

PATTERNS FOR HANDLING EROSION HAZARDS AND LAND CRITICALITY IN THE BAUMATA WATERSHED IN KUPANG DISTRICT

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ABSTRACT

Baumata watershed is located in Kupang district. The land use conditions are mostly forests, paddy fields, with low root depth and play a major role in the process of causing soil damage. Previous studies often focused on single-method erosion estimation, lacking integration of erosion and land capability analysis through spatial GIS approaches. This research examines the current level of erosion hazard in the existing land use of the Baumata Watershed and its area by considering the Regional Spatial Planning (RTRW) of Kupang Regency and its surroundings in the Baumata Watershed. The method used is the MUSLE method where the method uses an approach from the surface runoff factor. The data processing uses a Geographic Information System (GIS). The erosion rate watershed is 3,402,685 tons/ha/year with a watershed area of 2,439.35 ha. Land rehabilitation and soil conservation (ARLKT) directions that are appropriate for the conditions of the Baumata watershed are 87 annual crop cultivation areas. About 21 % (2,127.42 ha), Seasonal Plant Cultivation Areas 10.67 % (260.38 ha), and Buffer Areas 2.11 % (51.55 ha). The existence of data and information on the magnitude of erosion rates and land criticality in the Baumata watershed in Kupang district can be used to anticipate early landslide disasters in the area.

Keywords: Erosion; Land Criticality; MUSLE; GIS.

1. Introduction

A watershed is a land area that is topographically limited by mountain ridges that collect and store rainwater and then channel it to the sea via the main river. This land area is called a water catchment area (DTA or catchment area) which is an ecosystem whose main elements consist of natural resources (soil, water, and vegetation) and human resources as the utilization of natural resources [1].

The emergence of critical land indicates suboptimal land use, with an imbalance between utilization and conservation efforts. This issue can impact the socio-economic conditions around the watershed [15]. Currently, almost all large rivers in Indonesia have been classified as critical watersheds. Meanwhile, in terms of the erosion rate, it can be stated that the erosion rate in several rivers in Indonesia is very high [2].

Policies related to watershed management should encourage the implementation of land management practices that are conducive to preventing land and water degradation. It must always be realized that the costs incurred for watershed rehabilitation are much more expensive than the costs incurred for efforts to prevent and protect the watershed [16]. Earlier studies often focused solely on erosion estimation using methods such as USLE or MUSLE without integrating land capability analysis and spatial approaches using GIS. However, watersheds like Baumata, which have high land criticality levels, require a more comprehensive approach to address land degradation and environmental disaster threats.

The Baumata Watershed is one of the watersheds in Kupang Regency which contributes large amounts of river water to the downstream part [17] of Kupang City. However, along with the extraordinary increase in forest damage resulting in greater potential for floods and landslides and increasing from year to year, improvements to management aspects regarding the management of the Baumata watershed must be carried out immediately in addition to repairing facilities and infrastructure that have been damaged by the disaster [18].

2. Material and Method

Baumata watershed is a cross-regional watershed, namely it is right on the border between the Kupang City area and Kupang Regency. The Baumata watershed is a cross-regional watershed, namely it is right on the border between the Kupang City area and Kupang Regency. There are 10 (ten) sub-districts/villages included in the Baumata watershed, including: 7 villages in Kupang district, namely Tarus Village, East Penfui Village, Baumata Village, North Baumata Village, West Baumata Village, East Baumata Village, Oeltua Village, and 3 sub-districts in Kupang City, including: Lasiana Village, Penfui Village and Kolhua Village.

2.1 Data and Tools

The data used in this research includes:

- Annual Rainfall Data for the last 10 years.
- Rain Gauge Station Map.
- Noelmina River Area Unit Map
- Watershed map.
- Existing land use map, land slope, land height.
- Land use map.
- Data on geological conditions.
- Map of soil solum depth, soil texture and soil structure.
- Population data.

All data in the form of spatial data (maps) will be digitized to obtain a digital map in CAD format with the same scale and coordinates. Then exported as vector data for the ArcView GIS program. The equipment used includes software from geographic information systems (GIS), namely Autodesk Map 2004, ArcView GIS 3.3, and Surfer Ver.8.0 as well as Ms Office for data analysis and a set of computers.

2.2 Methodology

2.2.1 Average Rainfall

The average rainfall [12] data analyzed is in a certain period. Determination of the value of rainfall is taken according to the rain observation station (SPH) in the region [13]. The rain observation stations taken according to (planning) have at least 3 comparison stations for data consistency and homogeneity. This method is used to calculate the average rainfall by taking into account the area of influence of each station.

There are 3 types of methods used to determine the average rainfall height over a certain area from rainfall figures at several measuring or recording post points, namely [3][20] the arithmetic Method, the Polygon Thiessen method, and the Isohyet method [14][19]. By regional conditions and the distribution of rain observation stations [21]. The Polygon Thiessen method of average rainfall is used. The formula for determining average rainfall is the Thiessen Polygon Method as follows:

$$P = \frac{A_1 P_1 + A_2 P_2 + \dots + A_n P_n}{A_1 + A_2 + \dots + A_n} \quad (1)$$

Where P is the regional average rainfall (mm). P₁, P₂, ..., P_n is the rainfall recorded at rain gauge posts 1, 2, ..., n. A₁, A₂, ..., A_n is the area of polygons 1, 2, ..., n. n is the number of rain gauge posts (Model Equation 1).

2.2.2 Design Rainfall Analysis

In planning this design rain, the Log Pearson III method was chosen [4] with the consideration that this method is more flexible and can be used for all data distributions. The stages for calculating maximum design rainfall using the Log Pearson III method. Calculate the logarithm of design rainfall with a certain return period

$$\text{Log}X = \overline{\text{Log}X} + G.Sd \quad (2)$$

Where:

$\overline{\text{Log}x}$ = Logarithm of design rainfall.

$\overline{\text{Log}x}$ = Logarithm of average rainfall.

G = Constant (from table)

Sd = Standard deviation.

2.2.3 Probability Distribution Testing

The probability distribution test is carried out to determine which probability distribution equation can be used to show the statistical distribution of the sample data being analyzed. Testing the suitability of rain data can be determined using Chi-square and Kolmogorov Smirnov.

2.2.4 Rain Intensity

Rain intensity analysis is determined by three methods, namely: Bell, Van Breen, and Hasper Weduwen.

2.2.5 Land Use

This understanding shows that land is a landscape where all living things live and survive by making use of it.

2.2.6 Flow Coefficient

The value of the flow coefficient is used to determine the design debris in the testing area. For determining the flow coefficient with the following equation (3):

$$C_m = \frac{C_1.A_1 + C_2.A_2 + \dots + C_n.A_n}{A_1 + A_2 + \dots + A_n} \quad (3)$$

$$C_m = \frac{\sum_{i=1}^n C_i.A_i}{\sum_{i=1}^n A_i}$$

Where:

C_m = Average drainage coefficient.

$C_1, C_2, \dots, C_n$ = Flow coefficient according to surface conditions.

$A_1, A_2, \dots, A_n$ = Area of drainage area adjusted to surface conditions

2.2.7 Planning Debt

In drainage planning, in general, the discharge calculation used is the rational method. The calculation of the design discharge is used to determine the value of the peak flood plan discharge in an area. The formula for calculating the planned flood discharge using the rational method is as follows.

$$Q = 0,00278 .Cs. C.I.A \quad (4)$$

Where:

Q = Planning debt (m³ /sec)

C = Surface flow coefficient

I = Rainfall intensity (mm/hour)

A = Watershed area (ha)

2.2.8. Estimation of Erosion Rates Based on the MUSLE / MPUKT Method

To estimate the amount of erosion in this study, the MUSLE (Modified Universal Soil Loss Equation) or MPUKT (Midified Universal Soil Loss Equation) method was used. This method is a modification of USLE (Universal Soil Loss Equation) or PUKT (Universal Soil Loss Equation).

The equation of MUSLE [5] as below:

$$A = R_w \times K \times L \times S \times C \times P \quad (5)$$

Where:

- A = Amount of soil loss per unit area of land (tons/ha)
- R_w = Surface runoff erosivity index (mm).
- K = Soil erodibility index.
- L = Slope length factor.
- S = Slope factor.
- C = Plant factor/ground cover vegetation factor.
- P = Plant management action factor.

2.2.9 Estimated Land Criticality

- a. Permissible Erosion (E_{dp})
Calculate the allowable erosion value based on the equivalent depth of soil and the expected sustainability of soil resources (age) using the equation:

$$E_{dp} = (\text{Equivalent soil depth} / \text{Soil sustainability})$$

- b. Erosion Level (TBE)
The erosion level (TBE) is obtained by comparing the level of erosion on a land unit with the effective depth. The classification of erosion hazard levels can be seen in the following table 1.

Table 1. Classification of Erosion Hazard Levels

Erosion Soil Solum (cm)	Erosion Class (ton/ha/year)				
	I (<15)	II (15-60)	III (60-180)	IV (180-480)	V (>480)
A. High (> 90)	SR	R	S	B	SB
B. currently (60-90)	R	S	B	SB	SB
C. shallow (30-60)	S	B	SB	SB	SB
D. very shallow (<30)	B	SB	SB	SB	SB

Source: Utomo, WH, 1994

2.2.10 Land Capability Classification

The work carried out to assess the factors that determine the usability of land, then grouping or categorizing land uses according to their characteristics is called 'Land Capability Classification'.

2.2.11 Soil Rehabilitation and Conservation Patterns

The RLKT pattern land conservation program (Land Rehabilitation and Soil Conservation) is a long-term plan (25 years) that contains general directions regarding:

1. Use/utilize land according to its capabilities.
2. RLKT methods or techniques for each land use area
3. The priority order for handling watersheds or sub-watersheds is according to their level of criticality.

RLKT pattern conservation program format which is implemented at the watershed or sub-watershed scale in Java and consists of land use directions, RLKT directions, and the order of watershed criticality levels.

2.2.12 Geographic Information Systems (GIS)

GIS is a computer system that has the following four capabilities in handling geographically referenced data: [a] Input, [b] Data management (data storage and retrieval), [c] Data analysis and

manipulation, [d] Output. In GIS, data is stored in digital format, large amounts of data can be stored and retrieved quickly and efficiently. Another advantage of GIS is the ability to manipulate data and analyze spatial data by linking data or attribute information to unite different types of data in a single analysis [6].

3. Result and Discussion

3.1 Delineation of the Baumata Basin

Before hydrological analysis is carried out, this study first determines the catchment area or watershed in the river and tributaries of the Baumata River. The process of determining the Baumata watershed requires Digital Elevation Model (DEM) data and river network maps which can be downloaded on the official website <https://www.tanahair.indonesia.go.id/portal-web> belonging to the Geospatial Information Agency (BIG). The total area of the Baumata watershed resulting from watershed delineation using ArcSWAT is 2,439.3505 Ha.

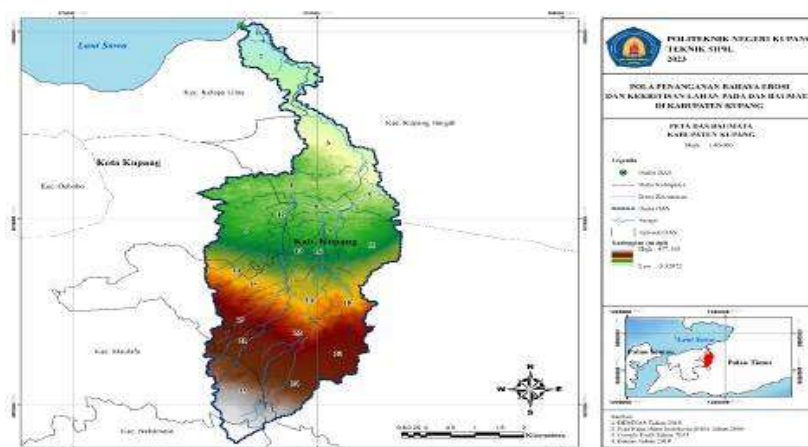


Figure 1. Baumata Watershed
Source: Arc GIS 10.8 Analysis, 2023

3.2 Average Rainfall Analysis

Based on data on the distribution of rain stations sourced from BWS Nusa Tenggara II and BMKG Lasiana Kupang, there are three rain stations closest to the Baumata River, namely the BMKG Lasiana Rain Post, the BMKG El Tari Rain Post and the Tarus Rain Post. Hydrological analysis requires regional average daily rainfall data with a minimum period of ten years. Analysis of regional average rainfall in this study uses the Thiessen Polygon method considering the condition of the study area which has an uneven distribution of rain posts.

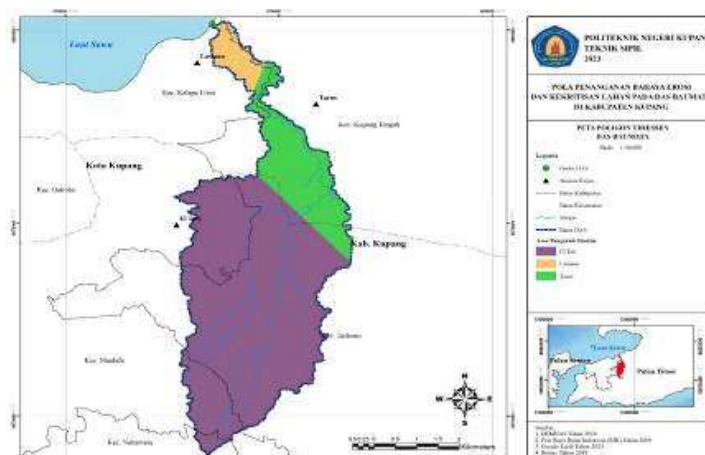


Figure 2. Thiessen Polygon of the Baumata Watershed
Source: Analysis Arc GIS 10.8, 2023

From the analysis results, El Tari Rain Station has the largest area of influence, namely 1,868,797 Ha (76.61%), after that Tarus Station 456,096 Ha (18.70%), and finally Lasiana Station 11,4457 Ha (4, 69 %). The results of the regional average maximum daily rainfall analysis are presented in Table 2.

Table 2. Average Rainfall

No.	Year	Thissen Coef			Average Rainfall (mm)
		St Lasiana	St El Tari	St Tarus	
		0.047	0.766	0.187	
1	2012	1210.70	1191.00	1166.50	1187.342
2	2013	1916.80	2128.00	2264.60	2143.629
3	2014	1393.00	1579.10	1598.50	1573.994
4	2015	1355.10	1290.21	1585.50	1348.465
5	2016	865.90	1106.30	964.00	1068.413
6	2017	1428.80	1606.70	1631.50	1602.988
7	2018	1331.70	1433.80	1318.00	1407.356
8	2019	957.60	1035.00	1060.50	1036.135
9	2020	1237.40	1224.70	1283.50	1236.289
10	2021	2050.20	2680.80	2172.50	2556.170

Source: Analysis, 2023

3.3 Design Rainfall

Design rainfall is the largest rainfall that may occur in an area with a certain opportunity. In this study, the design rainfall analysis method used is the Log Pearson Type III method.

Table 3. Design Rainfall Analysis Method Used is the Log Pearson Type III Method

No	Tr (year)	R average (Log)	Sd (log)	Skew. Coef (Cs)	Prob. (%)	K	Rainfaal Design	
							Log	mm
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
1	1.01	2.07	0.20	0.82	99	-1.721	1.71	51.86
2	2	2.07	0.20	0.82	50	-0.135	2.04	109.18
3	5	2.07	0.20	0.82	20	0.778	2.22	167.59
4	10	2.07	0.20	0.82	10	1.337	2.34	217.82
5	25	2.07	0.20	0.82	4	1.997	2.47	297.04
6	50	2.07	0.20	0.82	2	2.461	2.57	369.23
7	100	2.07	0.20	0.82	1	2.902	2.66	454.29
8	1000	2.07	0.20	0.82	0.1	4.266	2.94	861.57

Source: Analysis, 2023

3.4 Design Discharge Calculation

Calculated rainwater runoff discharge, several things must be used, namely the land use of the research area, so that we can determine the flow coefficient in the research area. Determining the discharge of rainwater runoff using the rational method;

$Q_{ah} = 0.278 \times C \times I \times A$. The work steps are as follows.

Watershed Area Calculation (A)

Calculation of the area of the drainage area uses the Arcgis 10.3 application following the calculation steps:

1. Collect data that will be used in making the map that will be used, namely administrative data, and road network data, this data is in the form of a shp file.
2. Enter data into the ArcGis 10.3 application
 - a. Input the shp file used
 - b. Input the layer into ArcGis 10.3 so that the lines and flow boundaries appear

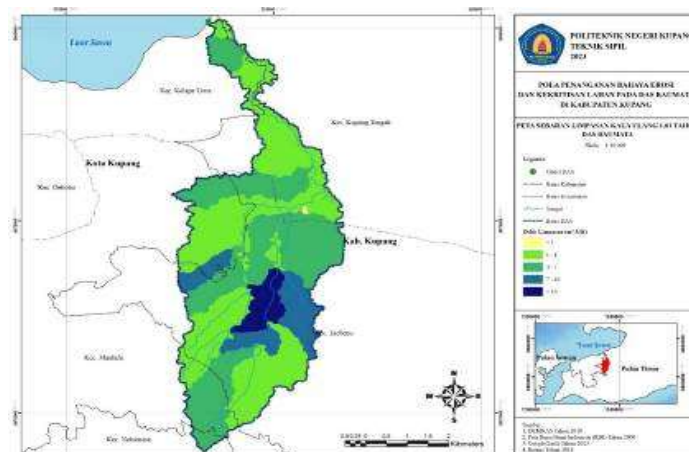


Figure 4. Distribution of Surface Runoff Discharge at the 1.01 Return Period Of the Baumata Watershed

Source: Arc GIS 10.8 Analysis, 2023

3.4 Erosion Rate Analysis MUSLE Method

a. Surface Runoff Erosivity Index (Rw)

Estimate the sediment results from each surface runoff event by replacing the rain erosivity index with surface runoff erosivity (Rw) with the formula:

$$Rw = 9.05x(Vo. Qp)^{0.56}$$

In this study, the Rw value is calculated per Baumata sub-watershed. Thus, the monthly average rainfall (R) and rainy days (Rn) are the same for all 25 sub-watersheds, which is the regional average of 3 (three) rain stations.

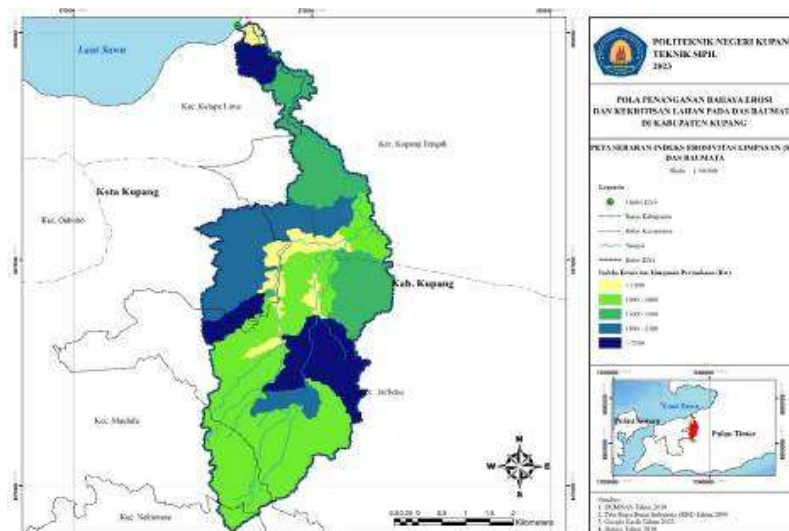


Figure 5. Distribution of Surface Runoff Erosivity Index (Rw)

Source: Analysis Arc GIS 10.8, 2023

b. Soil Erodibility Index Analysis (K)

Soil that has a high erodibility (K) value with the same rainfall will erode more easily than soil with a low erodibility (K) level. K values are estimated by looking at the map and referring to the tables listed in the reference. The K factor data is entered into the attribute data on the soil type map.

Table 6. Crop Management Factors and Soil Conservation Action Factors (CP)

No	Land Use	CP Factor	Area (m ²)	Area (Ha)	Prosentase (%)
1	Lake/Situ	0.000	44739.981	4.474	0.18
2	Building	1.000	13978.813	1.398	0.06
3	grassland	0.010	2666467.660	266.647	10.93
4	Domestic Air Port	0.800	253948.991	25.395	1.04
5	Plantation/Garden	0.020	74601.967	7.460	0.31
6	Settlements and Places of Activity	0.200	3563505.714	356.351	14.61
7	Field	0.200	146714.274	14.671	0.60
8	Rain-Fed Rice Fieldsn	0.200	501206.064	50.121	2.05
9	Shrubs	0.010	12292031.883	1229.203	50.39
10	Open Land	1.000	8126.482	0.813	0.03
11	Moorland/Field	0.430	4828183.694	482.818	19.79
Total			24393505.522	2439.351	100.00

Source: Analysis Return, 2023

e. Erosion Rate Analysis

The overlay results of the prediction of erosion rates in the Baumata watershed using the MUSLE method can be seen in Figure 8 and a summary of the calculations can be seen in Table 7.

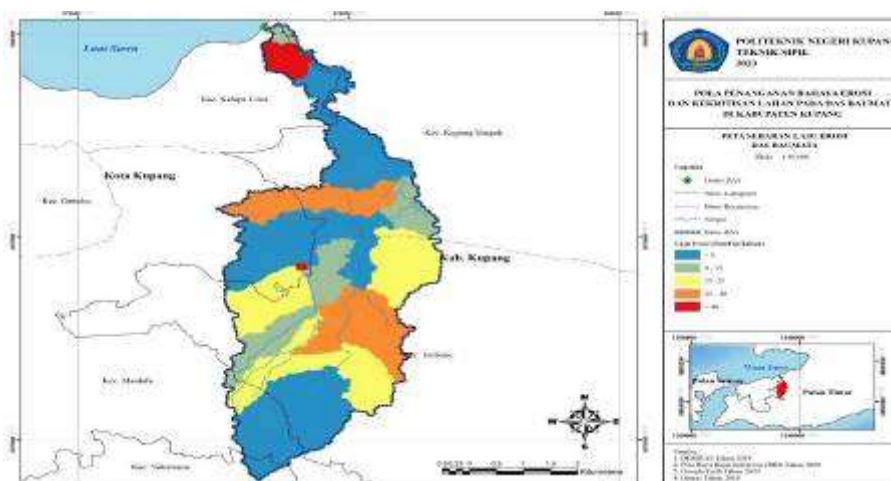


Figure 7. Distribution of Land Erosion Rates in the Baumata Watershed

Source: Arc GIS 10.8 Analysis, 2023

In Figure 6, the slope classification distribution for the Baumata Watershed highlights that most areas have steep slopes, leading to higher potential erosion rates. This finding correlates with the results shown in Figure 7, where the land erosion rate is predominantly in the 'Heavy' category for slope lengths exceeding critical thresholds.

3.5 Erosion Hazard Level (TBE)

The soil solum in the Baumata watershed is predominantly less than 30 cm. This is the reason why most of the TBE in the Baumata DAS is of heavy value. In Table 7, the erosion hazard levels (TBE) reveal that 49.80% of the watershed area falls under 'Light' erosion, while 25.52% is categorized as 'Heavy.' These findings emphasize the need for targeted conservation measures, particularly in areas marked as 'Heavy' and 'Very Heavy,' as shown in the accompanying spatial map (Figure 8).

Table 7. Percentage of TBE in Baumata Watershed

No	Erosion Hazard Level (TBE)	Area (m ²)	Area (Ha)	Percentage (%)
1	Very Light	413796	41.38	1.70
2	Light	12148309	1214.83	49.80
3	Medium	3192935	319.29	13.09
4	Heavy	6226273	622.63	25.52
5	Very Heavy	2413479	241.35	9.89
Total		24394792	2439.48	100.00

Source: Analysis, 2023

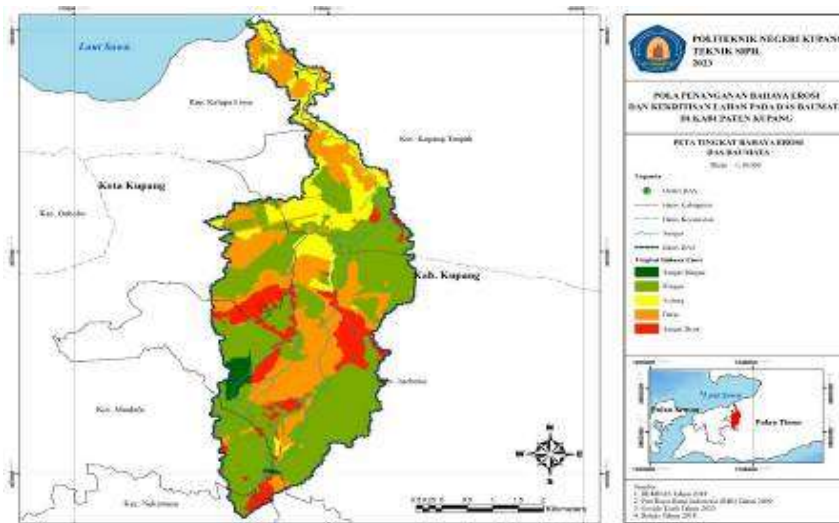


Figure 8. TBE of Baumata Watershed

Source: Arc GIS 10.8 Analysis, 2023

3.6 Land Capability Classification

Land capability classification aims to determine the land's capability based on soil properties and limiting factors that influence its use for certain uses (Table 8 and Figure 9).

Table 8. Percentage of Land Capability Classes in the Baumata Watershed

No	Land Capability Classes	Area (m ²)	Area (Ha)	Percentage (%)
1	IIIe	478.18	0.05	0.00
2	IIIg	2354391.20	235.44	9.65
3	IVe	9418232.65	941.82	38.61
4	IVs	10207051.79	1020.71	41.84
5	VIIe	2413351.69	241.34	9.89
Total		24393505.52	2439.35	100.00

Source: Analysis Arc GIS 10.8, 2023

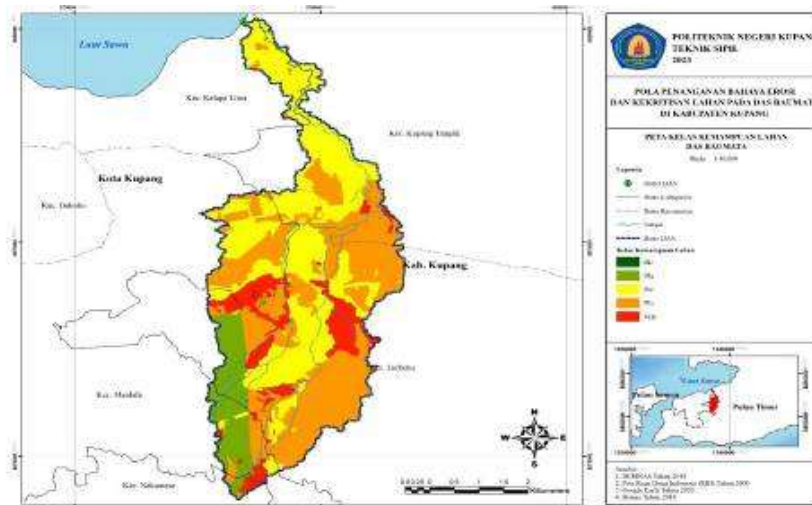


Figure 9. Land Capability Classes of the Baumata Watershed
Source: Arc GIS 10.8 Analysis, 2023

3.7 Land Use Directions

Referring to the regional development plan of Kupang City and Kupang Regency and based on physical and environmental developments in the Baumata watershed area, directions for utilizing the Baumata watershed can be determined. The coverage of areas designated as Protected Areas, Buffer Areas, Annual Crop Cultivation Areas, and Annual Crop Cultivation Areas/Settlements can be seen in the following Figure 10.

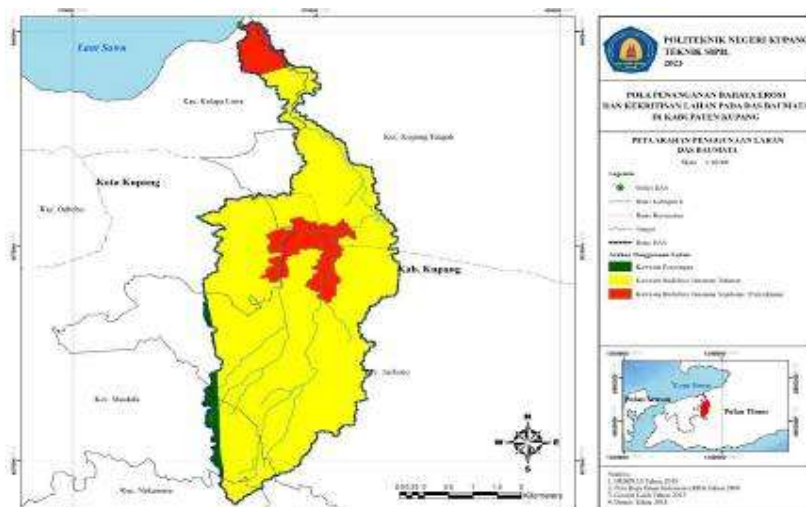


Figure 10. Land Use Directions for the Baumata Watershed
Source: Arc GIS 10.8 Analysis, 2023

Table 9. Percentage of Baumata Watershed Land Use Directions

No	Land Use Directions	Area (m ²)	Area (Ha)	Percentage (%)
1	Buffer Area	515510	51.55	2.11
2	Annual Crop Cultivation Area	21274171	2127.42	87.21
3	Seasonal Crop Cultivation Areas / Settlements	2603825	260.38	10.67
Total		24393506	2439.35	100.00

Source: ArcView GIS 3.3 Spatial Analysis, 2023

3.8 Conservation of the Baumata Watershed

a. Vegetative Conservation

The results of the land capability class analysis in the Baumata watershed are dominated by Class IVs, then Class IVe, VIIe, IIlg and IIIe. For this reason, efforts to vegetatively conserve the Baumata watershed can be carried out by adjusting land use to the land capability class. The following (Table 10) are recommended Baumata watershed conservation efforts according to land capability classes.

Table 10. Recommendations for Baumata Watershed Conservation Efforts Based on Land Capability Classes

No.	Land Capability Class	Area (Ha)	Percentage (%)	Soil Properties in Each Class	Recommendations for Conservation Efforts	Intensity/ Kind Land Use
1	IIIe Class III	0,05	0,00	Very rough, covered in loose rock	Leave it as a protected forest, nature reserve, etc.	Protected forest or nature reserve
2	IIlg Class III	235,44	9,65	Very rough, covered in loose rock	Leave it as a protected forest, nature reserve, etc.	Protected forest or nature reserve
3	Ive Class IV	941,82	38,61	Very rough, covered in loose rock	Leave it as a protected forest, nature reserve, etc.	Protected forest or nature reserve
4	Ivs Class IV	1.020,71	41,84	Very rough, covered in loose rock	Leave it as a protected forest, nature reserve, etc.	Protected forest or nature reserve
5	VIIe Class VII	241,34	9,89	Very rough, covered in loose rock	Leave it as a protected forest, nature reserve, etc.	Protected forest or nature reserve
	Total	2.439,36	100,00			

Source: Arc GIS 10.8 Analysis, 2023

b. Mechanical Conservation

Mechanical land conservation efforts aim to reduce the rate of surface runoff so that its destructive power is reduced and to collect surface runoff and then channel it through buildings or channels that have been prepared.

Table 11. Recommended Locations for Control Dams and Oeltua Reservoir Locations

No.	Building	Coordinate UTM Zone 51S		Village	District	Regency/City
		X	Y			
1	Check dam recommendations 1	573759.789	8869792.174	Kolhua	Maulafa	Kota Kupang
2	Oeltua Reservoir	573774.728	8870102.647	Kolhua	Maulafa	Kota Kupang
3	Check dam recommendations 2	575079.962	8874063.775	Baumata Utara	Taebenu	Kab. Kupang
4	Check dam recommendations 3	574235.578	8874664.759	Penfui	Maulafa	Kota Kupang

Source: Analysis, 2023

4. Conclusion

The Baumata watershed is currently experiencing a high erosion rate of 3,402,685 tons/ha/year over an area of 2,439.35 ha. The erosion hazard levels and land criticality classifications show that 49.80% (1,214.77 ha) of the land has light erosion hazards, while 25.52% (622.59 ha) faces heavy hazards. Medium hazard areas cover 13.09% (319.28 ha), very heavy hazards account for 9.89% (241.34 ha), and very light hazards make up 1.70% (41.38 ha). Regarding land capability, the

watershed predominantly falls under Class IVs (41.84% or 1,020.71 ha) and Class IVe (38.61% or 941.82 ha), with smaller areas in Class VIIe (9.89% or 241.34 ha) and Class IIIe (0.05 ha).

To address these challenges, recommended land rehabilitation and soil conservation measures (ARLKT) include allocating 87.21% (2,127.42 ha) of the watershed for annual crop cultivation, 10.67% (260.38 ha) for seasonal crop cultivation, and 2.11% (51.55 ha) for buffer zones. Mechanical interventions, such as constructing control dams or check dams, are suggested for areas with heavy and very heavy erosion hazards, with three sites identified as suitable locations. Alongside these efforts, vegetative conservation is also essential. Future research could focus on integrating remote sensing technologies with GIS to improve erosion rate assessments and land capability analysis. Additionally, studies on the long-term effectiveness of conservation measures could provide valuable insights into reducing erosion rates and enhancing land productivity.

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