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| RESEARCH ARTICLE

An Analysis of Erosion Hazard Levels Using the USLE Method in the Mandalika Special Economic Zone

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| ABSTRACT
The Mandalika Special Economic Zone (SEZ) is located in Pujut District, Central Lombok Regency, West Nusa Tenggara Province, which has been designated as a tourism area. Land use changes due to tourism development have caused increased erosion, sedimentation, and flood discharge. This study aims to estimate the extent of erosion and sedimentation in the watersheds located in the Mandalika SEZ, namely the Tebelo, Ngolang, and Balak watersheds. Erosion calculations were performed using the Universal Soil Loss Equation (USLE) method, and sedimentation was calculated using the Sediment Delivery Ratio (SDR) following the Menhut (2005) method. The results show erosion rates of 101,189.01 tons/year (Tebelo watershed), 79,158.05 tons/year (Ngolang I watershed), 16,387.94 ton/year (Ngolang II watershed), 123,557.66 tons/year (Balak I watershed), and 2,701.15 ton/year (Balak II watershed). The level of erosion hazard in all watersheds varies from very light to very severe. The sedimentation values produced reach 8,666.24 m^3/year (Tebelo watershed), 7,019.14 m^3/year (Ngolang I watershed), 1,986.82 m^3/year (Ngolang II watershed), 9,990.7 m^3/year (Balak I watershed), and 447.25 m^3/year (Balak II watershed).

| KEYWORDS
Erosion, Erosion Hazard Level, Sedimentation, USLE, SDR, Tebelo Watershed, Ngolang Watershed, and Balak Watershed

| ARTICLE INFORMATION
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1. Introduction
According to Ministry of Public Works No. 589/KPTS/M/2010, one of the problems in water resource management on the island of Lombok is the degradation of watershed areas, characterized by the conversion of forest and water catchment areas into cultivated land. Land use activities that do not take conservation into account increase erosion, sedimentation, and peak flood discharge.

The Indonesian government is developing the Mandalika Special Economic Zone (SEZ) as one of its top priority destinations to drive tourism-based economic growth. The Mandalika SEZ, which was established through PP No. 52 of 2014, is located in Pujut Subdistrict, Central Lombok Regency, and lies downstream of three watersheds: Tebelo, Ngolang, and Balak. These three watersheds have hilly topography and sandy loam soil types with high flow rates during the rainy season, making them prone to erosion.

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Development has caused significant changes in land cover. Open areas and water catchment areas have been converted into built-up areas and agricultural land in hilly areas, accelerating soil degradation and reducing the land's ability to absorb water. The impact can be seen in the accumulation of sediment at the bottom of rivers during the dry season, which causes siltation and increases the risk of flooding during the rainy season (Yudane, 2022). A concrete example of this is the mudslide that occurred on January 30, 2021, in the villages of Kuta and Mertak, Mandalika SEZ, which flooded 16 hamlets and 350 houses (TalikaNews, 2021).

Given the strategic role of the Mandalika Special Economic Zone and its impact on the regional economy, it is necessary to conduct a study on erosion, erosion hazard level (EHL), and sedimentation in the Tebelo, Ngolang, and Balak watersheds as key factors triggering flooding in the area. This study focuses on analyzing erosion hazard levels using the USLE method to support sustainable watershed management.

2. Method

The research location is in the Mandalika SEZ watershed, specifically in the Tebelo, Ngolang, and Balak watersheds, Pujut District, Central Lombok Regency. The areas of the Tebelo, Ngolang, and Balak watersheds are 15.61 km^2, 14.44 km^2, and 25.03 km^2, respectively. The research location can be seen in Figure 1.

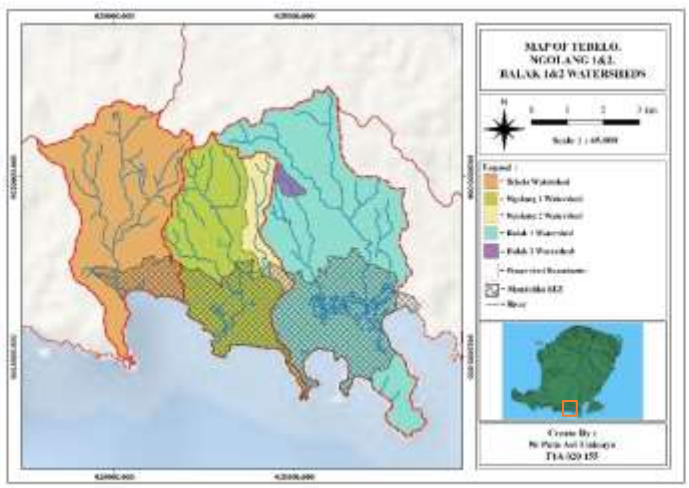

Figure 1. Research Location Map

The empirical model used to predict the amount of soil erosion in this study is the USLE (Universal Soil Loss Equation) method based on the relationship between erosion determinants and the amount of erosion developed by Wischmer and Smith (1987). The USLE equation is as follows:

$$\mathbf{E_A = R \times K \times LS \times C \times P} \quad \mathbf{(1)}$$

Where E_A is the amount of soil eroded (tons/ha/year), R is the rainfall erosivity value (cm), K is the soil erodibility factor, LS is the slope length and steepness factor, C is the soil cover factor by plants, and P is the soil conservation practice factor.

Rainfall erosivity factor (R) is the ability of rainfall to release and transport soil particles due to the impact of raindrops and surface runoff. Rainfall erosivity values can be calculated using the equation proposed by Lenvain (DHV, 1989), as follows:

$$\mathbf{R = 2.21 \times Pm^{1.36}} \quad \mathbf{(2)}$$

Where R is rainfall erosivity and Pm is monthly rainfall (cm)

Soil erodibility factor (K) is a factor that determines how easily soil is eroded. This factor indicates the resistance of soil particles to weathering and transport by the kinetic energy of rain (Asdak, 2007). Soils with large aggregates tend to have high resistance because they require greater kinetic energy to be transported, while fine aggregates are more resistant due to their high cohesion. Conversely, silt and fine sand particles have low resistance, resulting in high erodibility values. The K factor values for the study location are shown in Table 1.

Table 1. K Factor Values for Several Soils in Indonesia (Puslitbang Pengairan Bogor, 1985)

Soil Type	K Value
Brownish-Gray Alluvial	0.193
Mediterranean brown and reddish-brown complex	0.323
Mediterranean brown grumusol gray regosol brown and lithosol complex	0.188

Slope length (L) and slope steepness (S) factors, which are combined into the LS factor. The LS value increases with increasing slope length and steepness, thereby increasing the potential for erosion. The LS value is determined based on slope class (Kironoto et al., 2020).

Table 2. Slope Class Assessment and LS factor (Kironoto et al., 2020)

Slope Class	Slope Gradient	Description	LS Value
I	0-8	Flat	0.40
II	8-15	Gentle	1.40
III	15-25	Slightly steep	3.1
IV	25-40	Steep	6.80
V	> 40%	Very steep	9.5

Factor C reflects the influence of land cover on erosion, taking into account the presence of vegetation, litter, and soil surface conditions. Dense vegetation and protected soil surfaces can reduce the impact energy of rainfall and reduce surface runoff, resulting in a smaller C value and reduced erosion. Conversely, open land has a high C value because there is no protection for the soil. Meanwhile, the P value is determined by the type of land management or conservation measures applied. The C factor is determined based on land use patterns, and the P factor value is based on conservation measures tailored to the slope gradient at the study site.

Table 3. C Factor Values (Kodoatie and Sjarief, 2005)

Land Use Type	C Value
Secondary Dry Forest	0.03
Shrub	0.07
Secondary Swamp Forest	0.15
Dryland Agriculture	0.1
Dryland Agriculture Mixed with Shrubs	0.1
Settlements	0.6
Rice Fields	0.1
Fishpond	0.05
Open Land	1
Water	0.05

Table 4. P Factor Values for Various Specific Soil Conservation Measures (Arsyad, 2010)

Specific Soil Conservation Measures	P Value
Bench terraces	
- Good construction	0.04
- Keep construction	0.15
- Poor construction	0.35
- Traditional terrace	0.4

Plant strip:	
- Bahlia grass	0.4
- Clotararia	0.64
- With contour	0.2
Soil preparation and planting along contour lines	
- Slope 0%-8%	0.5
- Slope 8%-20%	0.75
- Slope > 20%	0.9
No erosion control measures	1

The amount of soil loss per land unit obtained from the USLE equation is used as the basis for determining the level of erosion hazard. Furthermore, to determine the distribution of each erosion hazard class, grouping and analysis of the distribution in each land unit is carried out.

Table 5. Erosion Hazard Level (Kironoto et al, 2020)

Erosion Hazard Level	Erosion Rate (tons/ha/year)	Description
I	<15	Very Light
II	15-60	Light
III	60-180	Keep
IV	180-480	Heavy
V	> 480	Very Heavy

Sedimentation is a process of depositing eroded material that is carried or collected in a certain place. In the context of a watershed, only some of the eroded material will be carried into the river, while the rest will settle in certain areas before reaching the main stream. To calculate the amount of sediment from a catchment area or watershed, one method is to calculate the Sediment Delivery Ratio (SDR), which can be calculated using the following equation:

$$Y = E \times SDR \qquad (3)$$

Where Y = sediment yield (tons/year), E = total erosion (tons/year), and SDR = Sediment Delivery Ratio. In this study, the SDR value can be estimated using the Menhut (2005) method, through interpolation of the relationship between watershed area and SDR.

Table 6. Relationship Between Watershed Area and SDR Value

Area		SDR (%)
Km^2	Ha	
0.1	10	53
0.5	50	39
1	100	35
5	500	27
10	1000	24
50	50	15
100	10,000	13
200	20	11
500	50,000	0.85
26,000	2,600,000	0.49

3. Result and Discussion

3.1 Erosion Calculation Using the USLE Method

Erosion values were calculated for three watersheds, namely Tebelo, Ngolang, and Balak. For analysis purposes, the Ngolang and Balak watersheds were divided into two sub-watersheds based on the catchment area of the sediment retention basin resulting from land erosion and the remaining catchment area, so that each was divided into Ngolang 1 and Ngolang 2 (SEZ Mandalika Retention Pond) and Balak 1 and Balak 2 (Bajak Reservoir).

The average rainfall in the region was calculated using the Polygon Thiessen method. From Figure 2, it was found that only one rain station had the most influence on the research location, namely ARR Rembitan, which means that 100% of the rainfall at ARR Rembitan applied to each research location. Rainfall analysis used historical data spanning 34 years (1989-2023), reflecting long-term rainfall variations in the study area.

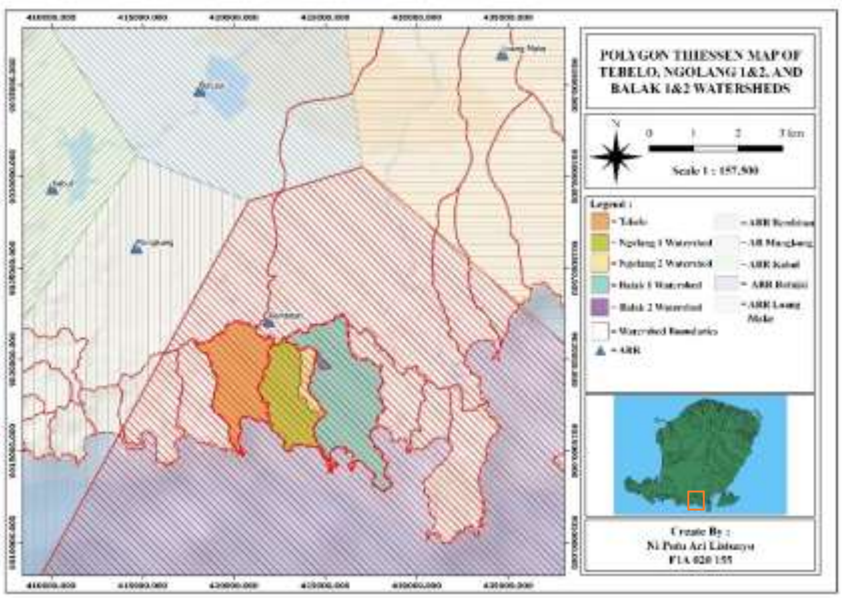

Figure 2. Polygon Thiessen of the Tebelo Watershed, Ngolang 1&2Watershed, and Balak 1&2 Watershed

The RAPS test is used to test the inconsistency between data at the rain gauge station itself by detecting shifts in the mean value. Based on the RAPS test results, the ARR Rembitan rainfall data is declared consistent with the critical value (99% confidence) in the table.

The R factor in the USLE method uses monthly rainfall data calculated based on the percentage of the Polygon Thiessen calculation results. Thus, the average monthly rainfall at each research location was 32.9 cm, and the average rainfall erosivity value over 34 years in the Tebelo, Ngolang 1, Ngolang 2, Balak 1, and Balak 2 watersheds was 969.45 cm/year.

The K factor at each research location is determined based on soil type. It is known that this area consists of three types of soil, namely brown alluvial grumusol with a K value of 0.193, brown mediterranean grumusol gray regosol brown and lithosol with a K value of 0.188, and brown mediterranean and reddish brown mediterranean with a K value of 0.323.

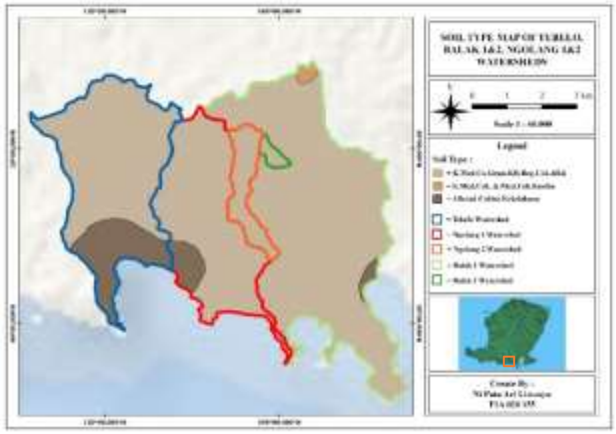

Figure 3. Map of the Tebelo Watershed, Ngolang 1&2 Watershed, and Balak 1&2 Watershed Soil Type

The slope length and steepness factor (LS) used Digital Elevation Model (DEM) data obtained through QGIS software, which was then adjusted to the LS factor values in Table 2.

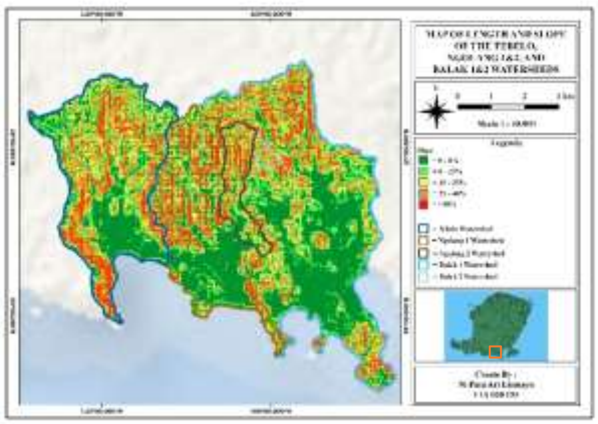

Figure 4. Map of Length and Slope of the Tebelo Watershed, Ngolang 1&2 Watershed, and Balak 1&2 Watershed

The land cover factor (C) was obtained from the land cover map owned by the BPKHTL agency in region VIII. Land cover at the research location was highly variable, which was then adjusted to the C value in the table.

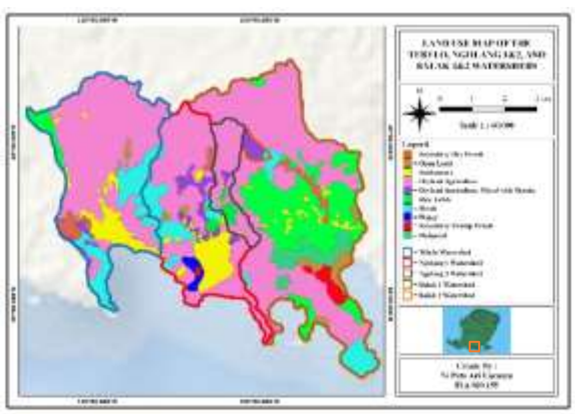

Figure 5. Land Use Map of the Tebelo Watershed, Ngolang 1&2 Watershed, and Balak 1&2 Watershed

The Land Management factor (P) was determined based on soil cultivation and planting along contour lines in the form of slope percentages according to Digital Elevation Model data at the research location.

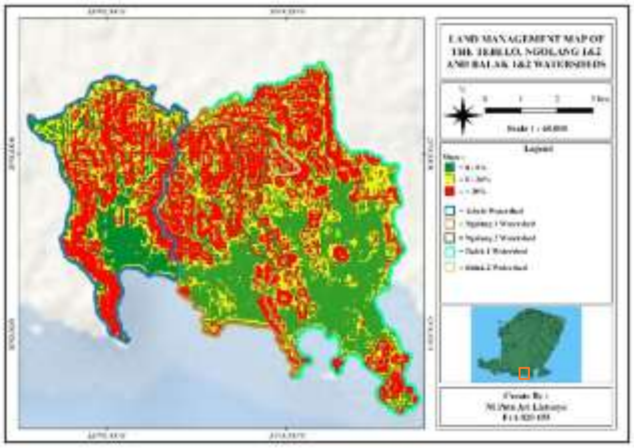

Figure 6. Land Management Map of the Tebelo Watershed, Ngolang 1&2 Watershed and Balak 1&2 watershed

The USLE erosion analysis was obtained by overlaying the five parameter values, namely : R, K, LS, C, and P, which were processed mathematically using a vector map- based union technique using the QGIS application. After all parameters were combined into one layer, the amount of erosion was calculated using a vector calculator by multiplying all parameters. The erosion values at the research location are as follows:

Table 7. Recapitulation of Erosion Values for The Tebelo, Ngolang 1 & 2, and Balak

DAS	Average Erosion (tons/ha/year)	Area (ha)	Total erosion (tons/year)
Tebelo	64.84	1,560.67	101,189.01
Ngolag 1	65.78	1,203.31	79,158.05
Ngolang 2	68.12	240.58	16,387.94
Balak 1	50.16	2,463.16	123,557.66
Balak 2	67.07	40.27	2,701.15

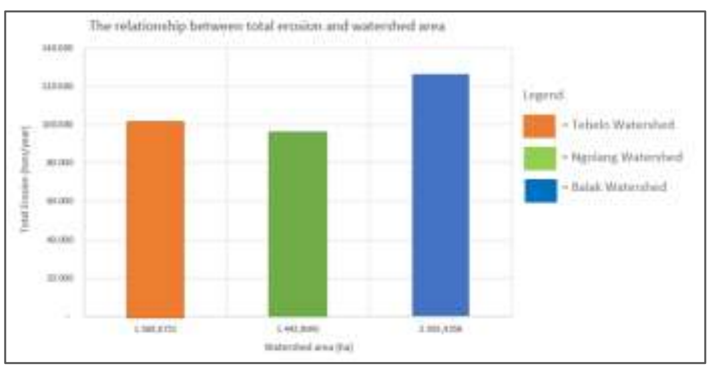

Figure 7. Graph Showing the Relationship Between Total Erosion & Watershed Area

Based on the table above, the average value in the Tebelo watershed is 64.84 tons/ha.year or 101,189.01 tons/year, the Ngolang watershed is 133.90 tons/ha/year or 95,545.99 tons/year, and the Balak watershed is 117.07 tons/ha/year or 126,259.82 tons/year. The magnitude of erosion varies due to several factors such as LS and C factors, because the steeper the LS and the sparser the land cover, the higher the erosion that occurs, and vice versa.

3.2 Clasiffication of Erosion Level Distribution

Table 8. Recapitulation of Erosion Hazard Levels in the Tebelo Watershed

Erosion Hazard Class	Erosion Hazard Level	Area (ha)	%
I	Very Light	293.57	18.81
II	Light	734.79	47.08
III	Keep	503.16	32.24
IV	Heavy	14.80	0.95
V	Very Heavy	14.35	0.92

Table 9. Recapitulation of Erosion Hazard Classes in the Ngolang 1 Watershed

Erosion Hazard Class	Erosion Hazard Level	Area (ha)	%
I	Very Light	275.04	22.86
II	Light	517.24	42.98
III	Keep	384.69	31.97
IV	Heavy	13.78	1.14
V	Very Heavy	12.57	1.04

Table 10. Recapitulation of erosion hazard classes for the Ngolang 2 watershed

Erosion Hazard Class	Erosion Hazard Level	Area (ha)	%
I	Very Light	36.66	15.24
II	Light	104.36	43.38
III	Keep	99.22	41.24
IV	Heavy	0.34	0.14

Table 11. Recapitulation of erosion hazard classes in the Balak 1 watershed

Erosion Hazard Class	Erosion Hazard Level	Area (ha)	%
I	Very Light	929.82	37.75
II	Light	816.0	33.08
III	Keep	667.09	27.08
IV	Heavy	45.20	1.83
V	Very Heavy	5.05	0.20

Table 12. Recapitulation of erosion hazard classes in the Balak 3 watershed

Erosion Hazard Class	Erosion Hazard Level	Area (ha)	%
I	Very Light	3.90	9.68
II	Light	19.65	48.79
III	Keep	16.72	41.53

The results of erosion hazard classification show that the dominant categories are Very Light to Keep across all analyzed watersheds, while severe to very severe classes are only found in areas with steeper slopes or less than optimal land cover. This pattern indicates that most watershed areas are still at a manageable level of erosion risk, while locations with high erosion hazards require priority conservation measures.

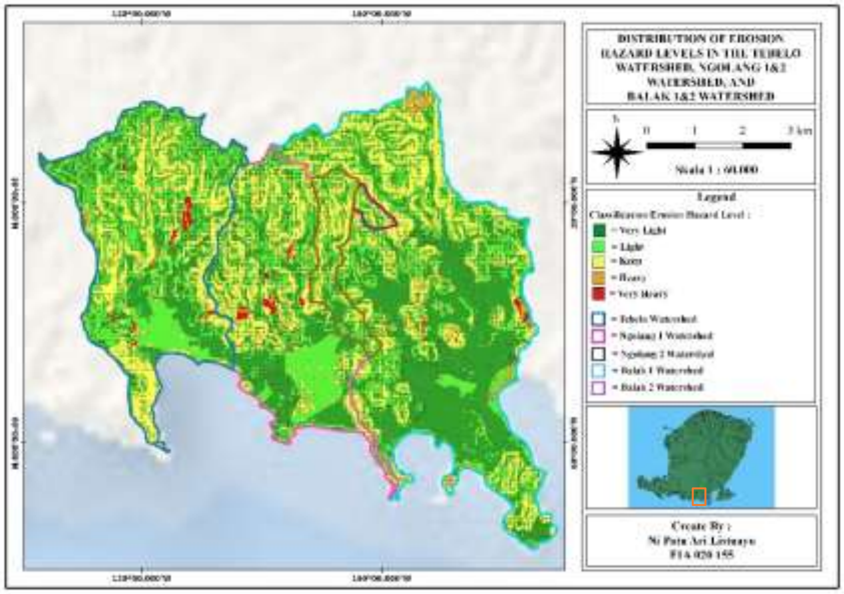

Figure 8. Distribution of Erosion Hazard Levels in the Tebelo Watershed, Ngolang 1&2 Watershed, and Balak 1&2 Watershed

3.3 Calculation of SDR and Sedimentation Values

The amount of sedimentation is obtained by multiplying the total erosion by the SDR value, which can be obtained using the Menhut (2005) method with table value interpolation based on the land area at each research location.

Table 13. SDR values in the Tebelo, Ngolang 1&2, and Balak 1&2 Watersheds

DAS	SDR	Sedimentation (m^3/year)
Tebelo	0.227	8,666.234
Ngolang 1	0.235	7,019.14
Ngolang 2	0.322	1,986.825
Balak 1	0.207	9,990.696
Block 2	0.424	447,254

Based on the results of Table 13, the highest sedimentation occurred in the Balak 1 watershed with a value of 9,990.696 m^3/year, followed by the Tebelo watershed with 8,666.234 m^3/year. The lowest sedimentation was found in the Balak 2 watershed, which was 447.254 m^3/year. These variations indicate that differences in watershed characteristics, including area, affect the amount of sediment produced in each region.

3.4 Verification of Sediment Result

This study verified the Ngolang 2 watershed (retention pond catchment area) by comparing the results of sedimentation calculations using the SDR method with the dead storage capacity of the SEZ Mandalika retention pond. The dead storage capacity of the retention pond is 1,586.24 m^3/year, while the sedimentation calculation results in the Ngolang 2 watershed based on the USLE method and the Menhut equation are 1,986.82 m^3/year. This comparison shows a difference of 25%.

4. Conclusion

Based on erosion estimates using the USLE method, varying erosion rates were obtained at each research location. The Tebelo watershed produced erosion of 101,189.01 tons/year, the Ngolang 1 watershed 79,158.05 tons/year, the Ngolang 2 watershed 16,387.94 tons/year, Balak 1 watershed produced 123,557.66 tons/year; and 2,701.15 tons/year in the Balak 2 watershed. Distribution the erosion hazard level (EHL) in the five watersheds shows a relatively uniform distribution of classes, dominated by light to keep classes with the following proportions for each location: the Tebelo watershed is dominated by light (47.08%)

and keep (32.24%) classes, while the Ngolang 1 watershed also shows a dominance of light (42.98%) and keep (31.97%) classes. The Ngolang 2 watershed has a more concentrated TBE distribution in the light (43.38%) and Keep (41.24%) classes. In a wider area, the Balak 1 watershed was dominated by very light (37.75%), light (33.13%), and Keep (27.08%) classes, while the Balak 2 watershed showed the highest TBE in the light (48.80%) and Keep (41.53%) classes. Sedimentation calculations show that the Balak 1 watershed is the largest contributor with a value of 9,990.70 m^3/year, followed by the Tebelo watershed with 8,666.23 m^3/year, the Ngolang 1 watershed with 7,019.14 m^3/year, Ngolang 2 watershed at 1,986.82 m^3/year, and Balak 2 watershed at 447.25 m^3/year. The amount of sedimentation in the Balak 1 and Tebelo watersheds is consistent with the high total annual erosion in both areas.

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