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Research Article

Analysis of the Erosion Hazard Level Using the USLE Method with the ARCGIS Application in the Upstream of the Pengga Reservoir

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ABSTRACT

This study evaluates the erosion hazard level in the upstream region of the Pengga Reservoir by applying the Universal Soil Loss Equation (USLE) method, integrated with Geographic Information System (GIS) tools in ArcGIS. Soil erosion is recognized as a critical environmental concern in upstream reservoir catchments due to its contribution to accelerated sedimentation, which in turn reduces reservoir storage capacity and operational lifespan. The research was conducted within the Dodokan Watershed, encompassing the West Lombok and Central Lombok Regencies in West Nusa Tenggara Province, Indonesia. The analysis was based on secondary data, including rainfall records from the Meteorology, Climatology, and Geophysics Agency (BMKG), soil characteristics, topographic features, and land use and vegetation cover data. The USLE model was used to calculate five contributing factors: rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover-management (C), and support practices (P), which were processed using spatial analysis in ArcGIS.

The results indicate that erosion hazard levels across the study area vary from very light to very severe. The total estimated annual soil loss is 405,204.65 tons/ha/year, with approximately 70.37% of the catchment experiencing very light erosion and 4.05% experiencing very severe erosion. The estimated sediment yield, calculated using the Sediment Delivery Ratio (SDR), is approximately 30,038.52 m^3/year. These findings offer valuable insights for regional soil conservation planning and contribute to the development of sustainable reservoir management strategies.

Keywords: USLE; ArcGIS; Pengga Reservoir; Sedimentation; Dodokan Watershed

1. INTRODUCTION

Soil erosion represents one of the most pressing environmental challenges due to its profound impacts on ecosystems, water quality, and the storage capacity of reservoirs. In upstream catchment areas, soil erosion contributes to excessive sedimentation, which significantly reduces both the effective capacity and operational lifespan of reservoirs. This issue is particularly critical in the upstream area of the Pengga Reservoir, where ongoing anthropogenic activities and land use changes exacerbate erosion risks.

The Pengga Reservoir is among the most erosion-prone reservoirs in the region. In 2022, the Nusa Tenggara I River Basin Organization (BWS-NT1), under its Operations and Maintenance Work Unit, initiated rehabilitation efforts across Lombok and Sumbawa Islands. These efforts focused on sediment dredging, structural rehabilitation of dam components, and improvements to supporting infrastructure.

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Constructed within the Dodokan Watershed (DAS), the Pengga Reservoir plays a vital role in regional water management. The watershed spans two administrative regions—West Lombok Regency (18.90%) and Central Lombok Regency (81.10%)—and serves multiple functions, including irrigation, flood control, and water supply (Khalis Ilmi, 2020) [1].

This study aims to assess the level of erosion hazard in the upstream area of the Pengga Reservoir using the Universal Soil Loss Equation (USLE) method, integrated with ArcGIS. Identifying areas with high erosion potential is essential for the development of effective conservation and land management strategies, thereby ensuring the reservoir's long-term sustainability in providing clean water and mitigating floods (Pratama, Legono, and Rahardjo, 2019). The USLE is one of the most widely applied empirical models for estimating long-term average annual soil loss due to sheet and rill erosion. It accounts for several critical factors including rainfall erosivity, soil erodibility, slope length and steepness, land cover, and conservation practices. With advancements in Geographic Information System (GIS) technology, the spatial application of USLE has become increasingly accurate and efficient. The integration of USLE with ArcGIS enables high-resolution mapping and analysis of erosion-prone areas (Khalis Ilmi, 2021). The importance of this research is underscored by several key considerations: (1) Soil erosion reduces soil fertility, thereby affecting agricultural productivity and ecosystem resilience; (2) High erosion rates in upstream regions accelerate sedimentation in reservoirs, decreasing their storage capacity and functional lifespan; (3) Changes in rainfall patterns due to climate change may exacerbate erosion processes, making it crucial to understand the contributing factors; and (4) Human activities such as deforestation, intensive agriculture, and poorly managed infrastructure development further intensify erosion risks. By employing the USLE model in conjunction with ArcGIS technology, this study seeks to provide a comprehensive spatial assessment of erosion hazard levels in the upstream area of the Pengga Reservoir, while offering practical recommendations for erosion mitigation and soil conservation.

1.1. Objectives of Research

The following are the research objectives:

1. Find out the rate of erosion in the Catchment area of Pengga Reservoir.
2. Analyze the level of erosion hazard in the upstream area of the Pengga Reservoir using the USLE method combined with the ArcGIS application to map and evaluate the level of soil erosion in the upstream area of the Pengga Reservoir.
3. Find out how much sediment volume is in the Catchment area of Pengga Reservoir

2. METHODOLOGY

2.1. Location of Research

The study area is located within the Dodokan River Watershed, specifically in the upstream region of the Pengga Reservoir. Administratively, the Pengga Dam is situated in Pelambik Village, West Praya District, Central Lombok Regency, West Nusa Tenggara Province, Indonesia.

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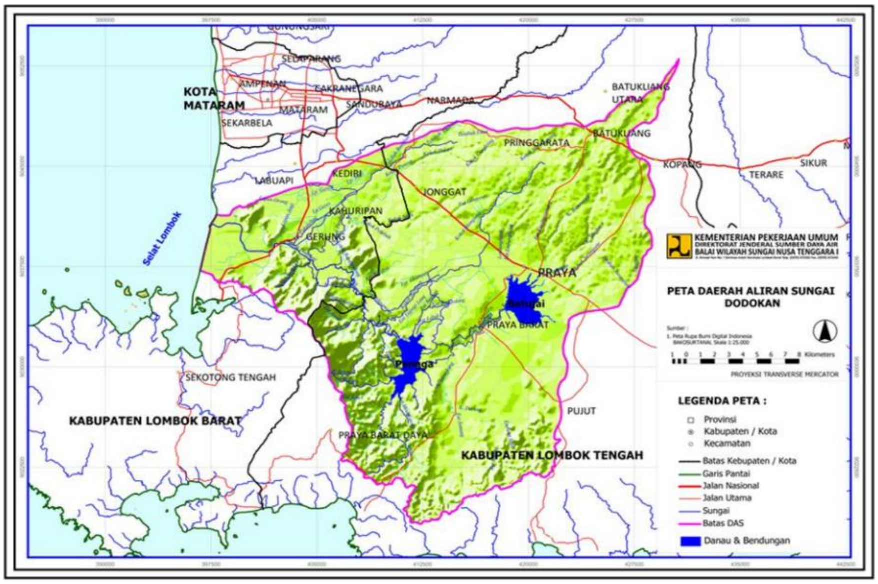

Fig. 1. Location map of Pengga Reservoir

2.2. Method of Collecting Data

Data collection represents a critical component of this research. In general, data sources can be categorized into two types: primary and secondary. This study exclusively relies on secondary data, which refers to information obtained indirectly through existing documentation, such as recorded observations, measurement reports, institutional analyses, project documentation, and relevant regional policy regulations. The utilization of secondary data ensures a comprehensive and consistent foundation for the erosion analysis conducted in this study.

Table 1. Research data and data sources

No	Data Type	Data Source Agency	Data Category
1	Rain Data	BWS NT 1- Unit Hidrologi (PSDA)	Secondary
2	Soil Type Data	Map of Soil Type – Dinas Pertanian/Dinas Kehutanan Prov.NTB	Secondary
3	Land Use Data	BPDAS Moyosari	Secondary
4	Map of DEM	USGS/DEMNAS – Download Peta SHP Lombok Island	Secondary
5	Watershed Map	BWS NT 1 – Water Allocation	Secondary

2.2.1. Data of Research

a. Monthly and annual rainfall data is collected from the Meteorology, Climatology and Geophysics Agency (BMKG) and other related agencies.

b. Soil Properties Data, consisting of data on soil texture, soil structure, and organic matter from field surveys and previous research reports.

c. Topographic data, from contour maps or Digital Elevation Model (DEM) with high resolution.

d. Land Use and Vegetation Data, from available satellite imagery or GIS data.

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2.2.2. USLE Analysis with ArcGIS

a. Determination of the R Factor (Rain Erosivity), calculating the R factor based on rainfall data using a formula by the USLE method

b. Determination of the K Factor (Soil Erodibility), calculating the K factor based on the soil property data that has been collected.

c. Determination of LS Factors (Topography), using DEM data to calculate LS factors with spatial analysis in ArcGIS

d. Determination of Factor C (Land Cover and Management), classifying land use and vegetation cover data from satellite images to determine Factor C.

e. Determination of the P Factor (Soil Management Practices), using land management practice data to calculate the P factor. The P factor was excluded due to limited field data on conservation practices and the predominance of unmanaged land, thus, it was assumed as 1 without compromising the validity of the analysis.

f. Integration of Factors in the USLE Model, using ArcGIS to integrate all factors (R, K, LS, C, and P) in the USLE model to predict the level of erosion in the upstream area of Pengga Reservoir.

2.2.3. Mapping of Erosion-Prone Areas

a. Produce erosion hazard level maps based on USLE analysis results

b. Identify areas with high, medium, and low erosion rates.

3. RESULTS

3.1. Dodokan Catchment Area Map

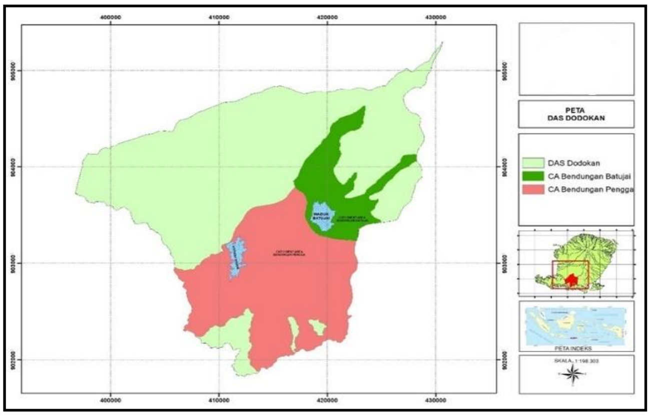

Fig. 2. Map of the Dodokan Catchment Area

The Dodokan watershed encompasses an area of 578.62 km², with a watershed perimeter measuring 179.10 km and a main channel length of 64 km. The river network is classified into eight stream orders, exhibiting a bifurcation ratio close to 3, indicating that the watershed has a tendency for rapid increases in river discharge, which can lead to flooding events, while the recession of water levels tends to occur more gradually. Furthermore, the Dodokan watershed displays a combination of rectangular and dendritic drainage patterns and demonstrates a moderate drainage density, consistent with the findings of Khalis Ilmi (2020).

3.2. Characteristics of the Pengga Reservoir Catchment Area

3.2.1. Topography and Slope Analysis

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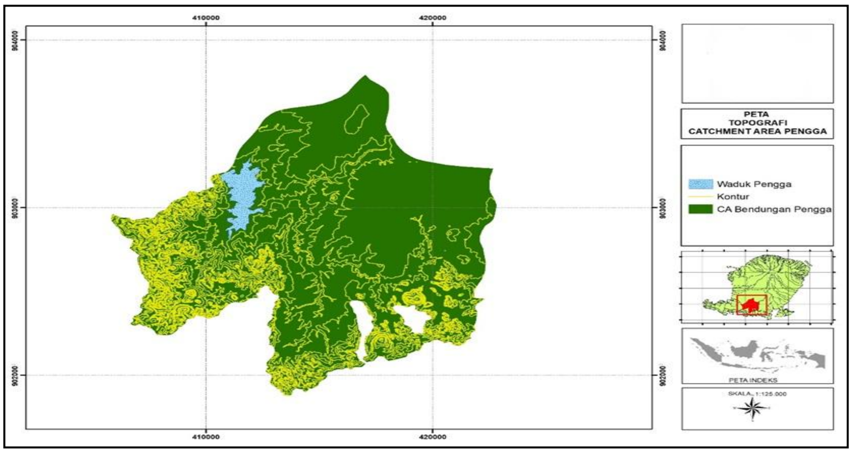

Fig. 3. Topography in the Pengga Reservoir Catchment Area

Pengga Dam irrigates approximately 3,585 hectares of agricultural land in West Lombok Regency, comprising 520 hectares of newly developed rice fields and 3,065 hectares of expansion areas formerly irrigated by the Gebong irrigation system. Hydropower generation, utilizing a specific head and height, supports the electricity demands of downstream communities as well as reservoir operations, with an installed capacity of 400 kVA prior to the release of reservoir water for irrigation purposes. The primary water source for Pengga Dam is the Penujak River, which is hydraulically linked to Batujai Dam and is subject to substantial flood runoff. Consequently, Pengga Dam effectively mitigates flood discharge by approximately 750 m^3/s, reducing peak flow rates from 2,450 m^3/s to 1,700 m^3/s, thereby attenuating potential adverse downstream impacts.

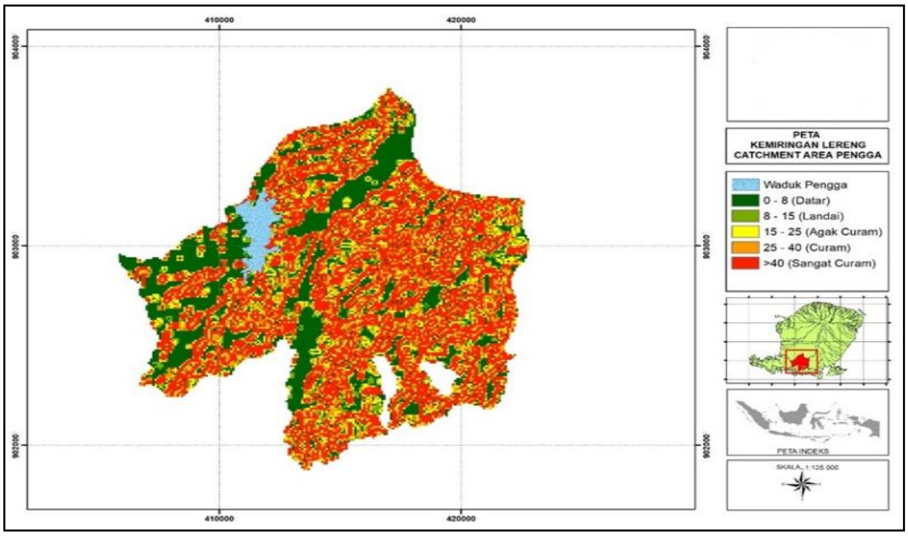

Fig. 4. Slope map in the Pengga Reservoir Catchment Area

From the spatial analysis of the map, the slope was obtained based on DEMNAS map data, which was then processed into slope classes and then classified into 5 slope classes. A table of areas of land with a certain slope is obtained, which is indicated by the LS value.

Pengga Reservoir Catchment Area slope data is based on the equation below.

Percentage of flat slope = (Area of Flat Slope)/(Area of Pengga Dam CA)

= (41,99 km2)/(177,54 km2) x 100

= 24 %

Table 2.

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Slope data in the Pengga Reservoir Catchment Area

Sloop	Wide (km2)	Percent (%)	Value LS
0-8% (Flat)	41,99	24%	0.4
8-15%(Slooping)	13,51	8%	1.4
15-25%(Sloop)	18,80	11%	3.1
25-40%(Steep)	26,54	15%	6.8
>40%(Very Steep)	76,79	43%	9.5
Total	177,54	100%	21,2

3.2.2. and Use Analysis

Based on land cover data from BPDAS Moyosari (2018) Pengga Dam Catchment Area, Pengga Dam Catchment Area is dominated by agricultural and plantation land use types. This is supported by the results of our spatial analysis using the Pengga Reservoir Catchment Area land use map, along with the Pengga Reservoir Catchment Area Land Use Map and Table.

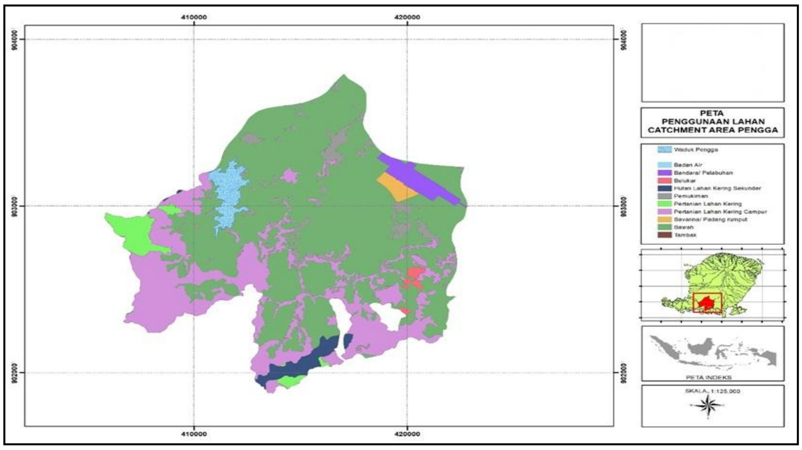

Fig. 5. Land use map in the Pengga Reservoir Catchment Area

The following is the calculation of the percentage of land area based on land use categories in the Pengga Dam Catchment Area

Area of Secondary Dry Land Forest Use

Percentage Land Use = $\frac{\text{Area of Secondary Dry Land Forest Use}}{\text{Wide CA Pengga Reservoir}}$ =

= (3,80 km2) / (177,54 km2) x 100

= 2,14 %.

Table 3. Land Use in the Pengga Dam Catchment Area

Land Use	Wide (Km2)	Persentage	Value C
Water body	4,09	2,30	0,051
Airport/harbour	3,75	2,11	1,000
Thicket	0,91	0,51	1,000
Secondary Dryland Forest	3,80	2,14	0,001
Residential	9,53	5,36	1,000
Dryland farming	5,08	2,86	0,500
Mixed dry land agriculture	43,89	24,70	0,100

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Savanna meadow	1,54	0,86	0,300
ricefield	105,08	59,14	0,01

3.2.3. Soil Type and Erodibility Analysis

According to soil type data obtained from BPDAS Moyosari (2018), the Pengga Dam Catchment Area consists of two types of soil: Mediterranean Complex Brown Grumosol Gray Regosol Brown & Litosol, and Mediterranean Complex Brown & Mediterranean Reddish Brown. The results of our spatial analysis are supported by the following map and table of soil types.

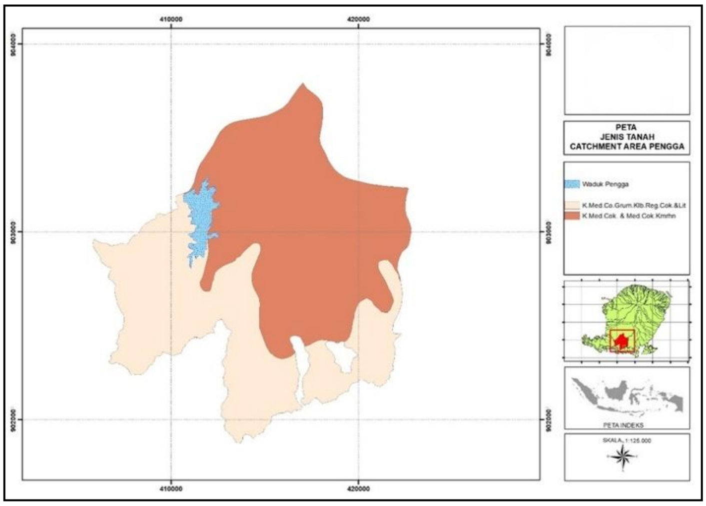

Fig. 6. Map of Soil Types in the Pengga Reservoir Catchment Area

The following is a calculation of the percentage of land area based on soil type in the Pengga Dam Catchment Area.

$$\text{Percentage Soil Type} = \frac{\text{K.Med.Co.Grum.Klb.Reg.Cok.\&Lit}}{\text{Wide CA Reservoir}}$$

$$= \frac{80{,}99 \text{ km2}}{177{,}54 \text{ km2}} \times 100$$

$$= 45{,}58\ \%$$

Table 4. Soil types in the Pengga Reservoir Catchment Area

Type o Soil	Wide (km2)	Percentage (%)	Value (K)
K.Med.Co.Grum.Klb.Reg.Cok.&Lit	80,99	45,58	0,075
K.Med.Co.&Med.Cok.Kmrhn	96,67	54,41	0,116

3.3. Hydrological Characteristics of the Pengga Reservoir Catchment Area

Rainfall data in the Pengga Reservoir Catchment Area is used as one of the parameters to determine the rate of land erosion, namely as a rain erosivity factor (R).

3.3.1. Regional Rain Analysis

This research used five Rain Stations: Batujai Station, Kabul Station, Mangkung Station, Pengga Station, and Rembitan Station. Data from the 2012–2022 period is used for regional rainfall analysis. The following image shows the location of the rain stations.

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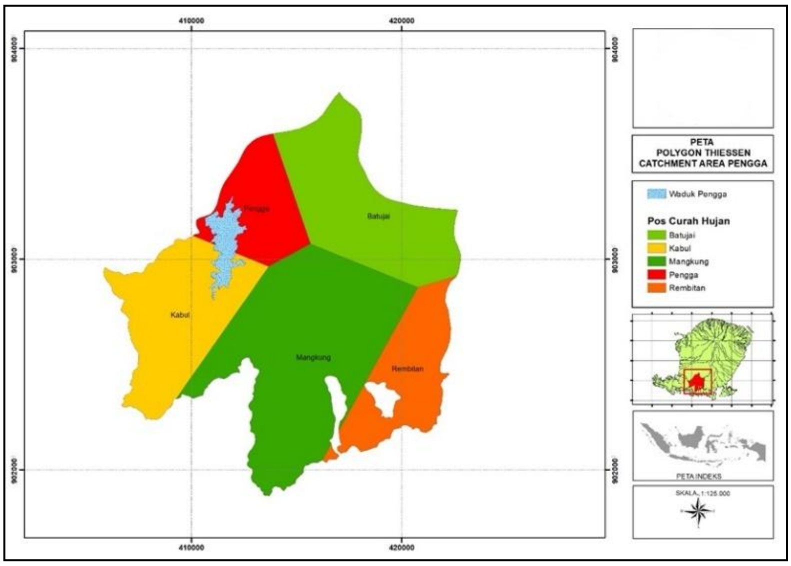

Fig. 7. Thiessen Catchment polygon map of Pengga Reservoir Area

Based on the Thiessen polygon map that has been created, the area coefficient will be obtained for each existing rain station. This value will be used to calculate the average monthly rainfall in the Dam Catchment Area. The area coefficient for each rain station can be seen in the following figure and table.

Table 5. The thiessen coefficient for the area of each station

No	Station	Wide	Coefficient
1	Kabul	34,5547	0,19
2	Mengkung	62,9186	0,35
3	Pengga	19,4458	0,11
4	Batujai	38,5767	0,22
5	rembitan	22,17	0,12

The rain data used comes from 2012 to 2022. Monthly rainfall is calculated in the Pengga Reservoir Catchment Area on average using the area coefficient of each rain station from the calculation results of the Thiessen polygon method.

The following is a calculation of monthly rainfall for the Pengga Reservoir Catchment Area in January 2012:

Average rainfall in January 2012

= ∑ (Coefisient Thiessen x monthly rainfall).

= (Coefisient Thiessen ARR Kabul x Monthly rainfall January ARR Kabul) + (Coefisient Thiessen ARR Mangkung x Monthly rainfall Januari ARR Mangkung) + (Coefisient Thiessen ARR Pengga x Monthly rainfall Januari ARR Pengga) + (Coefisient Thiessen ARR Batujai x Monthly rainfall Januari Batujai) + (Coefisient Thiessen ARR Rembitan x Monthly rainfall ARR Rembitan)

= (Thiessen Coefficient ARR Kabul x Rain in January ARR Kabul) + (Thiessen Coefficient ARR Mangkung x Rain in January ARR Mangkung) + (Thiessen Coefficient ARR Pengga x Rain in January ARR Pengga) + (Thiessen Coefficient ARR Batujai x Rain in January Batujai) + (Thiessen Coefficient ARR Rembitan x Moon Rain ARR Rembitan)

= (0,19 *115 + 0,35*253 +0,11 *181 + 0,22 * 364+0,12*253)

= 242 mm.

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Table 6. Monthly regional average rainfall

Year	Jan	Feb	Mar	Apr	Mei	Jun	Jul	Ags	Sep	Oct	Nov	Dec
2012	242	156	157	77	91	1	5	3	9	35	160	179
2013	182	176	143	142	119	46	6	1	1	72	100	377
2014	350	156	111	96	34	0	17	3	4	1	93	194
2015	151	122	218	149	60	2	1	1	1	0	62	215
2016	209	228	131	73	22	78	21	32	111	108	190	258
2017	230	326	130	108	6	53	31	5	6	80	287	336
2018	320	194	170	52	14	17	8	14	16	13	168	159
2019	259	266	184	134	16	24	9	9	17	39	138	172
2020	136	208	233	155	91	14	7	13	19	96	175	215
2021	372	415	168	104	14	41	2	16	51	104	305	263
2022	214	212	156	108	66	59	21	20	73	255	153	298
Everage	242	224	164	109	49	30	12	11	28	73	166	242
R	**169**	**151**	**99**	**57**	**19**	**10**	**3**	**2**	**9**	**33**	**101**	**169**

3.3.2. Rain Erosivity Analysis (R)

Calculation of the rain erosivity factor as shown in the analysis equation above requires monthly rainfall data. Monthly average rainfall data is obtained from the average data results. The calculation of the erosivity of rain in January is given here.

Rain Erosivity (R) in January = 2.21*(Rain)m1.36

= 2,21*(242/10)1,36

= 168,7 cm/ha

For analysis of subsequent years, it is calculated in the table below

Table 7.

Average value of rain erosivity

Year	Jan	Feb	Mar	Apr	Mei	Jun	Jul	Ags	Sept	Oct	Nov	Dec
R	168,7	151,2	99,0	56,9	18,9	10,0	2,7	2,4	9,0	33,0	101,2	168,7

Total erosivity is obtained from the sum of the average monthly erosivity in a year. Total erosivity in the Pengga Dam Catchment Area.

= 168,7+151,2+99,0+56,9+18,9+10,0+2,7+2,4+9,0+33,0+101,2+168,7

= 822 cm/ha/tahun.

3.3.3. Erosion Analysis with USLE

Erosion analysis using the USLE method on Brown Mediterranean & Reddish Brown Mediterranean Complex soil types (K = 0.075), with paddy field land use (C = 0.01) and on a flat slope of 0 – 8% (Ls = 0.4).

E = R x K x LS x C x P

Here, the researcher does not calculate Conservation Actions (P), so the equation formula becomes.

E = R x K x LS x C

= 822 x 0,075 x 0,4 x 0,01

= 0,2466 tons/Ha/year

The erosivity value for the Brown Mediterranean & Brown Mediterranean Complex soil types, with paddy field land use and on a flat slope, is 0.2466 tons/ha/year.

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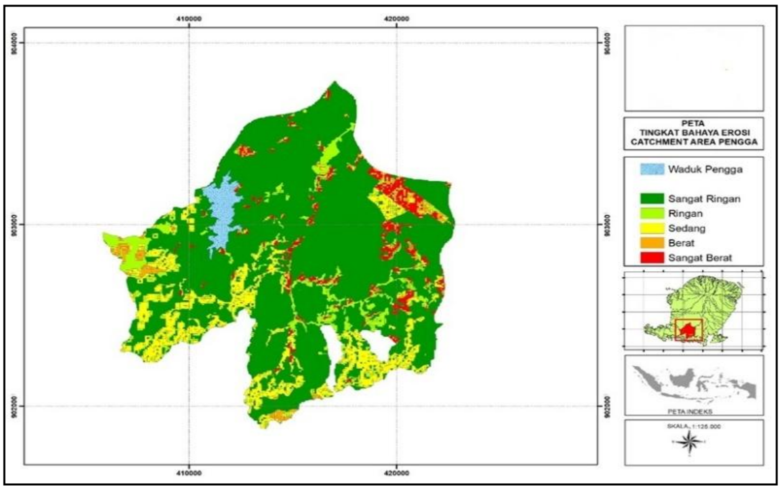

Figure 8. Erosion danger level in the Pengga Reservoir Catchment Area

Table 8. Erosion hazard level in Pengga Reservoir Catchment Area

Erosion Hazard Level	Erosion (Ton/Ha/Year)	Wide (Km2)	Percentage (%)
Very Light	18.120,28	124,37	70,37
Light	29.187,33	16,88	9,55
Medium	70.666,16	23,36	13,22
Serious	188.664,78	4,97	2,81
very serious	98.566,10	7,16	4,05
Jumlah	**405.205,65**	**176,75**	**100**

The calculation results in the erosion hazard level table are from the erosion classification in the Analysis in the ArcGIS application by grouping according to the existing erosion hazard level, such as the erosion hazard level is very light and then accumulated so that annual erosion is obtained at 18,120.28 Tonss/Ha/Year with an area area 124.37 Km2.

3.3.4. Sediment Analysis

Next, based on the results of previous land erosion analysis, calculations were carried out to calculate the transport of sediment entering the river. The sediment supply coefficient (SDR) value is the ratio of the amount of sediment that is carried by the river flow or deposited in the reservoir to the amount of soil that is eroded in the river basin or reservoir catchment area.

SDR = Y/ Ea
Dengan :
SDR = Sediment Delivery Ratio
Y = sediment analysis results (tons/ha/year)
Ea = The amount of soil eroded by erosion in a unit area per unit of time (tons/ha/year)

The sedimentation value will then be calculated based on the land erosion value obtained from the USLE method calculation. First, it is necessary to calculate the sediment conductivity ratio (SDR). This will be done using the Vannoni equation method (1975) to calculate the SDR.

SDR = 0,42 × A^-0,125
CA = 177,68 km² = 17.768 Ha
SDR = $0{,}421 \times A^{-0.125}$

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$= 0{,}421 \times 17.768^{-0.125}$
$= 0{,}1238 = 12{,}38\ \%$

According to DPMA 1984, sediment yield = Y = E*SDR, the sediment value is calculated after obtaining the SDR value. The sediment value obtained is divided by the volume weight value of the sediment. Data from research conducted by showed that the sediment volume weight was 1.67 tonss/m3, so for calculations it was assumed that the sediment volume weight in each watershed was 1.67 tonss/m3. The following is a calculation of the sediment value in the Pengga Reservoir Catchment Area.

$Y = E \times SDR$
$Y = 405.205 \times 0{,}1238$
$= 50.164{,}34$ tons/year

$$Y = \frac{50.164{,}34}{1{,}670} = 30.038{,}52\ m^3/year$$

3.4. Principal Results

The analysis was conducted in the Pengga Reservoir Catchment Area, which is one of the four major dam systems in the Lombok River Region. This catchment spans approximately 177.68 km². Topographically, the area is dominated by very steep slopes, with gradients exceeding 40% covering about 43% of the total catchment. Such geomorphological characteristics significantly influence the region's vulnerability to erosion.

In terms of land use, irrigated rice fields occupy the largest portion of the catchment, accounting for 105.08 km² or 59.14% of the total area. Mixed dryland agriculture—including water bodies, shrubs, forests, agricultural lands, and settlements—covers approximately 43.89 km² (24.70%). Regarding soil characteristics, the dominant types are classified as K.Med.Cok. and Med. Cok. Kmrhn, which together comprise 54.41% of the catchment area, contributing to the overall soil erodibility.

Rainfall erosivity (R) was calculated at 822 cm/ha/year, derived from data collected at five rainfall stations and processed using the Thiessen polygon method to determine regional weighting. Using the Universal Soil Loss Equation (USLE) model integrated with ArcGIS, the estimated total soil erosion in the Pengga Catchment is approximately 405,204.65 tons/ha/year.

Spatial analysis of erosion hazard levels reveals significant variation across the catchment. The upstream and downstream zones are predominantly characterized by very light to light erosion, whereas the central area shows a higher concentration of moderate to very severe erosion categories. The classification breakdown is as follows:

Very Light Erosion: 124.37 km² (70.37%) — 18,120.28 tons/ha/year

Light Erosion: 16.88 km² (9.55%) — 29,187.33 tons/ha/year

Moderate Erosion: 23.36 km² (13.22%) — 70,666.16 tons/ha/year

Severe Erosion: 4.97 km² (2.81%) — 188,664.78 tons/ha/year

Very Severe Erosion: 7.16 km² (4.05%) — 98,566.10 tons/ha/year

The total potential sediment yield, calculated using a Sediment Delivery Ratio (SDR) of 0.1238, is estimated at 30,038.52 m³/year.

When compared to similar studies, such as those conducted by Ramadhani et al. (2019) and Hariyanto et al. (2019), the erosion rate in the Pengga Catchment is significantly higher. For example, Ramadhani et al. reported erosion rates ranging between 120,000 and 260,000 tons/ha/year in the volcanic highlands of Banyuwangi. In contrast, our study recorded an erosion rate of over 400,000 tons/ha/year. This indicates that the Pengga Catchment Area is in critical need of targeted soil and water conservation measures, particularly in areas with intensive land use and steep slopes. Our findings also reinforce the concerns highlighted by Salehudin et al. (2015), who emphasized the Pengga Reservoir's vulnerability to sedimentation. However, the present study provides more detailed spatial insights by leveraging updated geospatial datasets and advanced GIS-based analytical tools.

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4. CONCLUSIONS

Based on the results of the analysis of the erosion hazard level using the Universal Soil Loss Equation (USLE) method, the following conclusions can be drawn:

1. The total erosion hazard rate in the Pengga Dam Catchment Area is 405,205 tons/Ha/Year.

2. The level of danger of erosion in the Pengga Reservoir Catchment Area is:

– 70.37% of the Catchment Area (124.37 km2) experienced erosion of 18,120.28 tons/Ha/Year, with the classification of very light erosion hazard level

– 9.55% of the Catchment Area (16.88 km2) experienced erosion of 29,187.33 tons/Ha/Year with a classification of light erosion hazard level.

13.22% of the Catchment Area (23.36 km2) experienced erosion of 70,666.16 tons/Ha/Year with a classification of moderate erosion hazard level.

– 2.81% of the Catchment Area (4.97 km2) experienced erosion of 188,664.78 tons/Ha/Year with a classification of severe erosion hazard level.

– 4.05% of the Catchment Area (7.16 km2) experienced erosion of 98,566.10 tons/Ha/Year; the erosion hazard level was very heavy, amounting to 405,204.65 tons/Ha/Year.

3. The volume of sediment is 30,038.52 m3/year. This is obtained by finding the SDR value so that the SDR value is 0.1238 or 12.38%. Then, to find the erosion value, use the equation, Y = E x SDR, so that we get the sediment volume in the Pengga Reservoir Catchment Area is 30,038.52 m3/year.

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