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Regional Case Study

Impact of Monitoring Land Use Changes to Anticipate Management of Erosion Rates in the Brantas Hulu Watershed

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Abstract

Land use change in river basins is an important issue for policymakers. In this case, it is essential to carry out comprehensive monitoring for decision-making. Land use monitoring must be carried out continuously so that changes that occur over a certain period can continue to be monitored. In this case, the Brantas Hulu watershed includes Batu City, Malang City, and Malang Regency. This river basin is considered critical due to massive land use changes. This condition directly encourages an increase in sedimentation rate in rivers and reservoirs. This research aims to obtain the results of monitoring land use changes and determine the handling of erosion rates by monitoring land use changes in the Brantas Hulu watershed. The method used to determine the spatial characteristics of soil erosion in the Upper Brantas watershed uses the Universal Soil Losses Equation (USLE) method. The research results show that erosion conditions in the Brantas Hulu watershed are dominated by class I/very light erosion hazards (36.43%).), class II/light (22.35%), class V/very heavy (16.07%), class III/moderate (13.09%), and class IV/heavy (12.05%). The proposed control measures for erosion sites include structural and non-structural approaches.

Keywords: Monitoring changes in land use; erosion rate in brantas river; erosion handling

1. Introduction

The Brantas Hulu watershed is in East Java Province covering areas in Batu City, Malang City and Malang Regency with the outlet point according to research being at the Sutami/Karangkates Reservoir. The area of the Brantas Hulu watershed is 2,006.76 km2 with a population of ±2,500,000 people (Perum Jasa Tirta I, 2022). The issue that is currently developing is that there is large and massive exploitation in the Brantas Hulu watershed area, which causes changes in land use.

Changes in land use from vegetation areas to built-up or agricultural areas have a significant impact on increasing erosion and sedimentation. With a very dense population, changes in land use cannot be avoided. Therefore, good carrying capacity in the upstream area of the Brantas River is needed and collaborative management of policy stakeholders is needed (Handayani et al., 2023).

In this case, it is essential to carry out comprehensive monitoring for policymakers to sharpen decision making. Monitoring carried out on land use must be continuous so that changes that occur over a certain period of time can continue to be monitored. Changes in land use will make a watershed area critical or, conversely, land that receives conservative reforestation activities will become something good. Conservation in the Brantas Hulu watershed is the most important effort in sediment management, conservation of river watersheds can reduce the potential for sedimentation by 3.16% of total sedimentation and sedimentation management (Mardwiono et al., 2022). Where sedimentation is influenced, one of them is the rate of uncontrolled erosion in the upstream part.

High rates of erosion and sedimentation can have an impact on reducing river capacity (Kardhana et al., 2024). Reducing river capacity can create a high potential for flooding during the rainy season. For example, there was a major flood in Batu City in 2021 which was the result of a reduction in river capacity (Handayani et al., 2023). Sedimentation problems in the downstream parts of the Brantas Hulu watershed, namely the Sutami and Sengguruh Reservoirs. In the case of the Sutami Reservoir, in the next 10 (ten) years, the Sutami Reservoir intake will be covered by sediment. The service life of this reservoir becomes shorter, so there will be large economic losses because the reservoir is very important for energy and raw water.

This research aims to obtain the results of monitoring land use changes and determine the handling of erosion rates in accordance with the results of monitoring land use changes in the Brantas Hulu watershed. Erosion analysis in this research uses the Universal Soil Loss Equation (USLE). Although the USLE model has long been available, comprehensive research covering the entire Upper Brantas watershed is still limited. In addition, existing research often relies on data that is less representative of the watershed and only on sub-watersheds in the Brantas Hulu area (Pambudi & Moersidik, 2019). The land use data used is based on planning data which cannot yet be interpreted as conditions in the field. The data used each year is also very limited (Mardwiono et al., 2022). This research is different from previous research because it uses land use data from field observations and rainfall data for more than 20 years so the research is more comprehensive. The hope is that it can speed up decision making to deal with erosion in the Brantas Hulu watershed

2. Methods

2.1. Brantas Hulu Watershed

2.1.1. Location

The Brantas River area is a national strategic river area and is under the authority of the Central Government (Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2015). The Brantas River is the second largest river on the island of Java with a river length of ± 320 km and a watershed area of ± 14,103 km^2. At the location of this research, namely the Brantas Hulu watershed, including the cities of Batu, Malang, Blitar, where massive land use changes occurred.

The location of the Brantas Hulu Watershed uses the outlet point at Sutami Dam. We use it at Sutami Dam because the area is included in the Brantas Hulu watershed system (Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2010) . Sutami Dam is also the largest dam in the cascade system in the region At the exit point there are 2 reservoirs, namely Sutami Reservoir and Sengguruh Reservoir. In this case, the Sengguruh Reservoir has the benefit of being a hydroelectric power plant as well as an operational and maintenance reservoir for the Sutami Dam. The research location for the Brantas Hulu watershed can be seen in Figure 1.

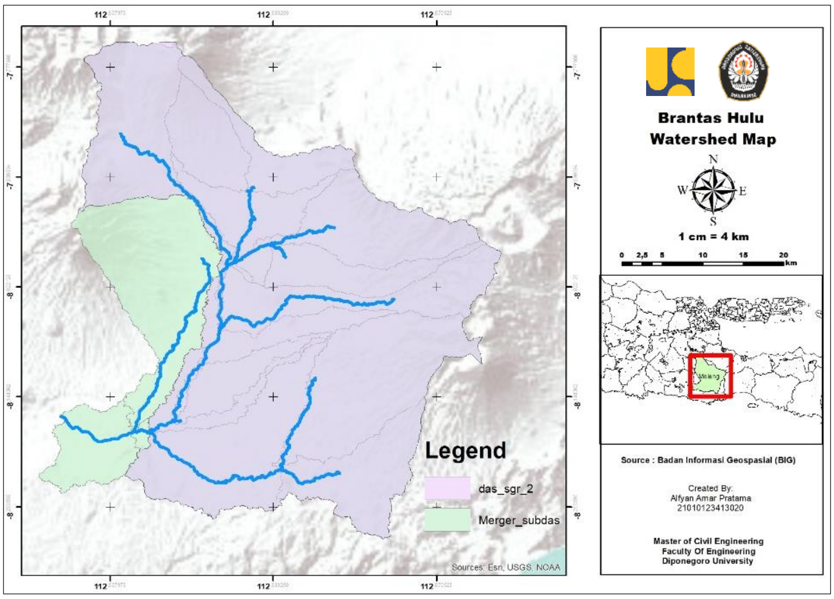


Figure 1. Layout of the Brantas hulu watershed

2.1.2. Land use monitoring

Monitoring changes in land use using real field data produced from Balai Pemantapan Kawasan Hutan dan Tata Lingkungan (BPKHTL) Wilayah XI Yogyakarta, Kementerian Lingkungan Hidup dan Kehutanan. BPKHTL carries out an inventory of data on changes in land use data using satellites belonging to the Kementerian Lingkungan Hidup dan Kehutanan. This activity is an annual routine activity. The data used is in *.shp format in spatial form, making it easier to process the data. Data used for more than 20 years. The use of long data to accommodate extreme conditions, a change which over 20 years has represented conditions in the field and is integrated with erosion management.

2.2. Data Collection and Selection Criteria

2.2.1. Erosion analysis

The methodology used in this research begins with data collection, continues with GIS-based erosion calculations and concludes with zonal erosion analysis. Various input data were collected including digital elevation models (DEM), rainfall, soil, slope gradient, land cover, and agricultural practices.

Collecting information about land use information is very important because most of the land in the Brantas Hulu watershed is a critical area used for agriculture, especially dry land agriculture, which significantly affects soil erosion (Valiant, 2014).

The USLE Method is used to calculate the amount of erosion. The USLE method states the magnitude of soil erosion as a function of rainfall energy, soil erodibility (resistance to erosion), topographic factors, and land cover. USLE is an excellent tool for estimating average erosion. This capability helps determine whether an area is susceptible to high levels of erosion and evaluate the overall impact of erosion over a long period of time. So you can know the level of erosion to monitor changes over time and prioritize areas for conservation intervention.

The USLE method is empirical, USLE can quickly evaluate erosion risk across a variety of landscapes, making it easier to identify areas vulnerable to soil erosion and prioritize conservation efforts. Its wide acceptance and credibility in erosion modeling studies is further enhanced by its long history of application and validation in various locations. This capability helps determine whether an area is susceptible to high levels of erosion and evaluate the overall impact of erosion over a long period of time. When comparing erosion rates under various land management scenarios or assessing the success of erosion control. USLE uses the equation of (Wischmeier & Smith, 1978). The USLE equation following equation (1):

$$A = R \times K \times LS \times C \times P \tag{1}$$

Where:

A : amount of soil erosion
R : erosivity of rainfall
K : soil erodibility factor
LS : terrain length and slope factor
C : land cover factor
P : land management factors

2.2.2. Erosivity of Rainfall (R)

Various erosivity formulas have been developed based on the characteristics of research locations in various parts of the world (Alewell et al., 2019). Calculation of rain erosivity using the Bols equation in (Asdak, 2007). The Bols Erosivity Formula is a formula that is widely used based on empirical research on the island of Java (Suripin, 2004), where the Brantas Hulu watershed is located. The erosivity factor equation can be seen in Equation (2(.

$$R = 6{,}119 \times P_b^{1{,}211} \times N^{-0{,}474} \times P_{Max}^{0{,}526} \tag{2}$$

Where:

R : Erosivity of rainfall
P_b : Total monthly rainfall
N : Number of rainy days in a month
P_{max} : Maximum daily rainfall in a month

This research uses data from 37 rain stations. The rain stations consist of 6 rain stations from Perum Jasa Tirta I Malang (Persero) and 31 rain stations UPT PSDA Malang, Jawa Timur. Rain stations are spread across the Brantas Hulu watershed area with the length of rainfall data used being 20 years of recording between 2002 and 2023. The length of the data is considered sufficient for rainfall analysis according to Indonesian standards (Badan Standardisasi Nasional, 2016).

2.3. Soil Erodibility Factor (K)

For the soil erodibility formula, use the Kusle equation with the data used using (Russell & Jackson, 2014) data base. The equation used according to (Wawer et al., 2005) can be seen in Equation (3).

$$K_{Usle} = F_{csand} \times F_{cl-si} \times F_{orgc} \times F_{hisand} \tag{3}$$

Where:

F_{csand}: K value indicate of soil with a high or more coarse sand content from the ground
f_{cl-si} : K value indicate of soil with a ratio of clay to silt
f_{orgc} : K value indicate of soil with high organic carbon content
F_{hisand} : K value indicate of soil with a very high sand content

2.4. Length and Slope Factor (LS)

The LS factor describes the influence of land topography on the rate of erosion, where topographic conditions are represented in the length and steepness of the terrain. Formulas that express the relationship between length and slope have been developed extensively, and each formula can produce different values depending on where the formula was developed. The equation used according to (Wood & Dent, 1983) can be seen in Equation (4).

$$LS = 34.7046 \left(\frac{L}{22.1}\right)^m \times (cos\ cos\ \alpha\ )^{1.503} \times \left(\frac{(sinsin\ \alpha\ )^{1.249}}{2} + (sin\ sin\ \alpha\ )^{2.249}\right) \tag{4}$$

Where:

L : Length of Slope

m : Slope

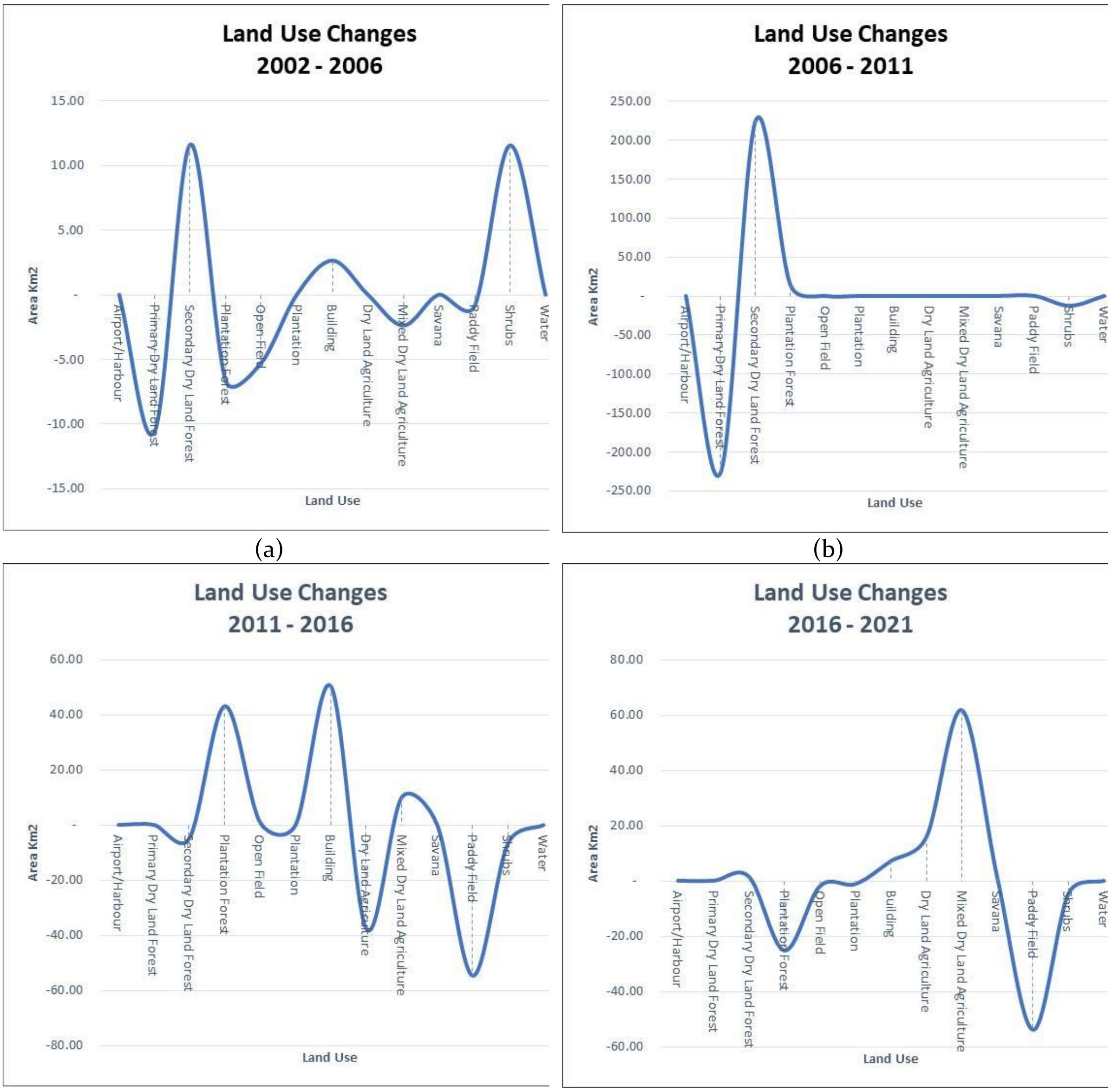
2.5. Land Cover Factor (C)

The land cover factor (C) shows the effectiveness of land cover in an area in reducing the rate of erosion. The data used to determine the C value is based on land cover maps sourced from the Balai Pemantapan Kawasan Hutan dan Tata Lingkungan (BPKHTL) Wilayah XI Yogyakarta which covers the Java and Bali regions. The length of data used is 20 years with the data format namely *.shp.

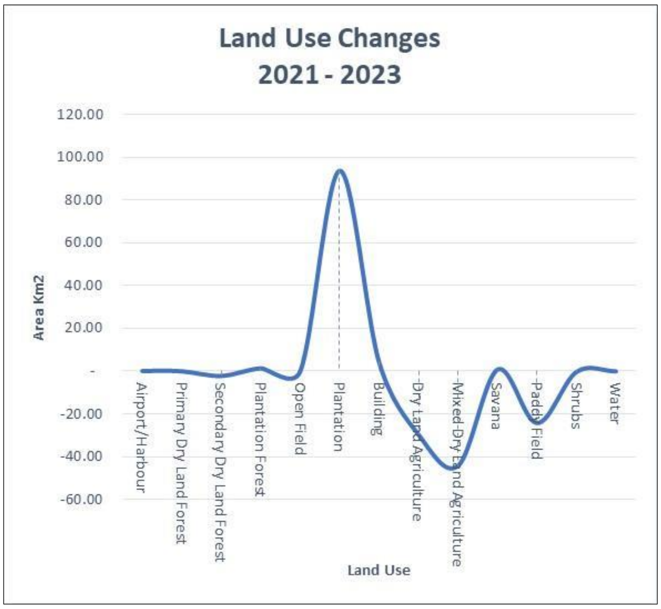
3. Result and Discussion

3.1. Land Use Monitoring

Monitoring changes in land use in the Brantas Hulu watershed location starting from the period 2003 to 2022. This condition is considered to represent the condition of changes in land use at the Brantas Hulu watershed location. These monitoring efforts are related to the age of the reservoirs downstream of the Brantas Hulu watershed, namely the Sutami reservoir and the Sengguruh reservoir.The land use maps displayed, namely 2003 and 2022, can be seen in Figure 3. Complete changes in land use will be displayed via graphs for the 5 year period. The graph can be seen in figure 2 to figure 6.



(a) (b) (c) (d)



(e)

Figure 2. Graph of Land Use Changes (a) 2002-2006 (b) 2006 – 2011 (c) 2011 - 2016 (d) 2016 – 2021 (e) 2021 - 2023

In accordance with the graph for changes in land use per 5 (five) years can be seen in the figure 2 to figure 6. Land use changes were seen to be massive in 2006, which occurred in the designation of primary dry land forest which changed to secondary dry land forest at 11.28%. From the land use change data above, it can also be seen in residential areas in the period 2002 to 2022, with an increase in area of 3.2% or an area of 64.3 km². These changes occurred more towards a reduction in land function, from primary dry land forests to densely populated settlements.The increasing people population and reduced water absorption in the upstream section are worsening the condition of the watershed.

With a total watershed area of 2,006.76 km² in 2022, the largest area will be plantations with an area of 93.94 km². Dry agricultural crops and mixed agricultural crops experienced a decline with an area of 29.74 km² and 44.21 km². This indicates that market demand for plantation crops has increased and is strengthened by the condition of the Sengguruh reservoir which has experienced an increase in sedimentation rates. The effective storage capacity of the reservoir was originally 2.5×10^6 m³ to 0.75×10^6 m³. This is a reduction in storage of 30% (Perum Jasa Tirta I, 2022).

Changes in land use in Figures 7 include plantations and rice fields dominating the Brantas Hulu watershed. This condition is exacerbated by land conversion caused by population growth so that settlements increase very rapidly. Also reinforced by the journal, according to (Subagiyo et al., 2020), the condition of Batu City's agricultural sector is starting to be threatened due to transfer conversion of agricultural land to built-up land to support the tourism sector. For the upstream part, namely Batu City, there is increasingly widespread construction of residential houses in the elite Batu tourist area as well as plantations with many single roots such as secondary crops, apples, strawberries, potatoes, etc. plantations due to large market demand. Agricultural crops or shallow plants that often replace trees are unable to hold the soil, thus worsening soil erosion (Sulaeman et al., 2022).

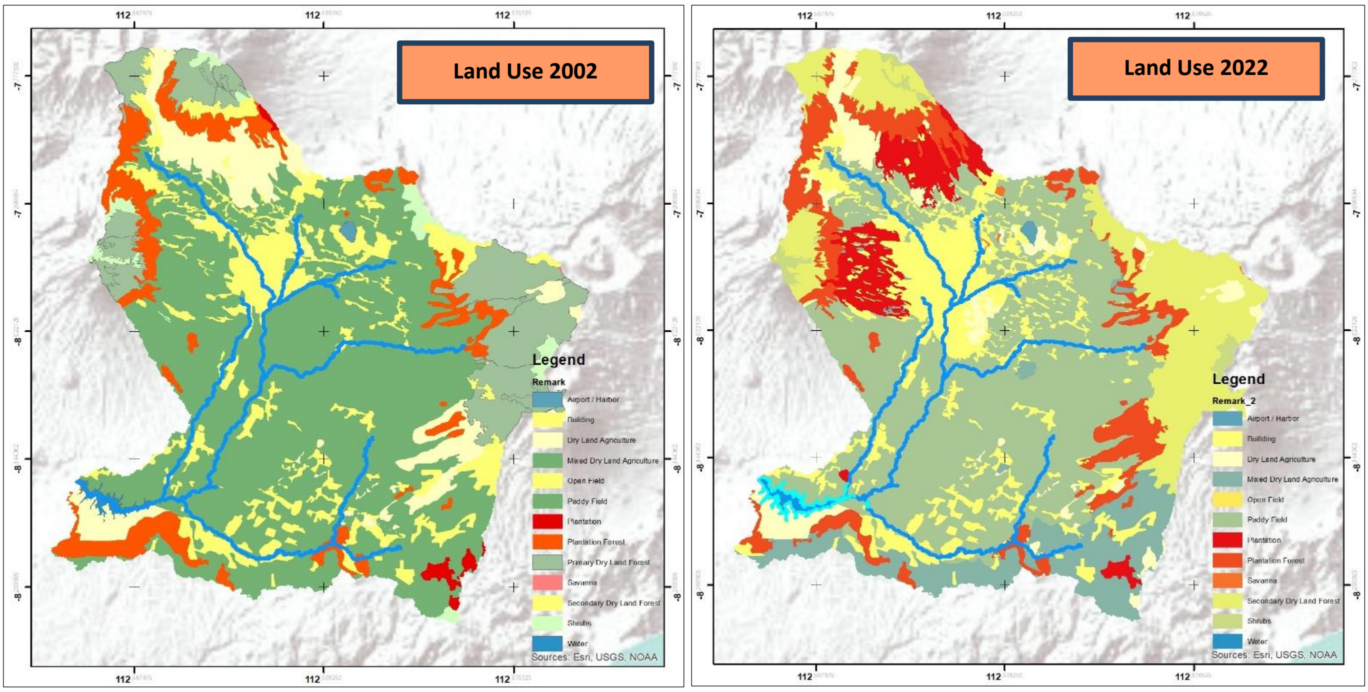


Figure 3. Land Use Map 2002 and 2022

3.2. Erosion analysis

For erosion analysis using the USLE model, the rainfall erosivity (R) value was obtained from 37 rainfall post stations spread across the Brantas Hulu watershed. Then use the Thiesen polygon model to get regional rainfall. For the erodibility value (K), use FAO data as the basis for calculations and then use equation (3)(Wawer et al., 2005). For the LS value, use equation (4) (Wood & Dent, 1983) . For the land use value (C) use data measurements from the Balai Pemantapan Kawasan Hutan dan Tata Lingkungan Wilayah XI Yogyakarta, Kementerian Lingkungan Hidup dan Kehutanan.

After the data was collected from 2003 to 2022, it was continued to be analyzed using GIS for creating digital maps and spatial analysis. Brantas Hulu watershed data uses Digital Elevation Model (DEM) data obtained from the Indonesia Geospatial Portal which was accessed in April 2024. The data is processed spatially to make reading easier in the watershed area.

Data that has been collected using the GIS tool uses equation (1) by entering the specified input. Then erosion rate data was generated from the range 2003 – 2022. The data is adjusted to the year of calculation. The results of the erosion rate are shown in Figure 8.

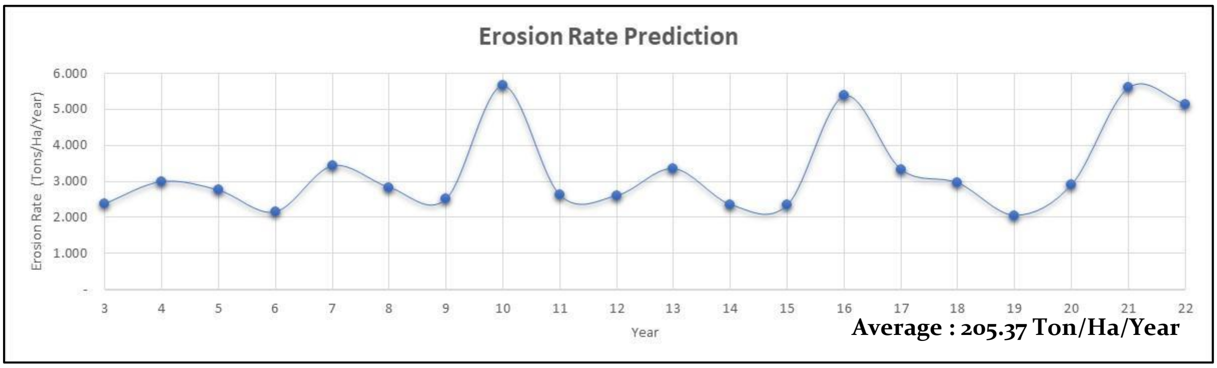


Figure 4. Predicted in erosion rates 2003-2022

The results of the analysis on the rate of erosion each year show that it fluctuates. The causes are changes in land use and rainfall conditions. The predicted conditions for the greatest erosion rate will occur in 2010, 2016, 2021 and 2022. The land use change that occurred in 2010 was the change in land use from primary dry land forest to secondary dry land forest. The same thing happened in 2016, the paddy fields turned into building. Large rainfall in 2010 and 2016 also caused flooding in Malang City and Malang Regency (Kompas.com, 2010),(Kompas.com, 2016). In 2020 and 2021, the predicted erosion trend is above average. Based on interviews with the Sengguruh reservoir management unit, this condition resulted in the reservoir's dead storage capacity becoming full and flushing was carried out to increase storage. This is a problem because downstream conditions in the Sengguruh Reservoir are stagnant water in the Sutami Reservoir. so that the flushing results have a direct impact on the Sutami reservoir's inundation. The average rate of erosion produced in the period from 2002 to 2022 was 205.37 tons/ha/year.

The erosion analysis map provides a visual representation of the spatial distribution of watershed erosion levels in tons/ha/year. The erosion hazard level is an estimate of the maximum amount of soil that will be lost on a piece of land, if crop management and soil conservation measures do not change. The maximum amount of land lost must be less than or equal to the amount of land formed through the soil formation process so that land productivity remains high. In addition, the level of erosion is further classified into five class categories (Hardjowigeno, 1993). From the lightest class I category (under 15 tons/ha/year) to the highest class V category (more than 480 tons/ha/year). The results of the analysis show that erosion conditions in the Brantas Hulu watershed are dominated by class I/very light erosion hazards (36.43%), class II/light (22.35%), class V/very heavy (16.07%), class III/moderate (13.09%), and then class IV/heavy (12.05%). The erosion hazard classes in the Brantas Hulu watershed can be seen in Table 1.

Tabel 1. Erosion class Brantas hulu watershed

Erosion Class	Rate of erosion (Tons/ha/yr)	Class Description	Area (Km^2)	Percentage
I	< 15	Very Light	731.01	36.43%
II	15 – 60	Light	448.60	22.35%
III	60 – 180	Moderate	262.78	13.09%
IV	180 – 480	Heavy	241.83	12.05%
V	>480	Very Heavy	322.54	16.07%
Total			2.006,76	100%

The percentage in the Brantas Hulu watershed is class I where the location is in a flat position, namely Malang City and Central Malang Regency. Locations with class V are on the northern slopes and western parts of the watershed. This sediment is a type of humus soil located in the downstream area of the Brantas Hulu watershed (Puslitbang, 2014). The Handling location can be seen in figure 9.

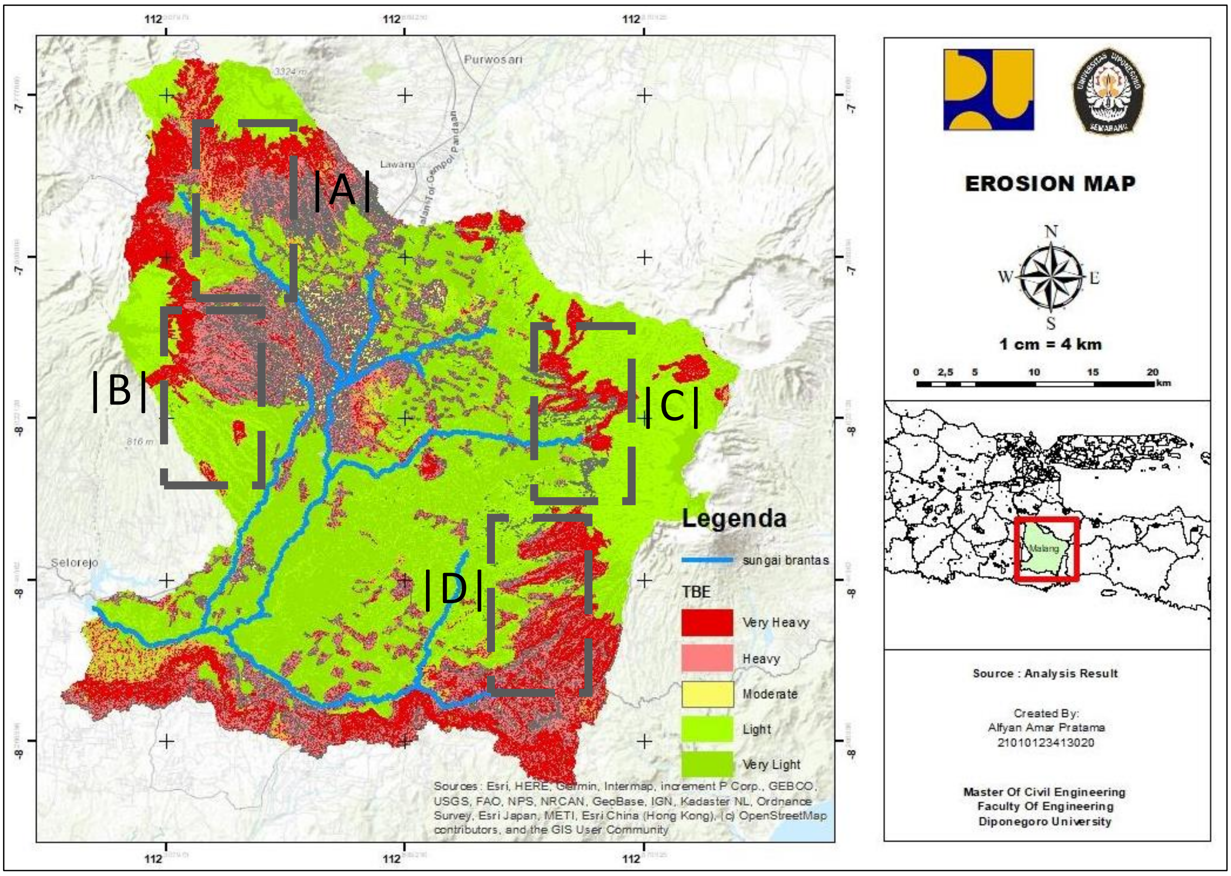


Figure 5. Erosion map

Location |A| is on the slopes of Mount Arjuno near Batu City. Conditions of changes in land use change from Primary Forest to Secondary Forest, and some open land turned into settlements. The condition of the soil and land cover in this area is very vulnerable to erosion. The use of land for agriculture in steep areas worsens the condition. The application of terracing techniques, especially bench terraces, can effectively reduce high soil erosion. This terracing method has been proven to be effective and efficient for agriculture, especially horticulture (Chen & Wei, 2016).

Location |B| is on the slopes of Mount Kawi in the western part of Malang City. Conditions that are almost the same as location |A| erosion comes from dry land farming. Soil conservation efforts should be prioritized because soil conditions are very easily eroded. Implementing reforestation can help stabilize the soil and increase land cover (Meseret, 2015). According to the report (Perusahaan Umum (Perum) Jasa Tirta I, 2015), Perum Jasa Tirta I Malang (Persero) has carried out reforestation at several points in the Brantas Hulu watershed. The location planted is a tree with fibrous roots. The hope is to repair the watershed location which has already experienced damage.

Location |C| is on the slopes of Mount Bromo where it is dominated by volcanic soil material composed of eruptions and has a texture consisting of finer sand ash. This texture is very susceptible to erosion. Vegetation cover in the form of mulch can protect soil surfaces that are vulnerable to erosion. Mulch protects soil from erosion by functioning as a physical barrier, absorbing rainwater, reducing runoff speed, retaining moisture and improving the quality of soil structure (Prosdocimi et al., 2016).

Location |D| is on the slopes of Mount Semeru where sand is mined from the eruption of Mount Semeru. And exacerbated by changes in land use which contribute to increased erosion and loss of reservoir capacity (Shrestha et al., 2021). The construction of a check dam, sediment traps and gully plugs will help sediment enter the reservoir storage. Maintenance efforts are also highly recommended to be carried out regularly. Especially along the Lesti river and Brantas river, there are many check dams that are not carried out routinely due to difficult locations, minimal access and limited budget for maintenance. For this reason collaboration between parties is needed to find the best solution to resolve this problem.

Grouping plants to reduce the erosion process is very influential in reducing the rate of erosion (Marhendi, 2013). More precisely at point |A| and |B|. These two points are plantation locations with types of plants that have short roots. By grouping plants, policy makers can pay special attention to mitigating the reduction in erosion rates. At each location, balancing plants such as bamboo should be built. Bamboo is very easy to find according to each region. Apart from that, bamboo has high economic value, bamboo also has a strong fibrous root structure so it is able to resist erosion (Budiwati, 2015).

The results of this research provide a comprehensive understanding where the process of erosion over a period of 20 years can be described well. In particular, decision makers can provide policies to mitigate locations prone to erosion. Mitigation can take the form of strategies for handling erosion such as terracing, reforestation and sustainable management practices. This research can produce guidelines for the planning process for land use, agriculture and infrastructure development. The following is a design map of the location where reforestation, terracing, mulching and check dams will be handled, which can be seen in Figure 10. The planting system can be seen in Figure 11.

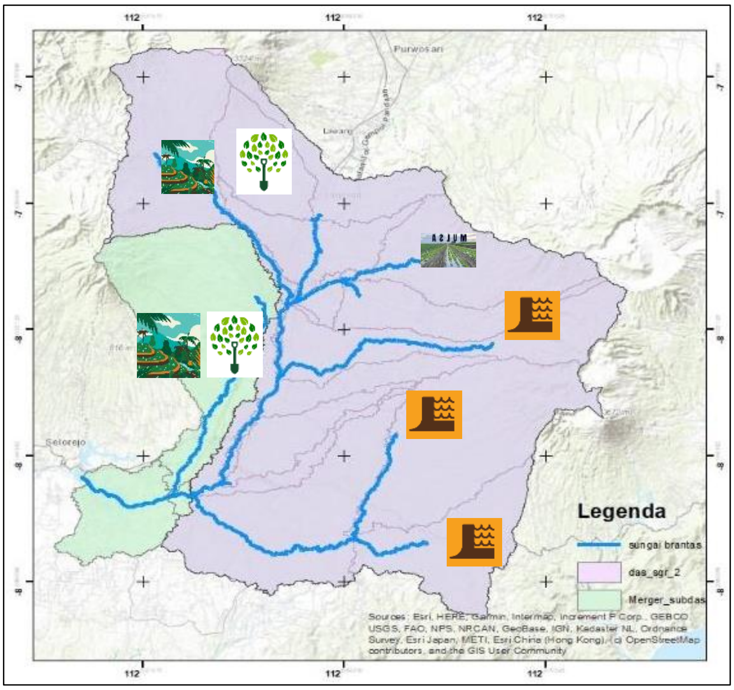


Figure 6. Erosion management map

Figure 7. planting system on agricultural land

4. Conclusions

Changes in land use in the period 2002 to 2023 will greatly affect the condition of the watershed, especially the Brantas Hulu. Added to this are natural conditions such as very heavy rainfall. This condition worsens the rate of erosion in sub-watersheds in the Brantas Hulu area. Flood conditions in areas, especially in parts of Malang City and Malang Regency, indicate that these locations are not ready to accommodate water due to land conversion.

Changes in land use were seen to be massive in 2006, which occurred in the designation of primary dry land forests which underwent changes. to secondary dry land forest of 11.28%. From the land use change data above, it can also be seen in residential areas in the period 2002 to 2022 with an increase in area of 3.2% or an area of 64.3 km². With a total watershed area of 2,006.76 km² in 2022, the largest area will be plantations with an area of 93.94 km². Dry agricultural crops and mixed agricultural crops experienced a decline with an area of 29.74 km² and 44.21 km² respectively.The erosion rate is further classified into five class categories. From the lightest class I category (under 15 tons/ha/year) to the highest class V category (more than 480 tons/ha/year). The results of the analysis show that erosion conditions in the Brantas Hulu watershed are dominated by class I/very light erosion hazards (36.43%), class II/light (22.35%), class V/very heavy (16.07%), class III/moderate (13.09%), and class IV/heavy (12.05%). The handling area can be adjusted according to needs. This treatment includes terracing, reforestation, making mulch and handling sedimentation by building structures in the form of gully plugs with small areas up to the construction of sediment control buildings.

Recommendations in the form of structural and non-structural efforts. for structural treatment in the form of constructing check dams at river points that have high erosion potential. as well as non-structural in the form of reforestation, terracing and mulching. Repairing watershed locations is very helpful in handling damaged watersheds. Starting from river care communities that were built in each village with the hope that these communities could become a means of protecting river watersheds.

Handling can start with mitigation from monitoring results produced on an ongoing basis. This research also invites comprehensive monitoring and invites all relevant stakeholders to save river watersheds.

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Additional Information

Balai Pemantapan Kawasan Hutan dan Tata Lingkungan (BPKHTL) Wilayah XI Yogyakarta, Kementerian Lingkungan Hidup dan Kehutanan is institution under Ministry of Environment and Forestry which take care of strengthening forest area and environment arrangement in Area XI Yogyakarta. Perum Jasa Tirta I Malang (Persero) under Ministry of State-Owned Enterprises of The Republic of Indonesia. Unit Pelayanan Teknis Sumber Daya Air (UPT SDA) Malang Jawa Timur under Malang Water Resources Works Departments.

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