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Analysis of Erosion and Sedimentation Rates in Karian Reservoir using the USLE Method on the Reservoir's End-of-Life Capacity

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Abstract

Karian Reservoir is a multipurpose reservoir designed to meet raw water needs, provide irrigation water supply, reduce flooding, and generate micro-hydropower potential. It has a dead storage capacity of 46.4 million m³ with a projected service life of 100 years, based on the time required for sediment to fill the dead storage. The planned sedimentation rate of 579,162 m³/year was determined using an empirical formula derived from sediment curves based on tributary surveys conducted in 1995. If sedimentation exceeds dead storage capacity, the reservoir's lifespan and ability to meet water demands will be compromised, making it crucial to analyze sedimentation rates and distribution. Erosion rate analysis using the USLE method for the period 2017-2023 resulted in an average erosion rate of 1,249,177.27 tons/year, with a Sediment Delivery Ratio of 0.304 and a trap efficiency of 95%, leading to a sedimentation rate of 328,397.28 tons/year. The sediment deposition distribution over 100 years, estimated using the Empirical Area Reduction Method, indicated that the new base level would rise by 10.17 meters to an elevation of 30.17 meters. The remaining dead storage capacity is 21.12 million m³ (45.48%), with an effective storage capacity of 112.83 million m³ (96.38%). Theoretically, Karian Reservoir can still achieve its full service life.

Keywords: *Engineering, Karian reservoir, Erosion, USLE, Sedimentation, Empirical Area Reduction*

1. Introduction

Sedimentation is a major challenge in reservoir management. The sedimentation that occurs reduces the reservoir's capacity by an average of 1-3% each year (Reseda, 2022). he sedimentation that occurs originates from land erosion in the Catchment Area (CA) (Zefri et al., 2022). Erosion is the detachment of soil or sediment layers due to the tension of wind or water on the soil surface (Widodo & Suyana, 2015). The process of erosion is determined by hydrological factors, especially rainfall intensity, topography, soil characteristics, land cover vegetation, and land use..

Rainwater that flows on the surface of the land in the form of runoff and rivers carries soil particles that are released due to erosion (Hajigholizadeh et al., 2018). Material resulting from land erosion is carried by the river discharge flowing into the reservoir, some will be deposited at the bottom of the reservoir and the rest will be released with the outflow (Pamuji & Ikhsan, 2017). Bottom sediments will settle at the bottom of the reservoir and will reduce the storage capacity (Issa et al., 2016).

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Karian Dam is one of the National Strategic Projects located in Pasir Tanjung Village, Rangkasbitung District, Lebak Regency, Banten Province. Karian Dam is a multifunctional dam, with benefits including: meeting raw water needs, irrigation water supply, flood reduction, and potential micro-hydropower. The Karian Reservoir is projected to provide a benefit of 14.6 m³/second for meeting raw water needs and irrigation water supply. The condition of the Karian Reservoir can be seen in Figure 1.

Figure 1. Condition of the Karian Reservoir in 2023.

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Figure 1 shows the condition of the Karian Reservoir in 2023. The reservoir's storage area has a lot of vegetation resulting from erosion occurring from the upstream areas as well as around the reservoir.

The construction of the Karian Dam was based on the Design Review of 2015 and was completed in 2023. The Karian Reservoir has a dead storage capacity of 46.40 million m³, with a service life of 100 years. The useful life of the reservoir is determined by how long the dead storage capacity will be filled with sediment (Achsan et al., 2015). The planned sedimentation rate is 579,162 m^3/year ((SNVT Pembangunan Bendungan Karian, 2015). The obtained value comes from historical inflow, which serves as input in the empirical formula derived from the sediment curve (sedigraph) formed from the relationship between sediment yield and discharge measured in the tributaries in 1997. If the planned sedimentation rate is assumed to remain unchanged for 100 years, the deposited sediment will reach 57.9162 million m³ and fill the available dead storage.

The calculation of sedimentation rates in reservoirs can also take into account land erosion occurring in the CA, one of which is by using the USLE Method. The Universal Soil Loss Equation (USLE) method is an erosion model designed to predict the average soil erosion over a long period from a land area used for specific land use and management (Hidayati et al., 2021). The greater the level of erosion hazard, the more sedimentation will occur in the Karian Reservoir. Sedimentation can cause failures in meeting water needs or dam safety if the sedimentation that occurs exceeds the planned levels (Moehansyah et al., 2002).

The extent of the erosion that has occurred is one of the impacts resulting from changes in land cover. There was a change in land use area in 2019-2021 in Lebak Regency (Dinas Lingkungan Hidup Kabupaten Lebak, 2022). The condition of the CA of the Karian Reservoir has also changed compared to the planning stage, especially regarding changes in land cover and rainfall. Changes in land cover and rainfall will affect the extent of land erosion that occurs (Abhipraya et al., 2024).

Each reservoir has a different sediment distribution pattern because each has different characteristics and systems (Mahmud et al., 2020). In addition, the shape of the reservoir, the reservoir operation system, and the size of the sediment particles also affect the sediment distribution in the reservoir (Siwu et al., 2021). The Empirical Area Reduction Method is a method for estimating the reduction in reservoir area due to sedimentation. This method was proposed by Whitney M. Borland and Carl L. Miller in 1960, and revised by Lara in 1962 (Irawati Putri, 2017). This Area Reduction Method has a relatively lower error rate compared to the Empirical Area Addition Method (Tukaram et al., 2016).

Based on the above issues, this research was conducted with the aim of analyzing the rate of erosion and sediment occurring in the CA of the Karian Reservoir and the sediment distribution occurring in the Karian Reservoir, as well as the capacity of the Karian Reservoir at the end of its useful life.

2. Materials and Methods

2.1 Materials

The data needed to support this research are rainfall erosivity (R), soil erodibility (K), slope gradient (LS), land cover (C), and soil management factor (P), as well as the HVA curve of the Karian Reservoir.

The rainfall data used is the result of daily rainfall measurement readings conducted by the Cidanau-Ciujung-Cidurian River Basin Organization from 2017 to 2023. There are 4 rainfall stations located around the Catchment Area (CA). Figure 2 shows the location and coordinates of the 4 rainfall stations in the CA of the Karian Reservoir. The four rainfall stations are: PCH Ciminyak Cilaki, Pasir Ona, and Banjar Irigasi.Figure 1 shows the condition of the Karian Reservoir in 2023. The reservoir's storage area has a lot of vegetation resulting from erosion occurring from the upstream areas as well as around the reservoir.

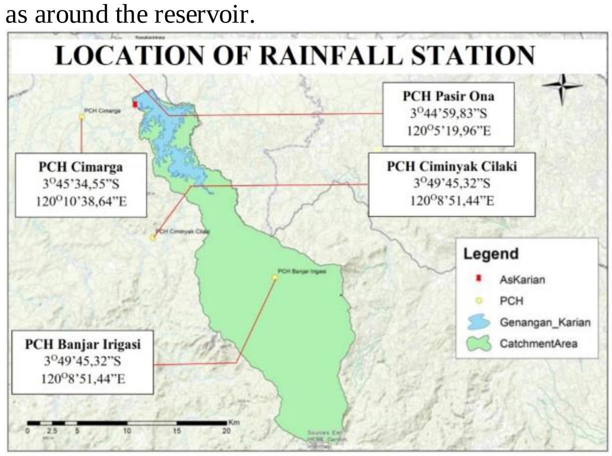

Figure 2. Location of the Karian Watershed Rainfall Station.

2.2 Methods

The analysis used in this research is the USLE Method and the Empirical Area Reduction Method. The USLE method was used to determine the amount of land erosion occurring in the Karian watershed. The USLE method excels in simplicity, data availability, and ease of application for long-term studies compared to the RUSLE and MUSLE methods in calculating erosion rates. The Empirical Area Reduction Method is used to calculate the sediment distribution deposited at each elevation of the Karian Reservoir. Sediment distributed at each elevation will affect the capacity of the Karian Reservoir.

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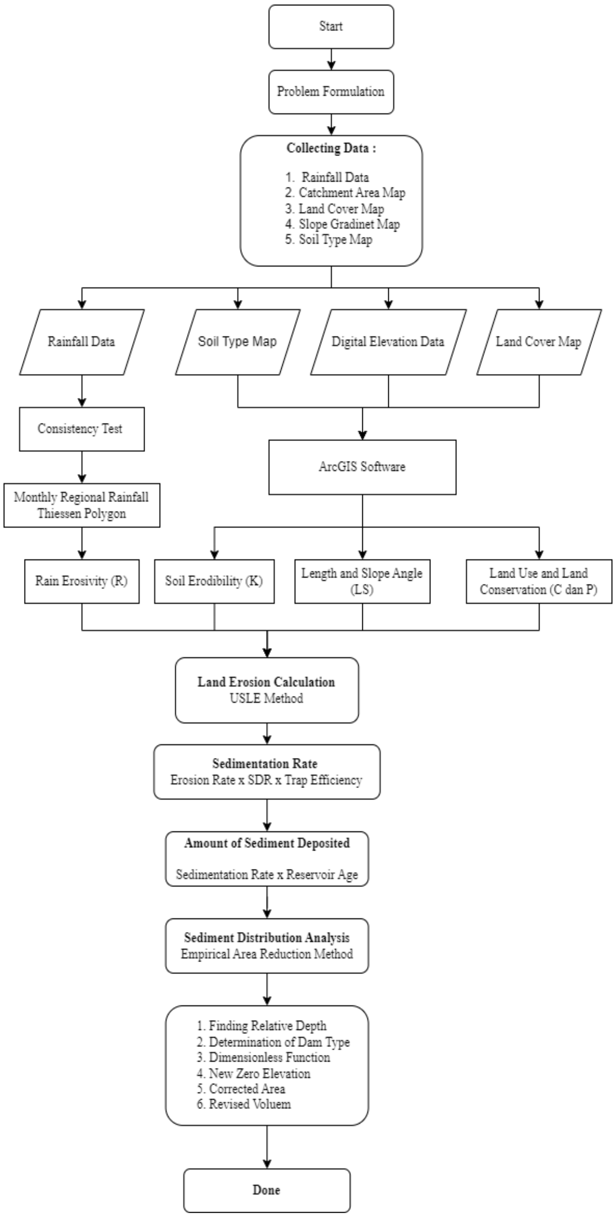

Figure 3. Flowchart of sediment rate and distribution research.

The research is broadly divided into three stages: hydrological analysis, erosion and sedimentation analysis, and sediment distribution analysis. Detailed calculations are explained below. Hydrological analysis includes rainfall data from each rain gauge, which is tested using the Rescaled Adjusted Partial Sums (RAPS) Test, Outlier Test, and Double Mass Curve Test to examine the boundaries and consistency of the rainfall data. Monthly regional rainfall data is obtained using Thiessen polygon analysis. Erosion and sedimentation analysis is conducted using monthly regional rainfall data from the Thiessen Polygon, soil type data, slope gradient data, land cover data, and land conservation data analyzed using the USLE Method integrated with Arc-GIS software to obtain the erosion rate. The erosion rate multiplied by the Sediment Delivery Ratio (SDR) and trap efficiency will yield the sediment rate (Vioni Auliya Damayanti et al., 2023). Sediment distribution includes the distribution of deposited sediment analyzed using the Empirical Area Reduction Method based on technical data from the Karian Reservoir.

Erosion Rate with the USLE Method

The USLE formula is always associated with five causal factors: climate, soil, topography, land cover, and human activities or actions (Marhendi, 2018). The erosion rate of the USLE Method is calculated using Equation 1.

$$A = R\ x\ K\ x\ LSx\ C\ x\ P \quad (1)$$

with A = erosion rate per unit area per unit time, R = rainfall erosivity, K = soil erodibility, LS = slope length and steepness, C = land use factor, and P = soil conservation factor.

Rain Erosivity Factor (R)

Rain erosivity occurs partly due to the impact of raindrops directly hitting the soil and partly due to the flow of water over the soil surface. The magnitude of erosivity that occurs can be calculated using the Lenvain equation as shown in Equation 2.

$$R = 2{,}21\ P^{1{,}36} \quad (2)$$

with R = rainfall erosivity index, P = monthly rainfall (cm). The Lenvain equation is based on the study of rainfall erosivity using rainfall data from the island of Java. The Lenvain erosivity equation is simpler compared to other erosivity equations because it only utilizes monthly rainfall.

Soil Erodibility Factor (K)

Soil erosion factors represent the characteristics of the soil that contribute to land erosion.

Length and Slope Factor (LS)

The slope length and steepness factor (LS) were obtained from the analysis of the topographic map of the Reservoir. The topography in this study uses a Digital Elevation Model (DEM) obtained from Ina-Geoportal.

Land Cover Factor (C)

The land cover factor (C) represents the influence of crop patterns and land use on soil erosion. Basically, the C value ranges from 0 to 1; the higher the C value, the less vegetation there is in the area to prevent erosion.

Soil Conservation Factor (P)

The soil conservation factor (P) is the ratio of the amount of land erosion from a specific conservation action to the amount of erosion on land without

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conservation actions. Conservation actions include: strip planting, contour tillage, bunds, and terraces. The value of P = 1 for land without conservation. The land cover data used is from the years 2017-2023, sourced from the Esri Sentinel-2 Land Cover Explorer.

Sediment Delivery Ratio (SDR)

The sediment yield from a CA can be estimated through the calculation of the Sediment Delivery Ratio (SDR) (Ar). The SDR value has several equations that can be used, the SDR value based on USDA SCS is written in Equation 3.

$$SDR = 0{,}51\ x\ A^{-0{,}11} \quad (3)$$

with A = Watershed Area (mil^2)

Analysis of the Empirical for Area Reduction Method

The Area Reduction Method is carried out in several stages. The first stage determines the shape and type of the reservoir based on the relationship between the depth and capacity of the reservoir plotted on logarithmic paper, followed by calculating the dimensionless factor using Equation 4.

$$F = \frac{S_d - V_h}{H.A_h} \quad (4)$$

with F = Dimensionless factor as a function of the amount of sediment deposition, volume, depth, and area of the reservoir, Sd = the amount of sediment deposit (m^3), Vh = the volume of the reservoir at each elevation (m^3), H = the initial water depth of the reservoir (m), Ah = the area of the reservoir at each elevation (m^2).

After obtaining the F value, the elevation of the sediment deposited in the reservoir, which serves as the new zero elevation, is calculated based on the intersection of the line formed through the relationship of the F value points with the curve of relative depth (p) according to the appropriate reservoir shape type (in stage 1) using the graph in Figure 4.

Then calculate the relative area (a) based on the relative depth (p) using equations 5-8 according to the type of reservoir shape (Morris & Fan, 2010).

Type I : $= 5.074\, p^{1.85}(1-p)^{0.36}$ (5)
Type II : a $= 2.487\, p^{0.57}(1-p)^{0.41}$ (6)
Type III: a$= 16.967\, p^{1.15}(1-p)^{2.32}$ (7)
Type IV: a$= 1.486\, p^{-0.25}(1-p)^{1.34}$ (8)

The area of sediment distributed at each elevation of the reservoir is calculated by multiplying the value of a at each elevation by the value of Z. The value of Z is obtained from the initial area of the reservoir at the new elevation divided by the value of a at the new base elevation. The next step is to calculate the sediment volume at each elevation after the sediment area distribution is known, so that the remaining area and storage volume at each reservoir elevation can be obtained.

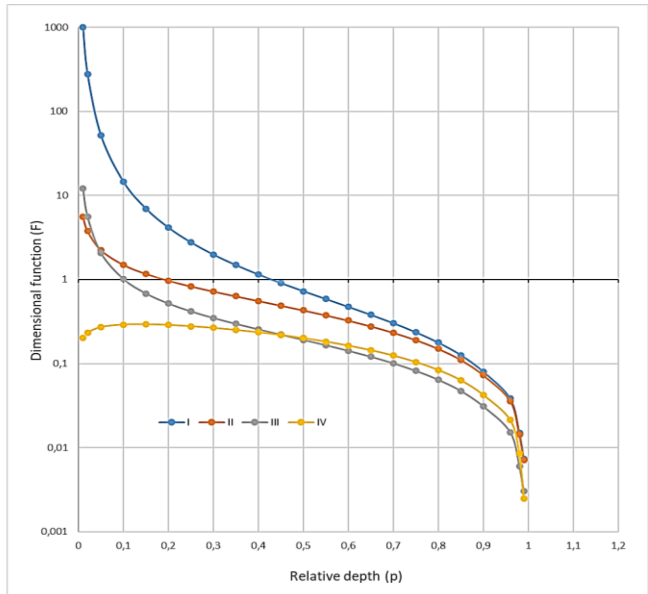


Figure 4. Reservoir type curve to determine the new zero depth

3. Results and Discussion

Consistency Test

The consistency tests used are the RAPS Test, Outlier Test, and Double Mass Curve Test on the data from each rainfall station. The testing is conducted to detect whether the available rainfall data falls within the upper and lower limits and to identify any deviations in the rainfall data. The test results can be seen in Table 1

From Table 1, it is concluded that the data from the four rainfall stations are consistent based on the RAPS

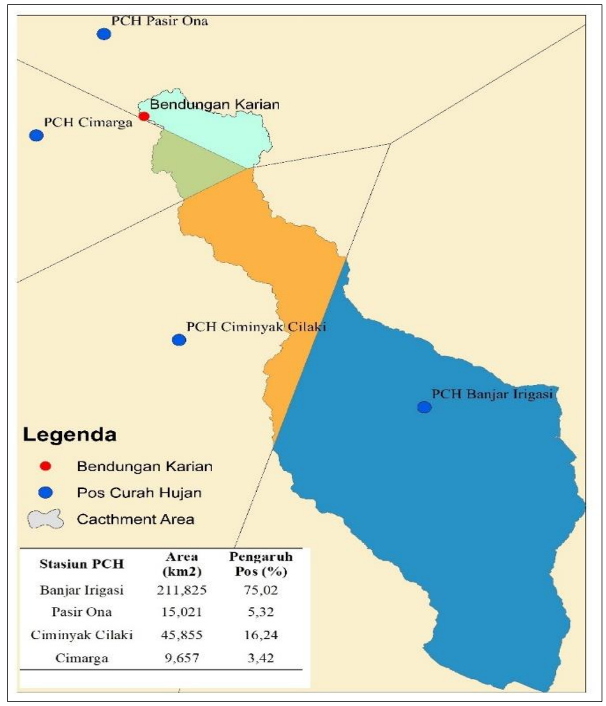
Tabel 1. Results of the RAPS Test, Outlier, and Double Mass Curve

Rainfall Station	RAPS Test	Outlier Test	Double Mass Curve (R^2)
Banjar Irigasi	Consistent Data	Meeting the upper and lower limits	0,9653
Ciminyak Cilaki	Consistent Data	Meeting the upper and lower limits	0,9918
Cimarga	Consistent Data	Meeting the upper and lower limits	0,9942
Pasir Ona	Consistent Data	Meeting the upper and lower limits	0,9962

Test, meet the upper and lower limits of the Outlier Test, and the R2 value from the Double Mass Curve Test approaches 1, meaning the rainfall data can be used for further analysis.

Monthly Regional Rainfall

The influence of each rainfall station on the Karian DTA was calculated using the Thiessen Polygon. The Thiessen polygon and the influence weights of each rainfall station are shown in Figure 5. The monthly rainfall for the region is obtained by summing the product of the monthly rainfall at each station with the weight of its influence on the CA Karian. The recap of regional rainfall at CA Karian can be seen in Table 2.



`**Figure 5**. Thiessen Polygon on the CA Karian Reservoir

Table 2. Regional rainfall in the CA of Karian Reservoir

Year	Regional Rainfall (cm)											
	Jan	**Feb**	**Mar**	**Apr**	**Mei**	**Jun**	**Jul**	**Agu**	**Sep**	**Okt**	**Nov**	**Des**
2013	45.75	28.76	7.51	8.28	17.75	4.64	6.36	5.35	9.15	9.51	14.61	21.36
2014	28.79	29.02	15.94	14.67	21.11	8.18	4.43	5.39	1.77	22.55	17.53	21.25
2015	18.23	19.00	14.06	20.00	15.25	2.94	0.78	0.98	1.72	4.58	20.16	16.37
2016	31.34	28.84	27.45	15.14	25.61	17.68	9.07	13.86	8.20	22.60	21.44	26.35
2017	39.06	32.94	31.72	47.73	40.92	18.31	39.60	19.90	15.66	31.10	33.25	25.53
2018	45.67	27.78	20.08	47.50	47.93	29.78	2.56	10.53	14.43	20.83	32.37	29.65
2019	41.75	42.91	28.93	49.11	38.15	5.62	10.70	13.87	5.12	27.09	25.36	33.89
2020	59.26	36.33	75.18	26.27	55.53	54.12	31.18	30.73	26.83	33.73	24.99	64.35
2021	29.11	45.11	16.22	57.18	45.29	48.86	21.67	33.42	65.07	44.07	30.85	45.91
2022	23.91	42.00	27.74	23.90	56.32	51.26	34.19	44.55	44.24	35.01	29.34	53.06
2023	43.66	47.48	44.52	24.04	28.19	45.23	34.19	3.04	0.99	24.27	33.18	23.32

Rain erosivity (R)

The rainfall used in the calculation of rainfall erosivity is the monthly regional rainfall. The monthly regional rainfall in the Karian CA is presented in Table 2. The Thiessen area rainfall is then input into Equation 2 to produce the rainfall erosivity (R) that occurs in the CA

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Karian. The recapitulation of rainfall erosivity occurring in the CA Karian can be seen in Table 3.

Table 3. Rain erosivity in the CA of Karian Reservoir

Years	Monthly Rainfall (cm)												Rain erosivity (cm)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2013	400.47	212.97	34.29	39.16	110.44	17.80	27.38	21.64	44.84	47.29	84.80	142.12	1,183.20
2014	213.25	215.62	95.46	85.23	139.90	38.51	16.72	21.82	4.81	152.97	108.62	141.16	1,234.07
2015	114.57	121.21	80.49	129.92	89.87	9.60	1.58	2.15	4.63	17.52	131.41	99.00	801.95
2016	239.38	213.79	199.87	88.96	181.88	109.87	44.31	78.92	38.65	153.48	142.80	189.04	1,680.95
2017	322.97	256.16	243.37	424.19	344.06	115.22	329.10	129.08	93.18	236.88	259.46	181.16	2,934.83
2018	399.48	203.18	130.66	421.37	426.59	223.36	7.93	54.33	83.39	137.34	250.13	222.04	2,559.80
2019	353.59	367.02	214.68	440.94	312.78	23.10	55.50	78.97	20.37	196.31	179.49	266.24	2,508.99
2020	569.27	292.61	786.89	188.29	521.07	503.18	237.73	233.08	193.75	264.56	175.96	636.77	4,603.17
2021	216.56	392.84	97.75	542.36	394.98	437.89	144.89	261.29	646.49	380.57	234.29	402.38	4,152.29
2022	165.68	356.46	202.76	165.60	531.23	467.40	269.48	386.24	382.59	278.30	218.83	489.87	3,914.46
2023	375.70	421.21	385.89	166.92	207.26	394.30	269.48	10.05	2.19	169.06	258.71	160.11	2,820.88

Soil Erodibility (K)

Based on the soil type map analysis using Arc-GIS software, it is known that there are 2 types of soil in the DTA Waduk Karian area, namely: Orthic Acrisols or what is called Yellowish Red Podzolic and Humic Andosol. The types of soil and the K values of the CA Karian Reservoir are shown in Table 4 and Figure 6. The area of the Red-Yellow Podzolic soil type is 273.830 km² with a K value of 0.166, and Andosol covering 8.528 km² with a K value of 0.278. The type of soil in the CA of the Karian Reservoir generally does not change throughout the year, except in the event of a natural disaster in the area.

Tabel 4. Type and value of erodibility in the Karian CA

Soil types	K	Area (km^2)
Humic Andosol	0.278	8.528
Orthic Acrisols	0.166	273.830

Source : (Dariah et al., 2004)

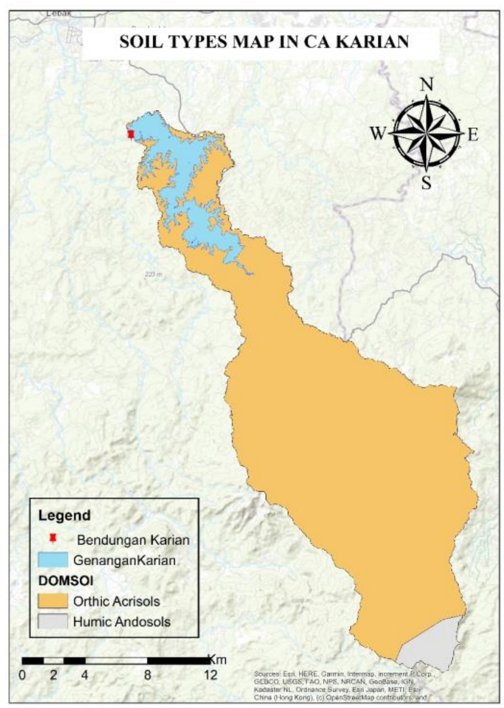

Figure 6. Soil types of CA Karian Reservoir.

Land Slope (LS)

Digital Elevation Model is processed using Arc-GIS software, resulting in slope gradients. The processed results are displayed in Figure 7 and Table 5.

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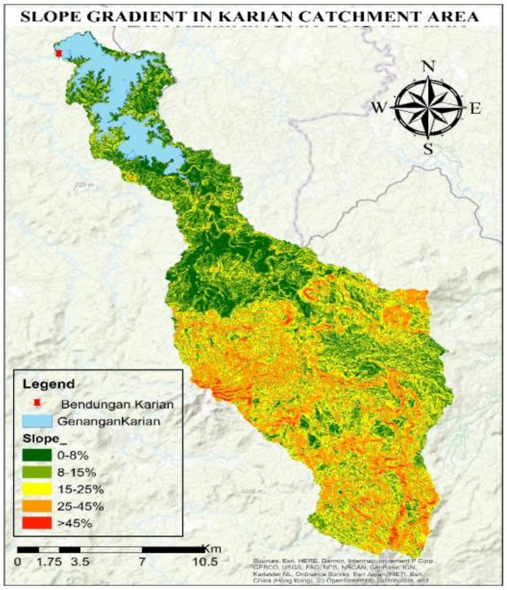

Figure 7. Slope map of the land in CA Karian.

Tabel 5. Slope Gradient Karian Watershed

No	Color	Slope (%)	Area (km^2)	LS
1.	Green	0 - 8	57.96	0.4
2.	Light Green	8 - 15	80.95	1.4
3.	Yellow	15 - 25	79.45	3.1
4.	Orange	25 – 45	59.56	6.8
5.	Red	> 45	4.44	9.5
Total			282.36	

Source: (Kironoto & Yulistiyanto, 2000)

Land Cover (C)

The land cover map of the CA Karian sourced from the Esri Sentinel-2 Land Cover Explorer was processed using Arc-GIS software, resulting in a land cover interpretation map from 2017-2023 displayed in Figure 8. Figure 8 is the result of the interpretation of the CA Karian Reservoir, which shows that land use for settlement has increased, while land cover in the form of plantations and grasslands tends to decrease each year.

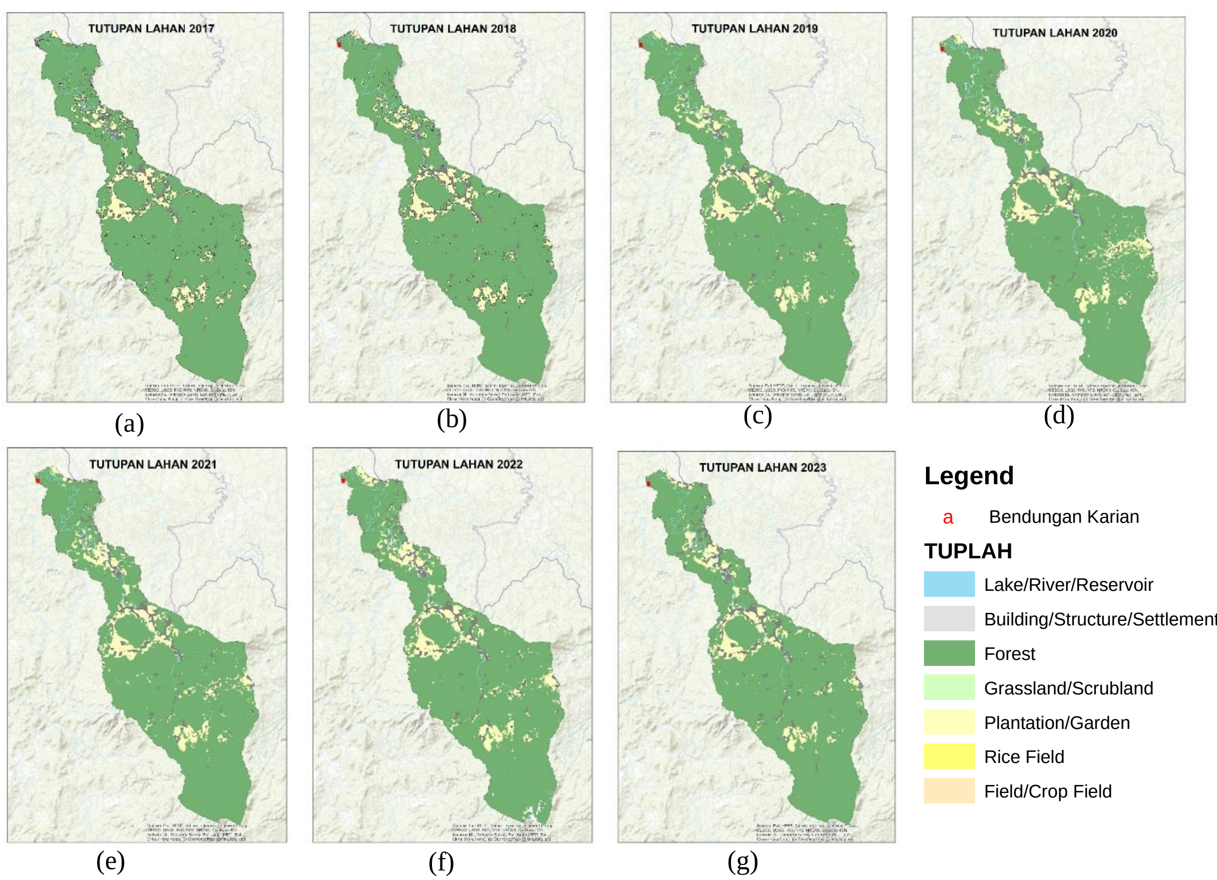

Figure 8. Land cover map of CA Karian in (a) 2017, (b) 2018, (c) 2019, (d) 2020, (e) 2021, (f) 2022, (g) 2023.

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USLE Method Erosion Rate

The erosion rate is calculated using Equation 1 by overlaying rainfall erosivity data, soil erodibility, land cover, and slope gradient using GIS software. The erosion hazard level (EHL) occurring in the VA of the Karian Reservoir is displayed in Figure 9. The erosion rate that occurred from 2017 to 2023, calculated using the USLE Method, was 981,614.17 tons/year, 836,844.91 tons/year, 617,248.29 tons/year, 1,833,220.19 tons/year, 1,656,820.48 tons/year, 1,619,851.76 tons/year, and 1,198,641.05 tons/year. The magnitude of the erosion tends to fluctuate, which may be caused by the varying erosivity of rainfall each year

Pendugaan Laju Sedimentasi

Sediment Yield is calculated by multiplying the erosion rate by the Sediment Delivery Ratio, while the actual sedimentation rate is obtained by multiplying the sediment yield by the trap efficiency. The SDR value using Equation 3 with a CA area of 282.384 km² = 109,019 mi² is obtained as 0.304. The trap efficiency value obtained is 95% based on the Brune Curve. Using a sediment bulk density of 1.1 ton/m^3, the average actual sedimentation value is 328,397.52 m3/year with details as shown in Table 6.

Table 6. Sedimentation rate Karian Reservoir

Year	Erosion rate (ton/yr)	Sediment yield rate (ton/yr)	Sediment actual	
			(ton/yr)	(m^3/yr)
2017	981,614.17	298,803.52	283,863.34	258,057.58
2018	836,844.91	254,735.73	241,998.94	219,999.04
2019	617,248.29	187,890	178,495.96	162,269.05
2020	1,833,220.19	558,033	530,130.90	481,937.18
2021	1,656,820.48	504,336	479,119.60	435,563.28
2022	1,619,851.76	493,083	468,428.98	425,844.53
2023	1,198,641.05	364,867	346,623.21	315,112.01
Average	**1,249,177.27**	**380,249.76**	**361,237.28**	**328,397.52**

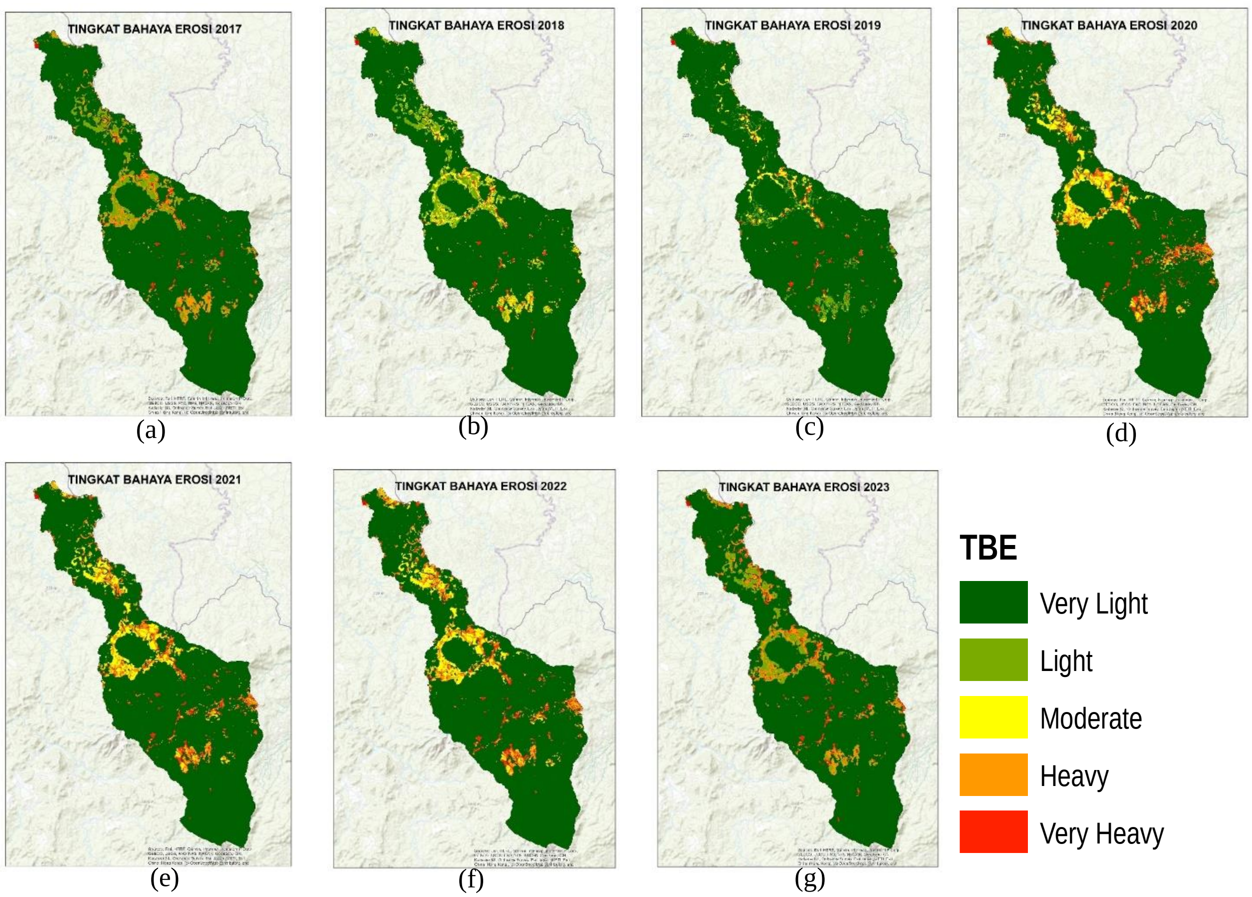

Figure 9. Level and class of erosion hazard in year (a) 2017, (b) 2018, (c) 2019, (d) 2020, (e) 2021, (f) 2022, (g) 2023.

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The average sedimentation rate produced in the study was 328,397.52 m³/year, which differs from the planned sedimentation rate of 579,162 m³/year. The existing difference is caused by the different methods used in calculating the sedimentation that occurs. The sedimentation rate value from the planning results is calculated based on an empirical equation between sediment yield and discharge, which is derived from the sediment curve (sedigraf) obtained from measurements in the tributaries in 1997. Measurements were conducted on the tributaries, but there is a possibility that the suspended sediment measured does not settle in the reservoir but rather in the channel of the tributaries.

Sediment Distribution in Karian Reservoir

The sedimentation rate is predicted to settle in the Karian Reservoir over 100 years at 328,397.28 tons/year or a total of 32,839,752.38 tons. Based on the results of depth and capacity plotting as shown in Figure 10, a value of m = 2.47 was obtained. Based on Table 7, the Karian Reservoir is a Type III Reservoir with a hill-mountain shaped reservoir.

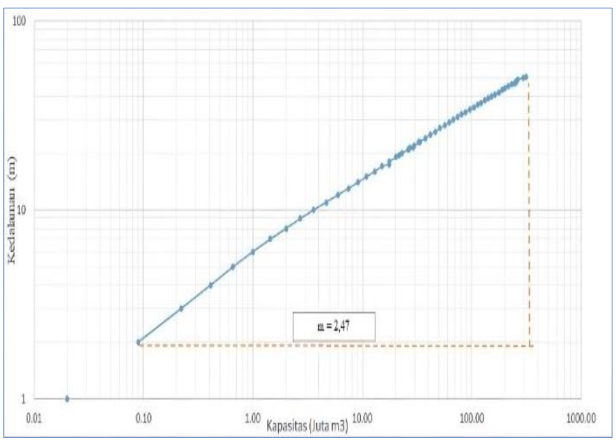

Figure 10. Depth-Capacity Relationship Curve of the Karian Reservoir

Table 7. Type Reservoir

Shape of Dam	Type Curve	m
Lake	I	3.5 - 4.5
Plain – Foothill	II	2.5 – 3.5
Hill – Mountain	III	1.5 – 2.5
Mountain	IV	1.0 – 1.5

Source : (Kironoto & Yulistiyanto, 2000)

The value of F at the Karian Reservoir was calculated using Equation 4 and plotted to form a line that intersects with the relative depth curve (p) of a type III reservoir as shown in Figure 11, resulting in a Po of 0.2 m.

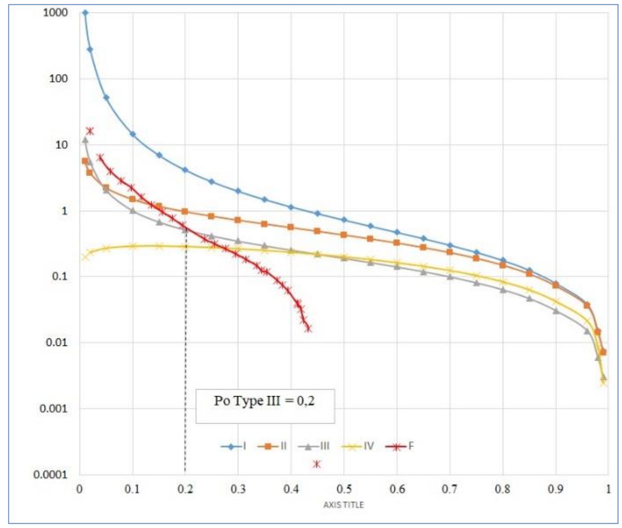

Figure 11. F and p values of Karian Reservoir

The new depth is obtained by adding the product of Po and the deepest depth to the base depth, resulting in a new depth at an elevation of +30.17 m.

The relative area of the Karian Reservoir is calculated using Equation 7, according to the Type III Karian Reservoir for each elevation. The corrected area (Ao) is calculated by dividing the area by the depth at the new zero elevation. The distributed area is calculated based on the product of the relative area and the corrected area, while the revised area and volume are the initial area and capacity minus the distributed sediment area and cumulative sediment volume. The change in the capacity of the Karian Reservoir over a useful life of 100 years can be seen in Table 8 and Figure 12.

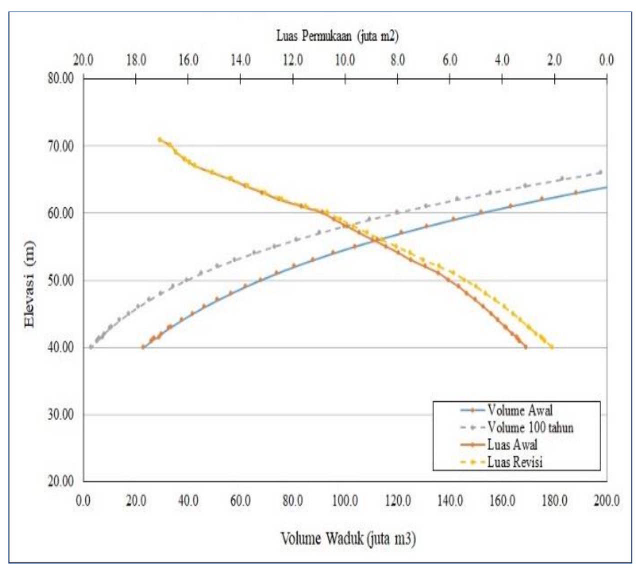

Figure 12. Curve Of Reservoir Storage Capacity Changes

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Table 8. Changes in the storage capacity of the Karian Reservoir

Elevation (m)	Volume (million m^3)		Area (km^2)	
	Initial (T_0)	T_{100}	Initial (T_0)	T_{100}
FWL (+70,85)	314.71	281.87	17.05	17.05
NWL (+67,50)	253.88	221.06	15.93	15.91
LWL (+46,00)	46.4	21.12	4.71	3.91

Based on the analysis conducted, the sediment volume deposited over 100 years is 32.84 million m3, with the new zero elevation at +30.17 m. Sediment entering the reservoir is distributed at each elevation of the reservoir. The storage capacity at the minimum water surface elevation at the beginning of operation was 46.44 million m³, but it decreased to 21.12 million m³ or 54.52% at the 100-year service life. The effective storage elevation of +67.50 m has a capacity of 253.88 million m3 at the beginning of the reservoir's useful life and decreases by 3.62% to 221.06 million m3 at the end of its 100-year useful life.

4. Conclusion

The average land erosion rate occurring in the Karian CA is 1,249,177.29 tons/year. The average sedimentation rate calculated using the USLE method is 328,397.52 m³/year, so after 100 years of operation, the sediment entering the Karian Reservoir amounts to 32.84 million m³ and the new zero elevation of the reservoir rises to +30.17 m. The effective storage capacity still has 96.38% capacity, so in terms of operational water supply, it can still meet the water needs through the intake gate. Recommendations to maintain the sustainability of the Karian Reservoir include conducting bathymetric measurements of the Karian Reservoir at least once every 5 years to monitor sediment accumulation within the reservoir. Land cover control in the Karian Reservoir's catchment area requires special attention in spatial planning and land use in the Karian catchment area so that erosion and sedimentation can be anticipated. One of the efforts that can be made to control the sedimentation is through forest rehabilitation and land conservation strategies, such as reforestation and terracing.

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