# Nighttime Lights Satellite: Measuring SDG 10 Progress in South Sulawesi's South-North Development Corridor Using Spatial Econometrics and GWR Analysis

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**Abstract. Sustainable** Development Goal 10 (SDG 10) aims to reduce inequalities within and among countries by promoting inclusive and sustainable development. In South Sulawesi, Indonesia, regional disparities along the South-North Development Corridor persist, with uneven economic growth and human development outcomes. This study utilizes Nighttime Lights (NTL) satellite data from the Visible Infrared Imaging Radiometer Suite (VIIRS) for 2014, 2019, and 2024 as a proxy for socioeconomic development to assess progress toward SDG 10. NTL intensity is analyzed in relation to GRDP per capita, Human Development Index (HDI), and poverty rates using spatial econometric models and Geographically Weighted Regression (GWR). Ordinary Least Squares (OLS) regression establishes baseline relationships, while spatial models account for spatial dependence. Results show a strong, significant positive correlation between NTL intensity and economic growth across all years. However, relationships with HDI and poverty are weak and mostly insignificant, indicating that economic growth does not consistently translate into improved human development or poverty reduction. GWR analysis reveals spatial non-stationarity, with urban areas like Makassar exhibiting high NTL intensity and strong development linkages, while rural regions such as Selayar Regency show low NTL values and weaker socioeconomic performance. The findings highlight persistent urban-rural disparities and uneven development. This study concludes that NTL data, when combined with spatial analysis techniques, provides a valuable tool for monitoring regional inequalities and supporting targeted policy interventions. The results emphasize the need for location-specific strategies to achieve more inclusive and equitable development in South Sulawesi.

**Keywords:** Nighttime Lights; VIIRS; SDG 10; spatial econometrics; GWR; regional inequality; South Sulawesi


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# 1 Introduction

Reducing inequality within and among countries is a central objective of Sustainable Development Goal 10 (SDG 10) [1]. Despite national economic growth, many regions in Indonesia continue to experience significant disparities in development outcomes, particularly between urban and rural areas. South Sulawesi, one of Indonesia's key economic regions outside Java, exemplifies this challenge through its South-North Development Corridor, where economic activity and infrastructure development are heavily concentrated in the southern urban hub of Makassar, while northern and eastern districts remain relatively underdeveloped [2].

Traditional socioeconomic data, while valuable, often suffer from limitations such as infrequent updates, coarse spatial resolution, and administrative inconsistencies, especially at sub-provincial levels. In response, satellite-derived Nighttime Lights (NTL) data have emerged as a reliable proxy for measuring economic activity, urbanization, and infrastructure development [3]. The Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi NPP satellite provides high-resolution, radiometrically corrected NTL data, enabling fine-scale spatial analysis of human settlements and economic dynamics [4].

Recent studies have demonstrated the effectiveness of NTL data in estimating GDP [5], tracking urban expansion [6], and monitoring poverty [7]. However, limited research has applied these tools to assess progress toward SDG 10, particularly in the context of regional development corridors in Indonesia. Moreover, the assumption of spatial stationarity—common in conventional regression models—often fails to capture the localized nature of development drivers.

This study addresses these gaps by integrating VIIRS NTL data with socioeconomic indicators to evaluate progress toward SDG 10 in South Sulawesi. Using spatial econometric models and Geographically Weighted Regression (GWR), we examine the spatially varying relationships between nighttime lights and development outcomes, identifying areas of inequality and informing targeted policy responses.

# 2 Data and Methods

This study utilizes Nighttime Lights (NTL) satellite data from the Visible Infrared Imaging Radiometer Suite (VIIRS) for the years 2014, 2019, and 2024 as a proxy for socioeconomic development in South Sulawesi's South-North Development Corridor. The NTL data are combined with district-level socioeconomic indicators, including Gross Regional Domestic Product (GRDP) per capita, Human Development Index (HDI), and poverty rates. Administrative boundary shapefiles are used for spatial analysis.

Methodologically, the research employs Ordinary Least Squares (OLS) regression to establish baseline relationships between NTL intensity and development indicators. To account for spatial dependence and heterogeneity, spatial econometric models are applied. Furthermore, Geographically Weighted Regression (GWR) is used to explore

spatially varying relationships, allowing for the identification of localized patterns in development dynamics. This integrated approach enables a nuanced assessment of regional inequalities and progress toward SDG 10.

### 2.1 Data Sources

The study utilizes VIIRS nighttime lights data (Daily Cloud-Free Composite) for the years 2014, 2019, and 2024, sourced from the Earth Observation Group, NOAA. The data were processed to exclude background noise, transient lights (e.g., fires), and low-light outliers, and aggregated to the district level using zonal statistics in GIS.

Socioeconomic data include:

- GRDP per capita (in IDR, adjusted to 2020 constant prices)
- Human Development Index (HDI)
- Poverty headcount ratio (% population below the provincial poverty line)

All socioeconomic indicators are at the district level and obtained from the Central Bureau of Statistics (BPS) of South Sulawesi Province. Administrative boundary shapefiles were acquired from the Indonesian Geospatial Information Agency (BIG) and used for spatial analysis.

### 2.2 Analytical Methods

**Ordinary Least Squares (OLS) Regression.**

Baseline relationships between NTL intensity (mean radiance) and socioeconomic variables were first assessed using OLS regression:

$$Y_i = \beta_0 + \beta_1 NTL_i + \epsilon_i$$

Where $Y_i$ represents GRDP per capita, HDI, or poverty rate in district $i$ and $\epsilon$ is the error term.

**Spatial Econometric Models**

. To account for spatial dependence, we tested for spatial autocorrelation using Global Moran's I and Local Indicators of Spatial Association (LISA). Given significant spatial clustering, spatial lag (SAR) and spatial error (SEM) models were estimated:

Spatial Lag Model (SAR):

$$Y = \rho WY + X\beta + \epsilon$$

Spatial Error Model (SEM:

$$Y = X\beta + u, u = \lambda W\epsilon + \epsilon$$

where $W$ is the spatial weights matrix (queen contiguity), and $\rho$ and $\lambda$ are spatial parameters.

**Geographically Weighted Regression (GWR)**

. To explore spatial non-stationarity, GWR was applied:

$$Y_i = \beta_0(u_i, v_i) + \sum \beta_k(u_i, v_i) X_{ki} + \epsilon_i$$

where $(u_i, v_i)$ are the geographic coordinates of district $i$, and coefficients $\beta_k$ vary spatially. An adaptive bandwidth with bi-square kernel was used, selected via Akaike Information Criterion (AIC).

## 2.3 Results

### Descriptive Trends (2014–2024)

The analysis of Nighttime Lights (NTL) satellite data in conjunction with key socioeconomic indicators provides critical insights into regional development patterns and progress toward SDG 10 in South Sulawesi's South-North Development Corridor. Each figure in the study reveals distinct spatial dynamics that collectively illustrate the uneven nature of development across the province.

*NTL VIIRS Imagery (2014, 2019, 2024).*

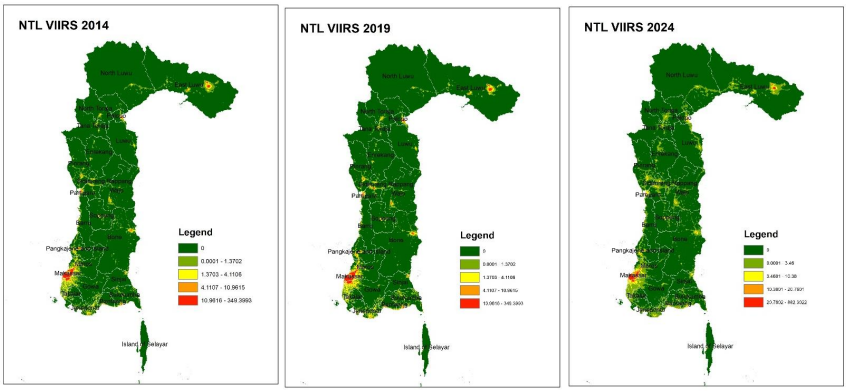


**Fig. 1.** South Sulawesi Province NTL VIIRS Imagery in 2014,2019 and 2024

The nighttime lights imagery clearly shows a concentration of luminosity in the southern part of South Sulawesi, particularly around Makassar City and its neighboring regencies—Gowa, Maros, and Takalar. These areas exhibit consistently high and increasing light intensity over time, reflecting sustained urbanization, infrastructure expansion, and economic activity. In contrast, northern and eastern regions such as

Selayar Islands, Tana Toraja, Luwu, and North Luwu display minimal changes in light emissions, indicating limited electrification, sparse population density, and slower economic development. The longitudinal comparison from 2014 to 2024 suggests modest improvements in some peri-urban zones, but no significant light expansion into remote districts. This visual disparity underscores the persistent core-periphery structure of regional development in South Sulawesi (Fig.1).

NTL intensity increased across South Sulawesi from 2014 to 2024, particularly in Makassar City, Gowa, and Maros—core areas of the South Sulawesi metropolitan region. In contrast, districts in the northern and eastern parts, such as Selayar Islands, Tana Toraja, and Luwu, exhibited minimal changes in light intensity.

GRDP per capita showed a similar spatial pattern, with high values in urban centers and lower values in remote districts. HDI levels improved province-wide but remained below the national average in several rural regencies. Poverty rates declined overall but persisted above 15% in isolated areas.

*GDRP per Capita Distribution.*

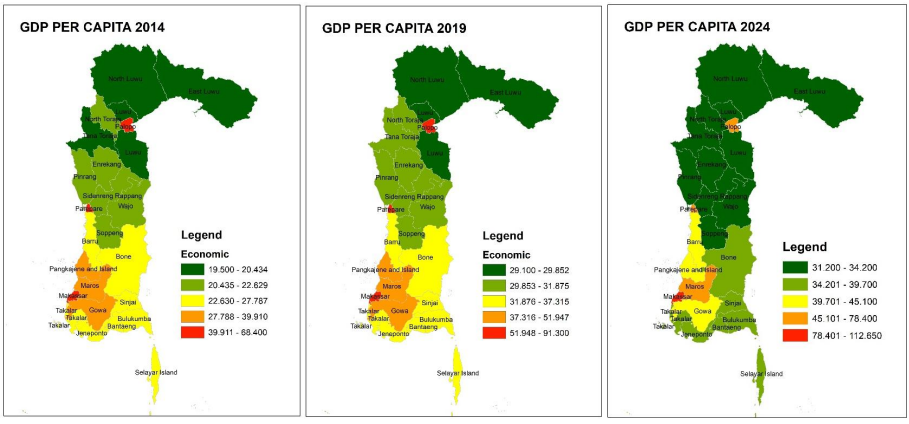


**Fig. 2.** South Sulawesi Province GDRP per Capita Distribution in 2014,2019 and 2024

This map aligns closely with the NTL patterns. Districts with high GRDP per capita—especially Makassar, Gowa, and Maros—overlap spatially with the brightest areas in the NTL imagery. This strong correspondence confirms that nighttime lights serve as a reliable proxy for economic output at the sub-national level (Fig. 2). However, some resource-rich but sparsely populated areas (e.g., parts of Luwu) show moderate GRDP without corresponding increases in nighttime lights, suggesting that economic gains may be concentrated in extractive sectors with limited local multiplier effects or broad-based electrification.

*Human Development Index (HDI).*

While HDI levels have improved province-wide, the spatial distribution reveals a more balanced pattern compared to NTL and GRDP. Even some low-luminosity areas, such as Tana Toraja, exhibit relatively high HDI due to strong performance in education and health indicators. This divergence highlights a crucial finding: economic growth, as reflected in NTL and GRDP, does not automatically translate into human development. The decoupling of economic and social progress suggests that investments in health and education have been more equitably distributed than income or infrastructure, offering partial resilience against spatial inequality (Fig. 3).

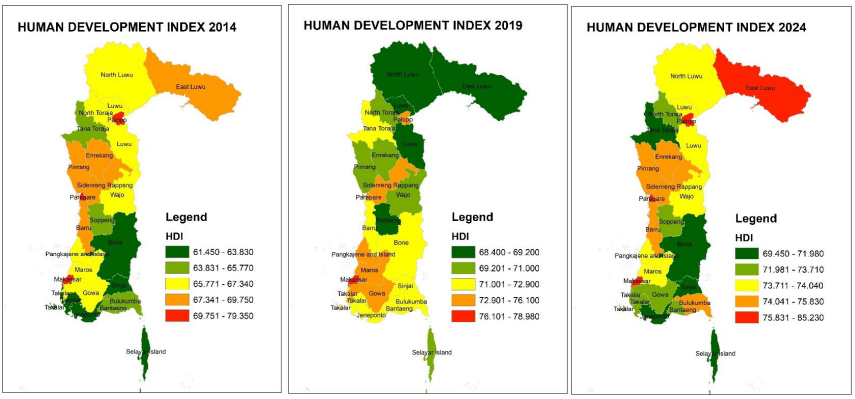


**Fig. 3.** South Sulawesi Province Human Development Index in 2014,2019 and 2024

*Poverty Levels.*

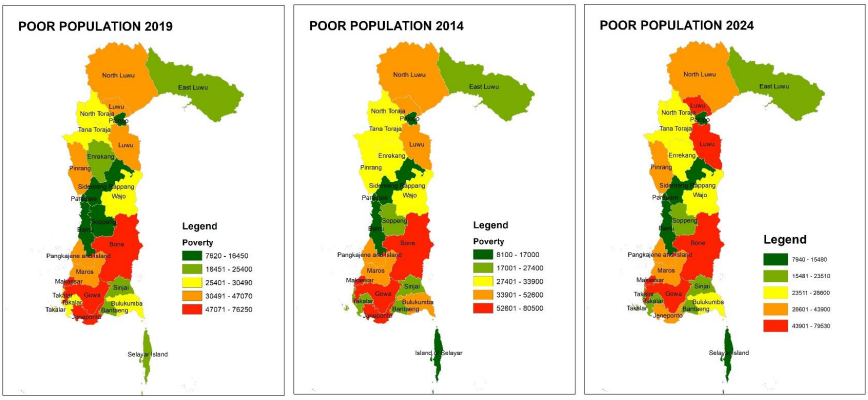


**Fig. 4.** South Sulawesi Province Poverty Level in 2014,2019 and 2024

Poverty remains concentrated in rural and geographically isolated districts, including Selayar, East Luwu, and parts of North Luwu—areas with the lowest NTL intensity. This reinforces the link between lack of physical connectivity, limited economic opportunities, and higher poverty incidence. Notably, some districts with moderate GRDP still experience high poverty, indicating unequal benefit-sharing and weak inclusiveness in growth processes (Fig. 4).

## 2.4 Regression Analysis

OLS results revealed a strong positive and statistically significant relationship between NTL intensity and GRDP per capita ($R^2 > 0.75$, $p < 0.01$), confirming NTL as a robust proxy for economic activity. However, the correlation with HDI was weak ($R^2 < 0.30$, $p > 0.05$), and the relationship with poverty was negative but insignificant in most years.

Spatial econometric models outperformed OLS, with lower AIC and significant spatial parameters ($\rho = 0.42$, $p < 0.01$ in SAR model), indicating strong spatial dependence in development patterns.

## 2.5 GWR Findings

GWR significantly improved model fit (AIC reduced by 18–22% compared to OLS), confirming spatial non-stationarity. Key findings include:

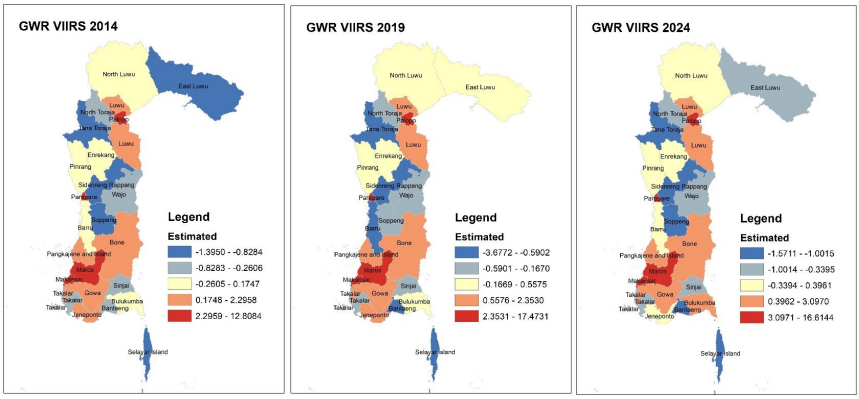


**Fig. 5.** GWR VIIRS Finding in 2014,2019 and 2024

- In Makassar City, the coefficient between NTL and GRDP per capita reached 0.89, reflecting high economic density and infrastructure efficiency.
- In Selayar Regency, the same coefficient dropped to 0.32, indicating weaker economic returns from observed lighting.
- The influence of accessibility and infrastructure investment on NTL intensity varied significantly, with stronger effects in connected districts than in geographically isolated ones.
- HDI-NTL relationships were strongest in districts with higher education and health facility coverage but negligible elsewhere.

These results illustrate that development drivers operate differently across space, and blanket policy approaches may fail to address localized constraints (Fig. 5).

## 3 Discussion

The findings confirm that while South Sulawesi has experienced overall economic growth, development remains spatially unequal. The strong correlation between NTL and GRDP validates the utility of satellite data in monitoring economic activity, especially in data-scarce regions. However, the weak linkage between NTL and human development indicators suggests that growth is not sufficiently inclusive.

Urban centers like Makassar benefit from agglomeration economies, infrastructure networks, and investment inflows, reflected in high NTL intensity. In contrast, rural and island districts face structural barriers—limited connectivity, lower public service access, and fragmented markets—that constrain development despite modest improvements.

The GWR results emphasize the importance of place-based policies. For instance, improving road connectivity in Selayar may yield higher development returns than similar investments in already well-connected areas. Likewise, poverty reduction strategies must consider local economic structures and service accessibility.

This study aligns with previous research highlighting the value of NTL in SDG monitoring [8], but extends it by incorporating spatially explicit modeling to uncover heterogeneity in development processes. Unlike national averages, geospatial analysis reveals hidden disparities critical for equitable policy design.

## 4 Conclusion

This study demonstrates that Nighttime Lights satellite data, combined with spatial econometric methods, provide a powerful framework for assessing progress toward SDG 10. By revealing spatial disparities in development outcomes across South Sulawesi's South-North Corridor, the analysis highlights the limitations of aggregate economic growth in reducing inequality.

Key conclusions are:

NTL intensity is a reliable proxy for economic activity but less effective in capturing human development and poverty dynamics.

Significant regional disparities persist between urban and rural areas, with remote districts lagging in infrastructure and development outcomes.

The spatially varying impacts of development drivers necessitate tailored, location-specific interventions.

## 5 Acknowledgment

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