Jurnal Teknologi Sistem Informasi dan Aplikasi | ISSN: 2654-3788
Penerbit: Fakultas Ilmu Komputer Universitas Pamulang | e-ISSN: 2654-4229
Vol. 8, No. 2, April 2025 (96-111) | DOI: https://doi.org/10.32493/jtsi.v8i2.5049

Dynamic Modeling Of Changes In Socio-Economic Activities Around Pandaan Gate - Malang Tolll Using Night Light And Machine Learning Analysis

Ester Parmanes[1*], Agustina Nurul Hidayati1[2], Agung Witjaksono[3] Firman Afrianto[4]

[1,2,3] Program Studi Perencanaan Wilayah dan Kota, Institut Teknologi Nasional Malang, Jl. Sigura-gura, Kelurahan Sourcesari, Kecamatan Lowokwaru, Kota Malang, Indonesia, 65145
[4] Ikatan Ahli Perencanaan Jawa Timur, Perumahan Griya Shanta, J 295, Kelurahan Mojolangu, Kecamatan Lowokwaru, Kota Malang, Indonesia 65142
e-mail: [1]parmanesester@gmail.com, [2]agustina.nurul.h@lecturer.itn.ac.id, [3]agungw@lecturer.itn.ac.id
[4]firmanafrianto@mail.ugm.ac.id

Submitted Date: Maret 11, 2024 | Reviewed Date: Maret 20, 2024
Revised Date: April 15, 2025 | Accepted Date: April 30, 2025

Abstrak

This Study analyzes the influence of the construction of the Pandaan – Malang Toll Road on dynamics of socio – economic activities based on the image of Night Time Light (NTL), an approach that is still rarely applied comprehensively in infrastructure evalyation in Indonesia. This study integrates NTL time series analysis (2013-2023), zone statistics, distance correlation to toll gates, Local Indicator of Spatial Association (LISA), and Random Forest prediction models for 203 and 2040. The results showed a significant increase in the value of SUM and MEAN NTL in villages with high accessibility, such as Sawojajar, Banjararum, Madyopuro, Pandaan, and Mergosono. The distance – NTL correlation strengthened in 2023 ($r = 0.462$; $p < 0.001$), indicating the influence of toll operations on the intensity of night activities. LISA's analysis confirms the expansion of the High - High (HH) cluster along the toll corridor, which continues to increase in the predictions of 2030 and 2040. Random Forest produces good predictive performance with low MSE values and consistent spatial patterns. This research contributes to the development of data-driven methods for infrastructure impact evaluation, as well as providing a basis for evidence-based regional planning.

Keywords: Machine Learning; Night-Time Light (NTL); Random Forest; LISA; Toll Road Infrastructure.

1 Introduction

Infrastructure is the main foundation in regional development because it plays an important role in supporting population mobility, distribution of goods and services, and economic activities that support adequate regional growth that has been proven to be able to improve connectivity, accelerate distribution flows, and reduce logistics costs which have implications for increasing productivity and national economic efficiency. (Idola Arga et al., 2022) Explaining that good infrastructure not only expands public access to economic activity centers, but also encourages the acceleration of regional growth through increasing production and consumption activities. Infrastructure, especially land transportation such as roads and toll roads, has a strategic role in shaping spatial structures and distributing economic activities more evenly. (Maryaningsih et al., 2014). Thus, the analysis of infrastructure development is not limited to the provision of physical facilities, but also as a planning tool that determines the spatial pattern of development and the socio-economic dynamics of the community.

Strategic transportation infrastructure of toll roads as a role to accelerate mobility, increase accessibility and reduce logistics costs to encourage socio-economic growth. This study shows that toll road operations can provide a level of activity, making changes trigger the emergence of new businesses and ablution the connected psychic structure.

Infrastructure is a key factor in driving regional economic growth. The availability of infrastructure services increases the efficiency of economic activities through increased productivity

ISSN: 2654-3788
e-ISSN: 2654-4229
DOI: https://doi.org/10.32493/jtsi.v8i2.5049

and reduced production costs. In addition, infrastructure development contributes to improving people's welfare by expanding access to work, strengthening economic stability, and supporting the sustainability of the overall economic system (Febriansyah & Gautama, 2022)

Various studies on the development of transportation infrastructure show that changes and availability of infrastructure affect regional economic performance, which are generally analyzed using conventional economic indicators such as Gross Regional Domestic Product (GDP), regional economic growth, and regional accessibility (Febriansyah & Gautama, 2022; Suraji et al., 2025). These findings confirm the important role of infrastructure in driving economic activity, but the approach used is still aggregate and administrative and therefore not yet fully able to represent the spatial and temporal dynamics of socioeconomic activities. Therefore, this study uses Night-Time Light (NTL) data as a proxy for socioeconomic activity because it is able to describe the intensity of human activities and spatial and temporal changes in the area (Suraji et al., 2025)

Night-Time Light (NTL) is a remote sensing data that records the intensity of artificial light at night and has been widely used as an indicator of socioeconomic activity. NTL data obtained from the VIIRS Day/Night Band (VIIRS-DNB) sensor, managed by the National Oceanic and Atmospheric Administration (NOAA), is able to measure nightlight radiation on the Earth's surface and detect changes in human activity spatially and temporally. In the context of regional planning, NTL has proven to be effective in describing urban growth patterns, concentration of socioeconomic activities, and dynamics of space utilization. Various studies show that variations in the intensity of night light are strongly correlated with the level of economic development and human activity, so that NTL is a relevant alternative indicator to complement the limitations of conventional economic data that are aggregate and administrative (Afrianto Firman & Tri Dimas, 2023; Pérez-Sindín et al., 2021; Putraga Hariyadi et al., 2023)

Although the use of Night-Time Light (NTL) data has been widely used to map human activity and identify regional growth patterns, most previous studies have been descriptive and have focused only on depicting changes in night light without linking them to predictive models. Such as the morphological analysis of Malang City or the study of light pollution dynamics, it is still limited to mapping changes in light intensity without integrating it with a computational model that is able to predict the development of regional activities in the future. At the global level, studies on the influence of industrial activities on light pollution in the Pearl River Delta suggest that NTLs can consistently represent patterns of human economies and activities, but no studies have been directed at predicting long-term spatial-temporal dynamics (Jiang et al., 2025)

To date, very few studies have combined NTL data with machine learning techniques, especially models such as Random Forest, to quantitatively analyze and predict changes in the socio-economic activity of an area. In addition, no research has been found that specifically applies NTL integration, spatial analysis, and machine learning to understand the dynamics of areas in toll road corridors in Indonesia, including the Pandaan-Malang Toll Road which is one of the strategic growth corridors in East Java. This research gap demonstrates the need for an accurate spatial approach to machine learning by generating evidence-based long-term predictions. (Afrianto Firman & Tri Dimas, 2023)

The Pandaan-Malang Toll Gate is the location of the research because the strategic area has increased accessibility between the Pasuruan and Malang Raya areas. (Andi Septian Prasetyo, 2019; Zar). The variety of activities highlights the increasingly intense spatial dynamics along with the operation of toll roads, expanding the pattern of community movement and distribution of economic activities. These characteristics make the spatial ideal for analysis through satellite image-based approaches and computational techniques. Based on this context, this study formulates three main questions: (1) How is the development of socio-economic activities around the Pandaan-Malang Toll Road gate based on changes in the intensity of Night-Time Light (NTL) in the 2013-2023 period? (2) To what extent does the distance to the toll gate affect the growth rate of regional activities? and (3) how can the dynamics of the region's activity patterns be predicted until 2030 and 2040 using machine learning models? With the aim of (1) analyzing the development of socio-economic activities on the Pandaan-Malang Toll Corridor through changes in the intensity of Night-Time Light (NTL) during the 2013-2023 period, (2) Identifying the influence of distance on toll gates on the growth rate of regional activities, and (3) Predicting the dynamics of changes in activities

Jurnal Teknologi Sistem Informasi dan Aplikasi **ISSN: 2654-3788**
Penerbit: Fakultas Ilmu Komputer Universitas Pamulang **e-ISSN: 2654-4229**
Vol. 8, No. 2, April 2025 (96-111) **DOI: https://doi.org/10.32493/jtsi.v8i2.5049**

until 2030 and 2040 using a machine learning approach.

Scientifically, this research contributes to strengthening the spatial-temporal analysis method by integrating NTL satellite data, spatial analysis, and Random Forest algorithms into a single computational framework that is able to describe the dynamics of regional change quantitatively and evidence-based. This approach is in line with the direction of modern geospatial research that emphasizes the importance of data-driven predictive modeling and spatial intelligence systems, as demonstrated by the development of data-enabled urban intelligence frameworks in the study (Ji et al., 2021) The use of remote sensing for early warning systems in flood cases in Nigeria by Idowu & Zhou (2019). Thus, this study not only strengthens the monitoring of socio-economic activities in areas affected by toll road infrastructure development, but also provides methodological contributions through the application of geospatial machine learning techniques to support more responsive and adaptive regional planning decision-making.

2 Method

a. Learning Area

This research is located in the area passed by the Pandaan-Malang Toll Road, namely Pasuruan and Malang Raya Regencies. The area was chosen because it has different development characteristics, which are directly influenced by the presence of toll gates along the route. Toll gates play a major role in encouraging and accelerating the socio-economic movement of the local community.

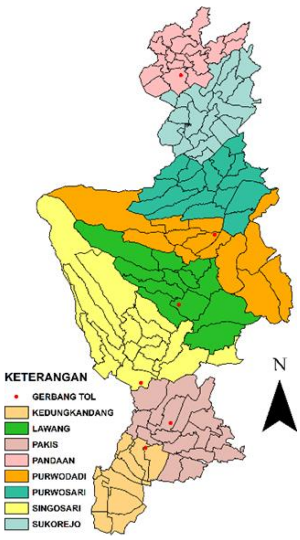

Figure 1. Map of District and Village Administration Boundaries

Source : Pengolahan Data 2024

This research aims to provide a better understanding of how human activities and infrastructure changes affect and are influenced by economic and social factors, as well as provide useful data for more effective analysis by utilizing time series data (time series) that allow monitoring of the development of economic and social activities from year to year. The method used for data collection in this study is secondary data collection.

Table 1. Delineasi Gerbang Tol

Kota	Kecamatan	Gerbang Tol
Kabupaten Pasuruan	Pandaan	Gerbang Tol Lawang
	Purwodadi	Gerbang Tol Singosari
	Lawang	Gerbang Tol Pakis
Kabupaten Malang	Singosari	Gerbang Tol Kedungkandang
	Pakis	Gerbang Tol Lawang
Kota Malang	Kedungkandang	Gerbang Tol Singosari

Source : Data Processing 2024

b. Data Penelitian

This study uses various important data sources to see the impact of toll roads. Pandaan - Malang about economic and social aspects in Pasuruan and Greater Malang Regencies, especially in areas that are passed by toll roads. The method applied involves secondary data collection, with the main focus on Night Time Light (NTL) satellite imagery covering the area along the Pandaan - Malang Toll Road. The main data used came from the VIIRS (Visible Infrared Imaging Radiometer Suite) satellite and covered the period from 2013 to 2023. This time span was chosen to allow a comparative analysis of the conditions before and after the construction of the toll road, so that it can be evaluated how infrastructure affects economic and social development in the area passed.

Table 2 Source Data

Data	Source	Informasi
Batas Administrasi	BIG	Batas
Citra Satelit Malam	VIIRS	Tahun 2013 - 2023
Titik tol	Google Satelit	

Source : Pengolahan Data, 2024.

ISSN: 2654-3788
e-ISSN: 2654-4229
DOI: https://doi.org/10.32493/jtsi.v8i2.5049

c. Analisis Zona Statistik

Statistical zonal analysis is a spatial analysis method to summarize the value of raster data based on a specific zone defined by vector data. In this study, the analysis zone was formed in the form of a circular buffer with a radius of 1–5 km from the toll gate point to calculate the Night-Time Light (NTL) intensity statistics. This approach is used to study changes in the intensity of human activities as the distance from toll road infrastructure nodes increases (Winsemius & Braaten, 2023)

The NTL value in each zone was calculated using a raster statistical function, thus producing information about the average and total intensity of night light as an indicator of socio-economic activity. This method is relevant because previous NTL studies have shown that the intensity of night light is positively correlated with economic activity, urban development, and social mobility (Jiang et al., 2025) . The Statistical Zone technique is widely used in the analysis of changes in light pollution and the dynamics of human activities, such as in studies on changes in light pollution in the Pan-Third Pole region (2023) as well as various studies that map the level of urban activity based on NTL. Thus, the use of Statistical Zone Analysis in this study provides a strong basis for identifying variations in activities in toll gate affected zones and assessing the impact of accessibility on regional development.

d. LISA (Local Indicator of Spatial Association)

Local Indicators of Spatial Association (LISA) are used to detect the presence of spatial autocorrelation at the local level in each observation area. This method is an extension of the global Moran's Index which allows the identification of patterns of spatial relationships between regions in more detail. A high local Moran's Index value indicates that an area has similar values to the surrounding area, thus forming a distribution pattern that is spatially grouped (Rachmadsyah, 2024).

Mathematically, LISA is represented through Moran's Local I which is formulated as:

$$Ii = Zi \sum_{j} \text{Wijzj}$$

Dimana :

I_i= Moran's local index value at the i location
z_i= the value of the standardized variable at location i
w_{ij} = a spatial weight that indicates the proximity relationship between locations i and j
z_j= standardized values at neighboring locations j high and significant values indicate clustering of similar values (e.g. areas with high NTL values surrounded by other high-value areas).I_i

In the context of this study, LISA was used to identify whether the area around toll gates formed activity groupings based on night light intensity (NTL). Through this analysis, it can be found whether the toll gate affected zone is included in the category of activity hotspots (high-high) which indicates the concentration of economic growth, or is it in the coldspot (low-low) pattern that indicates low activity at night. This technique has been widely used in the study of night light dynamics and urbanization mapping to look at the spatial patterns of regional growth (Jiang et al., 2025; Singla Samriddhi, 2020)

e. Machine Learning

The machine learning stage in this study uses the Random Forest Regression algorithm to predict the value of Night-Time Light (NTL) intensity in 2030 and 2040 based on historical data for the period 2013–2023. The machine learning approach was chosen for its ability to capture nonlinear relationships, its resistance to overfitting, and its effectiveness in data-driven modeling and prediction, especially in dynamic and complex systems. In this modeling, the data was compiled by including the variables of the year and the distance of the buffer zone from the toll gate as a feature (X), while the average value of NTL in each buffer zone was used as the target variable (y), in line with the principles of historical data-driven predictive modeling that emphasizes the data structure and medium-term prediction goals up to (Rebello et al., 2022).

Prior to modeling, the NTL data from the statistical zone extraction was normalized using a minimum-maximum scale to maintain the consistency of the value range:

$$Xnorm = \frac{\mathrm{X} - \mathrm{X}\min}{\mathrm{X}\max - X\,min}$$

The model is validated using Mean Squared Error (MSE), Root Mean Square Error (RMSE), and determination coefficient (R^2) metrics to ensure optimal model performance. After the model is validated, the NTL values for 2030 and 2040 are predicted by including those years as the input model. The prediction results are then exported in GeoTIFF format using the same spatial

Jurnal Teknologi Sistem Informasi dan Aplikasi **ISSN: 2654-3788**
Penerbit: Fakultas Ilmu Komputer Universitas Pamulang **e-ISSN: 2654-4229**
Vol. 8, No. 2, April 2025 (96-111) **DOI: https://doi.org/10.32493/jtsi.v8i2.5049**

reference as the 2023 NTL imagery to remain compatible with subsequent spatial analysis.

The entire modeling process was carried out using Python (scikit-learn) for the Random Forest algorithm, Google Earth Engine for NTL extraction and pre-processing, and ArcGIS Pro/QGIS for buffer distance calculation and spatial data management

f. Research Framework

The research flow is explained in detail in the image :

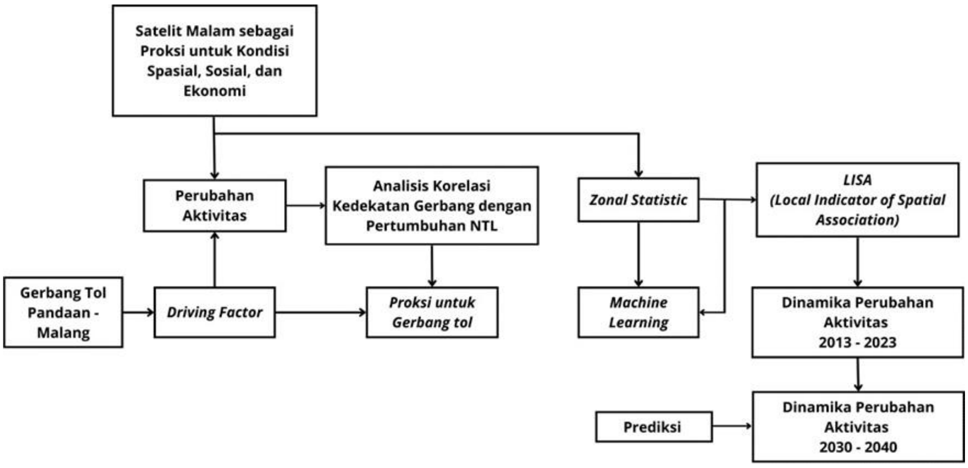

Figure 2. Research Framework

3 Results and Discussion

a. Night Analysis - Time Light

The analysis of night-time light (NTL) was carried out using VIIRS Day/Night Band (DNB) imagery for the period 2013-2023 as a proxy for social, economic, and spatial activities in the area around the Pandaan-Malang Toll Gate. NTL imagery is used because it is able to represent the intensity of human activities at night, such as population density, the presence of commercial buildings, electricity use, and urbanization patterns (Jiang et al., 2025). The initial process includes downloading data from NOAA/VIIRS and pre-processing it through Google Earth Engine to produce an annual composite that is cloud-free and has been normalized

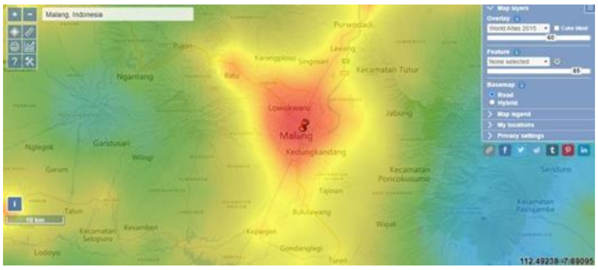

Figure 3 NTL Data Capture
Source : https://www.lightpollutionmap.info

Then NTL is processed and shows the existence of Activity Change (Activity Change) referring to changes in social, economic, and spatial activities in an area due to the existence of the Pandaan - Malang toll road as a proxy for night activities as seen from the intensity of light in the area.

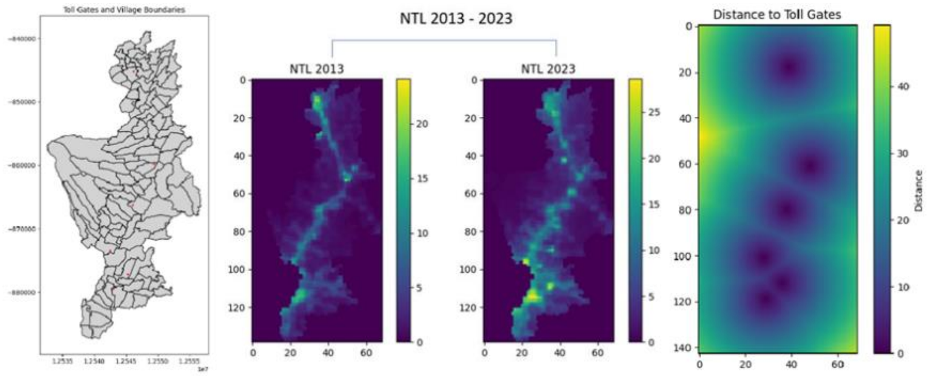

Figure 4. Night Light Intensity with District Administration Boundaries and Proximity to Toll Gates
Source : Night Satellite Analysis

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Figure 4 shows the change in night light intensity (NTL) in Pasuruan and Malang Raya Regencies from 2013 to 2023 as well as their proximity to toll gates as an infrastructure node. On the 2013 NTL map, most areas show low intensity shown in blue-purple, especially in areas far from urban hubs. However, in 2023 there has been a significant increase in light intensity in some locations, indicated by the green to bright yellow color. The most striking increase was seen in the southern part of Malang City, especially in Kedungkandang District, as well as in the area around the Lawang, Singosari, and Purwodadi toll gates.

The distance map to the toll gate in Figure 4 also shows a consistent spatial pattern, i.e. the closer a location is to the toll gate, the higher the night light intensity value. This phenomenon shows the distance decay effect, where economic and social activities are more concentrated in the 1-3 km zone of the accessibility node. This pattern is in line with previous research on the Cipali and Bocimi Toll Corridors, which also showed that activity growth tends to be localized around toll road entry and exit points as the main connectivity hub. These findings are reinforced by studies (Jiang et al., 2025) which confirms that Night-Time Light (NTL) is sensitive to regional growth dynamics related to transportation infrastructure.

b. Analysis of the correlation between distance to the Toll Gate and NTL growth.

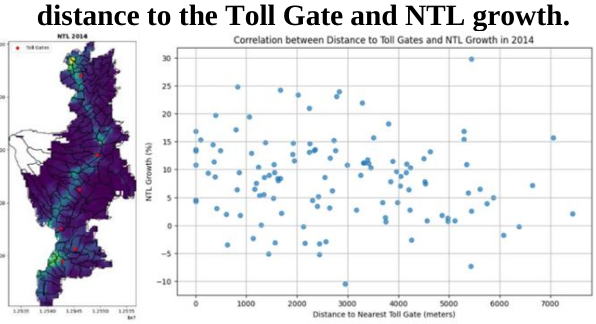

Figure 5. Toll Gate Points and Night Satellite Images and Diagrams Plots Spread Between NTL Growth and Proximity to Toll Gates 2014
Source : Correlation Analysis Results 2024

Figure 5 shows a map of night light intensity (NTL) in 2014 and a scatter plot diagram illustrating the relationship between the distance to the toll gate and the value of NTL growth in that year. On the NTL map, the purple color indicates low light intensity, while the red dot indicates the location of the toll gate as the main node of accessibility. The scatter plot on the right side shows the spread of the NTL value to the toll gate distance within a spatial radius of several kilometers.

To test the relationship between the distance to the toll gate and the growth of night light intensity, a Pearson correlation coefficient (r) with a value range of -1 to +1 was used, where:

r = -1 → perfect negative correlation,
r = 0 → no correlation,
r = +1 → a perfect positive correlation.

In addition, p-values are used to test the statistical significance of the correlation value. The smaller the p-value, the stronger the evidence that the observed correlation did not occur by chance (Miftahuddin et al., 2021).

Correlation Results in 2014

- Correlation coefficient (r) = -0.142
- p-value = 0.124
- Interpretation: insignificant relationship ($p > 0.05$)

These results show that in 2014, the period before the full operation of the Pandaan - Malang Toll Road, there was no strong relationship between the distance to the toll gate and the intensity of night activities. This is natural because the physical construction of toll roads has not fully impacted economic and social activities in the region. Community activities at that time were still dominantly influenced by existing spatial patterns, such as city centers (Lowokwaru and Blimbing), not by toll gate nodes. (Ina Revayanti, 2019) (Ina Revayanti, 2019) (Jiang et al., 2025). Thus, the results of 2014 can be considered as a *baseline of* the initial conditions before tolls affect the dynamics of regional activities.

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e-ISSN: 2654-4229
DOI: https://doi.org/10.32493/jtsi.v8i2.5049

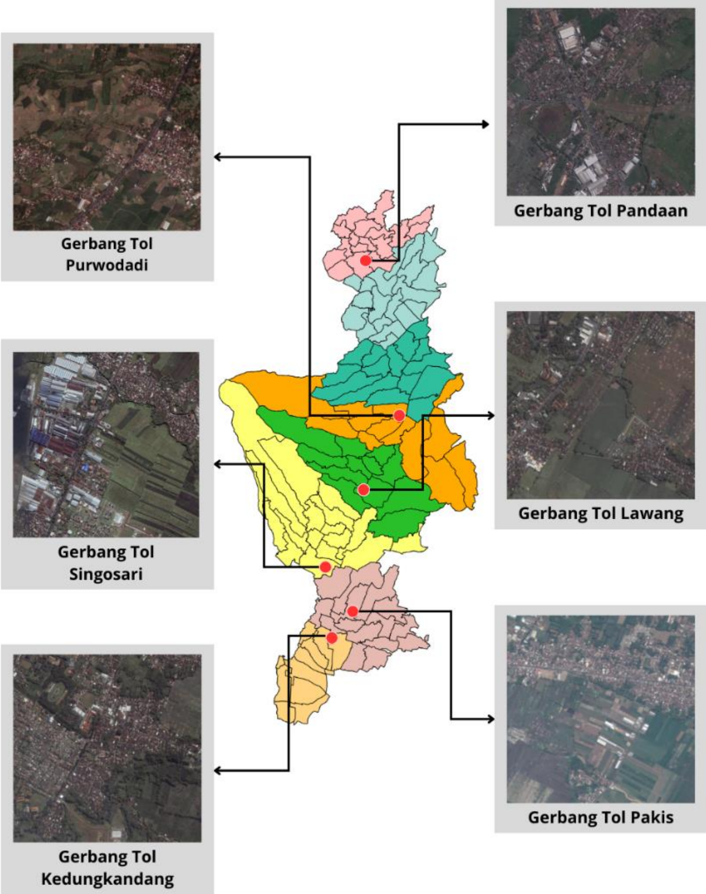

Figure 6. Esisting Conditions around the 2013 Toll Gate
Source : Google Satellite Data Analytics Processing 2024

Figure 6 shows the existing conditions in 2013 in five parts of the area representing the area around the toll gate points. The satellite images show that before the toll road was operational, the spatial structure was still dominated by agricultural land, scattered settlements, and activity centers concentrated only in the urban area of Malang. There is no concentration of activity around the toll gate point.

This existing condition directly explains the correlation results in 2014 (r = -0.142; p = 0.124) which shows that there is no significant relationship between the distance to the toll gate point and the growth of NTL. In this period, night activities still fully follow the old spatial structure and have not been influenced by the existence of toll gates. Thus, Figure 6 is strong visual evidence that the correlation value of 2014 is in accordance with the real condition of the area in the pre-operational phase of the toll road.

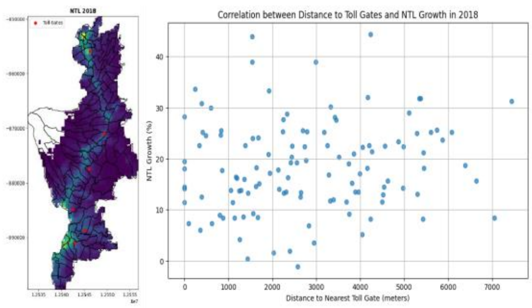

Figure 7. Toll Gate Points, Night Satellite Imagery and Scatter Plot Diagram between NTL Growth and Proximity to Toll Gates 2018
Source : Correlation Analysis Results 2024

Figure 7 shows the 2018 night light intensity (NTL) map as well as the scatter plot of the relationship between the distance to the toll gate point and the growth of the NTL. On the NTL map, it can be seen that some areas, especially around Singosari, Lawang, and Purwodadi, began to show a more pronounced increase in light intensity compared to 2014, marked by green to yellow colors. The scatter plot on the right side shows a more structured data distribution, especially at a distance of <3 km from the toll gate point.

Correlation Results in 2018

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a) Correlation coefficient (r) = 0.133
b) p-value = 0.150
c) Interpretation: the relationship was insignificant (p > 0.05), but the direction of correlation began to be positive.

The correlation value r = 0.133 shows that in 2018 there began to be a tendency for a positive relationship between proximity to toll gates and NTL growth, although the relationship has not been statistically significant. This is natural considering that 2018 is the pre-operational phase of toll roads, where construction activities, changes in local accessibility, and increased mobility around toll gate points begin to occur but have not yet resulted in a fully formed economic impact.

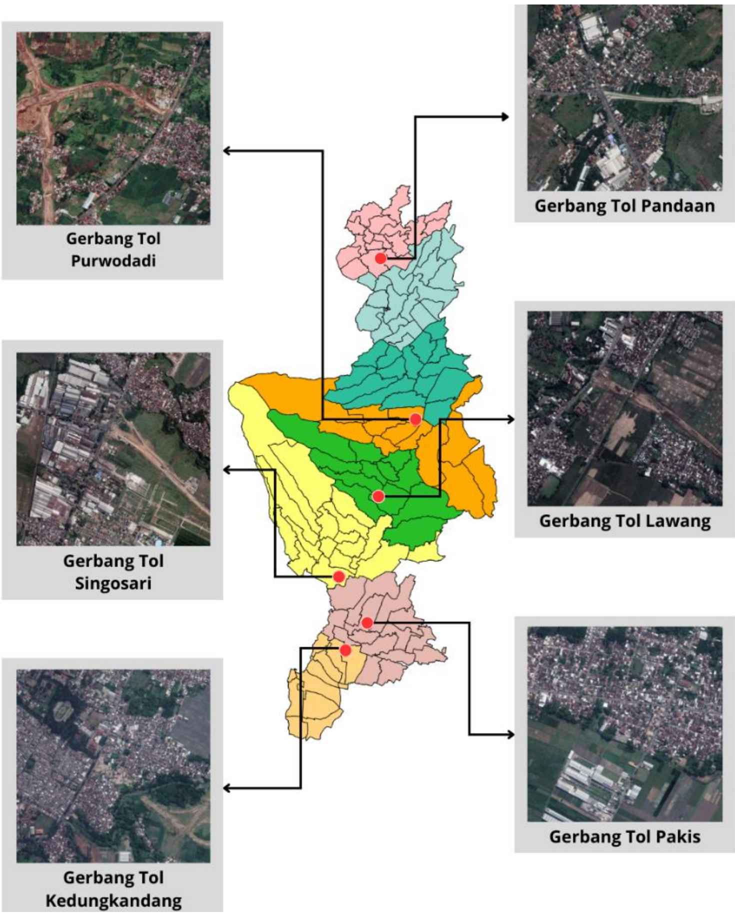

Figure 8. Existing Conditions around the 2018 Toll Gate
Source : Google Satellite Data Analytics Processing 2024

Images of existing conditions in 2018 show that several areas around toll gate points, especially Part I (Purwodadi), Part II (Pandaan), and Parts III and IV (Lawang-Singosari) have begun to undergo physical changes in the form of the growth of new settlements, widening of the road network, and the development of local trade areas. These changes favor the direction of a positive correlation, although it is not yet strong enough to produce a statistically significant relationship. Thus, the visual of the existing conditions of 2018 reinforces that the correlation value of the year reflects the transition situation: the influence of toll gates is beginning to be seen, but it has not yet fully affected the pattern of nighttime activity.

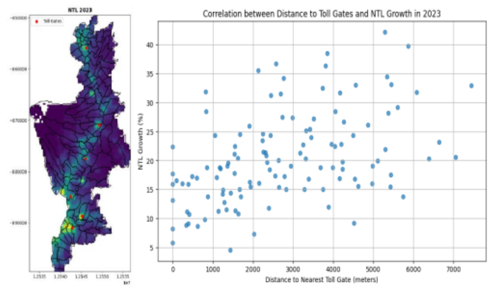

Figure 9. Toll Gate Points, Night Satellite Imagery and Distribution Plot Diagram between NTL Growth and Proximity to Toll Gates 2023.
Source : Correlation Analysis Results 2024

Figure 8 shows the 2023 night light intensity (NTL) map and the scatter plot of the relationship

ISSN: 2654-3788
e-ISSN: 2654-4229
DOI: https://doi.org/10.32493/jtsi.v8i2.5049

between distance to toll gate points and NTL growth. On the NTL map, there is a significant increase in light intensity in the areas around Singosari, Lawang, Purwodadi, and Kedungkandang, indicated by the bright green and yellow color. The scatter plots show a much clearer pattern compared to 2014 and 2018, with a tendency for higher NTL values at distances closer to the toll gate points.

Correlation Results in 2023

a) Correlation coefficient (r) = 0.462
b) p-value = 0.000
c) Interpretation: strong and significant positive associations ($p < 0.05$)

The value of r = 0.462 indicates that in 2023 there is a much stronger positive relationship between proximity to toll gates and NTL growth compared to 2014 and 2018. A very small P-value (0.000) indicates that the relationship is statistically significant. This means that the closer an area is to the toll gate point, the higher the increase in nighttime activity indicated through NTL intensity.

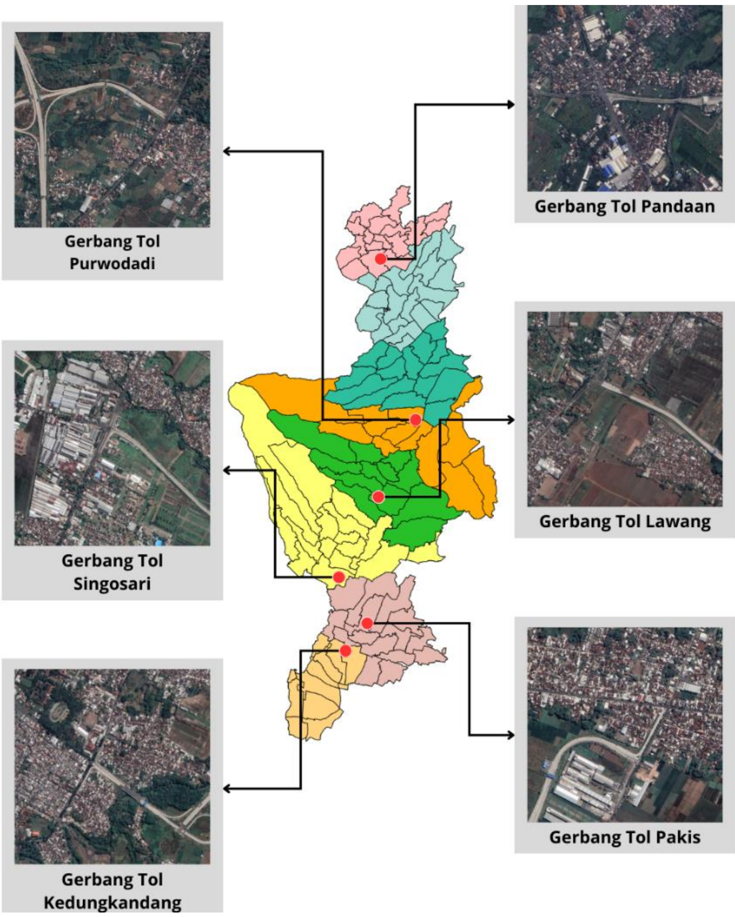

Figure 10. Existing Conditions around the 2023 Toll Gate
Source : Google Satellite Data Analytics Processing 2024

The picture of the existing conditions in 2023 shows a much more intensive physical development than in 2018. At the Pandaan Toll Gate and the Lawang Toll Gate, there is the growth of dense settlements, the formation of new road networks, and increasingly strong commercial activities. The Purwodadi Toll Gate and the Singosari Toll Gate show the expansion of the built-up area that follows the accessibility of the toll gate point, while the Toll Gate has experienced an increase in residential density and local connectivity. This visual clearly supports the correlation results in 2023: areas that are closer to the toll gate point are experiencing an increase in the intensity of economic and social activities detected by NTL. These physical changes are a strong indicator that toll infrastructure has served as a growth node and attracts a concentration of activity around it.

c. Statistics Zona

Furthermore, Zonal Statistics analysis was carried out to calculate the average intensity of Night Time Light (NTL) in 2013, 2018, and 2023.

ISSN: 2654-3788
e-ISSN: 2654-4229
DOI: https://doi.org/10.32493/jtsi.v8i2.5049

Figure 11 shows different levels of nightlight brightness, where each color represents a different level of brightness. The color spectrum ranges from blue to red, with red indicating the higher brightness of the night satellite light. In addition, the red dots shown on the map indicate the location of the toll gate.

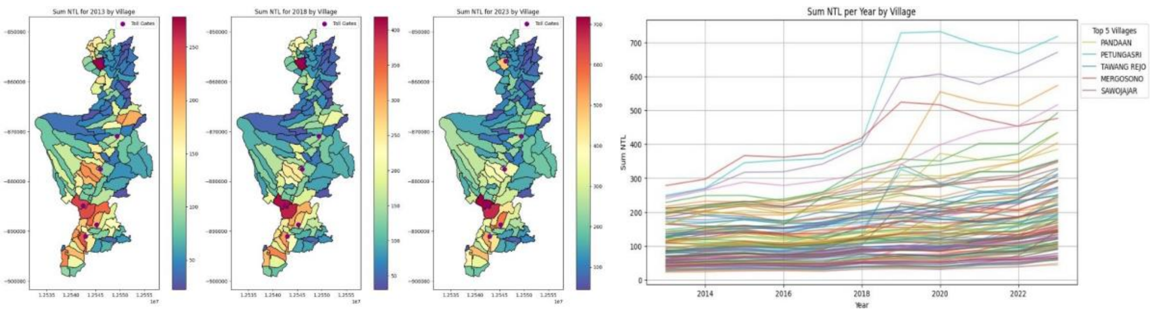

Figure 11. NTL Aggregate Analysis Map and Diagram 2013 - 2023
Source : Statistical Analysis Data Processing Zone 2024

The NTL SUM map for 2013, 2018, and 2023 shows a significant increase in nighttime activity in the Pasuruan and Malang Raya Regency areas. In 2013, light intensity was still low and unevenly distributed, dominated by urban areas such as Pandaan, Lawang, and Sawojajar. Entering 2018, an increase began to be seen in villages within a radius of 1-3 km from the toll gate point, reflecting the impact of the pre-operational phase of the Pandaan-Malang Toll Road on community mobility and activities. In 2023, the pattern of increasing the SUM NTL appears to be much stronger, marked by the red-orange color in villages near the toll gate node.

The trend chart of the 2013-2023 SUM NTL further confirms this phenomenon. Almost all villages experienced an increase in the value of SUM NTL, but the biggest spike occurred after 2018 in line with the start of toll operations. Villages such as Pandaan, Petungasri, Sawojajar, Tawangrejo, and Mergosono showed a two-fold increase compared to the 2013-2018 period. These villages are spatially located in high accessibility zones, close to toll gate nodes or on main connecting routes, so that nighttime activities increase the fastest.

Thus, the results of SUM NTL show that the construction of the Pandaan-Malang Toll Infrastructure plays a role as the main trigger for the growth of regional activities recorded through the increase in night light. This proves that SUM NTL is effective as an indicator of the total capacity of socio-economic activities on a village scale.

Table 3. Highest Accumulation Rating Values 2013 - 2023

No.	Desa/Kelurahan	2013	2018	2023	Tren Fluktuasi
1	Karang Jati	1	1	6	Turun
2	Banjararum	2	2	1	Naik
3	Tirtomoyo	3	3	2	Stabil
4	Madyopuro	4	5	4	Stabil
5	Saptorenggo	5	6	8	Turun
6	Bumiayu	6	7	9	Turun
7	Asrikaton	7	8	3	Naik signifikan
8	Cemorokandang	8	10	7	Naik
9	Candirenggo	9	15	15	Turun drastis
10	Mengubur	10	4	5	Naik
11	Martopuro	11	13	13	Stabil
12	Bedali	12	14	10	Naik
13	Purwosari	13	16	20	Turun
14	Randuagung	14	9	11	Naik

ISSN: 2654-3788
e-ISSN: 2654-4229
DOI: https://doi.org/10.32493/jtsi.v8i2.5049

No.	Desa/Kelurahan	2013	2018	2023	Tren Fluktuasi
15	Ardimulyo	15	12	12	Stabil
16	Capang	16	19	23	Turun
17	Turirejo	17	18	19	Stabil
18	Tunjungtirto	18	15	17	Turun sedikit
19	Dengkol	19	11	16	Naik
20	Sukodermo	20	23	21	Naik sedikit
21	Bunutwetan	21	17	14	Naik
22	Wonorejo	22	21	18	Naik
23	Dendono	23	22	22	Stabil
24	Banjarsari	24	25	25	Stabil
25	Dukuh Sari	25	24	24	Stabil

Sumber : Data Processing 2024

The NTL Accumulation ranking table shows the dynamics of the village position for 10 years based on total nighttime activities. Villages close to toll gate points tend to experience an increase in ranking, such as Banjararum (2nd position → 2 → 1), Asrikaton (7 → 8 → 3), Burbur (10 → 4 → 5), and Bedali and Randuagung. The increase in the ranking of these villages is in line with the 2023 SUM NTL map which shows the highest light intensity in the area. This suggests that accessibility to toll nodes accelerates the growth of built-up space activity.

On the other hand, several villages that are far from the toll gate have experienced a decline in ranking, such as Candirenggo, Capang, Purwosari, and Saptorenggo. This decline shows that the growth centers of activity are shifting towards villages with higher accessibility. Meanwhile, some villages remain stable (Tirtomoyo, Madyopuro, Martopuro), because from the beginning they already have an established activity structure and are not too affected by the existence of toll roads.

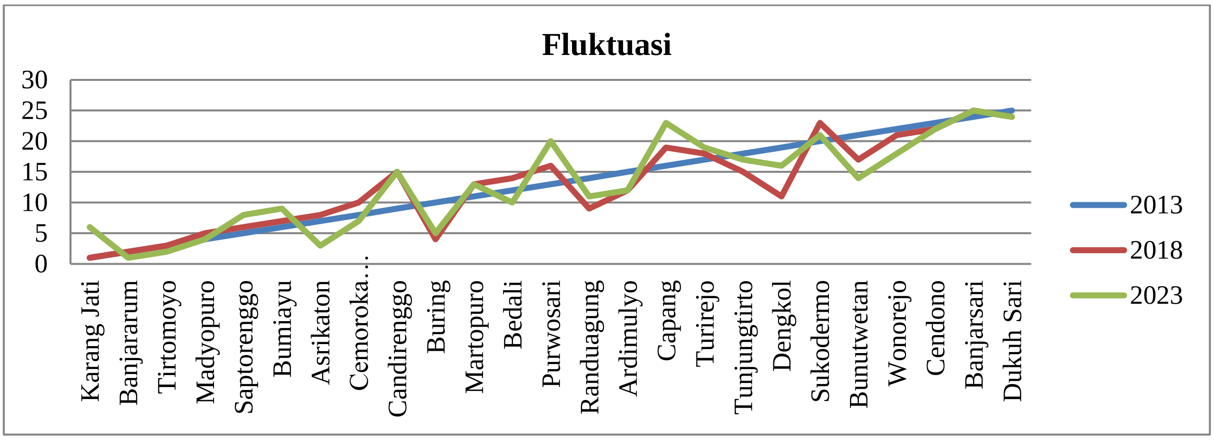

Figure 12. Highest Accumulation Fluctuation Chart 2013 - 2023
Source : Data Processing 2024

Figure 12 shows the fluctuations in the SUM NTL ratings for 25 villages during the 2013, 2018, and 2023 periods. This graph shows the dynamics of changes in village positions based on the level of nighttime activity recorded through satellite imagery. The blue (2013), red (2018), and green (2023) lines show how each village has experienced an increase, decrease, or stability in the rankings over a decade.

Villages on the left side of the graph such as Banjararum, Tirtomoyo, and Madyopuro show a relatively high position (low ranking = high activity), while villages on the right side of the graph such as Banjarsari, Cendono, and Dukuh Sari are consistently in the lower position, indicating a lower level of activity. The green line pattern (2023) which is more "up and down sharply" than in 2013 and 2018 reflects an increasingly clear difference in growth in the post-operational era of tolls. Villages such as Asrikaton, Cemorokandang, Bedali, and Randuagung showed a significant increase in rankings in 2023, while villages such as Candirenggo, Capang, and Purwosari actually experienced a decline.

This graph visually confirms the results of the ranking table: villages closer to toll gate points tend to see an increase in ranking (activity increases), while villages located further away experience a decline or stagnation. Thus, these fluctuations in the SUM NTL rating reinforce the evidence that changes in the intensity of night light are strongly influenced by the accessibility of toll gate nodes as new growth centers.

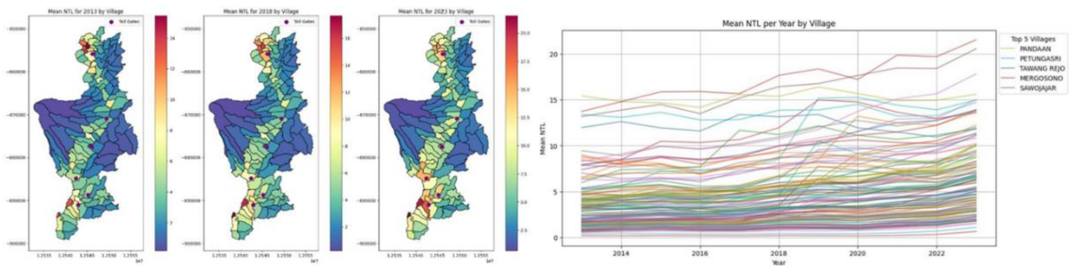

Figure 13. Analysis Map and MEAN Chart Zone Statistics 2013 - 2023
Source : Statistical Analysis Data Processing Zone 2024

The NTL Intensity map depicted by the MEAN NTL values in 2013, 2018, and 2023 shows changes in average light intensity per pixel that depict the density of community activities at the village level. In 2013, the areas with the highest Light Intensity values were concentrated in Pandaan, Sawojajar, and the southern part of Malang City. Most other regions still show low MEAN values, indicated by the dominance of blue. Entering 2018, the map shows an increase in light density in areas near toll gates, especially in Sawojajar, Madyopuro, Mergosono, and Banjararum. This pattern is consistent with the increase in residential, commercial, and connectivity activities after toll infrastructure development enters the initial operational stage.

In 2023, the increase in NTL Intelligence is even more pronounced. The red-orange color is concentrated in villages with a high density of activity such as Sawojajar, Madyopuro, Mergosono, Banjararum, and Pandaan. This increase shows a change in the pattern of activity density: not only the total activity increase (SUM), but the distribution of activities that is increasingly tight in certain areas, especially in areas with high accessibility.

The trend graph shows that the MEAN NTL increased across the villages during the 2013-2023 period, but at a very different growth rate. The villages with the sharpest increase are Sawojajar, Mergosono, Pandaan, and Madyopuro, which achieved an average light value of > 15 nW/cm²/sr in 2023. A special increase occurred after 2018, when the Pandaan-Malang Toll Road began operating and encouraged the concentration of activities in areas with high connectivity. These villages show that in addition to the growth of total activity (SUM), there is a thickening of activity (densification) that is distributed in areas that were previously not congested. Meanwhile, villages such as Tambaksari, Menyerlah, and Gunungrejo remained at low levels with no significant increase, indicating that the growth in activity density did not occur in villages far from the toll gate node.

Table 4. Highest Intensity Rating Values 2013 - 2023

Tidak	Desa/Kelurahan	2013	2018	2023	Tren Fluktuasi
1	Pandaan	1	3	6	Turun
2	Sawojajar	2	1	1	Naik dan stabil tinggi
3	Petungasri	3	4	4	Stabil
4	Mergosono	4	2	2	Stabil tinggi
5	Tawang Rejo	5	5	11	Turun
6	Mengubur	6	17	17	Turun signifikan
7	Jogosari	7	8	10	Turun ringan
8	Pagentan	8	13	8	Naik kembali

ISSN: 2654-3788
e-ISSN: 2654-4229
DOI: https://doi.org/10.32493/jtsi.v8i2.5049

Tidak	Desa/Kelurahan	2013	2018	2023	Tren Fluktuasi
9	Sekarpuro	9	14	9	Naik
10	Mangliawan	10	9	7	Naik
11	Madyopuro	11	10	3	Naik signifikan
12	Sourcesuko	12	11	20	Turun
13	Glagah Sari	13	17	16	Turun ringan
14	Wonorejo	14	20	22	Turun
15	Suwayuwo	15	16	14	Naik ringan
16	Nogosari	16	7	12	Naik lalu turun
17	Banjararum	17	12	5	Naik tajam
18	Losari	18	21	18	Stabil
19	Gunungrejo	19	19	24	Turun
20	Kedungkandang	20	15	15	Stabil
21	Source Porong	21	6	19	Fluktuatif
22	Tirtomoyo	22	23	14	Naik
23	Tambak Sari	23	24	25	Turun
24	Sidoluhur	24	22	21	Naik ringan
25	Menyerlah	25	25	23	Naik ringan

Source : Data Processing 2024

The MEAN NTL ranking table shows how the position of the village changes based on the average intensity of light. Sawojajar has consistently been ranked the highest from 2018 to 2023, showing that this region is a center for stable and high activity density growth. Villages such as Madyopuro, Banjararum, Mangliawan, and Sekarpuro experienced a significant increase in ranking, in line with the results of maps and graphs showing the growth in activity density in the toll corridor. In contrast, villages such as Mengebur, Sourcesuko, Gunungrejo, and Tambaksari showed downgrades, which illustrates activity that has weakened or remained historically low. This ranking movement shows that activity growth is uneven and concentrated in villages that have spatial proximity to toll gates or are on core connectivity routes.

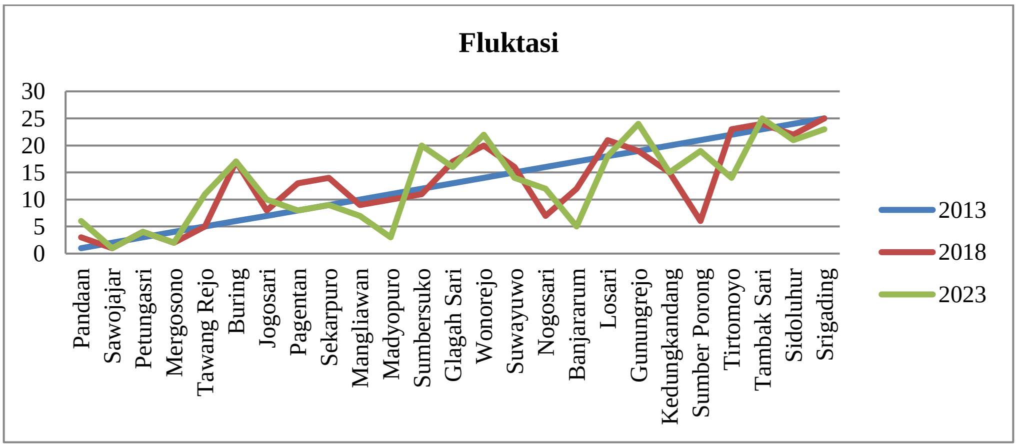

Figure 14. Highest MEAN Fluctuation Chart 2013 - 2023
Source : Data Processing 2024

The MEAN NTL fluctuation graph shows the dynamics of changes in village rankings visually. Villages on the left side of the graph such as Sawojajar, Mergosono, Pandaan, and Madyopuro are ranked at the top and show a line pattern that rises or remains high in 2023, signaling a continuation of activity density growth. Villages such as Buri, Sourcesuko,

Jurnal Teknologi Sistem Informasi dan Aplikasi **ISSN: 2654-3788**
Penerbit: Fakultas Ilmu Komputer Universitas Pamulang **e-ISSN: 2654-4229**
Vol. 8, No. 2, April 2025 (96-111) **DOI: https://doi.org/10.32493/jtsi.v8i2.5049**

Gunungrejo, and Tambaksari appear to have fallen to a low ranking in 2023, as can be seen from the green line which has dropped significantly. Villages with a middle position such as Sekarpuro, Nogosari, and Tirtomoyo show a fluctuating pattern, indicating unstable growth dynamics. This graph provides visual verification of the ranking table, that the highest and most stable growth in activity density occurred in villages close to the toll gate node.

d. Local Indicators of Spatial Associations (LISA)

The Local Indicator of Spatial Association (LISA) is used to see the pattern of grouping activities in a region. (Anselin, 1995).Through LISA, each village is grouped into two main patterns:

a) High-High (HH) → a village with a high activity value surrounded by a high-value village. This shows hotspots, which are areas that are the center of growth in socio-economic activities.
b) Low-Low (LL) → a village with a low activity value surrounded by a low-value village. This describes cold spots, which are areas that are still developing slowly or with minimal activity.

By mapping HH and LL, LISA analysis helps show where activity tends to be concentrated, where lagging areas are located, and how activity cluster patterns change from year to year. Because this study uses night light imagery (NTL), LISA is very effective in revealing how community activities form growth clusters that are influenced by the presence of toll gate points.

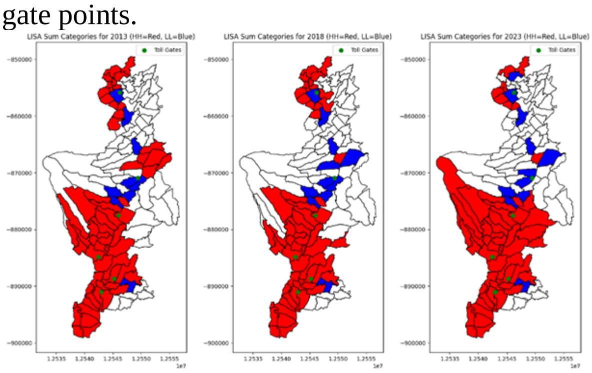

Figure 15. Dynamics of Accumulation Change 2013 - 2023
Source : LISA Data Analysis Processing 2024

The LISA SUM NTL maps for 2013, 2018, and 2023 show significant changes in the concentration pattern of nighttime activities in the Pasuruan-Malang area. In 2013, the pattern of High-High (HH) or activity hotspots was still limited to the southern area (Kedungkandang, Saptorenggo, Buring, and parts of Pandaan). Most villages in the central-northern region are in the Low-Low (LL) category, showing low activity and are not spatially connected. Entering 2018, the HH pattern began to expand following the location of toll gate points, especially in villages located in the radius near the nodes of Pandaan, Purwodadi, Lawang, Singosari, and. This increase reflects the appearance of an agglomeration effect around toll gates. Some previously stable LL areas are starting to change to non-significant categories, signaling a transition of activity.

In 2023, the HH hotspot area drastically expanded almost the entire central to southern part of the HH zone, indicating a very strong and localized increase in nocturnal activity. This strengthens the conclusion that accessibility to toll gates is the main trigger for the formation of new socio-economic activity clusters in the Pandaan-Malang corridor.

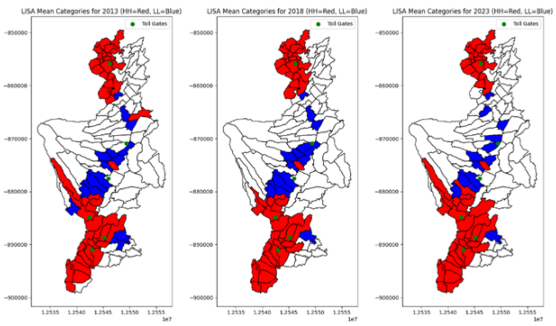

Figure 16. Dynamics of Intensity Change 2013 - 2023
Source : LISA Data Analysis Processing 2024

The 2013 NTL Index LISA pattern shows that the areas with the highest activity density (HH) are in villages such as Sawojajar, Madyopuro, Buring, and Pandaan. Other villages are still in the LL category or insignificant. In 2018, the HH category began to surround the toll gate area - specifically Singosari, Lawang, and Pandaan. This shows that there is an increase in activity density around toll gates that have just started operating. On the other hand, some villages that are far from toll roads are still in the LL category. In 2023, the HH category will be more dense and form a large cluster structure from Pandaan-Purwosari-Lawang-Singosari to Kedungkandang. This signifies an intensification of highly localized and centered activities in areas with high accessibility. The northeastern village remains LL, showing consistent spatial gaps.

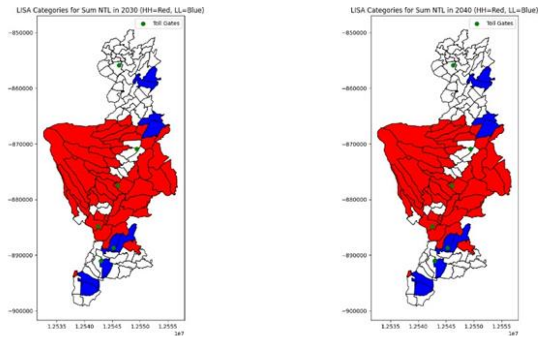

Figure 17. Predictions of the dynamics of future Accumulation NTL changes 2030 and 2040
Source : LISA Data Analytics Processing 2024

The LISA SUM NTL prediction in 2030 shows that most of the central-south region will remain in the HH category, but the HH cluster is moving further north following the main path and expansion of population activity. Areas that were previously non-significant turned into HH, indicating progressive growth. By 2040, the predictions show an almost full dominance of the HH category in all major corridors and the environment around toll gates. The LL area is shrinking and only remains in areas outside the toll area. This shows that toll road construction will result in a concentration of long-term activities that will continue to increase until 2040.

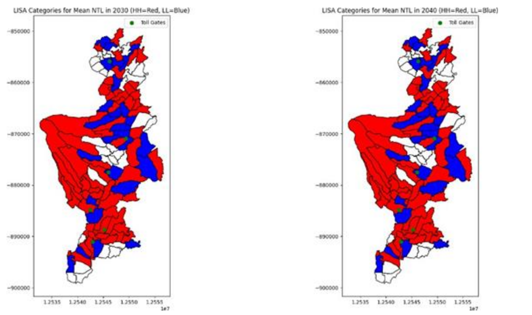

Figure 18. Predicted dynamics of Intensity NTL changes coming 2030 and 2040
Source : LISA Data Analysis 2024

The MEAN NTL 2030 prediction map shows that the HH cluster is starting to spread evenly along the toll corridor, with greater intensity in areas that have dense settlement growth such as Sawojajar, Madyopuro, Singosari, and Banjararum. LL Village mostly remains in the less connected northern and eastern regions.

By 2040, the HH cluster will grow stronger and fill almost the entire central to southern part. This shows that the growth in activity density will spread following the development of urban sprawl and transportation connectivity. LL Village remains isolated in the northern part away from the main transport node.

4. Conclusion

This study proves that the image of Night-Time Light (NTL) is effectively used as a proxy for socio-economic activities to analyze the impact of the construction of the Pandaan-Malang Toll Road. The results of the NTL Intensity Accumulation analysis showed a significant increase in nighttime activity in villages that have high accessibility to toll gate points. Villages such as Sawojajar, Madyopuro, Banjararum, Pandaan, Petungasri, and Mergosono consistently became the areas with the highest light intensity values, both in total (SUM) as NTL Accumulation and density (MEAN) as NTL Intensity. Correlation analysis shows that the relationship between distance to toll gates and new activity growth appears strong in post-operational years, with greater positive correlation values in 2023. LISA's analysis confirms this finding through a pattern of High-High (HH) clusters that are growing from 2013 to 2023, even dominating the central-south region in the 2030 and 2040 predictions. This shows that toll roads not only increase activity in total, but also trigger the concentration, densification and expansion of new growth clusters along the regional corridor.

Random Forest's prediction model shows good performance, demonstrated by low error and spatially consistent prediction patterns. The predictions show that areas with high accessibility will continue to grow until 2040, while areas with low access tend to remain in the category of low activity (LL). Overall, this study confirms that the existence of toll infrastructure plays a strong role in driving the dynamics of spatial-based socio-economic growth, which is clearly recorded through changes in the intensity of night light.

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