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Analysis of Erosion Rates in 2020 and 2024 Using Geographic Information Systems in the Liliba River Border Area, Liliba Village, Oebobo District

Glory Mei Sanada Silalahi[1], Muhammad Husain Hasan[2], Poppy Haryani[3]

[123]Geography Education Study Program, Faculty of Teacher Training and Education, Nusa Cendana University, Indonesia

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Abstrak

Kelurahan Liliba, Kota Kupang, merupakan kawasan sempadan sungai di wilayah semi-arid yang mengalami tekanan akibat perkembangan permukiman dan perubahan penggunaan lahan. Meskipun memiliki musim kemarau yang panjang, curah hujan yang terkonsentrasi pada musim hujan berpotensi meningkatkan laju erosi dan risiko degradasi lahan. Penelitian ini bertujuan menganalisis perubahan laju erosi dan dinamika tingkat bahaya erosi yang dipengaruhi oleh perubahan penggunaan lahan pada kawasan sempadan Sungai Liliba periode 2020–2024, serta menyusun arahan penggunaan lahan yang mendukung pengelolaan lingkungan secara berkelanjutan sesuai dengan Rencana Tata Ruang Wilayah (RTRW) Kota Kupang. Metode yang digunakan adalah Universal Soil Loss Equation (USLE) yang mencakup faktor erosivitas hujan (R), erodibilitas tanah (K), panjang dan kemiringan lereng (LS), penggunaan lahan (CP) yang dianalisis secara spasial menggunakan Sistem Informasi Geografis (SIG) untuk membandingkan kondisi tahun 2020 dan 2024. Hasil penelitian menunjukkan bahwa rata-rata laju erosi meningkat dari 300,45 ton/ha/tahun pada tahun 2020 menjadi 889,09 ton/ha/tahun pada tahun 2024. Perubahan tersebut diikuti pergeseran dominasi tingkat bahaya erosi dari kelas berat seluas 253,75 ha pada tahun 2020 menjadi kelas sangat berat seluas 281,32 ha pada tahun 2024. Berdasarkan hasil analisis, arahan penggunaan lahan disusun sesuai tingkat bahaya erosi dengan menekankan penerapan konservasi tanah dan air serta perlindungan kawasan sempadan sungai. Penelitian ini menunjukkan bahwa perubahan penggunaan lahan pada kawasan sempadan sungai di wilayah semi-arid berkontribusi terhadap peningkatan bahaya erosi, sehingga diperlukan pengelolaan penggunaan lahan yang terintegrasi untuk mendukung keberlanjutan lingkungan di Kelurahan Liliba.

Abstract

Liliba Subdistrict , Kupang City , is area border rivers in semi-arid regions that experience pressure consequence development settlements and changes use Land . Despite having a long dry season, concentrated rainfall during the rainy season has the potential to increase erosion rates and the risk of land degradation. This study aims to analyze changes in erosion rates and the dynamics of erosion hazard levels influenced by changes in land use in the Liliba River riparian area for the period 2020–2024, as well as to develop land use guidelines that support sustainable environmental management in accordance with the Kupang City Spatial Plan (RTRW). The method used is *the Universal Soil Loss Equation* (USLE) which includes factors of rainfall erosivity (R), soil erodibility (K), slope length and gradient (LS), land use (CP) which are analyzed spatially using Geographic Information Systems (GIS) to compare conditions in 2020 and 2024. The results of the study show that the average erosion rate increased from 300.45 tons/ha/year in 2020 to 889.09 tons/ha/year in 2024. This change was followed by a shift in the dominance of the erosion hazard level from a heavy class covering an area of 253.75 ha in 2020 to a very heavy class covering an area of 281.32 ha in 2024. Based on the results of the analysis, land use guidelines are prepared according to the level of erosion hazard by emphasizing the implementation of soil and water conservation and protection of riparian areas. This study shows that changes in land use in riparian areas in semi-arid areas contribute to increasing erosion hazards, so integrated land use management is needed to support environmental sustainability in Liliba Village

E-mail: akhmad.firli@student.upi.edu

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PENDAHULUAN

Indonesia is located in the region climate tropical with two seasons main marked with change weather , temperature , and direction enough wind extreme (Kurniadi et al., 2024). These climatic conditions, combined with varied topography and diverse rock characteristics, produce fertile soil. However, on the other hand, these conditions can also have adverse impacts on humans, such as hydrometeorological disasters, including floods, landslides, forest fires, and drought (Yanfatriani et al., 2024). As time goes by and human activity increases, environmental damage becomes more severe, which ultimately triggers an increase in the frequency and intensity of hydrometeorological disasters that occur in various regions of Indonesia.

Rainfall is one of the factors that significantly influences the rate of erosion. According to the report BPS (2023), semi-arid regions such as East Nusa Tenggara experience unique seasonal rainfall patterns, where 70% of annual rainfall is concentrated in 3-4 months with extreme intensity (100-600 mm/month). This condition increases the risk of erosion considering the projected increase in extreme rainfall and the possible negative impacts of land use changes (Eekhout & de Vente, 2022). Erosion is the process of moving soil particles from one location to another due to natural forces such as water, wind, or human activities (Borrelli et al., 2017). This erosion process has significant impacts on the environment, such as decreased soil productivity, land degradation, and landslides.

The Liliba Watershed is one of the important areas in Kupang City, East Nusa Tenggara Province, with an area of approximately 4,543 ha. Based on data from the East Nusa Tenggara Provincial Disaster Management Agency (BNPB), almost all of NTT, including Kupang City, is prone to landslides and floods. (Fatima, 2023). Population growth in Kupang City has led to an increase in the need for land for settlements, agriculture, and other activities. This condition has triggered land conversion in the Liliba Watershed area, from forests or green areas to residential areas and other non-conservation activities. Similar findings were reported by Mbas et al., (2022), who found that land disturbance caused by human activities and the absence of conservation practices accelerate erosion by reducing vegetation cover and increasing soil susceptibility to runoff. Land conversion that is not accompanied by soil and water conservation measures has led to increased erosion, decreased soil quality, reduced spring discharge, and a higher risk of landslides.

Semi-arid regions like Kupang City have distinct climatic characteristics compared to most parts of Indonesia. Annual rainfall tends to be concentrated in a few months of the rainy season with high intensity, while the dry season lasts longer. These conditions create unique environmental vulnerabilities, where high rainfall energy in a short period of time can produce high surface runoff and trigger intensive erosion processes, especially in riverbank areas that are under pressure from land-use changes. In addition to increasing pressure on the environment, residential development in the Liliba River riparian area also has the potential to increase disaster risks for the surrounding community. Population growth and urban land demand encourage the use of riverbank areas for residential development, despite these areas having a relatively high level of vulnerability to erosion and riverbank landslides (Fatima, 2023). If erosion rates continue to increase, the impacts will not only result in land loss but also threaten riverbank stability, increase sedimentation, damage residential infrastructure, and disrupt social and economic activities. In semi-arid regions, changes in land use accompanied by increased extreme rainfall events can accelerate land degradation and increase environmental risks for communities living in erosion-prone areas (Eekhout & de Vente, 2022). Therefore, erosion management in the Liliba River riparian area needs to be understood not only as a land conservation effort but also as part of disaster risk reduction and urban community protection. In recent years, residential development in Liliba Village has shown quite rapid growth, potentially reducing vegetation cover and increasing land vulnerability to erosion.

Various studies have utilized the USLE method to estimate erosion rates in watersheds, agricultural areas, and hilly areas. Borrelli et al. (2017) showed that land-use change is a major factor in increasing soil loss globally. In semi-arid regions, Baiamonte et al. (2019) found that land cover changes significantly increased soil erosion, while Eekhout and de Vente (2022) explained that climate change and increased extreme rainfall events can accelerate land degradation in erosion-prone areas. In Indonesia, Neolaka et al. (2022) utilized the USLE method to map erosion-prone areas in Kupang City.

However, these studies generally focus on estimating erosion rates and mapping erosion vulnerability without specifically analyzing the dynamics of changes in erosion hazard levels influenced by residential expansion in urban riverbank areas.

Furthermore, studies on changes in erosion hazard levels in river corridors in semi-arid urban areas are still relatively limited. Therefore, this study fills this gap by analyzing changes in erosion rates and erosion hazard dynamics due to land-use changes in the Liliba River riparian area during the 2020–2024 period using a Geographic Information System-based USLE approach.

Research on erosion rates is crucial for disaster mitigation and sustainable land management. Erosion prediction is a method for estimating current erosion rates and determining erosion hazard levels, thereby determining policies regarding necessary conservation measures. The *Universal Soil Loss Equation (USLE*) method has been widely used due to its simplicity and relatively low data requirements (Arsyad, 2010). By utilizing Geographic Information Systems (GIS) technology and remote sensing data, spatial erosion analysis can be conducted efficiently and accurately to support sustainable spatial planning.

METHOD

Location and Time of Research

The research was conducted in Liliba Village, Oebobo District, Kupang City, which has an area of 13 km² with the Liliba River, which is 3.7 km long, passing through the area. Astronomically, Liliba Village is located at coordinates -10° 9' 43" South Latitude – 123° 38' 10.025" East Longitude, as depicted in Figure 1.

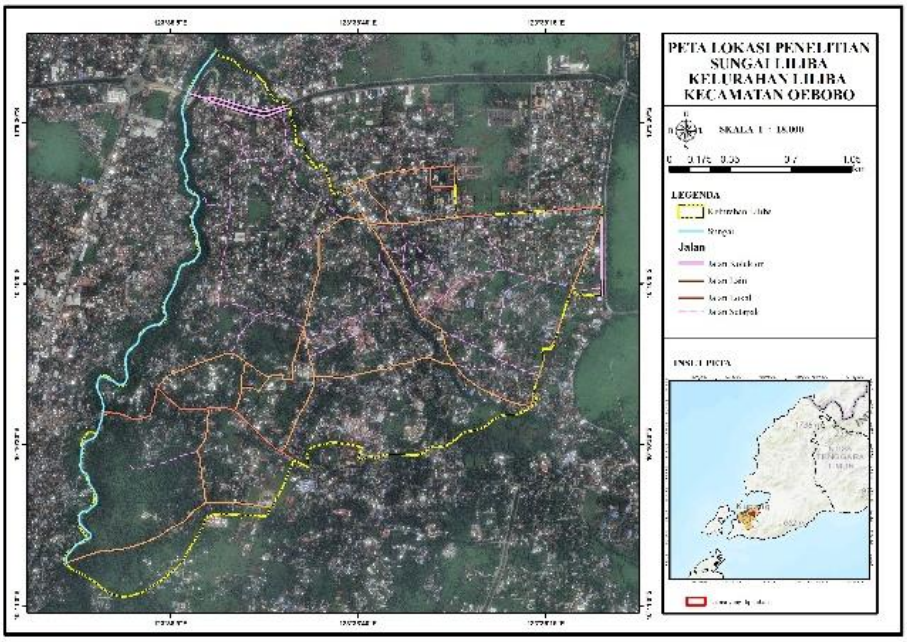


Figure 1. Research Location Map
Source: Research Results 2025

The research was conducted from June 2025 to January 2026, encompassing data collection, spatial data processing, and field validation. The location was selected based on the high potential for erosion due to land-use changes and the topography, which varies from gentle to very steep slopes.

This study uses a quantitative descriptive approach with Geographic Information System-based spatial analysis. This approach was chosen because of its ability to integrate various geospatial data to produce comprehensive information on the distribution and level of erosion hazard (Neolaka et al., 2022).

The data used include primary data in the form of field documentation and secondary data in the form of Sentinel-2 satellite imagery, rainfall data, DEM (*Digital Elevation Model*), and soil type maps. Topographic data was obtained from the National Digital Elevation Model (DEMNAS) published by the Geospatial Information Agency (BIG) with a spatial resolution of 8 meters. DEM data is used to generate LS (slope length and steepness) factors that describe the effect of slope length and steepness on erosion potential. The integration of these data allows for multi-temporal analysis to compare erosion conditions in 2020 and 2024. The flow of this research is depicted in the Thinking Framework (Figure 2) below.

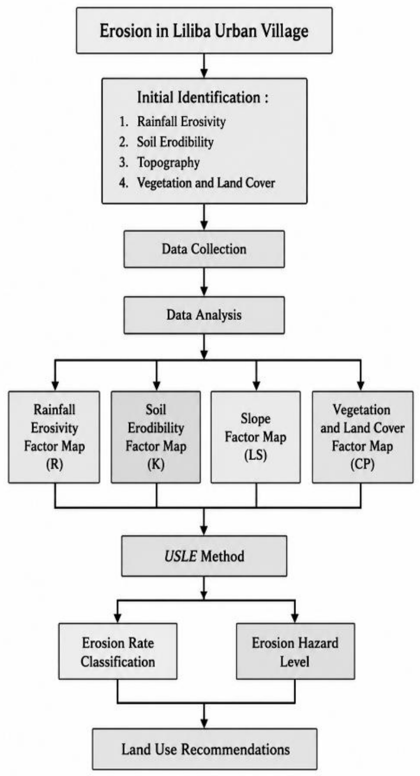


Figure 2. Thinking Framework
Source: Research Results 2025

Data Collection and Instrumentation

Data collection was carried out in several stages. Sentinel-2 satellite imagery data from 2020 and 2024 with a resolution of 10 meters was obtained from the *Copernicus Data Space Environment portal* for land cover change analysis. Monthly rainfall data from 2015-2024 was obtained from the BMKG Kupang City Station for calculating rain erosivity. DEM data with a resolution of 8 meters was obtained from the Geospatial Information Agency (BIG) for slope analysis. Soil type data at a scale of 1:50,000 was obtained from the Center for Agricultural Land Resources Research and Development (BBPSDLP) to determine soil erodibility factors.

The research sample was determined using a purposive sampling method based on land units formed from an overlay of land use maps, slope maps, and soil type maps. The overlay resulted in 17 land units representing the characteristics of the research area (Pasaribu, 2017). One sample point was taken from each land unit for field validation using a *Global Positioning System (GPS*) and a camera for documentation.

The accuracy of the image interpretation results was tested through a ground check, producing an interpretation accuracy level of 88.24%, exceeding the minimum standard of 85% stipulated in Geospatial Information Agency Regulation No. 15 of 2014.

Data analysis

Analysis of erosion rate using the USLE (*Universal Soil Loss Equation*) method as in formula 1.

$$A = R \times K \times LS \times CP \quad (1)$$

Where :
A = amount of erosion (tons/ha/year)
R = rainfall erosivity factor
K = soil erodibility factor
LS = slope length and gradient factor
CP = land cover and crop management factors.
(Source: Wischmeier & Smith, 1978)

Rain erosivity was formulated by Lenvain (1989), where calculating using this equation is simpler and closer to reality (Arif, 2024). The calculation of the R factor uses the formula in formula 2.

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

Where :
R = erosivity Rain
p = rainfall Rain monthly
(Source : Lenvain, 1989)

The R value then interpolated in a way spatial use method *Inverse Distance Weighted* (IDW) in ArcGIS 10.8 for produce map distribution erosivity Rain .

The soil erodibility factor (K) is determined based on the soil type by referring to the erodibility index table from Kironoto et al (2021)and Arsyad (2010)as in Table 1.

No	Soil Type	K value
1	Chocolate Latosol	0.26
2	Reddish Yellow Latosol	0.12
3	Red Latosol	0.12
4	Complex Mediterranean , Grumusal	0.21
5	Latosol	0.31
6	Alluvial, Gleisol district, Alluvial gleik,	0.47
7	Regosol	0.40
8	Latosol, Chromic podsolic, Haplic oxisol	0.31
9	Mediteran haplik, Mediteran molik, Rezina	0.46
10	Lytic Cambisol, Eutric Cambisol, District Cambisol	0.33

Table 1. Soil Erodibility Value (K)
Source: Kironoto et al (2021) and Arsyad(2010)

The soil erodibility factor (K) value is determined based on the type of soil found in the research area. The determination of the K value refers to the soil erodibility index of Kironoto et al (2021)and Arsyad (2010). The K values used in this study are presented in Table 1. From Table 1, the soil types found in Liliba Village are Eutric Regosol (K=0.40), Renzina (K=0.46), and Litic Cambisol (K=0.33).

The slope length and gradient (LS) factors are calculated based on the slope gradient class obtained from Digital Elevation Model (DEM) data. The determination of the LS value refers to the LS factor table according to Christian and Stewart as quoted by Pasaribu (2017)The LS factor values are presented in Table 2.

Table 2. LS Factor Values

No	Gradient (%)	Classification	LS Value
1	0-8	Flat	0.25
2	8-15	Sloping	1.20
3	15-25	A bit steep	4.25
4	24-45	Steep	9.50
5	>45	Very Steep	12.00

Source : Christian and Stewart in Pasaribu (2017)

Closing factor land and management plants (CP) are determined based on map use land results interpretation Sentinel-2 MSI imagery in 2020 and 2024 with resolution spatial 10 meters gained from the Copernicus Data Space Ecosystem.

Interpretation use land done through visual digitization (*on-screen digitizing*) based on element interpretation image like hue , color , texture , shape , pattern , site, and association. Interpretation results Then verified through survey field (*ground check*) for ensure suitability class use land . The determination of the CP value refers to the CP index published by Bappenas (2012). The CP factor values are presented in Table 3.

No	Land Use	CP Value
1	Settlement	1.00
2	Swamp/ forest swamp	0.001
3	pond	0.001
4	Factory/ building	1.00
5	Airport / port	1.00
6	Salting	1.00
7	River	0.001
8	Sand	1.00
9	Lake/ dam	0.001
10	Open land/ field grass	0.02
11	Shrubs	0.1
12	Irrigated rice fields	0.02
13	cistern rice fields Rain	0.05
14	Forest	0.001
15	Garden	0.3
16	Field	0.28

Table 3. Determination of CP Value Based on Land Use Type
Source :Bappenas (2012)

All over USLE factors (R, K, LS, and CP) then processed and *overlaid* use device ArcGIS software for produce map rate erosion and levels danger erosion. Classification of erosion hazard levels refers to Arsyad (2010)

Validation and Preparation of Land Use Directives

Validation of the analysis results was conducted through ground checks at 17 sample points representing each land unit. The level of interpretation accuracy was calculated using the formula in Formula 3.

Level of Correctness =
(Number of Correct Points)/(Number of Survey Points) x 100 (3)

The validation results showed an accuracy of 88.24%, indicating a high level of reliability in image interpretation and spatial analysis. Land use guidelines were developed based on erosion hazard analysis, taking into account topographic characteristics, soil type, and existing land cover conditions (Akbar, 2024).

Conservation guidelines are structured in stages according to erosion hazard class, ranging from vegetative to mechanical techniques to ensure sustainable land use.

RESULTS AND DISCUSSION

Dynamics of Factors Causing Erosion

The analysis results show that the rainfall erosivity factor (R) experienced a significant increase from 798.25 MJ mm /ha/year in 2020 to 1,152.58 MJ mm /ha/year in 2024, or an increase of 44.3%. The rainfall map for Liliba Village can be seen in Figures 2 and 3.

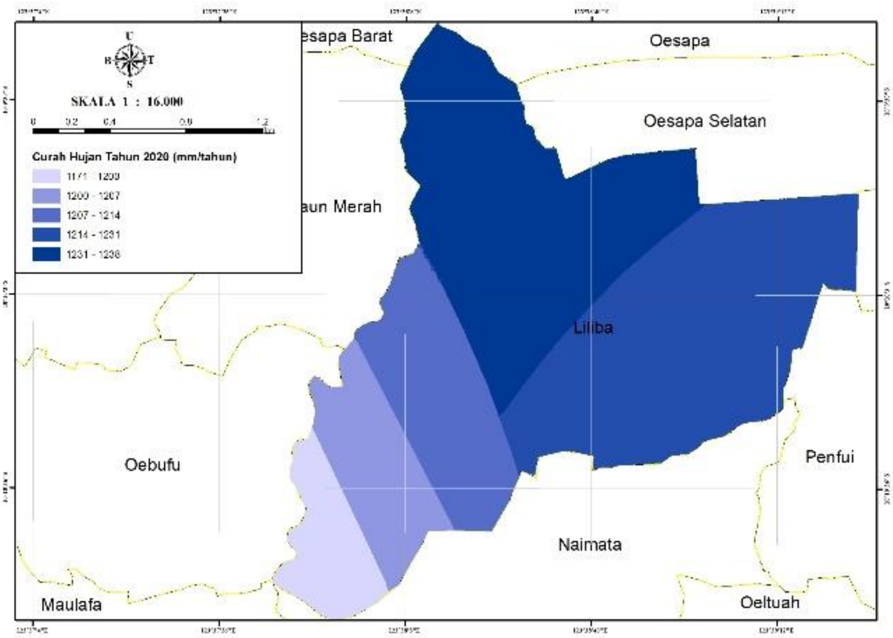


Figure 2. Rainfall Map for 2020
Source: Research Results 2025

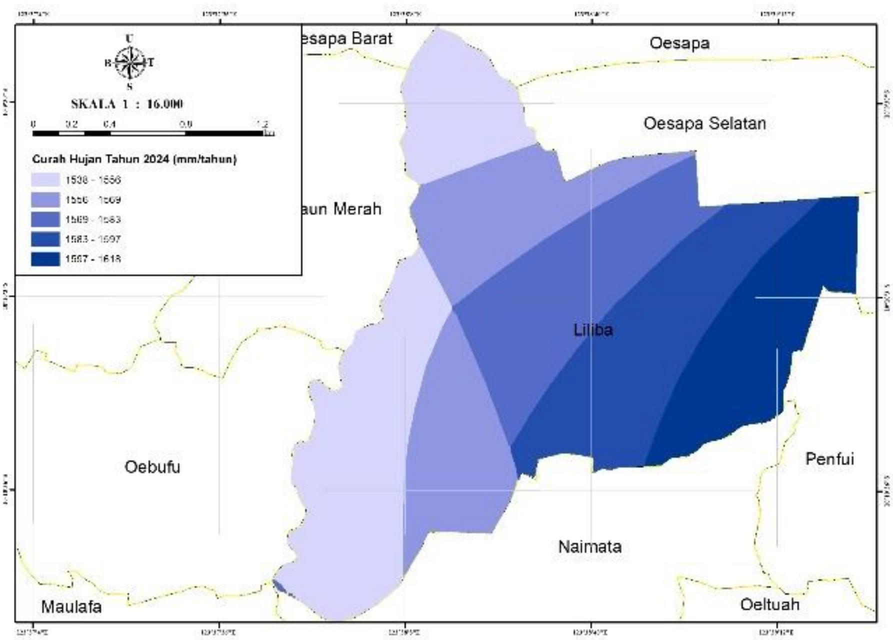
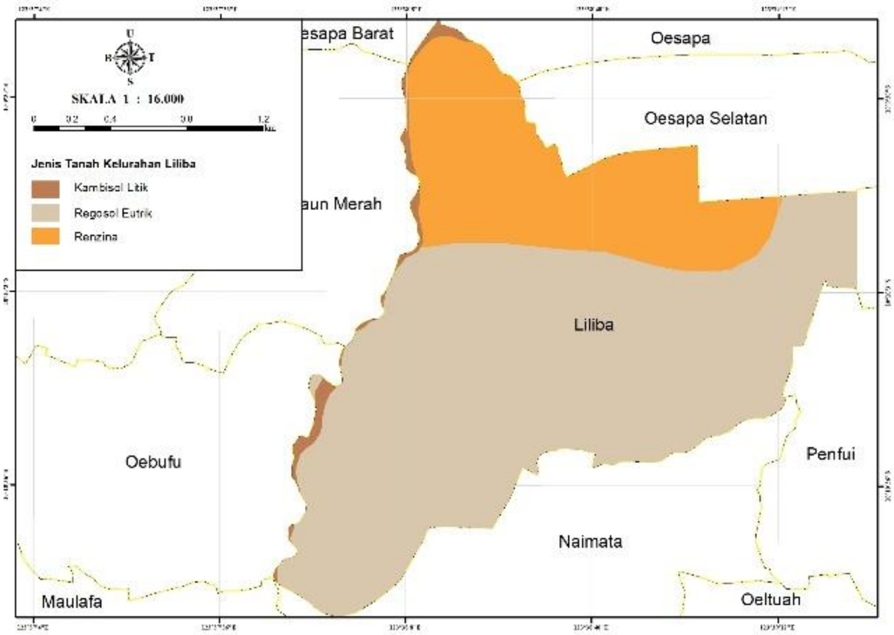


Figure 3. Rainfall Map for 2024
Source: Research Results 2025

This increase is due to rainfall anomalies that have occurred in Kupang City in recent years, particularly in January-March and December (Erniati et al., 2025). Rainfall distribution in Liliba Village shows a very clear seasonal pattern, with 75% of the total annual rainfall concentrated in just four months, confirming that this region is characterized by a long dry season and peak rainfall focused at the beginning to the end of the year. This condition increases the risk of erosion because high rainfall intensity in a short period can trigger large surface runoff.

The soil erodibility factor (K) shows a variation in values between 0.33 and 0.46 depending on the soil type. The soil type map is presented in Figure 4.



Source: Research Results 2025
Figure 4. Soil Type Map

Based on Table 4, the soil erodibility factor (K) in Liliba Village shows a variation in values between 0.33 and 0.46. Renzina soil type has the highest erodibility value (K=0.46) with an area of 118.66 ha (26%), followed by Eutric Regosol (K=0.40) covering 324.95 ha (72%), and Litic Cambisol (K=0.33) covering 5.07 ha (1%).

Table 4. Type and Area of Land in Liliba Village, Oebobo District

No	Soil Type	Wide (Ha)	(%)
1	Regosol Eutrik	324.95	72
2	Renzina	118.66	26
3	Lytic Cambisol	5.07	1
	Total	448.67	100

Source : Research Results 2025

The high erodibility value of Renzina soil is caused by the high $CaCO_3$ content (>40%) and the less stable soil structure so that it is easily dispersed when receiving rain impacts (R. Y. Mahardika, 2020). Eutric Regosol which dominates the research area also has a fairly high sensitivity to erosion because it is a young soil with shallow solum, good drainage, a texture that tends to be somewhat coarse, and low organic matter content.(Hartono, 2016) .

Table 5. Slope Gradient of Liliba Village, Oebobo District

No	Slope Gradient	Classification	Area (Ha)	%
1	0 – 8	Flat	148.94	33
2	8 – 15	Sloping	204.46	46
3	15 – 25	A bit steep	40.69	9
4	24 – 45	Steep	5.32	1
5	>45	Very Steep	49.26	11
	Total		448.67	100

Source: Research Results 2025

The high erodibility value of Renzina soil is caused by the high $CaCO_3$ content (>40%) and the less stable soil structure so that it is easily dispersed when receiving rain impacts. (R. Y. Mahardika, 2020)The slope gradient (LS) factor in Liliba Village (Figure 5) shows significant variations (Table 5), ranging from flat classes (0-8%) covering an area of 148.94 ha (33%) to very steep (>45%) covering an area of 49.26 ha (11%). The gentle slope class (8-15%) dominates with an area of 204.46 ha (46%), while the steep class (25-45%) has the smallest area of 5.32 ha (1%).

The largest LS value is at a slope gradient of >45% with an index of 12.00, which is found in the VKLSg, VRESB, VRSB, and VRSg land units. The interaction between high slope gradients and soil types that have high erodibility creates conditions that are very susceptible to erosion, because the speed of surface flow increases drastically on steep slopes so that the ability to transport sediment also increases (Silvia et al., 2025).

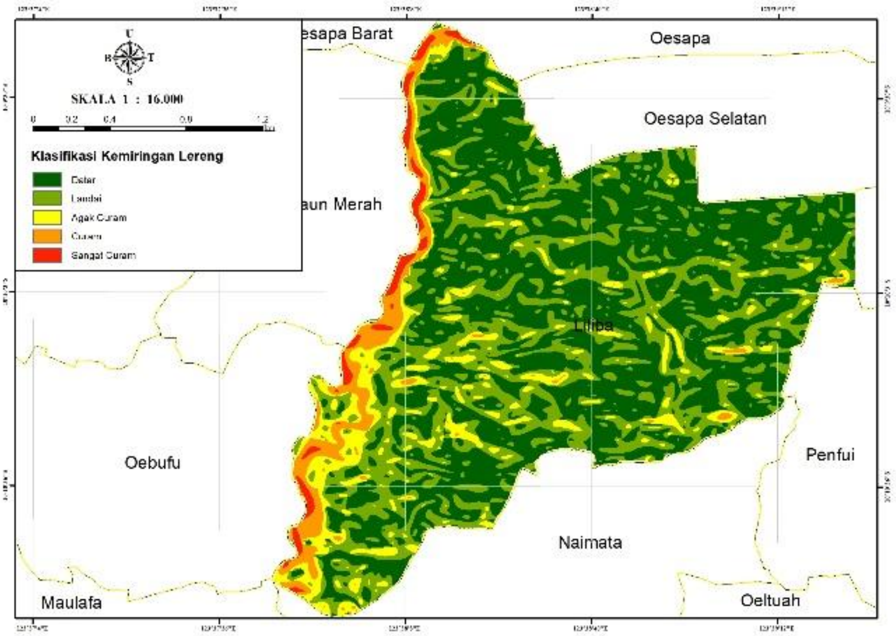


Figure 5. Slope Map
Source: Research Results 2025

Land use factors (CP) experienced significant changes during the 2020-2024 period, as can be seen in Figures 6 and 7.

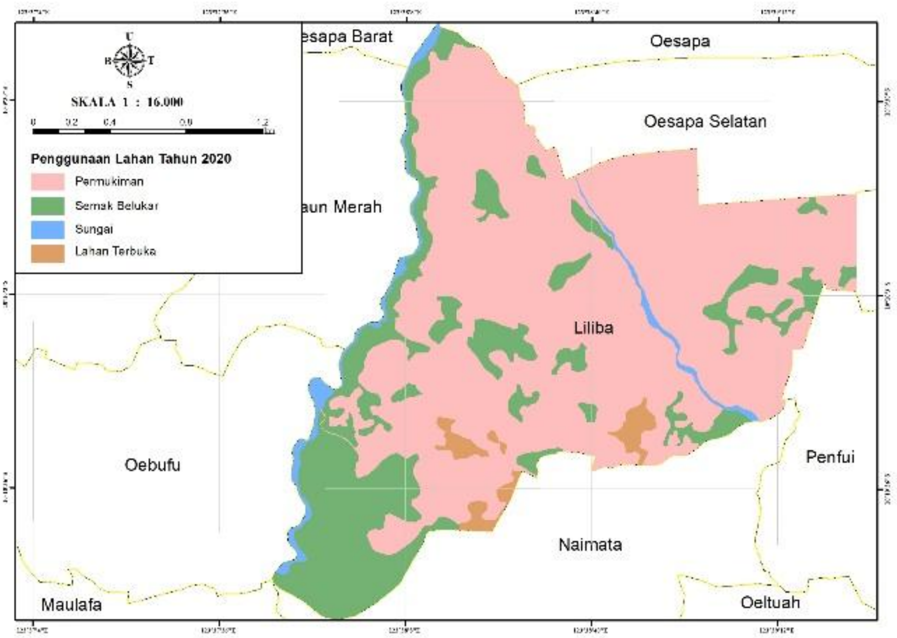
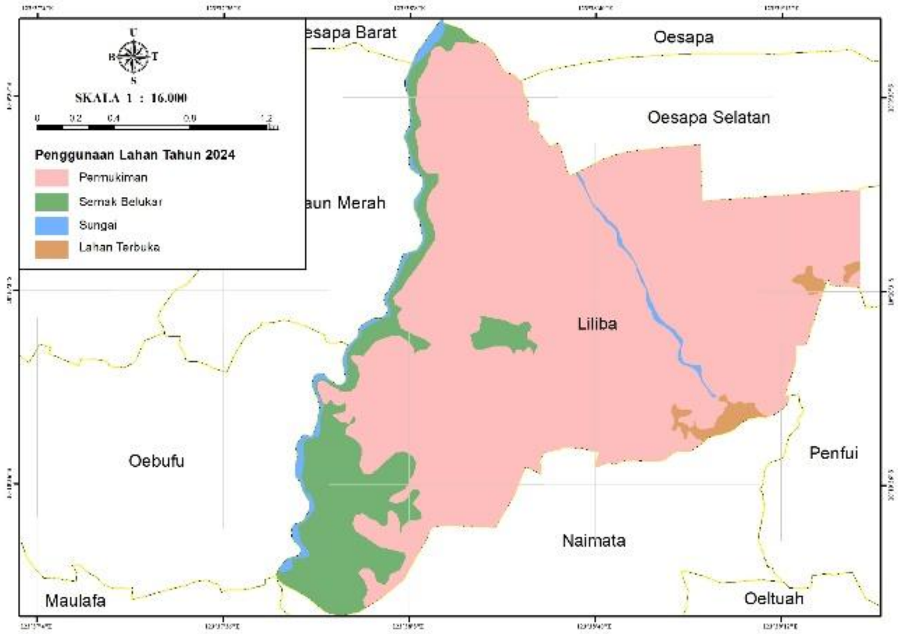


Figure 6. Land Use Map 2020
Source: Research Results 2025



Source: Research Results 2025

Figure 7. Land Use Map for 2024

The area of settlements increased from 325.72 ha (72.62%) in 2020 to 374.61 ha (83.51%) in 2024, an increase of 48.89 ha. Conversely, the area of scrubland decreased drastically from 101.74 ha (22.68%) to 58.60 ha (13.06%), a decrease of 43.14 ha, as shown in Table 6.

Table 6. Land Use in Liliba Village, Oebobo District

No.	Land Use	2020 Area (Ha)	2020 %	2024 Area (Ha)	2024 %
1	Settlement	325.72	72.62	374.61	83.51
2	Check the bushes	101.74	22.68	58.60	13.06
3	River	11.80	2.63	9.37	2.09
4	Open Land	9.40	2.09	6.09	1.36
	Total	**448.67**	**100**	**448.67**	**100**

Source : Research Results 2025

Change This impact straight to the increase mark CP factor because settlement own CP value = 1 which indicates No existence protection surface land , whereas bush thicket has CP=0.1 which is still give protection to energy runoff .

Change of function land vegetation towards the built-up area remove ability experience closing land in dampen collision rain and maintain structure aggregate land , so that speed up occurrence erosion (Mahardika & Muta'ali, 2018).

Increased Erosion Rates and Changes in Erosion Hazard Levels

The calculation results show that the average regional erosion rate increased from 300.45 tons/ha/year in 2020 to 889.09 tons/ha/year in 2024. The erosion rate map for 2020 can be seen in Figure 8 and the erosion rate map for 2024 can be seen in Figure 9. The results of the overlay of erosion hazard level maps for 2020 and 2024 show the dynamics of changes in the erosion hazard level in the Liliba River border area.

Based on Figure 11, changes were dominated by the Increase category (increased erosion hazard level), which was distributed across most of the study area. This increase occurred primarily in areas that experienced changes from Moderate to Severe and from Severe to Very Severe. This condition indicates that land vulnerability to erosion increased during the observation period.

Meanwhile, the Stable category was found in several areas that experienced no change in erosion hazard levels between 2020 and 2024. These areas are generally located in land units with relatively unchanged land use characteristics and physical conditions during the observation period. The Decrease category was only found in a small portion of the area, indicating a decrease in erosion vulnerability compared to conditions in 2020.

The predominance of areas experiencing increased erosion hazard levels indicates that changes in land use and environmental conditions in the Liliba River riparian area contribute to the increased potential for land degradation. These results reinforce the finding that river riparian areas in the semi-arid region of Kupang City require more integrated land use management through the implementation of soil and water conservation, protection of riparian vegetation, and control of land use in areas with high erosion hazard levels. The percentage change in erosion rates is presented in Figure 11.

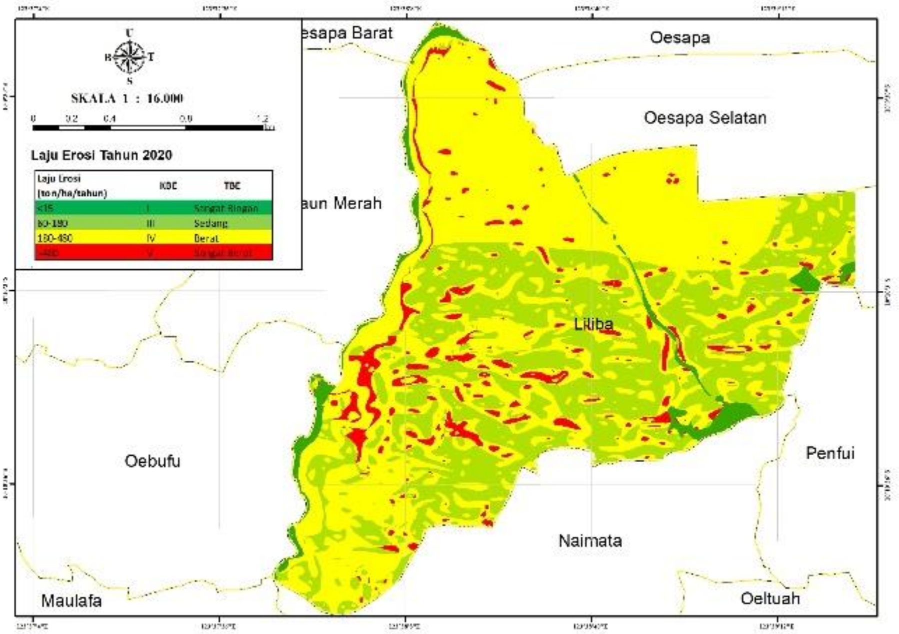
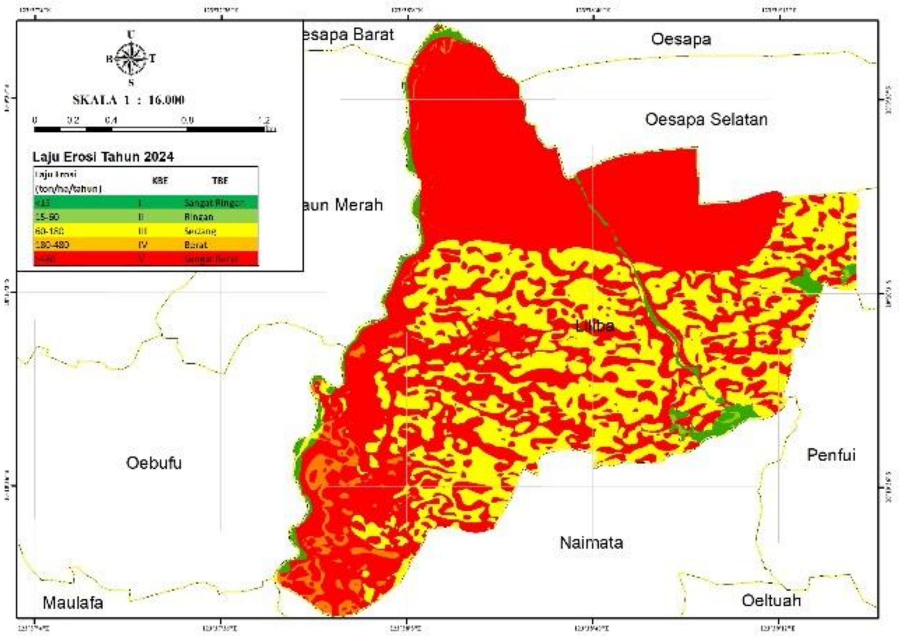
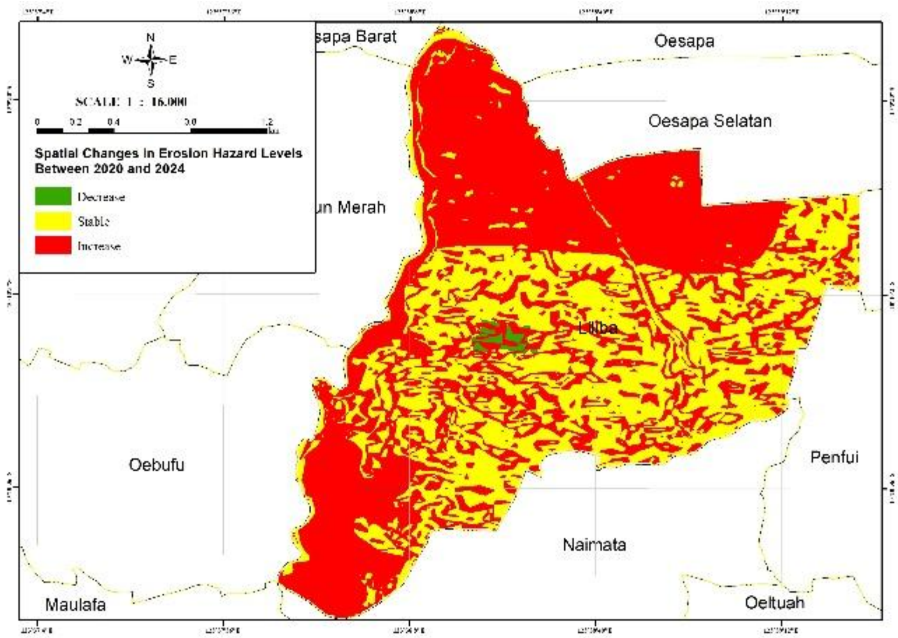


Figure 8. Erosion Rate Map for 2020
Source: Research Results 2025



Source: Research Results 2025
Figure 9. Erosion Rate Map for 2024



Source: Research Results 2025

Figure 10. Map of Erosion Rate Changes in 2020 and 2024

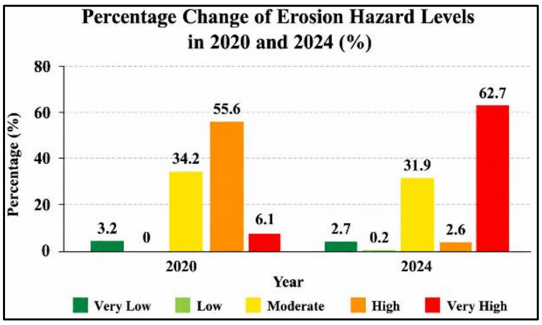


Figure 11. Percentage Change in Erosion Rate
Source: Research Results 2025

The lowest erosion rate values in both observation periods were found in the IRESg land unit (river area) with values of 0.08 tons/ha/year (2020) and 0.12 tons/ha/year (2024), while the highest values were found in the IIIRPm land unit with a value of 1,560.58 tons/ha/year (2020) and the IVREPm land unit with a value of 4,379.80 tons/ha/year (2024).

This drastic increase in erosion rates is caused by a complex interaction between increased rainfall erosivity (R), residential expansion on steep slopes, and the combination of sensitive soils and steep slopes (K and LS). Increased rainfall acts as an initial trigger because the greater kinetic energy of the rain accelerates the release of soil particles.

However, significant increases in erosion did not occur without changes in land use, particularly the 48.89 ha increase in residential area, which changed the CP value to 1.00 and removed soil-retaining vegetation.

This condition aligns with research Dinh et al (2021)stating that rainfall is a factor that significantly influences the rate of erosion, but its impact is magnified by land cover conditions and soil characteristics.

The distribution of erosion hazard (EBH) classes experienced a significant shift between 2020 and 2024. In 2020, the Erosion Hazard Class (EBH) was dominated by the Severe (IV) category with an area of 253.75 ha (56.6%), followed by the Moderate (III) category with an area of 153.37 ha (34.2%), Very Severe (V) with an area of 27.25 ha (6.1%), and Very Light (I) with an area of 14.30 ha (3.2%). In 2024, there was a shift in dominance to the Very Severe (V) category with an area of 281.32 ha (62.7%), the Moderate (III) category decreased to 142.91 ha (31.9%), the Severe (IV) category decreased drastically to 11.49 ha (2.6%), the Very Light (I) category became 12.03 ha (2.7%), and the Light (II) category appeared with an area of 0.92 ha (0.2%). These changes indicate that more than half of the area experienced increasingly intensive land degradation during the observation period.

Analysis of changes in TBE classes using the overlay method shows that changes in erosion rates are dominated by an increase in erosion class, particularly from Severe to Very Severe with an area reaching 250.01 ha or 55.74% of the total area.

In addition, there is a change from Moderate to Very Severe class covering an area of 2.19 ha (0.49%), from Moderate to Severe class covering an area of 10.97 ha (2.44%), and from Very Light to Very Heavy class covering an area of 0.32 ha (0.07%). The area that did not experience changes in erosion class is also quite extensive, particularly in the Moderate (140.22 ha or 31.26%) and Very Light (12.03 ha or 2.68%) classes. This condition indicates that the Liliba River border area is increasingly vulnerable to damage due to erosion and requires serious handling in land management.

Interactions Between Erosion Factors

The increase in erosion is not the result of a single factor, but rather the result of a strong interaction between erosion-causing factors. The interaction between increasing R and CP values causes a drastic increase in surface runoff because the change in land use from shrubs (CP=0.1) to residential areas (CP=1) eliminates the rain-retaining function, reduces infiltration, and focuses the impact energy of rain directly on the ground surface.

This phenomenon is the main trigger for the erosion spike in 2024 and is in line with research Baiamonte et al (2019)that states that land cover management can reduce excessive soil loss and protect the topsoil from the effects of rainfall.

The high rate of erosion in land units dominated by Renzina and Regosol soils is influenced not only by slope and rainfall factors, but also by the physical characteristics of the soil. Renzina soils generally develop from limestone with a high calcium carbonate ($CaCO_3$) content . Despite their relatively good fertility, these soils tend to have an aggregate structure that is easily dispersed when receiving high-intensity rainfall. This aggregate dispersion increases the soil's susceptibility to particle release and splash erosion, which then develops into sheet erosion and rill erosion.

Meanwhile, Regosol soil is a young soil that generally has weak horizon development and a low level of aggregate stability. According to the soil erodibility theory proposed by Arsyad (2010), soil with less stable aggregates is more susceptible to particle release when exposed to the kinetic energy of rain. This condition becomes even more critical in semi-arid areas such as Kupang City, where rainfall generally occurs for a relatively short duration but with high intensity. This phenomenon causes rapid increase in surface runoff and increases the capacity for sediment transport.

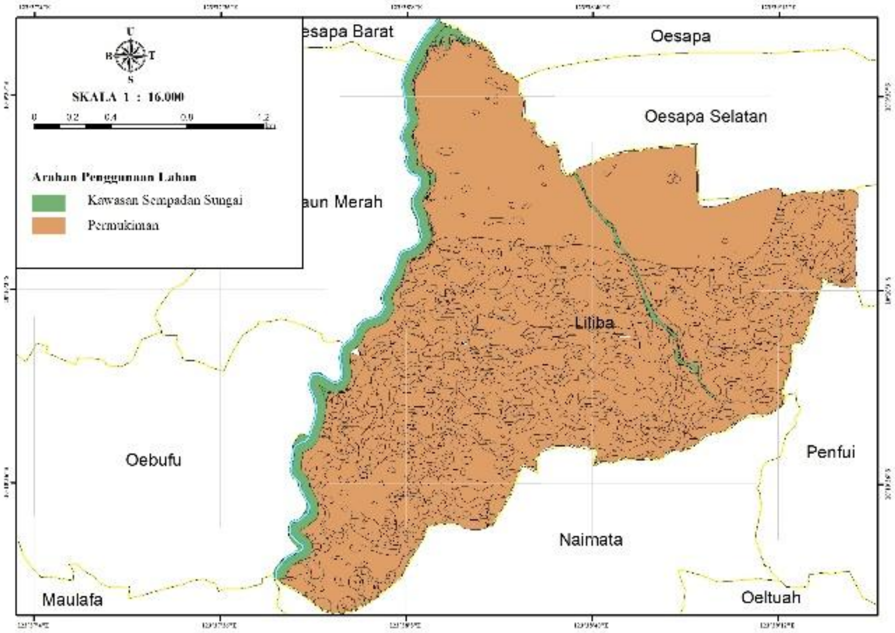
Therefore, the combination of Renzina and Regosol soil characteristics, relatively steep slopes, and concentrated seasonal rainfall patterns are the main factors contributing to the high rate of erosion in the Liliba River riparian area.

Increasing the R value in steeply sloped areas increases sediment transport capacity, so erosion occurs not only in open land but also in settlements built on slopes. When rainfall intensity is high, steeply sloped areas experience accelerated flow and increased sediment transport capacity. Research Tarigan & Mardiatno (2021)confirms that slope uniformity influences the level of erosion that occurs, where the greater the slope, the higher the erosion rate. However, it should be noted that steep slopes do not necessarily cause severe erosion if supported by good vegetation (Neolaka et al., 2022).

The analysis shows that the surge in erosion in 2024 was the result of the interaction of R as a trigger, and CP, LS, and K as the main reinforcing factors. Land use change to residential areas proved to be the most influential factor because it changed land cover conditions, increased runoff, and accelerated sediment transport in a short time. This condition was exacerbated by the presence of easily dispersed soil in areas with steep slopes, which amplified the erosion process because sediment released by rainfall was directly transported by surface runoff. Therefore, sustainable land management must consider all these factors in an integrated manner to prevent further land degradation.

Land Use Guidelines Based on Erosion Hazard Level

Land use guidelines in Liliba Village are determined based on the erosion hazard level (EBV), slope shape, and soil characteristics that dominate each land unit. The land use guidelines map is presented in Figure 12.



Source: Research Results 2025
Figure 12. Land Use Direction Map

This guidance aims to direct land use according to erosion vulnerability, thereby reducing soil loss and maintaining environmental sustainability. Areas with high actual erosion values are prioritized in land management planning because they have a greater potential for soil degradation than other areas. Maintaining Asdak (2014)ground cover vegetation is one of the most effective and economical methods for preventing surface erosion, as vegetation protects the soil from the impact energy of rainwater, increases infiltration, and reduces surface runoff.

Land use guidelines in Liliba Village are formulated by considering the TBE (Earthly Land Use), slope gradient, and the characteristics of the dominant soil types in each land unit. Furthermore, these guidelines also refer to the spatial planning policies outlined in the (RTRW)Kupang City Spatial Plan to ensure that spatial use remains aligned with the designated area functions. The analysis shows that most of Liliba Village is being designated as a medium-density residential area spread across the central to eastern parts of the area. Meanwhile, the area along the Liliba River, particularly in the western to southern parts, is designated as a riverbank protection zone, which functions as a control zone to maintain bank stability and reduce surface runoff into the river body.

In areas classified as very light erosion hazard, land use still allows for residential activities with relatively simple conservation management. Land units located in river boundary zones are designated as riparian vegetation protection areas with a minimum width of 10–15 meters from the river bank. This provision is in line with PUPR Ministerial Regulation No. 28/PRT/M/2015 concerning River and Lake Boundary Lines, which emphasizes the importance of buffer zones along rivers to maintain bank stability and control surface flow. Recommended riparian vegetation includes plants with strong root systems such as vetiver (*Chrysopogon zizanioides*), bamboo (*Bambusa sp* .), gamal (*Gliricidia sepium*), and ketapang kencana (*Terminalia mantaly*). These plants have the ability to strengthen soil structure and increase slope stability around river banks. The presence of riparian vegetation has also been shown to reduce the amount of sediment entering the river body and slow surface runoff before it reaches the water channel (Dunn et al., 2022).

In land units that function as residential areas with very low erosion hazard levels, land management focuses on the use of productive yards while still paying attention to soil and water conservation aspects. Vegetated yard systems can increase rainwater infiltration, reduce surface runoff, and protect the topsoil from rain impact energy.

Additional conservation efforts that can be implemented include the construction of infiltration wells, biopore holes, and the use of ground cover plants to maintain soil moisture and structure. According to Arsyad (2010), a combination of ground cover vegetation and simple infiltration techniques such as Biopores can increase water absorption capacity while suppressing sheet erosion on residential land.

In the low erosion hazard class, land units that continue to function as settlements require strengthening of land cover through the application of vegetative conservation techniques. Planting ground cover plants, especially legumes, can help reduce the impact energy of rainwater and increase the roughness of the soil surface, thus slowing surface runoff. Furthermore, the application of small contour ridges and grassy drainage channels can help direct water flow so that it is not concentrated in a single point, which can accelerate the erosion process. This approach aims to reduce sheet erosion, which commonly occurs on land with moderate slopes.

In areas with moderate erosion hazard, land management requires a combination of vegetative conservation techniques and light mechanical techniques. The creation of small-scale terraced gardens, rain gardens, and simple embankments can help shorten the effective slope length, thereby reducing runoff energy. Vegetation with strong root systems is recommended to increase soil stability and strengthen slope structure. Vegetation systems such as vetiver are known to have excellent erosion resistance because their dense, vertical roots strengthen soil aggregates and increase stability (Aziz & Islam, 2023). In land units located in riparian areas with moderate erosion, management is directed at protecting permanent riparian vegetation to maintain riverbank stability and reduce sedimentation.

In the severe erosion hazard class, land use that remains functional as a settlement requires stricter development controls and the application of more intensive conservation techniques. Recommended techniques include the construction of stone embankments to strengthen slopes, controlled drainage systems to regulate surface water flow, and the construction of communal infiltration wells to increase rainwater infiltration. Planting deep-rooted vegetation such as vetiver, calliandra, and gamal is also necessary to increase soil stability and restrain soil mass movement on slopes. Arsyad (2010)stated that a combination of vegetative and mechanical techniques is the most effective approach in controlling erosion in areas with relatively steep slopes.

The implementation of land use and soil conservation guidelines in Liliba Village requires consideration of the socioeconomic conditions of the community that has long lived along the Liliba River. Given that the majority of the study area is a developed residential area, erosion control cannot rely solely on structural approaches or strict restrictions on land use. Therefore, a more realistic and sustainable community-based mitigation approach is needed. Conservation efforts such as planting vetiver, bamboo, gamal, and other riparian vegetation can be implemented in a participatory manner to strengthen riverbanks and reduce surface runoff. Furthermore, the implementation of infiltration wells, biopores, rain gardens, and the use of productive yards can be implemented at the household level, making them more easily adopted by the community without altering the primary function of the residential area. The local government also needs to encourage educational programs and increase public awareness regarding erosion risks, the importance of maintaining riparian vegetation, and community-based environmental management. This approach will not only contribute to reducing river erosion and sedimentation but also increase community capacity to support sustainable management of the Liliba River riparian area.

CONCLUSION

The results of the study indicate that the erosion rate in Liliba Village experienced a very significant increase from 5,107.69 tons/ha/year in 2020 to 15,114.50 tons/ha/year in 2024, with a difference of 10,006.81 tons/ha/year. This increase caused a change in the distribution of erosion hazard classes (TBE), where in 2020 it was dominated by the Severe class (253.75 ha or 56.6%), but in 2024 it changed to a dominance of the Very Severe class (281.32 ha or 62.7%). This condition indicates that the Liliba River riparian area is increasingly vulnerable to erosion damage and requires more serious land management handling. Land use guidelines have been prepared based on the level of erosion hazard by considering topographic characteristics, soil type, and land cover conditions, where the higher the level of erosion hazard, the more limited land use and the greater the need for conservation measures.

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