NIGHTLIGHT DATA AS A PROXY FOR ECONOMIC ACTIVITY: A QUANTITATIVE ANALYSIS OF INDIA

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ABSTRACT

Gross Domestic Product (GDP) is the standard measure of economic activity; however, data collection challenges continue to exist particularly in low-income and developing regions. Satellite-based nightlight data has become a useful substitute for evaluating economic performance in recent years, providing an independent, real-time, and geographically consistent indicator of economic growth. This study assessed the efficacy of nightlight intensity as an indicator of economic activity in Indian states, particularly in Tamil Nadu. This study incorporated econometric models to examine the association between nightlight intensity and economic development using nightlight data from the VIIRS Night Lights dataset (SHRUG 2.0 – Pakora) and GSDP data from the Reserve Bank of India's Handbook of Statistics on Indian States (2023-24). With an R^2 value of 0.967, the Ordinary Least Squares (OLS) regression model for Tamil Nadu (2017–2023) shows a significant connection, suggesting that nightlight intensity explains 96.7% of the variance in GSDP. Regression analysis for 2022 across Indian states produces a R^2 value of 0.7738, so reinforcing the reliability of nightlight data in representing economic activity. Nightlight data has drawbacks despite its benefits, especially when it comes to recording activity in the unorganized sector, rural areas with low levels of power, and advancements in energy efficiency. Nevertheless, nightlight data continues to serve as an effective tool in augmenting conventional economic indicators, offering significant insights for policymakers and researchers.

Keywords: Night Lights, GSDP, VIIRS, Satellite data, SHRUG

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I. INTRODUCTION

Gross Domestic Product (GDP) is the standard measure of economic performance, yet data collection challenges persist in many regions, particularly in low-income and developing countries **(Henderson et al., 2012).** Real-time economic analysis is frequently restricted by the reliance on official statistics, which is a result of inconsistent reporting, delays, and discrepancies in data collection methodologies **(Chen & Nordhaus, 2011).** Nevertheless, the quality and reliability of official economic statistics can be inconsistent in the majority of developing economies, such as India, as a result of infrastructural issues, bureaucratic inefficiencies, and report delays. In order to overcome these obstacles, researchers have implemented alternative indicators, including nightlight intensity, to estimate economic activity.

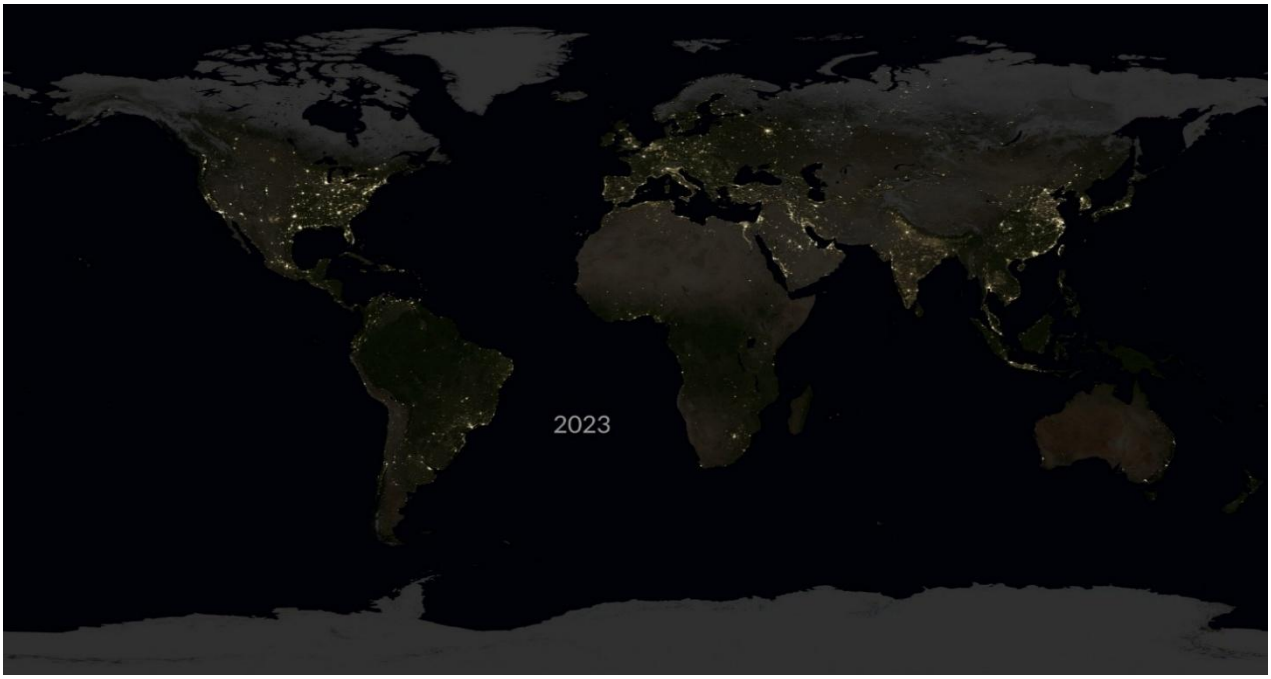

Fig 1: Global Night lights Image (2023) | Source: NASA Scientific Visualization Studio

Electrical consumption is intricately associated with economic activity, which is subsequently reflected in the intensity of nighttime lighting. A consistent and real-time measure of human activity and development is provided by satellite-based nightlight data, particularly from the Visible Infrared Imaging Radiometer Suite (VIIRS) and the Defence Meteorological Satellite Program (DMSP) **(Ghosh et al., 2010).** These data sources have been effectively employed to monitor regional inequalities, estimate GDP, and evaluate the economic consequences of crises **(Storeygard, 2016).** In regions where official statistics are limited or unreliable, research has

shown a robust correlation between economic growth and nightlight intensity **(Elvidge et al., 1997)**.

In economic research and policymaking, the utilization of night light data as a proxy for economic activity has garnered substantial recognition. This method employs satellite imagery to evaluate infrastructure growth, urbanization, and economic development by capturing artificial nocturnal illumination. The visible indicator of economic productivity and human activity is the emission of nighttime lights from residential, commercial, and industrial areas. This approach is particularly advantageous in regions where conventional economic data is either unavailable, incomplete, or unreliable, rendering it an effective instrument for economic analysis.

India is an ideal location for the investigation of the relationship between GSDP and nightlight intensity. Analyzing the intensity of nightlight across various states and districts can offer valuable insights into economic trends, given the country's significant regional economic disparities, disparities in industrialization, and unequal infrastructural development. Also, nightlight data is a critical instrument for economic planners, researchers, and policymakers, as it can function as a near-real-time indicator of economic fluctuations, despite the latency in official GDP reporting at the sub-national level.

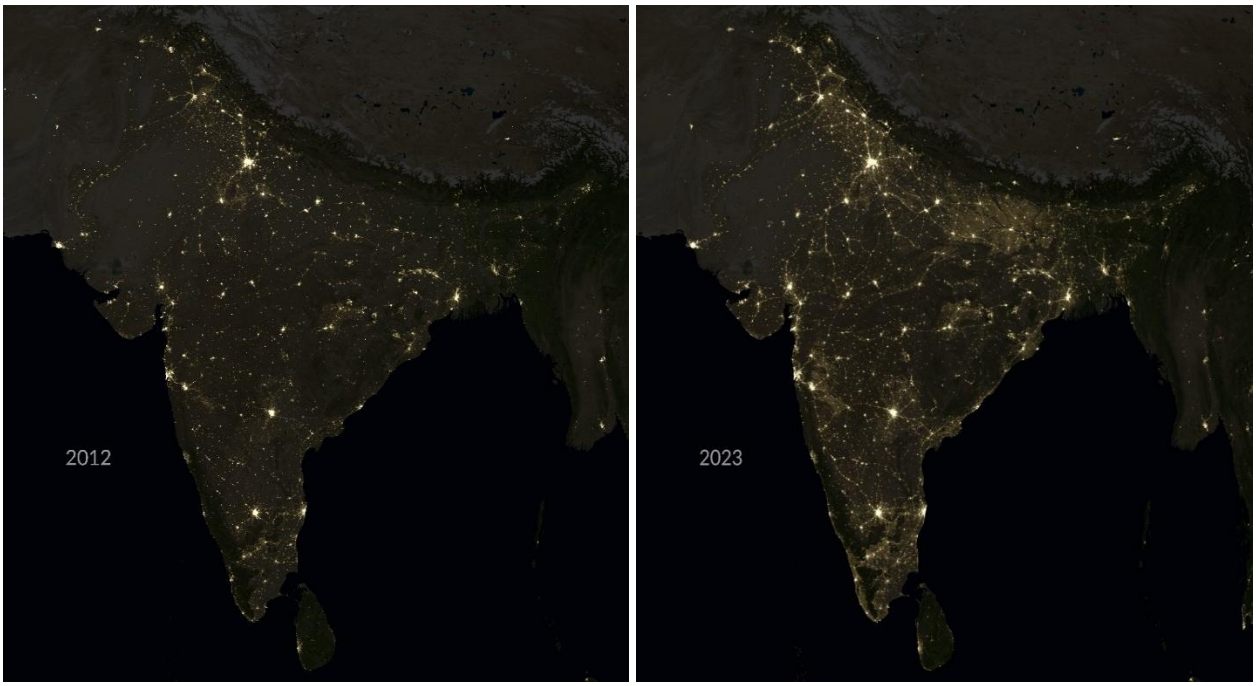

Fig 2: Night Lights Data in India (2012 vs. 2023) | Source: NASA Scientific Visualization Studio

Night Light analysis is essential for comprehending economic disparities, as it identifies areas of underdevelopment and directs targeted policy interventions for poverty alleviation and infrastructure investment. It also assists in the examination of the nighttime economy by identifying industries that operate after the sunset, including transportation, tourism, and entertainment. Night light data facilitates strategic decision-making in resource allocation and sustainable urban development by monitoring economic resilience and mapping infrastructure expansion.

In general, night light data improve economic assessments by offering reliable, spatially detailed, and timely insights into economic dynamics. It is an indispensable instrument for governments, researchers, and policymakers to formulate effective development strategies and assess policy outcomes due to its capacity to augment conventional economic metrics. Consequently, this paper examines the degree to which GDP can be accurately estimated across various regions based on nightlight intensity.

1.1. Objectives of the Study

The primary objective of the study is to evaluate nightlight data as a proxy for measuring economic activity. The secondary objectives of the study are as follows.

- To analyze the correlation between nightlight intensity and Gross State Domestic Product (GSDP) across Indian states for the year 2022.
- To assess the relationship between nightlight intensity and GSDP growth of Tamil Nadu from 2017 to 2023.
- To examine the relationship between the growth rate of GSDP and nightlight intensity across Indian states for the year 2020 and 2021.

1.2. Research Methodology of the Study

This study utilized a quantitative approach to examine the relationship between Gross State Domestic Product (GSDP) growth and nightlight intensity across Indian states. Nightlight intensity data for the period 2012–2021 has been sourced from the Visible Infrared Imaging Radiometer Suite (VIIRS) Night Lights dataset, provided by the Development Data Lab (SHRUG 2.0 – Pakora). GSDP data has been collected from the Reserve Bank of India's Handbook of Statistics

on Indian States (2023-24). The nightlight intensity has been adjusted by removing externalities such as atmospheric conditions, pollution, and seasonal variations, ensuring a more accurate representation of economic activity. The data has been processed and analyzed using MS Excel and Python, employing various econometric and statistical tools. Scatter plots have been used to visualize the correlation between GSDP growth and nightlight intensity. Ordinary Least Squares (OLS) regression models and statistical regressions in MS Excel have been applied to assess the strength and direction of this relationship.

1.3. Hypothesis of the Study

H_1: There is a significant positive relationship between night lights intensity and Tamil Nadu's GSDP for the period 2017 to 2023.

H_2: There is a significant positive relationship between night light intensity and state-wise GSDP across different states in India for the year 2022.

II. REVIEW OF LITERATURE

Mathen et al. (2024) examined how night light records represented India's economic activity and geographical inequalities. The study examined whether VIIRS-based nighttime lights better predict subdistrict-level economic activity than DMSP-OLS data. The study used statistical and economic methods to compare the two datasets and confirm its findings against SHRUG subdistrict-level per capita consumption spending. DMSP-OLS has measurement errors owing to top coding and blurring, hence VIIRS data is more accurate. VIIRS-based evening lights correlated well with economic activity, suggesting their greater application for economic monitoring and policy planning. The research showed that VIIRS data should be used for policy analysis in India to better understand spatial economic patterns and regional inequalities.

Dasgupta (2022) estimated COVID-19's economic effect in India using VIIRS satellite Night Time Light (NTL) data. NASA's Black Marble radiance dataset (VNP46A1) and panel regression and machine learning models were used to create a data processing system. For better prediction, electricity use and precipitation data are added. The model predicted a 24% year-over-year GDP decrease in Q1 FY2020, matching the Indian government's 23.9% decline. Nightlight intensity, power use, and economic output were strongly correlated, making NTL a useful proxy

for real-time economic evaluations, especially in data-deficient locations. The study showed the limits of conventional economic indicators and NTL's short-term economic monitoring potential.

Musthyala et al., (2022) introduced ReGNL, a neural network-based model for rapid GDP prediction using nighttime lights (NTL) during disruptive events like COVID-19. VIIRS-DNB satellite data, geographical coordinates, and machine learning were used to enhance GDP calculation. The model was trained to forecast GDP in normal and crisis situations using data from 50 U.S. states (2014–2020). ReGNL has a smaller weighted error than ARIMA time-series models (0.69 vs. 1.94 in Q2 2020). NTL, latitude, and longitude improve GDP projections, making them resilient to economic shocks. The study stressed the need of granular data for real-time policy choices in data-poor places.

Price and Atkinson (2022) used VIIRS data and transfer learning to improve GDP forecast. The researchers created a data-driven regionalisation approach to address rural under-representation in night-light-based GDP calculation. The study examined 178 nations with 178,000 photos using a Convolutional Neural Network (CNN) trained on fine-resolution daylight satellite imagery and Monte Carlo significance sampling. The model achieved a R^2 of 0.86 (validation) and 0.89 (whole study area), exceeding conventional techniques. For detailed economic regionalisation, the study demonstrated that satellite-based GDP estimates might be utilised for real-time economic monitoring, particularly in areas with limited data.

RESULTS AND DISCUSSION

3.1. Ordinary Least Squares (OLS) regression model: Analyzing the Relationship Between Tamil Nadu's GSDP and Night Lights Intensity (2017–2023)

Null Hypothesis (H_0): There is no significant relationship between night lights intensity and Tamil Nadu's GSDP.

Alternative Hypothesis (H_1): There is a significant positive relationship between night lights intensity and Tamil Nadu's GSDP.

Table 1: OLS Regression Table|

OLS Regression Results

Dep. Variable:	GSDP	R-squared:	0.967
Model:	OLS	Adj. R-squared:	0.960
Method:	Least Squares	F-statistic:	146.4
Date:	Tue, 25 Feb 2025	Prob (F-statistic):	6.81e-05
Time:	03:57:31	Log-Likelihood:	-113.33
No. Observations:	7	AIC:	230.7
Df Residuals:	5	BIC:	230.5
Df Model:	1		
Covariance Type:	nonrobust		

	coef	std err	t	P>|t|	[0.025	0.975]
const	4.478e+07	7.24e+06	6.188	0.002	2.62e+07	6.34e+07
Night_Lights	60.2937	4.983	12.099	0.000	47.484	73.104

Omnibus:	nan	Durbin-Watson:	2.401
Prob(Omnibus):	nan	Jarque-Bera (JB):	0.509
Skew:	-0.313	Prob(JB):	0.775
Kurtosis:	1.837	Cond. No.	9.04e+06

Source: Analyzed using Secondary data

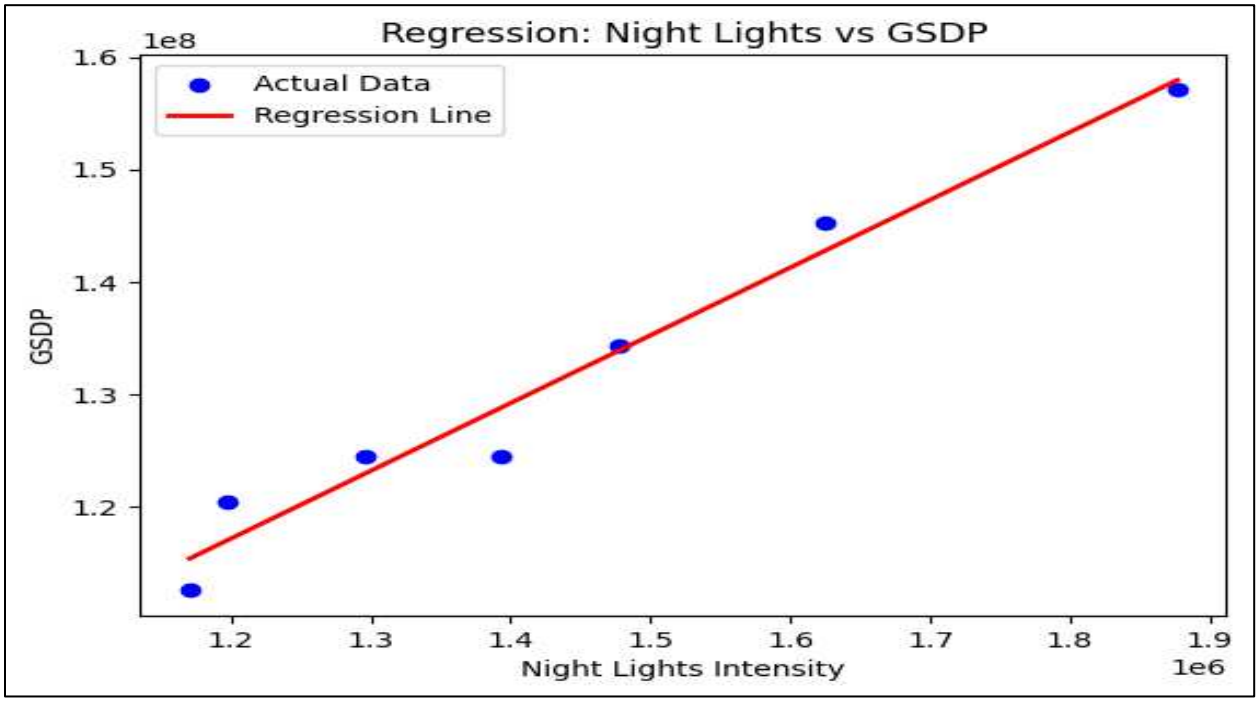

Fig 3: Regression Line | Source: Computed using Secondary data

This study estimates the relationship between Tamil Nadu's Gross State Domestic Product (GSDP) and night lights intensity using an Ordinary Least Squares (OLS) regression model. The econometric equation derived from the regression is:

GSDP = 44,780,000 + 60.29 X Night Lights

where:

- GSDP represents the predicted Gross State Domestic Product of Tamil Nadu (in INR million).
- Night Lights represents the intensity of night-time luminosity, serving as a proxy for economic activity.
- 44,780,000 is the intercept, indicating the estimated GSDP when night lights intensity is zero.
- 60.29 is the coefficient of night lights intensity, suggesting that for every additional unit increase in night-time luminosity, the GSDP increases by ₹60.29 million.

The regression model shows a strong explanatory power, with an R-squared value of 0.967, indicating that night lights intensity accounts for 96.7% of the variation in GSDP. The adjusted R-squared of 0.960 confirms the robustness of the model. The F-statistic of 146.4 ($p < 0.01$) suggests that the model is highly significant, enhancing the relevance of night-time luminosity as a proxy for economic activity. The coefficient of night lights intensity is highly significant ($p < 0.01$) from a statistical perspective, confirming a strong positive association between economic growth and increased urban and industrial illumination.

The Durbin-Watson statistic of 2.401 suggests that there are no significant autocorrelation issue, and the Jarque-Bera test p-value of 0.775 suggests that the residuals follow a normal distribution, giving the model reliable for interpretation. The scatter plot (Fig 4) illustrates the relationship between Night Lights Intensity and GSDP for Tamil Nadu from 2017 to 2023. The regression line (in red) shows a strong positive correlation, indicating that as night lights intensity increases, GSDP also rises. The results substantiate the utilization of satellite-based night light data as a real-time indicator of economic expansion. In regions where official GSDP data is inadequate or unavailable, luminosity data can be a valuable proxy for monitoring economic

activity. Thus, Tamil Nadu's economic growth is closely associated with night-time luminosity, underscoring its significance as an alternative indicator of economic performance.

2.2. Regression Model Showing the Relationship Between Night Lights Intensity and State-wise GSDP in India (2022)

Null Hypothesis (H_0): There is no significant relationship between night light intensity and state-wise GSDP.

Alternative Hypothesis (H_1): There is a significant positive relationship between night light intensity and state-wise GSDP.

Table 2: Regression Table – Night Lights Intensity and State-wise GSDP in India (2022)

Statistic	**Value**	**Statistic**	**Value**
R Square	0.7738	Intercept (Constant)	5844147.46
Adjusted R Square	0.766	Slope (Night Lights Intensity)	49.91
F-statistic	99.21	P-value (Intercept)	0.3941
Significance F	7.22×10^{-11}	P-value (Night Lights Intensity)	7.22×10^{-11}
Standard Error	28388794.42		

Source: Analyzed using secondary data

The regression analysis examines the relationship between state-wise GSDP and night lights intensity for the year 2022. The R^2 value of 0.7738 indicates that approximately 77.38% of the variation in GSDP across states can be explained by night lights intensity, demonstrating a strong association between these variables. The F-statistic of 99.21, with a significance level of **$p < 0.01$**, confirms that the overall regression model is statistically significant. The coefficient for night lights intensity is 49.91, and its corresponding p-value (**$p < 0.01$**) suggests a strong positive relationship, meaning that an increase in night lights intensity is significantly associated with higher GSDP levels. However, the intercept has a p-value of 0.3941, indicating that the base level of GSDP, independent of night lights intensity, is not statistically significant. The standard error of 28,388,794.42 reflects the variability in the model's predictions. Overall, the results suggest that

night lights intensity serves as a reliable proxy for economic activity, reinforcing its validity as an indicator of regional economic performance.

2.3. Comparison of Economic Growth and Nightlight Intensity: State-Wise Trends in India

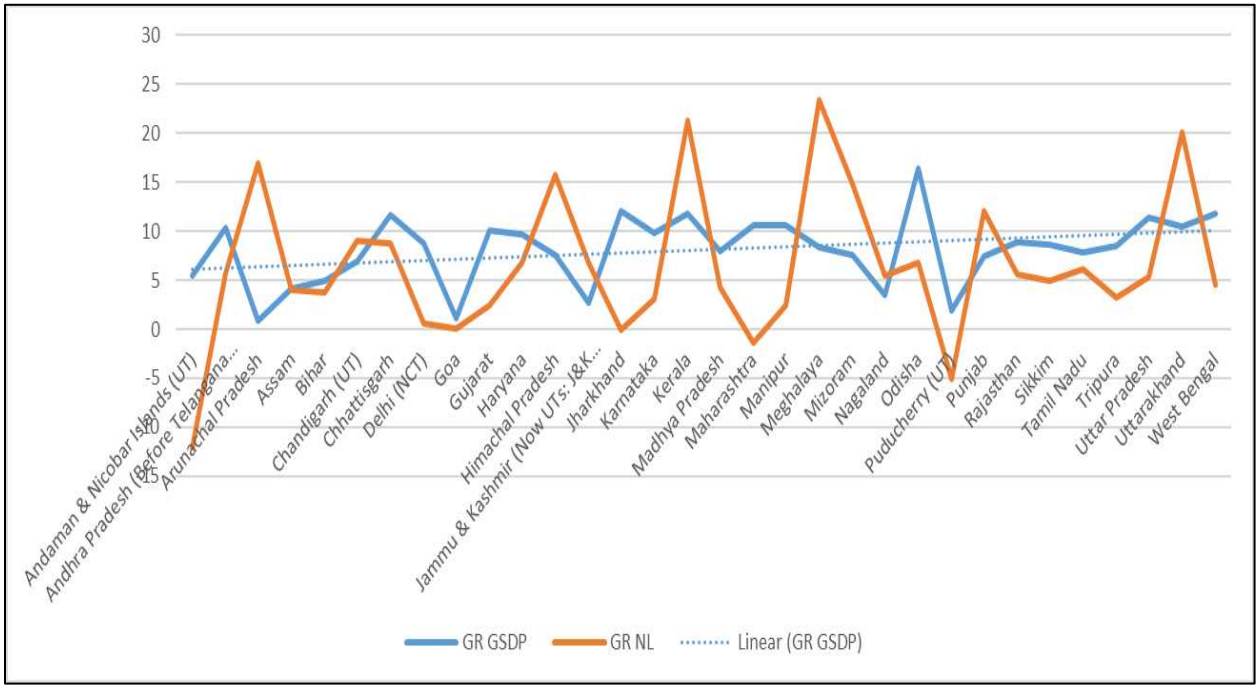

Fig 5: Line Chart showing state-wise trends in Economic Growth and Nightlight Intensity in India| Source: Computed using secondary data

The Growth Rate of Gross State Domestic Product (GSDP) and Growth Rate of Nightlight Intensity are compared in the line chart across different Indian states and union territories. The blue line denotes the GSDP growth, which is comparatively consistent across the majority of states. The orange line denotes the nightlight growth, which exhibits substantial volatility. The dotted linear trend line is included to denote the general direction of GSDP growth. A significant conclusion from the chart is that the proliferation of nightlights is highly irregular in different states.

Rapid urbanization, infrastructure expansion, or increased electrification may be indicated by abrupt surges in nightlight intensity in certain states, including Arunachal Pradesh, Madhya Pradesh, and West Bengal. Conversely, states such as Odisha, Punjab, and Jharkhand exhibit low

or negative nightlight growth, which may be attributed to economic factors that do not have a significant impact on nighttime luminosity or delayed urban development.

III. CONCLUSION

Nightlight data is increasingly used as a proxy for economic activity in economic research and policy analysis. In areas where economic data is few or delayed, satellite-based nightlight intensity provides a reliable, consistent, and real-time economic development indicator. Nightlight data provides an additional economic indicator by reflecting urbanisation, infrastructural expansion, and electrification trends across states and regions. The findings of this study highlight the positive relationship between nightlight intensity and economic performance, as measured by Gross State Domestic Product (GSDP). Higher nightlight increase may be linked to superior economic performance due to urban development, industrial activity, and electrification. Variations in nightlight increase among states show the difficulties of utilising one indicator alone for economic assessment. Despite its advantages, nightlight data has limitations. Agriculture and informal labour markets are often under-represented, and rural places with little power may look economically undeveloped while being productive. Seasonal changes and energy efficiency improvements can also affect nightlight intensity. Nightlight data is a strong analytical tool, but it should be utilised with standard economic indicators to better understand economic dynamics.

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