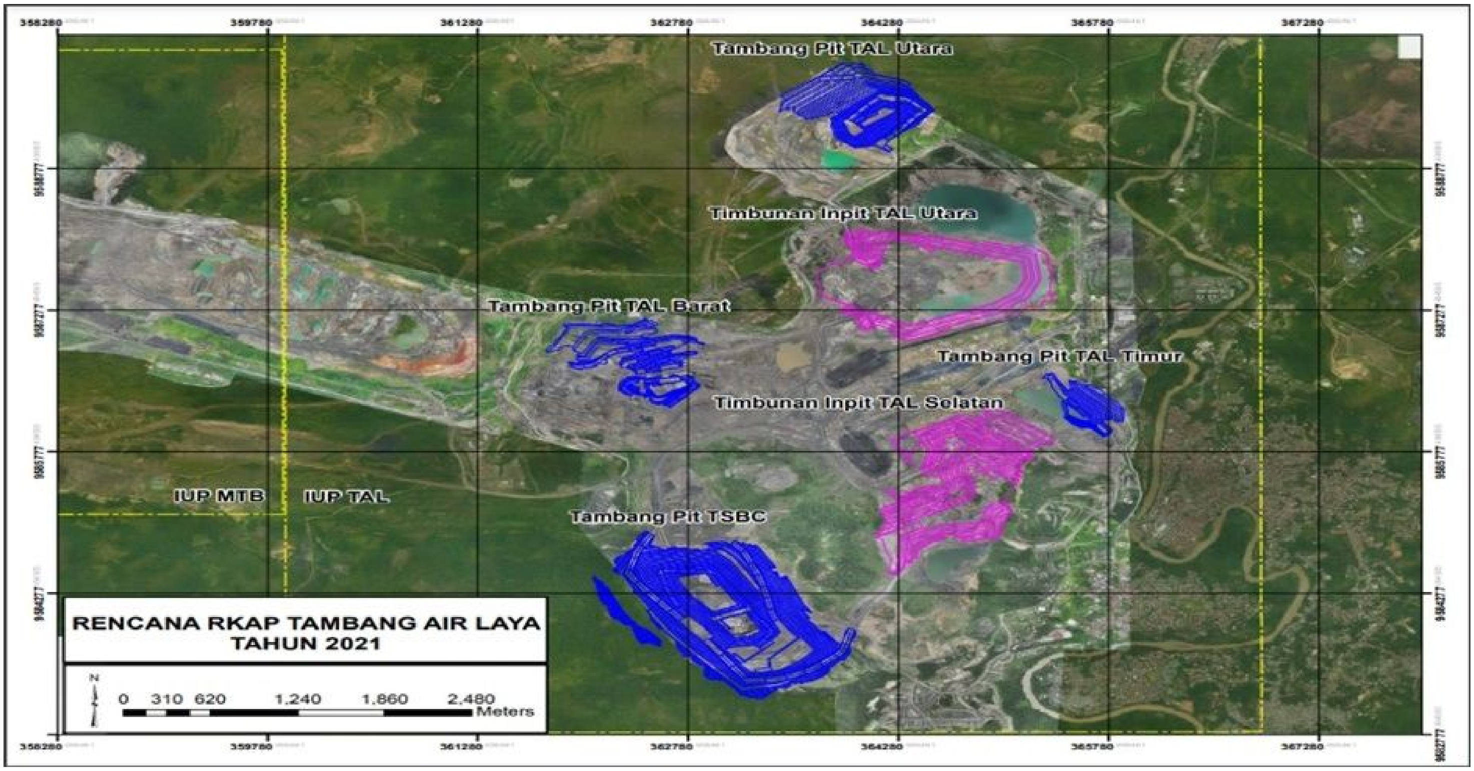
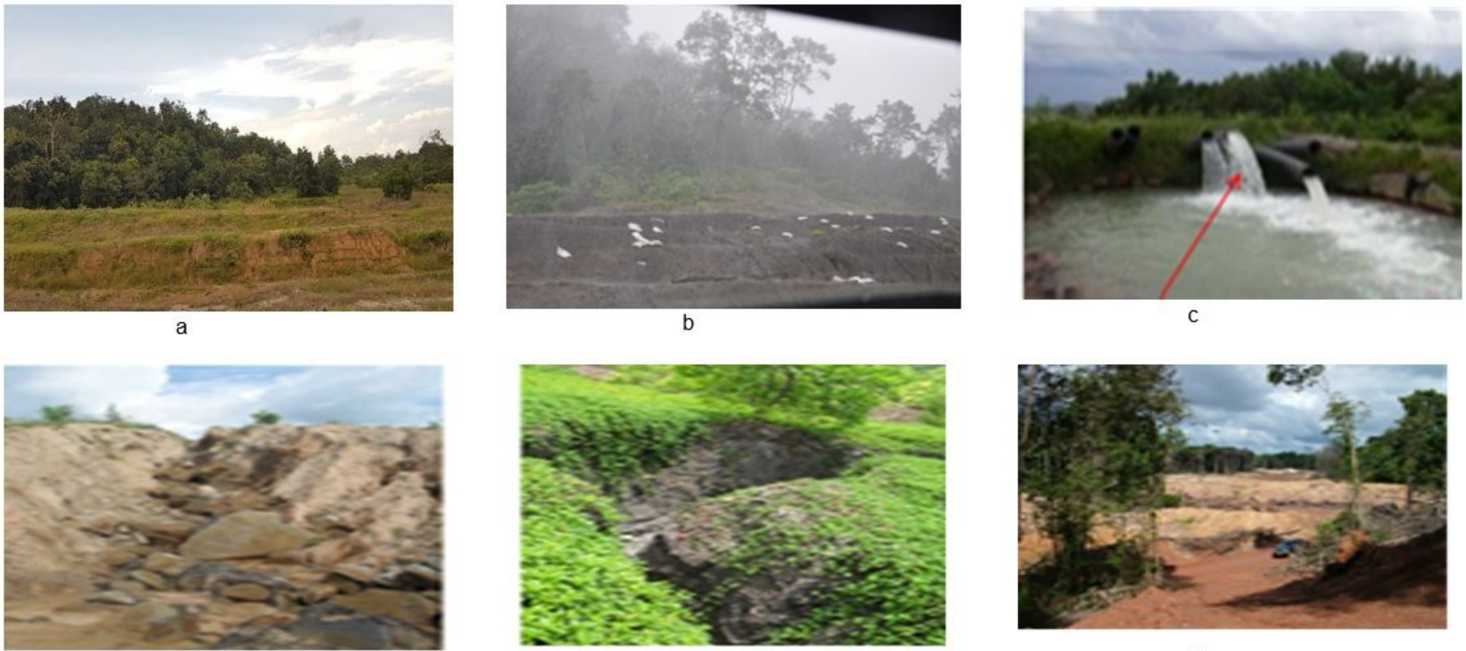


Figure 1

Research Location. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.



a b c d e f

Figure 2

Land erosion and water depletion

a b

Figure 3

Reclamation of TAL PTBA

a b

Figure 4

Planting of legume cover crops at PTBA Tambang Air Laya

Figure 5

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

Figure 6

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

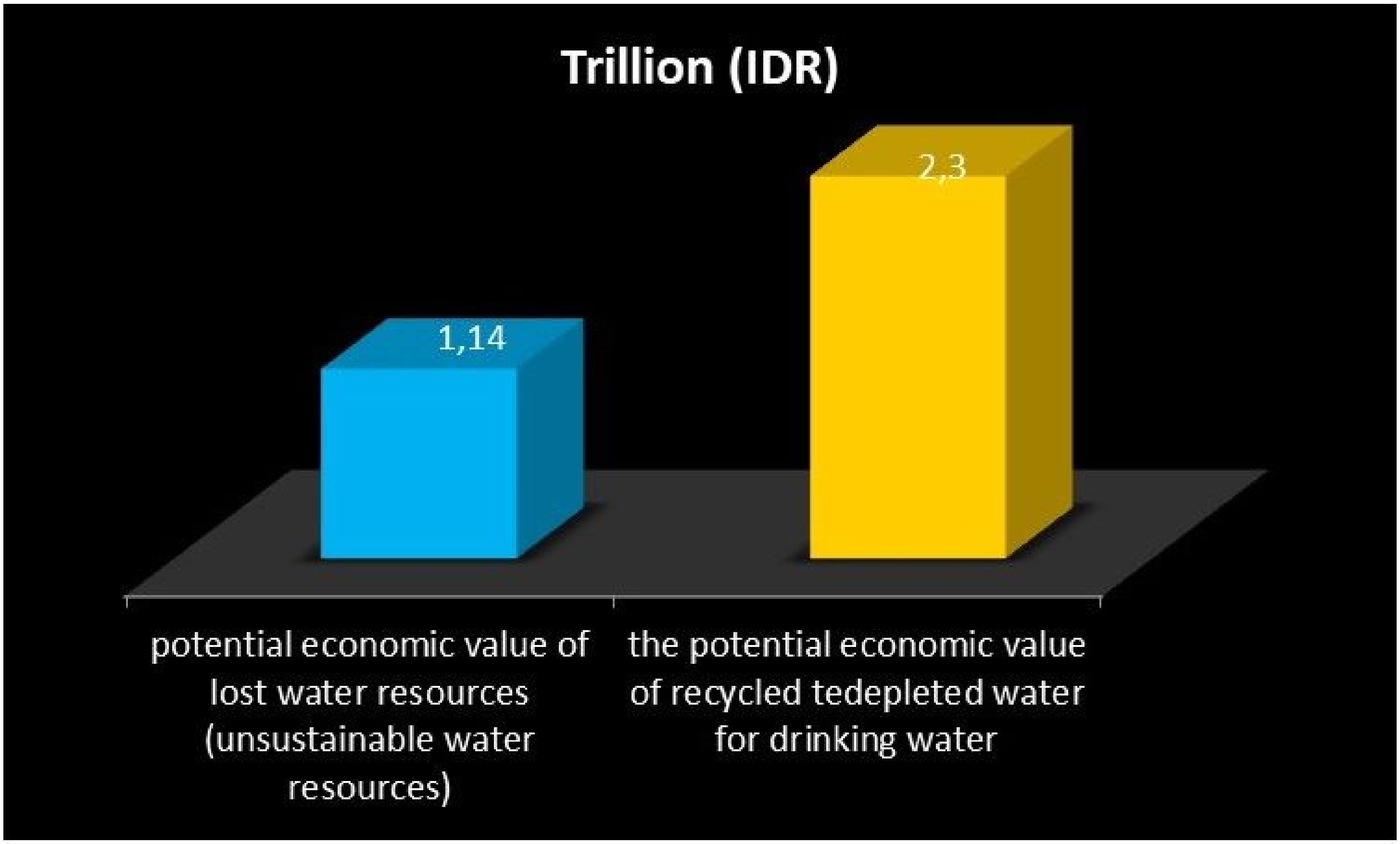


Figure 7

Potential economic value of water resources

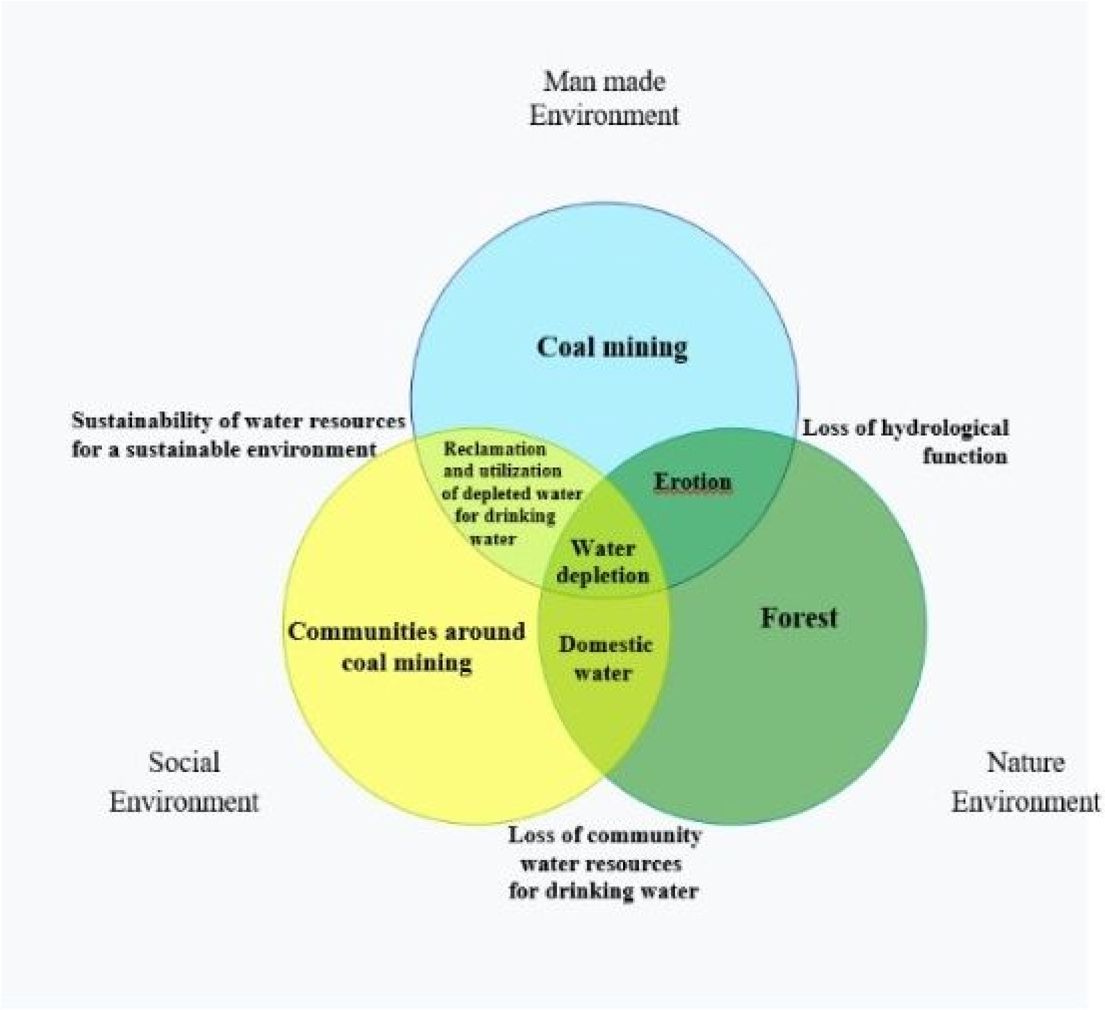


Figure 8

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