



Analysis and Evaluation of Land Suitability in Kupang City, Indonesia for Sustainable Settlement Development

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ABSTRACT

Kupang City, as the capital of Nusa Tenggara Timur Province, faces significant challenges in land management and settlement development due to rapid population growth and urbanization. This study aims to analyze and evaluate land suitability for sustainable settlement development, considering relevant environmental factors. The method used is Spatial Multi-Criteria Analysis (SMCA), which integrates geospatial data from the Digital Elevation Model (DEM), including slope, road networks, rivers, economic activity centers, and coastlines. The analysis results indicate that out of the total area analyzed, 7,227.04 hectares have high suitability, 4,341.12 hectares have moderate suitability, and 3,967.85 hectares have low suitability. Areas with high suitability are generally located near roads, economic activity centers, have lower slope gradients, and are far from rivers and coastlines, making them ideal for infrastructure development. The discussion emphasizes the importance of spatial and participatory-based spatial planning, as well as the need for monitoring low-suitability areas to prevent disaster risks. In conclusion, this study provides policy recommendations for more sustainable settlement development in Kupang City, integrating land suitability analysis and involving the community in the planning process, thereby creating

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1. INTRODUCTION

Kupang City, as the capital of Nusa Tenggara Timur Province, faces significant challenges in land management and settlement development [1]. The rapid population growth, coupled with fast-paced urbanization, has increased the demand for land for settlement [2]. However, without careful planning, this development could lead to negative impacts on the environment, infrastructure, and the quality of life of the community [3], [4]. Therefore, the analysis and evaluation of land suitability for sustainable settlement development is crucial to ensure that urban growth can proceed harmoniously with the environment [5].

Kupang City has unique geographical characteristics, with varied topography and a dry climate. This makes it vulnerable to issues such as drought and soil degradation. An assessment of land suitability that does not consider these factors could have severe consequences, both for the residents of the area and for the infrastructure being built [6]. Therefore, it is essential to integrate environmental risk analysis at every stage of land suitability assessment [7],[8]. In addition to environmental risks, unplanned settlement growth can also lead to significant ecosystem damage. Deforestation, pollution, and the loss of biodiversity are some of the negative impacts often associated with unsustainable land development.

Geographic Information Systems (GIS) are a highly effective tool for spatial analysis and data-driven decision-making [9]. By utilizing GIS, urban planners can integrate various geospatial data, such as topography, land use, infrastructure, and disaster risks, to produce comprehensive land suitability maps [10], [11]. This approach not only improves the accuracy of the assessment but also enables the identification of areas most suitable for settlement development, thereby reducing potential negative impacts on the environment [2]. Through GIS-based land suitability analysis, it is hoped that ideal locations for settlement development can be identified that minimize environmental impacts while supporting the preservation of natural resources.

This study uses the Spatial Multi-Criteria Analysis (SMCA) method. The use of Spatial Multi-Criteria Analysis (SMCA) is highly effective in supporting sustainable settlement development [11]. This method allows the integration of various relevant criteria, such as physical, environmental, social, and economic factors, into a comprehensive analytical framework [2]. By utilizing geospatial data and modeling techniques, SMCA can provide objective, evidence-based assessments of land potential for development, as well as identify areas that are most suitable and have low risk for construction [12]. Furthermore, this method supports stakeholder participation, making decisions more inclusive and considerate of the local community's needs. Therefore, SMCA plays an important role in formulating sustainable and environmentally friendly development strategies in Kupang City.

Government policies on settlement development in Kupang City need to be based on accurate data and thorough analysis. Land suitability analysis can serve as the foundation for formulating better regulations and policies, ensuring that investment and infrastructure development are directed to more suitable areas [7]. This not only enhances land use efficiency but also ensures that development aligns with the needs of the community and environmental conditions [7]. Community involvement in the planning process is crucial to creating a sustainable environment. Through transparent and data-based land suitability analysis, the community can better understand the rationale behind planning decisions and actively participate in the development of their environment. This will increase the community's sense of ownership and responsibility toward their surroundings, as well as foster collaboration between the government and the public in spatial management.

This study aims to conduct an analysis and evaluation of land suitability in Kupang City for sustainable settlement development. It is hoped that the results of this study will provide useful recommendations for urban planners and stakeholders in creating a safe, comfortable, and sustainable living environment. Thus, this research not only contributes to the development of scientific knowledge but also provides practical solutions to the challenges faced by Kupang City. Given the complexities and challenges that Kupang faces, this study is expected to serve as a reference for other cities in Indonesia dealing with similar issues. Through a systematic, data-driven approach, it is hoped that settlement development in Kupang City can be carried out in a more sustainable, safe, and responsive manner, addressing both community needs and environmental conditions.

2. RESEARCH METHOD

This research was conducted in Kupang City, Nusa Tenggara Timur Province, Indonesia. The study used Digital Elevation Model (DEM) data, which was processed to generate slope maps, along with data on road networks, river networks, economic activity centers, coastlines, and buildings obtained from the official website of the Indonesian Geospatial Information Agency. The entire spatial analysis was performed using ArcGIS 10.8 software. The method employed is Spatial Multi-Criteria Analysis (SMCA). Spatial Multi-Criteria Analysis (SMCA) is an analytical method used to evaluate and prioritize various alternatives based on multiple spatial criteria [13], [2]. This method integrates geospatial data with multi-criteria analysis techniques to assist decision-making in the context of spatial planning, resource management, and land suitability evaluation [14]. The research variables used in this study include slope, distance from roads, distance from rivers, distance from coastlines, and distance from economic activity centers. To obtain spatial data on the distance from roads, rivers, coastlines, and economic activity centers, buffer analysis was conducted, and slope classification was performed based on Table 1.

Tabel 1. Variabel Kesesuaian Lahan Permukiman

No	Variables	Classification	Score	Weight	Suitability Level
1	Slope	0- 8 %	3	20	High Suitability
		9-15 %	2		Medium Suitability
		>15 %	1		Low Suitability
2	Distance from Road	0 - 100 m	3	30	High Suitability
		101 – 750 m	2		Medium Suitability
		>750 m	1		Low Suitability
3	Distance from River	0 - 50 m	1	10	Low Suitability
		51 – 100 m	2		Medium Suitability
		>100 m	3		High Suitability
4	Distance from Economic Center	0 - 400 m	3	30	High Suitability
		401 – 1000 m	2		Medium Suitability
		>1000 m	1		Low Suitability
5	Distance from Shoreline	0 - 100 m	1	10	Low Suitability
		101 – 1000 m	2		Medium Suitability
		>1000 m	3		High Suitability

Source: [2], [15]

All the variables were then assigned scores and weights based on their suitability for built-up land development. The five variables were then overlayed using the Weighted Overlay tool in ArcGIS software, followed by spatial mathematical calculations to generate a land suitability map using the formula: Settlement Land Suitability = Slope Score * Slope Weight + Distance from Road Score * Distance from Road Weight + Distance from River Score * Distance from River Weight + Distance from Economic Center Score * Distance from Economic Center Weight + Distance from Shoreline Score * Distance from Shoreline Weight. The land suitability for settlement was then classified into three categories: low, medium, and high. The land suitability map for settlements in Kupang City was then overlayed with data on the distribution of built-up land and buildings for the affected area.

3. RESULTS AND DISCUSSIONS

3.1. Variable Land Suitability Level

The distance from roads has a significant influence on determining the development of residential areas, particularly in terms of accessibility and land value. The closer a location is to a main road, the higher its accessibility, which makes it easier for residents to reach various public facilities and services, such as markets, schools, and hospitals [16]. However, locations that are too close to highways may also face risks such as air pollution and noise, so it is important to consider a balance between accessibility and environmental impacts in settlement planning. The land suitability analysis in Kupang City shows that areas within 0-100 meters of a road have a significant area of 11,393.42 hectares, making them the most strategic locations for sustainable settlement development. Meanwhile, areas within 101-750 meters of a road cover 4,098.45 hectares, which can also be considered for development, although with slightly reduced accessibility. On the other hand, areas more than 750 meters from a road are very limited, covering only 44.14 hectares, indicating that these locations are less ideal for settlement development due to low accessibility. These findings emphasize the importance of considering road infrastructure distances in spatial planning to ensure easy access and connectivity for residents.

The slope of the land significantly affects the development of residential areas, as it is a key factor in determining land suitability. Steep slopes can increase the risk of natural disasters such as landslides and erosion, which could potentially endanger residents' safety [17]. The land suitability analysis in Kupang City shows that the most suitable areas for sustainable settlement development are those with a slope of 0-8%, covering 10,776.27 hectares. Areas with slopes of 9-15% also show good potential, with an area of 2,820.17 hectares, while areas with slopes greater than 15% covering 1,939.56 hectares are considered less suitable for settlement development. These findings highlight the importance of considering the physical characteristics of the land, particularly the slope, in spatial planning to ensure that settlement development is not only meeting current needs but is also sustainable and safe from disaster risks. The slope map of Kupang City can be seen in Figure 1.

The distance from the coastline significantly influences the determination of settlement area development, particularly in terms of accessibility, environmental risks, and socio-economic impacts. Areas close to the coastline are often more attractive to developers and residents because they offer beautiful views and easy access to marine resources, which can increase property values. However, development near coastal areas also faces high risks, such as erosion, pollution, and impacts from climate change, including sea level rise. Unplanned development near the coastline can damage coastal ecosystems and threaten environmental sustainability, making it essential to integrate spatial planning that takes this distance into account to ensure settlement growth is sustainable and safe for both the community and the surrounding environment [18].

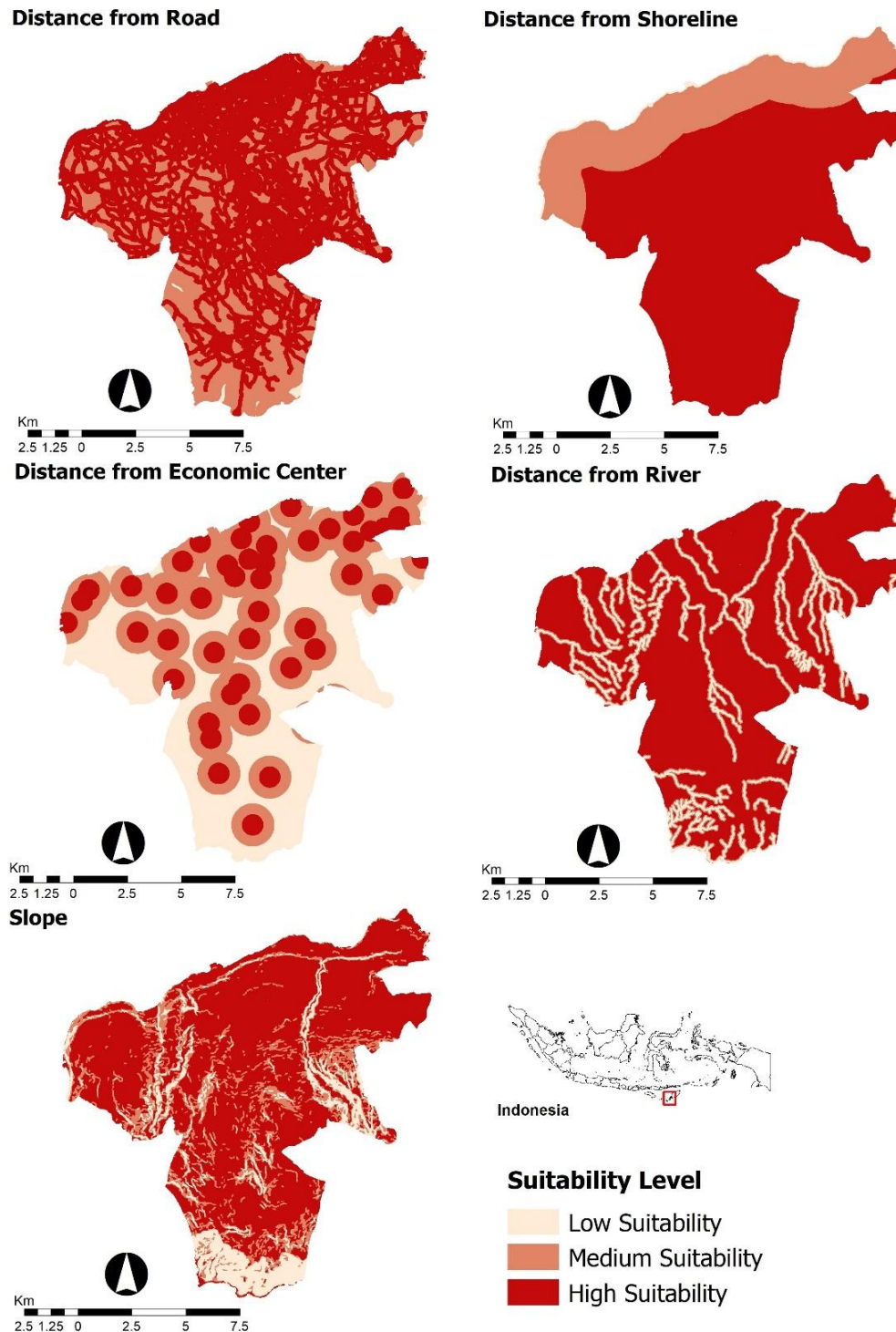


Figure 1. Land Suitability Variables

From the total land area analyzed, areas within 0 to 100 meters of the coastline only cover 174.19 hectares and are categorized as low suitability. This indicates that locations very close to the coast may face high risks related to natural disasters such as tidal flooding, abrasion, and tsunamis, making them less ideal for sustainable settlement development. In contrast, areas within 101 to 2000 meters from the coastline cover 3,914.98 hectares and are classified as moderately suitable. Although there are still some risks, these areas can be considered for development with careful planning. Meanwhile, land located more than 2000 meters from the coastline covers 11,446.85 hectares and is categorized as highly suitable. This location offers better potential for settlement development, as it is safer from disaster risks and provides more space for infrastructure and community development.

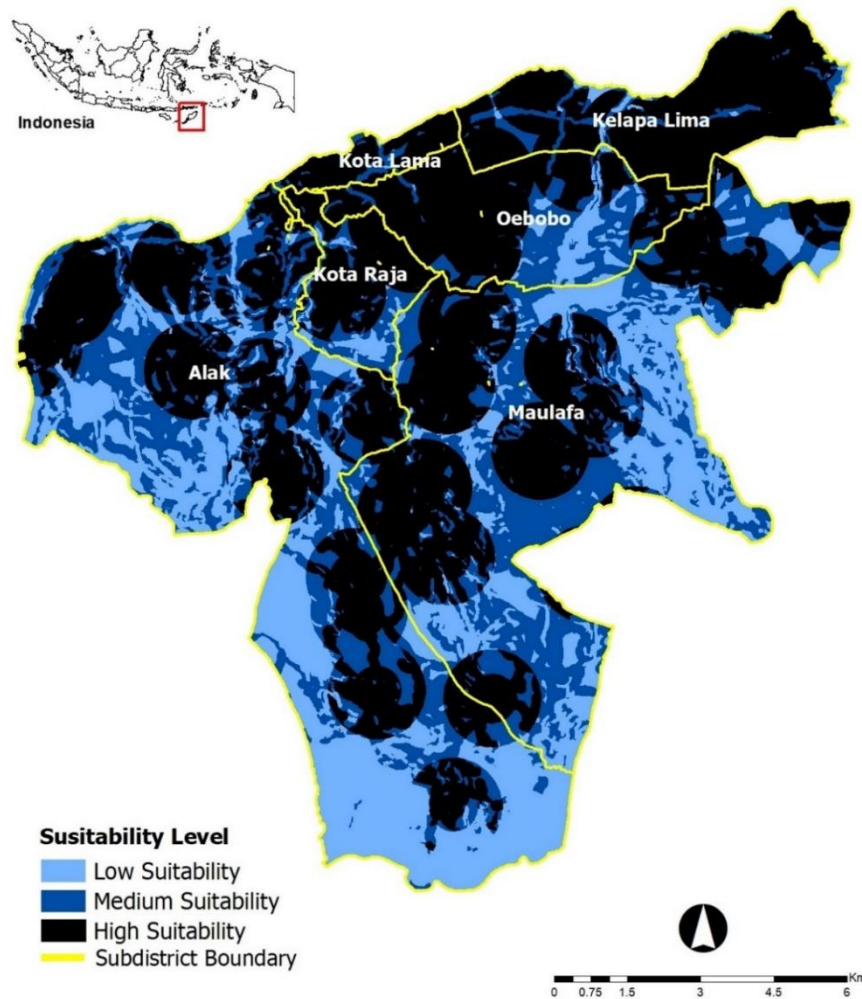


Figure 2. Map of Land Suitability Levels in Kupang City

The distance from economic activity centers significantly influences the determination of settlement area development, particularly in terms of accessibility and the ease of acquiring daily necessities. The closer a location is to an economic activity center, such as a market or shopping center, the more attractive it becomes to potential residents, who seek comfort and efficiency in daily activities. This also impacts land value, as locations near economic centers tend to have higher prices [19]. Furthermore, proximity to economic activity centers can stimulate local economic growth by facilitating access to employment and public services. However, it is also important to consider potential negative impacts, such as high population density and pollution, which require careful planning to balance settlement development with quality of life. Areas within 0 to 400 meters of an economic center cover 3,319.26 hectares and are categorized as highly suitable. This shows that locations near economic activity centers are prioritized for settlement development, as they provide better access to necessary facilities, jobs, and services. On the other hand, areas within 401 to 1000 meters of an economic center cover 6,174.45 hectares and are classified as moderately suitable. Although still viable for development, these locations may require more attention in terms of accessibility and infrastructure to support settlement growth. Meanwhile, land located more than 1000 meters from an economic center covers 6,042.29 hectares and is categorized as low suitability. These locations are less ideal for settlement development, as the greater distance from economic activity centers can hinder residents' access to services and job opportunities.

The distance from rivers influences settlement development decisions by considering accessibility, disaster risks, and environmental quality. Areas close to rivers are often more attractive to developers because they provide water resources and transport access, thereby increasing land value in the surrounding area. However, settlements too close to rivers are also at high risk of flooding and erosion, especially in areas prone to flooding during the rainy season [20]. The distance from rivers significantly impacts the land suitability for sustainable settlement development. Areas within 0 to 50 meters from a river cover 1,983.66 hectares and are categorized as low suitability. This indicates that locations very close to rivers are at high risk of flooding and other environmental issues, making them less ideal for safe and sustainable settlement

development. In contrast, areas within 51 to 100 meters from a river cover 1,774.72 hectares and are classified as moderately suitable. Although they still carrying some risks, these areas can be considered for development with careful planning and appropriate risk mitigation. Meanwhile, land located more than 100 meters from a river covers 11,777.63 hectares and is categorized as highly suitable. This location offers better potential for settlement development as it is safer from flooding risks and provides more space for infrastructure and community development.

3.2. Land Suitability for Residential Development

The results of the land suitability analysis for residential development in Kupang City reveal a clear division among low, moderate, and high suitability categories based on several key variables, including slope gradient, distance from roads, distance from rivers, distance from the coastline, and distance from economic activity centers. Of the total analyzed area, land with low suitability covers 3,967.85 hectares. This land is located in areas with steep slopes or too close to rivers and coastlines, situated far from roads and economic activity centers, increasing the risks of flooding and erosion, making it less ideal for safe residential development. On the other hand, areas with moderate suitability cover 4,341.12 hectares. This land has potential for development but requires special attention in planning and risk management, particularly concerning accessibility and environmental impacts. Meanwhile, areas with high suitability cover 7,227.04 hectares, indicating that these lands have more stable and secure conditions for residential development. Highly suitable land is typically located at optimal distances from roads, rivers, and economic activity centers and has lower slopes, making it more suitable for sustainable infrastructure and residential development. Spatially, the land suitability levels can be observed in Figure 2.

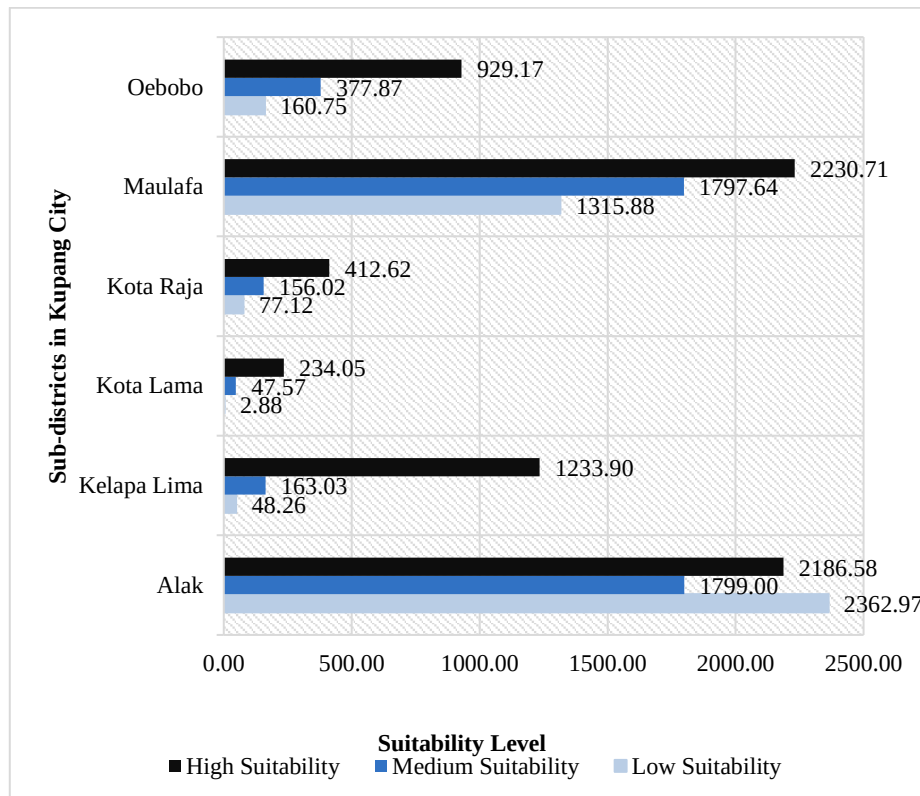


Figure 3. Land suitability level per sub-district of Kupang City

The results of the land suitability analysis for residential development in Kupang City reveal significant variations among sub-districts based on low, moderate, and high suitability categories. Alak Sub-district has the largest area of low suitability, covering 2,362.97 hectares, followed by Maulafa with 1,315.88 hectares, indicating challenges in residential development in these areas. Meanwhile, Kelapa Lima and Kota Raja sub-districts have high-suitability areas of 1,233.90 hectares and 412.62 hectares, respectively, highlighting better potential for development. Overall, Maulafa Sub-district also shows a significant area of high suitability, totaling 2,230.71 hectares, suggesting that despite the challenges, there are substantial opportunities for sustainable residential development in the region. These findings emphasize the importance of considering the specific characteristics of each sub-district in spatial planning to achieve sustainable

development in Kupang City. The land suitability levels in each sub-district of Kupang City are illustrated in Figure 3.

3.3. The Distribution of Buildings Across Land Suitability Levels in Kupang City

The analysis of building distribution in Kupang City reveals that out of a total of 120,010 identified buildings in 2024, the majority are located in areas with high suitability levels. With 85,855 units, buildings in high-suitability areas reflect optimal land use and alignment with sustainable residential development. This indicates that infrastructure and residential development in Kupang City tend to be directed toward locations with supportive physical and environmental characteristics, such as good accessibility and lower disaster risks. On the other hand, there are 31,804 buildings situated in areas with medium suitability and 9,709 units in areas with low suitability. While the number of buildings in medium-suitability areas is substantial, the presence of buildings in low-suitability areas highlights higher potential risks related to factors such as slope gradient, proximity to rivers, and coastal lines. Spatially, the distribution of buildings across land suitability levels in Kupang City can be observed in Figure 4.

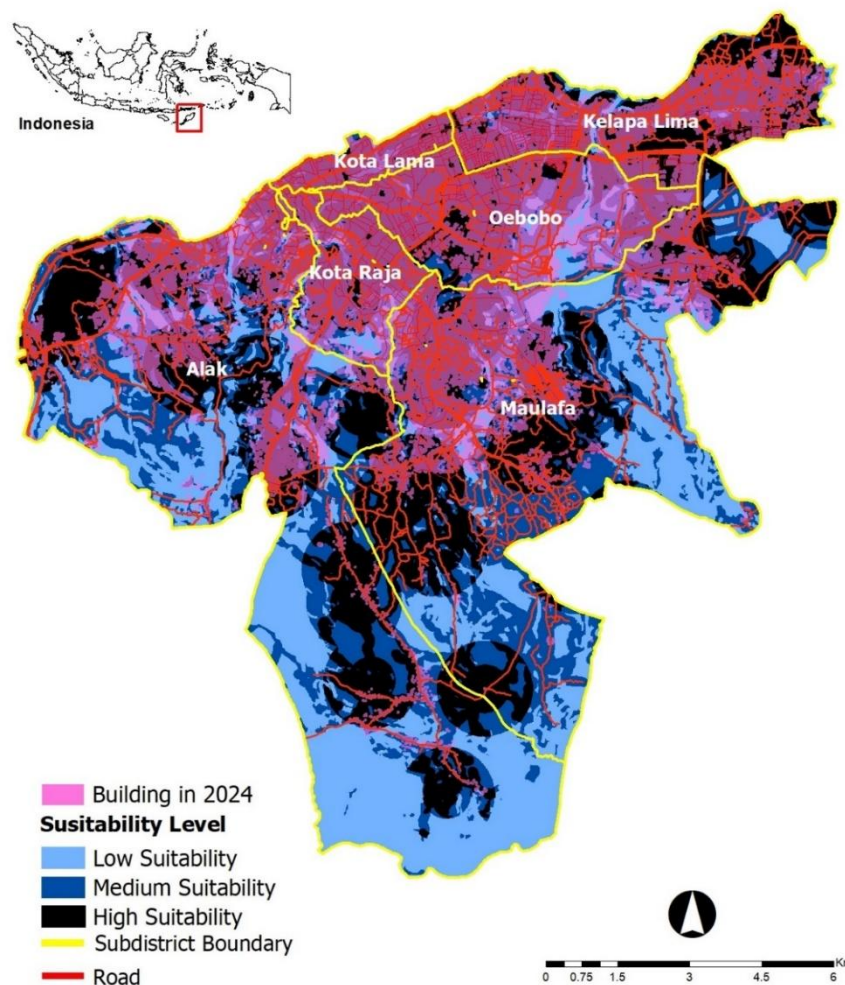


Figure 4. Map of Building Distribution based on Land Suitability Level in Kupang City

The analysis of the total building area across different land suitability levels in Kupang City shows that high-suitability areas have the most significant coverage, totaling 997.69 hectares, reflecting great potential for sustainable residential development. Meanwhile, medium-suitability areas cover 304.46 hectares, indicating space for more planned development, albeit with some risk considerations. On the other hand, low-suitability areas cover only 82.95 hectares, suggesting that development in these regions should proceed cautiously to mitigate potential issues arising from less supportive environmental factors. These findings emphasize the importance of prioritizing development in high-suitability areas to achieve sustainable development goals in Kupang City.

Based on the findings of the land suitability study in Kupang City, the proposed policy recommendations emphasize the need for a more integrated and data-driven spatial planning approach. Local

governments are advised to prioritize residential development in high-suitability areas, such as the Kelapa Lima and Kota Raja sub-districts, which exhibit better potential for sustainable infrastructure and residential development. Additionally, strict monitoring and management are essential for low-suitability areas, such as the Alak and Maulafa sub-districts, to prevent inappropriate developments that could increase the risk of natural disasters, such as floods and erosion. Another recommendation is to actively involve the community in the planning and environmental development processes. By providing transparent access to land suitability analysis information, communities can better understand the decisions made and actively participate in spatial management. This approach not only fosters a sense of ownership and responsibility toward the environment but also promotes collaboration between the government and citizens in creating safe, comfortable, and sustainable residential environments. Through this participatory approach, residential development in Kupang City is expected to be more responsive to the needs of the community and the prevailing environmental conditions.

4. CONCLUSION

The conclusion of this study highlights the critical importance of land suitability analysis in Kupang City to support sustainable residential development amidst the challenges of rapid population growth and urbanization. The analysis identifies areas with high, medium, and low suitability based on various variables such as proximity to economic activity centers, slope gradient, and accessibility, providing guidance for more effective spatial planning. By integrating environmental factors and involving the community in the planning process, residential development in Kupang City is expected to be conducted harmoniously, safely, and responsively to the needs of the community and environmental conditions. This approach aims to improve the quality of life for residents while ensuring sustainable urban growth.

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