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# THE IMPACT OF LAND USE CHANGES ON THE SERVICE LIFE OF WLINGI RESERVOIR

**Indang Dewi Rarasati[1], Suripin[2], Dyah Ari Wulandari[2], Dwiva Anbiya Taruna[4]**
[1,2,3] Departemen Teknik Sipil, Fakultas Teknik, Universitas Diponegoro, Tembalang, 50275, Semarang, Jawa Tengah, Indonesia
[4] Magister Teknik Lingkungan Jalur Rekayasa Sumber Daya Air, Universitas Teknologi Delft, Mekelweg, Belanda
Email: indangdewii23@gmail.com

**ABSTRACT**

*One of the factors that can affect changes in the capacity of a reservoir is the amount of sedimentation that settles at the bottom of the reservoir. Several reservoirs in Indonesia have experienced shallowing due to sedimentation, which has caused a significant reduction in the service life of the reservoir, including the Wlingi reservoir in the Brantas Hulu watershed. The increase in sedimentation rate is caused by high land erosion. Land erosion comes from changes in land use in a River Basin Area. The benefits of the Wlingi Reservoir are as a flood controller of 2.37 m3/s, irrigation supply of 13,600 hectares, as a power plant that can drive the turbine of a PLTA unit with a power of 2 x 27 MW so that it can provide additional electrical energy of ±164.98 million kWh/year. Numerous studies have examined the impact of land use changes on erosion rates. In this study, land use data comes from ESRI satellite imagery, which differs from previous studies. This study aimed to obtain sediment yield from land use changes in the Brantas Hulu Watershed with the Wlingi Reservoir outlet point from 2018 to 2023 and to predict the remaining service life of the reservoir. The method used to calculate the erosion rate is USLE, which uses GIS (Geographic Information System) software. The results showed that undisturbed forests dominated land use, and land use changes for 6 years were volatile. The average sediment rate for 6 (six) years was 0.011 mm/year. The predicted service life is that Wlingi Reservoir can only serve for 91 years. These findings highlight the urgency of implementing effective sediment management strategies. Without intervention, sedimentation will reduce the reservoir's capacity to support irrigation and hydropower, impacting regional water management and food security and limiting flood mitigation capabilities in East Java.*

**KEYWORDS** *Engineering, Wlingi Reservoir, Sedimentation, Land Use Changes, Erosion Rates, Brantas Hulu Watershed, Service Life*



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## INTRODUCTION

Reservoirs are containers used to store water when there is excess water so that it can be utilized as needed. Reservoirs are also referred to as artificial containers formed due to the construction of dams. Reservoirs are also infrastructure in supporting food, energy and water sufficiency. The utilization of water for these three things is a determining factor in increasing national development. Although until now the dam/reservoir has only irrigated about 800 thousand hectares or 11% of the 7.5 million hectares of technically irrigated land, the role of the dam or reservoir is very vital (Amron, 2011). Behind the enormous benefits of reservoirs, there are several reservoirs that experience high sedimentation rates characterized by siltation (Adzan & Samekto, 2008). The increase in sediment rate is caused by high land erosion (Marheni & Sulastri, 2013). Land erosion comes from changes in land use in a watershed. Land erosion, triggered by land use changes such as agricultural expansion and deforestation, causes increased sedimentation and shortens the service life of reservoirs. As was the case with Sutami Reservoir, there was a significant increase in sedimentation due to deforestation in 1998. Erosion is the movement or transportation of soil or parts of soil from one place to another by natural media. In an erosion event, soil or parts of soil in one place are eroded and transported, then deposited in another place. This erosion and transportation of soil occurs through natural media, namely water and wind (Arsyad, 2010). According to (Kim, 1991) and (Lanyala et al., 2016), soil erosion in watershed ecosystems generally occurs due to land use that ignores the principles of soil and water conservation.

Wlingi Reservoir is one of the dams in Indonesia with a *cascade* type that began operating in 1977 which has a total storage of 24 million $m^3$ and a dead storage of 18.8 million $m^3$ with the main function as flood control, irrigation water supply, and Hydroelectric Power Plant (PLTA). Research from (Juldah et al., 2023) modeled land use change using data from BIG for 3 years at Ngancar Dam with the results of land erosion in 2011 of 97,028.49 tons/year, 2016 of 100,432.21 tons/year, and 2020 of 103,628.90. So that the remaining life of the Ngancar Reservoir is 3.7 years. Another study, conducted by (Suroso et al., 2007) on Sutami Dam using land use data from Perum Jasa Tirta 1 from 1994 to 2004 resulted in a sediment rate of 1,044,000 m3 / year, so it is estimated that the age of Sutami Reservoir will end in 2023. Research conducted in Tilong Reservoir by (Fallo et al., 2013) using land use data for 1 year resulted in an erosion rate of 25,428.155 tons/year. In this study, land use change modeling uses satellite images obtained from ESRI for 6 years, from 2018 to 2023. This is used to determine the trend of sediment change and the service life of the Wlingi Reservoir.

Sediment entering Wlingi Reservoir is currently in the form of material from land erosion, river cliffs, and landslides due to the increase in tourist sites and land use changes around Wlingi Reservoir (Perum Jasa Tirta 1, 2021) , Therefore, research is needed to predict the magnitude of erosion and sedimentation results. Various new models to predict soil erosion have been investigated, such as WEPP (Water Erosion Prediction Project) (Oost et al., 2000), WaTEM/SEDEM (Water and Tillage Erosion Model/Sediment Delivery Model) and EUROSEM (European Soil Erosion Model) (Morgan et al., 1998). These models can provide more detailed results than the commonly used USLE (Universal Soil Loss Equation) (Wischmeier and Smith, 1978). However, these newer models require larger datasets, and some are limited to specific land uses, such as agriculture. Even models that combine machine learning with empirical methods have also been investigated (e.g., Avand et al., 2022), but are still impractical for widespread use due to high data demands, including up to 14 variables required for training and implementation.

## RESEARCH METHOD

### Location

The research was conducted in the Upper Brantas Watershed with an outlet point at Wlingi Dam, Jegu Village, Sutojayan Subdistrict, Blitar Regency, precisely at coordinates 8°8'23.57 "S and 112°14'54.60 "E. This watershed has an area of 72,488.70 ha or 724.89 km$^2$. However, in some parts of the banks of the Brantas River, there are steep slopes and even almost vertical cliffs. Wlingi Reservoir is one of several reservoirs in the Brantas River Basin. The construction of this reservoir was initiated by conditions in 1961, when agricultural land was shrinking due to limited irrigation water, increasing electricity demand, and government initiatives to realize rice self-sufficiency to reduce Indonesia's dependence on rice imports.

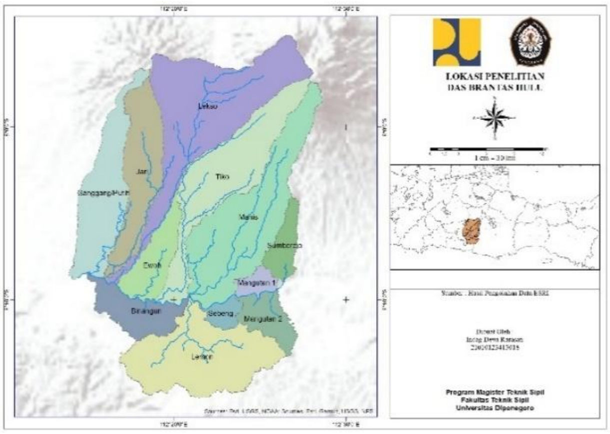


Image1 . Research Location

### Data Collection

Data is an important element needed in determining the success of the analysis. The data required is as follows:

1) Land use data for 2018, 2019, 2020, 2021, 2022, and 2023 were obtained from ESRI Sentinel-2 imagery (Figure 2) at 10m resolution created by *Impact Observatory*, *Microsoft*, and ESRI. Land use data can be downloaded from the *website* ( https://www.arcgis.com/home/item.html?id=cfcb7609de5f478eb7666240902d4d3d ). The data downloaded from ESRI can be enhanced using GIS processing software to improve the sharpness of the images and the details of land use in the study sites according to the needs of the analysis. Based on this period of data availability, other datasets will use the same period. The disadvantage of data taken using satellites is that it cannot penetrate if there are clouds covering the object under review.

Image2 . ESA Sentinel-2 Image View

Based on Figure 2, there are different colors, which indicate different land uses. Colors are identified with different *"values"*. The relationship between *value* and land use can be seen in Table 1.

Table1 . ESRI Land Use

| ***Value*** | ***Name*** | ***Description*** |
|---|---|---|
| 1 | Water | Areas that consistently contain water throughout the year, excluding areas with water that appears only occasionally or temporarily; have almost no sparse vegetation, no rock outcroppings, and no artificial elements such as piers; examples include rivers, ponds, lakes, oceans, and salt flats that are always flooded. |
| 2 | Trees | Large dense assemblages of tall (~15 feet or more) vegetation, generally with a closed or dense canopy; examples are forested vegetation, clusters of tall, dense vegetation in savannas, plantations, swamps, or mangroves (tall/dense vegetation with temporary water or a canopy too dense to detect water underneath). |
| 4 | Flooded vegetation | Areas with a variety of vegetation types that are clearly mixed with water throughout most of the year; areas that are seasonally inundated with water and consist of a mixture of grasses, shrubs, trees, and open ground; examples are flooded mangroves, emergent vegetation over water, rice paddies, and other intensively irrigated and flooded agriculture. |
| 5 | Cultivated Plants | Cereals, grasses, and other crops grown by humans at a height below that of trees; e.g., corn, wheat, soybeans, and regular fallow. |
| 7 | Building | Man-made structures; large highway and railroad networks; large, uniform impervious surfaces, including parking structures, office buildings, and residential areas; e.g. residential houses, small villages/cities/dense cities, paved roads, asphalt. |

| ***Value*** | ***Name*** | ***Description*** |
|---|---|---|
| 8 | Open Land | Rocky land has very sparse or no vegetation throughout the year; large areas of sand and desert with little or no vegetation; Examples: rocks or open ground, deserts and dunes, dry salt flats, dry lake beds, mines. |
| 9 | Snow/Es | Large, uniform areas of permanent ice or snow, usually only in mountainous regions or at higher latitudes; e.g. glaciers, permanent snow cover, snowfields. |
| 10 | Cloud Cover | There is no land cover information due to continuous cloud cover. |
| 11 | Shrubs | Open spaces covered by uniform grass, with little or no overlying vegetation; grains and weeds that have never been clearly cleared by humans (i.e., unmapped land); Examples: natural meadows and fields with sparse or no tree cover, open grasslands with few or no trees, parks/golf courses/grasslands, pastures. Mixed small groups of plants or single trees scattered across the landscape *leaving bare soil or rock; dense clearings in dense forest, clearly not taller than the trees; e.g., moderate to rare* |

Source: ESRI

2) data
3) Rainfall data from Doko, Sumber Agung, and Wlingi Dam stations for 6 (six) years, from 2018 - 2023 obtained from Perum Jasa Tirta 1 as the manager of the Wlingi Dam.
4) Technical data and major inspections of the Wlingi Dam from the Dam Engineering Center.

**Basic Theory**

***Erosion Forecast USLE Method***

Of the several methods to predict the amount of surface erosion, the USLE method developed by Wischmeir and Smith (1978) is the most commonly used method to predict the amount of erosion (Chay Asdak, 2002). The USLE equation categorizes the various physical and management parameters that affect erosion rates as shown in equation 1.

$$EP = R \times K \times LS \times C \times P \quad (1)$$

where,

EP = potential erosion (tons/ha/year)
R = rainfall erosivity
K = soil erodibility
LS = slope slope
C = land use
P = conservation action

***Rain Erosivity Factor (R)***

The rainfall erosivity factor is shown in equation 2.

$EL30 = 6.21(RAIN)^{(1.21)}(DAY)^{(-0.47)}(MAXP)^{(0.53)}$ (2)

***Soil Erodibility Factor (K)***

To get the "K" value, you can follow equation 3 from Williams

$$KUSLE = f_{csand} \cdot f_{cl-si} \cdot f_{orge} \cdot f_{hisand} \quad (3)$$

$$f_{csand} = \left(0,2 + 0,3 \cdot exp\left[-0,256 \cdot m_s \cdot \left(1 - \frac{m_{silt}}{100}\right)\right]\right) \quad (4)$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0,3} \quad (5)$$

$$f_{orge} = \left(1 - \frac{0,25 \cdot orgC}{orgC + exp[3,72 - 2,95 \cdot orgC]}\right) \quad (6)$$

$$f_{hisand} = \left(1 - \frac{0,7 \cdot \left(1 - \frac{m_s}{100}\right)}{\left(1 - \frac{m_s}{100}\right) + exp\left[-5,51 + 22,9 \cdot \left(1 - \frac{m_s}{100}\right)\right]}\right) \quad (7)$$

where,

$K_{USLE}$ = soil erodibility value
$M_s$ = sand content (%)
$M_{silt}$ = silt content (%)
$M_c$ = clay content (%)
OrgC = Organic carbon content (%)

***Slope factor (LS)***

To get the slope value, you can use the slope class which can be seen in Table 2.

Table2 . Slope Factor (LS)

| **Slope (%)** | **Slopes** | **LS Value** |
|---|---|---|
| 0 - 8 | Flat | 0,40 |
| 8 - 15 | Ramps | 1,40 |
| 15 - 25 | Somewhat Steep | 3,10 |
| 25 - 40 | Steep | 6,80 |
| > 40 | Very steep | 9,50 |

Source: Kironoto, 2010

***Land Use (C) and Crop Management (P) Factors***

To get the C and P values, it can be determined from the land use. The C and P values can be seen in Table 3.

Table3 . CP Value

| **C-value** | **Conservation Land Use** |
|---|---|
| 0,005 | Water Body |
| 0,001 | Undisturbed Forest |
| 0,001 | Open Land |
| 0,001 | Shrubs |

| | |
|---|---|
| 0,60 | Settlements |
| 0,40 | Dryland Agriculture |
| 0,20 | Plantation |

Source: Bappenas, 2012

**Erosion Hazard Level**

To determine the Erosion Hazard Level (TBE), the erosion rate can be grouped into several classes. The relationship between erosion rate, erosion hazard class and erosion hazard level can be seen in Table 4.

Table4 . Erosion Hazard Level

| Erosion Hazard Class | Potential Erosion Rate | Erosion Hazard Level |
|---|---|---|
| I | <15 | Very Light |
| II | 15 - 60 | Lightweight |
| III | 60 - 180 | Medium |
| IV | 180 - 480 | Weight |
| V | > 480 | Very Heavy |

Source: Hariati et al, 2022

***Sediment***

*Sediment* yield is the calculation of the amount of sediment that settles in the river and sediment in the channel or reservoir originating from the watershed measured at a certain period of time (Supangat, 2014). Based on the calculation of the erosion rate using the USLE method, the value of sediment yield can be determined by the equation:

SY = SDR x EP (8)

where,

SY = Sediment production value (tons/ha)
SDR = Sediment receiving ratio
Ep = Erosion rate (tons/year)

The SDR value can be determined by the equation proposed by Roehl (1962) as follows:

SDR = 0.41 x $A^{-0.3}$ (9)

where,

SDR = Sediment Reception Ratio
A = Watershed area (ha)

***Trap***

To find out how much sediment is retained or deposited in the reservoir, you can use the ratio between the amount of sediment deposited in the reservoir and the total incoming sediment transport (Brune, 1953). The empirical relationship to estimate the efficient value of the reservoir watershed is expressed in the graph of the relationship between the storage capacity and the annual discharge of the reservoir in Figure 3 below.

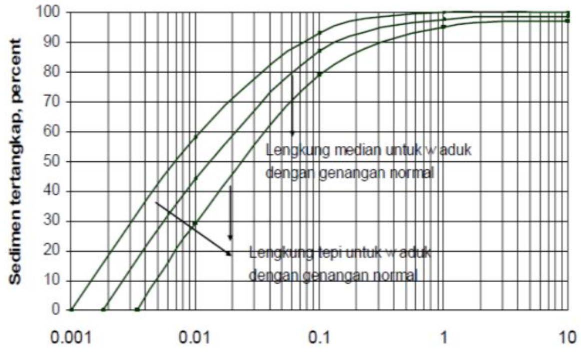


Image3 Brune Graphics

**Research Phase**

The research stages are used to determine the overall research flow. The research flow chart can be seen in Figure 4.

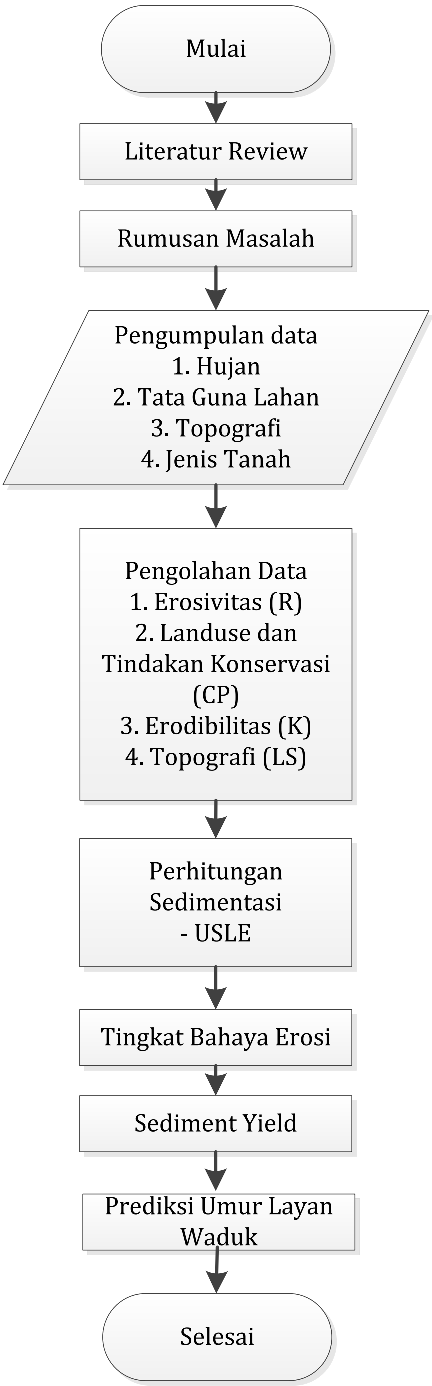


Image4 . Flowchart

## RESULT AND DISCUSSION

### Land Use Analysis

There are 7 (seven) land uses, the percentage area of each land use can be seen in Table 5.

Table5 . Percentage of Land Use in the Upper Brantas Watershed

| Land Use | Percentage (%) |
|---|---|

| | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|---|
| Water Body | 0,44 | 0,43 | 0,40 | 0,43 | 0,42 | 0,44 |
| Undisturbed Forest | 42,57 | 39,06 | 48,72 | 45,79 | 44,51 | 37,12 |
| Open Land | 0,09 | 0,09 | 0,07 | 0,06 | 0,06 | 0,07 |
| Shrubs | 6,06 | 7,91 | 2,31 | 2,26 | 1,21 | 3,39 |
| Settlements | 21,93 | 22,84 | 21,72 | 23,02 | 22,00 | 25,45 |
| Dryland Agriculture | 28,91 | 29,61 | 26,76 | 28,38 | 31,71 | 33,53 |
| Plantation | 0,004 | 0,001 | 0,01 | 0,04 | 0,08 | 0,002 |

Source processed from ESRI data

Based on Table 5, it is found that the Upper Brantas Watershed with the outlet point of the Wlingi Dam is dominated by "Undisturbed Forest". There was a very significant decrease in the land use of "Plantation" in 2023 due to the Right of Use (HGU) of clove plantation land has expired, so it is estimated that there is a change in land use from plantations to shrubs (Antara, 2023) while other land uses are fluctuating.

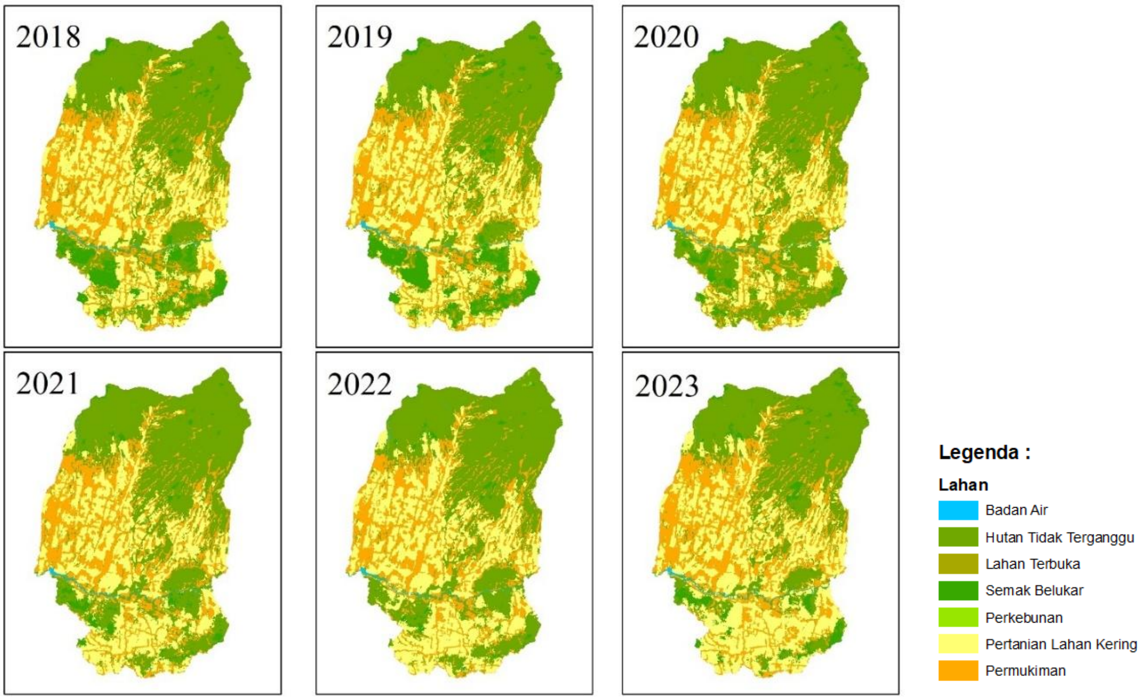


Image5 . Land Use

Based on Figure 4 and Table 5, in the Upper Brantas watershed with the outlet point of the Wlingi Dam. Land use is quite varied, where the largest land use is "Undisturbed Forest" with a percentage of 42.96%.

**Slope Analysis**

In practice in the field, the length of the slope (L) is calculated at the same time as the steepness factor (S) to get the slope value (LS). In this study used DEMNas data to be processed using GIS application into a map according to the slope according to (Kironoto, 2000) . The slope map can be seen in Figure 5. Based on Table 6, it can be seen that the determination of the LS factor value is determined based on the slope.

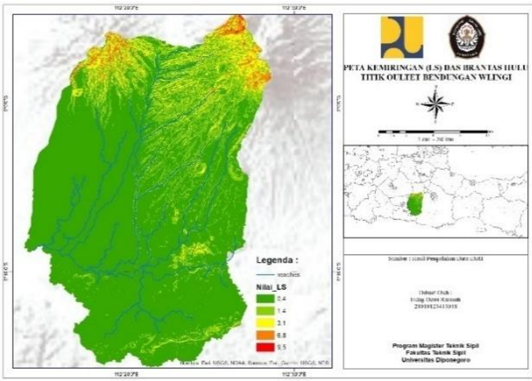


Image6 . Length and Slope

Table6 . LS value as per Slope

| Slopes | | DAS UPSTREAM | BRANTAS | LS Value |
|---|---|---|---|---|
| | | Area (km$^2$) | Percentage (%) | |
| 0% - 8% | Flat | 563,048 | 77,72 | 0,40 |
| 8% - 15% | Ramps | 105,768 | 15,60 | 1,40 |
| 15% - 25% | Somewhat Steep | 42,033 | 5,80 | 3,10 |
| 25% - 40% | Steep | 13,568 | 1,87 | 6,80 |
| > 40 | Very steep | 0,982 | 0,14 | 9,50 |

Source: Analysis Result

**Rain Erosivity Analysis**

The rainfall erosivity analysis starts with collecting monthly rainfall data, number of rainy days and maximum daily rainfall. The analysis is continued by entering equation (2). The rainfall erosivity values for 2018-2023 can be seen in Figure 6.

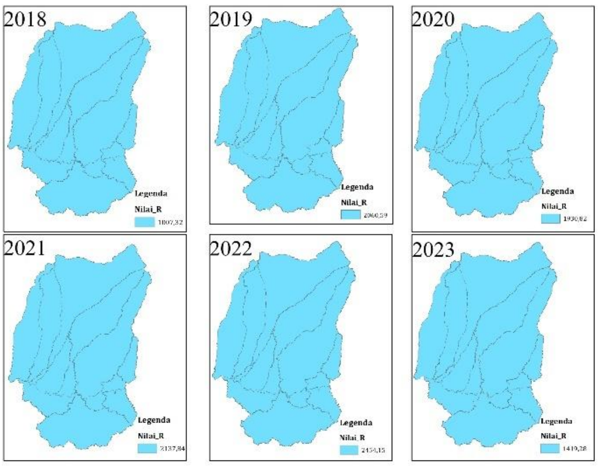


Image7 . Rain Erosivity

## Soil Erodibility Analysis

Soil erodibility analysis starts from collecting the content of a soil consisting of sandy loam, clay, clayey loam and sandy clay loam. The calculation results can be seen in Figure 7.

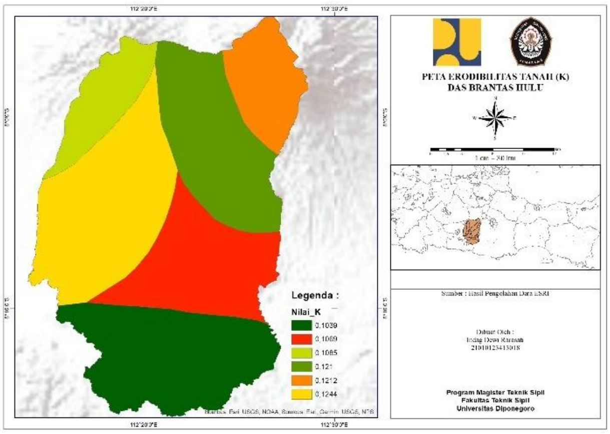


Image8 . Soil Erodibility

## Erosion Hazard Level

After all parameters are obtained, the erosion rate in each sub-basin is obtained. The erosion rate can be classified into the Erosion Hazard Level (TBE). The TBE in the Upper Brantas Watershed can be seen in Figure 8.

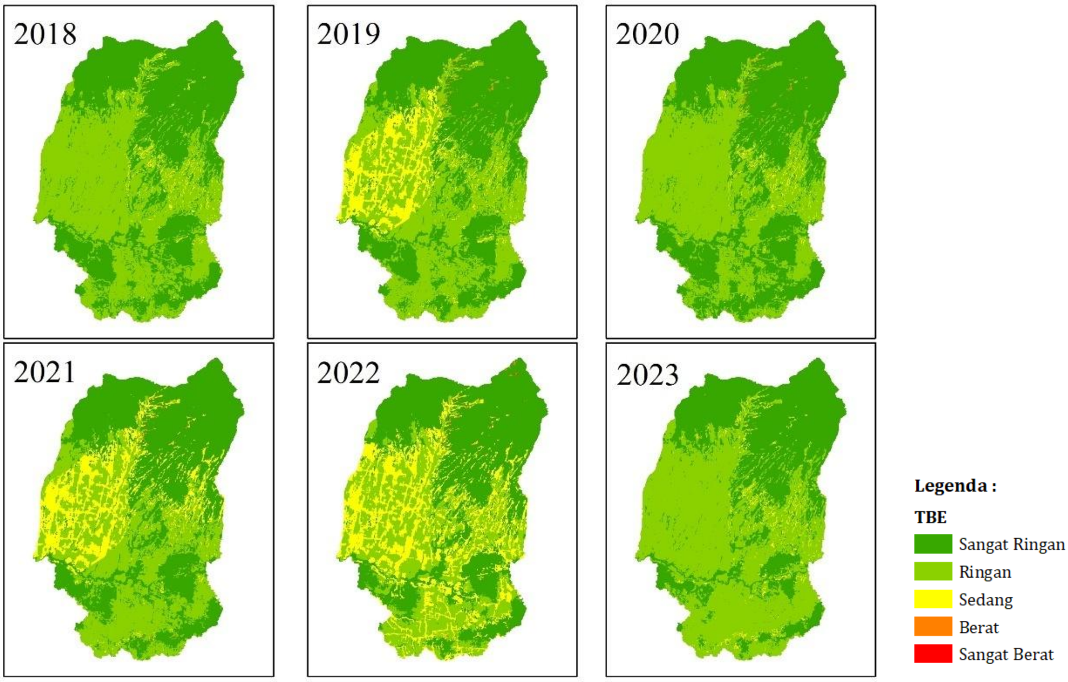


Image9 . Erosion Hazard Level

Table7 . TBE percentage

| TBE | Percentage (%) | | | | | |
|---|---|---|---|---|---|---|
| | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
| Very Light | 0,67 | 0,63 | 0,51 | 0,38 | 0,37 | 0,67 |
| Lightweight | 47,39 | 35,47 | 45,03 | 30,78 | 27,58 | 41,51 |
| Medium | 40,21 | 26,47 | 25,20 | 31,14 | 35,38 | 42,18 |
| Weight | 10,28 | 34,92 | 28,60 | 30,73 | 28,83 | 15,30 |
| Very Heavy | 1,45 | 2,51 | 0,66 | 6,97 | 7,84 | 0,33 |

Source: Analysis Result

Based on the results of the analysis shown in Table 7, the percentage of TBE with mild and moderate values dominates with mild values between 27.58% to 47.39% and moderate values between 25.20% to 42.18%. Figure 6 depicts a map showing the changes in TBE in each year.

**Sediment Yield Analysis**

The results of the erosion rate can be continued by calculating the sediment *yield* using equations (8) and (9). The sediment yield can be seen in Table 8.

**Analysis of Service Life Calculation**

**Table 8.** Sediment Volume, *Trap Efficiency* and Sedimentation Rate (2018-2023)

| Sediment | Year | | | | | |
|---|---|---|---|---|---|---|
| | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
| Sediment Volume (tons/year) | 13.005,30 | 27.462,72 | 23.814,62 | 27.709,66 | 33.045,55 | 21.123,18 |
| *Traps Efficiency* (tons/year) | 1.040,42 | 2.197,02 | 1.905,17 | 2.216,77 | 2.643,64 | 1.689,85 |
| Sedimentation Rate (mm/year) | 0,005 | 0,011 | 0,01 | 0,011 | 0,014 | 0,009 |

Technically, the service life of Wlingi Reservoir is calculated for 100 years. The dead storage of Wlingi Reservoir when it was operated in 1977 was 18.8 million $m^3$. From the results of bathymetric measurements conducted in 2019, the reservoir's dead storage has been filled with 2.81 million m of sediment[3]. After calculation, the average erosion rate from the beginning of the reservoir operation until 2019 was 380,714 $m^3$/year. While from the calculation of the average erosion prediction for 5 (five) years amounted to 7,937, 49 $m^3$/th. There is a significant difference in erosion rates, this indicates that the value of the erosion rate that occurs is not only sourced from the Upper Brantas Watershed with the outlet point of the Wlingi Reservoir alone, but there is an influence from the Upper Brantas Watershed which includes Senggruh Reservoir and Sutami Reservoir, as well as the eruption of Mount Kelud which occurred within a 15-year interval. According to the calculation of the predicted reservoir service life of the plan for 100 years is not fulfilled, the life of the reservoir is estimated to only be able to serve for 91 years.

## CONCLUSION

The study concluded that the Upper Brantas watershed, with the outlet point of Wlingi Reservoir, experienced fluctuating land use change during 2018-2023, with land use dominated by undisturbed forest (42.96%). Variations in the erosion hazard level (TBE) show that annual erosion rates vary from very light to very heavy, influenced by changes in rainfall erosivity and land use. The difference in erosion rates between USLE method calculations and reservoir baseline data indicates the additional influence of Sutami, Sengguruh and Mount Kelud Reservoirs. Based on the analysis, the service life of the Wlingi Reservoir is estimated to be only 91 years, requiring an increase in storage capacity, comprehensive watershed management and land conservation. Sedimentation control measures, improved irrigation infrastructure, water resources management, and government and community coordination are key to maintaining the benefits of Wlingi Reservoir in reducing floods, supporting food security, and generating electricity in East Java.

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