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Spatial analysis of built-up land development in 1995 and 2025 based on slope level in Ternate City, Indonesia

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ABSTRAK

Kota Ternate di Maluku Utara, Indonesia, mengalami pertumbuhan penduduk dan pengembangan lahan permukiman yang pesat, dengan topografi dan kemiringan lereng yang beragam yang mempengaruhi perluasan lahan terbangun. Studi ini menganalisis perkembangan lahan terbangun pada tahun 1995 dan 2025 berdasarkan tingkat kemiringan lereng dengan menggunakan citra Landsat dan data Digital Elevation Model (DEM). Hasil penelitian menunjukkan bahwa lahan terbangun berkembang pesat pada zona kemiringan 8-25% (meningkat 96,8-372%) dan zona >25% (+206,5%), yang mengindikasikan adanya tekanan pembangunan yang mendorong urbanisasi ke wilayah yang secara topografi sulit dijangkau. Konversi lahan hijau (berkurang 903,78 ha) juga mempengaruhi keseimbangan lingkungan, sementara badan air tetap stabil (67,58 ha). Dominasi lereng curam >40% (3.013,36 ha) merupakan tantangan utama bagi pembangunan berkelanjutan. Temuan ini menekankan perlunya pendekatan spasial berdasarkan analisis geomorfologi terpadu, khususnya mitigasi risiko longsor di zona lereng curam, sekaligus memenuhi kebutuhan permukiman.

ABSTRACT

Ternate City in North Maluku, Indonesia, is experiencing rapid population growth and residential land development, with diverse topography and slopes that affect the expansion of built-up land. This study analyzed the development of built-up land in 1995 and 2025 based on slope levels using Landsat imagery and Digital Elevation Model (DEM) data. The results showed that built-up land expanded rapidly in the 8-25% slope zone (an increase of 96.8-372%) and the >25% zone (+206.5%), indicating that development pressure pushed urbanization into topographically difficult areas. Greenland conversion (903.78 ha less) also affected the environmental balance, while water bodies remained stable (67.58 ha). The dominance of steep slopes >40% (3,013.36 ha) is a major challenge for sustainable development. These findings emphasize the need for a spatial approach based on integrated geomorphological analysis, particularly landslide risk mitigation in steep slope zones, while meeting settlement needs.

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1. INTRODUCTION

The development of built-up land in urban areas is an unavoidable phenomenon along with population growth and increased economic activity (Kamboj & Ali, 2021). Ternate City, as one of the cities in Indonesia, has experienced significant growth in recent years (Rakuasa & Khromykh, 2025a). This is characterized by the increasing need for land for settlements, trade, and other infrastructure. However, this growth may not always align with effective spatial planning, potentially leading to a range of issues, such as adverse effects on the environment and ecosystem balance (Sihasale, Latue, & Rakuasa, 2023). One of the factors that influences the development of built-up land is slope (Akbar & Supriatna, 2019; Rakuasa et al., 2025). The hilly and diverse topography in Ternate City provides its own challenges in land utilization. Steep slopes can increase the risk of erosion and natural disasters, such as landslides, which can threaten the safety of residents and infrastructure. Therefore, it is important to analyze the development of built-up land by considering the level of slope.

On August 25, 2024, landslides and flash floods occurred in Ternate City, North Maluku Province, Indonesia. The disaster was caused by prolonged heavy rainfall, which led to the flow of debris from the summit of Mount Gamalama. The geological conditions of Ternate Island, consisting of uncompacted volcanic material, as well as deforestation in upstream areas, exacerbated the situation by reducing the soil's ability to absorb water. This disaster caused 19 people to die, while 8 injured people are still being intensively treated in several hospitals in Ternate (CNN Indonesia, 2024). There were 25 houses and places of worship destroyed, and one bridge on the highway between villages on Ternate Island was broken (Rakuasa, Budnikov, & Adifan, 2024). In general, built-up land affected by landslides is on slopes >8%.

Spatial analysis is an effective tool for understanding the development pattern of built-up land (Ye Zhou, Wu, & Wang, 2022). By using geospatial mapping and analysis technology, we can identify areas that experience significant changes in land use from year to year (Zhang et al., 2018). This research aims to analyze the development of built-up land in Ternate City in 1995 and 2025 and relate it to the level of slope. Land use change in Ternate City is not only influenced by physical factors but also by social and economic factors (Achmadi, Dimyati, Manesa, & Rakuasa, 2023). Rapid population growth and urbanization cause the demand for built-up land to increase. This often results in the conversion of agricultural and forest land into residential and commercial land, which can impact environmental sustainability (Kusrini, Worosuprojo, Kurniawan, & Hizbaron, 2023).

Ternate City has unique geological characteristics, with the presence of an active volcano that affects land use patterns. Volcanic activity can affect land availability and soil quality, which in turn affects land use decisions by communities (Achmadi et al., 2023). This research will explore how slope factors in the context of built-up land development. In addition, it is important to involve the community in the land planning and management process. Community participation can help in identifying local needs and priorities, as well as raising awareness of the importance of maintaining environmental balance. Based on the above background, this research is expected to make a significant contribution to the understanding of built-up land development in Ternate City.

2. LITERATURE REVIEW

2.1 Spatial analysis

Spatial analysis is a set of techniques used to examine, explore, and process data from a spatial perspective with the aim of finding patterns, relationships, and phenomena that occur in a particular area (Rakuasa, Khromykh, & Rifai, 2025). These techniques are often applied in Geographic Information Systems (GIS) to combine, transform, and model spatial data to produce new information useful in location-based planning and decision-making (Ahmad Rifai & Rakuasa, 2025). Spatial analysis includes various methods, such as overlaying, spatial autocorrelation measurement, and statistical modeling, that help understand the distribution and interrelationship of geographic objects in space (Rakuasa & Khromykh, 2025b).

2.2 built-up land

Built-up land is a land area that has undergone a development or pavement process that changes natural or semi-natural conditions into artificial land cover, such as settlements, roads, public facilities, and other facilities created and maintained by humans to meet the needs of life and socio-economic activities (Hehanussa, Sumunar, & Rakuasa, 2025). Built-up land is often referred to as the built environment, which includes buildings and infrastructure that support the function of the area (Rakuasa & Budnikov, 2025). The development of built land affects the quality of the residential environment, where the increase in built land must be balanced with an increase in the quality of infrastructure so that the environment remains livable (Rakuasa, Budnikov, Joshua, & Latue, 2025).

2.3 Slope

Slope is an angular measure of the difference in elevation in a landscape, showing the relationship between the slope of the land and the horizontal plane. This definition refers to the difference in height of the earth measured in percent or degrees (Rakuasa, Budnikov, & Latue, 2025). Slope is an important topographic element because the steeper the slope, the greater the rate and amount of surface flow and erosion potential (Rakuasa, 2025).

3. METHODS

This study was conducted in Ternate City, North Maluku Province, Indonesia (Figure 1). This study used satellite images of Landsat 5 in 1995 and Landsat 8 in 2025 obtained from USGS with a spatial resolution of 30 meters for the analysis of built-up land development during the period. To analyze the slope of the slope in this research using National DEM Data from Geospatial Information Agency with a resolution of 8 meters. Arc GIS Pro software was used in this study to analyze the development of built-up land in 1995 and 2025 and slope analysis. In this research, guided classification was carried out on Landsat 5 images in 1995 and Landsat 8 images in 2025 using machine learning features in Google Earth Engine software. The machine learning algorithm used is Classification and Regression Tree (CART). This method consists of two methods, namely the regression tree method and the classification tree (Onisimo Muntaga, 2019). If the dependent variable is categorical, then CART will produce a classification tree. Meanwhile, if the dependent variable is continuous or numeric, CART will produce a regression tree. In supervised classification of Landsat imagery, the output is categorical, so the method used is classification tree (Abdelsamie et al., 2024).

In the classification tree method, the initial node is called the root node. Then, the node will generate several branches that represent various possible options. Each of these branches will generate new branches representing other options. Hence, this method is called “tree” because it resembles a tree with many branches. In this system, land cover mapping can be done quickly because the training data is fed into the machine to detect various characteristics of the image and put them into the specified classes (Pande et al., 2024). In addition, the images used can be automatically corrected. However, the weakness of this algorithm lies in the accuracy of the map which is based on the image used as well as the training data created, as the land cover classification is pixel-based or based on pixels from the image. Land cover of Ternate Island was classified into 4 classes consisting of built-up area, open area, vegetation, water body. Land cover maps in 1995 and 2025, especially the built-up area, were overlaid with slope to determine the development of built-up land on each slope class.

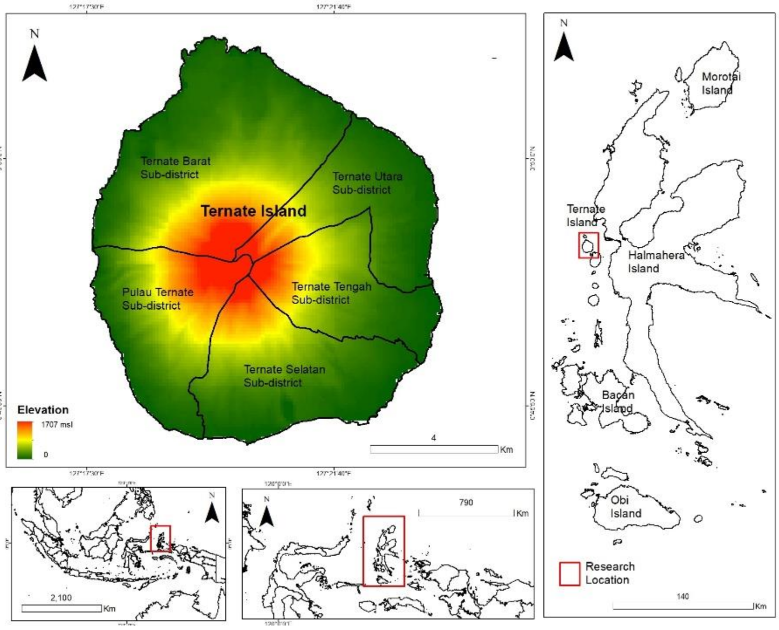

Figure 1. Research Location

4. RESULTS AND DISCUSSION

The distribution of area based on slope class in Ternate City in Figure 2 shows that areas with slope >40% have the largest area reaching 3,013.36 ha. The 25-40% slope class ranks second with an area of 2,255.56 ha, followed by 15-25% slope with an area of 2,077.30 ha. This data indicates that the topography of Ternate City is dominated by areas with steep slopes that naturally have limitations for settlement development. However, the gentle slope (0-8%) and mild slope (8-15%) classes are still available with an area of 1,041.78 ha and 1,771.89 ha, respectively, which have the potential for built-up area development.

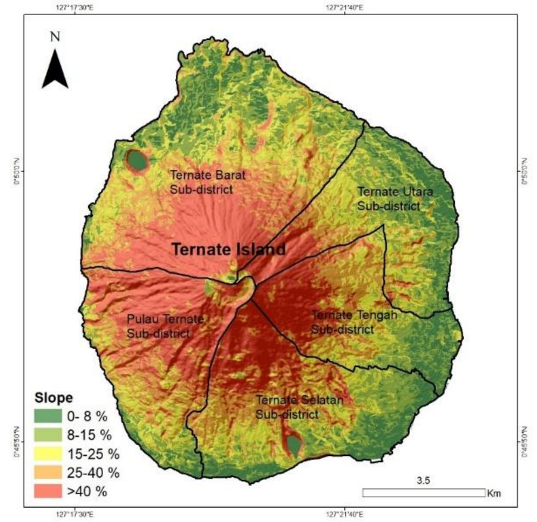

Figure 2. Slope of Ternate Island

The dominance of areas with steep slopes (>40%) poses challenges in the development of residential areas in Ternate City. Development in areas with high slope risks increasing vulnerability to landslides and soil erosion (L. Zhou, Dang, Mu, Wang, & Wang, 2021). The results of this study are in line with the findings of Kechebour, (2015) who stated that the limited flat land in the islands often triggers the expansion of settlements to steep slope zones. The need for a special approach in spatial planning for high slope areas is crucial to minimize environmental impacts. Further analysis is needed to evaluate the environmental carrying capacity before developing areas in high slope zones (Salakory & Rakuasa, 2022).

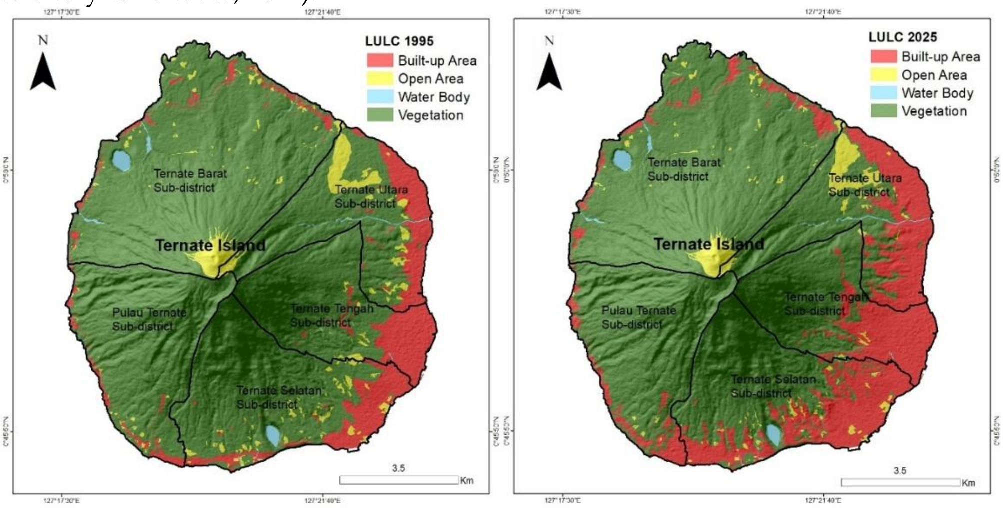

Figure 3. Land Cover of Ternate Island in 1995 and 2025

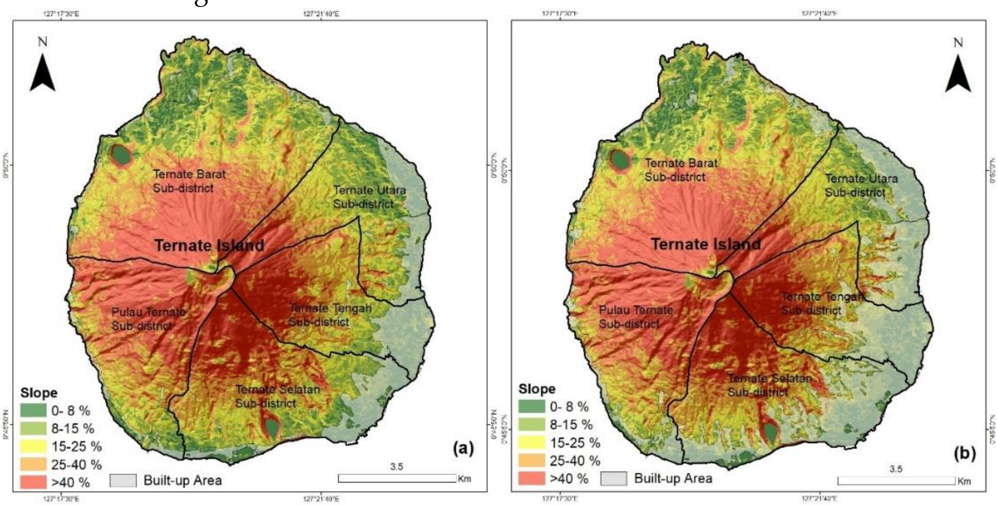

Figure 4. Development of Built-up Land in 1995 and 2025 by slope level

Land use change in Ternate City during the period 1995-2025 in Figure 3 shows a significant increase in built-up land from 1,134.22 ha to 2,120.46 ha. Open land decreased from 437.67 ha to 356.10 ha, while the area of water bodies remained stable at 67.58 ha. The area of vegetation decreased considerably from 8,522.28 ha to 7,618.50 ha, indicating land conversion to meet settlement needs. This pattern of change reflects high development pressure due to population growth and economic activity in urban areas (Rakuasa & Pakniany, 2022; Rakuasa et al., 2024). The growth of built-up land that has almost doubled in 30 years has an impact on the reduction of green open space in Ternate City. The conversion of vegetated land into built-up areas can affect ecosystem balance and increase flood risk (Rakuasa & Budnikov, 2025). The stability of the water body area indicates that development has not disrupted the main hydrological system in this area (Rakuasa, 2025). These findings emphasize the importance of implementing strict spatial policies to control urban expansion and maintain protected areas (Zhou et al., 2021). The need for sustainable development strategies is becoming increasingly urgent to maintain a balance between development needs and environmental sustainability (Calka & Szostak, 2025).

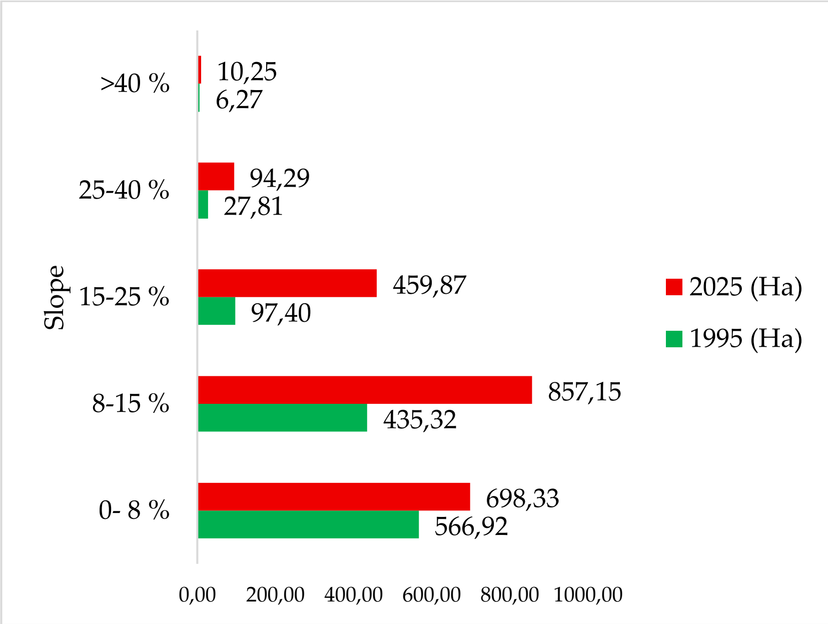

Figure 5. Area of Built-up Land Development in 1995 and 2025 by slope level.

Spatial analysis of built-up land development in Ternate City for the period 1995-2025 in Figure 5 shows significantly different expansion patterns based on the level of slope. In the 0-8% slope class, built-up land increased from 566.92 ha to 698.33 ha, indicating that sloping areas remain the main preference for settlement development. The 8-15% slope class saw the most dramatic increase from 435.32 ha to 857.15 ha, reflecting development pressures driving expansion into areas with moderate slopes. This pattern is consistent with previous research findings in island regions where flat land is limited (Bamrungkhul & Tanaka, 2022).

The development of built-up land on a 15-25% slope showed rapid growth from 97.40 ha to 459.87 ha, indicating the start of urban sprawl to areas with steeper topography. Areas with a 25-40% slope also experienced a significant increase from 27.81 ha to 94.29 ha, although still relatively small in absolute terms. The increase in built-up land in the >40% slope zone from 6.27 ha to 10.25 ha deserves special attention given the high vulnerability to geological disasters. This finding is consistent with studies in other volcanic regions that show settlement expansion into risky zones (Tian et al., 2016; Rifai et al., 2025).

The spatial distribution of built-up land development in Figure 5 follows a concentric pattern with the main expansion remaining in the sloping to undulating zone. However, the growth rate is relatively higher in the moderate slope zone (8-25%) compared to the gentle zone (0-8%), indicating population pressure pushing urbanization to less ideal areas. This pattern confirms the theory of push-pull factors in urban settlement development in restricted areas. Land conversion in high slope zones also has the potential to increase the risk of erosion and landslides, especially given the volcanic geology of Ternate City (Sihasale et al., 2023; Rakuasa & Khromykh, 2025a).

The policy implications of these findings emphasize the need to strengthen spatial regulations based on integrated geomorphological analysis. Development in slope zones >15% should require strict environmental impact assessments and the application of specialized construction techniques. Protection of protected areas and green open spaces in high slope zones should be strengthened to maintain ecological balance. Further research needs to integrate multi-disaster risk modeling with environmental carrying capacity analysis to support sustainable urban planning.

5. CONCLUSIONS

The results of this study reveal that the development of built-up land in Ternate City from 1995 to 2025 shows a significant expansion pattern across all slope classes, with the highest growth occurring in the 8-15% (from 435.32 ha to 857.15 ha) and 15-25% (from 97.40 ha to 459.87 ha) slope zones, indicating development pressure that drives urbanization to areas with steeper topography. Although the sloping zone (0-8%) remains a preferential area for settlements, the increase of built-up land in the >25% slope zone (from 34.08 ha to 104.54 ha) raises concerns regarding vulnerability to landslides and environmental degradation, especially given the volcanic geology of Ternate City. These findings emphasize the need for strict spatial policy implementation based on geomorphological analysis, risk mitigation, and sustainable development to balance settlement needs with environmental sustainability in areas with complex topography.

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