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Analyzing Economic Spatial Patterns of the Metro Manila Urban Agglomeration using Nighttime Light Data

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Abstract

The Philippines' largest urban agglomeration, Metro Manila, exhibits a concentration of economic activity in densely integrated regions. Although central cities benefit from optimal accessibility and agglomeration economies, this is at the expense of peripheral cities, causing regional economic disparities. This study examined Metro Manila's spatial economic patterns from 2015 to 2020. To capture economic heterogeneity, this study used nighttime light point data from 2015 to 2020 as a proxy for economic development, capturing granular patterns across the region. Spatial network weights were employed to define the neighborhood of the features, capturing economic interactions beyond geographical proximity. Global Moran's I indicated significant spatial clustering, with a gradual decline, suggesting signs of regional convergence. Cluster-outlier analysis revealed persistent core-periphery patterns, with central cities like Manila, Makati, and Quezon City exhibiting concentrated development, while peripheral cities like Valenzuela and North Caloocan lag due to congestion, poor infrastructure, and inadequate business facilities. Notably, Alabang in the Metro South emerged as an economic hotspot, outside the traditional urban cores. High-low outliers detected in Valenzuela highlight uneven intra-city development, while the detection of Forbes Park as a cold spot demonstrates nighttime light's limitation in measuring economic development. Directional analysis identified Mandaluyong as the economic center, reflecting its rapid growth during the period. The analysis showed economic activity following a North-South orientation, aligning with the region's geographical structure, with gradual expansion over time, supporting economic diffusion. Overall, the findings highlight the capability of nighttime light in formulating targeted policies for balanced regional development.

1. Introduction

Fang and Yu (2017) defined urban agglomerations as spatially dense and economically linked clusters of cities, interacting via shared infrastructure and market networks, featuring a core and periphery region. This results in the concentration of capital, resources, and people in a few interconnected regions, shaping the core-periphery structure of urban agglomerations.

Although urban agglomerations provide advantages like specialization and resource sharing due to proximity, this results in the concentration of resources in a few areas, usually central cities, causing uneven development. This follows the core-periphery model, where cities near economic cores experience rapid growth at the expense of peripheries. (Krugman, 1991).

As the global urban population is expected to increase from 55% to 68% by 2050, the world is experiencing a significant shift towards urbanization (United Nations, n.d.). Moreover, urban centers account for more than 80% of the global GDP (United Nations, 2023). While urban centers drive regional growth, this results in regional disparities. Hence, it is necessary to ensure sustainable and equitable development in the region.

Metro Manila, despite the opportunities like employment, industry clusters, and economic activity, has experienced significant challenges. As the region's population density rises to more than 20,000 persons per square kilometer, it has brought pressure on infrastructure and sustainable housing (Obanan, 2021). The existence of economically developed cities like Makati and Manila, and underdeveloped cities experiencing issues with traffic congestion, poor business infrastructure, and informal settlements, potentially reflects the core-periphery pattern of urban agglomerations. These disparities necessitate the systematic monitoring and determination of lagging regions to ensure sustainable, inclusive, and equitable regional development. This is especially crucial for Metro Manila, the Philippines' center for politics and economics. Although it is the country's smallest region, it is the most densely populated area in the country (Diokno-Sicat, 2019), potentially concentrating opportunity and vulnerability.

With 16 cities and 1 municipality, it is the country's largest urban agglomeration, accounting for more than a third of the country's total GDP (Rith et al., 2020). Cities like Makati, Taguig, Manila, and Quezon City have key economic roles, driving regional growth. However, these key cities coexist with lagging cities, resulting in uneven development in the region due to inequitable resource allocation, congestion, and poor infrastructure, highlighting the need for targeted policy interventions and promotion of equitable development. Metro Manila's spatial inequality makes it an ideal case in examining the core-periphery dynamics of urban agglomerations and the spatial distribution of uneven development.

Hence, this study aims to analyze the spatial economic patterns of Metro Manila, not bound by administrative boundaries, recognizing the heterogeneity of economic development due to inequitable access, resource allocation, and business infrastructure within cities. However, the Philippines lacks subnational GDP data. To address this gap, this study uses the nighttime light dataset of Chen et al. (2021) as a proxy for economic development to reveal the spatial patterns and distribution of Metro Manila's economic development, independent of administrative boundaries. Figure 1 shows the administrative boundaries of Metro Manila.

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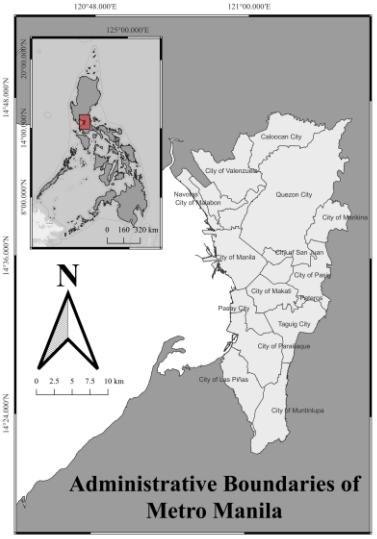

Figure 1. Metro Manila Administrative Boundaries

Metro Manila's spatial economic disparities remain unexamined. To fill the gap, this paper develops a framework to examine economic spatial patterns using granular nighttime light data. This study uses Global Moran's I to examine the overall spatial patterns of economic development. Cluster-Outlier Analysis detects local clusters and outliers to determine areas with concentration of growth and underdevelopment. Directional Analysis identifies the spatial shifts and trends of economic development to assess whether development in Metro Manila became more inclusive during the study period. By revealing the spatial economic disparities, this study aims to guide policymakers in promoting balanced regional development, supporting the Sustainable Development Goals (SDGs), specifically SDG 10 (Reduced Inequalities) and SDG 11 (Sustainable Cities and Communities).

Due to the lack of subnational GDP data in the Philippines, this study assumes nighttime light as an estimate of economic development, without considering other socioeconomic factors. Nighttime light emission is an ideal proxy due to its strong association with economic activity (Mellander et al., 2015). Furthermore, the travel time values used in the spatial network weights were network-derived, without considering traffic parameters. Additionally, this study only considers cities in Metro Manila, excluding interactions outside of the region, from 2015 to 2020.

2. Related Studies

2.1 Nighttime Light Data as Proxy for Economic Development of Urban Agglomerations

In developing countries like the Philippines, obtaining subnational economic data is an issue, potentially neglecting economic variations in a region. Granular economic data is necessary to target priority areas and to allocate resources efficiently and equitably.

Nighttime light data has shown strong evidence in approximating subnational economic data. Several studies, including studies of Tingzon et al. (2019) and Pagaduan (2023) in the Philippines, demonstrated the effectiveness of NTL in capturing economic development. However, the existing studies focus on aggregated NTL data, failing to capture the heterogeneity of economic activity in a region. Hence, this study offers a methodology accounting for heterogeneity by treating NTL as point data, revealing local spatial patterns missed in aggregated data.

2.2 Spatial Network Weights

In spatial analysis, it is crucial to define the neighborhood of features using a spatial weights matrix. In urban agglomeration studies, various spatial weights are used. Studies like those of Jin et al. (2018) implemented a rook contiguity matrix in describing the relationship between economic development and socioeconomic indicators. Meanwhile, Huang et al. (2020) defined a weight matrix based on train frequency data to capture economic interactions comprehensively. However, relying solely on contiguity when examining economic development does not accurately represent the economic interactions. While Huang et al. (2020) offered a comprehensive methodology for capturing economic interactions, a developing country like the Philippines lacks publicly available temporal data on train frequency or travel-related data.

Recent shifts consider network-based weights, like in the study of Song et al. (2024), where they determined that a graph-based spatial weight matrix performed better than a simple contiguity matrix. To capture complex economic interactions beyond contiguity while being independent of travel data availability, this study employed spatial network weights.

3. Materials and Methods

3.1 Datasets

Table 1 summarizes the datasets used in this study. These datasets were used to comprehensively assess the spatial structure, distribution, and trends of economic development in Metro Manila for 2015, 2018, and 2020. NTL served as a proxy for economic activity, providing spatial and temporal detail, while transportation-related datasets captured how people and resources flow via the city's road network.

Dataset	Source
Nighttime Light (NTL)	Chen et al. (2021)
Transportation Network	OpenStreetMap
Maximum speed per road type	RA 4136 and Land Transportation Franchising and Regulatory Board (LTFRB)
Transportation Fare	LTFRB

Table 1. Datasets and Sources

This study used the NTL dataset of Chen et al. (2021), having a spatial resolution of 500 m, to measure localized economic activity. This provides annual data from 2000 to 2023, integrating global nighttime light intensity through cross-sensor calibration of DMSP/OLS and NPP/VIIRS remote sensing images, enabling a long-term, consistent representation of economic activity.

To capture economic flow between cities, this study considered Manila's driving network, as the transportation network facilitated regional interaction. The network consists of trunk, primary, secondary, tertiary, busway, residential, and unclassified road types, capturing Metro Manila's connectivity comprehensively, rather than contiguity and simple proximity.

To quantify connections between cities, the study defines

vehicular speed using the maximum speed assigned per road type to compute travel time. This ensures that not all roads have equal weights since this varies depending on road type. A higher road classification would allow faster travel, leading to a lower travel time. The defined speeds align with Philippine Road Laws and LTFRB regulations.

Aside from travel time, transportation costs also affect economic interactions. Less time and cheaper fares are more optimal than more expensive fares. Therefore, to comprehensively capture the economic interactions in the region, transportation fares were integrated, adopting the methodology of Zhu et al. (2021).

3.2 Methods

The general workflow in assessing the spatiotemporal economic patterns of Metro Manila is shown in Figure 2. The workflow is divided into three main parts: calculation of the Global Moran's I to assess overall spatial clustering of economic activity, detection of local spatial patterns using the Local Moran's I, and the examination of the spatial shifts and trends employing directional analysis. Additionally, this study conceptualizes spatial relationships using spatial network weights to capture complex economic interactions that extend beyond contiguity and proximity.

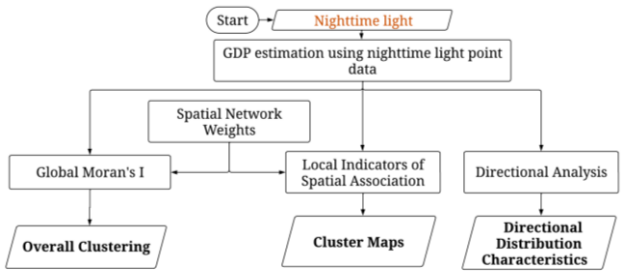

Figure 2. Methodology

3.2.1 Transformation to Nighttime Light Point Data: In this study, nighttime light data for 2015, 2018, and 2020 were transformed into point-based representations to measure local spatial patterns of economic activity, not restricted to city borders. This study considered the heterogeneity within cities and interactions across administrative boundaries. The NTL point values represent the spatial location of the nighttime light intensity associated with economic activity. The dataset was projected to the Universal Transverse Mercator (UTM) Zone 51N coordinate reference system (EPSG:32651) to ensure spatial consistency and accuracy. Additionally, the null values were filtered to ensure reliable results.

3.2.2 Spatial Network Weights Construction: The concept of spatial distance and contiguity has been alienated due to the spatial heterogeneity of network lines, highlighting the inequitable accessibility among cities, crucial in examining urban economic dynamics. Therefore, this study employed spatial network weights to capture complex economic interactions facilitated by the region's transportation network, not captured by contiguity and proximity weights. In this study, the edge weight used was the product of travel time (in seconds) and cost (in PHP), as defined by Zhu et al. (2021). The travel time was derived from the speed limits prescribed by LTFRB per road classification type and did not consider traffic conditions; hence, primary roads would require less travel time compared to secondary roads. Meanwhile, costs were defined using jeepney transportation fares for 2015, 2018, and 2020 published by LTFRB, as a function of distance. As the distance increases, the fare increases as well. The edges used are the minimum product of these two variables, representing the optimal path between points. In calculating the Global Moran's I and performing cluster-outlier analysis, the spatial network weights were used to define the neighborhood of NTL point features representing economic activity via transportation connectivity.

3.2.3 Global Moran's I: The Global Moran's I examines the degree of spatial clustering or dispersion by comparing the difference between the value of a specific feature and the global mean of all features, as well as comparing the values between pairs of neighboring features (Prasannakumar et al., 2011). NTL point data was used to measure the global spatial distribution of economic development, revealing the spatial structure of granular economic activity, capturing a more detailed representation of economic development distribution. Positive and negative Moran's I values indicate clustering and dispersion of NTL values, respectively. Meanwhile, a value of zero implies that the spatial distribution was random.

3.2.4 Cluster-Outlier Analysis: This captured the local spatial distribution of economic development, identifying local hotspots (high-high), cold spots (low-low), and outliers (low-high, high-low), which are vital in determining areas of stagnation, acceleration, or decline. NTL point data allowed for a finer-scale analysis of economic development, highlighting uneven development in cities. This point-based approach identified localized concentrations of economic activity across Metro Manila, revealing the uneven nature of economic development while highlighting emerging clusters and regions at risk of economic underperformance.

3.2.5 Directional Analysis: This examined the shifting spatial direction and extent of Metro Manila's economic development. Using the NTL point values as a proxy for GDP, the region's economic center of gravity over time was analyzed, revealing the concentration of Metro Manila's economic activity. Furthermore, the directional distribution of economic activity was employed to assess whether economic activity expanded, contracted, or remained stable. The major and minor axes were used to describe the primary and secondary directions of economic activity, while the azimuth measured its directionality.

3.2.6 Zonal Statistics: The zonal statistics were calculated to determine the mean values of the High-High, Low-Low, High-Low, and Low-High cluster-outlier zones for 2015, 2018, and 2020. The obtained values were used to measure the difference in economic intensity among the clusters during the period, using pairwise differences and ratios between zones to highlight their economic contrast.

4. Results and Discussion

4.1 Global Spatial Patterns of Economic Activity

Table 2 shows the calculated Global Moran's I during the study period. For 2015, 2018, and 2020, economic development, as estimated by NTL, exhibited strong positive spatial autocorrelation and was relatively stable during the study period. The p-values passed the significance test ($p < 0.1$), suggesting that there is less than a 1% likelihood that the clustering resulted by chance. The findings suggest that similar economic values cluster together, revealing signs of economic agglomeration in Metro Manila along transportation infrastructures. Hence, it can be concluded that functionally linked areas are economically similar, highlighting the importance of transportation networks in facilitating economic interactions and forming economic clusters.

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Despite the strong positive spatial autocorrelation, a gradual decline in the values was observed, indicating economic diffusion over time. The decrease in the Global Moran's I values from 0.648 in 2015 to 0.611 in 2020 implied the weakening of economic agglomeration or spreading to nearby areas. Although the shift may be insignificant, it suggests signs of economic convergence during the study period, where peripheries experienced modest economic growth, reducing regional disparities.

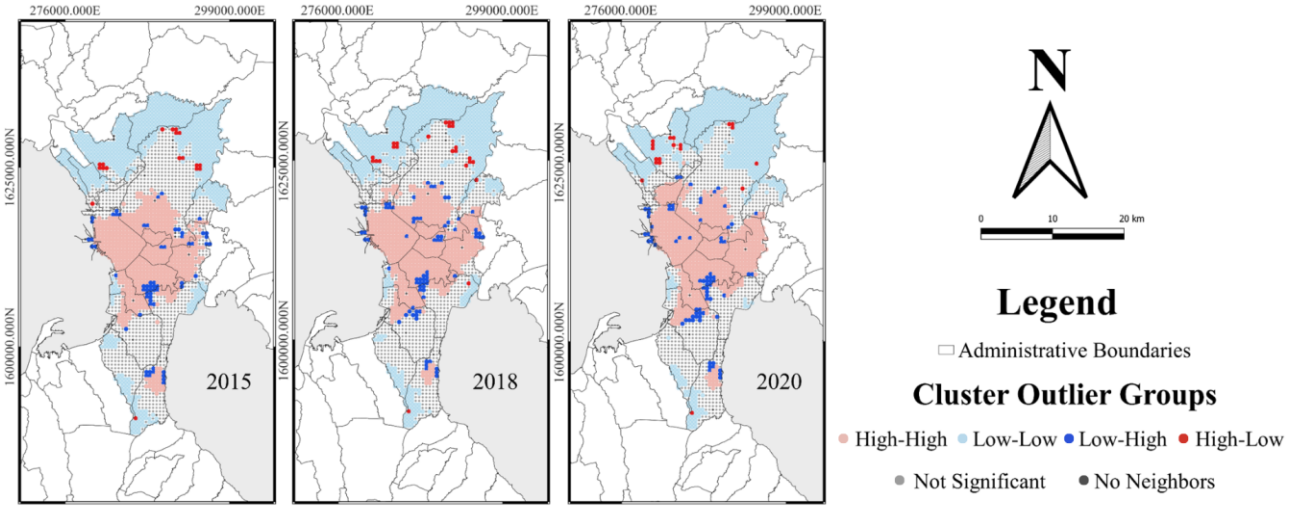

Figure 3. Cluster-Outlier Maps for 2015, 2018, and 2020

Year	Global Moran's I	z-score
2015	0.648*	129.770
2018	0.620*	131.848
2020	0.611*	137.780

** significant at 0.1*

Table 2. Global Moran's I of Economic Development

4.2 Local Clusters and Outliers of Economic Activity

While the Global Moran's I values revealed the degree of overall spatial clustering of economic development, cluster-outlier analysis detected hotspots, cold spots, and outliers of economic development in Metro Manila. As shown in Table 3, hotspots and cold spots increased and decreased, respectively. The area of hotspots expanded from 164 km² in 2015 to 182.75 km² in 2020, while cold spots decreased from 196.00 km² in 2015 to 181.25 km² in 2020, supporting the occurrence of economic diffusion in Metro Manila during the study period. As for the high-low outliers, an increase from 4.5 km² in 2015 to 6 km² in 2018 and a decline to 4.75 km² in 2020 indicate the unstable emergence of high-development areas in low-development zones. In contrast, low-high outliers steadily increased from 15.75 km² in 2015 to 18.75 km² in 2020, suggesting the gradual emergence of underdeveloped areas within high-development zones, signaling the existence of lagging areas unable to benefit from their proximity to economic zones, resulting in disparities in economic clusters.

Year	H-H	L-L	H-L	L-H
2015	164.00	196.00	4.50	15.75
2018	173.75	184.75	6.00	18.75
2020	182.75	181.25	4.75	18.75

Table 3. Cluster and outlier areas per year (in sq. km)

Figure 3 shows the local spatial patterns of Metro Manila's economic development. The local spatial patterns remained consistent over time, while outliers emerged in varying locations, suggesting instability and unsustainable growth. Hotspots of high economic activity were consistently found in central cities, namely, Manila, San Juan, Mandaluyong, Makati, Pasig, Pasay, Pateros, South Caloocan, and parts of Parañaque, Taguig, Muntinlupa, and Quezon City. In contrast, cold spots of low economic activity appeared in the peripheries, including Navotas, Malabon, Valenzuela, Caloocan North, Marikina, Las Piñas, Pasay's edges, Parañaque's edges, Muntinlupa's edges, and Taguig's edges. The findings align with the core-periphery structures of urban agglomerations, where central cities exhibit growth, while peripheries lag.

4.2.1 High-High Clusters: Hotspots were concentrated in central cities. Manila, the country's capital city, showed high economic activity due to its strategic location, locally and internationally. It has a dense population, nearly 13% of Metro Manila's population. It has a diverse economy, encompassing manufacturing, trade, real estate, storage, finance, and professional services. It also houses commercial and trading districts like Binondo and Quiapo, driving its economy and urban core status (Gamboa et al., 2019). Makati also exhibited clustering of high economic activity. It is the region's premier business district, housing Ayala Avenue, which hosts the concentration of corporate headquarters and financial centers due to its advantageous location.

These central hotspots were not isolated. Interconnected economic zones were formed due to spatial spillovers of economic activity, extending to nearby cities like San Juan, Mandaluyong, Pasig, and Quezon City. This was observed in South Caloocan and Pateros, highlighting the effect of proximity to economic zones on a city's economy.

Outside the urban core, Alabang in Muntinlupa emerged as a hotspot in the Metro South. From 2015 to 2020, Alabang experienced several real estate developments due to rising demand, including notable projects like Alabang West and Amaia Steps (The Philippine Star, 2015a, 2015b). Also, it has become a favorable location for business, home to Filinvest City, a premier central business district, attracting local and

international companies such as Shell, HSBC, Convergys, Insular Life, and Deutsche Bank (FILINVEST CITY, 2017). During the study period, it has become a competitive economic zone outside the region's central core.

4.2.2 Low-Low Clusters: Cold spots were mainly located along the peripheries, consistent with the core-periphery structure. Cities like North Caloocan and Valenzuela experienced low economic activity during the study period due to poor infrastructure, unemployment, and inequitable resource allocation. According to the city's Comprehensive Land Use Plan (CLUP), North Caloocan's trade and industry sector struggled economically due to limited support to MSMEs (Micro, Small, and Medium Enterprises), deteriorating infrastructure, and inadequate facilities, resulting in a low competitiveness ranking.

Aside from the city's poor economic activity, severe traffic congestion along major roads such as EDSA, C-3 Road, Congressional Road, and Novaliches-San Jose Road further limited accessibility in North Caloocan. Similarly, South Caloocan experiences the same traffic congestion issues. EDSA in South Caloocan records the highest annual average daily traffic at 106,378 vehicles, while North Caloocan's Congressional Road is at 25,158 vehicles daily (Caloocan Local Government, 2017). Despite both experiencing traffic congestion challenges, South Caloocan is situated near economic zones like Manila and Quezon City, receiving spatial spillover effects. In contrast, North Caloocan is at the periphery, highlighting how inaccessibility due to poor infrastructure and traffic congestion can negatively impact a city's economy.

Valenzuela, adjacent to North Caloocan, also exhibited low development, despite being a key industrial and logistic hub, due to its proximity to Northern Luzon (City of Valenzuela, 2018). However, its strategic location also resulted in its positional disadvantage because of traffic congestion along its major thoroughfares, compounded by narrow and poor road infrastructure. According to its CLUP, these factors make the roads inadequate in accommodating the high vehicular density, limiting economic growth, according to its CLUP (City of Valenzuela, 2018). The findings demonstrate how positional advantage, poor infrastructure, and inequitable resource allocation can be detrimental to a city's economy.

4.2.3 High-Low Clusters: The findings revealed high economic growth areas surrounded by underdeveloped areas. Malinta, Karuhatan, and Paso de Blas in Valenzuela were H-L outliers. From its CLUP, Malinta and Karuhatan act as the primary node, hosting the Valenzuela City Government Center and People's Park, integrating government, residential, retail, commercial, cultural, and institutional functions (City of Valenzuela, 2018). Paso de Blas serves as a commercial hub and community center, housing the Valenzuela Gateway Complex Central (VGC) Integrated Terminal, an intermodal transport terminal for public utility vehicles, including provincial buses, jeepneys, UV Express, tricycles, and city buses, facilitating transport within the city (City of Valenzuela, 2018). These zones serve as vital economic hubs, promoting development. However, the uneven development within cities, where activity is concentrated in primary and secondary nodes, results in economic disparity in the city, highlighting the need for equitable development.

4.2.4 Low-High Outliers: The results also identified underdeveloped areas within high-development zones. A notable result was the detection of Forbes Park, a residential zone home to some of the country's wealthiest Filipinos and expatriates (MAKATI.GOV, 2022). The counterintuitive result highlights a key limitation of nighttime light data in estimating economic development, as it mainly relies on visible light from infrastructure and commercial establishments instead of financial wealth. Since Forbes Park is a residential zone, low emissions were detected from this area, resulting in its classification as a cold spot.

4.2.4 Economic Intensity Differences among Cluster-Outliers: Table 4 shows the mean economic intensities of the cluster-outlier zones. Along with the economic diffusion from 2015 to 2018, an increase in economic intensity was also observed. However, the findings also demonstrate a decline in economic intensity in 2020, consistent with the economic decline due to the pandemic. This supports the possibility of economic diffusion despite the lack of economic growth, suggesting the feasibility of spatial redistribution of economic activity to other areas to form new hotspots.

CO Type	2015	2018	2020
H-H	39.334	40.945	36.088
L-L	8.564	9.570	9.304
H-L	23.992	27.025	24.281
L-H	15.157	17.315	14.292

Table 4. NTL Mean Values ($nW/cm^2/sr$) per Cluster

Comparison	2015	2018	2020
H-H and L-L	459.295	427.847	387.876
H-L and L-L	280.149	282.393	260.974
L-H and H-H	38.534	42.288	39.603
H-L and H-H	60.996	66.003	67.283

Table 5. Relative Difference (%) between NTL Mean Values

As shown in Table 5, from 2015 to 2018, H-H clusters were consistently 4.28 to 4.59 times greater than L-L clusters, with a decline in 2020 to only 3.8 times more. The economic hotspots remained brighter, attributed to the relatively high economic activity in these zones, as compared to the low economic zones where activity is limited. However, a 2020 decline was observed, which can be attributed to the pandemic, restricting growth in both zones. Central cities like Makati exhibit brighter areas than peripheries like Valenzuela due to the former's strategic position and business districts.

Transitional zones like H-L outlier were 2.61 to 2.80 times brighter than L-L clusters. Despite being situated within low economic zones, these zones thrive, highlighting localized growth signaling potential economic expansion or growing economic disparities in the cluster. Meanwhile, L-H outliers were approximately 60% dimmer than H-H clusters, despite these zones' proximity to central areas. This highlights the uneven development in developed areas, suggesting the need for targeted policy interventions.

H-L outliers were economically active, ranging from 24 to 27 NTL mean values, but were still 33% to 40% dimmer than H-H clusters. The relatively high brightness can be attributed to H-H clusters benefiting from their proximity to highly developed areas, in contrast with H-L clusters. These zones can signal economic expansion, but at the same time, may cause economic disparities due to inequitable development.

4.3 Directional Analysis

The analysis revealed Metro Manila's economic center, spatial shifts, and dispersion of economic activity from 2015 to 2020. Mandaluyong was identified as the economic center, with economic activity exhibiting gradual spatial dispersion.

4.3.1 Economic Center of Gravity: The findings revealed Mandaluyong as the economic center of gravity, inconsistent with the results of Z. Zhao et al. (2023), where the economic center was in the capital city. This suggests that economic activity was concentrated in the geographic center rather than the region's capital city, highlighting how proximity and accessibility to other cities promote economic activity.

Table 6 tabulates the position of Metro Manila's economic center of gravity over time, and Figure 4 shows its movement, fluctuating within Mandaluyong. In 2018, the center migrated 264.394 meters northeast and moved 83.210 meters southwest again, showing subtle shifts in the economic center, but remained in Mandaluyong, as shown in Table 7. The economic center was displaced 188.08 meters northwest from its initial position, a small shift considering the city is only 1.77% of the region's total area.

Year	Latitude	Longitude
2015	14° 35' 6.02" N	121° 01' 49.75" E
2018	14° 35' 14.6" N	121° 01' 50.36" E
2020	14° 35' 12.12" N	121° 01' 49.25" E

Table 6. Geographic coordinates of the economic center over time

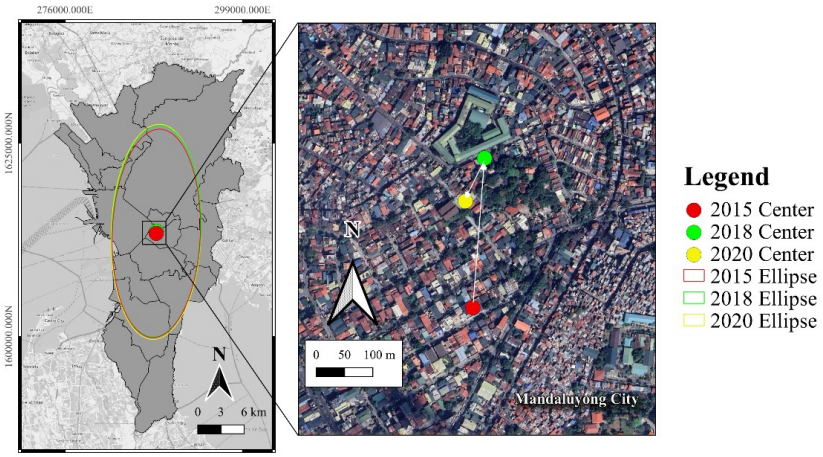

Figure 4. Directional Analysis Map

Year	Migration Distance (m)	Direction
2015-2018	264.394	NE
2018-2020	83.210	SW

Table 7. Migration distance and direction of economic center shifts

Mandaluyong's economic activity is mainly driven by commercial and service centers and the industrial sector, as indicated in its Comprehensive Land Use Plan (CLUP). The city's Central Business District (CBD), near the EDSA-Shaw-Pasig boundary, serves as an economic hub with industrial zones within the CBD situated along the Pasig River (Comandao et al., 2017). Furthermore, it is located at the intersection of major transportation routes, making it a strategic location for businesses and investors. Apart from its strategic location and high commercial density, it developed a more efficient process in acquiring permits and licenses, resulting in over 16,300 business registrations in 2017, attracting local and foreign investors. This has equated to over PHP 204 billion worth of investments by the first quarter of 2018 (Suerte Felipe, 2019). Mandaluyong's strategic location, business incentives, and high commercial density make it an attractive location for local and foreign investors, transforming it into Metro Manila's economic center.

4.3.2 Spatial Extent and Directionality of Development: Table 8 shows the parameters of Metro Manila's economic distribution ellipse from 2015 to 2020. The standard deviation ellipse (SDE) of Metro Manila's economic development was stable during the study period, as indicated by the minor changes in the axial ratios per year in Table 9. The stable distribution of economic activity is supported by the small fluctuations in the rotation angles, measured at 2.181°, 2.205°, and 1.924° for 2015, 2018, and 2020, respectively. Therefore, the obtained values suggest that the economic distribution in Metro Manila did not change significantly.

Year	Minor Axis (km)	Major Axis (km)	Rotation (°)
2015	5.703	13.479	2.181
2018	5.770	13.671	2.205
2020	5.825	13.929	1.924

Table 8. Ellipse parameters

Year	Area (sq. km)	Axial Ratio
2015	241.469	0.423
2018	247.804	0.422
2020	254.907	0.418

Table 9. Area and axial ratio of the ellipse over time

The ellipse followed a slightly northeast orientation, aligning with Metro Manila's geographic structure, as shown in Figure 4. The findings indicate that the concentration of economic activity lies along the North-South direction, potentially reflecting the location of most commercial areas and industrial zones, interconnected via key transportation networks. The results align with the location of major economic zones or central business districts (CBDs) along the north-south axis, like Makati, Ortigas Center, and Quezon City Triangle. Furthermore, the concentration of these institutions is heavily influenced by their strategic position, connected by the region's transportation network, shaping Metro Manila's economic spatial distribution.

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From 2015 to 2020, Metro Manila's economic ellipse exhibited gradual spatial expansion, as shown in Table 10. From 2015 to 2018, the SDE's area increased by 1.026%, with a 1.014% and 1.012% increase in the major and minor axes, respectively. In 2020, it expanded slightly more at a rate of 1.029%, with a 1.019% and 1.010% increase in the major and minor axes, respectively. It revealed gradual spatial dispersion, aligning with the decreasing Global Moran's I and increasing hotspot areas, indicating the reduction of economic agglomeration during the study period.

Year	Area Increase (%)	Major Axis Increase (%)	Major Axis Increase (%)	Spatial Variation
2015-2018	1.026	1.012	1.014	Expansion
2018-2020	1.029	1.010	1.019	Expansion

Table 10. Changes in area, major and minor axes length, and spatial variations

However, it may seem counterintuitive that economic activity expanded despite the economic decline in 2020, when the pandemic reduced economic activity. As a result of the quarantine's preventive measures, human mobility was restricted, limiting Metro Manila's economic growth, which declined from 7.0% in 2018 to -10.1% in 2020 (Congressional Policy and Budget Research Department, 2021). The decline aligns with the findings of decreased overall brightness in Metro Manila, as shown in Table 4, indicating decreased activity. Despite the decline, the expansion can be attributed to the spatial redistribution of light sources from essential services like health centers or residential areas due to prolonged stays at home. The findings suggest the careful interpretation of the expansion, as it can be attributed to the continued increase in nighttime light emissions despite limited economic activity due to the quarantine and lockdown measures. While the expansion of Metro Manila's economic ellipse may indicate the reduction of economic agglomeration, it should not be equated with economic growth.

5. Conclusions and Recommendations

The study analyzed the economic spatial patterns of Metro Manila's economic development from 2015 to 2020. The Global Moran's I values revealed clustering of similar economic development values in Metro Manila from 2015 to 2020. However, the gradual decrease over time indicates economic diffusion, signaling steady regional economic convergence.

Additionally, the cluster-outlier analysis detected local clusters and outliers of high and low economic zones, with Metro Manila exhibiting consistent local spatial patterns with gradual expansion and shrinkage of hotspots and cold spots, respectively. The patterns reflected the core-periphery patterns of urban agglomeration, wherein development is concentrated in central cities while peripheries lag due to inaccessibility and inequitable resource allocation. The advantageous positions of central cities make them optimal sites for the establishment of business districts, fueling the economy. Meanwhile, peripheries lag due to congestion, poor infrastructure, and inadequate commercial facilities. Notably, Alabang emerged as a hotspot in the Metro South, outside the traditional urban core. High-low outliers were also detected in Valenzuela, showing uneven intra-city growth, consistent with the city's node structure. However, false cold spots were also captured, like Forbes Park, highlighting a limitation of nighttime lights in measuring economic development. Moreover, the persistent NTL mean differences between the H-H and L-L zones support the economic disparities in the region, reinforcing the need for a more balanced regional development. H-L zones qualify as candidates for areas of economic expansion, and targeted investments in these areas can accelerate development, while L-H zones require policy interventions to ensure balanced development within highly developed cities.

Directional analysis determined Mandaluyong as Metro Manila's economic center of gravity during the study period, due to the region's strategic location being surrounded by highly developed cities, like Makati, Manila, and Quezon City. Also, it reflected Mandaluyong's rapid growth during this period via local and foreign investments. Furthermore, the findings revealed that economic activity followed a North-South orientation, following the region's geographical orientation.

This study demonstrated the potential of nighttime light (NTL) data as a proxy for economic development, especially crucial for developing countries that lack subnational economic data. Leveraging granular NTL data provides urban planners and policymakers with spatial and temporal insights into a region's development, revealing concentrated growth and lagging areas. This methodology provides data-driven insights, allowing effective targeting of underdeveloped regions by enhancing infrastructure, promoting equitable resource allocation, and providing business incentives to ensure balanced regional development.

Furthermore, this methodology demonstrates the ability to monitor spatial and temporal changes, allowing government agencies and organizations to evaluate their strategies and readjust if deemed necessary. This provides a scalable and cost-effective approach to monitor regional progress, crucial in achieving sustainable and inclusive growth. Especially in countries like the Philippines that lack the infrastructure to provide comprehensive and readily available economic data, the adoption of NTL-based analysis offers a viable alternative, empowering researchers, government agencies, and organizations to contribute to achieving inclusive, balanced regional growth. Overall, this study highlights the ability of geospatial and satellite data in addressing data gaps and the formulation of evidence-based frameworks to ensure an equitable and balanced regional development.

Further studies are recommended to integrate actual travel time values, factoring traffic congestion, rather than network-derived values, to reflect actual economic interactions and comprehensively define the spatial neighborhood. Additionally, this study highlighted a key limitation of nighttime light in measuring financial wealth, thus, it is suggested for future research to incorporate other socioeconomic indicators to accurately quantify economic development, without over-reliance on nighttime light emissions. Lastly, it is recommended to extend the study period and study area to capture long-term trends and account for external effects beyond the region's boundaries, respectively.

References

Caloocan Local Government., 2017. *CALOOCAN CITY COMPREHENSIVE DEVELOPMENT PLAN 2017-2019*. City Planning and Development Department, Caloocan City, Metro Manila, Philippines.

Chen, Z., Yu, B., Yang, C., Zhou, Y., Yao, S., Qian, X., Wang, C., Wu, B., & Wu, J., 2021. An extended time series (2000–2018) of global NPP-VIIRS-like nighttime light data from a cross-

sensor calibration. *Earth System Science Data*, *13*(3), 889–906. https://doi.org/10.5194/essd-13-889-2021

City of Valenzuela., 2018. *Comprehensive Land Use Plan of Valenzuela 2019-2028*. City Planning and Development Office, Barangay Karuhatan, Valenzuela City, Metro Manila, Philippines.

Comandao, A., Tolentino, R. G., Simbulan, V. B., de la Rosa, E., Mariscotes, B. D., Maravilla, R. T., Salas, C. L., Alcazar, G. F., Cloma, L., Rea, J. P., & Raposon Jr., A., 2017. *CITY PLANNING AND DEVELOPMENT DEPARTMENT COMPREHENSIVE LAND USE PLANNING TEAM 2017-2032*. City Planning and Development Department, Mandaluyong City, Philippines.

Congressional Policy and Budget Research Department., 2021. *2020 Gross Regional Domestic Product*. from https://cpbrd.congress.gov.ph/ff2021-32-2020-gross-regional-domestic-product/ (accessed 12 May 2025)

Diokno-Sicat, J., 2019. Philippine (Metro Manila) case study on municipal financing. *Working Paper Series - Macroeconomic Policy and Financing for Development Division*

Fang, C., & Yu, D. (2017). Urban agglomeration: An evolving concept of an emerging phenomenon. *Landscape and Urban Planning*, *162*, 126–136. https://doi.org/10.1016/j.landurbplan.2017.02.014

FILINVEST CITY., 2017, September 2. *Filinvest City rides growth in the Metro South | Filinvest City*. from https://filinvestcity.com/news/2017/09/filinvest-city-rides-growth-metro-south (accessed 12 May 2025)

Gamboa, M. A. M., Rivera, R. R. B., & Reyes, M. R. D., 2019. City Profile: Manila, Philippines. *Environment and Urbanization ASIA*, *10*(2), 331–358. https://doi.org/10.1177/0975425319859149

Huang, Y., Hong, T., & Ma, T., 2020. Urban network externalities, agglomeration economies and urban economic growth. *Cities*, *107*, 102882. https://doi.org/10.1016/j.cities.2020.102882

Jin, R., Gong, J., Deng, M., Wan, Y., & Yang, X., 2018. A Framework for Spatiotemporal Analysis of Regional Economic Agglomeration Patterns. *Sustainability*, *10*(8), 2800. https://doi.org/10.3390/su10082800

Krugman, P., 1991. Increasing Returns and Economic Geography. *Journal of Political Economy*, *99*(3), 483–499. https://doi.org/10.1086/261763

MAKATI.GOV., 2022. *Makati Web Portal*. from https://www.makati.gov.ph/barangay/forbes-park/23?tab=364 (accessed 12 May 2025)

Mellander, C., Lobo, J., Stolarick, K., & Matheson, Z., 2015. Night-time light data: A good proxy measure for economic activity? *PLoS ONE*, *10*(10). https://doi.org/10.1371/journal.pone.0139779

Obanan, S., 2021. Urbanization Trends with Philippine Context. *Academia Letters*. https://doi.org/10.20935/AL657

Pagaduan, J. A., 2023. Spatial Income Inequality, Convergence, and Regional Development in a Lower Middle-Income Country: Satellite Evidence from the Philippines. *The Developing Economies*, *61*(2), 117–154. https://doi.org/10.1111/deve.12354

Prasannakumar, V., Vijith, H., Charutha, R., & Geetha, N., 2011. Spatio-temporal clustering of road accidents: GIS based analysis and assessment. *Procedia - Social and Behavioral Sciences*, *21*, 317–325. https://doi.org/10.1016/j.sbspro.2011.07.020

Rith, M., Roquel, K. I. D. Z., Lopez, N. S. A., Fillone, A. M., & Biona, J. B. M. M., 2020. Towards more sustainable transport in Metro Manila: A case study of household vehicle ownership and energy consumption. *Transportation Research Interdisciplinary Perspectives*, *6*, 100163. https://doi.org/10.1016/j.trip.2020.100163

Song, Y., & Cibin, A., 2024. Optimizing Spatial Weight Matrices in Spatial Econometrics: A Graph-Theoretic Approach Based on Shortest Path Algorithms: A New York City Application of Crime and Economic Indicators. *International Review for Spatial Planning and Sustainable Development*, *12*(2), 181–200. https://doi.org/10.14246/IRSPSD.12.2_181

Suerte Felipe, C., 2019, October 3. *MANDALUYONG CITY, Small city with a bustling economy | The Manila Times*. from https://www.manilatimes.net/2019/10/03/supplements/mandaluyong-city-small-city-with-a-bustling-economy/625937 (accessed 12 May 2025)

The Philippine Star., 2015a, January. *Megaworld launches new Alabang West phase | Philstar.com*. from https://www.philstar.com/business/2015/01/09/1410863/megaworld-launches-new-alabang-west-phase (accessed 12 May 2025)

The Philippine Star., 2015b, November. *Amaia launches 10th Steps project in Alabang | Philstar.com*. from https://www.philstar.com/business/real-estate/2015/11/20/1523720/amaia-launches-10th-steps-project-alabang (accessed 12 May 2025)

Tingzon, I., Orden, A., Go, K. T., Sy, S., Sekara, V., Weber, I., Fatehkia, M., García-Herranz, M., & Kim, D., 2019. MAPPING POVERTY IN THE PHILIPPINES USING MACHINE LEARNING, SATELLITE IMAGERY, AND CROWD-SOURCED GEOSPATIAL INFORMATION. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII-4/W19*, 425–431. https://doi.org/10.5194/isprs-archives-XLII-4-W19-425-2019

United Nations., n.d.. *68% of the world population projected to live in urban areas by 2050, says UN | United Nations*. the United Nations. Retrieved June 7, 2025, from https://www.un.org/uk/desa/68-world-population-projected-live-urban-areas-2050-says-un (accessed 8 December 2024)

United Nations., 2023, October 31. *It's All about Cities: We Mustn't Flip the Coin on Sustainable Investment | United Nations*. the United Nations. Retrieved June 7, 2025, from https://www.un.org/en/un-chronicle/it%E2%80%99s-all-about-cities-we-mustn%E2%80%99t-flip-coin-sustainable-investment (accessed 7 June 2025)

Zhao, Z., Tang, X., Wang, C., Cheng, G., Ma, C., Wang, H., & Sun, B., 2023. Analysis of the Spatial and Temporal Evolution of the GDP in Henan Province Based on Nighttime Light Data. *Remote Sensing*, *15*(3), 716. https://doi.org/10.3390/rs15030716

Zhu, X., Wang, Q., Zhang, P., Yu, Y., & Xie, L., 2021. Optimizing the spatial structure of urban agglomeration: based on social network analysis. *Quality and Quantity*, *55*(2), 683–705. https://doi.org/10.1007/s11135-020-01016-3