The Impact of the Karo-Langkat Bypass Road Development on Land Cover Dynamics and Suitability Evaluation

Abstract

The construction of the **44.85 km Karo-Langkat bypass road**, which traverses critical conservation areas such as **Mount Leuser National Park** and the **Bukit Barisan Forest Park**, has significantly improved accessibility and economic development in **Karo and Langkat Regencies**. However, this infrastructure development has also triggered **substantial land cover changes**, raising concerns over long-term environmental sustainability. This study analyzes**land cover dynamics from 2012 to 2024**, predicts **future trends for 2037**, and evaluates their **alignment with the North Sumatra Provincial Spatial Plan (RTRW) 2017–2037**. Using **Landsat 7, 8, and 9 imagery**, validated with **60 ground truth points**, land cover changes were examined through the **Land Change Modeler (LCM)**, with future projections generated via the **Markov Chain model**. Results indicate a **470-hectare loss of primary forest** over 12 years, while **shrubland and open land increased by 200 hectares and 170 hectares, respectively**. If current trends persist, **primary forest may shrink to 1,700 hectares by 2037**, raising concerns over biodiversity loss and carbon emissions. The evaluation against the **RTRW 2017–2037** reveals that a **majority of land cover changes are inconsistent** with designated conservation areas, emphasizing the urgent need for regulatory intervention. This study highlights the **policy implications** of road-induced deforestation, advocating for **stricter spatial planning enforcement, agroforestry initiatives, and forest rehabilitation programs** to mitigate environmental degradation. The findings provide **data-driven insights for policymakers**, balancing regional development with ecosystem protection. Additionally, this research demonstrates the **value of Markov Chain modeling in land-use planning**, offering a predictive framework for sustainable decision-making.

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Keywords: Road development, land cover change, forest conservation, Markov Chain prediction, North Sumatra RTRW.

I. Introduction

Infrastructure development plays a strategic role in supporting economic growth, regional accessibility, and improving the quality of life for communities. Among various infrastructure projects, road construction offers significant social, economic, and interregional connectivity benefits (Alaloul, 2022; Sonata, 2017; ADB, 2021). The Karo-Langkat bypass road, connecting Karo and Langkat Regencies, is a critical project aimed at facilitating disaster evacuation for Mount Sinabung eruptions while promoting economic and tourism development in both regions (Tinambunan et al., 2020).

However, road development often leads to adverse environmental impacts, including habitat fragmentation, deforestation, land morphology alterations, and increased erosion risks (Gunawan, 2014). A study by Sulistiyono et al. (2015) indicated that road construction in Sumatra significantly heightens deforestation risks by providing easier access to forested areas. In the context of the Karo-Langkat bypass road, the project has intensified pressures on conservation areas, such as Mount Leuser National Park (TNGL) and the Bukit Barisan Forest Park, due to land clearing for agriculture and illegal logging (Hasan et al., 2020).

Land cover changes are often driven by socio-economic and biophysical factors. Human activities, such as land clearing for settlements, agriculture, and infrastructure, are primary causes of these changes (Handavu, 2019; Toh, 2018; Darmawan, 2002). Previous studies have found that proximity to roads is one of the dominant factors contributing to deforestation, alongside elevation and slope (Silis et al., 2015). Additionally, the growth of farming households has exacerbated deforestation in highly accessible areas (Linkie et al., 2004; Kumar et al., 2014).

Land cover is the physical representation of the Earth's surface, reflecting human activities or the biophysical conditions of an area (National Standardization Agency of Indonesia, 2014). Information on land cover changes is a critical element in sustainable development planning, particularly in spatial planning policy formulation (Jaya, 2010; Mukmin et al., 2016). Remote sensing and Geographic Information Systems (GIS) technologies have been widely employed to spatially and temporally map land cover changes, providing accurate data to support decision-making processes.

Tropical forests in Sumatra, including TNGL and the Bukit Barisan Forest Park, play a vital ecological role, such as carbon storage, regulating hydrological cycles, and serving as habitats for endemic flora and fauna (Hasan et al., 2020). The Sumatran orangutan, as an umbrella species in this region, is threatened by habitat fragmentation due to uncontrolled land clearing (Sulistiyono et al., 2024). Forest loss in this area not only impacts biodiversity but also contributes to global carbon emissions, exacerbating climate change (Sutaryono&Dewi, 2020).

Previous research has shown that deforestation in Sumatra is often linked to increased accessibility, population growth, and uncontrolled spatial use patterns (Munibah et al., 2006; Geist & Lambin, 2002). In the context of road development, studies in the Cidanau watershed revealed that road presence triggers forest conversion into built-up areas in a concentric pattern (Putri, 2009). Additionally, research in Sumatra has indicated that socio-economic factors, such as the number of farming households and elevation, significantly influence deforestation probabilities (Sulistiyono et al., 2015).

This study aims to identify land cover changes, analyze the influencing factors, and predict future land cover conditions using the Markov Chain and Land Change Modeler methods. Furthermore, it evaluates the alignment of land cover changes with RTRW spatial patterns to provide policy recommendations that support sustainable development. The findings of this study are expected to contribute significantly to the formulation of environmentally conscious spatial management strategies in the Karo-Langkat bypass road development area.

II. Research Methods

Research Location and Duration

This research was conducted within the Karo-Langkat bypass road development area, encompassing Karo and Langkat Regencies in North Sumatra Province. Covering approximately 4,475.61 hectares, the region includes critical conservation zones such as Mount Leuser National Park (TNGL) and Bukit Barisan Forest Park (Tahura). This location was selected due to the marked land-cover dynamics arising from road construction activities and associated socio-economic pressures. The research was conducted over a six-month period, from June to November 2024, encompassing data collection, analytical procedures, and the reporting process.

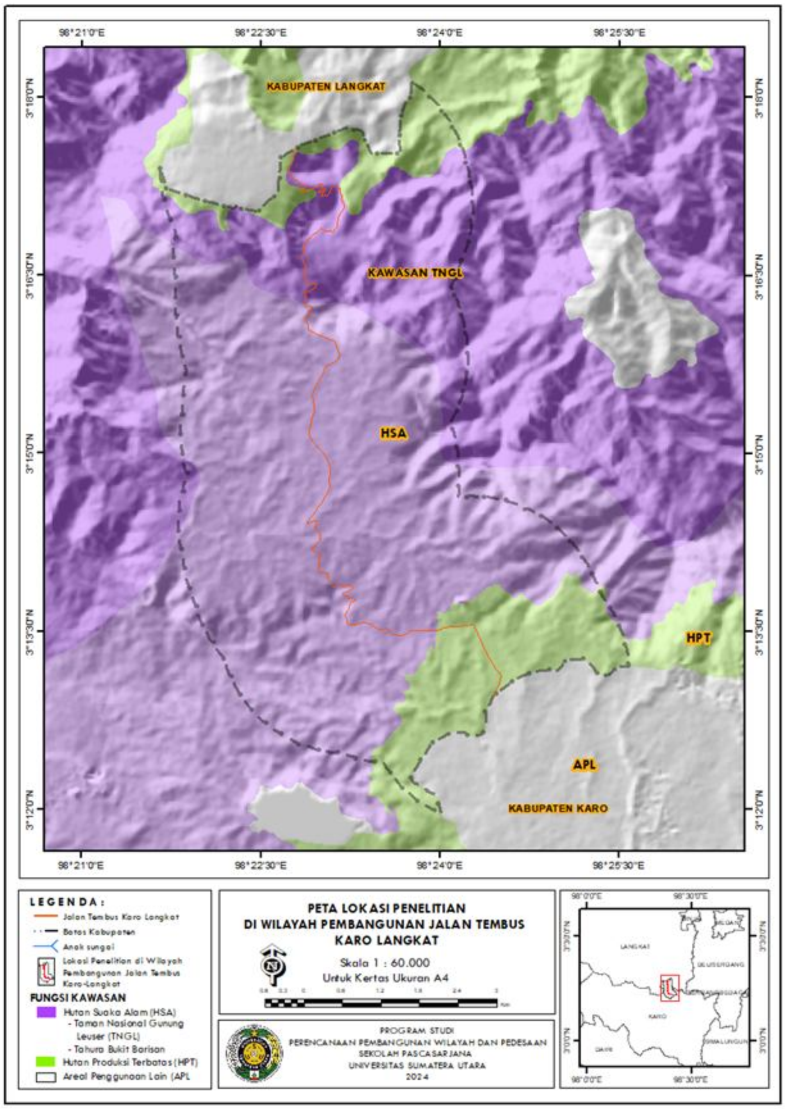

Figure 1. Research Location Map

Tools and Materials

The research employed a range of tools and materials to facilitate comprehensive data collection and analysis. A GPS device was utilized to record field coordinates for satellite image validation, while a digital camera captured visual documentation of field conditions. Data processing and analysis were conducted on a high-specification laptop equipped with spatial and statistical software packages.

The software utilized in this research included ArcGIS 10.8 for spatial analysis and cartographic representation, as well as TerrSet 2020 for land-cover change detection and forecasting via the Land Change Modeler (LCM). Microsoft Excel was employed for managing numerical data, including transition matrices and accuracy assessments, and Microsoft Word served as the main platform for documentation and report generation.

Primary materials comprised Landsat satellite imagery—specifically Landsat 7 TM (2012), Landsat 8 OLI (2018), and Landsat 9 OLI (2024)—each offering a 30-meter spatial resolution. In addition, various secondary data sources supported the research, notably the North

Sumatra Spatial Plan (RTRW) 2017–2037, Digital Elevation Model (DEM) data, and thematic maps (roads, rivers, and forested areas) provided by relevant institutions.

Data Types and Sources

This research integrated both primary and secondary data to ensure analytical rigor:

- **Primary Data:**
    - Visual interpretation of Landsat imagery to classify land cover based on temporal variations.
    - On-site validation through 60 purposively selected ground truth points, representing each land-cover class.
- **Secondary Data:**
    - North Sumatra RTRW 2017–2037 maps as references for spatial planning.
    - DEM data for examining elevation and slope, both pertinent to land-cover change analyses.
    - Road, river, and settlement maps obtained from the Forest Area Stabilization Center (BPKH) Region I Medan.

Data Collection Methods

1. **Visual Interpretation of Imagery**
   Landsat images were analyzed using on-screen digitizing techniques to derive accurate land-cover classifications. Spectral composite bands (5-4-3 for Landsat 7; 6-5-4 for Landsat 8 and 9) were employed to optimize vegetation differentiation.
2. **Field Validation**
   Ground-truthing was conducted to validate image interpretation results. Validation points were determined purposively to represent diverse land-cover categories.
3. **Secondary Data Collection**
   Relevant institutions provided the RTRW maps, administrative boundaries, and DEM data, all of which underpinned the spatial analysis and subsequent conformity assessment.

Data Analysis

1. **Preprocessing of Imagery**
    - Geometric correction was performed to align pixel coordinates with precise geographic references.
    - Radiometric correction was conducted to mitigate noise and enhance data quality for subsequent analyses.
2. **Land-Cover Classification**
    - Satellite imagery was categorized into five land-cover classes: primary forest, secondary forest, shrubland, open land, and dryland agriculture. Spectral and spatial criteria guided the classification process.
3. **Accuracy Assessment**
    - The classification for 2024 imagery was evaluated using an error matrix to compute overall and Kappa accuracies, adhering to a reliability threshold of >75%.
4. **Land-Cover Change Analysis**
    - Land Change Modeler (LCM) facilitated the examination of inter-class transitions across the study period, using transition matrices to compare temporal changes.
5. **Driving Factor Analysis**

- o Factors including proximity to roads, rivers, settlements, as well as topographic attributes (elevation and slope), were assessed through spatial overlays to elucidate their influence on land-cover changes.

6. **Land-Cover Change Prediction**
   - o Future scenarios up to the year 2037 were projected using Markov Chain methods, calibrated with 2012–2024 data. Kappa statistics were applied to validate predictive accuracy.
7. **Conformity Evaluation with RTRW**
   - o Predicted land-cover patterns for 2037 were juxtaposed with the North Sumatra RTRW 2017–2037 to assess alignment between actual land use and spatial-planning directives.

This research is anticipated to yield several key outputs. One of the primary deliverables is the production of land-cover change maps for 2012, 2018, and 2024, offering a detailed portrayal of spatiotemporal dynamics. Additionally, a validated land-cover prediction map for 2037 will be generated using robust scientific methodologies anchored in Kappa-based accuracy metrics.

A critical aspect of this research is the in-depth investigation of the factors driving land-cover shifts. By evaluating variables such as proximity to infrastructure, topographic conditions, and socio-economic activities, the study aims to clarify the mechanisms underpinning land-cover changes (Abate, 2023; Ali, 2024). Furthermore, the alignment of observed and projected land cover with the RTRW 2017–2037 will be thoroughly assessed to determine compliance with established spatial planning goals. The findings are expected to inform policy recommendations that facilitate sustainable land management and harmonize conservation imperatives with regional development objectives.

III. Results and Discussion

3.1 General Overview of the Research Location

The Karo-Langkat bypass road development site spans Karo and Langkat Regencies in North Sumatra Province, covering approximately 4,475.61 hectares. This road traverses Mount Leuser National Park (TNGL) and the Bukit Barisan Forest Park (Tahura), both of which are critical conservation areas. Geographically, the research location lies between 98°21'47"–98°25'35" E and 3°11'57"–3°18'06" N.

The study area is bounded as follows:

- **North:**Langkat Regency (Limited Production Forest)
- **East:**Langkat Regency (TNGL and the Bukit Barisan Forest Park)
- **South:** Karo Regency
- **West:**Karo and Langkat Regencies (TNGL)

Table 1. Distribution of the Study Area by Regency

Regency	Area (ha)	(%)
Langkat	1,036.97	23.17
Karo	3,438.64	76.83
Total	**4,475.61**	**100.00**

Source: Processed from the RTRW map.

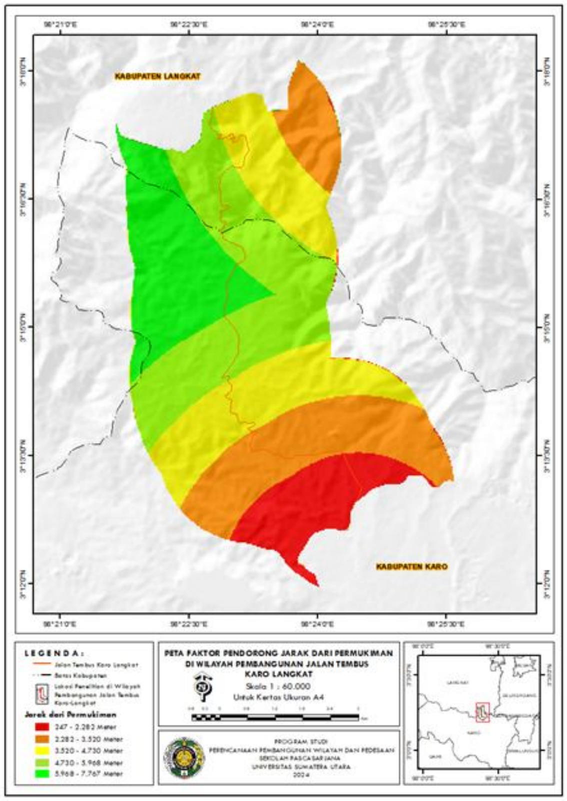

Figure 2. Map of Settlement Proximity in the Karo-Langkat Bypass Road Development Area

3.2 Regional Characteristics

3.2.1 Elevation

This region is part of the Bukit Barisan mountain range, with altitudes ranging from 805 to 1,714 meters above sea level (masl). Table 2 provides the distribution of area by elevation:

Table 2. Distribution of the Study Area by Elevation

Elevation Class (masl)	Area (ha)	(%)
855–1,104	247.07	5.52
1,104–1,276	347.14	7.76
1,276–1,397	1,232.46	27.54
1,397–1,488	2,379.31	53.16
1,488–1,714	269.63	6.02
Total	**4,475.61**	**100.00**

Source: Processed from the RTRW map.

Areas above 1,397 masl comprise more than half of the total area, indicating the predominance of mountainous terrain. Elevation thus serves as a key factor in assessing land-cover change.

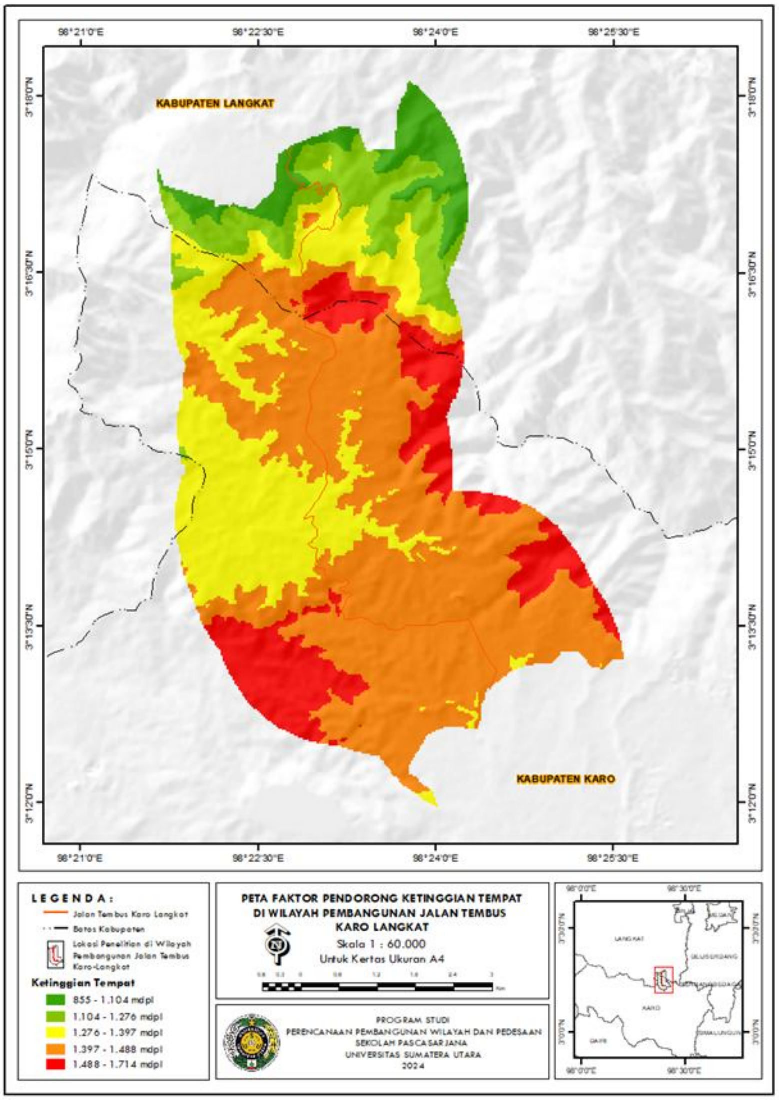

Figure 3. Elevation Map of the Karo-Langkat Bypass Road Development Area

3.2.2 Land Slope

Flat terrain (48.17%) constitutes the dominant slope category, followed by gentle slopes (23.72%), as detailed in Table 3:

Table 3. Distribution of Land Slope Classes in the Study Area

Slope Class (%)	**Area (ha)**	**(%)**
Flat (0–7)	2,156.45	48.17
Gentle (7–14)	1,061.82	23.72
Moderately Steep (14–23)	756.73	16.90
Steep (23–35)	413.54	9.24
Very Steep (>35)	88.07	1.97
Total	**4,475.61**	**100.00**

Source: Processed from the RTRW map.

The prevalence of flat to gentle slopes supports higher accessibility and the potential for human activities such as agriculture.

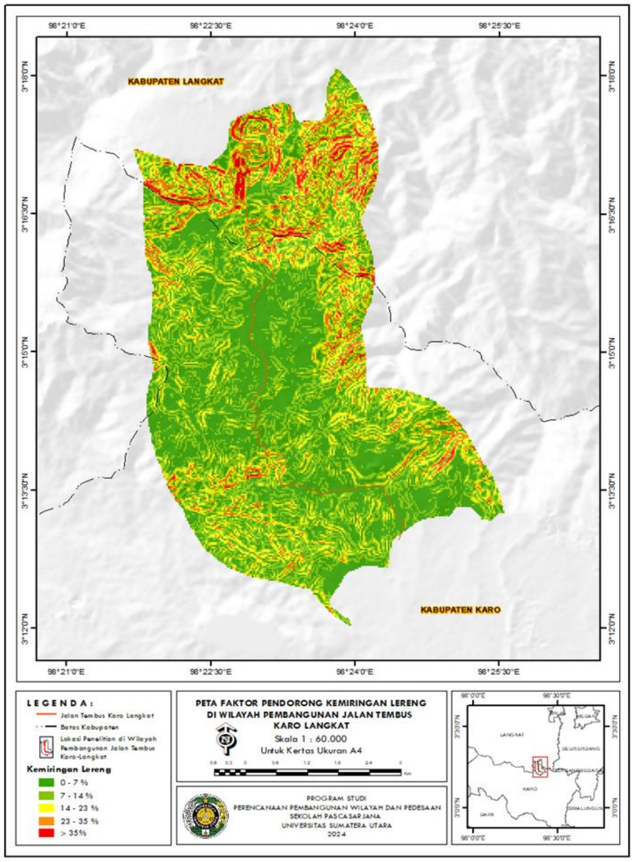

Figure 4. Slope Map of the Karo-Langkat Bypass Road Development Area

3.2.3 Accessibility

Accessibility was assessed based on the Euclidean Distance from roads, rivers, and settlements. The main road traversing this region is categorized into five distance ranges: (0–335 m), (335–703 m), (703–1,092 m), (1,092–1,519 m), and (1,519–2,014 m). Accessibility factors significantly influence land-cover changes, as elaborated in the driving-factor analysis.

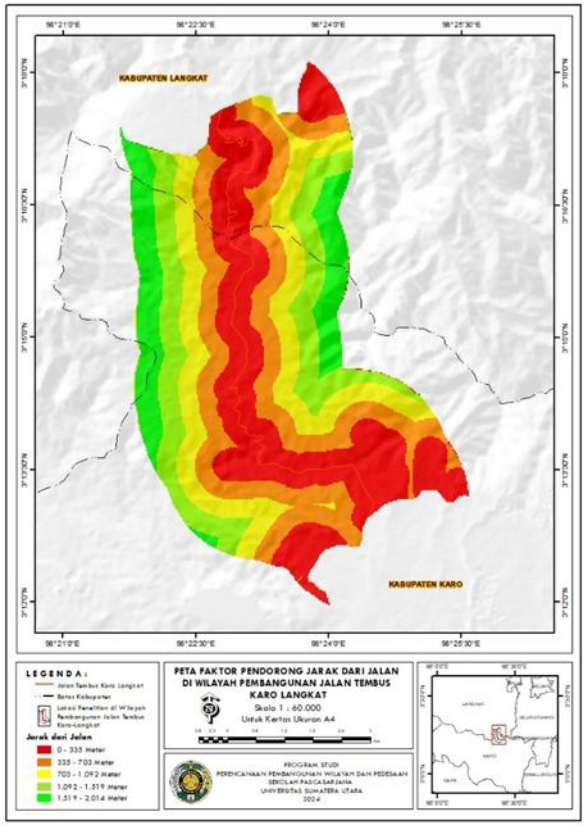

Figure 5. Road Accessibility Map in the Karo-Langkat Bypass Road Development Area

3.3 Spatial Plan (RTRW) Patterns

Based on the North Sumatra Provincial Spatial Plan (RTRW) 2017–2037, the study area is classified as follows:

Table 4. Distribution of Land Use According to North Sumatra RTRW 2017–2037

RTRW Spatial Function	Area (ha)	(%)	Description
Conservation (Protected)	3,717.18	83.05	Nature Reserve Forest (HSA)
Production (Cultivation)	758.43	16.95	Limited Production Forest
Total	**4,475.61**	**100.00**	

Source: Processed from the 2017–2037 North Sumatra RTRW map.

Conservation (protected) areas dominate the region, highlighting the crucial role of conservation initiatives in land management. Nonetheless, the land-cover data indicate significant changes within these conservation zones.

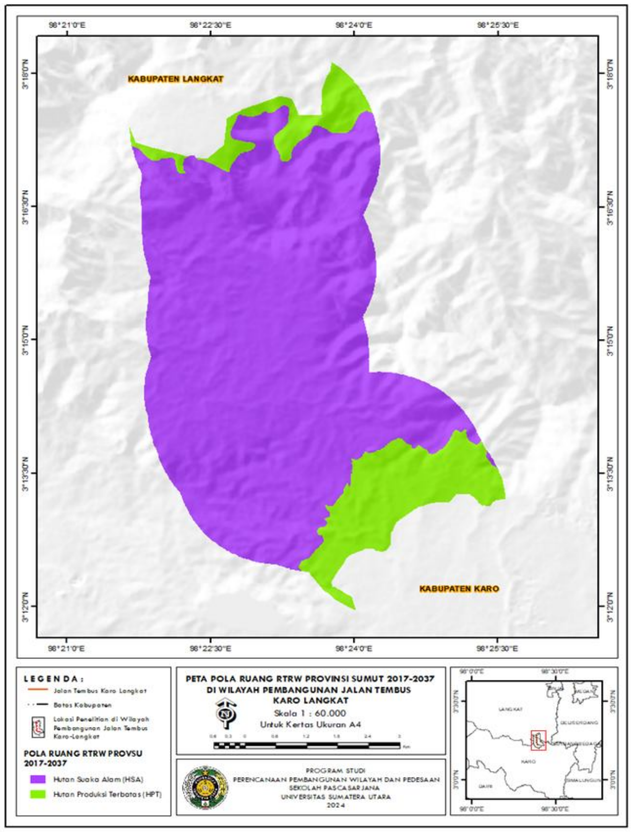

Figure 6. RTRW Spatial Plan Map in the Karo-Langkat Bypass Road Development Area

3.4 Land-Cover Change Analysis

3.4.1 Interpretation and Classification of Land Cover

Visual interpretation of Landsat imagery identified five main land-cover classes: primary forest, secondary forest, shrubland, open land, and dryland agriculture. Table 5 details their respective areas:

Table 5. Land-Cover Changes in 2012, 2018, and 2024

Land-Cover Class	2012 (ha)	2018 (ha)	2024 (ha)	Change (ha)
Primary Forest	1,749.33	1,707.12	1,571.04	-178.29
Secondary Forest	1,928.52	886.50	335.43	-1,593.09
Shrubland	186.03	511.74	770.67	+584.64
Open Land	22.50	54.45	50.94	+28.44
Dryland Agriculture	589.23	1,315.80	1,747.53	+1,158.30
Total	**4,475.61**	**4,475.61**	**4,475.61**	**0**

Source: Processed from Landsat imagery.

Primary and secondary forests have decreased significantly, while shrubland, open land, and dryland agriculture show an increasing trend. Forest loss appears to be strongly associated with land conversion for agriculture and other human activities.

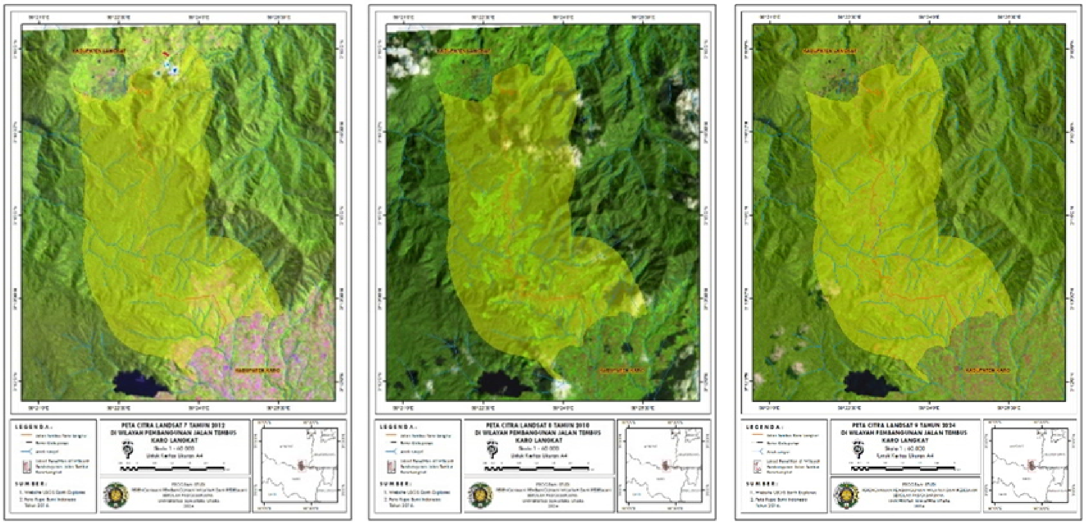

Figure 7. Land-Cover Maps for 2012, 2018, and 2024 in the Karo-Langkat Bypass Road Development Area

3.4.2 Projected Land-Cover Change in 2037

Projections derived from the Markov Chain method indicate continued trends through 2037. Table 6 illustrates the projected areas of each land-cover class:

Table 6. Land-Cover Projections for 2037

Land-Cover Class	2037 (ha)	(%)
Primary Forest	1,579.95	35.30
Secondary Forest	76.50	1.71
Shrubland	857.61	19.16
Open Land	79.29	1.77
Dryland Agriculture	1,882.26	42.06
Total	**4,475.61**	**100.00**

Source: Markov Chain Simulation Results.

These projections suggest a continued decline in primary forest, while dryland agriculture may rise to 42.06% of the total area by 2037.

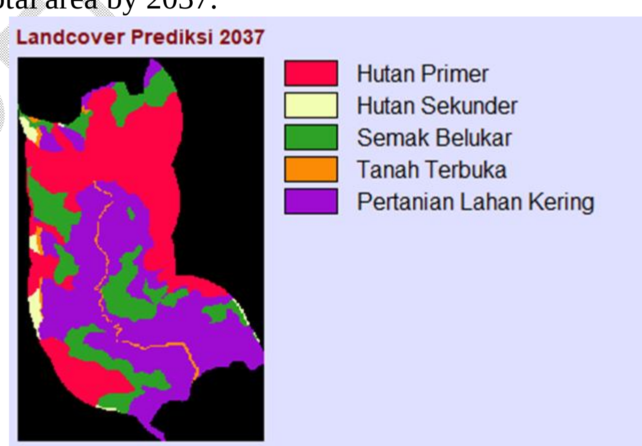

Figure 8. Predicted Land-Cover Map for 2037 in the Karo-Langkat Bypass Road Development Area

3.5 Evaluation of RTRW Spatial Conformity

An assessment of land-cover conformity with the RTRW demonstrates that only 37.01% of the land-cover area in 2037 complies with the spatial plan. Most non-conformities occur in the dryland agriculture (42.06%) and shrubland (19.16%) classes.

Table 7. Land-Cover Conformity with the RTRW in 2037

Year	Conforming (ha)	Non-Conforming (ha)	(%) Non-Conforming
2018	2,593.62	1,881.99	42.05
2024	1,906.47	2,569.14	57.40
2037	1,656.45	2,819.16	62.99

These inconsistencies highlight the need for stricter spatial policies to regulate land conversion in conservation areas. Mitigation measures, such as agroforestry and habitat restoration, are imperative to prevent further degradation.

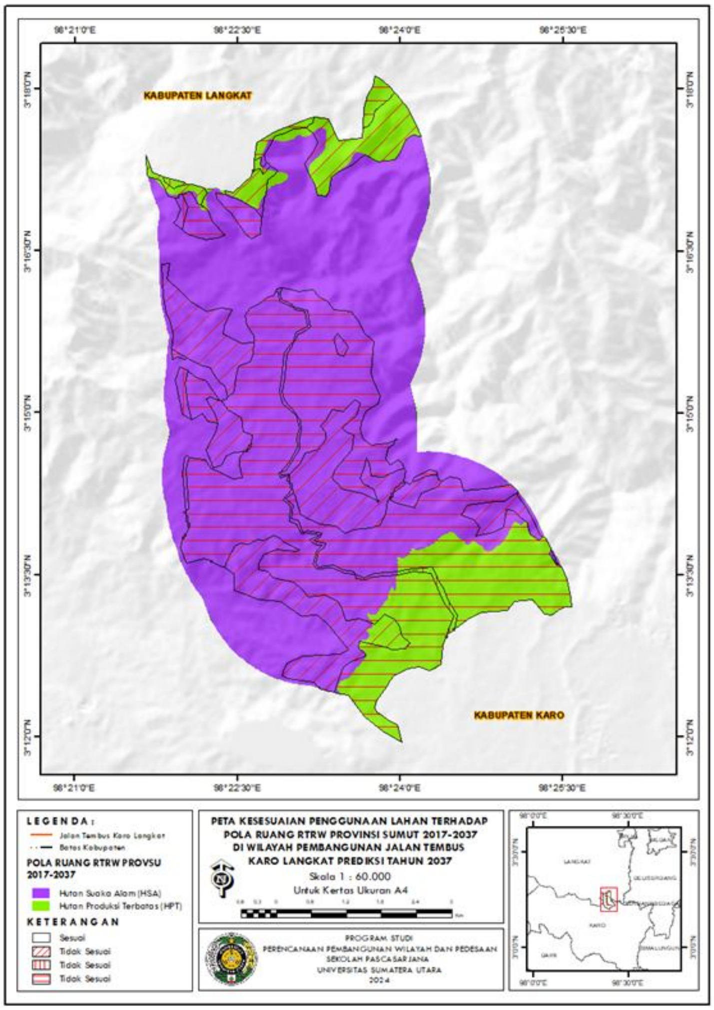

Figure 9. Land-Cover Conformity with the RTRW in 2037

3.6 Discussion

Land-cover changes in the Karo-Langkat bypass road development area reflect the intensified human pressures on conservation zones. Between 2012 and 2024, primary and secondary forests decreased by 178.29 ha and 1,593.09 ha, respectively, indicating substantial land conversion for agriculture. Yusri (2011) identified local land-clearing activities as a primary driver of deforestation, fueled by growing economic demands for agricultural expansion (FAO, 2021).

Forest loss has been exacerbated by improved accessibility associated with the main road. Gharaibeh et al. (2020) found that road construction offers greater access to previously remote areas, accelerating land conversions to non-conservation uses such as agriculture and residential development.

Projections through 2037 indicate that dryland agriculture will expand to 42.06% of the total area, while secondary forest may decline to a mere 1.71%. This is consistent with findings by Rimal et al. (2017), who observed that regions with high accessibility are more vulnerable to land-cover transformations driven by human activities.

The discrepancy between land-cover patterns and the RTRW underscores a major concern, with only 37.01% of the area in 2037 aligning with the 2017–2037 North Sumatra spatial plan. This misalignment, largely due to dryland agriculture and shrubland expansion, parallels the observations of Dani et al. (2017), who noted that inconsistencies between spatial planning and on-the-ground implementation frequently drive environmental degradation.

Cubic trend analysis illustrates that the most substantial changes occur in the southwestern portion of Karo Regency. As Eastman (2016) suggests, the cubic trend method can effectively capture the spatial dynamics of land-cover change with high accuracy.

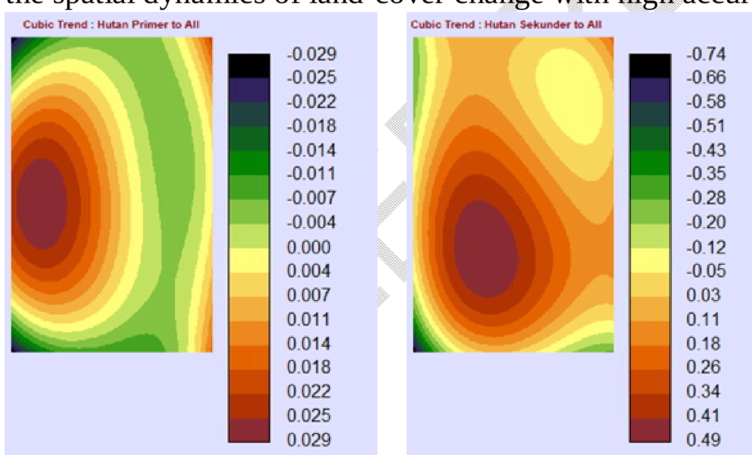

Figure 10. Cubic Trend in the Karo-Langkat Bypass Road Development Area

In addition, socio-economic ramifications of these land-cover changes must not be overlooked. While converting land to agriculture may offer short-term economic benefits, it can lead to long-term environmental challenges (Zhang, 2023 & Khan, 2023). Altman (1991) highlighted the inherent tension between immediate economic gains and broader ecological impacts, which pose a major challenge to sustainable resource management.

To mitigate the adverse consequences of land-cover change, community-based approaches—such as forest restoration initiatives and social forestry programs—are critical. Kubangun et al. (2017) demonstrated that involving local communities in conservation efforts can effectively reduce pressures on conservation areas.

In conclusion, the findings herein underscore the necessity of adopting more adaptive spatial policies and enforcing stricter regulations against spatial plan violations. Conservation-oriented measures such as agroforestry, habitat restoration, and public education on the importance of protected areas can serve as fundamental strategies to balance regional development with environmental preservation.

IV. Conclusion and Recommendations

This research has revealed that the construction of the Karo-Langkat bypass road exerts a significant impact on land-cover dynamics in the region. Primary forest areas have declined by 470 hectares over the 2012–2024 period, while open land and shrubland have increased by 170 hectares and 200 hectares, respectively. Projections through 2037 indicate continued reductions in primary forest, which may shrink to approximately 1,700 hectares. The principal factors influencing land-cover change include distance from roads, settlements, and rivers, with accessibility emerging as the dominant driver. The evaluation against the 2017–2037 North Sumatra Provincial Spatial Plan (RTRW) suggests that a portion of these land-cover changes is inconsistent with conservation designations, potentially exacerbating environmental degradation if left unmanaged.

Based on these findings, it is imperative to strengthen protection measures for key conservation areas such as Mount Leuser National Park (TNGL) and the Bukit Barisan Forest Park (Tahura) through more stringent regulations and consistent oversight. Such measures are crucial for preventing illegal land conversion that undermines the ecological functions of forest ecosystems. In addition, rehabilitation of degraded land along the Karo-Langkat bypass corridor must be undertaken in a concerted manner, involving local communities and environmental agencies. The government is further encouraged to promote environmentally sustainable agricultural practices so that local populations can utilize land resources without jeopardizing forest areas.

A revision of the 2017–2037 North Sumatra RTRW is warranted to reflect current on-site conditions, with particular emphasis on protecting conservation zones and managing space in accordance with sustainable development principles. Moreover, educational campaigns aimed at local communities must be intensified to enhance understanding of the long-term ecological benefits derived from forest conservation. Through this collaborative approach, the Karo-Langkat bypass road development is expected to generate economic benefits without sacrificing the existing ecosystems.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

References

Abate, S., & Moges, M. A. (2023). *Modelling of land use and land cover changes and prediction using CA–Markov model in the Andassa watershed, Blue Nile Basin, Ethiopia.Geocarto International*. https://doi.org/10.1080/10106049.2023.2210532

Alaloul, W. S., Musarat, M. A., Rabbani, M. B. A., Altaf, M., Alzubi, K. M., & Al Salaheen, M. (2022). *Assessment of Economic Sustainability in the Construction Sector: Evidence from Three Developed Countries (the USA, China, and the UK). Sustainability, 14(10), 6326*

Ali, S., Qureshi, S., & Shah, S. A. (2024). *The role of random forest and Markov chain models in predicting land use and land cover changes in Islamabad, Pakistan.Frontiers in Forests and Global Change*, *7*, 1345047. https://doi.org/10.3389/ffgc.2024.1345047

Asian Development Bank. (2021). *Economic and Financial Analysis: Dhaka–Sylhet–Tamabil Road Upgrade Project*

National Standardization Agency. (2014). Method of measuring changes in forest cover based on visual interpretation of optical remote sensing imagery. National Standardization Agency SNI 8033:2014.

Darmawan, A. R., Puspaningsih, N., & Saleh, M. B. (2018). Assessment of land-cover change using multi-layer perception and logistic regression methods in Mount Ciremai National Park. Conservation Media, 22(3), 252–261.

Food and Agriculture Organization of the United Nations. (2021, November 6). *COP26: Agricultural expansion drives almost 90 percent of global deforestation.* FAO Newsroom

Geist, H. J., & Lambin, E. F. (2001). What drives tropical deforestation? A meta-analysis of proximate and underlying causes of deforestation based on subnational case study evidence. LUCC Report Series, 4(1), 15–19.

Geist, H. J., & Lambin, E. F. (2002). Proximate causes and underlying driving forces of tropical deforestation. BioScience, 52(2), 143–150. https://doi.org/10.1641/0006-3568(2002)052[0143:PCAUDF]2.0.CO;2

Gunawan, H. (2014). Impacts of proposed road construction through protected areas on ecosystem and habitat balance. In National Inception Workshop: Building the resilience of Sumatra's tropical rainforests for climate change mitigation and biodiversity. Medan, 23–24 September 2014.

Handavu, F., Chirwa, P. W. C., &Syampungani, S. (2019). *Socio-economic factors influencing land-use and land-cover changes in the Miombo woodlands of the Copperbelt province in Zambia*

Hasan, S., Shi, W., Zhu, X., Abbas, S., & Khan, H. U. A. (2020). Future simulation of land use changes in rapidly urbanizing South China based on Land Change Modeler and remote sensing data. Sustainability, 12(11), Article 4350. https://doi.org/10.3390/su12114350

Jaya, I. N. S. (2010). Digital image analysis: A remote sensing perspective for natural resource management. IPB Press.

Khan, I., Lei, H., Shah, I. A., Ali, I., & Muhammad, I. (2023).*Agricultural land conversion and challenges for tenant farmers: A case study of district Mardan, Pakistan.Land Degradation & Development*, *34*(1), 640–650. https://doi.org/10.1002/ldr.5395

Kumar, A., Islam, T., Sekimoto, Y., Mattmann, C., & Wilson, B. (2020). Convcast: An embedded convolutional LSTM-based architecture for precipitation nowcasting using satellite data. PLOS ONE, 15(3), Article e0230114. https://doi.org/10.1371/journal.pone.0230114

Linkie, M., Smith, R. J., & Leader-Williams, N. (2004). Mapping and predicting deforestation patterns in the lowlands of Sumatra. Biodiversity and Conservation, 13(10), 1809–1818. https://doi.org/10.1023/B:BIOC.0000035867.90891.ea

Mukmin, E., Rahmat, S., &Novitasari, D. (2016). Analysis of land-cover changes and their impact on spatial planning in Malang Regency. Journal of Spatial Planning and Environment, 18(1), 23–33.

Munibah, K. (2008). Spatial model of land-use change using a cellular automata approach: A case study in the Cidanau Watershed, Banten Province. Globe Scientific Magazine, 10(2), 108–121.

Putri, F. (2009). Analysis of agricultural land conversion into built-up areas due to Jakarta–Merak toll road construction. Journal of Spatial Planning, 12(2), 45–60.

Silis, T., Rahayu, E., & Andriani, P. (2015). Spatial model of deforestation in Sumatra islands using typological approach. IOP Conference Series: Earth and Environmental Science, 47(1), 1–10. https://doi.org/10.1088/1755-1315/47/1/012010

Sonata, H. (2017). Environmental assessment of geometric improvements via construction of the SitinjauLaut Panorama I overpass. Civil Engineering Journal of Padang Institute of Technology, 4(1), 12–20.

Sulistiyono, N., Jaya, I. N. S., Prasetyo, L. B., &Tiryana, T. (2015). Spatial model of deforestation in Sumatra Islands using typological approach. Journal of Tropical Forest Management, 21(3), 99–109. https://doi.org/10.7226/jtfm.21.3.99

Sulistiyono, N., & Zahirah, A. (2024). Assessing the impact of road construction on the Sumatran orangutan (Pongoabelii) habitat in Pakpak Bharat District from 2003 to 2022. International Journal of Design & Nature and Ecodynamics, 19(2), 477–487. https://doi.org/10.18280/ijdne.190213

Sutaryono, &Dewi, A. R. (2020). Pembangunan perumahanpermukimandasar land management [Development of residential housing based on land management]. In Developments in settlement and regional development in Indonesia (pp. 7–20).

Toh, F. A., Angwafo, T. E., Ndam, L. M., & Ze, A. M. (2018). *The Socio-Economic Impact of Land Use and Land Cover Change on the Inhabitants of Mount Bambouto Caldera of the Western Highlands of Cameroon*. *Advances in Remote Sensing, 7(1), 25-45*

Zhang, Y., Li, X., & Wang, J. (2023). *Socio-economic impacts of agricultural land conversion: A meta-regression analysis.Land Use Policy, 132*, 106831. https://doi.org/10.1016/j.landusepol.2023.106831