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Research Article

The impact of soil and rock mining on freshwater provisioning services in Peniraman Village, Mempawah Regency, West Kalimantan

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Abstract

Various human activities can affect ecosystem services, including mining activities. Since 1960, Peniraman Village has been known for its soil and rock mining. Mining increases the risk of environmental degradation by increasing the demand for freshwater provisioning services. This study aims to assess the impact of damage from mining in Peniraman Village on groundwater potential and the environment's carrying capacity based on ecosystem service. Ecosystem services are analyzed using two determinants: land cover and landscape, with a spatial method. This study resulted in a large forest change between 1972 and 2020, which was estimated to lose 16.5 hectares of forest each year, whereas Peniraman Village will lose its forest in 26 years. There was also a land conversion in primary swamp forests into open land for various community activities from 1972-2020, mostly agriculture, settlement, and plantation. On the other hand, the mining area will be exhausted in 30-40 years given the current mining rate. These actions shifted the class of groundwater provisioning services from very high to very low. The water potential was calculated based on the ecosystem services that have intermediate and low-level class potential in Peniraman Village of 1,077.98 hectares, or 48.15% of the total area. Although 48.6 percent of the Peniraman Village area is still within the safe level for water availability based on supply and demand, the government and community should pay close attention to this issue to avoid further harm.

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Introduction

The role of ecosystem services is now increasingly being taken into account in decision-making to support the achievement of sustainable development goals. Ecosystem services (ES) are the benefits obtained by people through ecosystems. The concept of ecosystem services was introduced by Daily et al. (1997) and then adopted by the United Nations in the Millennium Ecosystem Assessment in 2005. They categorized ecosystem benefits into four types of services: provisioning, regulating, cultural, and supporting (Millenium Ecosystem Assessment 2005). Ecosystem services might well be analyzed using two determinants: land cover and landscape. Various human activities can affect ecosystem service, including mining activities.

Peniraman Village is one of the villages located in Sungai Pinyuh Sub-district, Mempawah Regency, West Kalimantan Province. Among its potentials is the abundance of rock commodities, which are widely utilized through mining activities known as "excavation C" and are now refer as rock mining. This mining activity has been going on since 1960 until now. Initially, the local community mined for personal benefits or infrastructure development needs in Peniraman Village, using traditional tools such as hoes, shovels, crowbars, and others.

Along with development, private companies emerged and conducted mining using large equipment such as bulldozers, excavators, loaders, and trucks. The community tends to perceive this activity in a positive way because it can increase work opportunities and reduce unemployment, especially for people with lower education, both as labourers and sellers at kiosks, which results in increasing their income and economy to support their needs. It also has an impact on village infrastructure development from ming company payments to local government (Sari et al., 2020). However, mining companies tend to be excessively exploitative, and the lack of proper environmental planning negatively impacts the environment, including landform changes in the mining area and the loss of several water sources used by the Peniraman community. Some of the mined rocks in Peniraman are granite.

Research conducted in Maddhapara Granite Mine, Bangladesh reveals that the use of granite mine effluent for irrigation without treatment has increased the risk of heavy metal pollution in groundwater in the future, posing a long-term environmental risk (Tanjil et al., 2019). Moreover, mining requires large land availability and water use but also causes large-scale changes in land use, land cover, and vegetation types that can permanently affect water availability (Maria and Purwoarminta, 2017).

This study aimed to assess the impact of damage from rock commodity mining in Peniraman Village on the potential of groundwater and the environment's carrying capacity, based on ecosystem service studies. The studied ecosystem benefit is freshwater provisioning service, focusing on its landscape and land cover in Peniraman Village using a spatial method. This spatial analysis, widely known as geographic information systems (GIS), saves cost and time and is applicable in various fields (Pambudhi et al., 2012).

GIS is a well-organized system of computer hardware, software, geographic data, and personnel designed to store, update, modify, analyze, and display all geographic information and model it. Each parameter in use, such as rainfall, land use, geological data, slope, and water table height, is modelled using the overlay technique in conjunction with the tiered method (Awanda et al., 2017).

Materials and Methods

The research site is within the administrative region of Peniraman Village, located in Sungai Pinyuh Sub-District of Mempawah Regency with an area of 2,313 hectares. Peniraman Village borders Nusapati Village to the north, Sungai Purun Kecil Village to the south and east, and the Natuna Sea to the west (Figure 1). This village has an average rainfall of 30 mm/month, with five rainy months annually. Most clean water resources are springs, dug wells, pumps, retention basins, and rainwater collection tanks. Peniraman is approximately home to 7,737 people (3,967 men and 3,770 women). The number of household heads is 1,988, with a population density of 334.50 per km^2.

Figure 1. Research location.

Materials

This study gathered both primary and secondary data. The primary datasets collected in this study were: ground check verification data for interpretation of Landsat land cover at the research site as a correction for the accuracy of Landsat obtained; and drone mapping in Peniraman Village as its land cover data for 2020. The secondary data needed in this study were spatial and non-spatial data. The spatial datasets used were as follows:

1. The downloaded satellite images are Landsat Thematic Mapper images. These Landsat images were selected because of the ease of obtaining data, wide coverage, and periodic record. The years of satellite images used in this study were 1980, 1990, 2000, 2010, and 2020. The satellite images were obtained from various sources: United States Geological Survey (earthexplorer.usgs.gov), The Ministry of Environment and Forestry (Kementerian Lingkungan Hidup dan Kehutanan, KLHK), Indonesian National Institute of Aeronautics and Space (Lembaga Penerbangan dan Antariksa Nasional, LAPAN), Geospatial Information Agency (Badan Informasi Geospasial, BIG), and others that have land cover databases.
2. The spatial data used include data on the administrative region of Peniraman Village using on-screen digitization by referring to the Village Border Map available at the Peniraman Village Office. The data is in the vector data format of polygons.
3. Kalimantan ecoregion and vegetation data obtained from the Ministry of Environment and Forestry with a scale of 1:250,000.

While the non-spatial data needed in the study were as follows:

1. Mining data in Peniraman Village. These data were used to support the existence of mining in Peniraman Village. The identification of mining in Peniraman Village was obtained from the data provided by the Energy and Mineral Resources Office of West Kalimantan Province. The data were then submitted to the village officials to clarify the location and position of the mine to be mapped.
2. Drawings or paintings of the Peniraman Village Map found in the village as a reference in digitizing more accurate village borders.

Method for landcover determination

Land cover is a condition that describes the biophysics that is on the earth's surface and that below the layer. Land cover is also the condition of the earth's surface that describes the activities carried out on the earth's surface, either intentionally or unintentionally (Zhai et al., 2018).

The land cover in Peniraman Village was determined using medium-resolution satellite imagery and the findings of a visual assessment of the land cover. An unsupervised classification approach to manually interpreting images was conducted by examining their color, hue, texture, shape, size, shadow pattern, and site visualization (Awanda et al., 2017). The land cover classification made in this study followed the Indonesian National Standard (SNI) 7645-1: 2014 concerning Land Cover Classification.

This study also conducted a ground check to verify the accuracy of the image interpretation. The ground check method used in the research was purposive sampling, which represents each land cover class in the research area, then calculated using the following equation:

$$\text{Accuracy test} = \frac{\sum \text{Accurate interpretation result spot}}{\sum \text{observed spot}} \ x \ 100\ \% \qquad (1)$$

Ground check is a technique used to check the results of the interpretation of land cover from the images obtained. The results were matched by taking one sampling point for each land cover. This activity also involved field verification to ensure that the objects in the field are based on the land cover. Figure 2 shows the procedures for determining land cover in Peniraman Village.

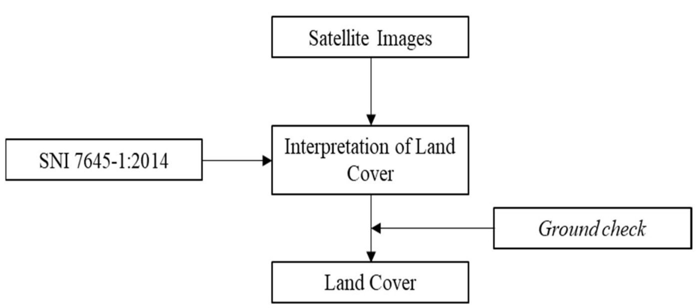

Figure 2. Landcover interpretation scheme.

Method for carrying capacity estimation

Ecosystem services are obtained by weighting and comparing the role or contribution of landforms based on their ecoregions and land cover to an ecosystem service. This ecosystem service value is used to calculate the environment's carrying capacity. Environmental carrying capacity is an aspect that must be considered before making spatial planning decisions. Analysis of the carrying capacity and capacity of water providers is regulated in the Minister of Environment Regulation No. 17 of 2009 concerning Guidelines for Determining Environmental Support Capacity in Regional Spatial Planning. The flow of this analysis is illustrated in Figure 3.

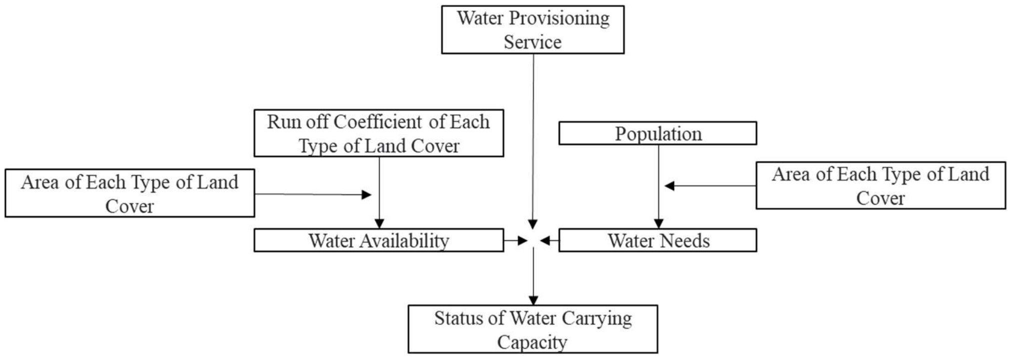

Figure 3. Scheme for determining the status of Water Supply Support Capacity in Peniraman Village.

The calculation of the ecosystem service coefficient with the following equation (Muta`ali, 2019):

$$KJE = KMP_{ec} x\ KMP_{lc} \quad (2)$$

where:

KJE	:	Ecosystem Service Coefficient
KMP_{ec}	:	Coefficient based on ecoregion.
KMP_{lc}	:	Coefficient based on landcover

The value of the ecosystem service index can be calculated after calculating the value of the Ecosystem Service Coefficient of each land cover classification. The value of the Ecosystem Service Index was calculated with the following equation (Muta`ali, 2019):

$$IJE_{Lx} = \frac{(KJEi.a\ x\ LPa)+(KJEi.b\ x\ LPb)+KJEi.c\ x\ LPc)\dots\dots\dots(KJEi.n\ x\ LPn)}{LAtot} \quad (3)$$

where:

IJE i.x	:	Value of Type I (water) Ecosystem Service Index in area x
KJE x	:	Ecosystem Service Coefficient of Type I (water) in polygon *a*.
LPa	:	Area of Polygon *a* with KJE *a* value
LAtot	:	Total Polygon Area

The flow of this analysis is illustrated in Figure 4.

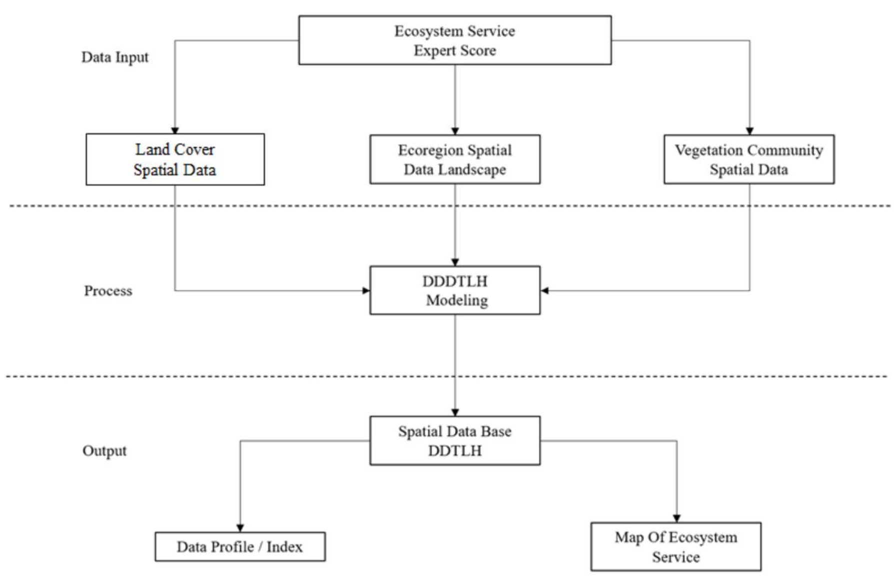

Figure 4. Ecosystem service calculation scheme.

Method for water provisioning ecosystem services mapping

ArcGIS software was used to build the ecosystem services map in Peniraman Village. This map was created using the ecosystem service index, which was graded from very low to very high. The map's coloring will make it easy to analyze the state of water supply ecosystem services in Peniraman Village. The classification of freshwater provisioning services in Peniraman Village is shown in Table 1.

Table 1. Classification of ecosystem service (Muta`ali, 2019).

Class	ES Score	Color
Very High	>4.21	Red
High	3.41-4.20	Pink
Medium	2.61-3.40	Yellow
Low	1.81-2.60	Light Green
Very Low	<1.81	Dark Green

Results and Discussion

Mining in Peniraman Village

Landslides in Sungai Pinyuh Sub-district are caused by the land's hilly morphology. The characteristics of landslide-prone areas in the villages of Sungai Pinyuh Sub-district are nearly identical, but the potential vulnerability varies due to the slope varying from flat (0-8 percent) to steep (>40 percent) in each village. There are six areas with moderate levels of vulnerability (hazard), with Peniraman Village having the highest level of vulnerability (vulnerable), with an area of 625 ha, or 3.22 percent of the area of Sungai Pinyuh Subdistrict. Furthermore, landslide-prone areas are only found in Peniraman Village, which has 223 ha or 1.15 percent of the total area of Sungai Pinyuh Sub-district (Rahmah et al., 2020).

Mining that causes steep slope walls and loss of vegetation or land cover, as well as inappropriate land use and management and community activities in landslide-prone areas, exacerbate the occurrence of landslides (Rahmah et al., 2020). According to data from the Energy and Mineral Resources Office of West Kalimantan Province, 14 of the 18 registered mining licenses were located in Peniraman Village, which indicated a high mining potential. Backfill, granite, andesite, and diorite were the rock commodities mined at Peniraman Village (Table 2). These commodities were in great demand to support development in the West Kalimantan region, especially around Sungai Pinyuh Sub-District. Quarry mining is used at Peniraman Hill. The cliff on the slope is rock, and the mining direction is random, so rock landslides are possible. Because mining is close to residential areas, landslides will have a significant impact on the community surrounding Peniraman Hill.

Table 1. Mining list in Peniraman Village.

No	Name Of Company	Area (ha)	Mining Commodity
1	Arifin_SDR	16.9	Backfill
2	PT. Borneo Mega Mine	5.4	Backfill
3	CV. Results Mandiri Utama	3.8	Backfill
4	PT. Hasindo Mineral Persada	8.0	Granite
5	CV. Lithosindo Jaya	4.4	Granite
6	Madruji Nanggi AN	16.05	Andesite
7	CV. Mega Makmur	4.0	Granite
8	CV. Restu Bumi	16.9	Backfill
9	PT. Sulenco Wibawa Perkasa	8.29	Granite and Andesite
10	PT. Total Optima Perkasa	7.16	Diorit
11	CV. Valindo Mining	13.76	Granite

Landslides are caused by the unstable slope of Peniraman Hill (Ikrima et al., 2021). The mining by hillside cutting that is not in accordance with the slope will inevitably cause land shifting due to the hill's being too steep. This condition will be even more dangerous when the weather is rainy. The high flow rate of rainwater cannot be absorbed due to the loss of vegetation on the top of the hill, resulting in the water going down quickly and carrying soil on the steep hill surface. Observations in Peniraman Village showed that the condition of the backfill mining is quite dangerous, as shown in Figure 5.

Ecoregion and vegetation in Peniraman Village

The Ministry of Environment and Forestry's Vegetation Community map, with a scale of 1:250,000, was used to identify vegetation types in Peniraman Village. As a result, there were four types of vegetation communities whose locations were similar to the landscape or ecoregion. This similarity occurs because the expanse of the earth's surface with all its phenomena includes several activities such as landforms, vegetation, and all parts of the surface that are affected by human activities (Mokatse et al., 2022). Peniraman Village has four types of ecoregions, namely: Fluvial Plain with alluvium material; Fluviomarine Plain with alluvium material; Organic Plain with peat material; and Volcanic Hills with deep igneous rock material. Details are described in Table 3. The ecoregions identified in Table 3 were then weighted to calculate water supply ecosystem services, particularly for groundwater.

Figure 5. Condition of backfill mining.

Table 2. Ecoregion and vegetation in Peniraman Village.

No	Ecoregion	Rock Formation	Vegetation	Area (ha)
1	Alluvium Fluvial Plains	Alluvial and Swamp Deposits	Coastal Terna Forest	720.82
2	Alluvium Fluvio-Marine Plains	Litoral deposit	Coastal forest	148.88
3	Peat Organic Plains	Scratched Alluvial Deposits	Pamah Freshwater Swamp Terna Forest	881.08
4	Volcanic hills of deep igneous rock	Mensibau Granodiorite	Plain Non-Dipterocarp Forest	488.07
	Total			2,238.84

The weighting was accomplished by combining multiple scores established in the former ecoregion computation (Muta`ali, 2019). The ecoregion scores and weights for Peniraman Village are summarized in Table 4.

Table 3. Scoring of Peniraman Village ecoregion.

No	Ecoregion	Score
1	Alluvium fluvial plains	3.23
2	Alluvium fluvio-marine plains	3.60
3	Peat Organic Plains	2.00
4	Volcanic hills made of deep igneous rocks	0.55

According to Table 4, the fluviomarine ecoregion with alluvium had the highest score, indicating that this landscape has a high impact on groundwater potential. The volcanic hills ecoregion with deep igneous rocks has the least influence on groundwater potential. However, this does not necessarily indicate that each ecoregion has a certain role as there are other factors to be taken into account, such as land cover. Similar to the ecoregions, the vegetation identified in Table 3 was also scored, with the results in Table 5. The table shows that the Pamah Non-Dipterocarp Forest has a dominant role in the potential for groundwater supply, as concluded from the higher score compared to other vegetation.

Satellite image of Peniraman Village

To identify the kind of land cover in Peniraman Village, satellite pictures of Landsat 7 and 8 data from 1972 to 2020 were collected from the USGS website. Furthermore, because each satellite has a different number of bands or layers, Landsat 4 and 5 were required to improve the studied images. Band settings for imaging are critical for identifying objects, which in this case is land cover. This technique is commonly known as remote sensing. Remote sensing is the science and art of acquiring numerous types of information about an observed region, phenomenon, or item (Sulistioadi et al., 2015). The list of obtained images is shown in Table 6.

Table 4. Scoring of vegetation in Peniraman Village.

No	Vegetation	Coefficient Score
1	Plain Non-Dipterocarp	5
2	Coastal Forest	4
3	Coastal Tern Forest	2
4	Plain Freshwater Swamp Tern Forest	5

Table 5. Obtained images list.

No	Satellite	Orbital Year	Resolution
1	Landsat 4-5 TM	1972 - Present	30 meters
2	Landsat 7 ETM	1999 - Present	30 meters
3	Landsat 8	2013 – Present	30 meters

Land cover in Peniraman Village

Land cover analysis based on the results of image interpretation and comparisons with relevant regulations shows that land cover in Peniraman Village has changed from 1972 to 2020, where in 1972 there were only four types of land cover, but in 2020 there were nine types. Table 7 displays land cover interpretation data in Peniraman Village from 1972 to 2020, while the land cover map for each year of data is presented in Figure 6.

Table 6. Interpretation of land cover in Peniraman Village.

No	Land Cover	Year (ha)				
		1972	1988	1999	2010	2020
1	Secondary Dry Land Forest	1,180.12	719.25	815.93	694.89	428.91
2	Open Land	-	10.79	7.29	553, 48	20.03
3	Secondary Mangrove	-	-	-	186.78	163.56
4	Plantation	-	-	-	-	532.70
5	Settlements	65.03	66.83	79.45	99.69	192.41
6	Mining	-	-	-	41.30	146, 57
7	Dryland Agriculture	-	330.48	299.05	253.76	332.00
8	Ricefield	-	94.71	95.47	96.27	96.16
9	Shrubs	-	-	-	261.56	326.50
10	Swamp Scrub	-	8.92	3.47	51.13	-
11	Primary Swamp Forest	764.61	827.35	750.99	-	-
12	Primary Mangroves	210.84	187.20	180.53	-	-

In addition, Table 8 shows the results of the ground check step as a way of testing the level of compatibility of image interpretation with actual conditions.

Table 7. Recapitulation of land cover ground check.

No	Year	Accuracy (%)
1	2020	92.86
2	2010	93.75
3	1999	66.67
4	1988	50.00
5	1972	75.00

Table 7 shows a significant loss of forests. Secondary dryland forest was the most common land cover in 1972; by 2020, it would be plantation. As evidenced by the decrease in secondary dryland forest area, this indicates a massive land use change from forest to non-forest. In 1972, secondary dryland forest was 1,180.12 ha (52.71% of the total area), but it became 428.91 ha in 2020, while plantations were recorded only in 2020 at 532.70 ha. Within 48 years, Peniraman Village has lost 751.12 hectares of forest (33.5% of the total area), which means that Peniraman Village might experience degradation due to excessive land use change. It can also be estimated that the forest loss was 16.65 hectares per year.

The area of forest affects the amount of water that can enter the ground, known as groundwater. The ability of the forest to infiltrate water into the soil will increase groundwater capacity. The process of water infiltration occurs with the help of forest vegetation. Changes in land cover vegetation occur in forests in the form of area reduction due to uncontrolled logging which will reduce evapotranspiration. This event will result in runoff due to the loss of forest vegetation as the absorption of water into the soil will be reduced (Asdak, 2002). The amount that enters the soil after being reduced by the evapotranspiration process ranges from 5-15%. Thus, forest loss of 16.65 hectares per year will have an impact on the groundwater potential of Peniraman Village. If forest loss continues or there is no control over activities that reduce forest area, it is predicted that Peniraman Village will lose its forest in 2046, or 26 years in the future.

In addition, land cover change from primary swamp forest to open land in 2010 is also an important concern. The water supply potential of primary swamp forests plays an important role in infiltrating rainwater into the soil. Primary swamp forests are located in fluvial landscapes and therefore have moderate to a high water supply potential.

From 1972 to 1999, the extent of primary swamp forest was still recorded and maintained, but in 2010 the data was no longer available. The area of primary swamp forest in 1999 was 750.99 hectares which changed in 2010 to 553.48 hectares of open land and the rest to shrubs. Over the past ten years, the primary swamp forest has changed due to the conversion of plantation land due to the opening of plantation land, especially for oil palm. The main cause of peatland degradation and abandonment was the conversion of forest land to oil palm plantations in peatland ecosystems. Oil palm development on peatlands also raises concerns about potential CO_2 emissions as a greenhouse gas (GHG) and loss of biodiversity (Riwandi et al., 2009).

Land clearing and canalization activities cause changes in hydrology. This leads to changes in land fertility, subsidence, and irreversible drying. Land clearing activities in oil palm plantations also cause changes in thickness, water table, and water content. The older the oil palm plantation, the lower the water content of the peatland. The water table is the most important ecological factor influencing biophysical changes in peatlands. The state of the water table will shift the decomposition from aerobic to aerobic, accelerating the rate of organic material breakdown. This influences the peatland's moisture content, ash content, pH, and organic C content (Suwondo et al., 2010). Therefore, land use change would not only reduce the potential for water infiltration into the soil, but also reduce the quantity and quality of water on the land.

Similar to ecoregions and vegetation being identified and scored, land cover also had a coefficient calculated. The interpretation of land cover images was one of the factors used in the calculation of freshwater provisioning ecosystem services in Peniraman Village, which required the coefficient of each land cover. The coefficient values of each land cover are presented in Table 9.

Table 9. Scoring of landcover (Widodo et al., 2015).

No	Land Cover	Coefficient
1	Secondary Dryland Forest	1.91
2	Open Land	0.37
3	Secondary Mangrove	1.18
4	Plantation	0.79
5	Settlement	0.28
6	Mining	0.37
7	Dryland Agriculture	0.60
8	Rice field	0.96
9	Shrub	0.29
10	Swamp	0.66
11	Secondary Swamp Forest	1.09
12	Primary Mangrove	1.18
13	Primary Swamp Forest	1.09

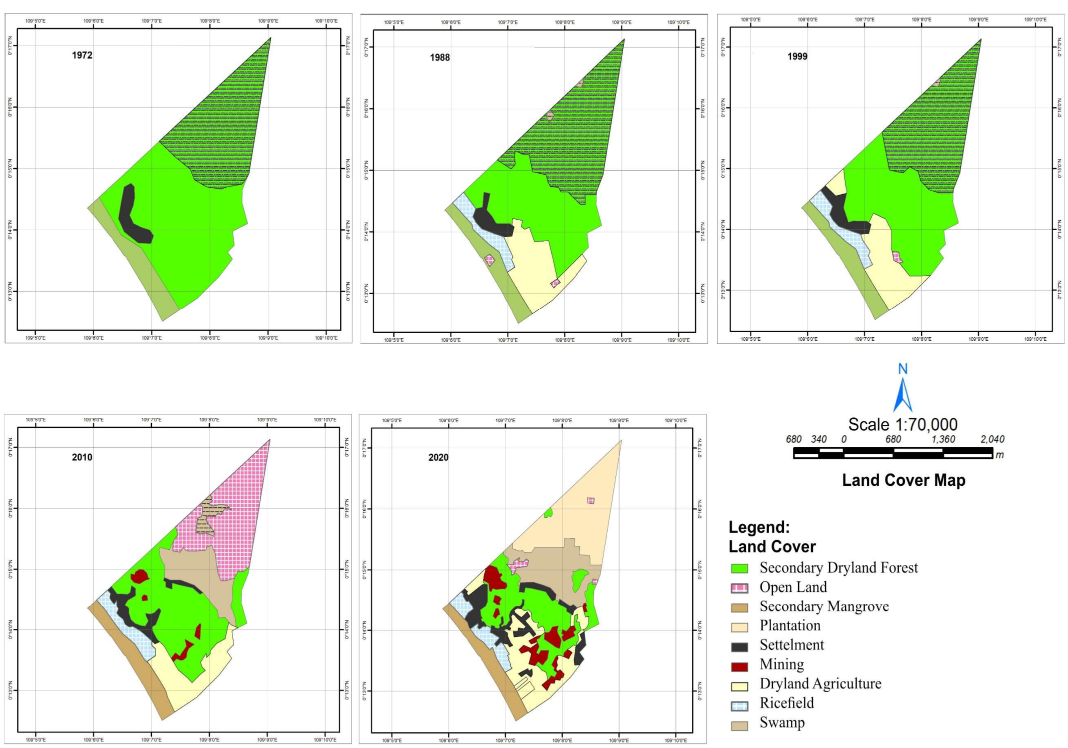

Figure 6. Land cover map.

Water provisioning ecosystem services in Peniraman Village

Water provisioning ecosystem service is the ability of nature to provide clean water for human needs. Depending on the potential in the area, clean water can be produced as groundwater or surface water. The calculation of the environmental carrying capacity, especially the provision of water to groundwater in an area, will be used as an evaluation tool for the use of regional space (Santoso, 2015). Ecosystems provide many benefits, including the provision of groundwater. Based on the results of overlaying several maps that have been described above, and several components contained in the map were scored, it can be concluded that there were several levels of groundwater provisioning ecosystem services that were calculated using Equation 3. The calculations made for ecosystem services from 1972 to 2020 are shown in Table 10. The distribution of ecosystem services in Peniraman Village is shown in Figure 7, and that of ecosystem services of the mining area is shown in Figure 8.

Table 8. Groundwater provisioning ecosystem services in the period of 1972-2020.

No	Year	Ecosystem Service (ha)			
		High	Intermediate	Low	Very Low
1	1972	0	1.361.62	725.16	152.07
2	1988	21.65	1,409.85	644.20	163.14
3	1999	0	1.363.88	708.94	166.02
4	2010	0	598.68	619.51	1,020.66
5	2020	0	499.91	578.07	1,160.86

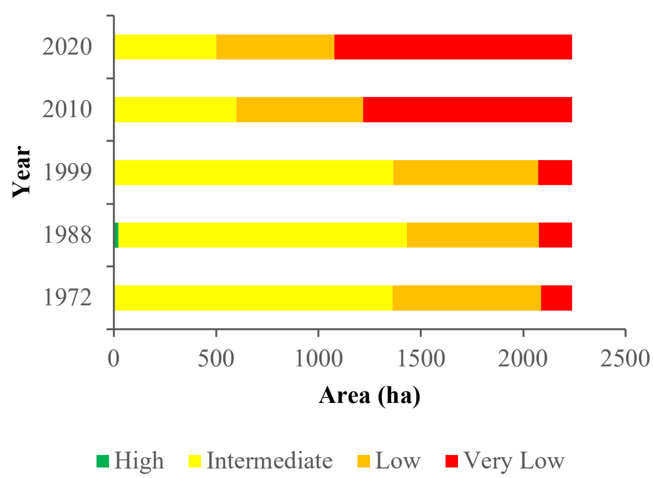

Figure 7. Distribution of ecosystem services in Peniraman Village.

Groundwater is inextricably linked to the landscape and land use that it underlies, and it is subject to anthropogenic activity on the land surface above. Changes in recharge and shifting water demands both have an impact on groundwater supplies (Prabhakar and Tiwari, 2015). Land cover has an important role in providing groundwater. This can be seen from the class division of each type of land use. Forests have the ability to infiltrate several other land uses. Based on land use class, a forest has an infiltration value of 5 or is relatively large compared to plantations/farms, uplands/fields, rice fields, and disturbed land settlements.

Ten-year trends were utilized in this research to detect changes in ecosystem services from year to year. In 1972, based on the digitization of land cover, there were 4 types of land cover: secondary dry forest, primary swamp forest, primary mangrove, and settlement. The dominant land cover was secondary dryland forest (52.71%), so the groundwater provisioning ecosystem services were dominantly on an intermediate index with a percentage of 60.82%, or 1,316.62 ha, and the rest was in poor condition (low-very low).

In 1988, there was a change in land cover from secondary dryland forest to paddy fields and dryland agriculture. However, water supply ecosystem services based on calculations were still dominated by a medium index (1,409.85 ha) and there was even a high index of 21.65 ha, but only in 0.97% of the Peniraman Village area. The high ecosystem services were provided in 1988 because it was part of the hills, which were previously a secondary dryland forest with high water potential. The land cover conversion in 1988 was related to human activities in Peniraman Village, which began to carry out farming activities such as the opening of paddy fields and mixed dryland agriculture. The increase in settlement areas also occurred due to government policies on transmigration. This may affect land degradation due to additional anthropogenic activities. In 1999, there were no major changes to the ecosystem services of groundwater provision. In 1999, there was no government program that changed the development paradigm in Peniraman Village. From the trend that occurred, the value of high-class groundwater supply ecosystem services in Peniraman Village had disappeared, and there was a decrease in the medium ecosystem class from 1,409.85 hectares or 62.97% to 60.92% or 1,363.88 hectares, while there was an increase for low and very low-class ecosystem services.

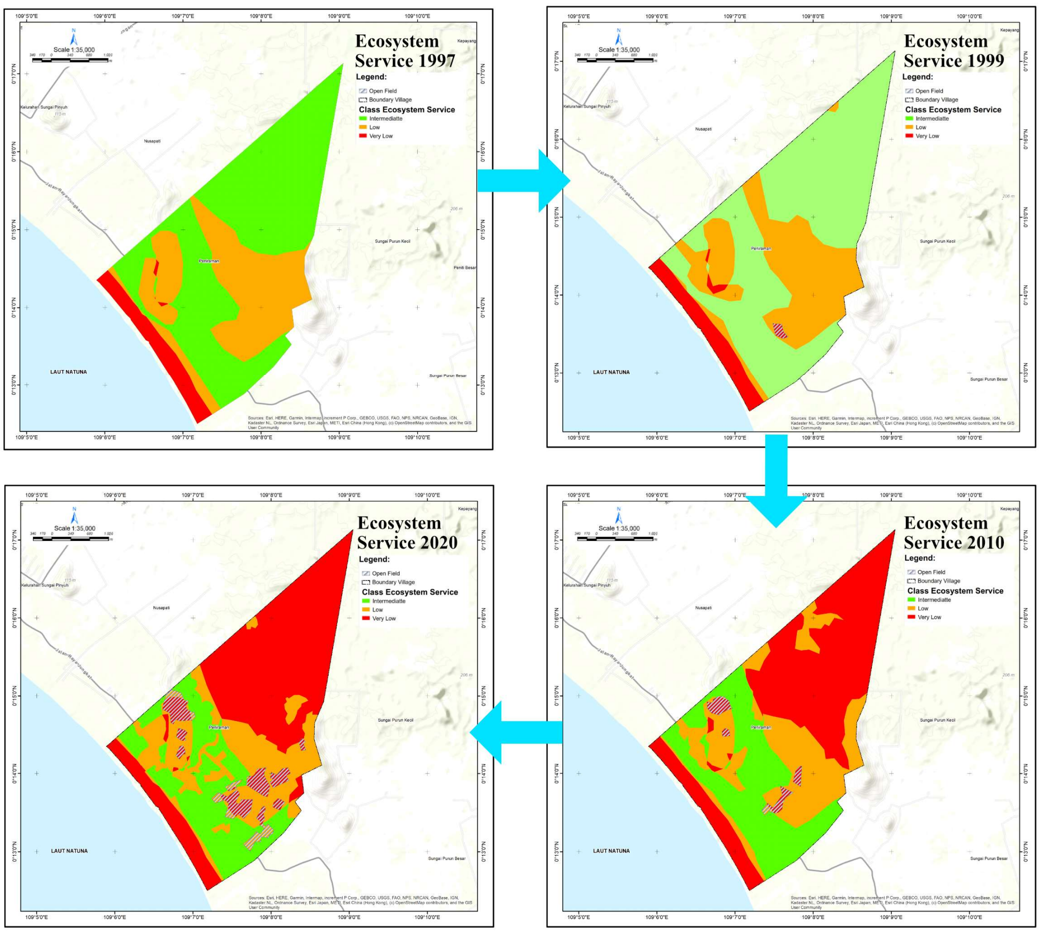

Figure 8. Ecosystem services of the mining area.

An extensive change was recorded in 2010. The intermediate ecosystem service class decreased from 1,363.88 ha (60.92% of total area) in 1999 to 598.68 (26.74% of total area) ha in 2010. Likewise, the very-low ecosystem service class increased from 166.02 ha in 1999 to 1,020.66 ha in 2010. Meanwhile, the low ecosystem service class decreased to 619.51 ha in 2010 from 708.94 ha in 1999. It could be concluded that there was an indication of a decrease in the ecosystem service class from medium to very low in 2010. Alternatively, there was a 34.18% decline in intermediate ecosystem services over ten years. As shown in Table 7, significant land cover changes happened in 2010, including an increase in open land (553.48 ha) and the start of mining activities (41.30 ha). In 2020, the state of water supply ecosystem services was similar to the previous period, with intermediate and low classes decreasing while very-low ones were increasing. The intermediate level class of ecosystem services decreased from an area of 598.68 hectares or 26.74% in 2010 to 499.91 hectares or 22.33%. Meanwhile, the low level class of ecosystem services decreased, and the very low level class of ecosystem services increased to 1,1160.86 hectares or 51.85% of the total area. Based on land cover change data in 2020, the plantation industry began to emerge with an area of 532.70 ha, mining activities increased to 145.57 ha, and settlements expanded from 96.27 ha in 2010 to 192.41 ha in 2020. To show the trend of increasing and decreasing water provisioning ecosystem services of in Peniraman Village, it can be seen in the ecosystem service index of each year, which is shown in Table 11.

Table 9. Clean water provisioning ecosystem services index in Peniraman Village.

No	Year	Ecosystem Service Index
1	1972	0.82
2	1988	0.72
3	1999	0.82
4	2010	0.71
5	2020	0.68

Table 11 indicates that the overall value of freshwater provision ecosystem services in Peniraman Village decreased from 1999 to 2020. Meanwhile, in 1972 and 1999 there is a decrease, then in 2010 it increases. The conditions in 2020 with an Ecosystem Services Index value of 0.68, have experienced the loss of several springs. The average loss of the value of the clean water provisioning ecosystem services index (Figure 9) every 10 years is 0.08. Continuous changes in land cover and landscape lead to changes in the extent of ecosystem services that provide groundwater from a very high class to a very low class. The water provisioning ecosystem services are largely determined by several characteristics of the ecoregion in the research site, such as the landscape and land cover of the area (de Groot et al., 2012). If there is no action to control land cover change, it is estimated that Peniraman Village will lose its underground water sources by 2080 with a remaining middle-class Ecosystem Services Index value of only 0.4, meaning an area of 294.06 hectares, or 13.3% of the total area. This rate of land cover change should be of concern to the government for several reasons, one of which is that land clearing policies for plantations require not only project-specific studies but also studies that examine the supporting services of plantation soils.

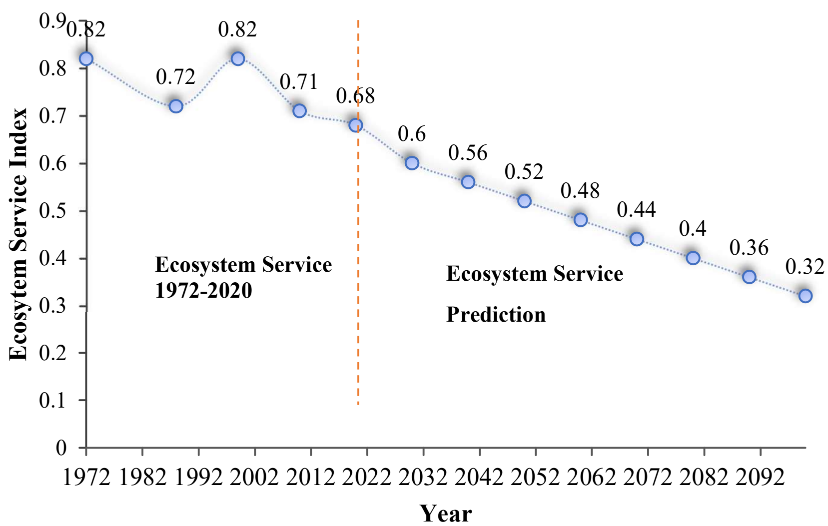

Figure 9. The predicted value of the water provisioning.

Environmental carrying capacity status of freshwater provisioning in Peniraman Village

Water availability, as defined by supply and demand concepts, is the availability of water that can meet the demands of living creatures. People in Peniraman Village tend to use shallow wells to obtain clean water. The discharge of shallow well water acquired in this study through pumping tests was 5,992.73 m^3/year, then distributed into a 5' x 5' box. The total water demand of the Peniraman Village community was 668,476.8 m^3/year, while the non-domestic was 928.82 m^3/year, including for plantations, wetland agriculture, and dryland agriculture. Based on the supply and demand principle, the carrying capacity status of the freshwater supply in Peniraman Village is calculable and shown in Table 12.

Table 10. Status of water carrying capacity in Peniraman Village.

No	Status	Area (ha)	Percentage
1	Deficit	1,149.50	51.34%
2	Surplus	1,089.35	48.66%

The research implemented two assessments: landscape-based proxies and land cover/land use-based proxies. Based on the principle of supply and demand, an analysis of freshwater carrying capacity shows that 48.6% of the Peniraman Village area is still within the safe level of water availability (surplus). Meanwhile, the water supply potential calculated based on the ecosystem services approach showed the potential for intermediate and low classes in Peniraman Village to cover an area of 1,077.98 hectares, or 48.15% of the total area. Therefore, there are similarities in water supply carrying capacity estimations, either based on ecosystem services or the supply-demand principle.

Water provisioning services in the mining area

Mining activities in Peniraman Village have been going on since 1960 (Sari et al., 2020). However, land cover data in 1972 did not record any mining activities. In 1999, mining areas were visible but not yet significant. Then, from 1999 to 2010, an increase of 34.01 ha happened. Likewise, from 2010 to 2020, an increase of 105 ha was subbed. Figure 10 shows the mining area's development in Peniraman Village. Mining can affect the geophysical-chemical conditions of the surrounding environment. Some of the impacts of mining on the surrounding environmental conditions include changes in the landscape, a decline in surface water quality, erosion and sedimentation. Changes in the landscape and the loss of vegetation in the hills will accelerate erosion and sedimentation of river areas. This will cause siltation and result in the loss of community water resources, especially surface water (Bargawa, 2015).

The mining area in Peniraman Village has low groundwater potential. The existence of this mining activity further changes the ecosystem service class from low to very low. Ecosystem services for groundwater provision are influenced by ecoregion characteristics, namely landscape and land cover (Nam et al., 2010). Ecosystem service calculations involve several factors, including landscape, vegetation, and land cover. Therefore, when mining activities occur, it will clearly affect the potential availability of groundwater in the activity area. The calculation of ecosystem services for freshwater provision in the mining area revealed that it ranked low. In 1999, there was a decrease in ecosystem services in the mining area, which was previously 439 ha of low ecosystem service class reduced to 431.71 hectares. In 2010, the remaining ecosystem services in the mining area were 397.3 ha, then 429.43 ha in 2020. Thus, the ecosystem service class declined by 105.27 hectares in ten years.

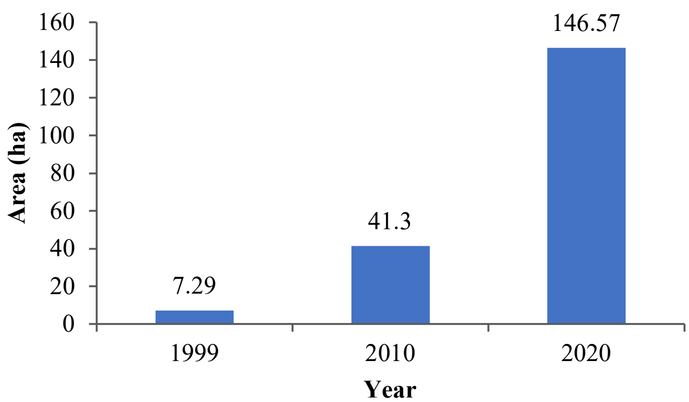

Figure 10. Development of mining land cover in Peniraman Village 1999-2020.

The loss of secondary dryland forest and landscape changes from hills to plains resulted in a shift in ecosystem service class from low to very low in the mining area. The demand for raw building materials to developing urban infrastructure (Pontianak City and Singkawang City) was so severe that mining companies increased production to accommodate this demand. If the current mining rate is retained, the Peniraman Village mining area will be done in the next 30-40 years, or in 2060, also with the loss of its hills and forests. The change from low (orange) to very low (red) ecosystem service class will certainly reduce the potential availability of groundwater. The predicted loss of ecosystem services from low to very low can be seen in Figure 11.

The groundwater potential can be calculated by the amount of water that seeps into the ground using the following equation (Bonita and Mardyanto, 2015):

$$R = (P-Et) \times Ai \times (1-C)$$

where:

R	=	Volume of water that infiltrates into groundwater (m^3/year)
P	=	Rainfall (mm/year)
Et	=	Evapotranspiration (mm/year)
Ai	=	Land Cover Area (m^2)
C	=	Runoff Factor

The annual rainfall data from BMKG Siantan, Mempawah Regency, was 1,9780.86 mm/year. The Pennman method calculated the evapotranspiration value, which was 1546 mm/year. Figure 12 depicts the computation of groundwater potential. As seen in Figure 12, from 1972 to 1999, the decrease in groundwater potential was not very significant. Mining activities in 1999 were still limited, so land cover changes did not occur widely. However, in 2010 and 2020, the potential for groundwater infiltration in the mining area decreased drastically.

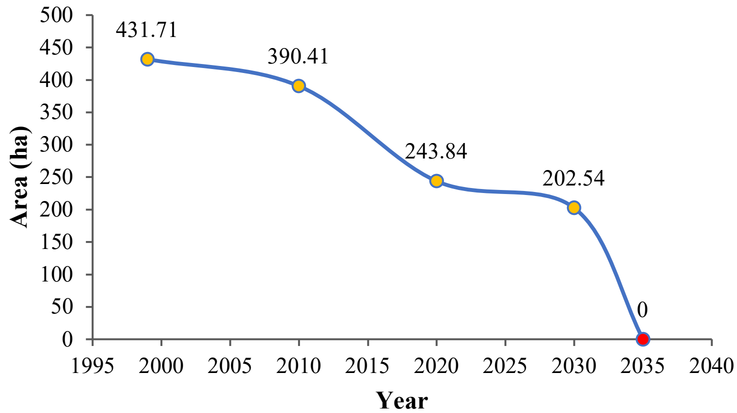

Figure 10. Decline in the class of ecosystem services in mining areas.

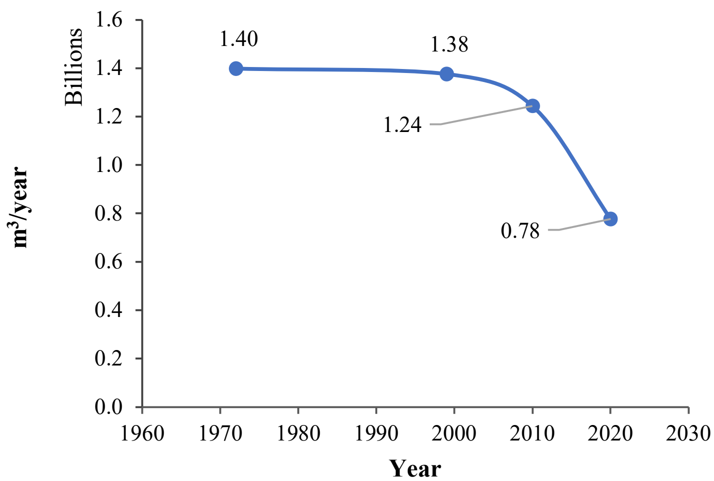

Figure 11. Groundwater recharge potential in Peniraman Village mining area.

In 2010, Peniraman Village experienced a loss of water infiltrating the soil of 11.07% from 1972, while in 2020, the water loss reached 44.45%. When Peniraman Village loses the mined area, it will also lose water that seeps into the ground, amounting to 1,398,699,973.71 m^3/year.

Land cover is one factor that influences groundwater infiltration areas, whereas plants on the soil influence groundwater infiltration (Wibowo, 2003). One of the impacts of mining is changing the landscape and land cover in the mining area (Hakim, 2017). The mining area's topography was once hills transformed into a plain, and the land cover in Peniraman Village's mining area changed from secondary dryland forest to open land.

Additionally, open-pit mines that extend below the natural water table are typically dewatered to produce a dry mining environment (Younger et al., 2002). In-pit pumps are commonly used for dewatering pits in very low permeability situations where groundwater inflow rates are minimal and unlikely to induce slope instability. Water is gathered in drains and channels within the pit and pumped to a disposal location via low points or sumps (Preene, 2015). In high-permeability conditions, in-pit pumping is frequently insufficient; hence vertical dewatering wells are typically built around the mine pit's perimeter by lowering the regional water table (Bozan et al., 2022). The groundwater will begin to recover when the mine is closed, but total recovery may take several years or may not occur at all (De Graaf et al., 2019).

Simulated research reveals that as aquifer transmissivity decreases, the recovery time of postmining groundwater levels increases. The final postmining water tables are heavily influenced by mine closure options and meteorological circumstances. The most critical decision is whether to backfill the pit to the water table or to let a pit lake form. Backfilling pits results in rapidly rising groundwater levels during the first decade after mining in moderately transmissive aquifer settings, with water-table recoveries exceeding 70%. If mine voids stay unfilled, evaporation from the pit lake surface becomes a deciding factor in determining whether the vacant mine pit becomes a groundwater terminal sink (Bozan et al., 2022). Therefore, groundwater recovery initiatives in Peniraman Village need to be considered by related stakeholders.

Conclusion

Peniraman Village is a village with potential for mining, and currently, there are several mining licenses for backfill, granite, andesite, and diorite commodities. The mining area continues to increase, which was around 34 ha during 1999-2010 and 105 ha during 2010-2020. However, if the mining rate is constant, the mining area will be depleted in 30–40 years (around 2060).

Meanwhile, the results of land cover identification show the magnitude of changes in forest areas to non-forest areas, as well as the existence of land conversion in primary swamp forests into open land for various community activities during 1972–2020. The most significant land cover degradation occurred in forest vegetation types, with Peniraman Village losing 16.5 hectares of forest each year. If current trends continue, Peniraman Village will lose its forest in 26 years (around 2046).

Despite the fact that 48.6 percent of the Peniraman Village area is within the safe level for water availability according to the principle of supply and demand, massive mining and land use changes in Peniraman Village affect the environment's carrying capacity for water supply. Given the reduction of vegetation to help absorb water in the soil, the area of available water supply also decreased. The index of freshwater provisioning services was changed to very low, whereas the medium and low classes in Peniraman Village have a total of 1,077.98 ha or 48.15% of the area. This issue should receive greater attention from the local government and community to mitigate disasters and other environmental problems.

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