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Characterizing and managing erosion sensitivity in the Jompi watershed, South East Sulawesi, Indonesia

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ABSTRACT

Soil erosion is a major environmental issue in watershed areas, particularly those experiencing land use changes, such as the Jompi watershed in Muna Regency, where forest conversion to agriculture, settlements, and open land accelerates erosion. Analyzing erosion sensitivity is crucial for identifying high-risk areas, guiding sustainable land management, and supporting soil and water conservation efforts to prevent land degradation and ensure agricultural productivity and ecological stability. The study was conducted in the Jompi watershed, Muna Regency, with the aim of analyzing erosion sensitivity in the Jompi watershed area. The research employed a combination of field surveys and laboratory analysis, supported by a land unit approach. Land units were created by overlaying slope maps, land use maps, and soil type maps using geographic information systems (GIS). The final determination of the number of Land units was based on ensuring uniform characteristics and excluding units that did not meet the required map accuracy scale. The results indicated that erosion sensitivity in the Jompi watershed ranged from very low to very high, with most of the area classified as having very low erosion sensitivity. Effective management of erosion sensitivity can be achieved through vegetation management, land use regulation, and soil quality improvement.

Keywords: Jompi watershed, erosion sensitivity, land unit, land use, GIS.

INTRODUCTION

Soil erosion is one of the significant environmental problems in watershed areas, particularly in regions experiencing land use changes. The Jompi watershed, located in Muna Regency, is a prime example of an area facing ecosystem pressure due to human activities such as converting forest land into agricultural fields, settlements, and open land. These land use changes result in the loss of soil cover vegetation, ultimately accelerating the rate of erosion [Owens, 2020]. Continuous erosion can lead to land degradation, reduced soil productivity, and disruption of the watershed's hydrological functions. The impacts are not limited to environmental damage but also threaten the social and economic sustainability of communities around the Jompi Watershed, which rely heavily on agricultural land as their main source of livelihood [Hussain *et al.,* 2021]. Therefore, it is essential to analyze Erosion sensitivity to mitigate these impacts.

Erosion sensitivity refers to the degree of vulnerability of a land area to erosion, whether caused by water or wind. Erosion sensitivity is influenced by the physical and chemical properties of the soil, topographic characteristics, land cover, and rainfall. The higher the susceptibility of a land area to erosion, the greater the risk of losing topsoil due to the scouring process [Kanianska *et al.,* 2024]. However, erosion sensitivity does not always result in actual erosion; rather, it indicates the potential for erosion to occur if land management practices are not adequately implemented [Martínez-Mena *et al.,* 2020; Tsunekawa and Haregeweyn, 2021].

The analysis of erosion sensitivity aims to facilitate land management and soil and water conservation planning. This data allows for the identification of areas with high erosion risk, enabling more effective and efficient land management [Silva *et al.,* 2024]. Additionally, erosion sensitivity analysis helps determine appropriate land use based on erosion sensitivity levels, supports environmental management policies, prevents land degradation, and enhances agricultural productivity. Information on erosion sensitivity is also essential for planning soil and water conservation measures, such as the construction of terraces, the management of ground cover vegetation, and the regulation of drainage channels to control surface run off [Nacishali, 2020]. The factors influencing erosion sensitivity include topography, soil type, land use, and rainfall. Understanding these factors is critical in determining more effective land management strategies [Nunes et al., 2023].

Based on this background, this study aims to analyze the erosion sensitivity in the Jompi watershed by considering biophysical characteristics and erosion-controlling factors – information on erosion sensitivity is crucial in supporting sustainable watershed management.

METHODS

This study was conducted from February to April 2024 and involved fieldwork, field observations in the Jompi watershed area of Muna Regency, and laboratory work for soil analysis. The tools used in the field included a GPS, measuring tape, soil auger, sample rings, sample plastic bags, label paper, machete, hoe, shovel, pounding block, office supplies, and a camera. Additionally, various tools were utilized for laboratory soil sample analysis.

The materials used in this study included a soil review map of Southeast Sulawesi at a 1:250,000 scale, a slope map (topographic map) at a 1:250,000 scale, and a land use map of Southeast Sulawesi Province at a 1:250,000 scale. The materials used for laboratory analysis included soil samples and chemical reagents for soil analysis.

This study employed a survey and laboratory testing method with a land unit (LU) approach. During the preparation stage, base maps and secondary data were collected to create the LU. The creation of LUs was carried out by overlaying the slope map, land use map, and soil type map of Southeast Sulawesi Province using ArcGIS 10.8. The final stage of LU determination was based on uniform characteristics, eliminating LUs that did not meet the area size criteria for

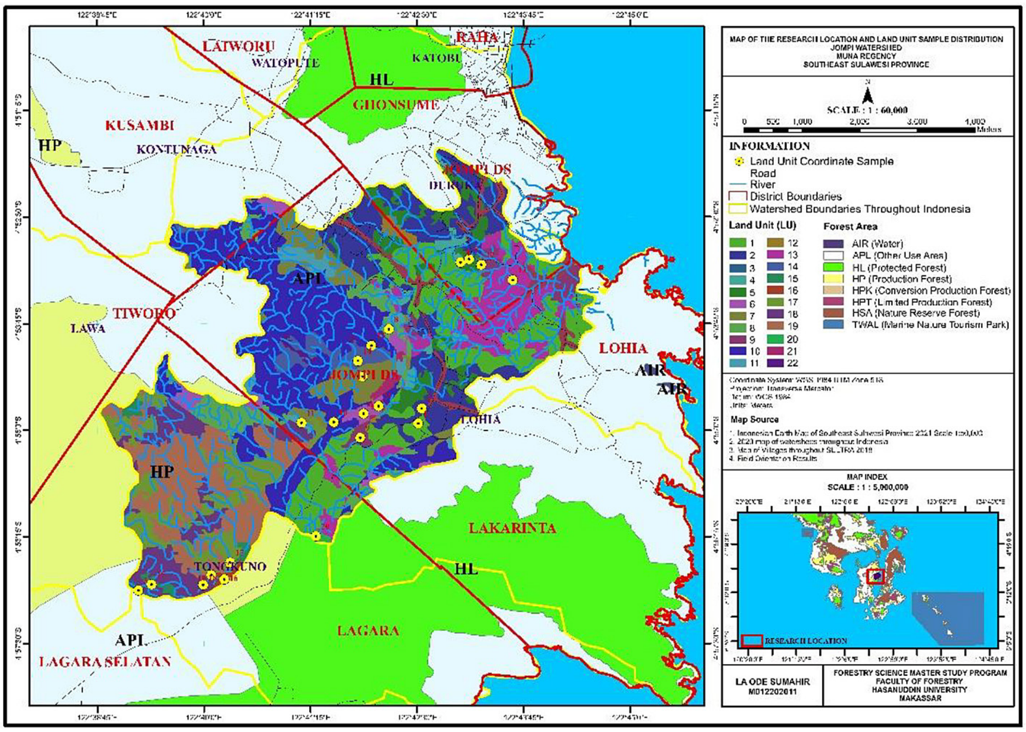

Figure 1. Land unit distribution in the Jompi watershed area, Muna Regency (ArcGIS analysis, 2024)

map accuracy. As a result, 22 LUs were identified (Figure 1). Field surveys were conducted for each LU, using undisturbed and disturbed soil sampling. Undisturbed soil sampling was conducted at each depth using sample rings to analyze soil permeability. At a 0–30 cm depth, soil samples were also taken to analyze soil organic matter and texture. Erosion sensitivity (ES) was determined based on the results of permeability, soil texture, and organic carbon (C-organic) analysis using the applicable formula. According to [Asdak, 2010], the calculation of ES is determined using the following equation:

$$KE = \{2.7 \times 10^{-4}(12 - OM)M^{1.14} + \\ + 3.25(S - 2) + 2.5(P - 3)/100 \quad (1)$$

where: KE – erosion sensitivity, OM – percentage of organic matter, S – soil classification code, P – soil permeability (cm/hour), M – (% silt + fine sand) × (100 - % clay).

The results of laboratory tests on soil texture and permeability and the calculated erosion susceptibility are then classified based on [Arsyad, 2010] (Table 1, 2, and 3) to facilitate descriptive explanation.

Table 2. Soil permeability classification

Category	Permeability (cm/hour)
Slow	< 0.5
Slightly slow	0.5–2.0
Moderate	2.0–6.25
Slightly fast	6.25–12.5
Fast	> 12.5

Table 3. Erosion sensitivity classification

Category	Erosion susceptibility
Very low	0.00 to 0.10
Low	0.11 to 0.20
Moderate	0.21 to 0.32
Slightly high	0.33 to 0.43
High	0.44 to 0.55
Very high	0.56 to 0.64

RESULTS AND DISCUSSION

Soil texture

Soil texture is the ratio of the percentage of sand, silt, and clay particles. In addition, soil texture indicates the roughness or smoothness of the soil [Hardjowigeno, 2010]. Based on its distribution, the soil texture in the Jompi watershed area is dominated by two categories: a fine texture category with sandy clay loam and clay loam classes covering 2,049.62 ha (41.06%), including UL 2, 3, 4, 5, 10, 11, 14, 15, 16, and a somewhat coarse texture category with sandy clay covering 1,562.67 ha (31.29%), including UL 6, 7, 8, 12, 13, 17, 18, 20. This is influenced by geological conditions, particularly the Wapulaka Formation. From a lithological perspective, the Wapulaka Formation consists of carbonate rocks such as limestone, shale, and claystone, which, when weathered, tend to produce fine to moderately fine-textured soils. Additionally, this formation contains conglomerates and sandstones, which can produce coarse or sandy soils when weathered [Malim and Amala RM, 2023]. For further details, refer to Table 4 and the soil texture distribution in Figure 2.

Soil permeability

Soil permeability is the property of soil that indicates how quickly or slowly water can pass through saturated soil, which can be measured by the rate of water infiltration in the soil over a specific period of time [Arsyad, 2010]. Based on its distribution, the soil permeability in the Jompi watershed area is dominated by two categories: moderate permeability with values between 0.5–2.0 cm/hour covering 1,653.82 ha

Table 1. Soil texture classification

Category	Soil texture
Fine	Soils with a fine texture, including sandy clay, silty clay, clay
Slightly fine	Soils with a slightly fine texture, including sandy clay loam, silty clay loam, clay loam
Moderate	Soils with a medium texture, including loam, silt loam, silt
Slightly coarse	Soils with a slightly coarse texture, including sandy loam, fine sandy loam, very fine sandy loam
Coarse	Soils with a coarse texture, including loamy sand, sand

Table 4. Soil texture analysis results in the Jompi watershed area

Land unit	Soil texture					Area	
	Sand (%)	Silt (%)	Clay (%)	Texture class	Category	(Ha)	(%)
1	20	30	50	Clay	Fine	744.94	14.92
2	57	23	20	Sandy clay loam	Slightly fine	518.71	10.39
3	47	26	27	Sandy clay loam	Slightly fine	7.95	0.16
4	60	17	23	Sandy clay loam	Slightly fine	58.58	1.17
5	51	22	27	Sandy clay loam	Slightly fine	210.56	4.22
6	53	30	17	Sandy loam	Slightly coarse	97.94	1.96
7	58	27	15	Sandy loam	Slightly coarse	244.73	4.90
8	58	25	17	Sandy loam	Slightly coarse	205.21	4.11
9	75	12	13	Loamy sand	Coarse	81.53	1.63
10	32	30	38	Clay loam	Slightly fine	1,026.91	20.57
11	42	30	28	Clay loam	Slightly fine	73.35	1.47
12	75	12	13	Sandy loam	Slightly coarse	32.88	0.66
13	57	23	20	Sandy loam	Slightly coarse	356.05	7.13
14	39	31	30	Clay loam	Slightly fine	108.30	2.17
15	48	23	29	Sandy clay loam	Slightly fine	34.85	0.70
16	38	28	34	Clay loam	Slightly fine	10.41	0.21
17	60	23	17	Sandy loam	Slightly coarse	343.55	6.88
18	62	21	17	Sandy loam	Slightly coarse	273.80	5.48
19	50	31	18	Loam	Moderate	514.39	10.30
20	74	12	14	Sandy loam	Slightly coarse	8.51	0.17
21	88	6	6	Sand	Coarse	24.29	0.49
22	85	6	9	Sand	Coarse	16.01	0.32

Note: Laboratory test results, 2024

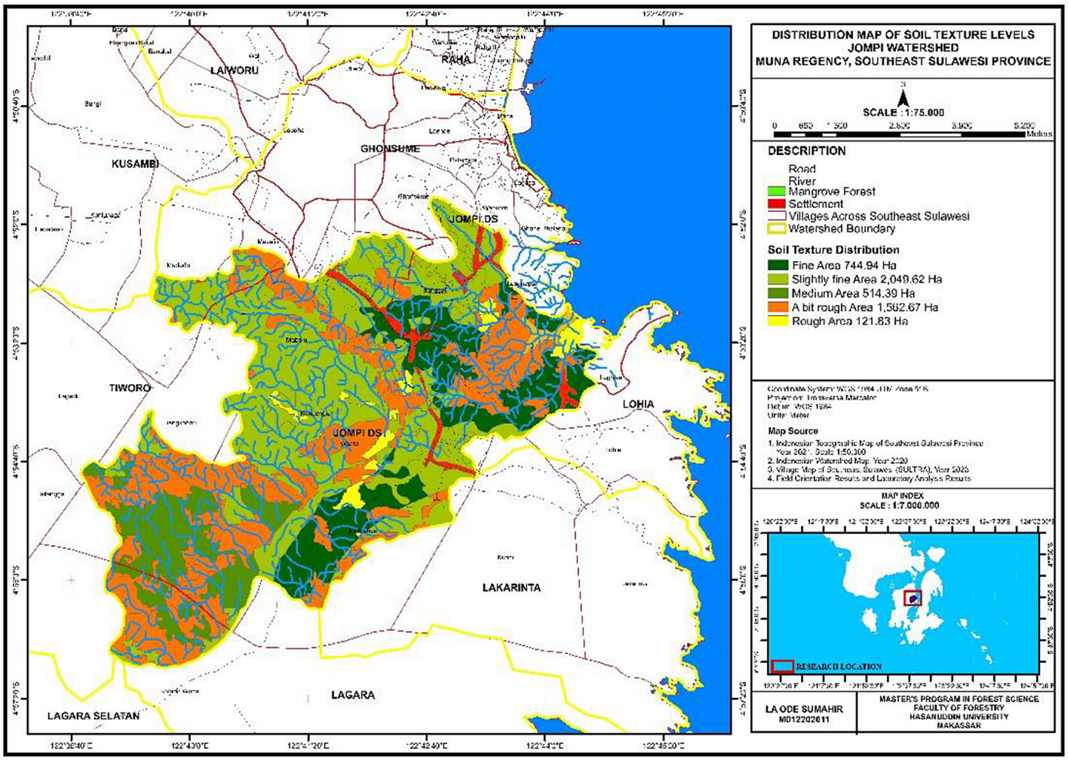

Figure 2. Soil texture distribution in the Jompi watershed area, Muna Regency (ArcGIS analysis, 2024)

(33.13%), including UL 2, 10, 11, 15, and rapid permeability with values > 12.5 cm/hour covering 1,458.16 ha (29.20%), including UL 7, 12, 17, 18, 19, 20, 21, 22. The permeability rate, whether slow or fast, is influenced by the soil texture in the study area, which contains significant fractions of clay, loam, and sand. The clay content in the soil is a key factor in determining permeability, as it affects the infiltration of water, while a higher percentage of sand results in faster permeability rates [Cai *et al.*, 2018]. For further details, refer to Table 5 and the permeability distribution map in Figure 3 below.

Erosion ensitivity

Erosion sensitivity is one of the indicators of erosion balance that measures the sensitivity of soil to water particles and flow [Sholikah *et al*., 2024]. The soil properties that influence sensitivity to erosion include soil texture, organic matter, structure, and permeability [Arsyad, 2010]. Furthermore, erosion sensitivity indicates the soil's resistance or durability level. Based on observations in the study area, the erosion sensitivity in the Jompi watershed area varies significantly. The very low erosion sensitivity category, with values ranging from 0.00 to 0.10, covers an area of 2,667.90 ha (53.44%), including land units 1, 2, 4, 5, 10, 11, and 15. The low erosion sensitivity category, with values ranging from 0.11 to 0.20, covers 580.65 ha (11.63%), including land units 3, 6, 13, 14, and 16. The medium erosion sensitivity category, with values between 0.21 and 0.32, covers 295.25 ha (5.91%), including land units 8, 9, and 10. The moderately high erosion sensitivity category, with values ranging from 0.33 to 0.43, covers 518.53 ha (10.38%), including land units 7 and 18. The high erosion sensitivity category, with values ranging from 0.44 to 0.55, covers 416.73 ha (8.35%), including land units 12, 17, 21, and 22. The very high erosion sensitivity category, with values between 0.56 and 0.64, covers 514.39 ha (10.30%), including land unit 19.

Table 5. Soil permeability analysis results in the Jompi watershed area

Land unit	Permeability value (cm/hour)	Category	Area	
			(Ha)	(%)
1	0.1	Slow	744.94	14.92
2	1.3	Slightly slow	518.71	10.39
3	4.9	Moderate	7.95	0.16
4	0.4	Slow	58.58	1.17
5	0.2	Slow	210.56	4.22
6	4.8	Moderate	97.94	1.96
7	13.5	Fast	244.73	4.90
8	7.3	Slightly fast	205.21	4.11
9	11.8	Slightly fast	81.53	1.63
10	0.5	Slightly slow	1,026.91	20.57
11	0.6	Slightly slow	73.35	1.47
12	22.0	Fast	32.88	0.66
13	4.8	Moderate	356.05	7.13
14	2.5	Moderate	108.30	2.17
15	0.7	Slightly slow	34.85	0.70
16	5.6	Moderate	10.41	0.21
17	19.97	Fast	343.55	6.88
18	14.5	Fast	273.80	5.48
19	21.1	Fast	514.39	10.30
20	13.9	Fast	8.51	0.17
21	18.3	Fast	24.29	0.49
22	19.3	Fast	16.01	0.32

Note: Laboratory test results, 2024

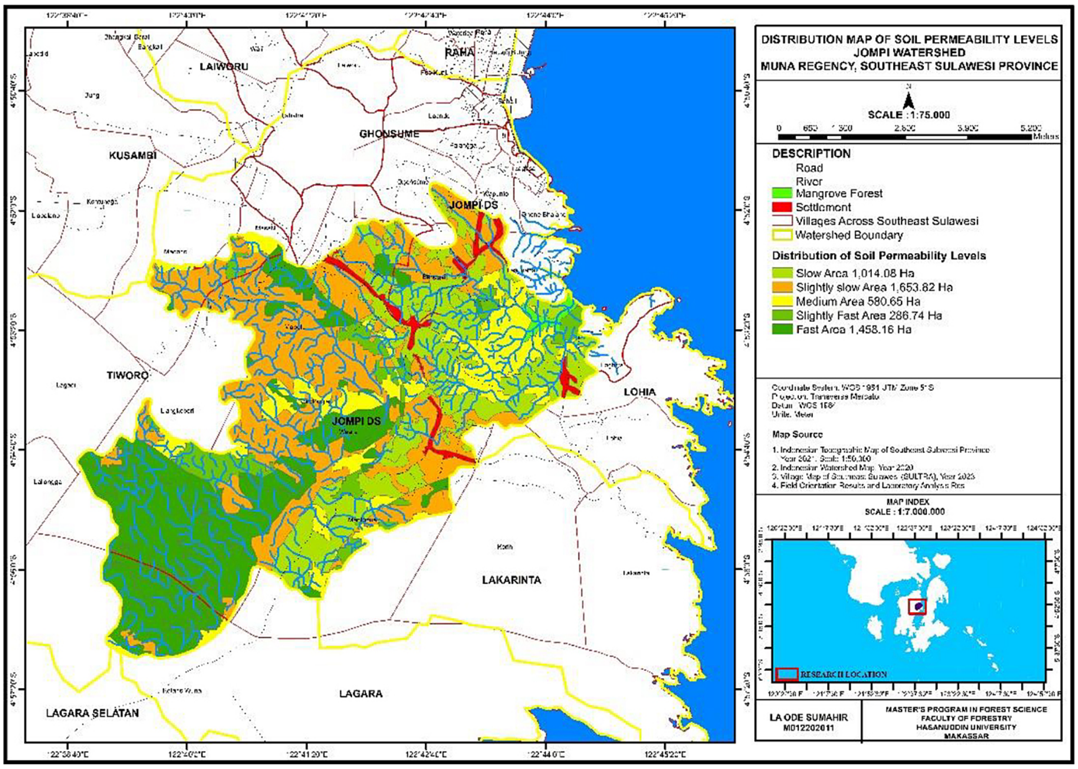

Figure 3. Soil permeability distribution in the Jompi watershed area, Muna Regency (ArcGIS analysis, 2024)

The data above shows that the very low erosion sensitivity category dominates the study area. This is influenced by the dominance of clay and sand textures, as well as slow and fast soil permeability. Soil with a higher clay content tends to have high erosion sensitivity, while soil with a higher sand content results in lower erosion sensitivity. Similarly, soil with fast permeability has low erosion sensitivity, while soil with slow permeability exhibits high erosion sensitivity [Marghmi *et al.,* 2024]. For further details, refer to Table 5 and the erosion sensitivity distribution map in Figure 4 below.

To manage erosion sensitivity in the Jompi Watershed, several measures need to be implemented, including vegetation management by maintaining and increasing vegetation cover, particularly in areas with high and very high erosion sensitivity, to strengthen soil structure and reduce the impact of raindrop energy [Mamo and Wedajo, 2023], land slope management by applying terracing or other soil conservation techniques in areas with steep slopes to reduce surface water flow velocity [Shen *et al.,* 2024], and land use regulation by controlling land use changes to match the land potential. Additionally, improving soil quality through the addition of organic matter and the implementation of agroforestry systems can enhance soil physical properties, increase infiltration capacity, and reduce erosion sensitivity [Ciawi *et al.,* 2023]. With proper management, erosion sensitivity in the Jompi Watershed can be minimized, reducing the risk of land degradation and ensuring the sustainability of the watershed's ecological functions.

CONCLUSIONS

The study concludes that erosion sensitivity in the Jompi watershed exhibited significant variation, ranging from very low to very high levels. The variation was primarily influenced by the soil texture and permeability characteristics of each Land Unit within the watershed. The spatial distribution of erosion sensitivity identified in this study provided a valuable basis for developing targeted and effective land management interventions. Management strategies to address erosion sensitivity include vegetation management, land use regulation, and soil quality improvement. Furthermore, tailored management approaches should be implemented to address the specific sensitivity levels of individual areas within the watershed.

Table 6. Results of erosion sensitivity analysis in the Jompi watershed area

Land unit	Erosion sensitivity value	Category	Area	
			(Ha)	(%)
1	0.05	Very low	744.94	14.92
2	0.07	Very low	518.71	10.39
3	0.15	Low	7.95	0.16
4	0.003	Very low	58.58	1.17
5	0.01	Very low	210.56	4.22
6	0.20	Low	97.94	1.96
7	0.41	Slightly high	244.73	4.90
8	0.22	Moderate	205.21	4.11
9	0.29	Moderate	81.53	1.63
10	0.06	Very low	1,026.91	20.57
11	0.08	Very low	73.35	1.47
12	0.52	High	32.88	0.66
13	0.15	Low	356.05	7.13
14	0.12	Low	108.30	2.17
15	0.03	Very low	34.85	0.70
16	0.16	Low	10.41	0.21
17	0.53	High	343.55	6.88
18	0.38	Slightly high	273.80	5.48
19	0.58	Very high	514.39	10.30
20	0.31	Moderate	8.51	0.17
21	0.45	High	24.29	0.49
22	0.47	High	16.01	0.32

Note: Calculation results and laboratory tests, 2024

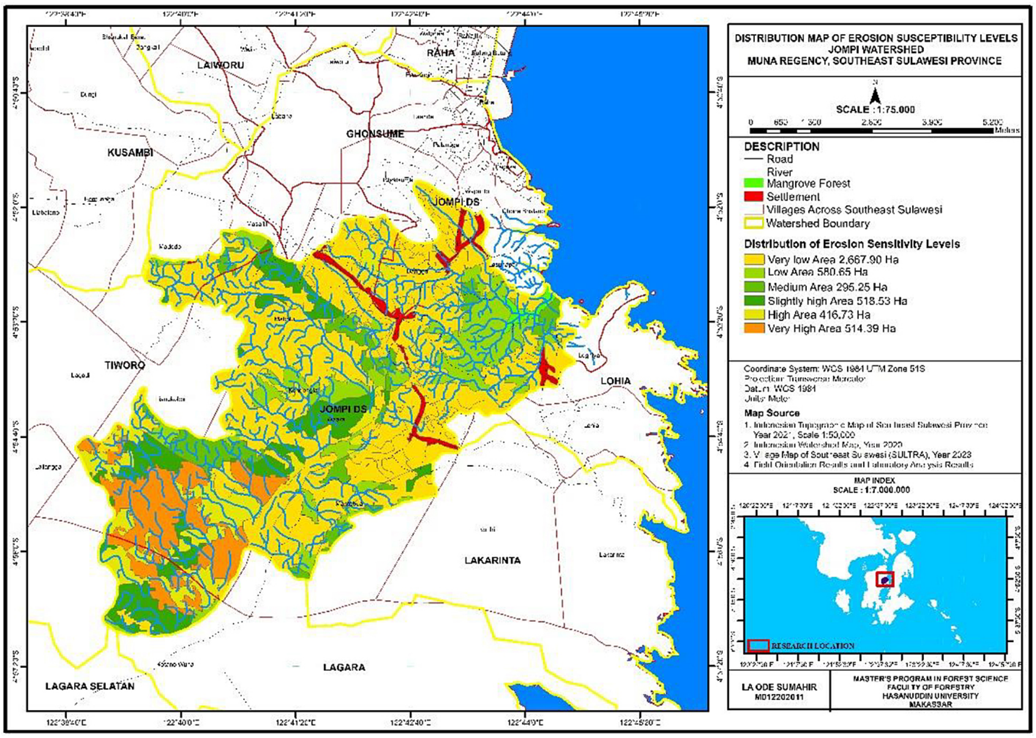

Figure 4. Distribution of erosion sensitivity in the Jompi watershed area, Muna Regency (ArcGIS analysis, 2024)

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