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Analysis of Erosion Hazard Index (IBE) and Its Distribution in Kamenti Tulap Watershed-East Coast Minahasa with Spatial Technology

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***Abstract*—Erosion is a disaster on agricultural land. Due to extreme weather, flash floods, erosion, and landslides occurred in several areas of Minahasa Regency. The Kamenti Tulap watershed is one of the areas on the East Coast of Minahasa that experienced the flash flood disaster and was affected by material losses and damaged agricultural land. The Kamenti Tulap watershed needs to be managed well because it is a source of drinking water and domestic needs and a source of livelihood for the local community as farmers. The erosion hazard index is needed to determine the condition of soil damage in the Kamenti Tulap watershed. This research aims to calculate the potential erosion, actual erosion, and erosion hazard index using the USLE-RUSLE-MUSLE method integrated with spatial technology to obtain its distribution in the Kamanti Tulap watershed. The materials used are base maps such as research area, watershed, slope, land use, soil map, and rainfall data. The result analysis is Kamenti Tulap Watershed with an 891.53 ha spread across the potential and actual erosion hazard index classes. The high class of potential erosion hazard index of 30.52% spread over 118 land units is generally moderately steep (25-40%). The very high class of actual erosion hazard index spread over 146 land units with a coverage area of about 13.81% and generally on mixed garden land. The government needs information on erosion hazard index classification to determine priority areas for land rehabilitation.**

***Keywords*— Watershed; erosion hazard index; spatial technology.**

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I. INTRODUCTION

Erosion is a disaster on agricultural land. Erosion is an indicator of soil damage in an area. In general, erosion means the topsoil's displacement, which causes topsoil loss by activity agent dynamics erosion such as water, ice, snow, air, plants, animals, and others [1]. Erosion is also a result of poor land management [2], and land use activities that are inappropriate based on the land's capability and carrying capacity [3]. Soil loss due to erosion is a global problem and has significantly increased land degradation [4]. Reduced crop production, decreased surface water quality, and changes in drainage canals can result from soil loss from agricultural land [5]. This soil loss intensifies due to different climatic conditions and land use [6], and degradation of ecosystems in the highlands and mountains [7]. The ever-increasing erosion has created a problem impacting livelihoods and food production [8]. Traditional land management systems for agricultural activities throughout the year usually trigger soil degradation. Moreover, if there are no adequate soil conservation practices, erosion will cause the land to become critical land [9]. A high erosion hazard class will cause a decrease in agricultural land productivity and change the hydrological function of the watershed [10]. The USLE method, coined by Wichmeier and Smith in 1978, can produce reasonable estimates of erosion up to a time interval of 10-20 years. The test parameters are simple and widely applied throughout the world, so the results are acceptable [11]. One such model is the Universal Soil Loss Equation (USLE) [12], [13]. Among the USLE factors, the management cover factor (C-factor) is the most crucial factor regarding the sensitivity of calculated soil loss and a critical factor in soil erosion control. Erosion of vitality of precipitation (R), erodibility (K), slope factor, and slope length (L.S.) [14].

Distribution of erosion hazard class requires spatial information technology. Information technology has become commonplace and necessary in all aspects of life [15]. Not only that, currently, information technology has even become the backbone of human life in providing and providing information [16]. Timely, fast, and accurate information is essential for human survival. The data and information needed must be easily accessed effectively and efficiently by various interested parties [17], [18]. A Geographic Information System is a combination of database management in collecting and storing large amounts of geospatial data, together with spatial analysis capabilities to determine the geospatial relationship between the entities of each data used, coupled with screen maps that function to describe the relationship of geospatial data in two and three dimensions in the form of maps [19], [20].

Geographic information systems are needed in the management of a watershed. The watershed is a water catchment area that has the power to control the water management process. One of the factors causing watershed damage is the increasing use of natural resources and population growth. There are approximately 62 watersheds in critical and very severe situations out of 458 watersheds in Indonesia, which are of concern. Human activities and worsening terrain erosion cause this condition [21]. If the watershed function is disrupted, then the hydrological system will also be disrupted, rainfall capture, infiltration, and water storage will be reduced, and there will be a high runoff [22].

Kamenti River is the main river in the Kamenti Tulap watershed, which is administratively located primarily in Kombi and Lembean Timur Districts, Minahasa Regency, North Sulawesi Province. The river flows to the east of the Minahasa Regency area so that it empties into the settlement on the outskirts of the Minahasa East Coast or what residents call the Kamenti settlement/village. The Kamenti Tulap watershed has a hilly topography with steep slope conditions upstream and sloping downstream. Most of the population depends on agricultural and plantation products, such as cloves, nutmeg, coconuts, and other fruit crops, as well as marine fish products that can reach 10,000 tons/year of production [23]. The Kamenti Tulap watershed is one of the areas on the East Coast of Minahasa that needs to be managed well because it is a source of drinking water and domestic needs as well as a source of livelihood for the local community as farmers.

Along with the construction of road network infrastructure of Trans Sulawesi, which connects the North Sulawesi Province and Gorontalo Province, then the Minahasa East Coast became a tourism destination. The beauty of the beach is a hidden natural attraction that local and foreign tourists have visited. The development of the Minahasa East Coast area into a tourism area has caused a tendency to change land use. The rate of land clearing in the area can accelerate the process of erosion. Most of the Minahasa East Coast area, especially the Kombi District are on high erosion hazard levels [24]. According to information from the Manado Post news media dated May 13, 2024, due to extreme weather, there were flash floods and landslides in several areas of Minahasa Regency. Tulap Village, which is located in the upper and middle part of the Kamenti Tulap watershed, experienced the flash flood disaster and was affected by material losses, especially in residential areas and damage to agricultural land.

The erosion hazard index is needed to determine the condition of soil damage in the Kamenti Tulap watershed. This research aims to calculate the potential erosion, actual erosion, and erosion hazard index that occur in the Kamenti Tulap watershed using the modified USLE (Universal Soil Loss Equation) method [25].

II. Materials and Method

The materials and method of this research will be explained below.

A. Location and Time

The research location is in the Kamenti Tulap watershed, which is administratively located in Minahasa Regency, consisting of 7 (seven) villages namely Eris, Kayubesi, Ranowangko Dua, Tulap, Kapataran, Kapataran Satu, and Seretan Timu Village. The villages are spread across 3 Sub-Districts namely Kombi, Lembean Timur, and Eris sub-district with an area of approximately 891.53 ha. This research was conducted from February to May 2024.

B. Materials and Tools

The materials used are base maps such as research area maps, watershed maps, slope maps, land use maps, soil maps, and rainfall data for 2019-2023. The tools used were computers with GIS software (ArcMap 10.8), GPS, digital camera, interview guidelines, and field observation guidelines.

C. Data Collection

The data collected was rainfall data and base maps. Rainfall data was obtained from Winangun Manado Geophysical Station and Bitung Maritime Meteorological Station, BPS-Statistics Sulawesi Utara Province in figure 2020-2024. The base maps were obtained from several sources such as Digital RupaBumi Indonesia Map, North Sulawesi KSP (One Map Policy) Map, North Sulawesi Province Spatial and Regional Plan (RTRW) Map, DEMNAS Map, and Maxar Technologies high-resolution satellite imagery.

D. Land Unit Map

In this study, all maps were inputted to the computer using GIS software, and the smallest observation unit was the land unit. The land unit map was done by overlaying the slope map, land use map, soil map, and rainfall map. The land unit map was created at a scale of 1:25,000 and eliminated land areas of less than 0.25 ha, resulting in 527 land units.

E. Erosion Calculation

The technique used in this research is the USLE method developed by [12] for erosion rates and modified with the Revised Universal Soil Loss Equation or RUSLE model [26] and Modified Universal Soil Loss Equation or MUSLE model [27]. The erosion rates based on USLE are as follows:

$$A = RKLSCP \quad (1)$$

Information:
A: amount of soil erosion (tons/years)
R: rain erosivity factor
K: soil erodibility factor
LS: slope length (L) and steepness factor (S)

C: land use/plant factor
P: soil conservation factor

The erosivity calculation formula used is based on RUSLE:

$$R = -129 + 12.61P \quad (2)$$

Information:
R: annual rainfall erosivity
P: annual rainfall in inches

The erosion calculation formula used is based on MUSLE:

$$Apotential = (0.224)RKLS/Ar \quad (3)$$

$$Aactual = (0.224)RKLSCP/Ar \quad (4)$$

Information:
$A_{potential}$: amount of potential erosion (tons/ha/year)
A_{actual}: amount of the actual erosion (tons/ha/year)
Ar: Area (ha)

F. TSL Calculation

Tolerable Soil Loss (TSL) is the estimated maximum amount of soil that can be lost to erosion each year [12]. The formula for calculating the TSL rate is as follows:

$$TSL = \frac{KE \times FK}{UGT} \quad (5)$$

Information:
TSL: erosion that can be tolerated (tons/ha/year)
KE: effective soil depth (mm)
FK: soil depth factor
UGT: resource life (400 years)

G. Erosion Hazard Index Calculation

Information on the erosion hazard index and its classification is needed to determine priority areas for land rehabilitation. The erosion hazard index calculates the ratio between the potential and actual erosion rate (A) and the tolerable soil loss (TSL) rate. The erosion hazard index formula used:

Equations should be placed flush-left with the text margin. Equations are centered and numbered consecutively starting from 1 as follows

$$ErosionHazardIndex = \frac{A(tons/ha/year)}{TSL(tons/ha/year)} \quad (6)$$

The classification of erosion hazard index according to [28] is as follows: (i) <1.0 is low; (ii) 1.01–4.0 is medium; (iii) 4.01–10.0 is high and (iv) > 10.01 is very high.

H. Utilization of Spatial Technology

In this research, the utilization of spatial technology uses ArcGIS 10.8 software. The calculation of the USLE-RUSLE-MUSLE method integrated with spatial technology uses the erosion spreadsheet method [25].

III. Result and Discussion

A. Potential Erosion Rate of Kamenti Tulap Watershed

In calculating the potential erosion rate in the Kamenti Tulap watershed, the crop management/land use factor (C) and soil conservation factor (P) were not considered. So, the potential erosion rate obtained is 352.12 tons/ha/year. Based on the slope class, the steep class (40-65%) has the largest erosion rate of about 3143.40 tons/ha/year. While the slope class with the lowest erosion rate is a flat class (0-3%), about 56.35 tons/ha/year. This is because the higher the slope factor class, the more the surface flow rate accelerated. The erosion rate in the moderate class (8-15%) is smaller than in the undulating class (3-8%). This is due to the high rainfall factor spread over the undulating class (3-8%). Table 1 and the slope map in Figure 1 compare potential erosion rates occurring on each slope class in the Kamenti Tulap watershed.

TABLE I
POTENTIAL EROSION RATE OF EACH SLOPE CLASS IN KAMENTI TULAP WATERSHED

Slope	Area (ha)	Erosion Rate (tons/ha/year)
Flat (0-3%)	1.04	56.35
Undulating (3-8%)	84.56	132.91
Moderately Sloping (8-15%)	282.49	104.33
Hilly (15-25%)	356.30	234.66
Moderately Steep (25-40%)	158.26	1021.04
Steep (40-65%)	8.89	3143.40
	891.53	**352.12**

Source: Analysis Result, 2024

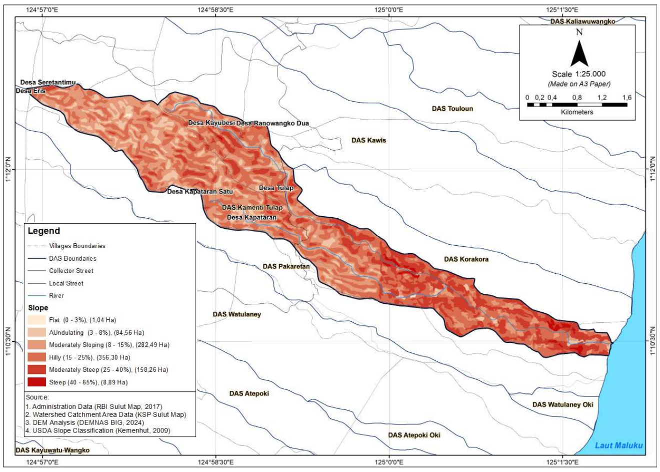

Fig. 1 Slope of Kamenti Tulap Watershed Map

B. Actual Erosion Rate of Kamenti Tulap Watershed

The actual erosion rate in the Kamenti Tulap watershed was analyzed with several factors, namely rain erosivity (R), soil erodibility (K), topography (LS) and crop management (C), and conservation factor (P). The average erosion rate extracted from 527 land units was 164.96 tons/ha/year. Based on the type of land use, open land is the type of land use with the largest erosion rate, which is around 1170.77 tons/ha/year. This is due to the influence of land cover (C) and conservation factor (P) that does not exist so that the surface flow rate is accelerated. The land use type with the smallest erosion rate is shrubs around 7.36 tons/ha/year. This is due to the influence of land cover (C) and conservation factor (P) is good. The comparison of actual erosion rates occurring in each land use in the Kamenti Tulap watershed is shown in Table 2 and the land use distribution map is in Figure 2.

C. Tolerable Soil Loss (TSL) in Kamenti Tulap Watershed

The soil type distributed in the Kamenti Tulap watershed is Eutropepts Dystrandepts. According to [28], the value of the soil depth factor is 1.0, while the effective soil depth is about

1250 mm, which indicates that the soil is too deep. The soil depth factor value multiplied by the effective soil depth will give the equivalent depth. The period sufficient to maintain soil sustainability, or what is referred to as the resource life of the soil, is 400 years [29]. Based on this, the amount of erosion that can still be tolerated is about 2.5 mm/year. If the bulk density is 1.2 g/cc, the tolerable soil loss (TSL) in the Kamenti Tulap watershed equals 30 tons/ha/year.

TABLE II
ACTUAL EROSION RATE OF EACH SLOPE CLASS IN KAMENTI TULAP WATERSHED

Land Use	Area (ha)	Erosion Rate (tons/ha/year)
Mixed Garden	766.67	147.06
Open Land	10.52	1170.77
Grasslands	61.54	155.59
Settlements	29.38	214.75
Shrubs	14.45	7.36
Field	8.98	670.07
	891.53	**164.96**

Source: Analysis Result, 2024

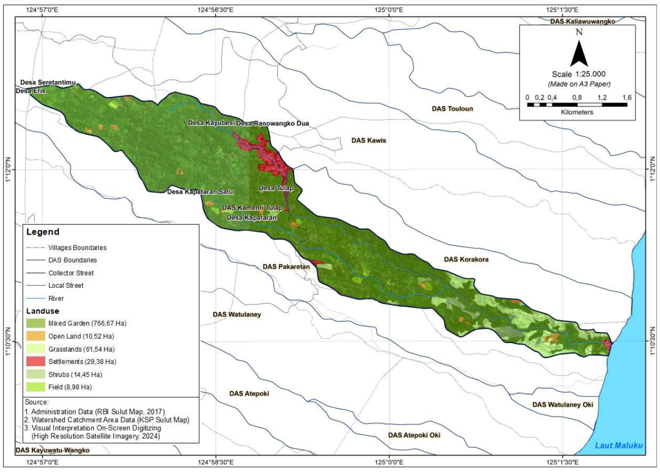

Fig. 2 Land Use of Kamenti Tulap Watershed Map

D. *Potential Erosion Hazard Index (PEHI) of Kamenti Tulap Watershed*

The low class of potential erosion hazard index class spread over six land units covering 362.79 ha or about 40.69% of the total area of the Kamenti Tulap watershed. The moderate erosion hazard index class is spread over 361 land units covering 128.80 ha or about 14.45%. The high erosion hazard index class is spread over 42 land units covering 127.87 ha or about 14.34% and the very high erosion hazard index class is spread over 118 land units covering 272.07 ha or about 30.52% of the Kamenti Tulap watershed area.

The result showed that the largest land unit (very high) erosion hazard index value of 312.15 has an erosion rate of 9364.61 tons/ha/year is ID 193 with an area of 0.26 ha. This land unit is located upstream of the Kamenti Tulap watershed in Kayubesi Village with moderate steep slope conditions. The land unit with the smallest erosion hazard index value (low) of 0.08 has an erosion rate of 2.55 tons/ha/year and ID 323 has an area of 111.09 ha. This land unit is also scattered upstream of the Kamenti Tulap watershed, which spreads in Kapataran Village and Kayubesi Village, with moderately sloping conditions.

Table 3 shows the classification and distribution of potential erosion hazard index values in the Kamenti Tulap watershed.

TABLE III
POTENTIAL EROSION RATE OF EACH SLOPE CLASS IN KAMENTI TULAP WATERSHED

PEHI Class	Number of Land Units	Area (ha)	Percentage (%)
Low (<1.0)	6	362.79	40.69
Moderate (1.01 – 4.0)	361	128.80	14.45
High (4.01-10.0)	42	127.87	14.34
Very High (>10.01)	118	272.07	30.52
	527	**891.53**	**100**

Source: Analysis Result, 2024

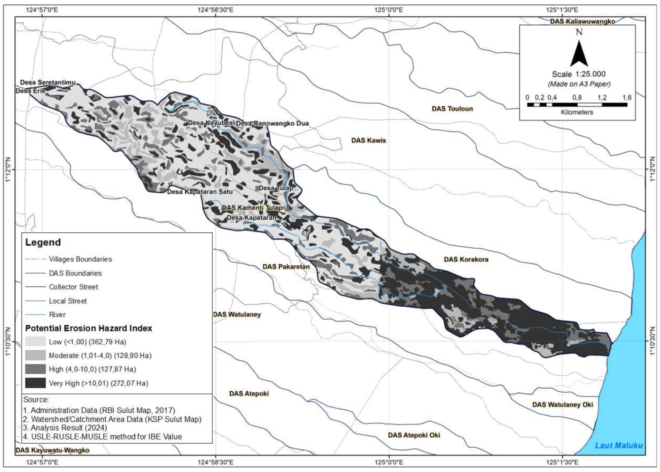

Fig. 3 Potential Erosion Hazard Index of Kamenti Tulap Watershed Map

E. *Actual Erosion Hazard Index (AEHI) of Kamenti Tulap Watershed*

The low class of actual erosion hazard index class spread over 38 land units covering an area of 448.66 ha or about 50.32% of the total area of the Kamenti Tulap watershed. The moderate erosion hazard index class is spread over 221 land units covering 172.03 ha or about 19.30%. The high erosion hazard index class is spread over 122 land units covering 147.70 ha or about 16.57%. The high erosion hazard index class is spread over 146 land units covering 123.14 ha or about 13.81% of the Kamenti Tulap watershed area.

The result showed that the most prominent land unit (very high) erosion hazard index value of 203.78 has an erosion rate of 6113.46 tons/ha/year and ID 70 with an area of 0.35 ha. This land unit is located downstream of Kamenti Tulap watershed, precisely in Kapataran Village and it's utilized as mixed garden. The land unit with the smallest erosion hazard index value (low) of 0.04 has an erosion rate of 1.27 tons/ha/year and ID 323 with an area of 111.09 ha. This land unit is scattered upstream of Kamenti Tulap watershed in Kapataran Village and Kayubesi Village with moderately sloping conditions, and it's utilized as an open land.

Table 4 shows the classification of actual erosion hazard index values in the Kamenti Tulap watershed, and Figure 4 shows the distribution. Preventing soil damage due to erosion is essential for farmers to sustain agricultural production [30]. Land with high and very high erosion hazard index classes needs to be improved restoration to reduce the erosion hazard index value. These efforts include making land improvements such as changing cropping patterns, making terraces, and planting based on contour lines.

TABLE IV
ACTUAL EROSION RATE OF EACH SLOPE CLASS IN KAMENTI TULAP WATERSHED

AEHI Class	Number of Land Units	Area (ha)	Percentage (%)
Low (<1.0)	38	448.66	50.32
Moderate (1.01 – 4.0)	221	172.03	19.30
High (4.01-10.0)	122	147.70	16.57
Very High (>10.01)	146	123.14	13.81
	527	**891,53**	**100**

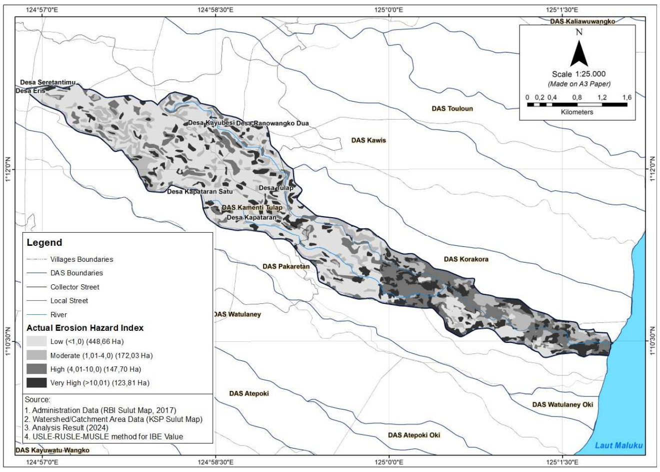

Fig. 4 Actual Erosion Hazard Index of Kamenti Tulap Watershed Map

To reduce erosion, it is necessary to observe the ability to absorb water into the soil, the absorption influenced by the soil physics that can keep water. Litter, organic matter, and soil fauna play an important role in enlarging soil pores. Soil pores caused by plant roots and soil organism activity will increase soil porosity and reduce soil density.

IV. CONCLUSION

Kamenti Tulap Watershed, with an area of 891.53 ha, is spread across the potential erosion hazard index classes: low class 40.69%, which covers 6 land units; moderate class 14.45%, which covers 361 land units; high class 14.34%, which covers 42 land units; and very high class 30.52%, which covers 118 land units. The slope is generally moderately steep (25-40%).

The actual erosion hazard index is spread across the following classes: low class spread over 38 land units with a coverage area about 50.32%; moderate class spread over 221 land units with a coverage area about 19.30%; high class spread over 122 land units with a coverage area about 16.57%; and very high class spread over 146 land units with a coverage area about 13.81%, generally on mixed garden land.

Good management of watersheds can increase agricultural production and impact an area's growth and development. Information on erosion hazard index classification is needed by the government to determine priority areas for land rehabilitation.

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