International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Comparison of Plumbon Reservoir Sediment Distribution Using Area Reduction and Area Increment Methods

Indah Candra Kumala
Faculty of Engineering, Brawijaya University, Malang

Abstract— *The comparison of the Plumbon Reservoir's sediment distribution using the area reduction and area increment methods is the goal of this study. The Plumbon Reservoir is where the study area is located. The Plumbon Reservoir is physically situated in Puloarjo Village in the Eromoko District of the Wonogiri Regency. Wonogiri Regency may be found in these geographic coordinates: 75° 8'24.02"S and 110° 50'04.22"E. The literature study is carried out by studying theories related to hydrology, dam hydraulics, and sedimentation. The literature that will be used as the basis for this thesis can be in the form of guidebooks, papers, theses, and so on. The data used in this thesis is secondary data obtained from the Bengawan Solo River Basin. Plumbon Reservoir Data. Thus, from the analysis of the study using the MUSLE method, an erosion rate of 10,837.94 tons/year or 9,843.72 m3 / year and sediments in the Plumbon watershed with MUSLE does not require calculation of the sediment release ratio (SDR), so the sediment rate SY = erosion total = 10,837.94 tons/year or 9,843.72 m ^{3} / year, Remaining volume at elevation +201 (dead storage) Plumbon Reservoir based on echosounding results in 2020 is 70,660.57 m ^{3} , Based on calculations of erosion using the MUSLE method, the remaining useful life of the Plumbon Reservoir is 11.2 years. Based on calculations of area reduction and area increment, the remaining useful life of the Plumbon Reservoir is 13.8 years. Based on the area increment calculation, the remaining useful life of the Plumbon Reservoir is 13.2 years..*

Keywords— *Plumbon Reservoir Sediment Distribution, Reduction Area, Increment Area.*

I. INTRODUCTION

Water is a priceless natural resource that God has given us inexhaustibly. All living things can use water to meet their needs because it is one of the foundations of life (Sobriyah, Setiawan, & Qomariyah, 2016). Indonesia has a lot of water, however it is not evenly distributed throughout the country in all areas and throughout all seasons (Lestari, Ramadhani, Sherawali, & Yudha, 2021). Consequently, a building or reservoir that can store water is required.

Gajah Mungkur Reservoir is the only reservoir in Wonogiri Regency. Plumbon Reservoir, which was built in 1928, is one of them. The Plumbon Reservoir site is located in Puloarjo Village, Eromoko District, Wonogiri Regency, approximately 15 km from Wonogiri City. The Plumbon Reservoir's primary use are as a tourist attraction and an irrigation system for a 1045 hectare region. This reservoir has a normal volume of 1.05 million m3, a minimal volume of 0.51 million m3, and an effective volume of 0.54 million m3, according to the storage volume planning. However, sediments settle over time, resulting in a decrease in the effective volume to 0.276 million m3, the minimum volume to 0.090 million m3, and the normal volume to 0.367 million m3 (PT. Mettana, 2016).

Sedimentation is an important component in dam planning, in addition to the hydraulic design of the dam. River water retention causes sediment carried by the water to be accommodated as well (Shiami, Lasminto, & Wardoyo, 2017). Sediment that flows in rivers consists of fine grains, which are mixed with river water, and grains that flow through the river bed, which is known as bed load (Soedibyo, 1987). Sediment that enters the reservoir will settle on its surface (Wulandari, 2022). Sediment distribution patterns in reservoirs vary depending on the shape of the reservoir, its operating system, and the size of the sediment grains (Mahmud, Darsono, & Triadi P., 2020). This distribution pattern helps calculate the effective volume available over the effective life of the reservoir (Siwu, Sangkawati, & Sriyana, 2021). The useful capacity of the reservoir for flood control, electricity production, and food production is affected by the reduced effective storage capacity of the reservoir due to sedimentation (Putra, SA & Wulandari, 2020).

Formulation of the problem

1. What is the rate of sedimentation entering the Plumbon Reservoir based on the MUSLE formula?
2. What is the distribution of sediment in the Plumbon Reservoir using the Empirical Area Reduction and Empirical Area Increment methods?
3. What is the service life of the Plumbon Reservoir?

Objective

1. Determine the sedimentation rate in the Plumbon Reservoir.
2. Comparing the rate of sedimentation that occurs in the Plumbon Reservoir based on echo sounding survey results with the Empirical Area Reduction Method and Empirical Area Increment Method calculation methods.

II. METHODOLOGY

A. Location

The Plumbon Reservoir is where the study area is located. The Plumbon Reservoir is physically situated in Puloarjo Village in the Eromoko District of the Wonogiri Regency. Wonogiri Regency may be found in these geographic coordinates: 75o8'24.02"S - 110o50'04.22"E.

B. Study of literature

Indah Candra Kumala, "Comparison of Plumbon Reservoir Sediment Distribution Using Area Reduction and Area Increment Methods," *International Research Journal of Advanced Engineering and Science*, Volume 8, Issue 3, pp. 67-76, 2023.

The literature study is carried out by studying theories related to hydrology, dam hydraulics, and sedimentation. The literature that will be used as the basis for this thesis can be in the form of guidebooks, papers, theses, and so on.

C. Data collection

Secondary data from the Bengawan Solo River Basin were used to create this thesis. Data for Plumbon Reservoir

III. RESULTS AND DISCUSSION

A. Hydrological Analysis

The first step in doing a study of water resources is a hydrological analysis. The rainfall data used for this hydrological analysis was obtained from a rain gauge station, namely the Plumbon Rain Station with the observation period 2014 – 2022. The rainfall data is shown in table 1 below:

TABLE 1. Rainfall Data at Plumbon Station

Year	Plumbon Station Rainfall (mm)		
	Annual	**Maximum Daily**	**Rainy day**
2014	1607	105	80
2015	1896	123	81
2016	2077	140	117
2017	1965,8	218	92
2018	1017.5	74	65
2019	802.4	68.6	40
2020	1582	88	92
2021	1987	99	89
2022	1949	88	117

Source: District PU Office. Wonogiri, 2022

The rain data that has been obtained from the rain station cannot be directly used in the calculations because it needs to be tested on the data. The purpose of data testing is to evaluate the accuracy and dependability of the data that will be utilized in calculations. The compatibility of the calculation findings with the actual situation will depend on the accuracy and dependability of the data used.

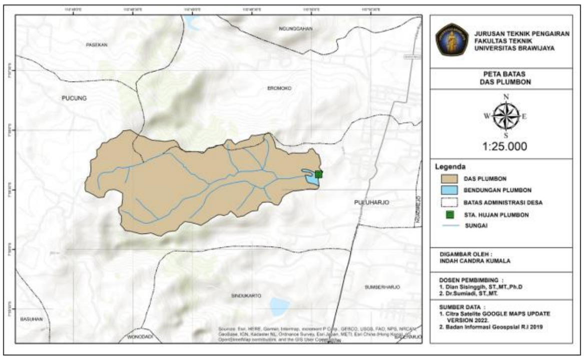

Figure 1. Map of the Plumbon Reservoir watershed
Source: Data analysis, 2022

1. Outlier Test

The first test is an outlier test which aims to see whether there is information that deviates quite far from the trend of the group. The following is the result of the Outlier test calculation for the Plumbon rain station.

TABLE 2. Outlier Test of Plumbon Rain Station

No.	Rain data		X logs	Information	
	Year	**Rn(mm)**			
1	2014	105.00	2.0212	stdev =	0.1544
2	2015	123.00	2.0899	Log mean X =	2.0206
3	2016	140.00	2.1461		
4	2017	218.00	2.3385	Kn =	2,036
5	2018	74.00	1.8692	Upper limit value, Xh:	
6	2019	68,60	1.8363	Xh =	216,259
7	2020	88.00	1.9445	value Lower limit, Xi:	
8	2021	99.00	1.9956	Xi =	50,854
9	2022	88.00	1.9445		

Source: Data analysis, 2022

From the calculation results, it is found that if the information at the station in question is outside the upper limit (Xh) and the basic limit (XL), namely data for 2017 with a value of 218 mm, to be precise on November 29 2017. Then the data in question is discarded because it is outside the threshold .

2. Homogeneity test

The accuracy of the field data, which was unaffected at the time of measurement, was then tested using a consistency test. The collected data must accurately reflect the field's actual conditions as well as hydrological processes. Hydrological data is said to be inconsistent if there is a difference between the measurement value and the actual value (Soewarno, 1995, p.23). The homogeneity test analysis was attempted using the RAPS (Rescaled Adjusted Partial Sums) procedure with the calculation results.

TABLE 3. Plumbon Rain Station Homogeneity Test

No	Year	Rain	sc*	[sc*]	Dy2	Sk**	[Sc**]
1	2014	105.00	6,80	6,80	5.78	0.30	0.30
2	2015	123.00	24.80	24.80	76,88	1.10	1.10
3	2016	140.00	41.80	41.80	218,41	1.85	1.85
4	2018	74,00	-24,20	24,20	73,21	1,07	1,07
5	2019	68,60	-29,60	29,60	109,52	1,31	1,31
6	2020	88,00	-10,20	10,20	13,01	0,45	0,45
7	2021	99,00	0,80	0,80	0,08	0,04	0,04
8	2022	88,00	-10,20	10,20	13.01	0.45	0.45
	Average	98.20		18.55			

Source: Calculation Results, 2022

N = 8
Dy = 22.58
Sk** max = 1.85
Sk**min = 0.04
Q = (Sk** max) = 1.85
R = Sk** max – Sk** min = 1.82

$\frac{Q}{\sqrt{n}}$ = 0.65 < with a probability of 90% from table 1.04

$\frac{R}{\sqrt{n}}$ = 0.64 < with a probability of 90% from table 1.18

thus it can be concluded that the data at the Plumbon rain station is homogeneous.

3. Parametric test

The F test and T test are used as parametric tests. By examining the significant probability value 5%, the F test, also known as the simultaneous test, is used to determine whether the independent variables have a combined effect on the dependent variable. The independent variable and dependent variable will both be significantly impacted if the significance probability value is less than 5%. To determine how closely related a partially independent variable is to the dependent variable, apply the T test or partial test. If the probability value of t <0.05, then the influence of the independent variables on the dependent variable is partially. If the probability value of t > 0.05; then there is no significant effect between each independent variable on the dependent variable. The calculation of the F test and T test in this study is presented in Table.4.

TABLE 4. Plumbon Rain Station Parametric Test

No	Year	Rainfall(mm)	No	Year	Rainfall (mm)
1	2014	105.00	5	2019	68,60
2	2015	123.00	6	2020	88.00
3	2016	140.00	7	2021	99.00
4	2018	74.00	8	2022	88.00
Average		110.50	Average		85.90
S1 _		28,219	S2 _		12,645
N1 _		4	N2 _		4
dk1 _		3	dk2 _		3
Uji F	α	5%			
	F hitung	4,98			
	F cr	3,39			
	Conclusion	Stable			
T test	et al	17			
	α	5%			
	σ	30,92			
	t	0.15			
	tcr	2,11			
	Conclusion	Stable			

Source: Calculation data, 2022

The table above shows that there is no significant value in the F test or T test. This shows that the rain data at Plumbon Station is stable, meaning that nothing is considered too significant.

4. *Pearson log type III rainfall*

In this study the design rain analysis method used was the Pearson Log Type III method on the grounds that this method can be used for all types of data distribution because there is no provision regarding the magnitude of the value of the statistical parameters Cs and Ck, while for the return period used is the 1st return period. years because it is considered the most dominant and occurs most frequently. The Pearson Log Type III calculation table is

TABLE 5. Pearson Log Method Calculations III

No	Year	Rainfall (mm)	X logs	(Log X - LogXaverage)²	(Log X - LogXrerata)³
1	2014	36	1,556	0.035626873	-0.0067246
2	2015	49	1,690	0.003009317	-0.0001651
3	2016	52	1,716	0.000843901	-2.452E-05
4	2018	57	1,756	0,000117106	1,2673E-06
5	2019	59	1,771	0,000665572	1,7171E-05
6	2020	64	1,806	0,003736467	0,0002284
7	2021	68	1,833	0,00764848	0,0006689
8	2022	68	1,833	0,00764848	0,0006689
	Jumlah	13,960			
	Average	1,745			
	Standard deviation	0.092			
	Bloated (Cs)	-1.302			

K	-2.091437983	
SD K	-0.19249054	
Sd K Log	1,553	
R 1.01 years	35,691	mm
Amount	13,960	
Average	1,745	

Source: Calculation data, 2022

After testing the data and continuing with data calculations, the rainfall at the research location with a return period of 1.01 years is 35.691 mm.

B. Design flood discharge analysis

The largest yearly discharge with a specific probability of occurrence or discharge with a specific likelihood of a return period is the design flood discharge. In this work, the Modified Rationale Method technique was used to determine the design flood discharge..

1. *Flow coefficient*

The runoff coefficient is the percentage of the amount of water that can run over through the soil surface from the total rainwater that falls on an area. Flow coefficient can be estimated by considering land use. The runoff coefficient figure is an indicator to determine whether a watershed has experienced disturbance (Asdak, 2004: 157). Changes in land use can result in increased run-off coefficients and high rainfall intensity so that the surface runoff discharge from rainwater becomes larger. Changes in land use cause the value of the flow coefficient every year is not always the same. For C values can be seen in Table 6.

TABLE 6. Flow Coefficient Values Based on Land Cover

No.	Land Use	C Factor Value
1.	Forest	0.02
2.	Shrubs	0.07
3.	Industrial plantation forest i	0.05
4.	Secondary swamp forest	0.15
5.	Plantation	0.40
7.	Mixed dry land farming	0.10
8.	Settlement	0.60
9.	Ricefield	0.15
10.	pond	0.05
11.	Open land or mining	1
12.	Body of water/water	0.05

Source: Suripin & Kodoatie and Syarief (2005) in Basri (2017)

Then the value of the runoff coefficient (C) in the Plumbon watershed can be seen in the following table.

TABLE 7. Calculation of Runoff Coefficient in the Plumbon Watershed

No.	Land Use	Wide		C	Area x C
		Ha	%		
1	Water body	3,12	0.84	0.05	0.156
2	Forest	292.66	79.25	0.02	5,853
3	Settlement	8,49	2.30	0.60	5,096
4	Fields	38,46	10,41	0.15	5,769
5	Check the Bushes	2.36	0.64	0.07	0.165
6	Farm/Farm	23,91	6.47	0.10	2,391
	Total	369,00	100,000		19,431
C value =19,431 / 369 = 0,053					

Source: Data analysis

From Table 7 the calculation of the runoff coefficient in the Plumbon sub-watershed is 0.053. This value is a combination of the value of each land cover area multiplied by the converted C value based on Table 6 and divided by the total area of the Plumbon Watershed. The table above shows the value of the runoff coefficient for the Plumbon watershed is 0.053.

2. Design flood discharge value

The rational approach has been adjusted such that the concentration of rain falls occurs more slowly. This approach may effectively explain the connection between rainfall and runoff flow for watersheds up to 5000 hectares in size. The erosivity index of surface runoff (Rw) will be determined in this study utilizing flood discharge analysis of the Modified Rational Method design with a return period of 1.01 years. This index will be utilized to calculate the quantity of erosion using the MUSLE method.

the amount of erosion using the MUSLE method.

The calculation of the peak discharge using the Modified Rational Method is carried out in the Plumbon watershed with the calculation of the peak discharge as follows:

Watershed area = 3.69 km2 = 369 Ha
Land Slope = 6.17 (GIS Analysis)
River Slope

$$=(\frac{\text{Elevasi Maksimum DAS} - \text{Elevasi Minimum DAS}}{\text{Panjang Sungai}}$$

= ((599-205) : 2980) = 0.13
Slope Length = 1,239 m
River Length = 2,980 m (PT. Mettana)
n = 0.04 (natural channel winding and there are plants)
So that,

1. Based on the previous analysis, it is known that the value of the Flow Coefficient (C) in the Plumbon Watershed = 0.053
2. Calculating t_0 (Overland Flow Time)
   $t_0 = \left[\frac{2}{3} \times 3{,}28 \times L \times \frac{n}{\sqrt{S}} \times \frac{1}{60}\right]$
   $= \left[\frac{2}{3} \times 3{,}28 \times 1.239 \times \frac{0{,}04}{\sqrt{6{,}157}} \times \frac{1}{60}\right]$
   = 0.727 hours
3. Calculating v (flow velocity)
   $v = 4.918 \times S^{1/2}$
   $= 4.918 \times (0.13)^{1/2}$
   = 1.788 m/s
4. Calculating t_d (Drain flow time)
   $t_d = \frac{L}{3600V}$
   $= \frac{2.980}{3600 \times 1{,}788}$
   = 0.463 Hours
5. Calculating t_c (Concentration Time)
   $t_c = t_0 + t_d$
   = 0.546 + 0.463 = 1.190 hours
6. Calculating C_s (Based coefficient)
   $$C_s = \frac{2t_c}{2t_c + t_d}$$
   $$C_s = \frac{2 \times 1{,}190}{2 \times 1{,}190 + 0{,}463}$$
   = 0.837
7. Calculate the intensity of mononobe rain
   $I = \frac{R_{24}}{24}\left(\frac{24}{t_c}\right)^{\frac{2}{3}}$, with R_{24} return period 1.01th = 35.691 mm
   $I = \frac{35{,}691}{24}\left(\frac{24}{1{,}190}\right)^{\frac{2}{3}}$ = 11.017 mm/hour
   So obtained:
   Qp = 0.278 x C_s x C x I x A
   = 0.278 x 0.8837 x 0.053 x 11.017 x 3.69 = 0.499 m3/s

3. Surface runoff erosivity index

The erosion process is always accompanied by a transport process, this is influenced by the size of the surface runoff, therefore in Utomo (1989) a Modification of the General Equation of Soil Loss (PUKT) is hereinafter referred to as MPUKT. Williams made a modification of the USLE to estimate the yield of sediment from each surface runoff event by replacing the erosivity index (R) with the erosivity of surface runoff (Rw) with the following calculation:

$Rw = 9.05\,(V\_0 .\, Qp)^{0.56}$
With :
V_0 = Surface Runoff Volume (m^3)
Qp = Peak flow rate (m^3/s)
The surface runoff volume is formulated
$V\_0 = R.\exp^{(-Rc/Ro)}$
Where :
Rc = 1000. Ms. pb. RD. $(Et/Eo)^{0.5}$
Ro = R/Rn
With :
Ro = Rain unit 1 mm
Rn = Number of rainy days (days)
R = Amount of rain for one year
Rc = Soil moisture storage capacity
Ms = Moisture content at field capacity (%)
pb = bulk density of topsoil (tonnes/m^3)
RD = Effective rooting depth (m), (Impermeable layer.)
Et/Eto = Comparison of actual evapotranspiration (Et) with potential evapotranspiration (Eto) with detailed values as follows:

The values of Ms, pb, K and Et/Eto for various soil textures are as follows:

TABLE 8 Values of Ms, pb, and K in Various Soil Textures

Soil Texture	Ms % w/w	pbs Mg/m3	K g/h	RD (m)	
Clay	45	1,1	0.02	Annuals and Grass	: 0.05m
Clay clay	40	1,3	0.4	Tree Plants, Woody Plants	: 0.10m
Dusty Clay	30	-	-		
Sandy Loam	28	1,2	0.3		
Dusty Clay	25	1,3	-		
Clay	20	1,3	-		
Fine Sand	15	1,4	0.2		
sandy	8	1.5	0.7		

Source: Utomo, 1989: 155

TABLE 9. Et/Eo Value of Several Kinds of Plants

Plant	Et/Eto
Paddy Field	1.35
Wheat	0.6
Corn	0.67-0.70
Cassava	0.62
Potato	0.70-1.0
Beans	0.62-0.69
Peanuts	0.5-0.87

Plant	Et/Eto
Tea	0.85-1.00
Rubber	0.9
Rubber	1,2
Palm oil	1,2
Prairie Grass	0.80 – 0.95
Forest	0.90 – 1.00
Bero Land	0.05

Source: Utomo, 1989:157

The following is the calculation of the surface runoff erosivity index (Rw) in the Plumbon Watershed

1. Based on the previous analysis, it is known that the peak flow rate in the Plumbon watershed is 0.499 m3/s.
2. Calculate Rc

Texture = Clay,

So that the pb value = 1.3 ton/m3 and the Ms value = 20% = 0.2

The determination of the RD and Et/Eto values for the Plumbon DAS is as follows:

- Forest has a value of RD = 0.1 m and Et/Eto = 0.9
- Irrigated rice fields have a value of RD = 0.05 m and Et/Eto = 1.35
- Grassland has a value of RD = 0.05 m and Et/Eto = 0.8
- Shrubs has a value of RD = 0.05 m and Et/Eto = 0.8

The recapitulation of RD and Et/Eto values for the Plumbon DAS is as follows.

TABLE 10. Value of RD and Et/Eto DAS Plumbon

Land Use	Wide		RD	Et/Eto
	Ha	%		
Forest	292.66	81,89	0.10	0.900
Ricefield	38,46	10.76	0.05	1,350
Shrubs	2.36	0.66	0.05	0.800
Moor/Field	23.91	6,69	0.05	0.800
Total	357	Average	0.091	0.941

Source : Data analysis, 2022

From the calculation above, the following values are obtained:

RD average = 0.091

Et/Eto = 0.941

Rc = 1000 x Ms x pb x RD x (Et/Eto)0.50

= 1000 x 0.2 x 1.3 x 0.091 x (0.933)0.50

= 22.641

3. Calculating Ro for 2014

R = 1607 mm (2014 Rainfall Data)

Rn = 80 Days (2014 Rainy Day Data)

Ro $= \frac{R}{Rn} = \frac{1607}{80} =$ 20.09 mm/day

4. Calculating Surface Runoff Volume (V0)

$V_0 = R \times \exp^{(-Rc/Ro)}$

$= 1607 \times \exp^{(-22.641/20.09)} =$ 520.61mm

5. Calculating the erosivity index of surface runoff (Rw)

$Rw = 9.05 \times (V_0 \times Qp)^{0.56}$

$= 9.05 \times (520.61 \times 0.499)^{0.56}$

$= 203.54\ m^2 /$ hour

This Rw value is also calculated for subsequent years to find the average Rw value and will later be used for erosion calculations using the MUSLE formula. The following table calculates the Rw value for each year as follows.

TABLE 11. Value of Rw each year

No	Year	Annual rainfall(mm)	Rainy day	Ro	Vo	Rw
1	2014	1607	80	20.09	520.61	203,54
2	2015	1896	81	23,41	720.71	244,20
3	2016	2077	117	17,75	580,14	216,26
4	2018	1017,5	65	15,65	239,55	131,78
5	2019	802,4	40	20,06	259,55	137,83
6	2020	1582	92	17,20	424,01	181,44
7	2021	1987	89	22,33	720.73	244,20
8	2022	1949	117	16,66	500.65	199,13
Average						194.80

Source: Data analysis, 2022

The table above shows that the average value of Rw for the Plumbon watershed is 194.80 m2 / hour. This value will then be used to calculate the sedimentation rate.

4. *Erosion rate analysis MUSLE method (Modified Universal Soil Loss Equation)*

By substituting run off for the erosivity of rain (R), the Modified Universal Soil Loss Equation approach improves upon the Universal Soil Loss Equation method. One way for examining the rate of erosion in a watershed is this one. In a watershed, the rate of erosion increases as the volume of runoff increases, and the rate of erosion decreases as the volume of runoff increases. Rain erosivity as a flow factor, soil erodibility (K), slope length (L), slope slope (S), plant cover (C), and soil conservation practices (P) are hydrological factors for erosion rate analysis utilizing the MUSLE method.

i. Soil erodibility (K)

According to Suripin (2002) the soil erodibility factor (K) shows the sensitivity of soil particles to peeling and transport of these soil particles by the presence of kinetic energy of rainwater. In the Plumbon watershed there are several types of soil that have an influence on the amount of erosion that occurs. The types of soil in the Plumbon Reservoir watershed are shown in Figure 2.

From Figure 2 it is obtained that the soil types in the Plumbon Reservoir are alluvial and latosol. The area and erodibility values of each type of soil can be seen in table 13. In this study, the K value was determined using the K value table as a result of research on several soil types in table 12 below.

TABLE 12. The composition and erodibility of soil in the Plumbon Reservoir watershed

No	Type of soil	Erodibility Factor (K)
1.	Alluvial	0.29
2.	Andosol	0.28
3.	glei	0.29
4.	Glumosol	0.16
5.	Latosol	0.26
6.	Litosol	0.13
7.	Mediterranean	0.16
8.	Organosol	0.29
9.	Red Podsol	0.20
10.	Regosol	0.31

Source: Otto Soemarwoto, Environmental Impact Analysis, p. 238

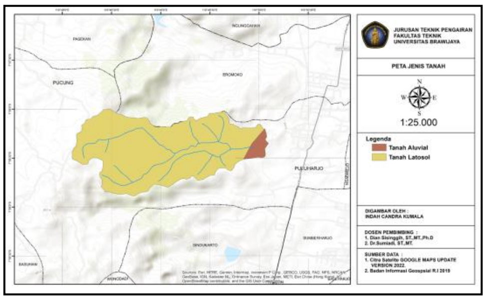

Figure 2. Types of soil in the Waduk watershed
Source: Data analysis, 2022

Soil types and erodibility values (K) in the Plumbon watershed can be seen in table 13 below:

TABLE 13. The composition and erodibility of soil in the Plumbon Reservoir watershed

No	Type of soil	K value	Wide		Area x K
			(Ha)	(%)	
1	alluvial	0.29	24,14	6,53	7.00
2	Latosol	0.26	345,28	93.47	89.77
	Amount		369,42	100.00	96.77
K value = 96.773/369.42 = 0.26					

Source: Calculation results, 2022

From table 13 it is found that the Latosol soil type has a percentage of 93.47% or an area of 345.28 Ha. Latosol soil is a type of soil that is formed due to weathering with high intensity. These soils can be found in areas with a tropical rainforest climate. This soil is similar to podsol soil which has a high iron or aluminum content and undergoes oxidation, giving it a reddish color.

Then for the next soil type is alluvial soil type which has a percentage of 6.53% or an area of 24.14 Ha. Alluvial soil is a type of soil that occurs due to silt deposits which are usually carried away by river flow. This soil is usually found in the downstream because it is carried from the upstream. This soil is usually brown to gray in color.

From the calculation results, the erodibility value (K) in the Plumbon watershed is 0.26. This value is a combination of the value of each type of land area multiplied by the K value and divided by the total area of the Plumbon Watershed.

ii. Length and slope (LS)

The length and slope of the slope are two topographical elements that affect runoff. The steeper and longer the land, the greater the runoff that causes erosion, and vice versa, the flatter and shorter the land, the less likely sedimentation will occur (Asdak, 2004 in Meylina, 2015). The slope of the Plumbon Reservoir watershed is shown in Figure 3.

There are many groups of length and slope classes based on the topography in the Plumbon watershed; the classification of the length and slope class groups is based on an analysis of the topographical map of Indonesia. Figure 3 depicts how the slopes of the Plumbon watershed are distributed. Based on Figure 3, it is known that the slopes' length and angle are determined by the outcomes of a DEM study, with each slope being assigned a class according to the Ministry of Forestry's slope classification system.

TABLE 14. Conversion of Slope Values into LS Values

No.	Class	Topography	Slope	*LS* value
1.	I	Flat	0-8	0.4
2.	II	Sloping	8-15	1.40
3.	III	Rather Steep	15-25	3,10
4.	IV	Steep	25-45	6,80
5.	V	Very Steep	45	9.50

Source: Kironoto, 2000

TABLE 15. Recapitulation of Slope in the Plumbon Reservoir

No	Topography	Slope (%)	LS value	Wide		A x LS
				(Ha)	(%)	
1	Flat	0% - 8%	0.40	10:29 p.m	6.04	8.92
2	Sloping	8% - 15%	1.40	39.10	10.60	54.74
3	Rather Steep	15% - 25%	3.10	60.70	16.45	188.17
4	Steep	25% - 40%	6.80	119.30	32.33	811.24
5	Very Steep	>40%	9.50	127.61	34.58	1212.30
	Amount			369.00	100.00	2275.36
LS value = 2275.36 / 369 = 6.17						

Source: Calculation results, 2022

From the results of the analysis of the slope with the help of software, the value of the slope for the Plumbon Reservoir watershed is 6.17. This value is the combined value of each slope area multiplied by the LS which has been converted according to table 4.14 and divided by the total area of the Plumbon Watershed. Based on Figure 4.3, it is known that the length and slope of the slope is > 40%, which is the widest compared to the percentage of the length and slope of the other slopes.

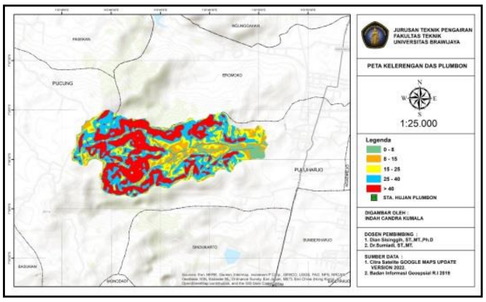

Figure 3. Plumbon Slope Map
Source: Data analysis, 2022

iii. Plant factors (C) and soil management (P)

The crop factor (C) displays the proportion of open soil erosion without cover crops and processing to the amount of erosion (Erosion Ratio or NE) that happens from an area with specific cover crops and management (Utomo, 1989, p. 231). A lot of information is needed to determine the value of C because different areas have varied climates, different types of plants, and different farming practices. Within a year, the C number's size is not necessarily constant (Asdak, 2002).

The human action factor value in soil conservation (P) is a comparison between the amount of eroded soil from land with a certain conservation measure to the amount of eroded soil on land without any conservation action (Soewarno, 1995: 775). In the field, factors C and P are closely related, so that the assessment will be easier if they are combined. In this study, the value of the CP factor was approached based on the results of research in Java which are presented in table 16 below.

TABLE 16. Value of Land Use and Land Management (CP) Factors

Land Use	CP coefficient
Water body	0.001
Forest	0.03
Mixed Garden	0.30
Plantation	0.40
Settlement	0.60
Ricefield	0.05
Moor	0.75

Source: RLKT (Land Rehabilitation and Soil Conservation) Book II, 1986, p.56

TABLE 17. Value of Land Use Factors and Plumbun Watershed Soil Management (CP)

No.	Land Use	Wide		CP coefficient
		Ha	%	
1	Water body	3,41	0.92	0.001
2	Forest	292.66	79.25	0.03
3	Settlement	8,49	2.30	0.60
4	Ricefield	38,46	10.41	0.05
5	Shrubs	2.36	0.64	0.30
6	Moor/Field	23.91	6,48	0.75
	Total	369		

Source: Calculation results, 2022

iv.Erosion calculation of the MUSLE method

The next step in calculating the erosion rate in the Plumbon Reservoir watershed is to use the following formula.

Examples of calculations in the forest:
Forest area = 292.66 Ha
Rw = 194.80
K = 0.262
LS = 6.17
CP = 0.03
Erosion Rate = Rw × K × LS × CP = 194.80 × 0.262 × 6.17 × 0.03 = 9.44 tons/Ha/year
Total erosion = A × Area = 9.44 × 292.66
= 2,762.63 tons/year

For other calculation results will be presented in table 18.

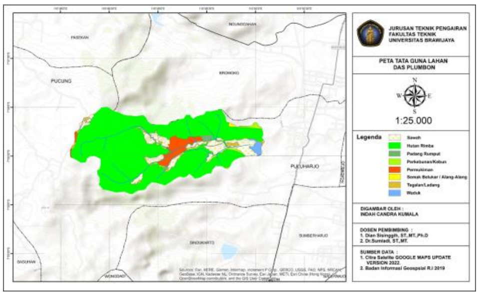

Figure 4. Land use map

Source: Data processing, 2022

TABLE 18. Sedimentation Value of Plumbon Reservoir

No	Land Use	Area (Ha)	RRw	K	LS	CP	A(Tons/Ha/year)	Total erosion =(A x area) (tonnes/year)
11	Water body	3,41	194.80	0.262	6,17	0.001	0.315	1.07
22	Forest	292.66	194.80	0.262	6,17	0.030	9,440	2,762.63
33	Settlement	8,49	194.80	0.262	6,17	0.60	188.80	1603.63
44	Fields	38,46	194,80	0.262	6,17	0.05	15,73	605,06
55	Check Bush	2.36	194,80	0.262	6,17	0.30	94,40	222,68
66	moor/ Farm	23,91	194,80	0.262	6,17	0.75	235.99	5.642,86
	Total	369						10.837,94

Source: Calculation results, 2022

The yearly erosion value that enters the Plumbon Reservoir is 10,837.94 tons/year, or is divided by its specific gravity if translated to mm/year. This figure was calculated using the MUSLE method. The specific gravity of the sediment in the Plumbon Reservoir watershed is calculated as follows.

v. Deviation test

The deviation test in this study aims to determine the deviation of the theoretical sedimentation rate of the MUSLE method from the sedimentation rate in the field in the Plumbon Reservoir. The following is a bathymetric data table for the Plumbon Reservoir.

TABLE 19. Plumbon Reservoir Bathymetry Measurement Results

Ket	2016 big inspection			2020	
	elevation	Wide	Vol. reservoir	Wide	Vol. reservoir
		(Ha)	(m^3)	(Ha)	(m^3)
	198.00	0.15	0.000	0.46	645
	199.00	1.69	9,952	1.84	5,830
INTAKE NO. 2	199.73	3.55	31,594	2,4	22,087
	200.00	4.24	39,645	2.61	28,100
	201.00	5.96	90.621	5,9	70.661
	202.00	8.01	160.451	7,65	138.442
	203.00	10.51	253.053	9,02	221.839
MAN	204.00	12.21	366.655	11,25	323.218
	205.00	13.70	496.245	13,48	424.597
TOP	206.00	14.80	638.743	15,7	525.976

Source: PT. Consultant Creation Techniques, 2020

From these results, it can be seen that the volume of the reservoir in 2016 at an elevation of +198 was 0 m3, with this it is assumed that this elevation is the new zero elevation of the Plumbon Reservoir. Based on the bathymetric measurement data of the Plumbon Reservoir, the analysis results show that every year sedimentation occurs in the Plumbon Reservoir of 10,859.25 m3/year

The formula used in this test is (Triatmodjo, 1992:5):

Qsim (MUSLE) = 10,837.94 tons/year

Soil Specific Gravity = 1.101 tons/m ^{3}, then

$$= \frac{10.837,94 \text{ ton/tahun}}{1,10 \text{ ton/m}^3} = 9,843.72 \text{ m}^3/\text{ year}$$

$$\text{Qobservation} = \frac{(366.655 - 323.218)}{4}$$

= 10,859.25 m ^{3}/ year

MUSLE calibration

$$d = \frac{E_1 - E_2}{E_1}\ x\ 100 =$$

$$\frac{10.859,25 \text{ m}^3 \text{ /tahun} - 9.843,721 \text{ m}^3 \text{ /tahun}}{10.859,25 \text{ m}^3 \text{ /tahun}} \text{x } 100$$

= 9.34 %

With :
d = Amount of Deviation (%)
E1 = Field Sedimentation Rate (tonnes/year)
E2 =Theoretical Sedimentation Rate (tonnes/year)

According to the calibration analysis's findings, the MUSLE method's sedimentation variation in field conditions is 9.34%. The results of estimating yearly sediment sizes using erosion and bathymetry calculations differ, but these numbers are still acceptable. From the results of the evaluation with relative error it can be concluded that the annual sediment value with erosion calculations is sufficient to represent the existing conditions in the field and the value does not have a significant impact on subsequent calculations.

vi. Trap efficiency

Determining the catch efficiency of the Plumbon Reservoir, catch efficiency is the ratio between the amount of sediment deposited in the reservoir and the total sediment entering the reservoir. The amount of sediment retained in the reservoir can be determined by first determining the trap efficiency based on the catch efficiency curve. The volume of the average annual discharge that enters the Plumbon Reservoir is I = 101,168,481.07 m3/year. The total capacity of the Plumbon Reservoir is C = 366,650 m3. Thus the ratio between the inflow of the reservoir and the capacity of the Plumbon Reservoir is the ratio of capacity to the inflow of the reservoir = $\frac{C}{I} = \frac{366{,}650}{101.168.481{,}07}$ = 0.00362. So with a value of 0.00362 plotted into the Brune curve is as follows.

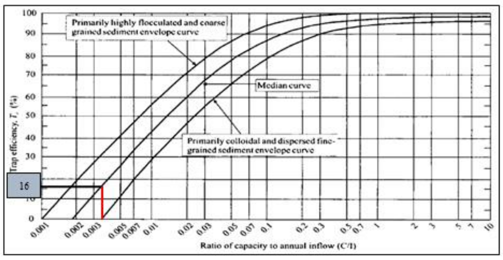

Figure 5. Catch efficiency value (trap efficiency) in Plumbon Reservoir
Source: Data analysis, 2022

The picture above shows that the efficiency value of the Plumbon Reservoir is 16% or 0.16. The decreasing catch efficiency value causes an increasing trend of sedimentation in the Plumbon Reservoir, thus causing a decrease in the reservoir's storage capacity.

vii. Analysis of the distribution of the mainstay of the Baran River

Reliable debit is debit that is expected to always exist or be available with certain reliability for a long time. The following presents the calculation of the mainstay discharge of the Baran River

- Calculating the mainstay discharge of the Baran River

The method for calculating the reliable discharge on the Baran River is using the FJ Mock method with detailed calculations starting from 2014 to 2022 (appendix). The results of the recapitulation of the mainstay discharge calculations on the Baran River are:

TABLE 20. Andalah discharge of the Baran River from 2014 to 2022 in (m^3/ sec)

Year	Month												Amount
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	dec	
2014	0.432	0.529	0.537	0.119	0.089	0.082	0.070	0.048	0.047	0.043	0.141	0.339	2,475
2015	0,609	1,105	1,136	0,312	0,084	0,083	0,076	0,072	0,071	0,065	0,151	0,206	3,969
2016	0,469	0,707	0,499	0,221	0,178	0,105	0,116	0,133	0,239	0,379	0,264	0,278	3,589
2017	0,392	0,920	0,673	0,281	0,132	0,129	0,118	0,112	0,206	0,179	0,735	0,338	4,215
2018	0,854	0,525	0,256	0,108	0,066	0,051	0,047	0,045	0,044	0,040	0,088	0,119	2,241
2019	0,534	0,404	0,793	0,149	0,053	0,052	0,048	0,045	0,044	0,041	0,040	0,037	2,240
2020	0,494	0,709	1,046	0,097	0,107	0,056	0,052	0,053	0,051	0,102	0,123	0,289	3,179
2021	0,620	0,874	0,469	0,303	0,076	0,169	0,102	0,080	0,105	0,089	0.367	0.235	3,490
2022	0.420	0.609	0.649	0.107	0.228	0.145	0.189	0.116	0.130	0.256	0.366	0.259	3,474
Amount	4,826	6,380	6,058	1,697	1.014	0.873	0.817	0.705	0.936	1.193	2,275	2,100	28,872
Average	0.536	0.709	0.673	0.189	0.113	0.097	0.091	0.078	0.104	0.133	0.253	0.233	3,208

Source: Calculation results, 2022

From the table above, the reliable discharge of the Baran River from 2014 to 2022 is obtained with an average monthly yield of 3.208 m3/second and an annual average of 101,168,481.07 m3/second. Calculation of the mainstay discharge in the Baran River will later be used to calculate the efficiency of the reservoir.

- Echo sounding sediment rate

Sounding is a process and activity aimed at obtaining a description (model) of the surface shape (topography) of the reservoir bottom. The process of delineating the bottom of the reservoir is called a bathymetric survey (Poerbandono, 2005). Bathymetry measurements were made in the Plumbon Reservoir in two times during the reservoir's operational term, namely in 2016 and 2020, as shown in table. The Plumbon Reservoir capacity curve is based on initial data, with 2016 designated as the initial year for this study's reservoir capacity curve determination.

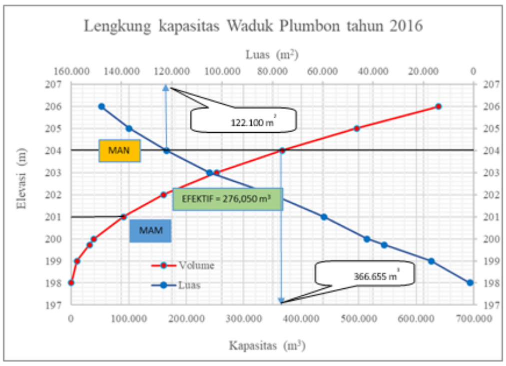

Figure 6. Plumbon Reservoir capacity curve in 2016
Source: Data analysis, 2022

IV. Conclusion

1. From the results of the study analysis using the MUSLE method, the erosion rate was 10,837.94 tons/year or 9,843.72 m3/year and the sediments in the Plumbon watershed with MUSLE did not require calculation of the sediment release ratio (SDR) so that the sediment rate SY = total erosion = 10,837 .94 tons/year or 9,843.72 m3 / year.
2. The remaining volume at +201 elevation (dead storage) of Plumbon Reservoir based on echosounding results in 2020 is 70,660.57 m^3, the Empirical Area Reduction method is 87,140 m^3 and for the Area Increment method 83,433.25 m^3.
3. The remaining useful life of the Plumbon Reservoir
   a. Based on erosion calculations using the MUSLE method, the remaining useful life of the Plumbon Reservoir is 11.2 years.
   b. Based on Area Reduction calculations, the remaining useful life of the Plumbon Reservoir is 13.8 years.
   c. Based on the calculation of the Area Increment, the remaining useful life of the Plumbon Reservoir is 13.2 years.

It is clear from the three approaches of applying the useful life approach that there is a discrepancy of about two years between the bathymetric data and the calculations made using the empirical method. Therefore, it may be said that the Plumbon Reservoir will continue to operate at its best for another 11–13 years. Regular land conservation and sediment dredging are required to maintain the integrity of the Plumbon Reservoir catchment, which serves as the Bengawan Solo's upstream basin.

Suggestion

1. It is necessary to carry out regular dredging in the Plumbon Reservoir, with this dredging it will be able to increase the useful life of the Plumbon Reservoir.
2. The sedimentation rate calculation method in the Plumbon Reservoir must be supported by complete and accurate data.
3. The quality and quantity of data play a significant role in determining the quality of the calculation of the sedimentation rate. Data with good quality and quantity produce good output too. On the other hand, bad data produces bad output.

References

[1] Arshad, Sitanala. (2000). Soil and Water Conservation. Bogor: IPB Press.
[2] Arsyad, A. (2006). Instructional Media. Jakarta: PT Raja Grafindo Persada.
[3] Ashdak, Chay. (1995). Watershed Processing Hydrology. Yogyakarta : Gajah Mada University Prees.
[4] Ashdak, C. (2004). Watershed Hydrology and Management. Jogjakarta: Gadjah Mada University Press.
[5] Ashdak, C. (2010). Hydrology and Watershed Management. Yogyakarta: Gadjah
[6] Mada University Press Fifth edition.
[7] Asdak, C. (2014). Hydrology and Watershed Management. Yogyakarta: Publisher
[8] Gadjah Mada UniversityPress.
[9] Asiyanto. (2011). Dam Construction Methods. Jakarta: University of Brawijaya Publisher
[10] Banuwa, Irwan Sukri. (2013). Erosion. Jakarta: Kencana.
[11] Bever, LD (1959). Soil Physics. John Wiley and Sons, inc New York.
[12] Budiyanto, Eco. (2002). Geographic Information System Using Arcview Gids.
[13] Yogyakarta: Andi.
[14] BR, Sri Harto. (1993). Hydrological Analysis. Jakarta: Gramedia Pustaka Utama
[15] CD Soemarto. (1999). Engineering Hydrology Edition – 2. Jakarta: Erlangga Publisher
[16] CD Soemarto. (1987). Engineering Hydrology. Surabaya: National Business
[17] Chow, V., Maidment, D. and Mays, L. (1988). Applied Hydrology. New York: McGraw-Hill Book Company.
[18] Damayanti, LD, Wulandari, DA, & Edhisono, S. (2022). Prediction of Sedimentation Pattern of Sepaku Semoi Reservoir. AGGREGATE, 673-678.
[19] Damayanti, VA, Prayogo, TB, & Sayekti, RW (2023). Analysis of the Impact of Sediments on the Useful Age of the Plumbon Reservoir. JTRESDA, 346-356.
[20] Ministry of Forestry and Plantations (Dephutbun). (1998). Basic Knowledge of Watershed Management. Jakarta: Directorate of Land Rehabilitation and Conservation
[21] dept. Public Works Center for the Brantas River Region, Surabaya. (2010). Final Report of the Tugu Dam Construction Project. Trenggalek Regency.
[22] dept. PU Directorate of Water Resources. (2009). Reservoir Sedimentation Survey and Monitoring. Jakarta.
[23] Ernawan, & Putri, AI (2017). Study of Sedimentation Distribution of Bening Reservoir, Madiun Regency. Media Civil Engineering, 1-9.
[24] Harjanti, WN, Darsono, S., & Suripin. (2020). Analysis of Sediment Distribution in Raknamo Reservoir with Area Reduction Empirical Method. Engineering Journal: Science Development Media and Engineering Applications, 1-9.
[25] Julien, PY (1995). Erosion and Sedimentation. Cambridge: Cambridge University Press.
[26] Lesmana, DM, Cahyadi, TA, SB., W., Nursanto, E., & Winarno, E. (2020). Comparison of Erosion Rate Prediction Results Using USLE, MUSLE, RUSLE Methods Based on Literature Review. PROCEDURE, Earth and Marine Technology Seminar, 307-312.
[27] Lestari, RI, Ramadhani, R., Sherawali, & Yudha, AT (2021). Water and the Impact of Scarcity on the Economy of Urban Communities: A Study of the Java Island Library. OECONOMICUS Journal of Economics, 38-49.
[28] Mahmud, G., Darsono, S., & Triadi P., T. (2020). Sedimentation Analysis and Prediction of Sediment Distribution in the Tilong Reservoir, Kupang Regency. Rang Engineering Journal, 227-233.
[29] Martha, W. and Adidarma, W. (1983). Get to know the Basics of Hydrology. Bandung: Nova.
[30] Mulyanto, H. (2008). Conservation Effects of the SABO System. Yogyakarta: Science Graha.
[31] Morris, GL, & Fan, J. (2009). Reservoir Sedimentation Handbook, Design and Management of Dams, Reservoirs, and Watersheds for Sustainable Use. New York: McGraw Hill. Co..
[32] Pattiselanno, SR (2018). Identification of Wai Ruhu River Rim Affected by Inundation, Based on Planned Flood Discharge Analysis (Q) Rational Modified Return Period Method 2, 5, 10, 50 Years. SYMMETRIC JOURNAL, 113-120.
[33] Putra, DS, SA, P., & Wulandari, DA (2020). Optimization of Maintenance Activities in the Gondang Reservoir, Karanganyar Regency Against Sedimentation. BRILIANT: Research and Conceptual Journal, 394-409.
[34] Putra, DS, Siwu, WP, & Wulandari, DA (2020). The Effect of Sedimentation on the Function of the Karian Reservoir. Journal UII, 43-51.
[35] Saputra, KD, & Abdurrosyid, J. (2022). Comparison between the USLE and MUSLE Methods in the Analysis of Land Erosion in the Cengklik Reservoir Catchment Area. CIVIL ENGINEERING DYNAMICS, 54-61.
[36] Shiami, FA, Lasminto, U., & Wardoyo, W. (2017). Sedimentation Rate at the Tugu Trenggalek Dam. ITS TECHNICAL JOURNAL, 125-130.
[37] Siwu, WP, Sangkawati, S., & Sriyana, I. (2021). Study of Sedimentation Distribution on the Planned Age of the Ciawi Reservoir in Bogor Regency. Rang Engineering Journal, 211-219.
[38] Sobriyah, Setiawan, AR, & Qomariyah, S. (2016). Review of Repeated Flood Discharge on the Water Level of the Krisak Reservoir, Wonogiri Regency. e-Journal of CIVIL ENGINEERING MATRIX, 706-713.
[39] Soedibyo, N. (1987). Library Management Volume 1. Bandung: Alumni.
[40] Soedibyo, N. (1988). Library Management Volume 2. Bandung: Alumni.

Indah Candra Kumala, "Comparison of Plumbon Reservoir Sediment Distribution Using Area Reduction and Area Increment Methods," *International Research Journal of Advanced Engineering and Science*, Volume 8, Issue 3, pp. 67-76, 2023.

[41] Soedibyo. (1993). Dam Engineering. Jakarta: PT. Pradnya Paramita.
[42] Soewarna. (1995). Hydrology Application of Statistical Methods for Data Analysis. Bandung: Nova.
[43] Suhardjono. (1984). Drainage. Malang: Faculty of Engineering, University of Brawijaya.
[44] Sukartaatmadja. (2004). Soil and Water Conservation. Bogor: IPB Press. Bogor
[45] Suripin. (2002). Conservation of Soil and Water Resources. Yogyakarta: Publisher Andi.
[46] Suripin. (2004). Sustainable Urban Drainage Systems. Yogyakarta: ANDI Offset.
[47] Thompson, RH (1957). Naturally Occuring Quinones. New York: Academic Press.
[48] Triatmodjo, Bambang. (1992). Hydraulics. Yogyakarta: Beta Offset.
[49] Triatmodjo, Bambang. (2008). Applied Hydrology. Yogyakarta: Beta Offset.
[50] Toyyibah, Noerhayati, E., & Rachmawati, A. (2020). River Sedimentation Rate Prediction
[51] Utomo, M., Sudarsono, Rusman, B., Sabrina, T., Lumranraja, J., & Wawan. (2016). Soil Science Management Fundamentals. Jakarta: Prenedamedia Group.
[52] Utomo, W. (1989). Soil Conservation in Indonesia. Jakarta: Rajawali Press.
[53] Ward, et al. (1995). Environmental Hydrology. Florida : Lewis.
[54] Wischmeier, WH and Smith, DD (1978). Predicting Rainfall Erosion Losses. A Guide to Conservation Planning. Maryland: The USDA Agricultural Handbook No. 537.
[55] Wulandari, DA (2022). Age Prediction of Gunungrowo Reservoir After Dredging. CIVIL ENGINEERING, 163-171.
[56] Yang, Chih Ted. (1996). Sediment Transport Theory and Practice. New York.