

Is Night-Time Light a Reliable Proxy for Sectoral GRDP?

A New Insight from
Remote Sensing Data from Indonesia

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Introduction

- Effective monitoring on economic growth and poverty is crucial to achieve Sustainable Development Goals in Indonesia
- However, East-West polarization persists in terms of socio-economic indicators, i.e. economic growth and poverty
- Growth is converging over time (national and province level), yet within-province inequality remains.

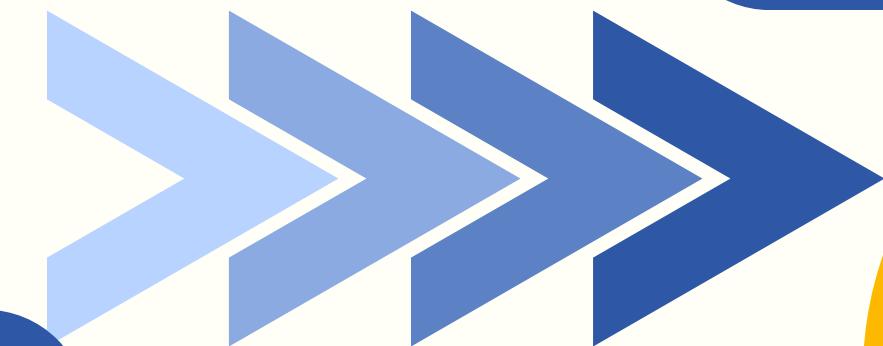




Motivation

Conventional data collection (surveys and administrative data)

- Limited in scope
- Costly
- time-consuming
- labor-intensive



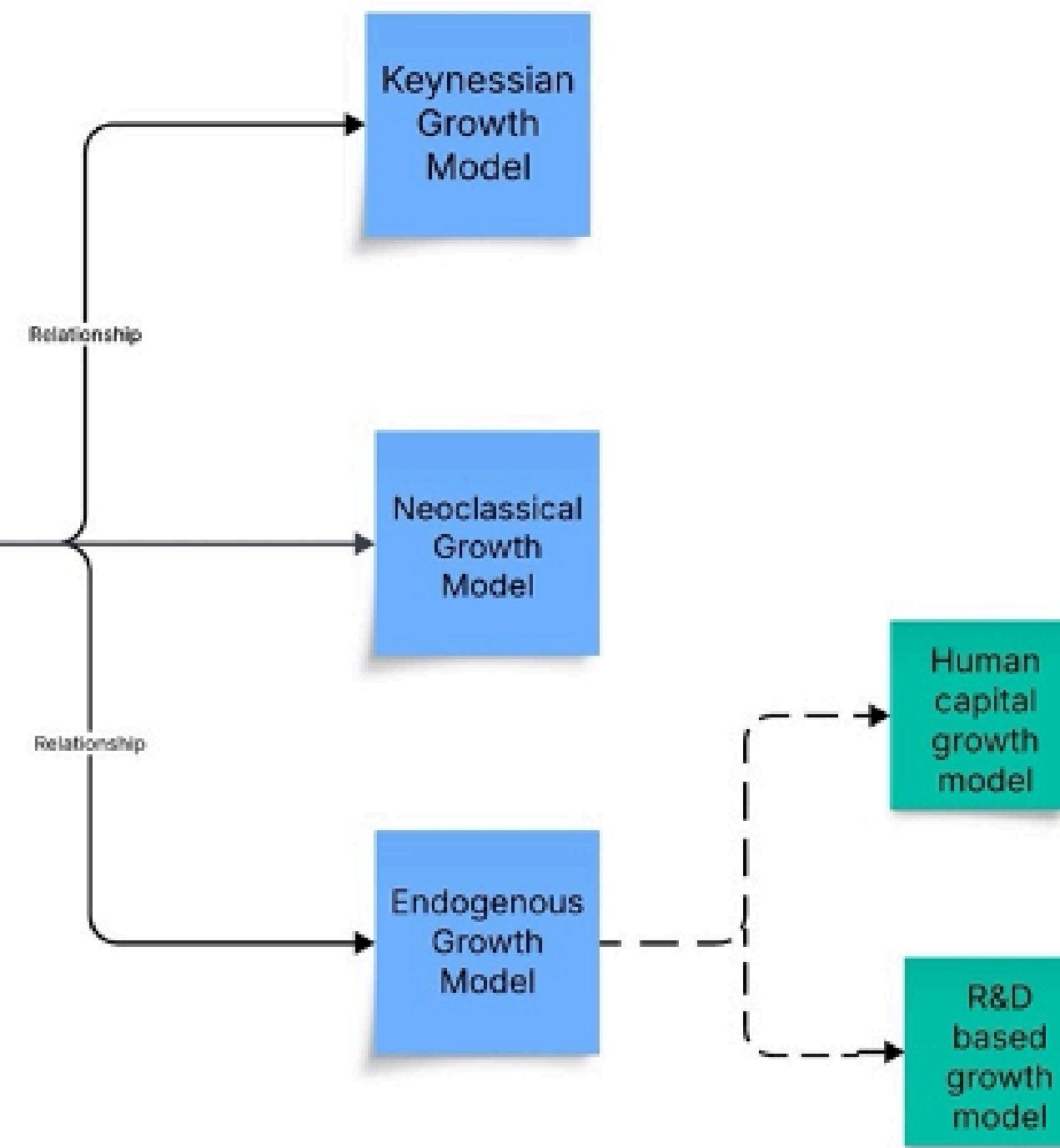
Alternative for Big data (such as Remote Sensing data, i.e. Night Time Light)

- Overcome infrequent data availability on socioeconomic development.
- Capturing informal economic activities, which are often overlooked by traditional surveys and administrative record
- Real-time, more efficient, less resources, and less labourious



Theoretical Framework

Growth Models



- Drawing on Keynesian, neoclassical, and endogenous growth theories that characterize the renaissance of economic growth, this dissertation develops an analytical framework that models night-time light data alongside fundamental economic components—capital, population, trade openness, and crop-land—derived from these underlying theoretical concepts.

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Existing Literature Review : Validating NTL-GRDP Association

A stylized overview

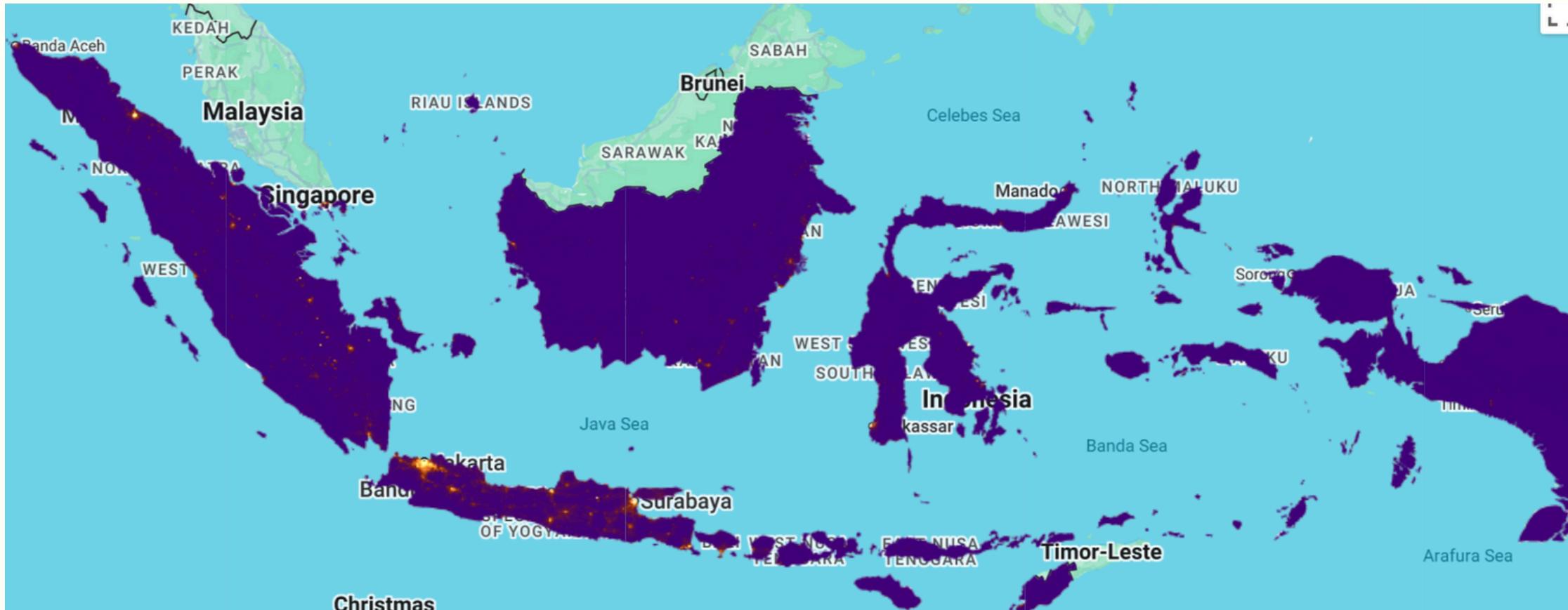
Initial Phase : (Elvidge et al. (1997), Chen & Nordhaus (2011), Henderson et al. (2012),

- **Source of data:** Defence Meteorological Satellite Program (DMSP)
- **Emphasis:** 1992-2013 time frame, across countries, subnational regions of one or a few countries
- **Drawbacks:** Calibration, geocoding inaccuracies, blurring, low resolution, top-coding

Second Phase : (Chen and Nordhaus (2015, 2019), Gibson and Boe-Gibson (2021); Zhang and Gibson (2022)

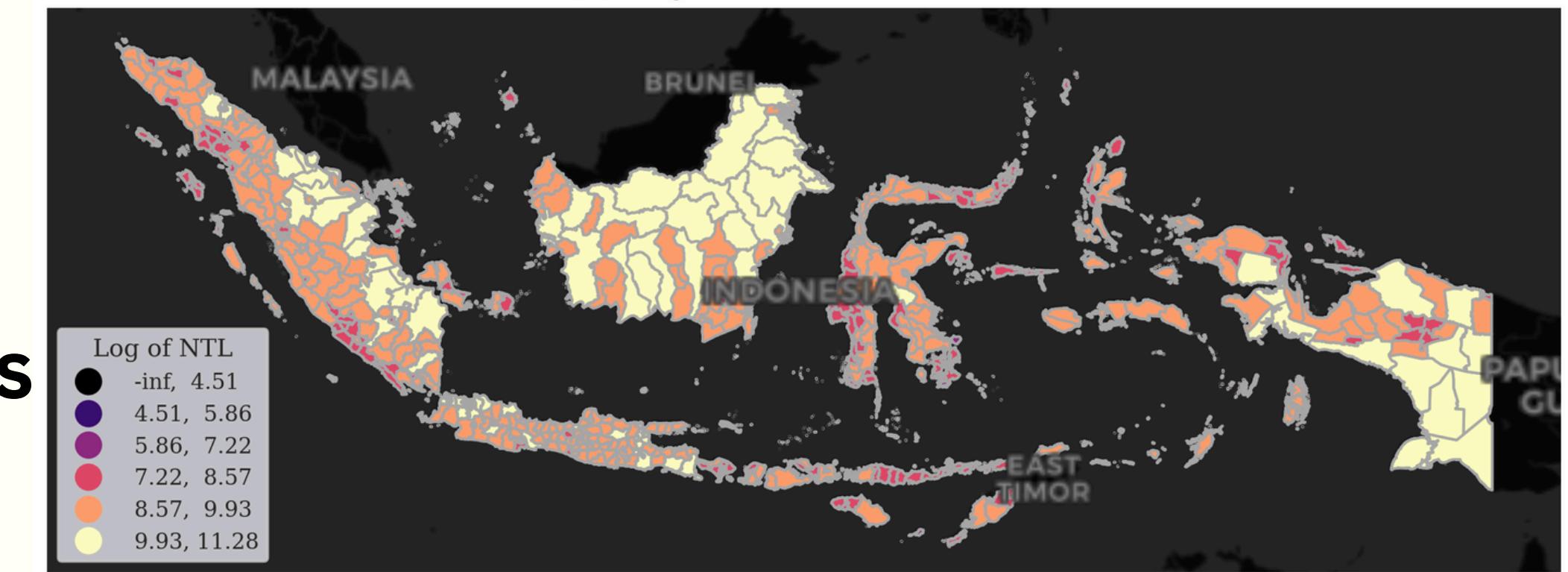
- **Source of data:** VIIRS Night-Time Like and VIIRS-Night Time masked
- **Emphasis:** 2013-present time frame, across countries, subnational regions of one or a few countries
- **Advantages:** better temporal comparability, higher spatial resolution, absence of geocoding mistakes, significantly reduced blurring, and elimination of top-coding.

Spatial aggregation...



From pixel

To administrative units



Research Contribution



VRIIS NTL 2013-2024

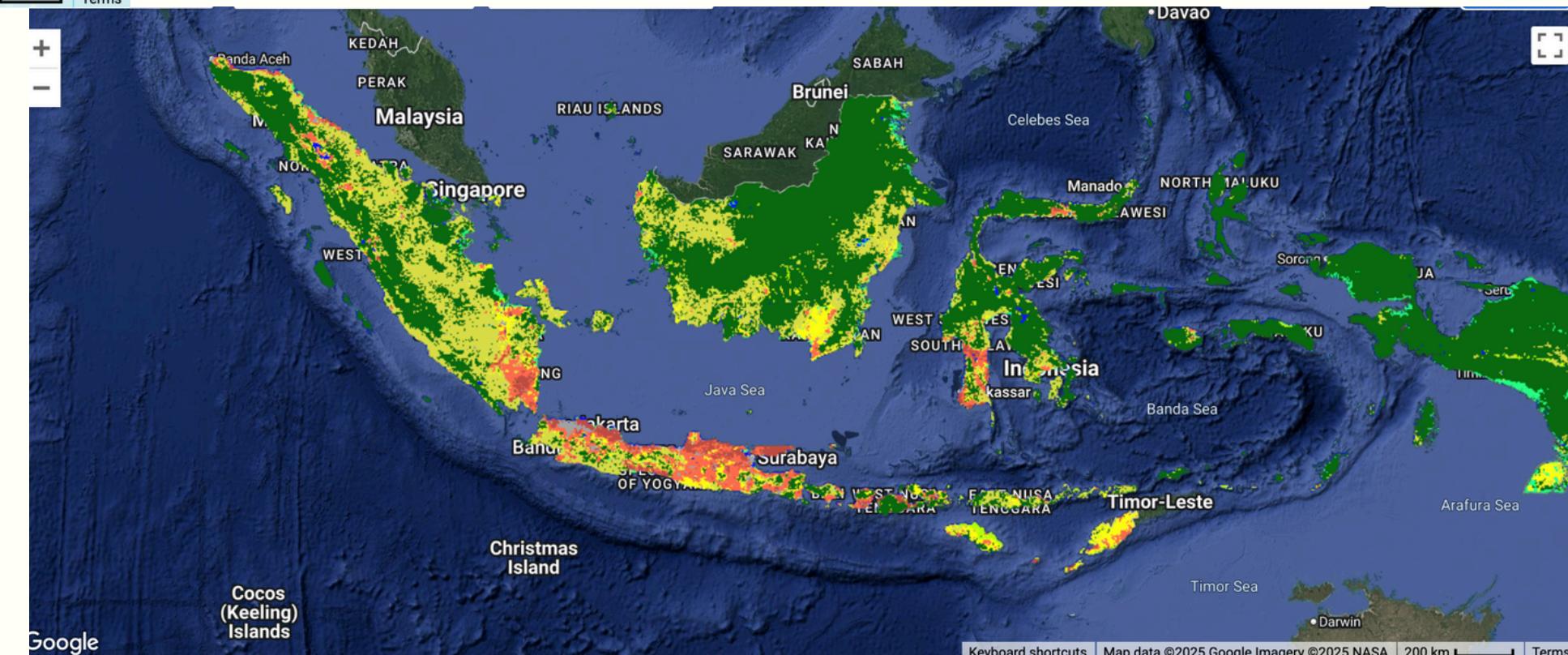
Research gap :

1. Keola (2015) argued that NTL is a weak proxy for predicting GRDP in agriculture or regions with >50 percent share of GRDP from agriculture sector.
2. NTL data could effectively capture economic activity in urban areas, but its ability to do so in rural regions is more limited (Chen and Nordhaus 2019; Zhang and Gibson 2022).

Solution!

Combining VRIIS Annual DNB/V2.1 and V2.2 with Modis Land Cover Data (MDC12Q1)

MODIS Land Cover, 2013- 2024



Data

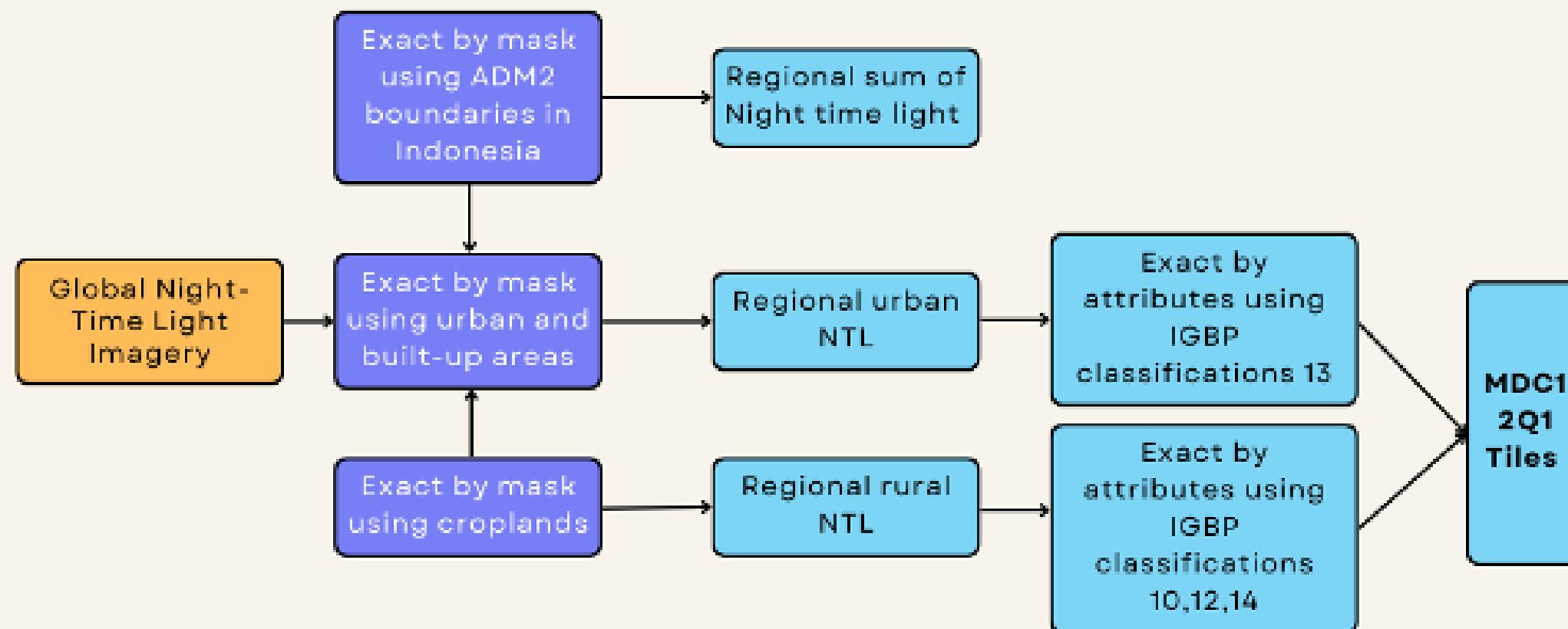
- Sub-national GRDP (district level)
 - 514 districts in Indonesia, 2019-2023
 - Total GRDP
 - GRDP by agriculture sector
 - GDRP by industry and services sector
 - Source : BPS-Statistics Indonesia
- Remote sensing data (district level)
 - 514 districts in Indonesia, 2019-2023
 - VIIRS masked ("NOAA/VIIRS/DNB/ANNUAL_V21 dan NOAA/VIIRS/DNB/ANNUAL_V21 ")
 - MODIS Land Cover("MODIS/061/MCD12Q1")
 - Source : Google Earth Engine

New research opportunities :

1. Study the NTL-GRDP association using new sub-national data (VRIIS masked) rather than DMSP
2. Predict sectoral GRDP (GRDP agriculture and non-agriculture) by combining VRIIS masked with MODIS Land Cover Data (to disaggregate NTL into urban and rural night-time intensity)

Mechanism Process of Disaggregating Data

Flowchart. Night-Time Extraction based on Land Cover Classification



Adapted from : Pagaduan (2022)

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Are Night-Time Light and MODIS Land Cover Reliable Proxy?

A Collection of Panel Data Framework

Pooled OLS Model

$$\begin{aligned}\log(GDP)_{it} = & \beta_{1\text{Pooled}} \log(NTL)_{it} + \beta_{2\text{Pooled}} \log(Pop)_{it} \\ & + \beta_{3\text{Pooled}} \log(Cropland)_{it} + \beta_{4\text{Pooled}} \log(PMTB)_{it} \\ & + \beta_{\text{Pooled}} \log(Net_{Export}) + \mu_i \\ & + \varepsilon_{it}\end{aligned}$$

Between Estimator Approach

$$\begin{aligned}\overline{\log(GDP)_i} = & \beta_{1\text{between}} \overline{\log(NTL)_i} + \beta_{2\text{between}} \overline{\log(Pop)_i} \\ & + \beta_{3\text{between}} \overline{\log(Cropland)_i} + \beta_{4\text{between}} \overline{\log(PMTB)_i} \\ & + \beta_{5\text{between}} \overline{\log(Net_Export)} + \mu_i + \bar{\varepsilon}_i\end{aligned}$$

Are Night-Time Light and MODIS Land Cover Reliable Proxy?

Within-Estimator Approach

$$\log(GDP)_{it} - \overline{\log(GDP)}_i = \beta_{1\text{within}} [\log(NTL)_{it} - \overline{\log(NTL)}_i] + \\ \beta_{2\text{within}} [\log(Pop)_{it} - \overline{\log(Pop)}_i] + \beta_{3\text{within}} [\log(Cropland)_{it} - \\ \overline{\log(Cropland)}] + \beta_{4\text{within}} [\log(PMTB)_{it} - \overline{\log(PMTB)}_i] + \beta_{5\text{within}} [\log(Net - \\ Export)_{it} - \overline{\log(Net - Export)}_i] + \varphi_t + \varepsilon_{it} - \bar{\varepsilon}_i$$

LSDV
(Least Square Dummy Variables)

$$Y_{it} = \alpha_0 + \sum_{k=1}^{I-1} \alpha_k D_{k,it} + \sum_{l=1}^{T-1} \theta_l T_{l,it} + \beta_1 X_{it} + \beta_2 Q_{it+} \dots + \beta_n R_{it+} + \mu_{it} \quad (6)$$

$\sum_{k=1}^{I-1} \alpha_k D_{k,it}$ are the cross-sectional dummies
 $\sum_{l=1}^{T-1} \theta_l T_{l,it}$ are the time dummies,

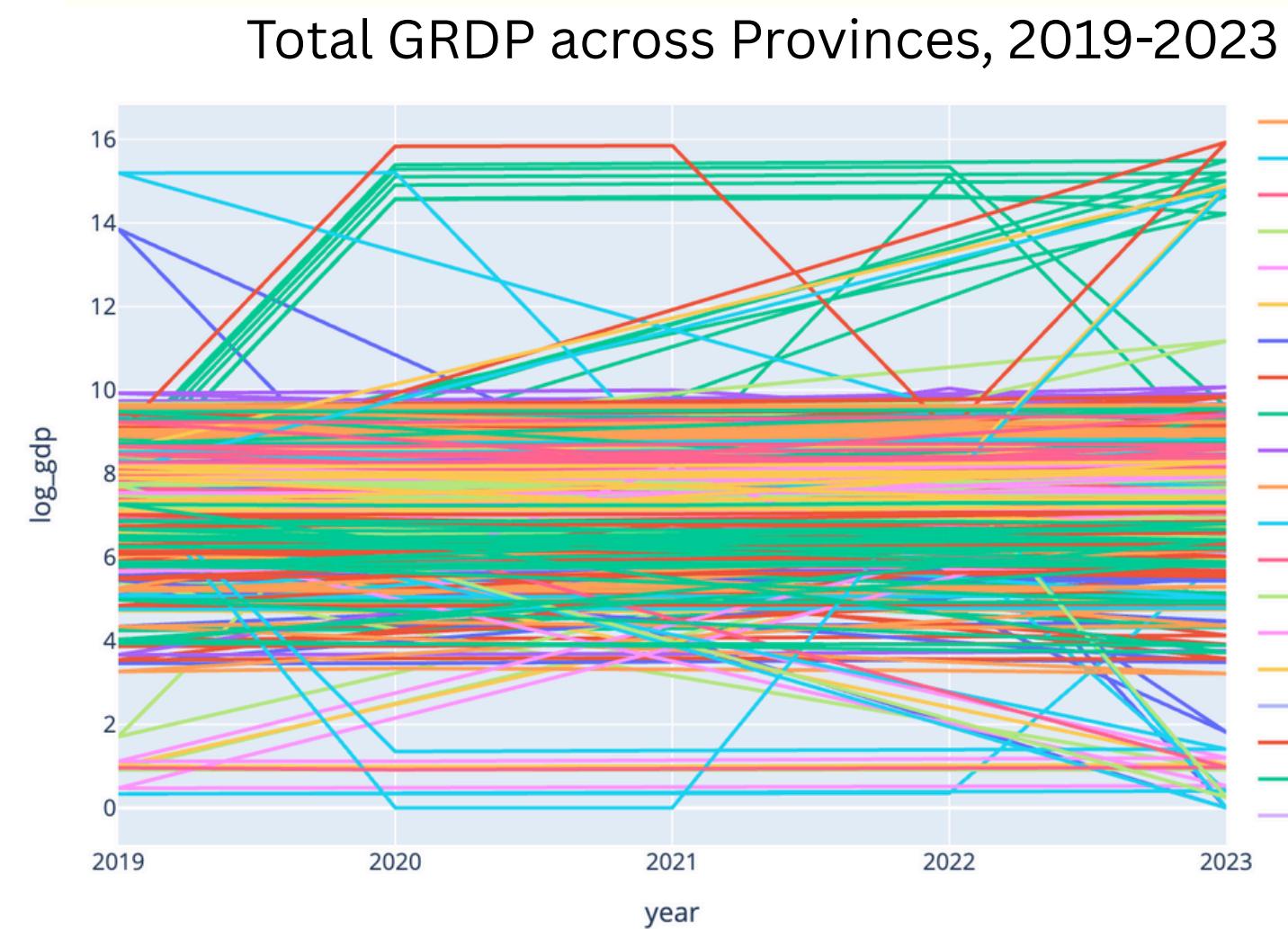
$$D_{k,it} = \begin{cases} 1 & \text{for } k = i \\ 0 & \text{otherwise} \end{cases}$$
$$T_{l,it} = \begin{cases} 1 & \text{for } l = t \\ 0 & \text{otherwise} \end{cases}$$

Three Stylized Facts

(1) Investigating Time Series Pattern

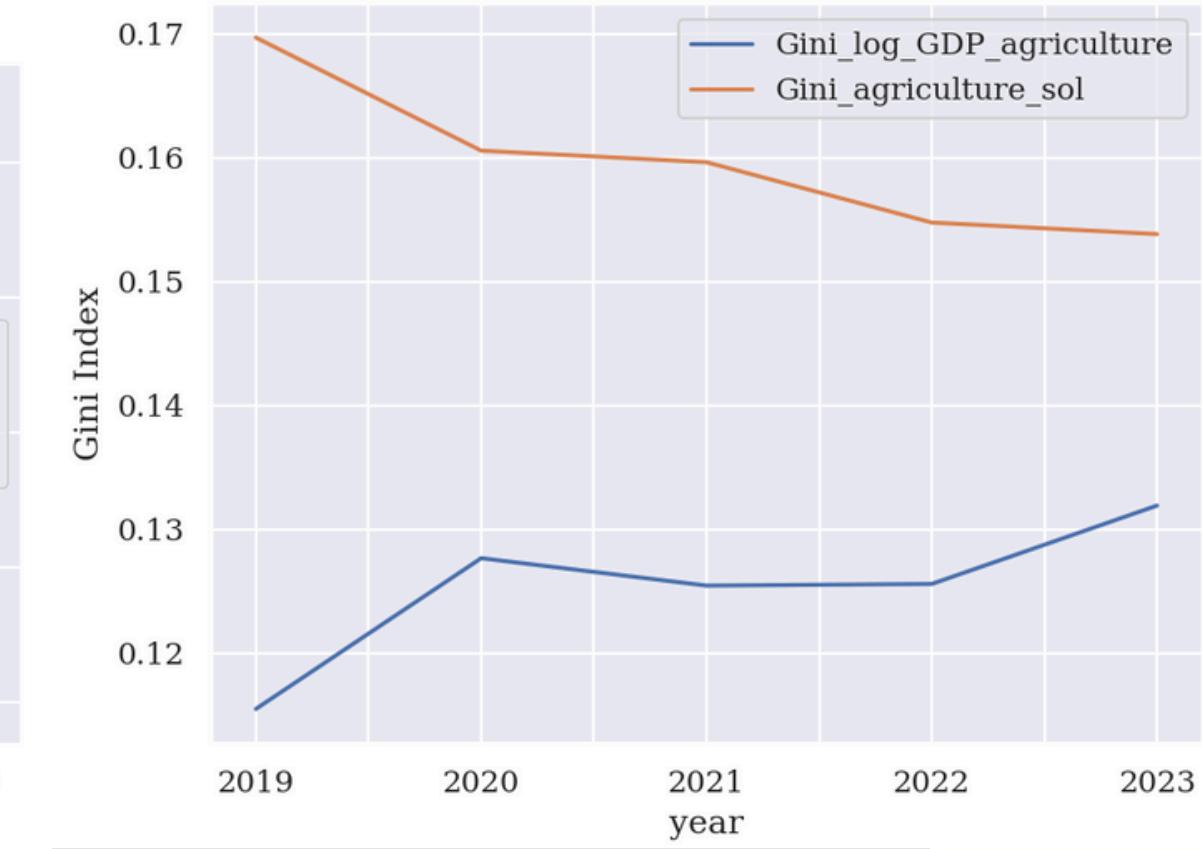
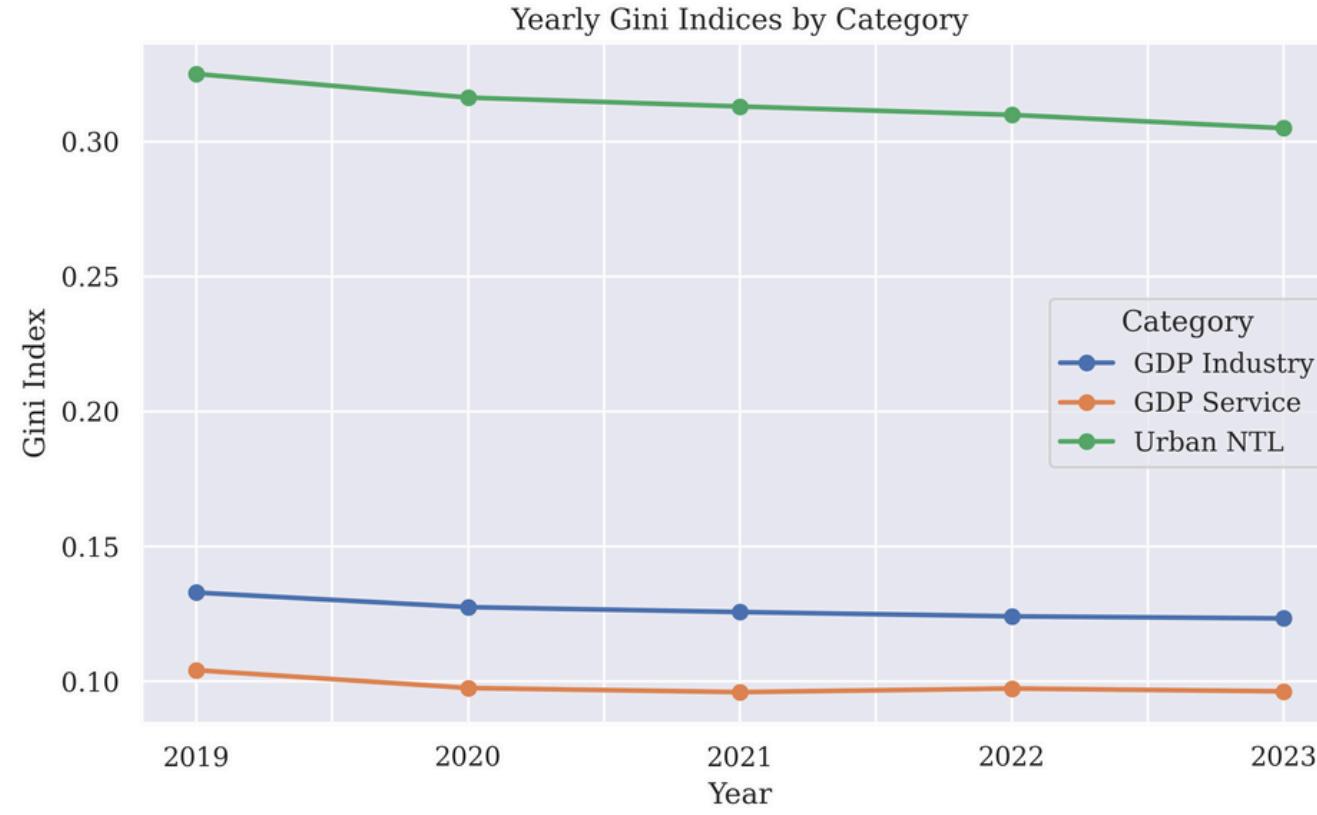
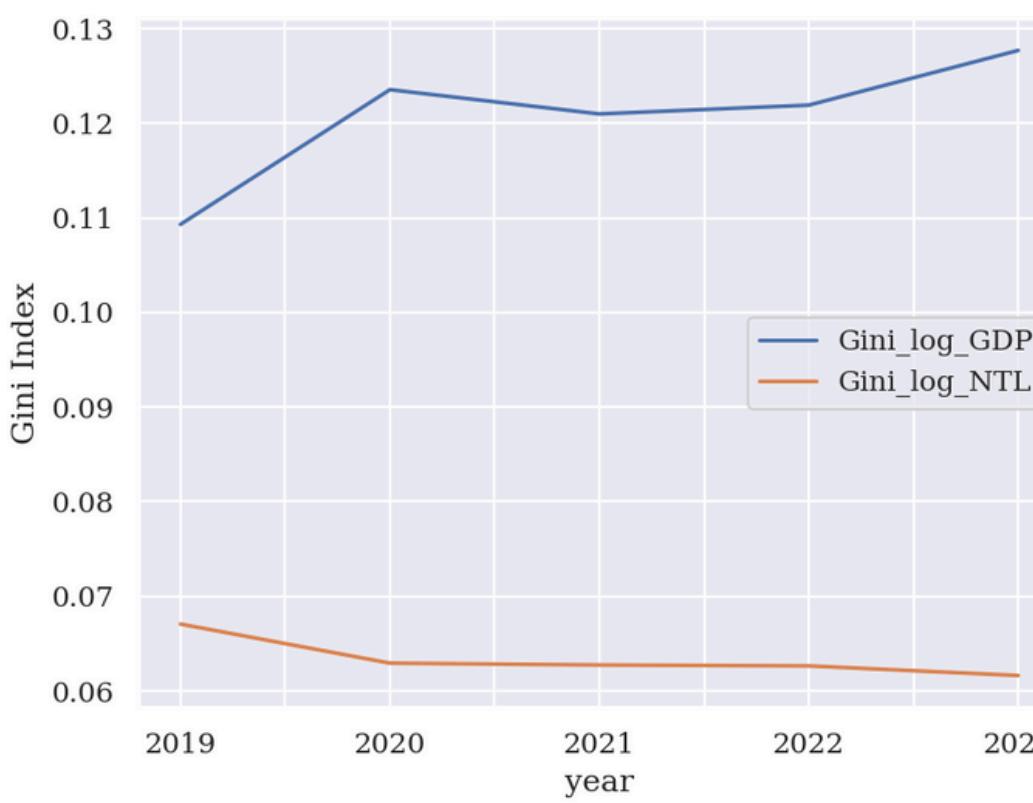


Total Night-time Light across Provinces, 2019-2023



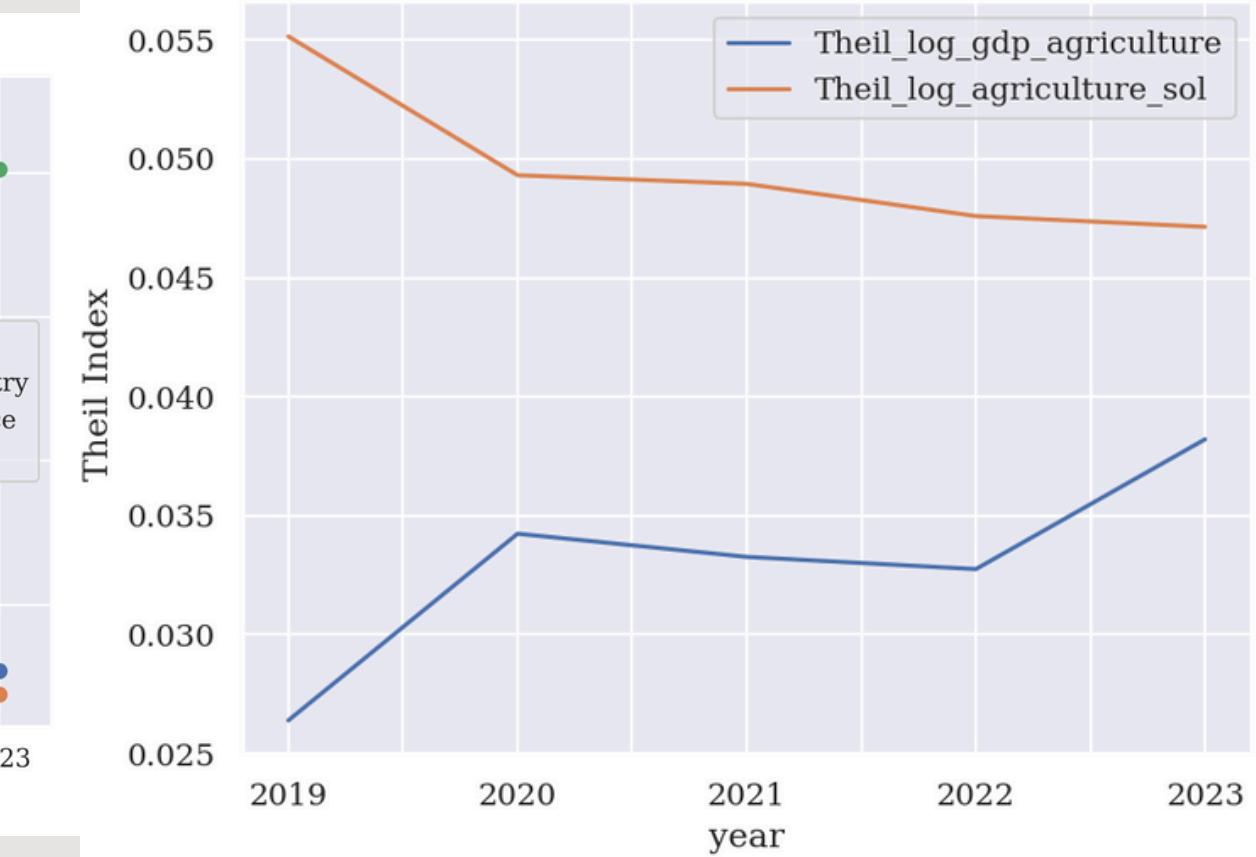
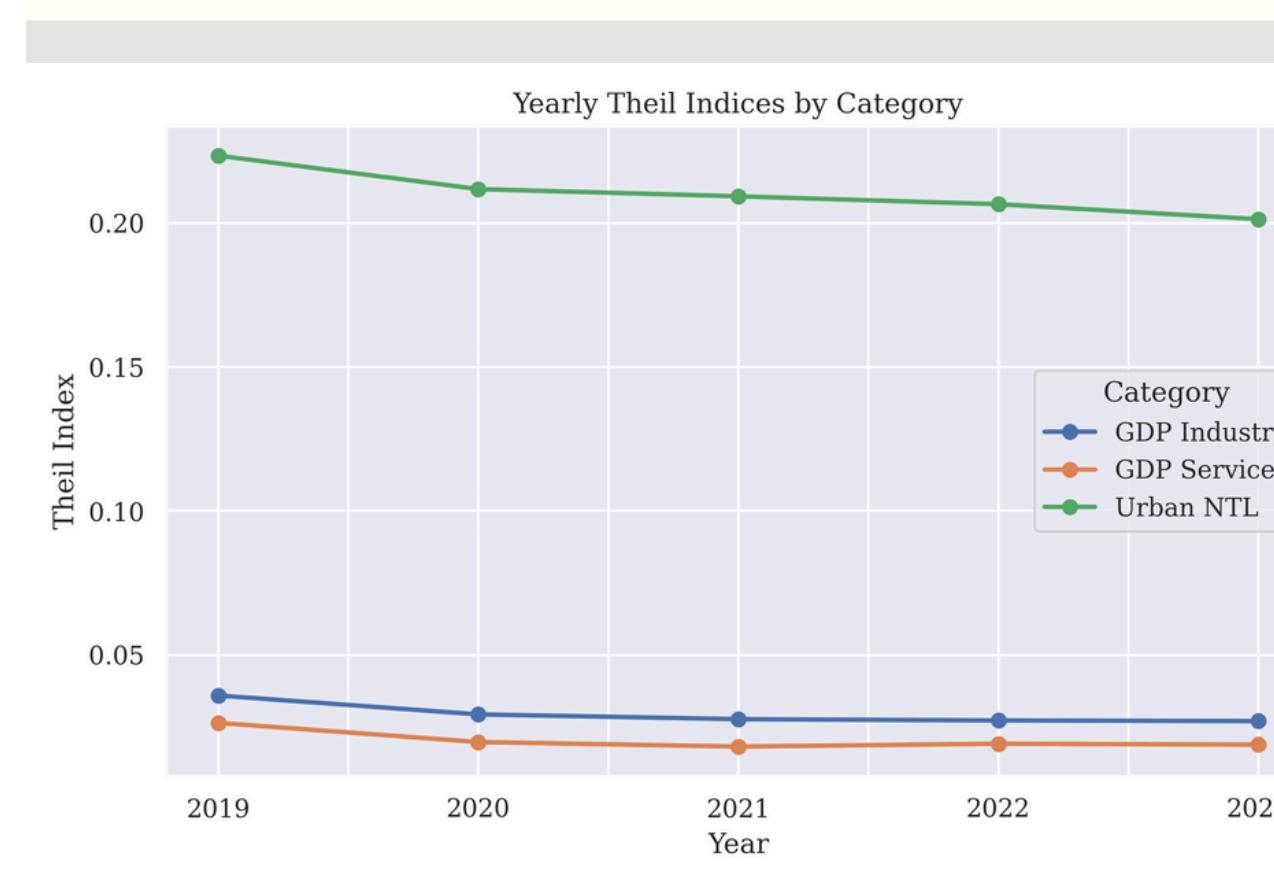
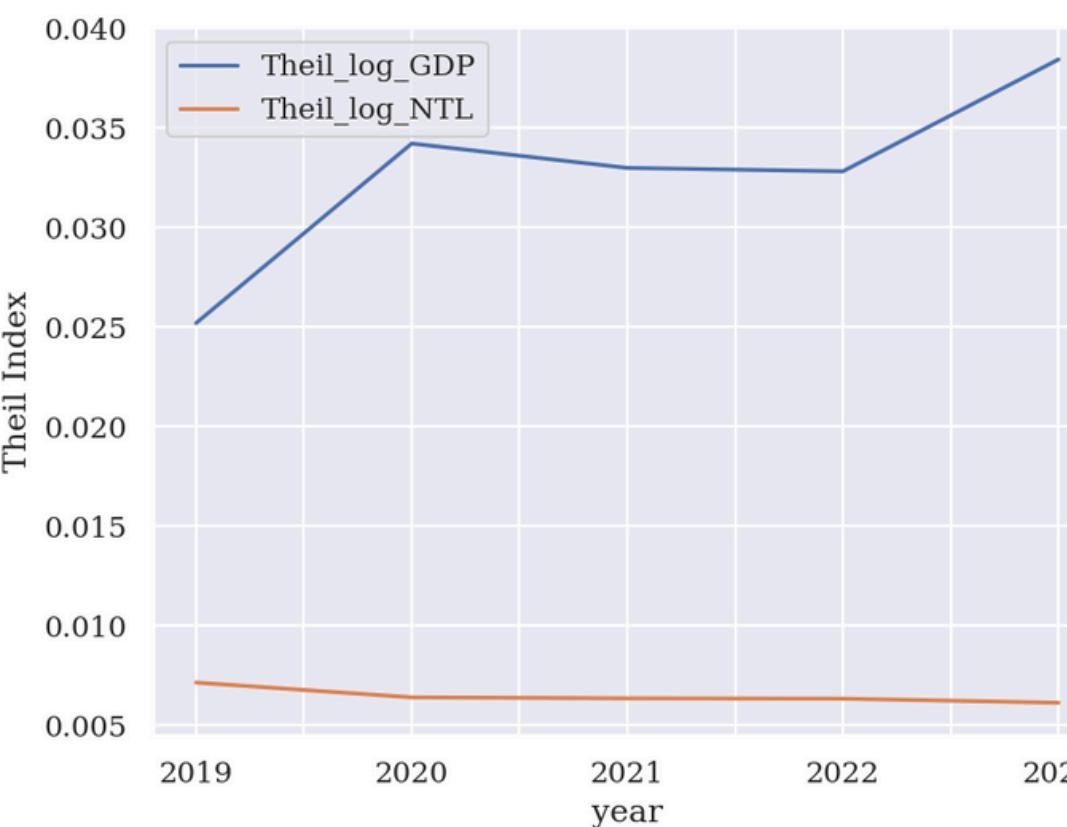
Total GRDP across Provinces, 2019-2023

(2) Comparing Inequality Dynamics (Gini Index)



In case of Indonesia, regional inequality (through Gini Index) in NTL is smaller than regional inequality in GRDP. Conversely, urban and rural NTL shows the opposite...

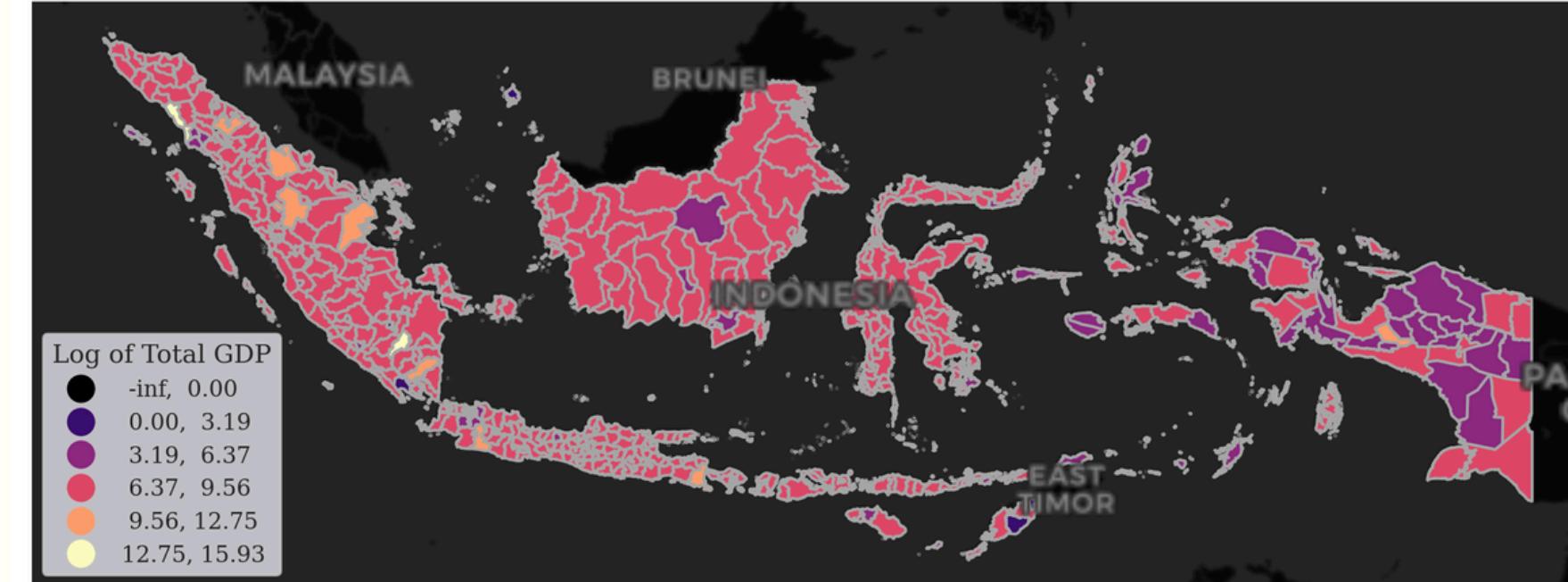
(2) Comparing Inequality Dynamics (Theil Index)



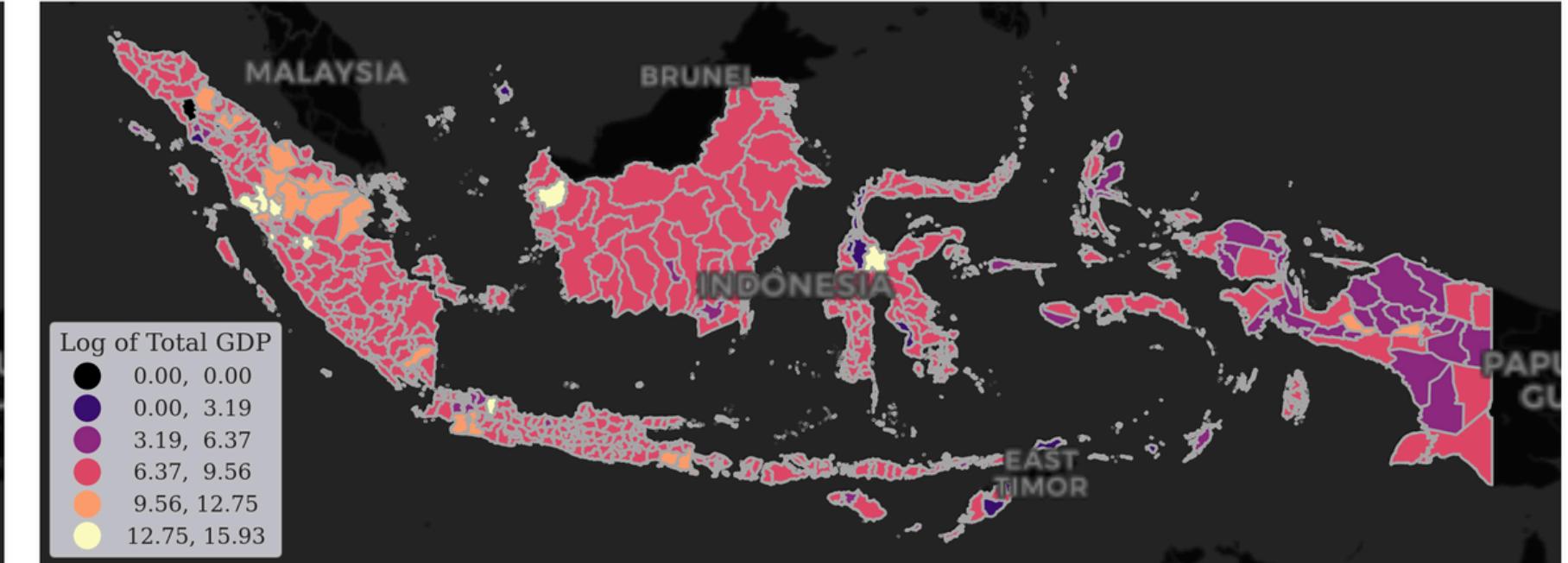
Using Theil Index, regional inequalities in total, urban, and rural NTL align with Gini Index's patterns...

(3) Spatial Distribution of Night Time Light and Total GRDP

(a) Log of Total GDP in 2019

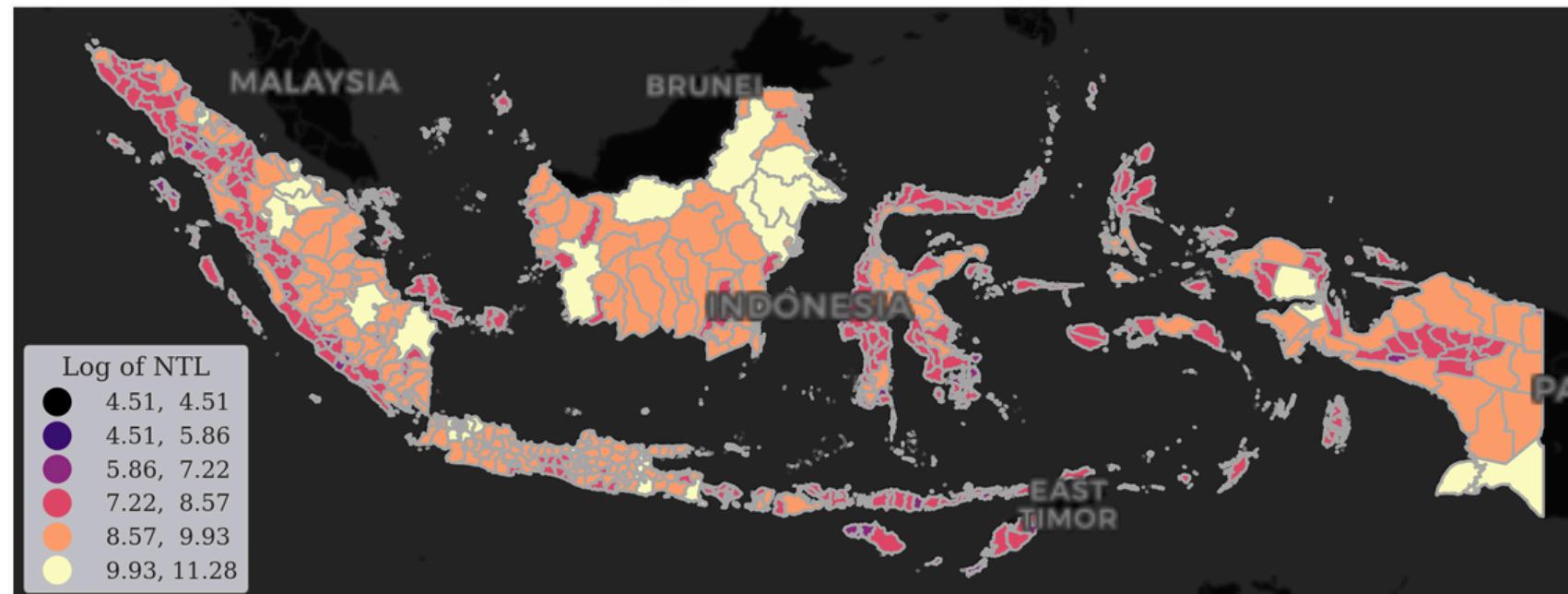


(b) Log of Total GDP in 2023

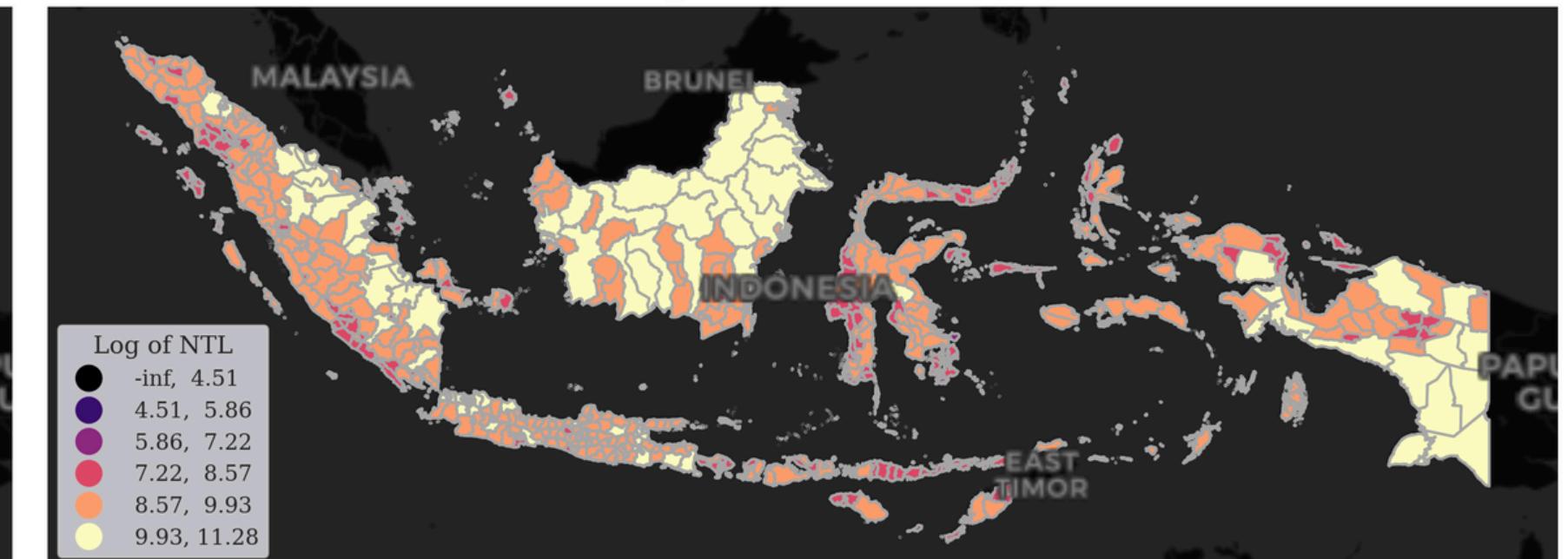


Both NTL and GRDP indicate that the easternmost regions are less illuminated than the western and central parts of Indonesia.

(a) Log of Total NTL in 2019

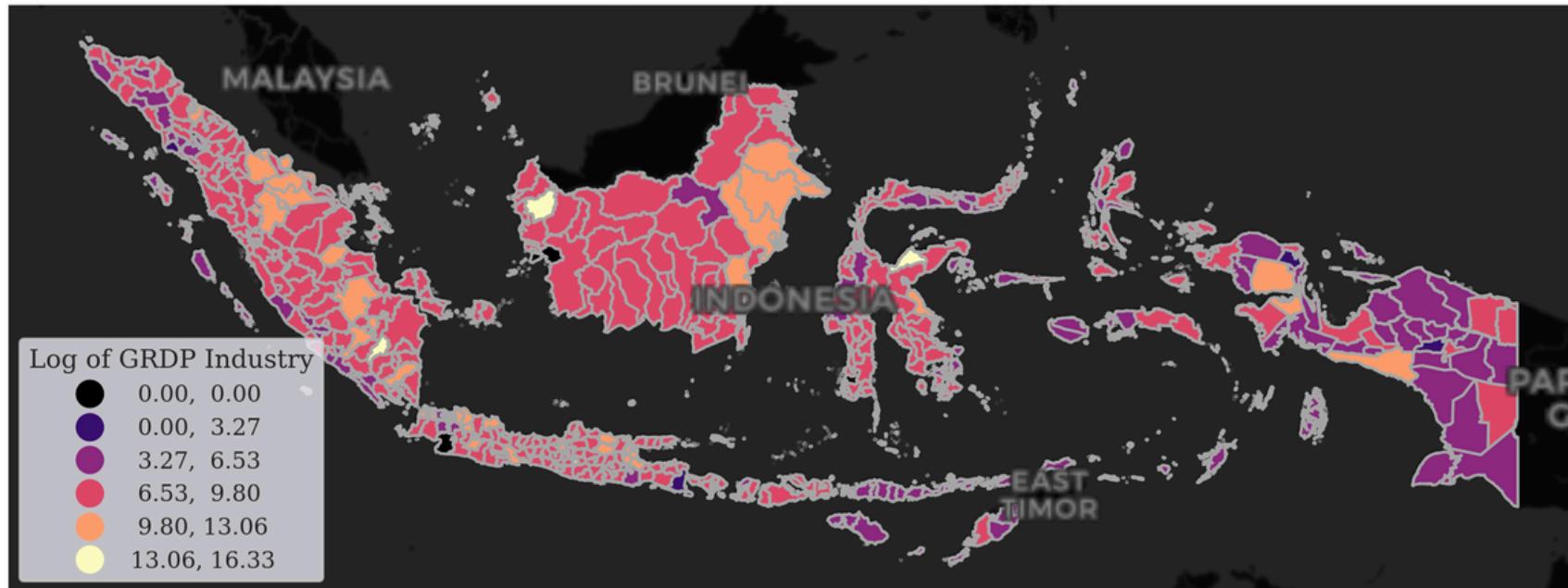


(b) Log of Total NTL in 2023

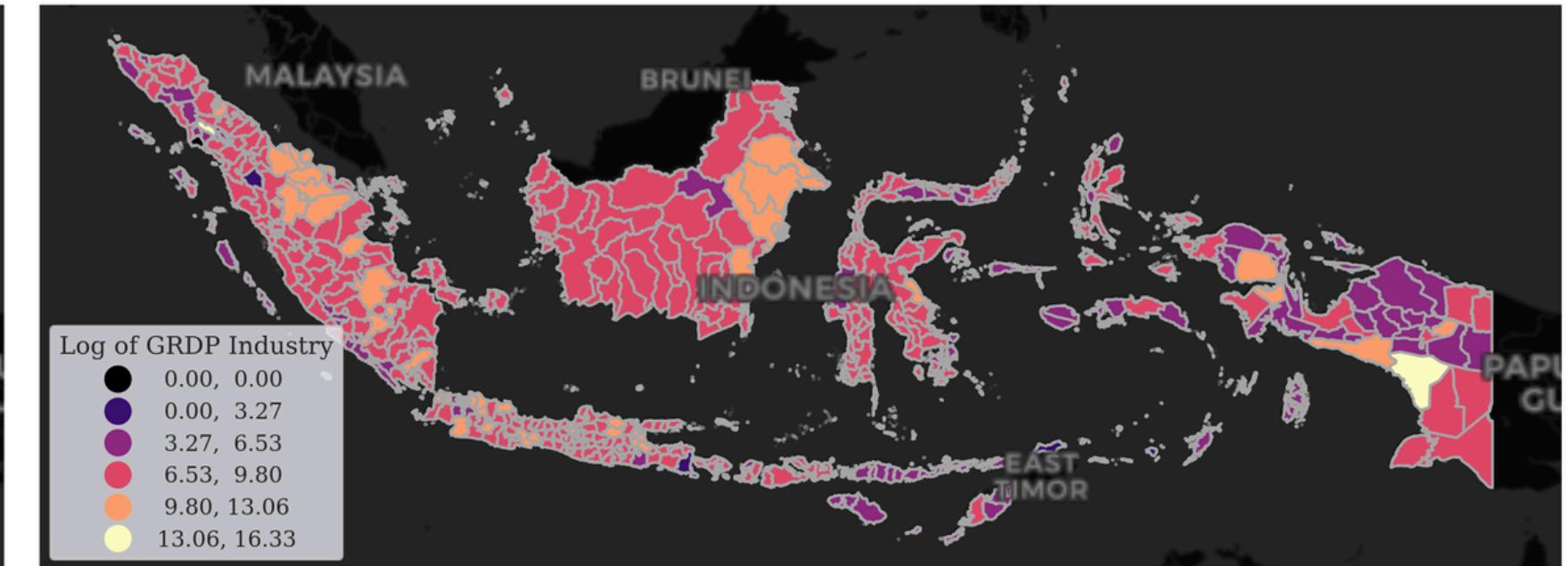


(3) Spatial Distribution of Urban Night Time Light and GRDP Industry

(a) Log of GRDP Industry in 2019

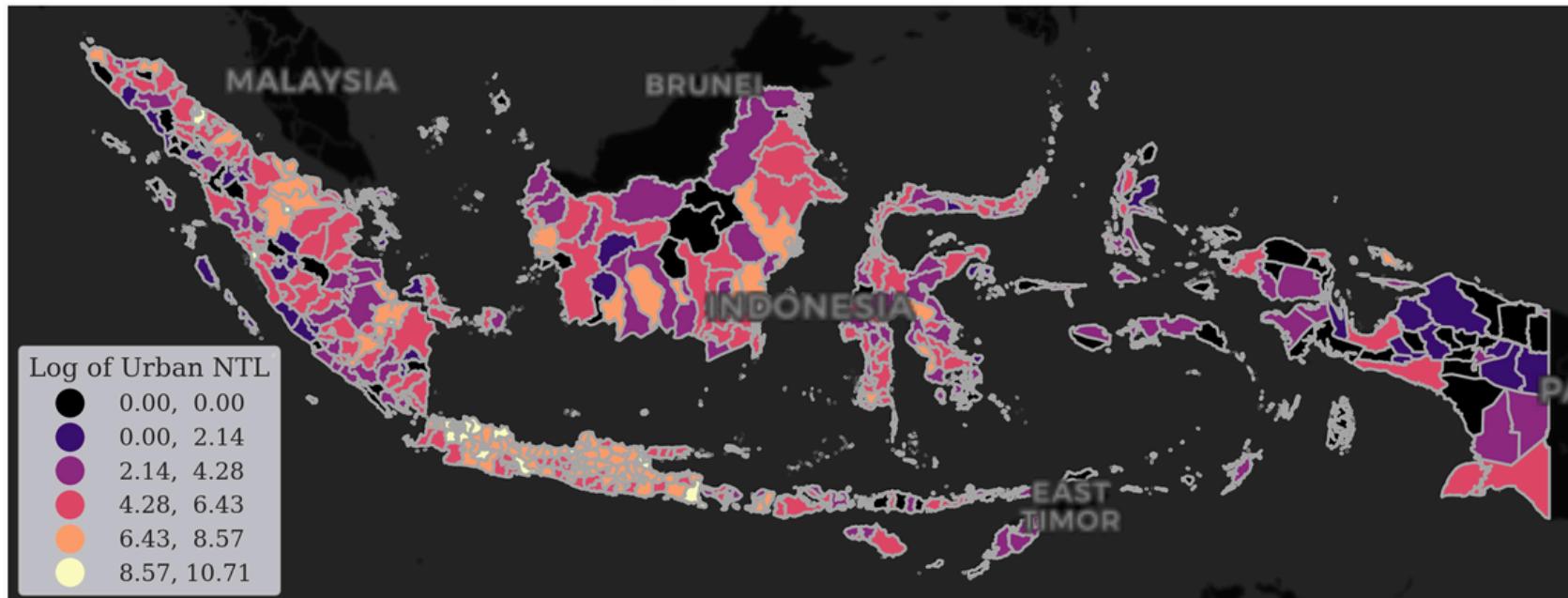


(b) Log of GRDP Industry in 2023

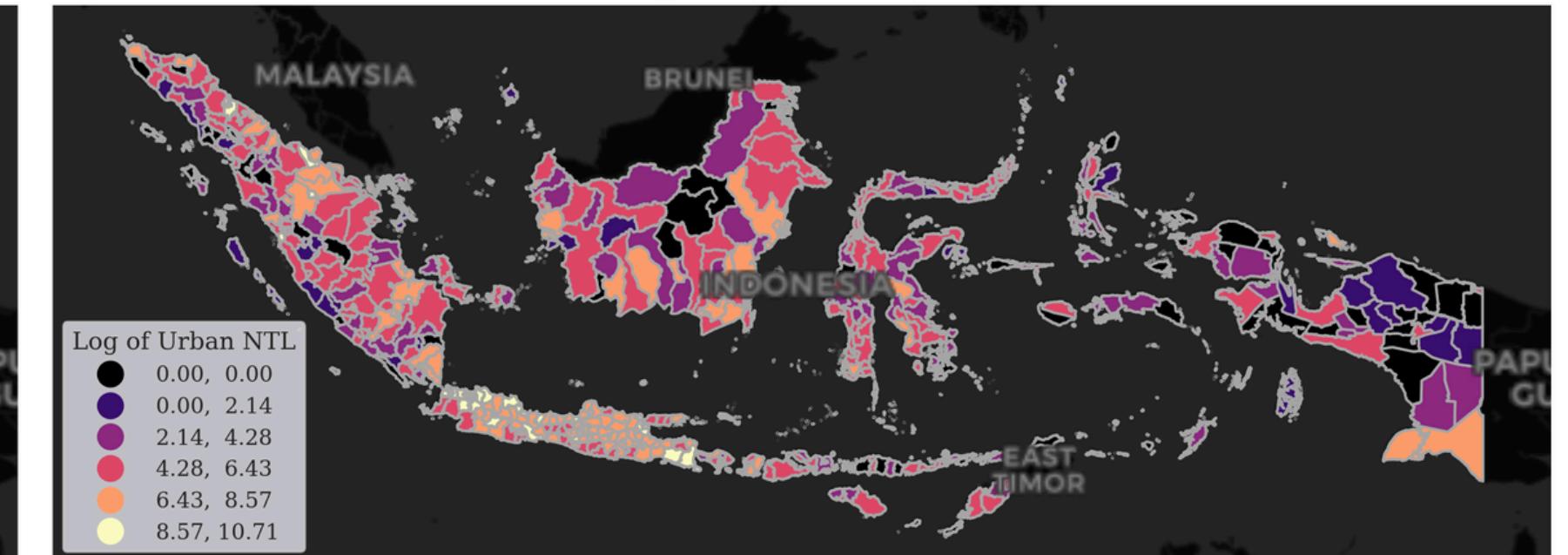


Both urban NTL and GRDP industry indicate that the easternmost regions are less illuminated than the western and central parts of Indonesia.

(a) Log of Urban NTL in 2019

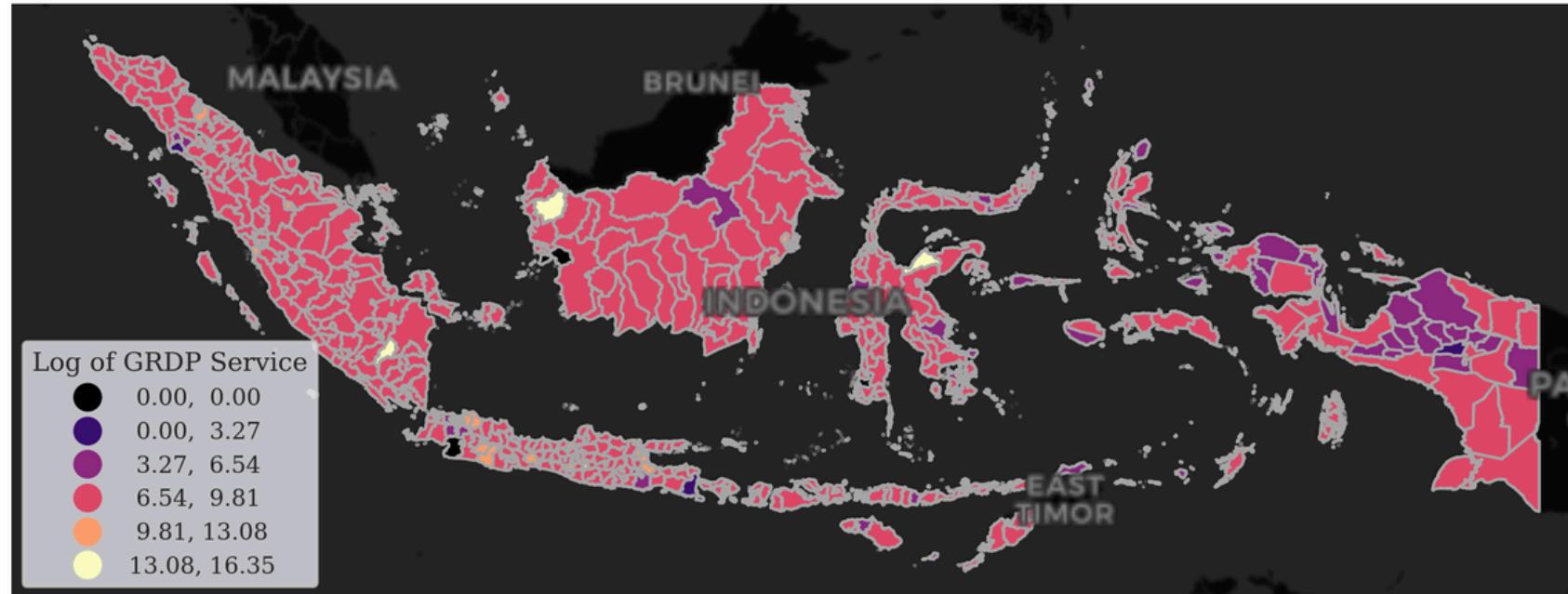


(b) Log of Urban NTL in 2023

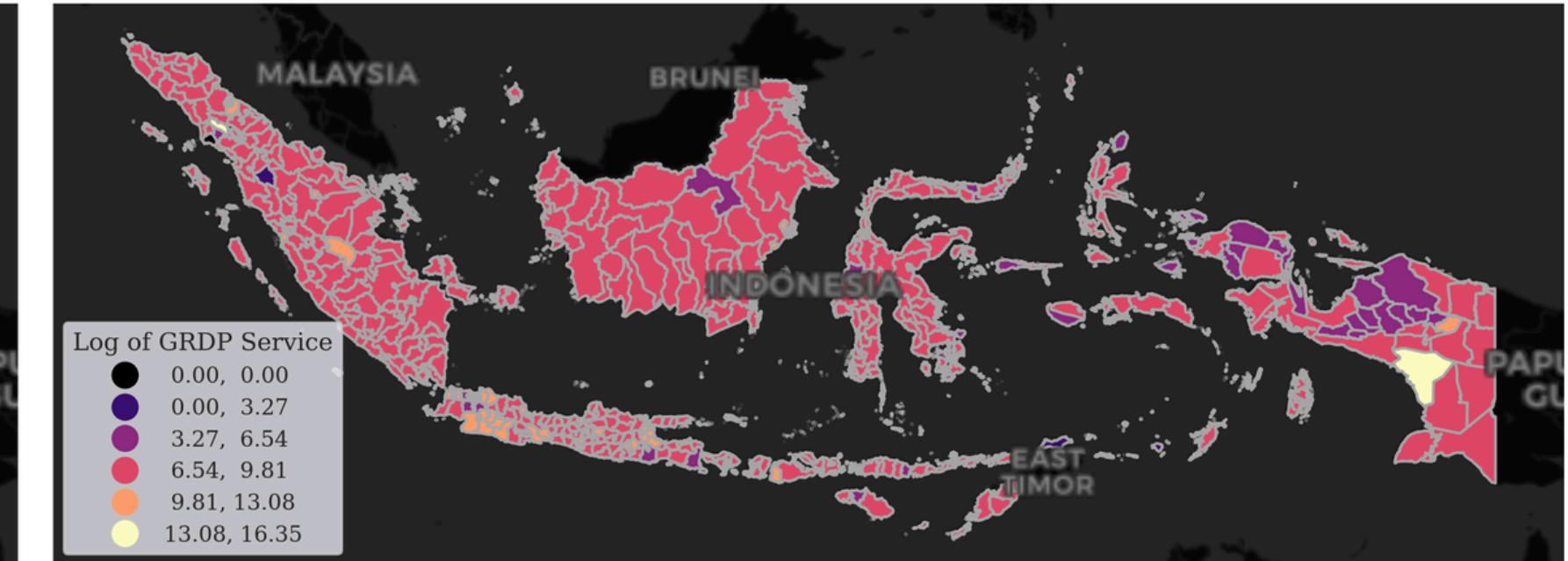


(3) Spatial Distribution of Urban Night Time Light and GRDP Services

(a) Log of GRDP Service in 2019

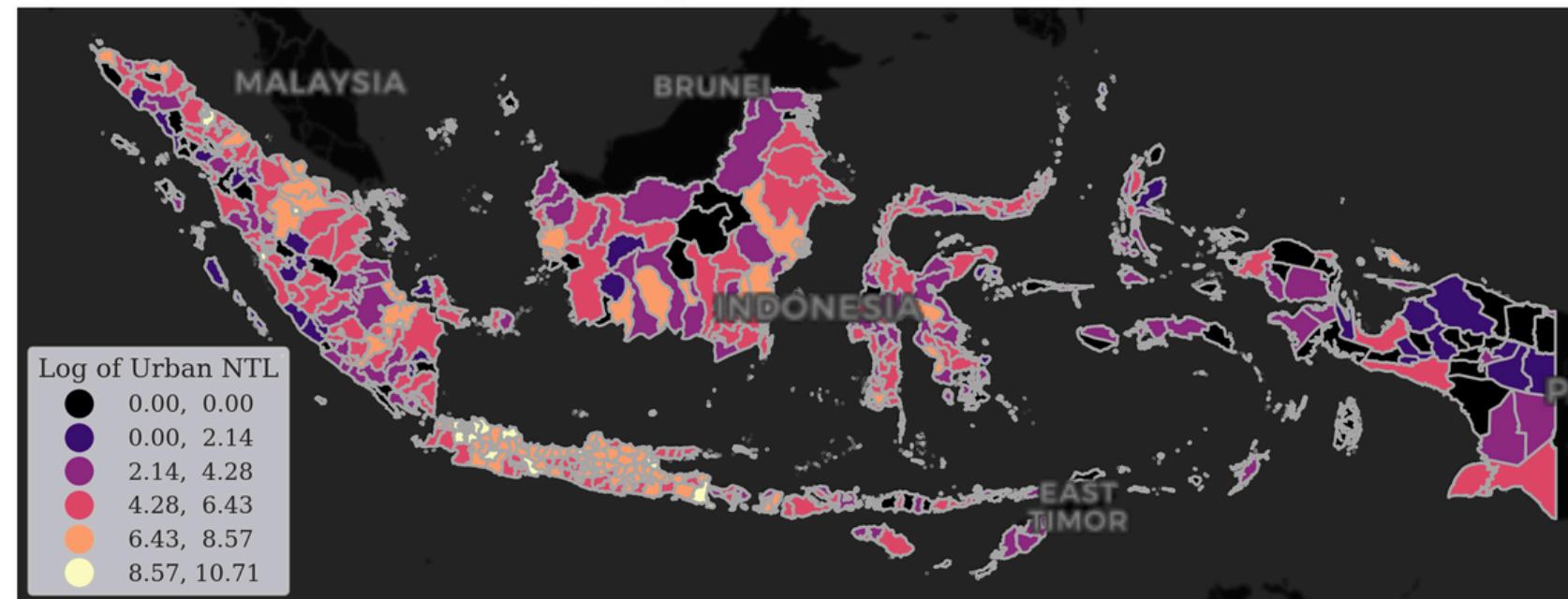


(b) Log of GRDP Service in 2023

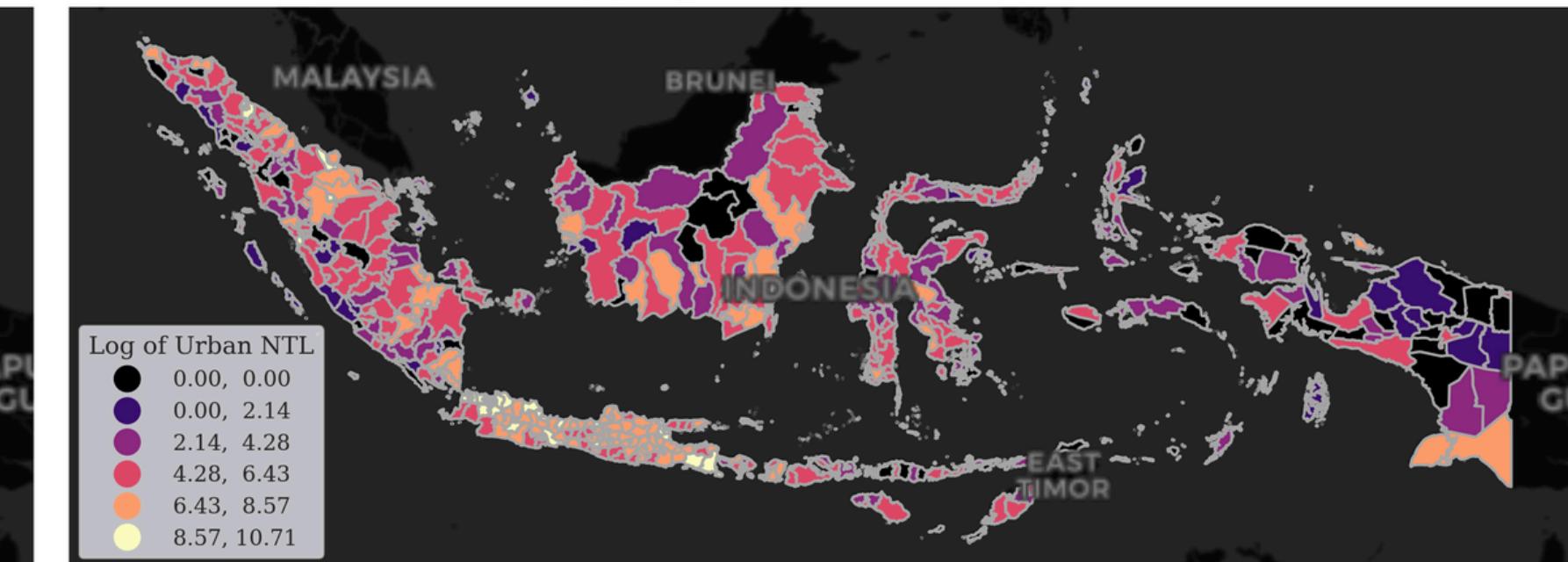


Both urban NTL and GRDP services indicate that the easternmost regions are less illuminated than the western and central parts of Indonesia.

(a) Log of Urban NTL in 2019

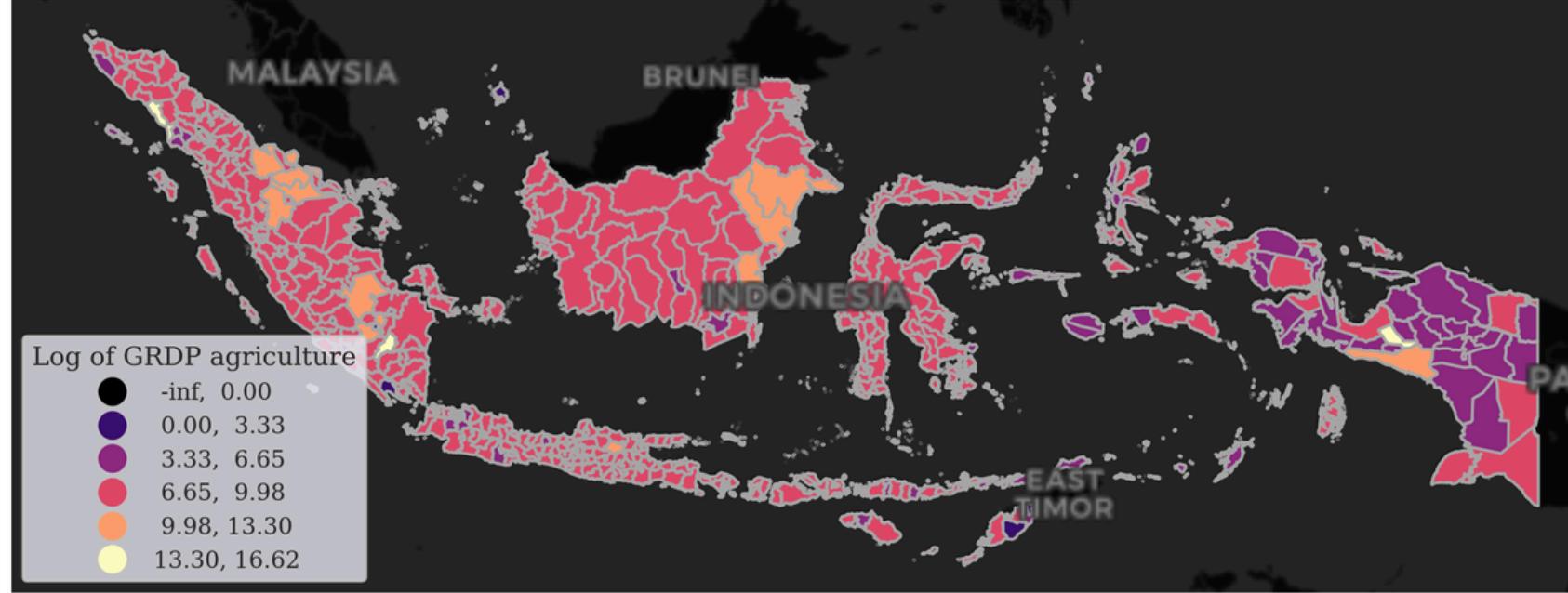


(b) Log of Urban NTL in 2023

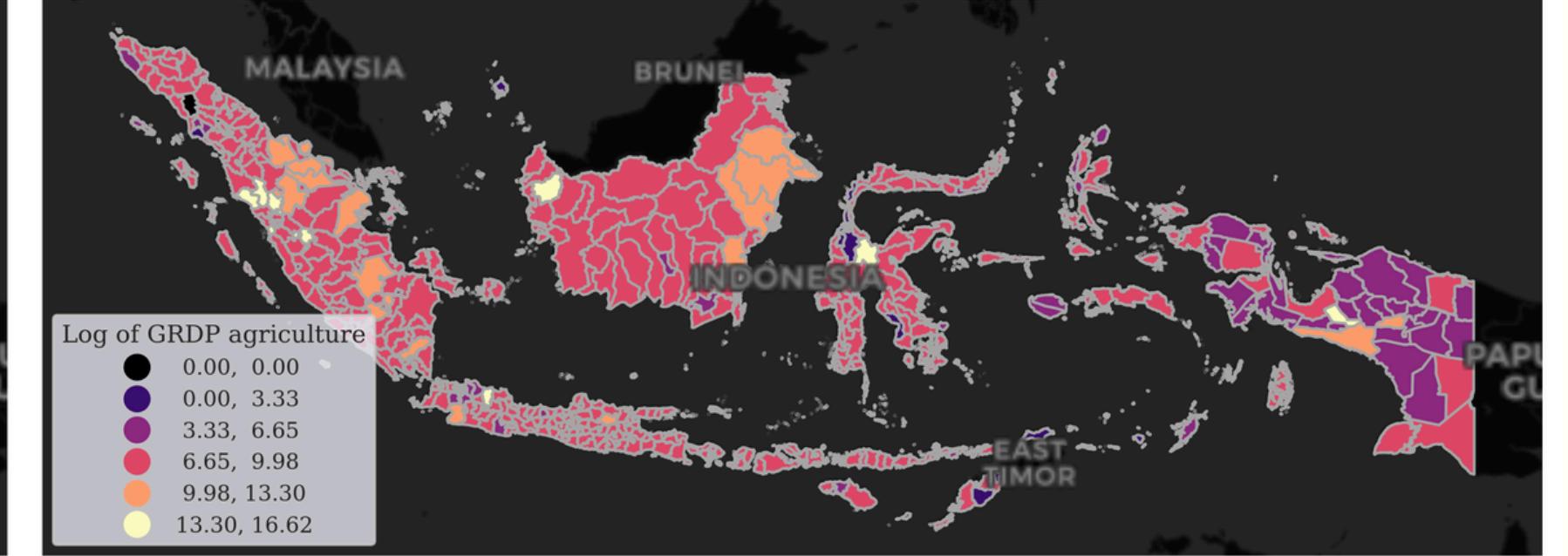


(3) Spatial Distribution of Rural Night Time Light and GRDP Agriculture

(a) Log of GRDP Agriculture in 2019

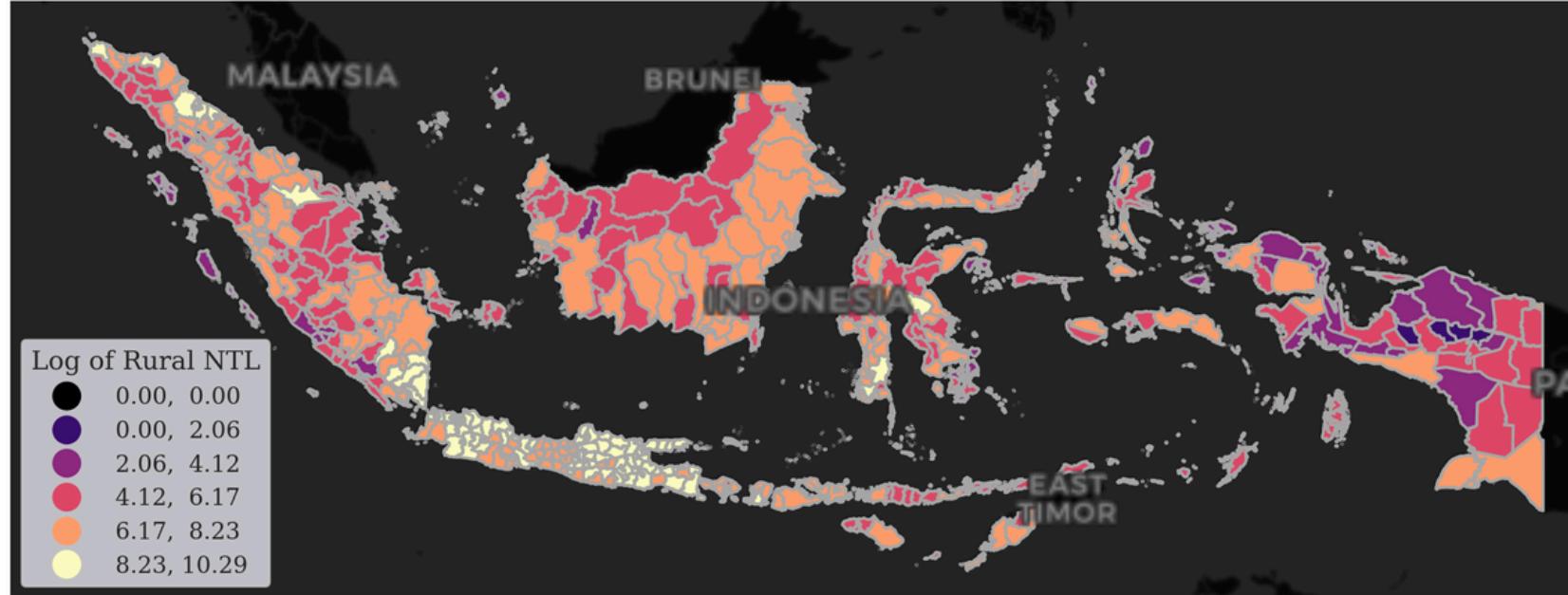


(b) Log of GRDP Agriculture in 2023

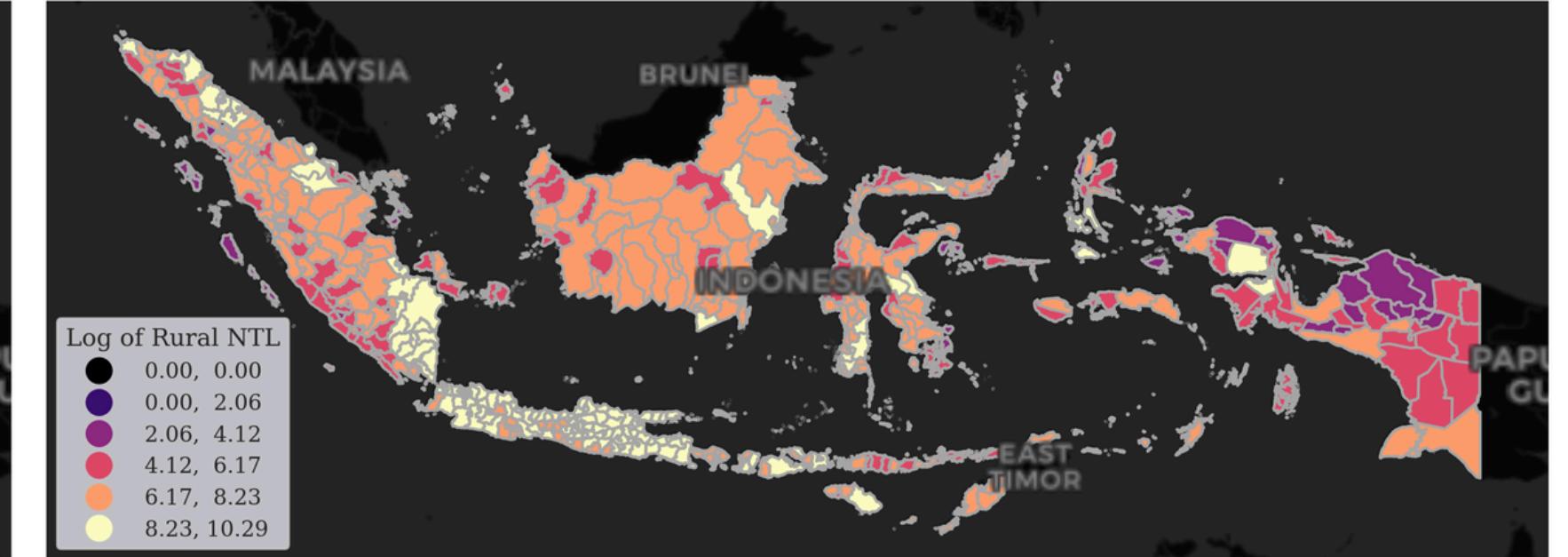


Both rural NTL and GRDP agriculture indicate that the easternmost regions are less illuminated than the western and central parts of Indonesia.

(a) Log of Rural NTL in 2019



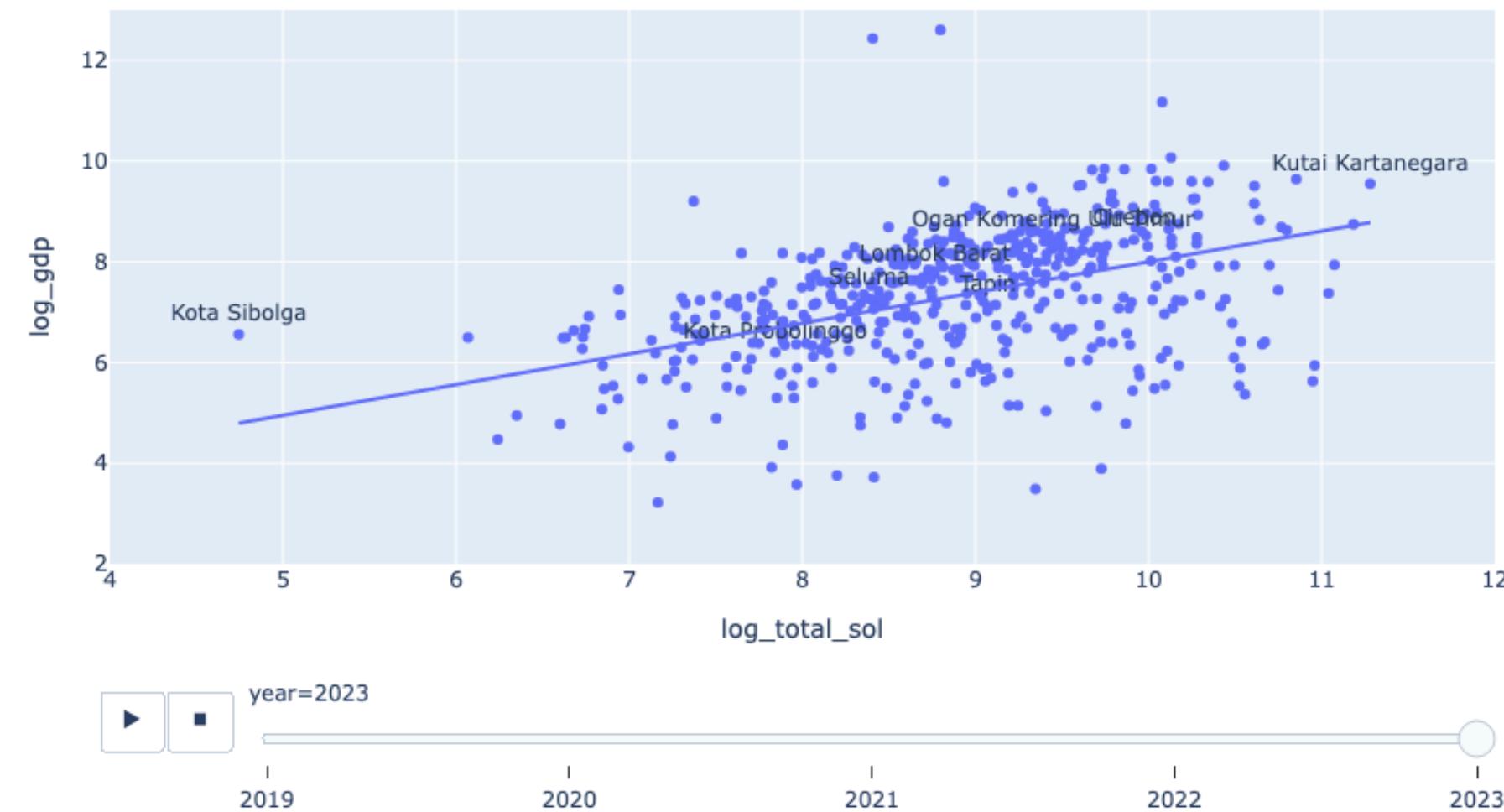
(b) Log of Rural NTL in 2023



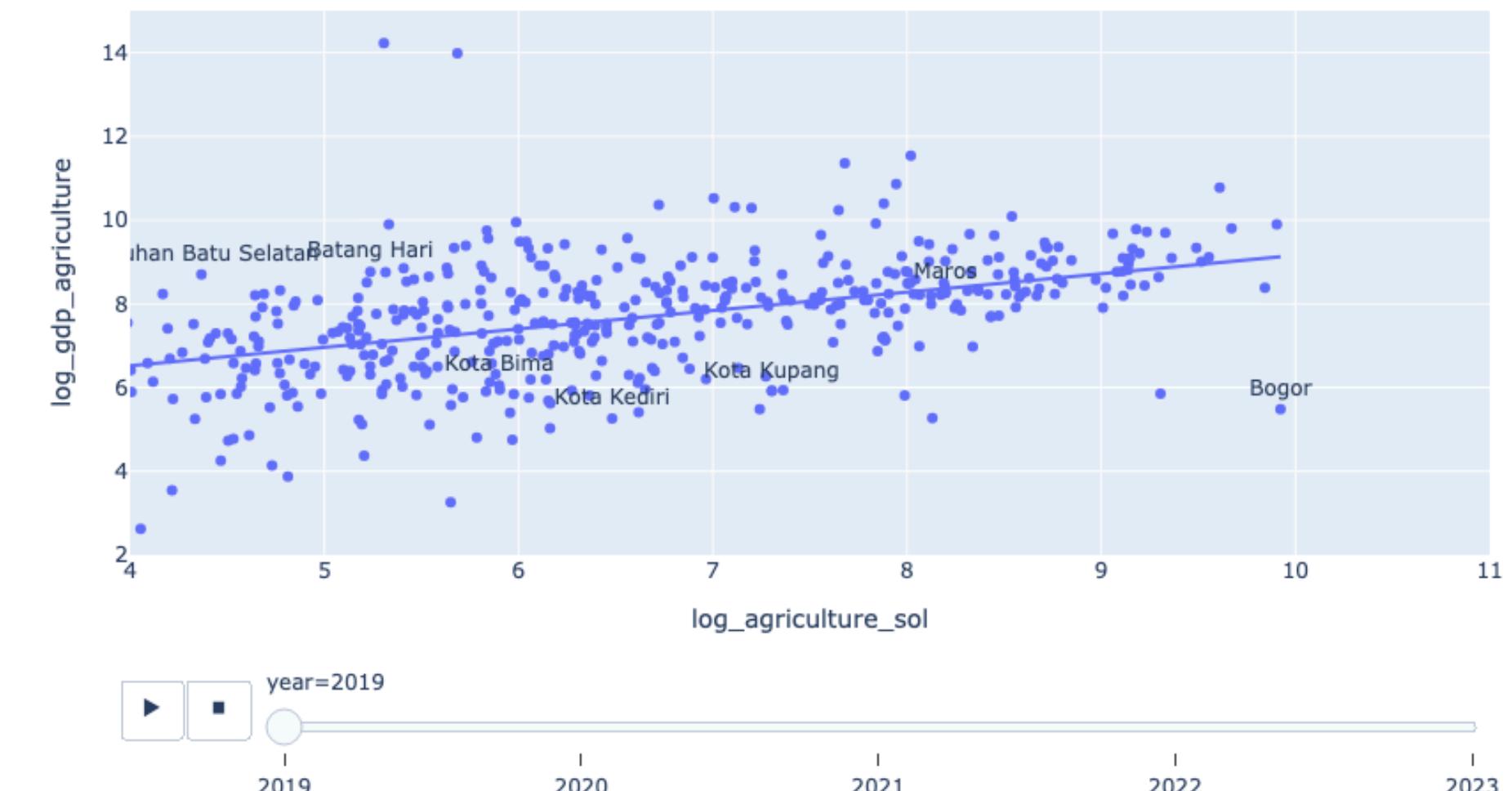
4. Predicting GRDP with Night-time lights

Plot Total GRDP-NTL Relationship with OLS Estimator

(a) Scatter Plot Total GRDP-NTL Relationship



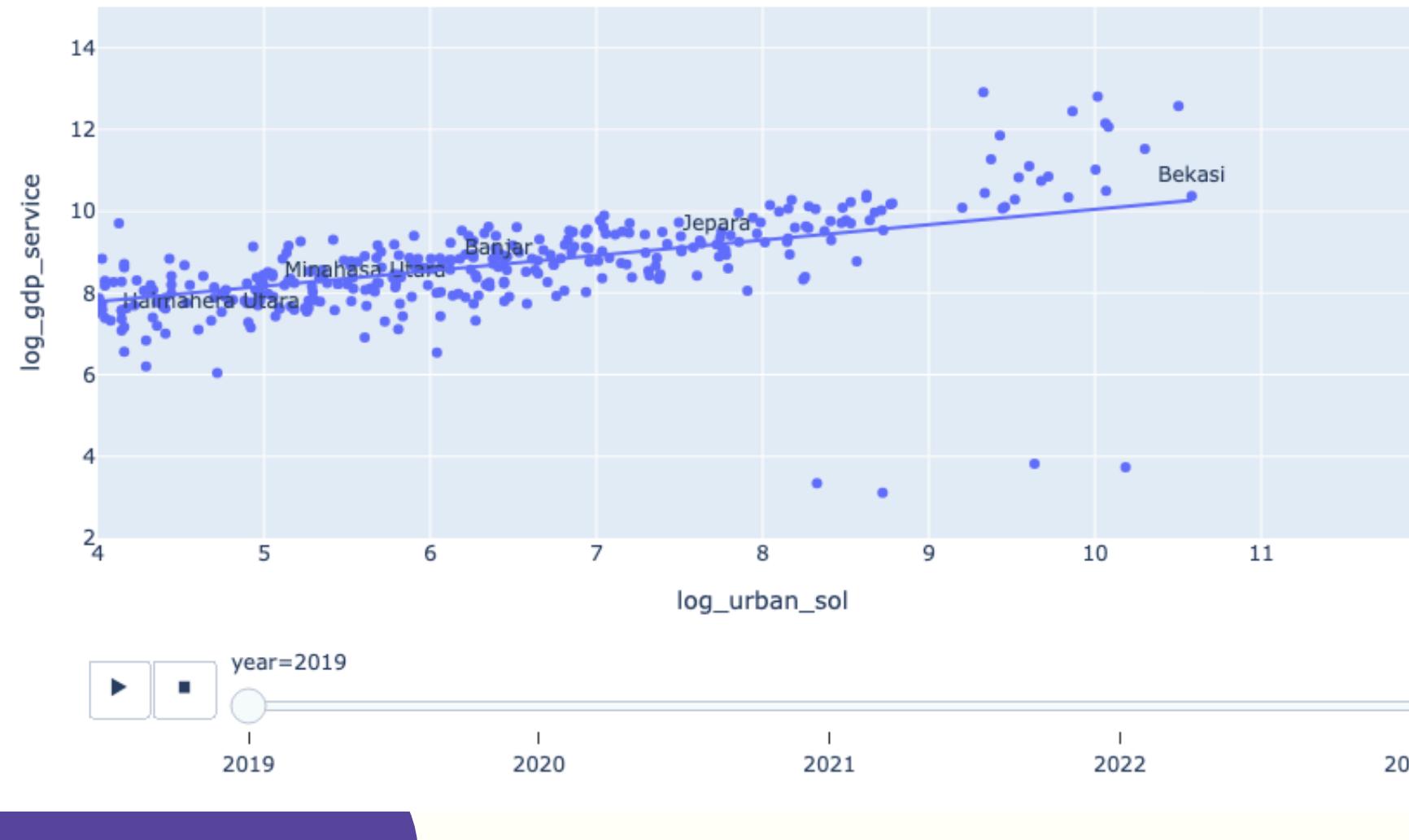
(b) Scatter Plot GRDP Agriculture-Rural NTL



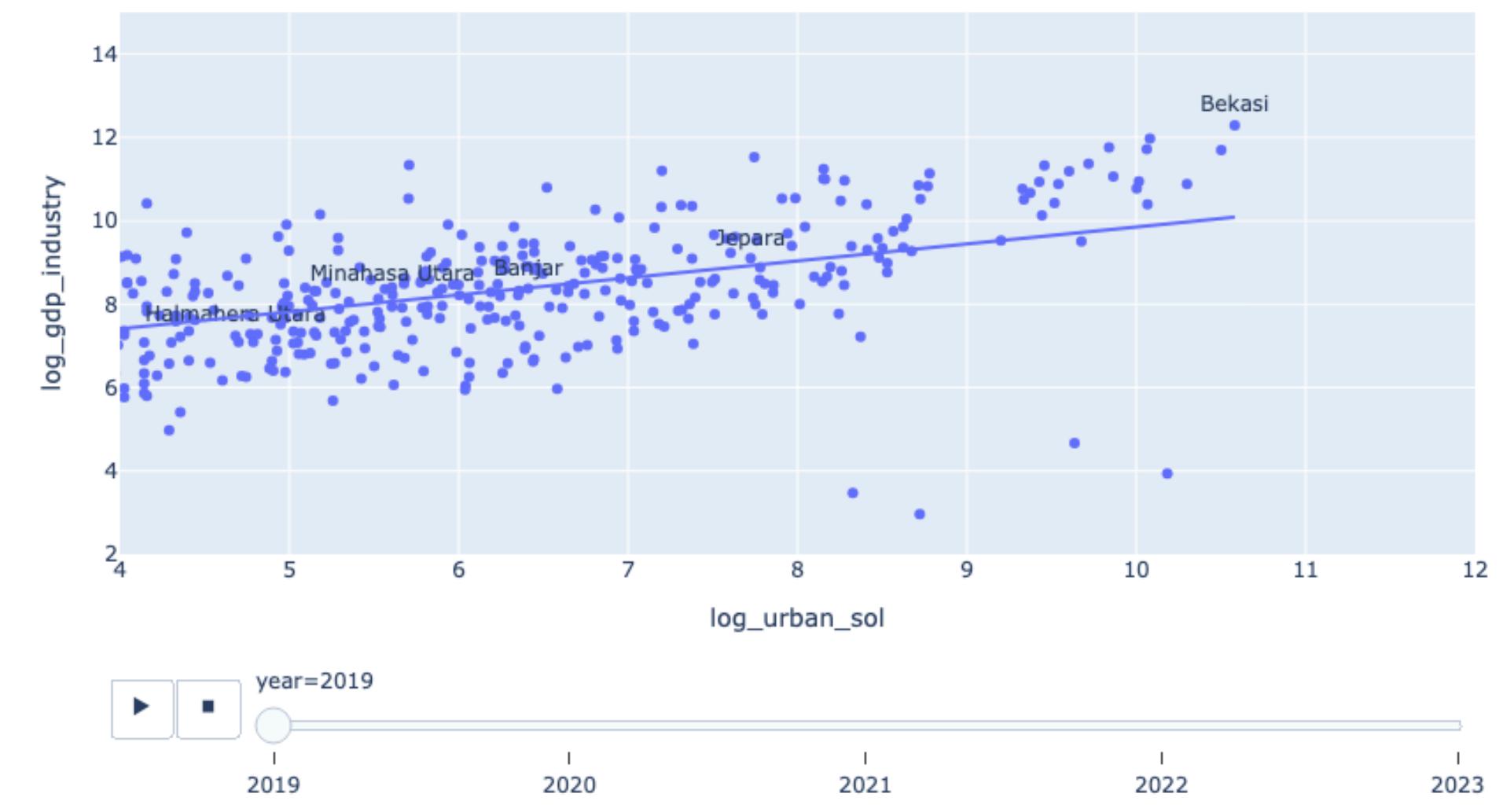
4. Predicting GRDP with Night-time lights

Plot Total GRDP-NTL Relationship with OLS Estimator

(c) Scatter Plot Total GRDP Service -Urban NTL



(d) Scatter Plot GRDP Industry - Urban NTL



4. Predicting GRDP with Night-time lights

Table 1. Within-estimator approach: Fixed Effect Regression between regional luminosity (NTL) and sectoral economy (GRDP)

| Variable | Total GRDP (log) | | | Industry GRDP (log) | | | Service GRDP (log) | | | Agriculture GRDP (log) | | | |
|---------------------------|---------------------|---------------------|---------------------|-------------------------------|---------------------|---------------------|-------------------------------|-------------------------------|-------------------------------|------------------------|---------------------|---------------------|--|
| Sum of NTL (log) | -0.008 (0.033) | | | -0.014 (0.024) | | | 0.007 (0.022) | | | 0.028 (0.036) | | | |
| Sum of NTL in urban (log) | | -0.119 (0.294) | | 0.002 (0.135) | | | -0.024 (0.127) | | | -0.67 (0.287) | | | |
| Sum of NTL in rural (log) | | | 0.058 (0.079) | | 0.012 (0.041) | | | 0.022 (0.041) | | | 0.100 (0.079) | | |
| Log Population | -0.052 (0.181) | -0.022 (0.185) | -0.056 (0.181) | 0.459 [*] (0.237) | | 0.464*** (0.237) | 0.40 ^{9*} (0.235) | 0.412 [*] (0.236) | 0.404 [*] (0.234) | 0.078 (0.238) | 0.084 (0.239) | 0.057 (0.235) | |
| Log Cropland | 0.051*** (0.014) | 0.051*** (0.014) | 0.049*** (0.014) | 0.038** (0.016) | 0.464*** (0.237) | 0.464*** (0.237) | 0.043** (0.017) | 0.044** (0.017) | 0.043** (0.017) | 0.053*** (0.015) | 0.054*** (0.014) | 0.052*** (0.014) | |
| Log pmtb | -0.042 (0.036) | 0.141 (0.105) | 0.138 (0.105) | 0.068 (0.119) | 0.037** (0.016) | 0.069 (0.119) | 0.056 (0.122) | 0.057 (0.123) | 0.056 (0.122) | 0.069 (0.119) | 0.068 (0.129) | 0.159 (0.109) | |
| Log Net Export | 0.062 (0.109) | 0.096 (0.128) | 0.029 (0.116) | 0.084 (0.093) | 0.069 (0.119) | 0.073 (0.095) | 0.101 (0.098) | 0.111 (0.101) | 0.092 (0.099) | 0.159 (0.109) | 0.159 (0.109) | -0.006 (0.118) | |
| Constant | 6.259*** (1.433) | 6.543*** (1.784) | 5.865*** (1.433) | 4.553*** (1.695) | 4.401** (1.755) | 4.339** (1.685) | 5.050*** (1.678) | 5.196*** (1.739) | 5.005*** (1.682) | 5.355*** (1.679) | 5.849*** (1.997) | 5.102*** (1.674) | |
| Observations | 2570 | 2570 | 2570 | 2570 | 2570 | 2570 | 2570 | 2570 | 2570 | 2570 | 2570 | 2570 | |
| Number of spatial unit | 514 | 514 | 514 | 514 | 514 | 514 | 514 | 514 | 514 | 514 | 514 | 514 | |
| Regional fixed-effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | |
| Year fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | |
| R ² | 85.36 | 90.00 | 85.37 | 90.00 | 90.00 | 90.00 | 84.88 | 84.88 | 84.88 | 86.52 | 86.52 | 86.54 | |

Note : pmtb stands for Fixed Capital Gross Formation.

Robust standard errors in parentheses ***p < 0.01; **p < 0.05; *p < 0.1

- After controlling for district and year fixed effects, all coefficients become non-significant.
- This result indicates that VIIRS-like NTL data (urban, rural, and total) is better suited for capturing snapshots of economic activity at specific times, rather than reflecting short-term changes influenced by factors such as economic policies, natural disasters, and other external events (Gibson et al. 2021).
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Preliminary Findings

Table 2. Between-estimator approach: Fixed Effect Regression between regional luminosity (NTL) and sectoral economy (GRDP)

| Variable | Total GDP (log) | | | Industry GDP (log) | | | Service GDP (log) | | | Agriculture GDP (log) | | | |
|---------------------------|---------------------|----------------------|---------------------|----------------------|---------------------|---------------------|---------------------|----------------------|----------------------|-----------------------|---------------------|---------------------|--|
| Sum of NTL (log) | 0.229*** (0.070) | | | 0.339*** (0.062) | | | -0.093* (0.050) | | | 0.432*** (0.073) | | | |
| Sum of NTL in urban (log) | | -0.252*** (0.032) | | 0.196*** (0.030) | | | 0.200*** (0.022) | | | -0.219*** (0.036) | | | |
| Sum of NTL in rural (log) | | | 0.120** (0.051) | | 0.431*** (0.039) | | | -0.262*** (0.035) | | | 0.241*** (0.054) | | |
| Log Population | -0.481* (0.259) | 0.829*** (0.268) | -0.256* (0.246) | 1.379*** (0.228) | 1.003*** (0.244) | 1.805*** (0.222) | 1.788*** (0.186) | 0.857*** (0.189) | 1.807*** (0.168) | -0.932*** (0.272) | 0.502* (0.294) | -0.515** (0.261) | |
| Log Cropland | 0.490*** (0.050) | 0.506*** (0.048) | 0.410*** (0.060) | 0.074* (0.044) | 0.060 (0.044) | 0.077 (0.054) | 0.085** (0.036) | 0.073** (0.034) | 0.258*** (0.041) | 0.493*** (0.053) | 0.506*** (0.053) | 0.334*** (0.064) | |
| Log pmrb | -0.047 (0.075) | 0.060 (0.071) | 0.001 (0.075) | 0.337*** (0.066) | 0.332*** (0.065) | 0.388*** (0.068) | 0.272*** (0.054) | 0.201*** (0.050) | 0.230 (0.051) | -0.004 (0.079) | 0.124 (0.078) | 0.088 (0.079) | |
| Log Net Export | 0.459 (1.596) | -0.320 (1.524) | -0.131 (1.607) | -2.547* (1.408) | -2.532* (1.389) | -2.919** (1.452) | -0.922 (1.150) | -0.405 (1.076) | 0.459 (1.596) | 0.426 (1.679) | -0.519 (1.674) | -0.727 (1.706) | |
| Constant | 3.914** (1.602) | -0.390 (1.641) | 4.635*** (1.614) | -3.746*** (1.413) | 0.411*** (1.496) | -3.242** (1.458) | -2.723** (1.154) | 0.842** (1.158) | -3.669*** (1.101) | 4.625*** (1.686) | 1.231** (1.802) | 6.030*** (1.713) | |
| Observations | 2570 | 2570 | 2570 | 2570 | 2570 | 2570 | 2570 | 2570 | 2570 | 2570 | 2570 | 2570 | |
| Number of spatial unit | 514 | 514 | 514 | 514 | 514 | 514 | 514 | 514 | 514 | 514 | 514 | 514 | |
| R ² | 29.87 | 35.97 | 29.17 | 47.18 | 48.51 | 44.04 | 49.41 | 55.74 | 54.24 | 28.86 | 29.29 | 26.90 | |

Note : pmrb stands for Fixed Capital Gross Formation.

Robust standard errors in parentheses ***p < 0.01; **p < 0.05; *p < 0.1

Table 3. LSDV-estimator approach: Fixed Effect Regression between regional luminosity (NTL) and sectoral economy (GRDP)

Preliminary Findings

- The R-squared values for all dependent variables are the highest than those obtained using within and between-estimator regression. The R-squared values for industry sector achieved 90 % , while for service, agriculture, and total GDP reached over 85 %
- The LSDV regression model also shows positive and significant coefficients for both urban and rural NTL predictors, although this significance does not hold for the overall model.
- Combining NTL with other socio-economic variables (reflecting agriculture productivity, trade openness, and physical and capital investment) could help capturing more comprehensive understanding.

| Variable | Total GDP (log) | | | Industry GDP (log) | | | Service GDP (log) | | | Agriculture GDP (log) | | |
|---------------------------|----------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|-----------------------|---------------------|---------------------|
| Sum of NTL (log) | -0.008 (0.025) | | | -0.014 (0.020) | | | 0.007 (0.022) | | | 0.028 (0.025) | | |
| Sum of NTL in urban (log) | | -0.119 (0.074) | | | 0.002** (0.061) | | | -0.024 (0.064) | | | -0.067 (0.074) | |
| Sum of NTL in rural (log) | | | 0.058 (0.049) | | | 0.013 (0.040) | | | 0.022 (0.042) | | | 0.101** (0.049) |
| Log Population | -0.052 (0.259) | -0.022 (0.341) | -0.056* (0.340) | 0.459* (0.278) | 0.464* (0.278) | 0.463* (0.278) | 0.409 (0.294) | 0.413 (0.295) | 0.404*** (0.294) | 0.078 (0.339) | 0.084 (0.340) | 0.057 (0.339) |
| Log Cropland | 0.051*** (0.008) | 0.051*** (0.008) | 0.049*** (0.008) | 0.038*** (0.007) | 0.037*** (0.006) | 0.037*** (0.007) | 0.043** (0.007) | 0.044*** (0.007) | 0.043*** (0.007) | 0.053*** (0.008) | 0.055*** (0.008) | 0.052** (0.008) |
| Log pmhb | 0.136*** (0.046) | 0.14*** (0.046) | 0.138*** (0.046) | 0.068* (0.037) | 0.069* (0.037) | 0.069* (0.037) | 0.056 (0.039) | 0.056 (0.040) | 0.056 (0.040) | 0.159*** (0.045) | 0.159*** (0.046) | 0.159*** (0.045) |
| Log Net Export | 0.062 (0.082) | 0.096 (0.085) | 0.029 (0.086) | 0.084 (0.067) | 0.079 (0.069) | 0.073 (0.070) | 0.101 (0.071) | 0.111 (0.073) | 0.092 (0.074) | 0.039 (0.082) | 0.068 (0.084) | -0.006 (0.086) |
| Constant | 6.5395*** (0.497) | 5.369*** (1.748) | 5.322*** (1.756) | 2.599* (1.440) | 2.469* (1.430) | 2.414* (1.436) | 3.531*** (1.436) | 4.205*** (1.514) | 6.197*** (1.514) | 4.641*** (1.755) | 4.799*** (1.743) | 4.493** (1.749) |
| Observations | 2570 | 2570 | 2570 | 2570 | 2570 | 2570 | 2570 | 2570 | 2570 | 2570 | 2570 | 2570 |
| Number of spatial unit | 514 | 514 | 514 | 514 | 514 | 514 | 514 | 514 | 514 | 514 | 514 | 514 |
| Regional fixed-effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Year fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| R ² | 85.36 | 85.38 | 85.37 | 90.00 | 90.00 | 90.00 | 84.88 | 84.88 | 84.88 | 86.52 | 86.52 | 86.52 |

Note : pmhb stands for Fixed Capital Gross Formation.

Robust standard errors in parentheses ***p < 0.01; **p < 0.05; *p < 0.1

Upcoming Works

- Extending observation period ; 2013- 2024
- Robustness Check : Pre, during, and post Covid-19 outbreak
- Small Area Estimation with NTL in village or sub-district level



Thank You

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