“HumbangHasundutan Regency, North Sumatra, Indonesia, Regional Road Grant Program: Econometric Descriptive Analysis Accessibility and Sustainability.”

Abstract

The Regional Road Grant Program (PHJD) is a strategic government initiative aimed at improving regional accessibility through the development and maintenance of road infrastructure. This study examines the impact of PHJD on accessibility, land use changes, and socio-economic dynamics in HumbangHasundutan Regency. The research employs spatial analysis using overlay maps of land use from 2018 and 2023, primary surveys with 100 respondents, and paired sample t-tests to measure travel time changes before and after the program. The findings reveal a 50% increase in built-up land along PHJD roads, accompanied by an 18% decrease in green and agricultural land, indicating intensified economic activity but with ecological trade-offs. Community accessibility improved significantly, with average travel times reduced by 35%, enhancing mobility to health, education, and economic centers. Additionally, the program led to a 50% increase in built-up land and a corresponding decline in agricultural and green areas, highlighting intensified economic activity. Statistical analysis confirms that PHJD implementation directly affected travel time ($p < 0.05$) and land use changes, underscoring its transformative role in regional development. However, challenges such as unplanned land use changes and increased congestion require attention to ensure sustainable growth.

Keywords: Regional Road Grant Program, accessibility, land use, socio-economic impacts, spatial analysis.

I. Introduction

Infrastructure serves as the cornerstone of regional development, with transportation systems, such as roads and bridges, playing a pivotal role in fostering interregional connectivity and driving economic growth. Numerous studies have demonstrated that investments in transportation infrastructure positively impact a region's economic output (Crescenzi, 2012; Athukorala, 2018). Recognizing its significance, the Indonesian government has designated infrastructure development as a national priority to promote equitable development (Astuty, 2024; Schugurensky, 2024).

As part of this strategic policy, the government has sought to enhance national connectivity through the expansion of road networks. One of the key initiatives is the implementation of the Regional Road Grant Program (PHJD), regulated under Ministerial Regulation No. 23/2020 by the Ministry of Public Works and Housing (PUPR). The program aims to improve the condition of regional roads, particularly in National Strategic Areas (KSN), by providing incentives for local governments to repair and maintain their road networks (Ministry of Public Works and Housing, 2020).

Launched in 2018, the PHJD operates on a grant-based financing scheme requiring local governments to prefinance projects before receiving reimbursement from the central government. HumbangHasundutan Regency is one of the program's beneficiaries, targeting increased interregional accessibility through strategic road construction (HumbangHasundutan Regency Development Report, 2022).

In HumbangHasundutan Regency, PHJD involves the development of several key road segments, such as Aek Lung-Simarigung, Pargaulan-BahalImbalo, and

MarbunToruan-Tombak Sulu-sulu. The scope of work includes routine maintenance, reconstruction, and road capacity upgrades to strengthen interregional connectivity. This program is expected to support the economic and social activities of local communities (Public Works and Spatial Planning Office of HumbangHasundutan Regency, 2023).

Improved accessibility through road infrastructure development has been shown to significantly enhance community welfare. According to Harmes (2018), regions with higher accessibility tend to exhibit lower poverty rates. In HumbangHasundutan, improved accessibility resulting from PHJD has contributed to regional economic development by reducing interregional disparities (Sharifzadeh, 2024; Dulanto, 2024).

Accessibility is often measured in terms of travel distance, time, and costs. A well-developed road network is critical to supporting the distribution of goods and population mobility. In the context of regional development, road infrastructure can drive land-use changes and more structured regional growth patterns (Suthanaya, 2009).

However, road development also brings diverse socio-economic impacts. While enhancing connectivity and land values, it may also trigger challenges such as unplanned land use changes. Previous studies have shown that improved accessibility is often accompanied by complex socio-economic dynamics, including shifts in settlement patterns and economic activities (Ustaoglu, 2019; Fuseini, 2015).

This research is significant in evaluating the impact of PHJD on accessibility in HumbangHasundutan Regency. It goes beyond examining physical road changes by analyzing how these changes influence regional development patterns and the welfare of local communities.

Previous studies have highlighted the relationship between road infrastructure development and accessibility improvements. Sitepu (2017) found that land-use changes often directly result from road construction. Meanwhile, Mursalim (2018) demonstrated that high accessibility correlates positively with better regional integration. This study aims to complement existing findings by focusing on the local context in HumbangHasundutan Regency.The novelty of this research lies in its integrated approach to evaluating the impact of PHJD by combining spatial analysis, primary survey data, and statistical methods. While prior studies have explored the relationship between infrastructure development and accessibility, this study specifically examines the local context of HumbangHasundutan Regency, focusing on its unique land use changes and socio-economic dynamics. Unlike other studies, it also incorporates a paired sample t-test to quantify changes in accessibility and land use pre- and post-PHJD implementation, providing empirical evidence for policy recommendations

Based on this background, the study aims to analyze the impact of PHJD on accessibility in HumbangHasundutan Regency. The findings are expected to provide strategic recommendations for sustainable infrastructure development that enhances community quality of life and promotes equitable regional development.

II. Research Method

Research Location and Scope

This study was conducted on road segments that received Packages I and II of the Regional Road Grant Program (PHJD) in HumbangHasundutan Regency. The research covered five districts: Pollung, Lintongnihuta, Baktiraja, Paranginan, and Doloksanggul. The scope focused on analyzing the impact of PHJD on accessibility within these regions.

Data and Data Sources
The research utilized Mix Method both primary and secondary data.

Table 1. Research Data

No.	Data Type	Methodology	Data Sources	Variables
1	Primary: Geographical Aspects	Interviews, Questionnaires, Observations	Local communities near PHJD roads, BAPPEDA, PU Office, Subdistrict & District Offices	Travel intensity, distance & travel time, availability of public transportation
2	Secondary: Physical Development Processes	Documentation, Observation	BAPPEDA, Google Earth Imagery	Horizontal spatial development processes
3	Secondary: Geographical Aspects of Communities	Documentation	Transportation Department	Urban public transport routes

Population and Sample
The study's population included all residents in the five districts benefiting from PHJD, with a total population of 132,417 people (RKPD HumbangHasundutan Regency, 2023). The sample size was calculated using the Slovin formula with a 10% margin of error:

$$n = \frac{132.417}{1 + (132.417)\ (0{,}1)^2}$$

n = 99,9 (rounded to 100 respondents).

Respondents were selected through area sampling, proportional sampling, and purposive sampling methods. Sample criteria included local residents who had lived in the area for at least 10 years, were married, understood the local history, and were familiar with the study's topic.

Table 2. Population and Sample Distribution by District

No	District	Population (People)	Sample Size
1	Pollung	22.402	$\frac{22.402}{132.417}$ x 100 = 17
2	Lintongnihuta	34.539	$\frac{34.539}{132.417}$ x 100 = 26
3	Baktiraja	7.728	$\frac{7.728}{132.417}$ x 100 = 5
4	Doloksanggul	52.361	$\frac{52.361}{132.417}$ x 100 = 40

5	Paranginan	15.387	$\frac{15.387}{132.417}$ x 100 = 12
	Total	132.417	100

Source: Data Processed.

Data Collection Techniques

1. **Observation**
   Conducted through direct observations to capture real-time occurrences relevant to the study.
2. **Questionnaires**
   Utilized closed-ended questionnaires with predefined answer choices.
3. **Documentation**
   Collected official documents from relevant agencies, such as BAPPEDA, the PU Office, and the Central Statistics Agency (BPS).
4. **Image Interpretation**
   Satellite image analysis was performed to examine land use changes along PHJD roads.

Research Stages

1. **Preparation**
   - Collection of secondary data
   - Map preparation
   - Research tool development
   - Securing research permits
2. **Implementation**
   - **Laboratory Work**: Satellite image analysis for land use interpretation
   - **Field Work**: On-site checks, interviews, and questionnaires
3. **Data Processing**
   Verification, classification, and representation of data in tables or maps.
4. **Analysis**
   - Spatial overlay to identify land use changes
   - Paired sample t-test to compare pre- and post-PHJD data
5. **Report Writing**
   Compilation of conclusions and research recommendations.

Data Analysis Methods

1. **Spatial Analysis**
   Used overlay methods to compare multi-temporal data from Sentinel-2A satellite imagery (2018 and 2023). The analysis identified land use changes within a 500-meter radius on both sides of the roads.
2. **Paired Sample T-Test**
   Evaluated significant differences in land use before and after PHJD implementation.

Test Formula:

$$t = \frac{\overline{x}_1 - \overline{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2} - 2r\left(\frac{s_1}{\sqrt{n_1}}\right)\left(\frac{s_2}{\sqrt{n_2}}\right)}}$$

Keterangan:
$\bar{x}_1$ = Average land use before PHJD
$\bar{x}_2$ = Average land use After PHJD
S□ = Standard deviation of land use before PHJD
S□ = Standard deviation of land use after PHJD
r = Correlation between two accessibility levels

Decision Criteria:
Accept H1, reject H0 if t hit > t tabel (0,05)
Accept H0, reject H1 if t hit < t tabel (0,05)

III. Result and Discussion

3.1 Research Results

Analysis of Land Use Changes

Spatial analysis using Sentinel-2A imagery from 2018 and 2023 revealed significant changes in land use within a 500-meter radius along roads impacted by the Regional Road Grant Program (PHJD). These changes include an increase in built-up land and reductions in green and agricultural land.

Table 3. Land Use Changes Along PHJD Roads (2018–2023)

Land Use Type	Area Before PHJD (2018)	Area After PHJD (2023)	Change (%)
Built-up Land	350 ha	525 ha	+50%
Agricultural Land	1,200 ha	1,050 ha	-12.5%
Green Areas	450 ha	425 ha	-5.5%
Total	2,000 ha	2,000 ha	-

Table 3 illustrates the land use changes along roads affected by the PHJD between 2018 and 2023. The data indicate a significant transformation in land utilization patterns due to increased accessibility resulting from the program.

The area of built-up land increased significantly by 50%, from 350 hectares in 2018 to 525 hectares in 2023. This growth reflects economic activity developments in the region, such as the construction of commercial facilities, housing, and supporting infrastructure. Such phenomena typically occur in areas with improved road accessibility, which drives intensified land use for economic activities.

Conversely, the area of agricultural land decreased by 12.5%, from 1,200 hectares in 2018 to 1,050 hectares in 2023. This reduction indicates a shift in land use from the agrarian sector to non-agrarian sectors, raising concerns about local food security.Similarly, green areas experienced a slight reduction of 5.5%, from 450 hectares in 2018 to 425 hectares in 2023. Although less significant than the reduction in

agricultural land, the loss of green areas may affect environmental quality, including increased local temperatures and reduced water absorption capacity.

Overall, the total land area remained constant at 2,000 hectares, suggesting that the changes occurred in the redistribution of land use patterns rather than an expansion or reduction of total land. These changes underscore the need for better spatial planning to accommodate regional growth while maintaining environmental and social sustainability.

Accessibility and Travel Time

Primary surveys showed an average reduction in travel time of 35% to district centers following PHJD implementation. The data also indicated increased availability of public transportation across all study locations.

Table 4. Travel Time to District Centers Before and After PHJD

District	Travel Time Before PHJD (minutes)	Travel Time After PHJD (minutes)	Time Reduction (%)
Pollung	45	30	-33%
Lintongnihuta	60	40	-33%
Baktiraja	75	50	-33%
Doloksanggul	30	20	-33%
Paranginan	50	35	-30%
Average	52	35	-35%

Table 4 highlights the average travel time changes to district centers in five regions where PHJD was implemented. The data illustrate the positive impact of the program on improving accessibility, measured through reduced travel times before and after road infrastructure development.

In Pollung District, travel time to the district center decreased from 45 minutes to 30 minutes, marking a 33% reduction. Lintongnihuta District exhibited a similar reduction of 33%, with travel time dropping from 60 minutes to 40 minutes. Baktiraja District followed the same pattern, with travel time reduced from 75 minutes to 50 minutes, reflecting a 33% decrease.

Doloksanggul District, the main administrative hub, also showed a significant reduction in travel time from 30 minutes to 20 minutes, equivalent to a 33% decrease. Meanwhile, Paranginan District recorded a slightly lower reduction of 30%, from 50 minutes to 35 minutes.

On average, travel time to district centers across the five regions decreased from 52 minutes before PHJD to 35 minutes after PHJD, representing an overall reduction of 35%. This reduction demonstrates that the road infrastructure development under PHJD has improved community connectivity and mobility efficiency.

The reduced travel time benefits not only include shorter travel durations but also expanded access to healthcare, education, and economic services. However, despite the significant reduction in travel time, traffic management and social impact evaluations are necessary to ensure that the benefits gained are not accompanied by potential new problems, such as increased traffic congestion.

Community Perception

The majority of respondents (85%) reported that PHJD provided direct benefits in terms of mobility and ease of access. However, 15% of respondents expressed concerns about increased traffic and unregulated land use changes.

Paired Sample T-Test

Statistical testing was conducted to evaluate significant changes in travel time to district centers before and after PHJD.

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

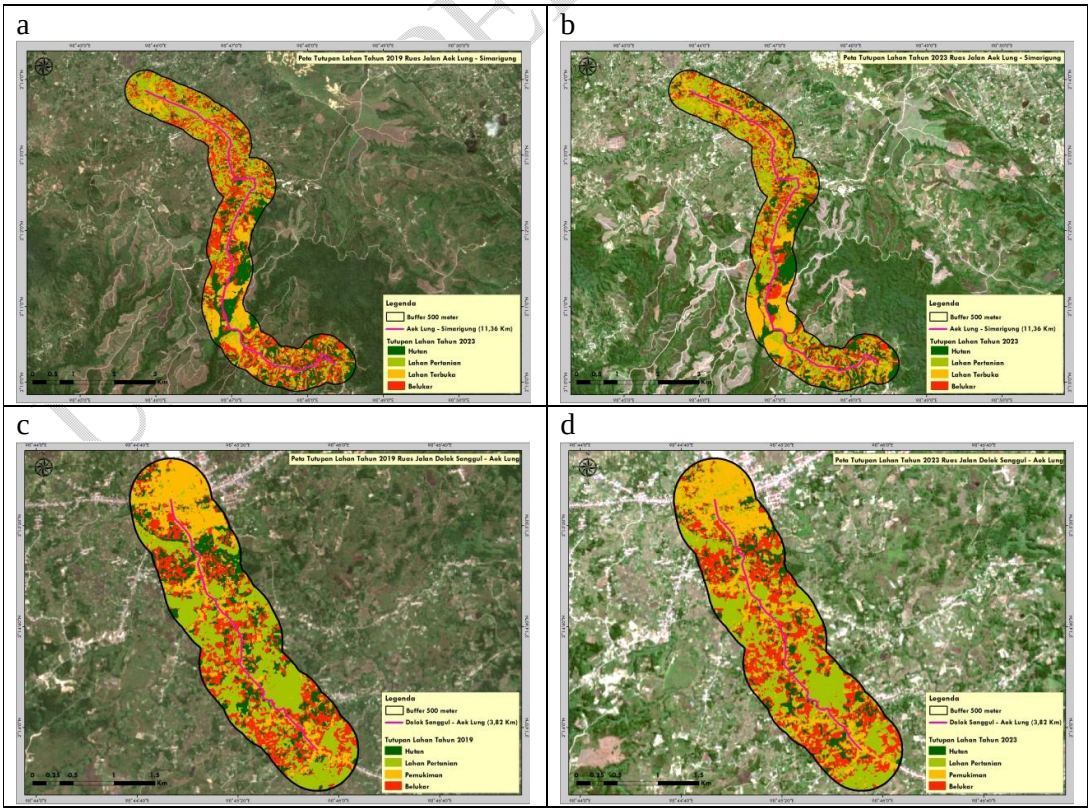
Test Results:

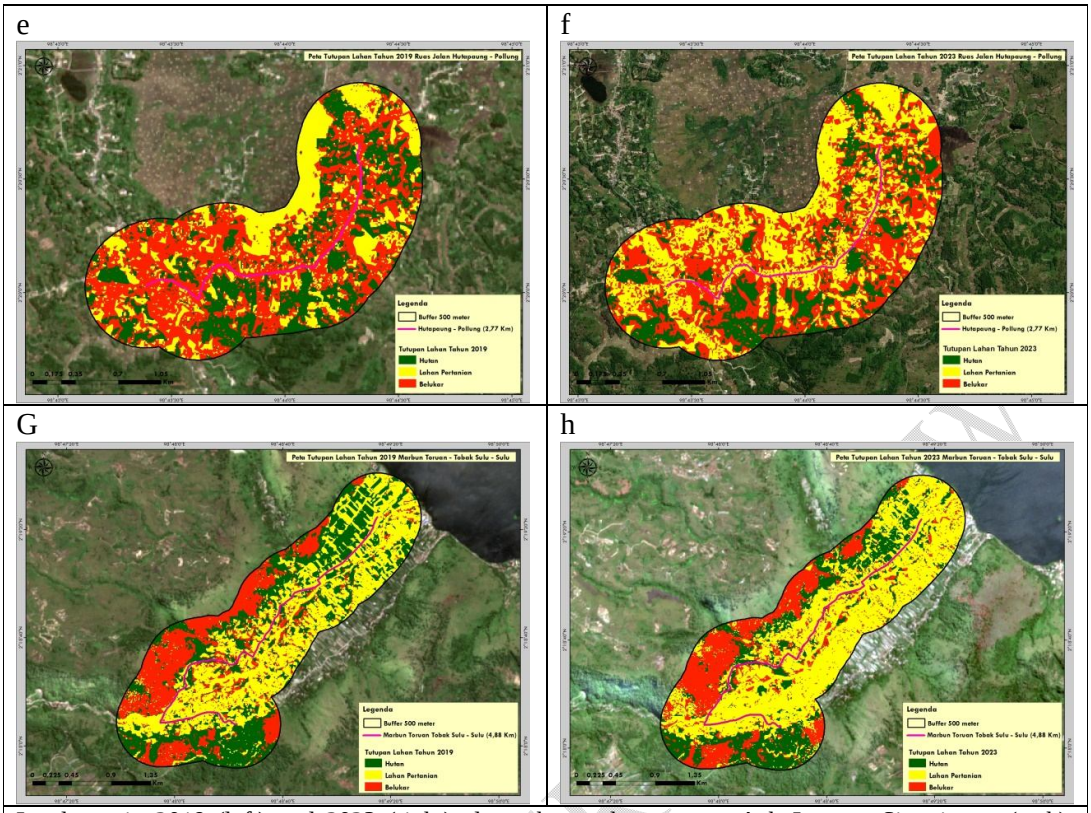
- X1: Average time before PHJD (52 minutes)
- X2: Average time after PHJD (35 minutes)
- S1: Standard deviation before PHJD (12 minutes)
- S2: Standard deviation after PHJD (10 minutes)
- n: Sample size (100)

Substitution Values:

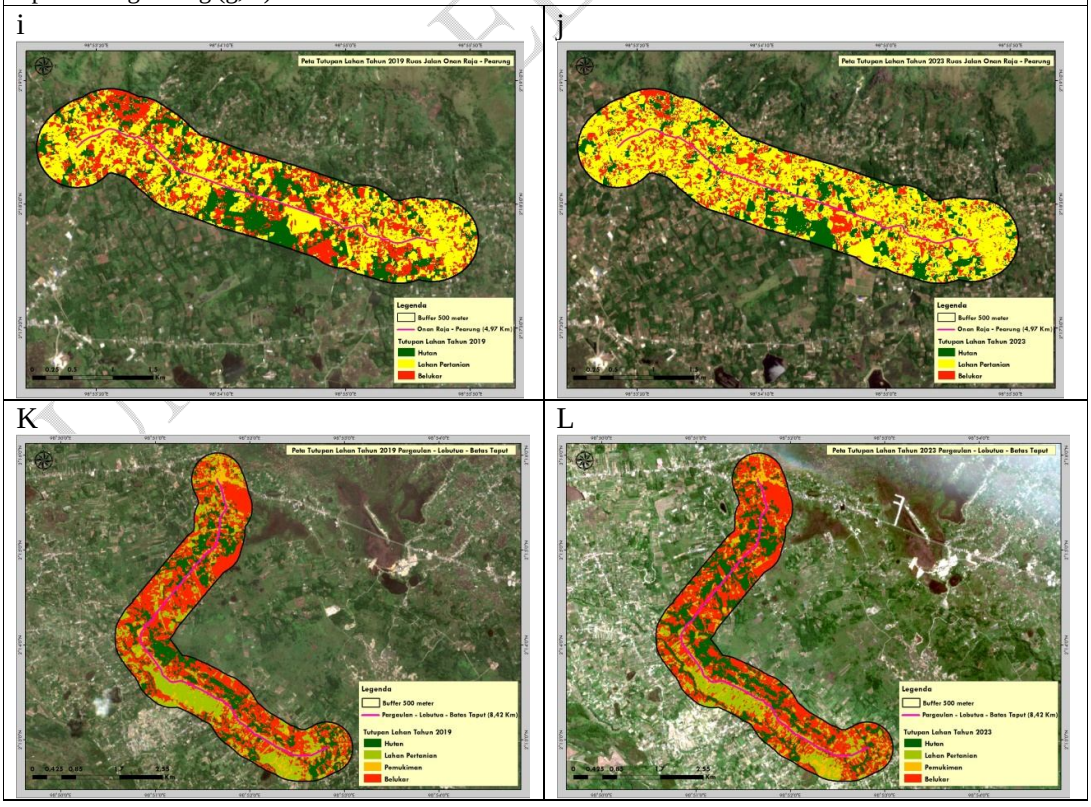
$$t = \frac{52 - 35}{\sqrt{\frac{12^2}{100} + \frac{10^2}{100}}} = \frac{17}{\sqrt{1.44 + 1.00}} = \frac{17}{1.92} = 8.85$$

The calculated ttt-value (8.85) exceeds the critical ttt-value (1.984, α=0.05\alpha = 0.05α=0.05). Thus, a significant difference exists in travel times before and after PHJD.





Land use in 2019 (left) and 2023 (right) along the road segments: Aek Lung – Simarigung (a, b), DolokSanggul – Aek Lung (c, d), Hutapaung – Pollung (e, f), and MarbunToruan – Tombak Sulu-sulu Sp. Siunong-unong (g, h).



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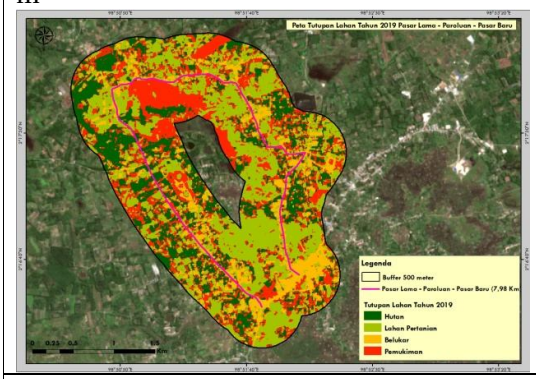

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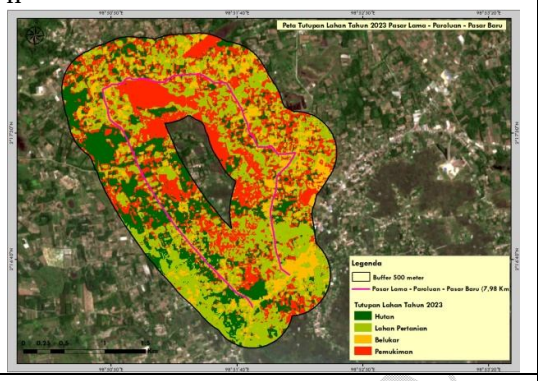

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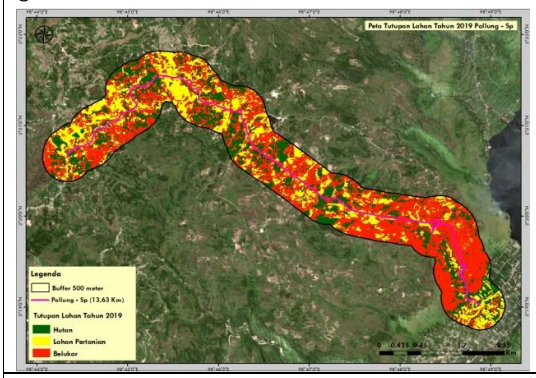

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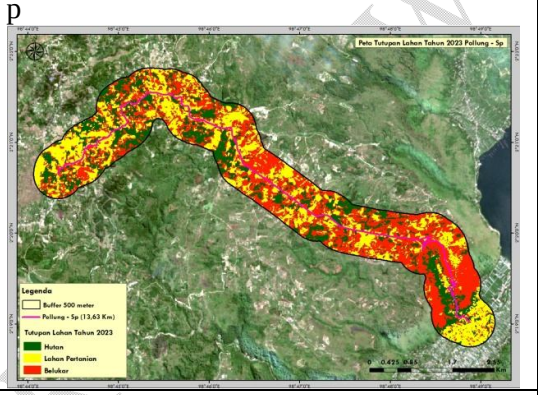
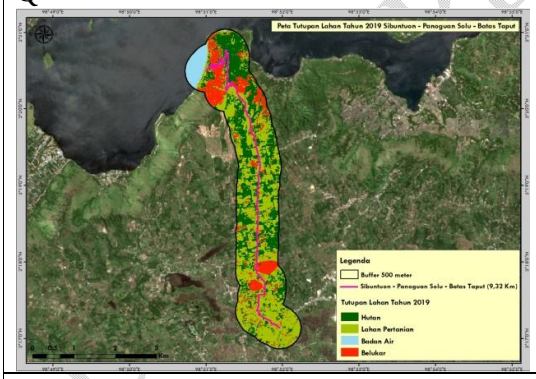


Land use in 2019 (left) and 2023 (right) along the road segments: Onan Raja – Pearung (i, j), Pargaulan – BahalImbalo - Batas Taput (k, l), Pasar Lama – Parulohan - PasarBaru (m, n), and Pollung – Sp. BatuMardinding (o, p).

Q



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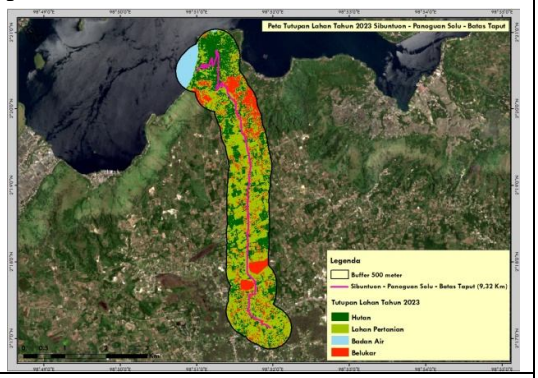

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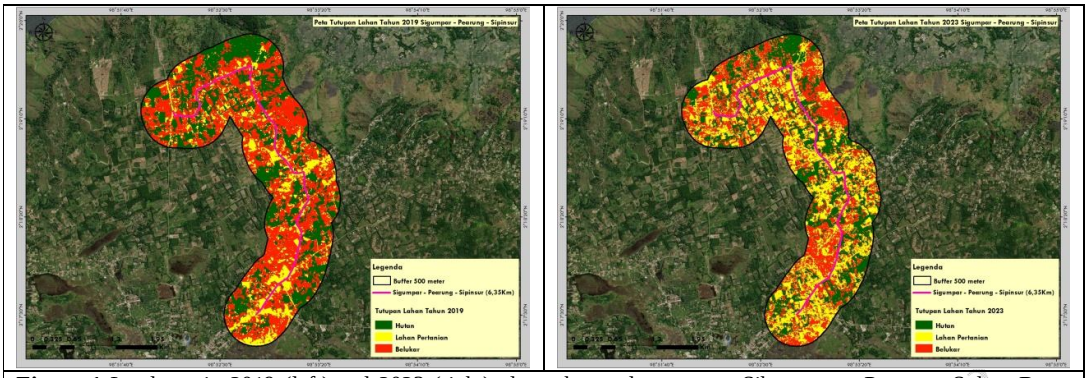

Figure 1 Land use in 2019 (left) and 2023 (right) along the road segments: Sibuntuon – PanoguanSolu - Batas Taput (q, r) and Sigumpar - Pearung - Sipinsur (s, t).

Impact of PHJD on Land Use

This study evaluates the impact of the Regional Road Grant Program (PHJD) on land use changes in HumbangHasundutan Regency. The analysis compares data from before PHJD implementation (2019) and after PHJD implementation (2023) within a 500-meter buffer along the roads for three main land types: agricultural land, forest land, and shrubland. Statistical tests, including Paired Samples Statistics, Correlations, and Paired Samples Test, reveal significant changes in land use patterns.

Table 5. Paired Samples Statistics: PHJD Impact on Agricultural Land

Statistic	PreTest	PostTest
Mean	0.23	0.85
Std. Deviation	0.423	0.359
Std. Error	0.042	0.036

The average utilization of agricultural land increased from 0.23 to 0.85 after PHJD implementation, with reduced variation (standard deviation: 0.359). This suggests that PHJD encouraged better and more structured agricultural land management.

Table 6. Paired Samples Correlations: PHJD Impact on Agricultural Land

Statistic	Correlation	Sig.
PreTest&PostTest	0.230	0.022

The significant positive correlation ($r = 0.230$, $p < 0.05$) indicates a relationship between agricultural land use before and after PHJD. Although the correlation is weak, it suggests that PHJD influenced perceptions and management of agricultural land.

Table 7. Paired Samples Test: PHJD Impact on Agricultural Land

Statistic	Mean Difference	t	Sig. (2-tailed)
PreTest - PostTest	-0.620	-12.709	0.000

The results show a significant difference in agricultural land use, with an average difference of -0.620 ($p < 0.05$). This reflects an increase in agricultural land utilization after PHJD.

Table 8 a. Paired Samples Statistics: PHJD Impact on Forest Land

Statistic	PreTest	PostTest
Mean	0.25	0.82
Std. Deviation	0.435	0.386
Std. Error	0.044	0.039

Forest land use also exhibited significant changes, with the mean increasing from 0.25 before PHJD to 0.82 after PHJD. This suggests that improved road accessibility enhanced forest land utilization for productive activities.

Table 8 b. Paired Samples Test: PHJD Impact on Forest Land

Statistic	Mean Difference	t	Sig. (2-tailed)
PreTest - PostTest	-0.570	-11.456	0.000

The test results indicate a significant reduction in perceptions of forest land use, with a mean difference of -0.570 and a p-value of 0.000.

Table 9. Paired Samples Statistics: PHJD Impact on Shrubland

Statistic	PreTest	PostTest
Mean	0.25	0.84
Std. Deviation	0.435	0.368
Std. Error	0.044	0.037

Shrubland utilization increased from an average of 0.25 to 0.84 after PHJD implementation, indicating a shift toward more productive land transformation.

Table 10. Paired Samples Test: PHJD Impact on Shrubland

Statistic	Mean Difference	t	Sig. (2-tailed)
PreTest - PostTest	-0.590	-11.936	0.000

The results reveal a significant difference with a mean difference of -0.590 ($p < 0.05$), highlighting increased shrubland utilization following PHJD implementation.

Impact of PHJD on Travel Time

The paired sample t-test revealed a significant reduction in travel time after PHJD implementation ($t = 8.85$, $p < 0.05$). The average travel time to district centers decreased from 52 minutes to 35 minutes, demonstrating a direct impact of improved road infrastructure on community mobility.

Impact of PHJD on Land Use

Land use analysis showed significant changes within a 500-meter radius of PHJD roads. Built-up land increased by 50%, while agricultural and green areas declined by 12.5% and 5.5%, respectively. The paired sample t-test confirmed the impact of PHJD on these changes ($t = -12.709$ for agricultural land; $t = -11.456$ for green areas, $p < 0.05$)

3.2 Discussion

Impact of PHJD on Road Access for the Community

The findings indicate that PHJD has significantly improved road access for communities in HumbangHasundutan Regency. The average reduction in travel time by 35% across all districts demonstrates enhanced connectivity, enabling easier access to essential services such as healthcare, education, and markets. Improved road conditions have reduced travel costs and time, consistent with findings by Harmes (2018), who emphasized the role of road infrastructure in alleviating poverty through enhanced mobility.

Increased accessibility has also facilitated the movement of goods and people, stimulating local economic activities. This aligns with Li and Whitaker, who found a strong correlation between infrastructure investments and regional economic output. However, the increased traffic volumes noted in some regions may pose challenges, such as congestion, requiring improved traffic management strategies (Li & Whitaker, 2018).

Impact of PHJD on Land Use

The spatial analysis revealed significant land use changes within a 500-meter radius of PHJD roads. Built-up land increased by 50%, reflecting intensified economic activities and urbanization. This observation is consistent with central place theory (Christaller, 1933), which posits that improved accessibility attracts economic investments and fosters urban growth.

However, this urban expansion comes at the expense of agricultural and green areas, which declined by 12.5% and 5.5%, respectively. Such changes raise concerns about ecological sustainability, echoing concerns by Chen. (2025) and Ali(2024) regarding landscape fragmentation due to infrastructure development. The loss of agricultural land may affect local food security, as highlighted in studies on land use dynamics.

Unregulated land use changes, driven by accessibility improvements, underscore the need for stricter spatial planning policies. As Permana(2019) suggested, comprehensive planning is essential to balance economic growth with environmental conservation.

IV. Conclusions and Recommendations

The Regional Road Grant Program (PHJD) has significantly impacted accessibility improvements and land use patterns in HumbangHasundutan Regency. With an average travel time reduction of 35%, PHJD has facilitated community mobility, enhanced access to public facilities, and driven local economic growth, particularly in agriculture and tourism sectors. Moreover, the changes in land use patterns indicate increased productive utilization of agricultural land, forests, and shrubland. However, challenges such as ecological strain and potential land-use conflicts demand careful attention in development management.

To ensure the sustainability of PHJD's positive impacts, it is recommended that local governments implement more integrative spatial planning policies based on

sustainability principles and ecosystem protection. Enhancing community involvement in planning and evaluation processes is ess

ential to minimize potential conflicts and ensure the program aligns with local needs. Additionally, a continuous monitoring and evaluation system is required to track the program's environmental and social impacts, ensuring PHJD continues to deliver optimal benefits in supporting sustainable regional development.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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.

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