Research Article

Erosion Prediction using Universal Soil Loss Equation (USLE) in Posigadan District, South Bolaang Mongondow Regency

Prediksi Erosi Menggunakan Metode USLE dan SIG di Kecamatan Posigadan, Kabupaten Bolaang Mongondow Selatan, Provinsi Sulawesi Utara

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Abstract: Soil erosion refers to removing topsoil caused by the action of water or wind, with its intensity influenced by natural factors specific to the location. This study aims to predict soil erosion, determine tolerable erosion levels, and provide recommendations for land use based on erosion predictions in the Posigadan District, South Bolaang Mongondow Regency, North Sulawesi Province. Conducted between February and April 2024, the research employed the Universal Soil Loss Equation (USLE) method integrated with Geographic Information System (GIS) technology. The USLE method's accuracy depends on factors such as rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), vegetation cover (C), and conservation practices (P). Meanwhile, GIS proved effective in assessing erosion risks across large areas. The findings revealed that predicted erosion values ranged from 35.59 to 605.06 tonnes/ha/year, categorized from low to very high. Tolerable erosion values ranged from 2.88 to 11.00 tonnes/ha/year. Without conservation measures, areas with low actual erosion were recommended for cultivating crop such as corn and peanuts. In contrast, areas with very high erosion were better suited for plantation commodity like cloves, candlenuts, and cocoa. The study concluded that erosion predictions fell into low, medium, high, and very high categories. Based on these results, land use recommendations included food and horticultural crops for areas with low erosion and plantation crops for areas with very high erosion.

Keywords: Erosion prediction; USLE; GIS

Abstrak: Erosi tanah adalah proses atau peristiwa hilangnya lapisan atas tanah yang disebabkan oleh gerakan air maupun angin. Besar kecilnya erosi bergantung pada faktor alam tempat terjadinya erosi. Penelitian ini bertujuan untuk mengetahui erosi yang terprediksi, erosi yang dapat ditoleransi, dan menentukan arahan penggunaan lahan berdasarkan hasil prediksi erosi di Kecamatan Posigadan Kabupaten Bolaang Mongondow Selatan Provinsi Sulawesi Utara. Penelitian dilaksanakan bulan Februari sampai bulan April 2024 di Kecamatan Posigadan Kabupaten Bolaang Mongondow Selatan Provinsi Sulawesi Utara. Penelitian menggunakan metode USLE yang dikombinasikan dengan sistem informasi geografis (SIG), dimana keakuratan metode USLE sangat bergantung pada erosivitas hujan (R), erodibilitas tanah (K), panjang dan kemiringan lereng (LS), tipe vegetasi (tanaman penutup) dan teknik konservasi (CP) sedangkan SIG sangat efektif dalam menghitung tingkat resiko erosi pada suatu wilayah yang luas. Hasil penelitian menunjukkan nilai erosi terprediksi berkisar 35,59 ton/ha/tahun hingga 605,06 ton/ha/tahun dengan kategori rendah hingga sangat tinggi, nilai erosi yang ditoleransi berkisar 2,88 ton/ha/tahun hingga 11,00 ton/ha/tahun dan tanpa tindakan konservasi, kategori erosi aktual rendah diarahkan untuk pengembangan tanaman pangan seperti (jagung dan kacang tanah) sedangkan pada kategori erosi aktual sangat tinggi diarahkan untuk pengembangan tanaman perkebunan seperti (cengkeh, kemiri, dan kakao). Berdasarkan hasil penelitian dapat disimpulkan bahwa nilai erosi terprediksi memiliki kategori erosi aktual rendah, sedang, tinggi dan sangat tinggi. Dari hasil tersebut maka arahan penggunaan lahan pada

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erosi aktual rendah diarahkan untuk tanaman pangan dan tanaman hortikultura sedangkan pada erosi aktual sangat tinggi diarahkan untuk tanaman perkebunan.

Kata kunci: SIG; USLE; Prediksi erosi

INTRODUCTION

Land is a fundamental resource on Earth, serving as a primary asset for individuals to meet their daily needs. However, its availability is increasingly jeopardized, particularly within the agricultural sector. Consequently, effective and sustainable land management practices are essential to enhance land productivity and support regional development, especially in agriculture (Rahman et al., 2015). Key natural resources for human survival include land and water. Soil degradation, which refers to the deterioration of soil quality, can arise from various factors, including (1) depletion of nutrients and organic matter in the root zone, (2) accumulation of salts in the root area, (3) excessive waterlogging on the soil surface, and (4) erosion. Such degradation diminishes the soil's capacity to sustain plant growth (Hariyanto et al., 2019).

Soil erosion is a natural process that occurs both on land and at sea, influenced by factors such as soil type, landscape characteristics, and climate. However, human activities now play a significant role in accelerating erosion. Practices such as improper cultivation that disregard soil and water conservation principles have exacerbated erosion, necessitating an evaluation of erosion rates to mitigate its impacts (As-syakur, 2008).

In South Bolaang Mongondow Regency, unpredictable seasonal patterns have led to the region being described as a "non-zoned" area. Without adequate preventive measures, hydrometeorological disasters, particularly floods, pose a significant risk. This vulnerability is further exacerbated by insufficient dam infrastructure, river siltation, and unsustainable forest management practices. These issues highlight the need for coordinated mitigation strategies, both structural and non-structural, to address disaster risks effectively (Urbanus et al., 2021). In Posigadan District, located within South Bolaang Mongondow Regency and home to a population of 14,159 people (BPS, 2021), many residents live along the coast, making them particularly vulnerable to natural disasters. Assessing erosion potential is critical, as accumulated erosion can lead to severe consequences such as flash floods. Understanding and addressing erosion risks is therefore essential to minimize the impact of such disasters and support sustainable land management.

The Universal Soil Loss Equation (USLE) method is one of the earliest and most widely utilized techniques for calculating soil erosion across various countries. By integrating Geographic Information Systems (GIS), the spatial distribution of relevant parameters can be analyzed more effectively. Each component of the USLE is computed using functions available within GIS software (Dabral et al., 2008). This integration is supported by Prayitno et al., (2015) findings that indicate the combination of the USLE method with GIS is particularly effective for assessing erosion risk over large areas. The accuracy of the USLE method is influenced by several key factors, including rainfall that initiates erosion (R), soil erodibility (K), slope sand steepness

(LS), vegetation type or land cover, and the conservation practices implemented (CP). Given these considerations, this research aims to determine the predicted erosion values by employing the USLE method in conjunction with GIS technology.

Based on the preceding discussion, the author undertook a study titled "Erosion Prediction Using the Universal Soil Loss Equation (USLE) Method and Geographic Information System (GIS) in Posigadan District, South Bolaang Mongondow Regency, North Sulawesi Province." The primary objectives of this research are to ascertain the predicted erosion values in the Posigadan District, determine the tolerable erosion value (Etol) for the same area, and establish appropriate land use directions within the Posigadan District of South Bolaang Mongondow Regency.

MATERIALS AND METHODS

Study Area

This research was conducted from February to April 2024 in Posigadan District, South Bolaang Mongondow Regency, North Sulawesi Province. Data analysis took place at the Soil Chemistry and Fertility Laboratory within the Faculty of Agriculture at Hasanuddin University in Makassar. The study employed an observational method, which included direct field surveys and soil sampling for subsequent laboratory analysis. Additionally, the estimation of erosion levels was performed using the USLE method in conjunction with Geographic Information System (GIS) technology.

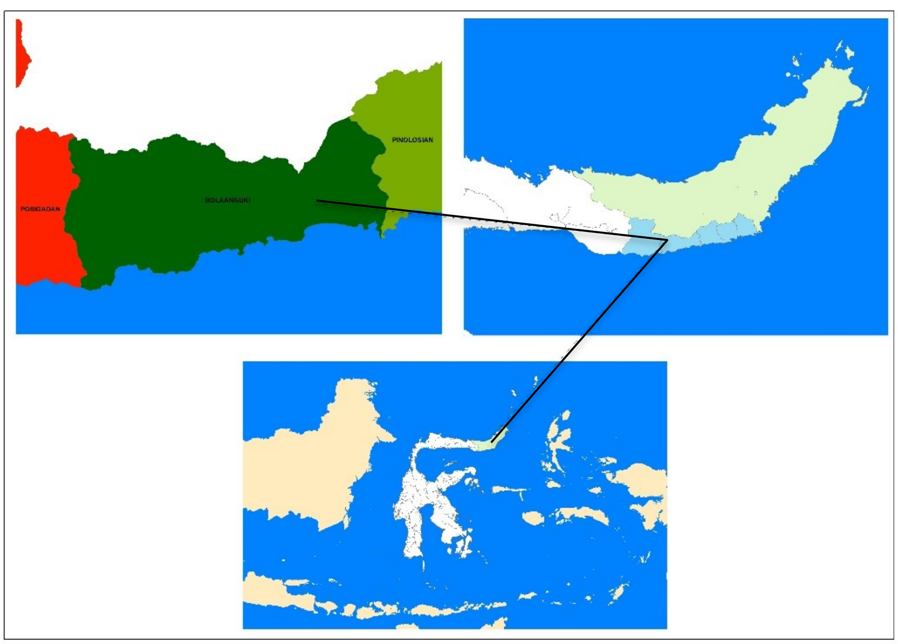

Figure 1. Map of Research Location

Data Source

Field research was conducted on a designated land unit utilizing the Geographic Information System (GIS) program to create a land unit map and identify sampling points. The study involved observing land characteristics, which included both external and internal properties. External characteristics were assessed through soil depth measurements taken after constructing soil profiles, while rainfall data was sourced from the Maritime Meteorological Station Bitung of the Meteorological, Climatological, and Geophysical Agency (BMKG) in North Sulawesi. Internal properties were examined in the laboratory, focusing on soil texture, soil structure, soil permeability, and the organic matter present in the soil.

Data Analysis

To obtain the predicted erosion value in each land unit based on field observations and laboratory analysis results, the USLE method can be used. The method includes the following:

1. Rain Erosivity Factor (R)

Rainfall data collected from observation stations at the research site was utilized to calculate the rainfall erosion factor (R) using the equation formulated by Bols (1978), as outlined by Fasya et al. (2023):

$$\mathbf{EI_{30} = 6{,}119\ (RAIN)^{1{,}21}(DAYS)^{-0{,}47}(MAXP)^{0{,}53}}$$

Where, EI30 = Annual average rainfall erosivity, RAIN = Annual average rainfall (cm), DAYS = Average number of rainy days per year (cm), MAXP = Average maximum rainfall in 24 hours per month for one year (cm).

2. Erodibility Factor (K)

The K factor was calculated using the equation of Wischmeier and Smith (1978):

$$\mathbf{100\ K = 1{,}292\ (2{,}1\ M^{1{,}14}\ (10^{-4})\ (12\text{-}a) + 3{,}25\ (b\text{-}2) + 2{,}5\ (c\text{-}3)}$$

Where, K = Soil erodibility value, M = Particle size (%very fine sand + %dust) x (100-% clay), a = Organic matter content (%), b = Soil structure code, and, c = Soil permeability code (cm/hr)

3. Length and Slope Factor (LS)

Length and slope (LS) factors are often integrated into the LS factor using the USLE equation. To obtain the LS value, one can use the equation (Arsyad, 2010).

4. Conservation technique factor (CP)

Vegetation index (C) and conservation measures (P) are processing factors, i.e. crops and soil protection affect the erosion rate. The CP value can be obtained based on the land use management system in the research area (Purba et al., 2020).

5. Determination of Tolerable Erosion

The tolerable erosion rate is influenced by factors such as soil depth, soil properties, and the type of substratum. Establishing limits for tolerable erosion rates is essential for mitigating erosion on both agricultural and non-agricultural lands, particularly on steep slopes (Lamato et al., 2019). To ascertain the tolerable or allowable erosion (T), one can refer to the guidelines for determining the soil T value as proposed by Arsyad (2010).

6. Direction Determination

Moreover, the direction of land use can be determined by evaluating the values of crop management factors, with conservation measures being adjusted according to the guidelines proposed by Arsyad (2010).

7. Geographic Information System Analysis

This analysis can be conducted using ArcGIS 10.8 software to generate various maps, including land unit maps, administrative maps, predicted total erosion maps, and land-use direction maps. Through this process, erosion rates are calculated using the Universal Soil Loss Equation (USLE), incorporating factors such as soil erodibility, slope, vegetation, and land cover within Posigadan District, South Bolaang Mongondow Regency, North Sulawesi Province (Sadewo et al., 2023).

RESULTS AND DISCUSSION

According to data from the Posigadan District BPS (2022), Posigadan District is one of the districts within South Bolaang Mongondow Regency, encompassing a total of 16 villages and covering an area of 435.94 km², with a population of 15,162 residents. Geographically, the Posigadan sub-district is situated between the Dumoga Nani Wartabone Protection Forest mountains and the coast of Tomini Bay, extending from east to west. Administratively, it is bordered to the north by Sang Tombolang District, to the south by Bolaang Uki District, and to the west by Bone Pantai District. At the same time, Gorontalo Regency in Gorontalo Province lies along its western boundary.

The estimated erosion rates for the research area range from 35.59 ton/ha/year to 605.06 ton/ha/year. The highest erosion rate, recorded at 605.06 tonnes/ha/year, occurs on slopes of 25-40% in SL3, which covers an area of 1,828.25 hectares, accounting for 15.76% of the total area. Conversely, the lowest rate of 35.59 ton/ha/year is found in SL2 on slopes of 0-3%, encompassing 1,191.25 hectares or 10.27% of the area. The slopes within the research site vary from 0-3% to 25-40%, resulting in LS values (length and slope factor) that range from 0.4 to 6.8. As illustrated in Table 1 and Figure 1, there is a clear trend indicating that steeper slopes correlate with increased erosion levels. Additionally, the length of the slope significantly influences the extent of erosion; longer slopes tend to facilitate greater soil loss due to surface runoff (Taslim et al., 2019). The slope gradient plays a crucial role in determining erosion rates, consistent with findings by Siregar et al. (2017), which highlight that while multiple factors affect erosion, the slope is the most significant. Although other factors also contribute to erosion, their impacts are generally less pronounced, becoming more substantial when considered collectively.

Table 1. Predicted Erosion Value (A)

SL	Slope	Determinants of Erosion				A (ton/ha/ Year)	Category Actual Erosion	Areas	
		R	K	LS	CP			Ha	%
1	0-3%	1379,53	0,33	0,4	0,43	78,30	Moderate	313,67	2,70
2	0-3%	1379,53	0,15	0,4	0,43	35,59	Low	1191,25	10,27
3	25-40%	1379,53	0,15	6,8	0,43	605,06	Very high	1828,25	15,76
4	15-25%	1379,53	0,21	3,1	0,05	53,46	Low	9,58	0,08
5	15-25%	1379,53	0,20	3,1	0,05	42,77	Low	1362,87	11,75
6	15-25%	1379,53	0,15	3,1	0,43	275,84	High	599,71	5,17
7	15-25%	1379,53	0,19	3,1	0,43	349,39	High	6293,65	54,26
				Total				11598,98	100,00

Description: SL = land unit

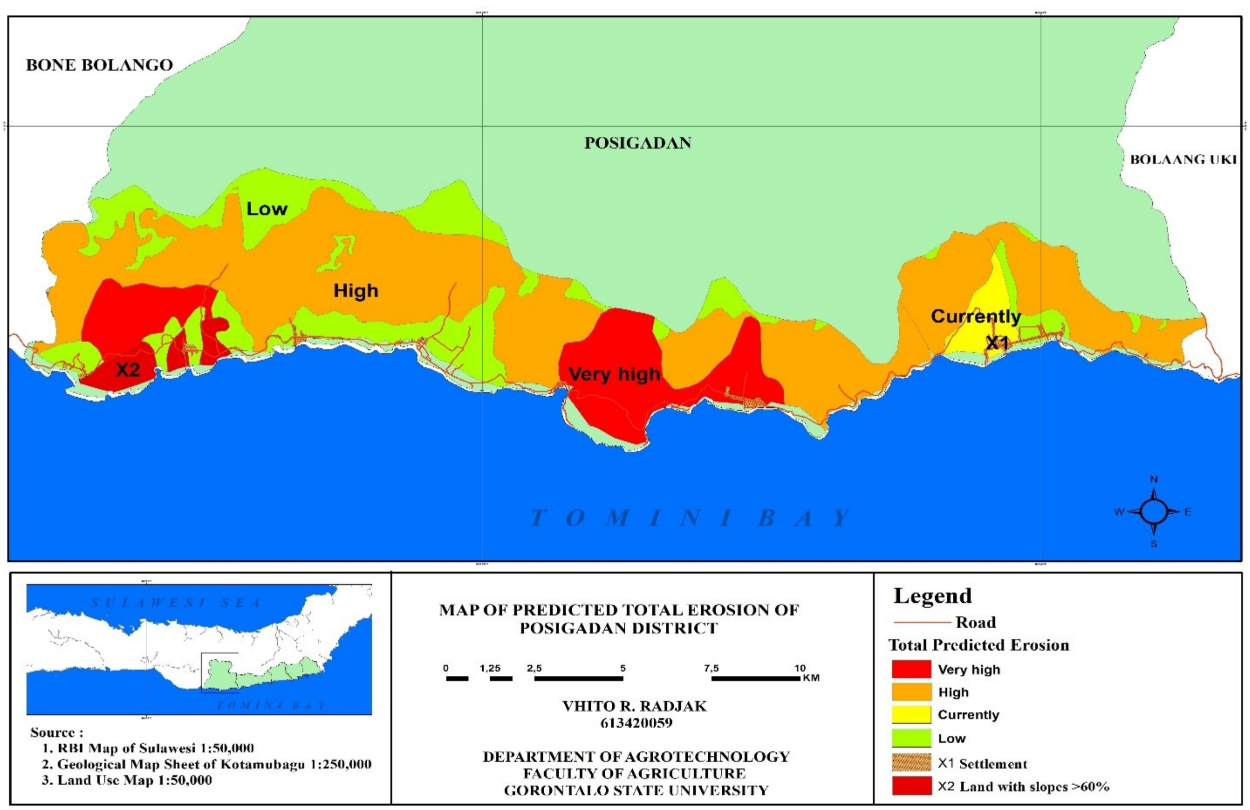

Figure 2. Map of Predicted Total Erosion of Posigadan District

The result of the predicted erosion values will inform the assessment of the tolerable erosion levels for each research site. The determination of the erosion tolerance limits is based on the methodology proposed by Hammer (1981), as outlined in Arsyad (2010), which is presented in Table 2.

Table 2. Tolerable Erosion Value (Etol)

Determinants of tolerable erosion (Etol)	Land Unit						
	1	2	3	4	5	6	7
Effective Depth (mm)	430	600	310	550	320	490	160
Soil type	Fluvent	Ustalf	Ustalf	Fluvent	Ustalf	Fluvent	Ustalf
Depth Factors	1,00	0,90	0,90	1,00	0,90	1,00	0,90
Equivalent Depths	430	540	279	550	288	490	144
Useful Life	500	500	500	500	500	500	500
Value T x 10	**8,60**	**10,80**	**5,58**	**11,00**	**5,76**	**9,80**	**2,88**

The analysis presented in Table 2 indicates that the tolerable erosion values for each research site range from 2.88 tonnes/ha/year to 11.00 ton/ha/year. The highest tolerable erosion value (Etol) is recorded in SL4 at 11.00 tonnes/ha/year, while the lowest is found in SL7 at 2.88 tonnes/ha/year. Factors such as soil depth, soil type, and projected land use over the next 500 years influence the tolerable erosion values at each research location. The findings reveal that the predicted erosion values across all land units in the study sites exceed the established Etol values. Consequently, it is essential to implement suitable and effective conservation measures to mitigate the erosion rates in the area (Widodo et.al, 2015).

Based on Table 3, the direction of land use in areas with low actual erosion is designated for food crops and horticultural crops, while areas experiencing very high actual erosion are allocated for plantation crops, as illustrated in Figure 2, the Posigadan Sub-district Direction Determination Map. Without conservation measures, land in the low actual erosion category, covering 2,563.70 ha (22.10%), is recommended for the cultivation of Agriculture crop such as corn and peanuts. These crops thrive optimally on slopes categorized as very low to moderate, particularly on slopes below 3%, aligning with the growth requirements for food crops (Wahyunto et al., 2016). Conversely, areas with very high actual erosion, spanning 1,828.25 hectares (15.76%), are directed toward plantation commodity sesuch as cloves, candlenuts, and cocoa. Soplanit et al. (2018) emphasize that when actual erosion surpasses tolerable limits, it is necessary to modify land use patterns and implement conservation measures to reduce erosion rates to acceptable levels. On the other hand, if actual erosion remains below the tolerable limit, the existing land use pattern should be preserved, as it effectively maintains erosion rates within acceptable thresholds.

Table 3. Direction Determination Value

Category Actual Erosion	SL	Recommendation	Areas	
			Ha	%
Moderate	1	crops (maize) and Horticulture crops (banana) + no conservation measures	313,67	2,70
Low	2, 4 and 5	Food crops (maize and groundnuts) + no conservation measures Plantation crops (cloves, candlenuts, and cocoa) + no conservation measures	2563,70	22,10
Very high	3	Plantation crops (Clove, candlenut, and cacao) + no conservation measures	1828,25	15,76
High	6 and 7	Plantation crops (Clove, candlenut, and Cocoa) + no conservation measures	6893,36	59,43
		Total	11598,98	100,00

Description: SL = land unit, Actual Erosion = RxKxLSxCP

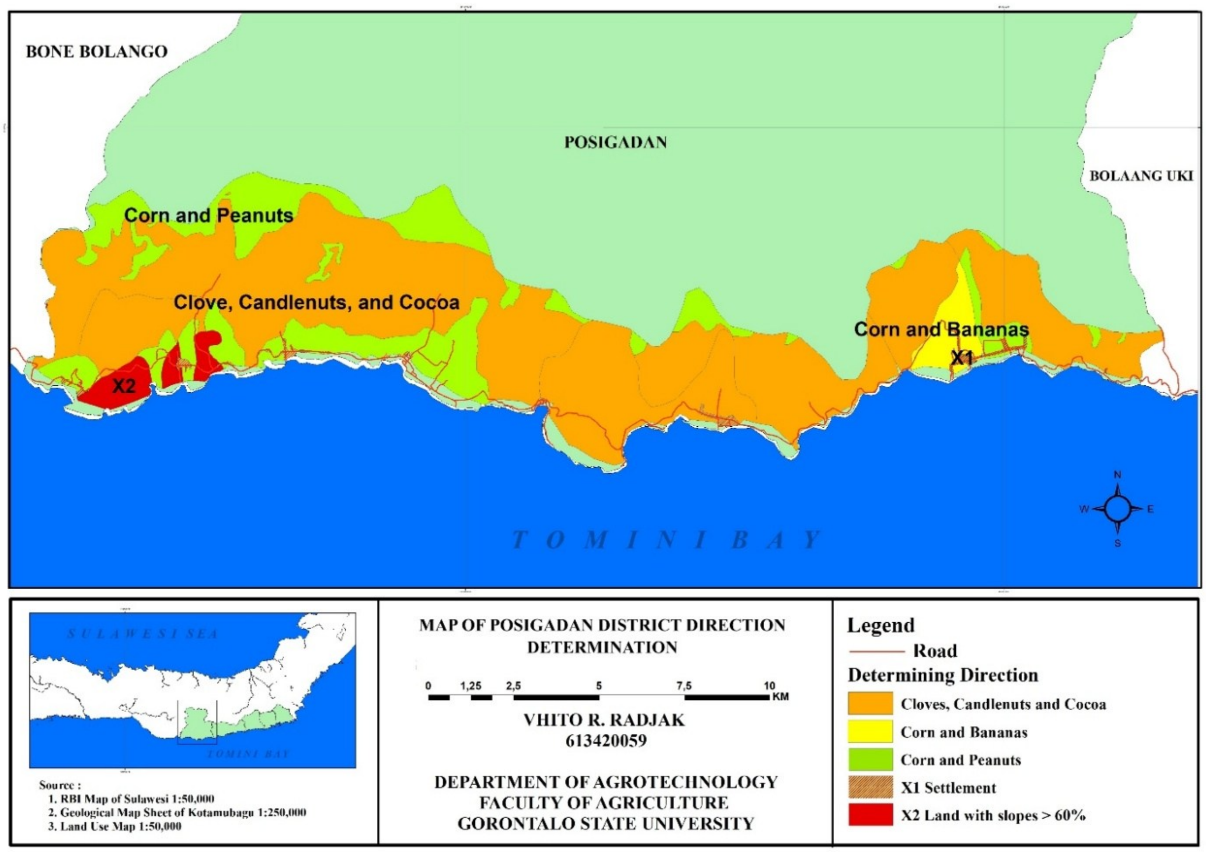

Figure 3. Map of Posigadan District Direction Determination

CONCLUSIONS

Predicted erosion values differ across land units. SL1 is categorized as having moderate erosion, with a value of 78.30 tonnes/ha/year. SL2, SL4, and SL5 fall within the light erosion category, exhibiting values between 35.59 tonnes/ha/year and 53.46 tonnes/ha/year. In contrast, SL3 is classified as having very high erosion, with a value of 605.06 tonnes/ha/year. SL6 and SL7 are categorized as high erosion areas, with values ranging from 275.84 tonnes/ha/year to 349.39 tonnes/ha/year. The tolerable erosion values (Etol) vary among the land units, with SL4 recording the highest at 11.00 ton/ha/year and SL7 the lowest at 2.88 tonnes/ha/year. All Etol values are significantly lower than the predicted erosion rates, indicating that erosion levels exceed the tolerance limits across all land units. In the absence of conservation measures, areas classified with low actual erosion are designated for the cultivation of Agriculture crops, such as corn and peanuts, while those with very high actual erosion are allocated for Plantation commodity, including cloves, candlenuts, and cocoa.

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