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Spatial-temporal analysis of built-up land development in landslide-prone areas: Disaster risk assessment

Heinrich Rakuasa[1,*]
[1.] *Department of Geography, Faculty of Geology and Geography, Tomsk State University, Tomsk 634028, Russian Federation.*
*Correspondence: heinrich.rakuasa@stud.tsu.ru

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ABSTRACT

Background: This study aims to analyze the development of built-up land in landslide-prone areas in Ambon City from 2014 to 2024, considering the increased disaster risk due to unplanned urbanization. **Methods:** The methods used include spatial temporal analysis utilizing Landsat 7 and Landsat 8 satellite imagery data, as well as landslide risk maps from the National Disaster Management Agency (BNPB). **Findings:** The results showed that built-up land in high-risk areas increased sharply, from 429.91 hectares in 2014 to 951.65 hectares in 2024, potentially increasing vulnerability to landslides. **Conclusion:** The study recommends the need for stricter spatial policies and better risk management to control development in landslide-prone areas. In conclusion, wise management and integration of landslide risk maps in urban planning are essential to mitigate the negative impacts of land use change and protect communities from disasters. **Novelty/Originality of this article:** This study offers a unique contribution by combining spatial-temporal analysis using Landsat satellite imagery with landslide risk maps to assess the impact of unplanned urbanization on landslide-prone areas, providing new insights into the relationship between urban development and disaster risk in Ambon City.

KEYWORDS: Ambon; built-up land; land development; spatial analysis.

1. Introduction

Ambon City, located in the eastern region of Indonesia, has a unique geographical condition with approximately 75% of its total area being a hilly area. This hilly topography causes many communities to build houses in areas with steep slopes, often above 20% (Aditian et al., 2018). This increases the risk of landslides, especially during high rainfall. Research on landslide potential in this area is essential to identify and map areas at risk, so that appropriate mitigation efforts can be made. Land use change in Ambon City is often triggered by population growth and the need for better infrastructure (Rakuasa et al., 2023). The development of settlements, roads and other public facilities is often done without considering the potential disaster risks. The development of built-up land in Ambon City is often not matched by good spatial planning. This can lead to increased vulnerability to landslides, which can result in loss of property and even lives. Previous studies have shown that land use change can contribute to increased disaster risk, especially in areas already prone to landslides (Hehanussa et al., 2024). Therefore, spatial-temporal analysis of built-up land development is essential to understand its impact on disaster vulnerability.

In the context of disaster mitigation, a deep understanding of the development pattern of built-up land is essential (Souisa et al., 2016). Using mapping technology and spatial

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analysis, researchers can identify areas most vulnerable to landslides and formulate better spatial management strategies (Harist et al., 2018). This is in line with the government's efforts in implementing sustainable and disaster-safe spatial utilization control policies. In addition, temporal spatial analysis can also provide useful information for urban spatial planning (Asmare, 2022). Ambon City also faces other challenges, such as climate change that can affect rainfall patterns and increase the frequency of natural disasters. Therefore, a comprehensive analysis of built-up land development and landslide potential is essential to formulate effective mitigation strategies (Rakuasa et al., 2022). This research is expected to contribute significantly to disaster risk reduction efforts in Ambon City. By knowing the development of built-up land over time, planners can make better decisions in spatial planning, including the determination of safe development sites and the development of environmentally friendly infrastructure. This is critical to creating a city that is not only economically thriving, but also safe for its citizens.

By understanding the relationship between built-up land development and disaster vulnerability, it is hoped that the results of this study can provide useful recommendations for local governments in formulating more effective disaster mitigation policies. Regular monitoring and evaluation of land use in landslide-prone areas is also necessary to reduce the risk of future disasters (Chen & Li, 2020). Based on this background, this study aims to analyze the development of built-up land in landslide-prone areas in Ambon City spatially and temporally. The results of this study are expected to provide useful information for the government and stakeholders in planning sustainable and safe development for the community.

2. Methods

This research was conducted in Ambon City which is located in Ambon Island and administratively Ambon City is the capital of Maluku Province (Figure 1). This study used data on landslide hazard areas in Ambon City from the National Disaster Management Agency (BNPB) and Landsat 7 satellite image data in 2014 and Landsat 8 satellite image in 2024 to identify land cover change in Ambon City, namely the development of built-up land in landslide-prone areas obtained from the United States Geological Survey (USGS). This research uses ArcGIS Pro software to conduct spatial temporal analysis.

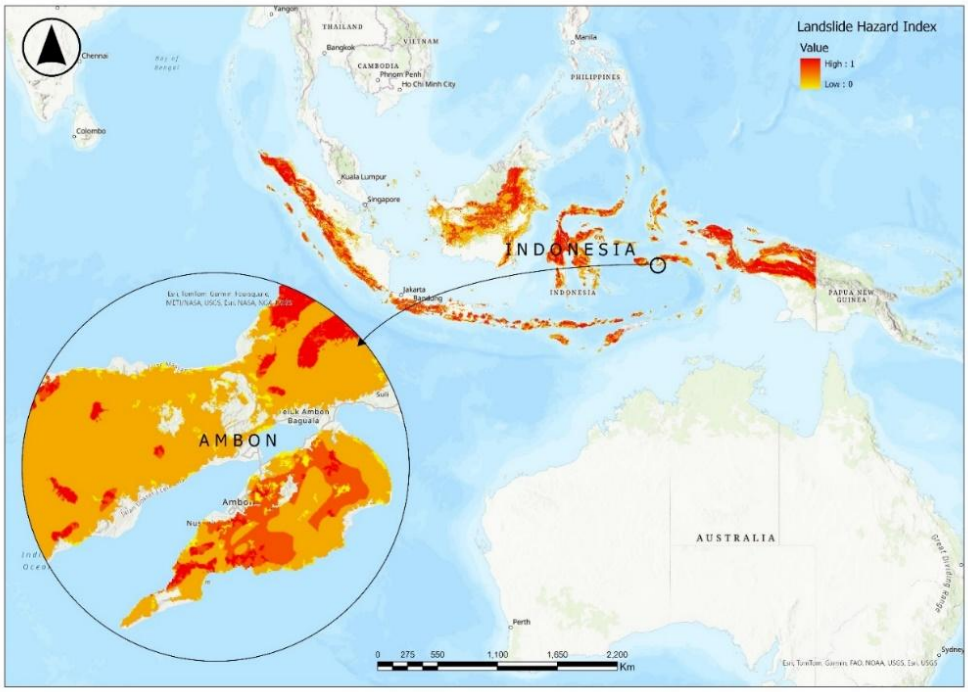

Fig. 1. Research location

The processing of Landsat 8 image data into a map of developed land begins by downloading the Landsat 8 image from the official USGS website (https://earthexplorer.usgs.gov/) and then the radiometric and geometric correction process is carried out. By performing radiometric and geometric corrections on Landsat 7 and 8 images, it can improve the quality and accuracy of the information obtained from these images. This allows for more precise analysis and produces more useful information in various applications, such as environmental monitoring, land use mapping, natural resource management, and scientific research. After the correction, the process of interpretation and digitization in ArcGIS Pro software was carried out to produce a map of built-up land of Ambon City in 2014 and 2024. Meanwhile, the data of landslide prone areas obtained from BNPB was cut according to the administrative boundaries of Ambon City in ArcGIS Pro software, which was then overlaid analysis with settlement maps in 2014 and 2024 to produce a map of settlement development in landslide prone areas in Ambon City in both years.

3. Results and Discussion

3.1 Landslide prone areas in Ambon City

Landslide-prone areas in Ambon City are areas that have a high potential to experience landslide disasters due to existing geographical and topographical conditions. Ambon City, which is located in a hilly and mountainous area, has many areas with steep slopes, often above 20%. Landslide prone areas in Ambon City are classified into five classes, namely very low, low, medium, high, high and very high. The very low class covers the largest area, which is 1,079.97 hectares, indicating that most of Ambon City is relatively safe from landslide risk. Meanwhile, the area with low hazard class occupies 20,004.56 hectares, which also shows a fairly large area with low risk. The area with Medium risk covers 216.14 hectares, while the area with high risk reaches 4,645.88 hectares. The very high risk area covers 1,444.76 hectares. From this data, it can be seen that while most of Ambon is in the safe to low risk category, there are a number of areas that have significant potential for landslides, especially those classified as high and very high.

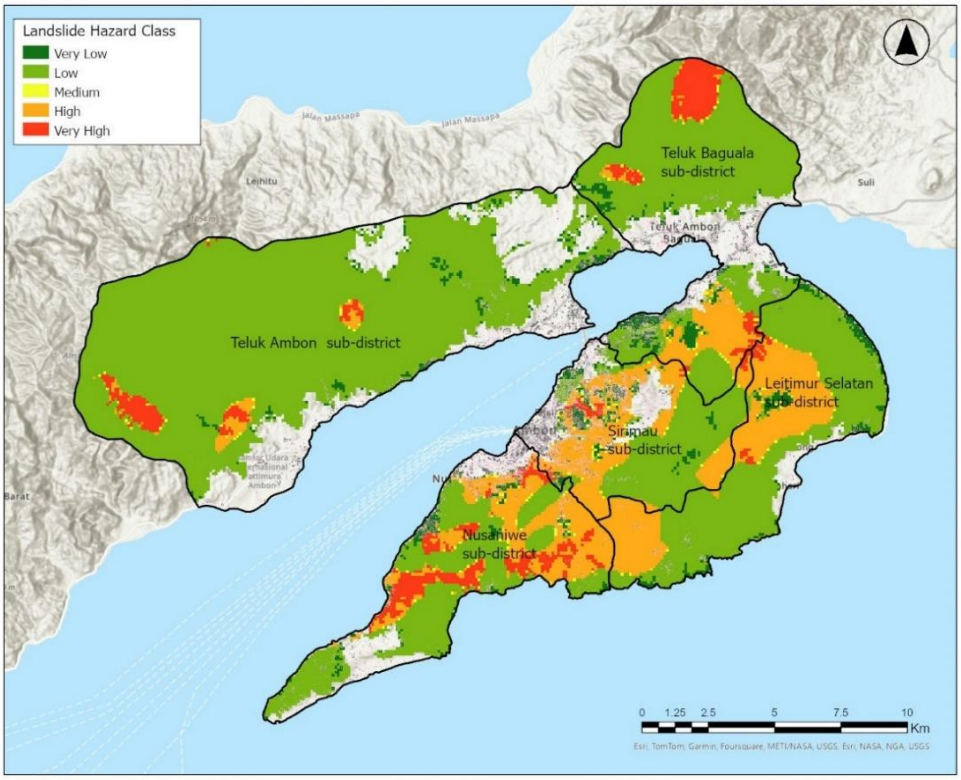

Fig. 2. Landslide hazard in Ambon City

Spatially, the landslide vulnerability map in Figure 2 shows that areas with high and very high risk are generally scattered in hilly areas or steep slopes around Sirimau, Nusaniwe, and South Leitimur sub-districts. These areas are likely under pressure from human activities, including settlement development and deforestation, which contribute to the increased risk of landslides (Somae et al., 2022). Some of the main factors that influence the occurrence of landslides in Ambon City include steep slopes, high rainfall, and land use changes, such as rapid urbanization (Rakuasa & Rifai, 2021). Areas that have poor land cover, such as deforested or poorly managed land, are more prone to landslides, especially in the rainy season. To reduce the impact of landslides, a comprehensive mitigation approach is needed. Measures such as reforestation, improved drainage infrastructure, and restrictions on development in landslide-prone zones need to be implemented (Safriani & Wibowo, 2022). In addition, strict monitoring of development activities in hilly areas is also important to prevent further environmental damage.

Based on available data and maps, Ambon City has several areas with high landslide risk that should be prioritized in the city's spatial planning. Mitigation efforts should be focused on areas with High and Very High risk to reduce potential damage and danger to the community. Further research and more detailed risk mapping are also recommended to support data-driven decision making in landslide disaster management in the region. These recommendations are based on data interpretation as well as references from several previous studies on landslide mitigation in areas with steep topography and dynamic land use such as Ambon.

3.2 Development of built-up land in Ambon City in 2014 and 2024

The results of the landslide vulnerability analysis in Ambon City, Indonesia, show a significant increase in the area of built-up land between 2014 and 2024. Based on the data provided, in 2014 the built-up land area was 3,469.99 hectares, while in 2024 it increased to 5,884.69 hectares. This increase of more than 2,400 hectares reflects the dynamics of increasingly intensive land use in Ambon City, which may affect the level of landslide vulnerability in the area. The increase in built-up land in this ten-year period indicates rapid urbanization in Ambon City. This urbanization tends to occur in areas that may have previously been forests or greenlands (Septory et al., 2023). When forests or natural vegetation are replaced by built-up land, slope stability decreases due to the loss of natural buffers provided by plant roots. This increases the risk of soil erosion and, ultimately, increases the likelihood of landslides, especially in areas with vulnerable steep slopes (Sugandhi et al., 2023).

Based on the analyzed landslide vulnerability map, several sub-districts such as Sirimau, Nusaniwe, and South Leitimur that have experienced development of built-up land are also areas that have a high risk of landslides. The increase in built-up land in these areas puts more strain on an already vulnerable environment, thus increasing the risk of natural disasters such as landslides. By 2024, with more developed land, this risk becomes more acute if not matched with adequate mitigation measures. A significant increase in built-up land can also impact the ability of the area to absorb rainwater. Areas covered by concrete, asphalt and buildings reduce water infiltration into the soil, which in turn increases runoff. This exacerbates the risk of landslides, especially during the rainy season, when the soil becomes saturated and unable to withstand the additional load of water moving quickly through the built-up ground surface (Susetyo et al., 2022).

With more and more built-up land, the biggest challenge is how to manage such development in a sustainable manner. Without proper spatial planning, development in landslide-prone areas can be fatal to the environment and society (Rakuasa & Somae 2022). In this regard, it is important to integrate landslide risk maps into urban planning so that areas with high landslide potential can be protected or restricted from development. To reduce the impact of these land use changes, Ambon City needs to implement spatial planning policies that take into account geological and topographical conditions (Salakory & Rakuasa, 2022). Reforestation in certain areas, development of better drainage

infrastructure, and restrictions on development on steep slopes are measures that need to be prioritized. In addition, there is a need for strict supervision of development permits in landslide-prone areas, to ensure that the growth of built-up land does not occur haphazardly.

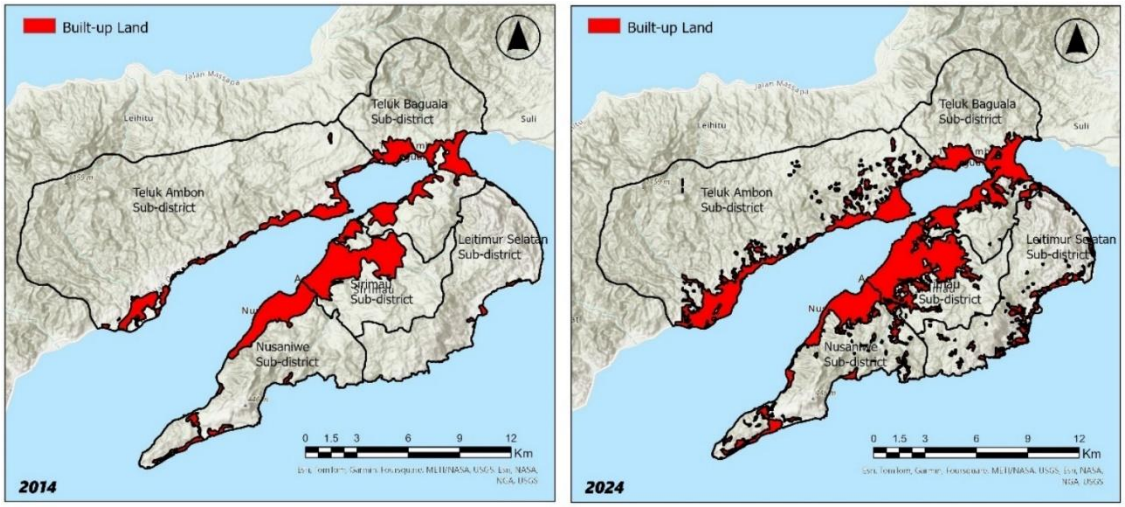

Fig. 3. Built-up land of Ambon City in 2014 and 2024

The increase in built-up land in Ambon City between 2014 and 2024 has a significant impact on landslide risk in several sub-districts. Areas that were previously relatively safe may now face higher risks due to loss of natural vegetation cover and increased (runoff) from built-up land. To reduce this risk, an integrated approach is needed that combines prudent spatial planning, sound environmental management, and proactive implementation of disaster mitigation measures. In several related studies, uncontrolled urbanization in natural disaster-prone areas has been shown to increase the frequency and intensity of disaster events, such as landslides (Ram & Gupta, 2022). Therefore, Ambon City needs to learn from the experiences of other cities with similar risks, such as Bogor or Bandung, in implementing effective mitigation solutions.

3.3 Development of built-up land in 2014 and 2024 in landslide prone areas in Ambon City

Based on the overlay of the development of built-up land between 2014 and 2024 in Ambon City in Figure 4, there is a significant increase in the area of built-up land in landslide-prone areas. In 2014, the total area of built-up land affected by landslides at various risk levels (from very low to very high) reached more than 1,300 hectares. By 2024, this figure has risen sharply, especially in the low to very high risk category. This data shows the increasing development pressure on lands with landslide potential, especially in previously low-risk areas.

In 2014, the area of built-up land in very low landslide risk areas only reached 344.23 hectares. Meanwhile, in 2024, this area increased to 490.86 hectares. This increase shows that development in areas that are relatively safe from landslides tends to continue to grow. However, zones with low to very high landslide risk also experienced a drastic increase, indicating that development in disaster-prone areas is also increasing rapidly. In 2014, built-up land in areas with high landslide risk reached 429.91 hectares, while areas with very high risk amounted to 71.83 hectares. By 2024, both figures increased sharply, with 951.65 hectares of built-up land in high-risk areas and 120.82 hectares in very high-risk areas. This increase indicates that more disaster-prone areas are being developed for settlements or infrastructure, potentially increasing material losses and casualties in the event of a landslide.

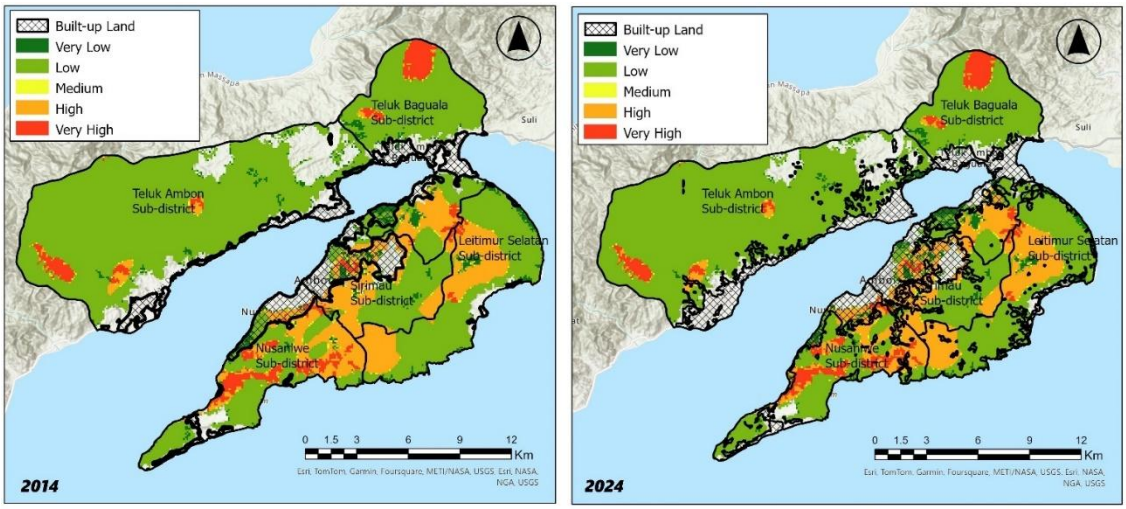

Fig. 4. Development of built-up land in Ambon City in 2014 and 2024

Development in landslide-prone areas has serious implications for disaster risk in Ambon City. As built-up land increases, especially in zones with high and very high landslide risk, slope stability and groundwater absorption are reduced, exacerbating the risk of landslides during the rainy season. As shown in the map, areas such as Sirimau and Nusaniwe that are heavily urbanized are likely to face higher landslide risks in the absence of adequate mitigation measures. Based on this data, it is clear that Ambon City needs stricter spatial policies and better risk management, especially in controlling development in areas with high landslide risk. Mitigation measures such as the construction of retaining walls, better drainage systems and reforestation in vulnerable areas are urgently needed. Otherwise, the increase of built-up land in these vulnerable areas may trigger more frequent and more severe landslides (Muin & Rakuasa, 2023).

The uncontrolled development of built-up land in landslide risk areas shows that urban growth is not accompanied by adequate risk analysis. As seen in the 2024 map, much of the new built-up land is in areas that are highly prone to landslides, particularly in Sirimau and South Leitimur sub-districts. This means that in addition to environmental challenges, Ambon City also faces a direct threat to the infrastructure that has already been built. Overall, the increase in built-up land between 2014 and 2024 in landslide-prone areas shows a worrying trend in terms of disaster risk in Ambon City. Without adequate mitigation measures, this growth could exacerbate the city's vulnerability to landslides, especially in high-risk areas (Rakuasa et al., 2024). The government and stakeholders need to consider the landslide risk map as a key reference in planning development and land development to minimize the adverse impacts that may occur in the future (BNPB, 2023).

4. Conclusions

This research shows that the development of built-up land in Ambon City, especially in landslide-prone areas, has increased significantly in the last decade. This increase, triggered by urbanization and infrastructure development, has the potential to increase vulnerability to landslides, especially in areas with steep slopes. Therefore, it is important to implement comprehensive mitigation strategies, including better spatial planning, reforestation and sustainable land use management. With close monitoring and in-depth spatial analysis, it is expected to reduce disaster risk and protect communities from the negative impacts of future land use change.

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Biographies of Author

Heinrich Rakuasa, Department of Geography, Faculty of Geology and Geography, Tomsk State University, Tomsk 634028, Russian Federation.

- Email: heinrich.rakuasa@stud.tsu.ru
- ORCID: 0000-0003-3978-5071
- Web of Science ResearcherID: IAO-6240-2023
- Scopus Author ID: 57910877100
- Homepage: https://www.researchgate.net/profile/Heinric-Rakuasa