ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jun1517

Spatiotemporal Analysis of Population Density Patterns for Urban Flood Resilience and Disaster Impact Modeling in the Municipality of Carmen, Davao del Norte

Kim Harvey C. Roca[1]; Charlyn T. Gorgonio[2]

[2]PhD
[1;2]University of Mindanao

Publication Date: 2026/07/14

Abstract: Population density is a critical planning indicator that influences infrastructure provision, public service delivery, and resource allocation. This study analyzed the spatiotemporal patterns of population density in the Municipality of Carmen, Davao del Norte, Philippines, from 2015 to 2024 and examined their implications for local planning and development. A descriptive-quantitative approach integrated with spatial and temporal analyses was employed using barangay-level population and land area data. Results showed that the municipal average population density increased from 441.71 persons/km² in 2015 to 505.26 persons/km² in 2024, representing a 14.38% increase over the study period. Barangays Ising, Sto. Niño and Tubod consistently recorded the highest population density, while Minda, Salvacion, and San Isidro remained the least densely populated. Seventeen of the twenty barangays exhibited increasing density trends. Spatial analysis revealed a high degree of persistence in the municipality's settlement structure, with population growth occurring primarily through the intensification of existing population centers rather than the emergence of new centers. The findings indicate that population density patterns in Carmen remain unevenly distributed across barangays and highlight the importance of incorporating population density analysis into local planning processes to support evidence-based development decisions and sustainable resource allocation.

Keywords: *Population Density, Spatiotemporal Analysis, Settlement Patterns, Local Planning, Carmen, Davao Del Norte.*

How to Cite: Kim Harvey C. Roca; Charlyn T. Gorgonio (2026) Spatiotemporal Analysis of Population Density Patterns for Urban Flood Resilience and Disaster Impact Modeling in the Municipality of Carmen, Davao del Norte.
International Journal of Innovative Science and Research Technology, 11(6), 3375-3383.
https://doi.org/10.38124/ijisrt/26jun1517

I. INTRODUCTION

Population density is a fundamental demographic indicator that defines the concentration of people within a certain geographic area and provides essential information for planning and decision-making in development (Angel et al., 2021). Apart from determining the number of people in a given space, population density also indicates patterns of human settlement, land use, and development intensity that influence the demand for infrastructure, public services, and community facilities (Yang et al., 2020). Urbanization and population growth are changing the spatial distribution of human settlements worldwide. Knowledge of population distribution has become an important concern for governments and planners seeking to improve sustainable development and efficient resource allocation (Haase et al., 2018). Population density information is also a key input for assessing development needs, prioritizing investments, and supporting evidence-based planning initiatives at different geographic scales (Leyk et al., 2019).

Rapid population concentration in specific areas can increase pressure on housing, transportation systems, public utilities, and social services, whereas in sparsely populated areas, infrastructure and service delivery may be inefficient (Arfanuzzaman & Dahiya, 2019). Urban growth and economic development may also lead to unequal distribution of infrastructure and public investments, resulting in disparities of access to essential services among communities (Pandey et al., 2025). Providing public facilities and services in low-density areas is typically more costly per capita, further complicating the challenges faced by local governments and planners (Miyauchi & Setoguchi, 2023). The conditions highlight the importance of understanding population density patterns as a foundation for informed planning and sustainable development interventions (McDonald et al., 2023).

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According to the Philippine Statistics Authority (2022), around 58.93 million Filipinos, or 54.0 percent of the country's total population, resided in urban barangays in 2020. This increasing population concentration within urban and developing communities places additional demands on infrastructure, public services, housing, and economic opportunities (Fragkais et al., 2013). As noted by Reyes et al. (2022), local planning and budgeting depend on the availability of localized demographic information that accurately reflects community conditions and development needs. In the same vein, Monorom et al. (2020) highlighted the importance of small-area population data for planning public facilities, infrastructure development, resource allocation, and service delivery. Also, Zander et al. (2018) demonstrated that population density is highly correlated with environmental and socio-economic conditions, underscoring its relevance to planning and development processes.

According to the Philippine Statistics Authority (2025), the population of the Davao Region has increased from 5,243,536 in 2020 to 5,389,422 in 2024. This shows that the region is experiencing continued demographic growth. Such growth is generally accompanied by rising demands for infrastructure, public services, and development interventions at the local level (Saniel & Salapa, 2024). These demographic changes also affect Carmen, a municipality of 20 barangays with diverse demographics. However, population growth is rarely uniform across communities (Damgo et al., 2023). This creates variation in population density and distinct development needs for barangays, meaning local planning tools must account for unique localized drivers rather than uniform projections (Chaves et al., 2022). Therefore, these differences are significant in understanding and supporting infrastructure planning, public service provision, resource allocation, and future development initiatives within the municipality through integrated geospatial data (Tabiongan, 2024; Monorom et al., 2020).

Despite the recognized importance of demographic information, local governments frequently face challenges in obtaining detailed evidence of population concentration changes within their jurisdictions. While population counts generated through census activities provide information on the number of residents, they often offer limited insights into the spatial distribution of populations and the varying levels of concentration across communities (Wardrop et al., 2018). Understanding where population concentrations are increasing, decreasing, or remaining stable is essential because such patterns influence infrastructure requirements, public service delivery, land-use decisions, and development priorities (Li et al., 2018). Wang and Zhou (2021) further noted that spatial patterns of population distribution play a critical role in regional planning and development decision-making. Consequently, population density information represents an important planning tool that extends beyond simple population counts by providing a clearer understanding of how people are distributed across space (Leyk et al., 2019).

Although numerous studies have examined population growth, urbanization, and demographic change at national, regional, and metropolitan scales, comparatively fewer studies have investigated population density dynamics within smaller administrative units such as barangays. Existing research has largely focused on broader demographic trends, while localized evidence describing how population density patterns evolve across communities remains limited (Wardrop et al., 2018). Furthermore, studies conducted in Mindanao have demonstrated the value of localized spatial assessments for planning and decision-making, yet similar investigations focusing specifically on barangay-level population density patterns remain limited in municipalities such as Carmen, Davao del Norte (Damgo et al., 2023). This gap constrains the availability of localized demographic information needed to support evidence-based planning, resource allocation, and development interventions. Therefore, the population density patterns and trends of barangays in the Municipality of Carmen from 2015 to 2024 were analyzed for their spatial and temporal characteristics, and the implications of population density dynamics for local planning and urban development were discussed.

➢ *Objectives*

The general objective of this study is to analyze the spatiotemporal patterns of population density in the Municipality of Carmen, Davao del Norte, from 2015 to 2024 and examine their implications for local planning and development. Specifically, this study aims:

- To determine the population density levels of the barangays in the Municipality of Carmen from 2015 to 2024.
- To analyze the spatial and temporal patterns of population density across barangays within the Municipality of Carmen from 2015 to 2024.
- To discuss the planning and development implications of the observed population density patterns in the Municipality of Carmen.

➢ *Theoretical Framework*

The main theoretical basis of this study is the Central Place Theory (Christaller 1933), which explains the distribution of population and settlements based on the availability of goods, services, and economic functions. According to the theory, centers of commerce, administration, and public services attract larger populations, resulting in higher population densities than in surrounding areas. The theory is used to explain the variations of population density of barangays and the concentration of population in areas of greater accessibility and service functions in the context of the

The study is also supported by the Growth Pole Theory suggested by Perroux (1955) and discussed by Parr (1999), which suggests that development is concentrated around specific growth centers where economic activities and investments are clustered. These growth centers attract people and spur growth in their adjacent areas, impacting settlement patterns over time. This perspective adds to the understanding of the temporal changes in population density and the increase in population concentration in some barangays of Carmen from 2015 to 2024. Together, these theories offer a

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jun1517

framework for understanding spatial and temporal patterns of population density and their implications for local planning and development.

➢ *Conceptual Framework*

The study adopted the Input–Process–Output (IPO) model as its conceptual framework to illustrate the systematic flow of data and analytical procedures used in examining population density patterns in the Municipality of Carmen, Davao del Norte, from 2015 to 2024.

The Input component consists of the population data of the twenty barangays of the Municipality of Carmen covering the period from 2015 to 2024. These data served as the primary source for determining population density and identifying demographic changes over time.

The Process component involves calculating population density, conducting spatial analysis, performing temporal analysis, and assessing patterns. Population density was computed by relating the population count to the corresponding land area of each barangay. Spatial analysis was conducted to examine population density across barangays, while temporal analysis was used to determine changes in population density over the 10-year study period. Pattern assessment was subsequently undertaken to identify areas exhibiting increasing, decreasing, or fluctuating population density trends.

The Output component comprises the population density levels, spatiotemporal population density patterns, and their corresponding planning and development implications. The findings provide insights into the distribution and dynamics of population concentration within the municipality, which may serve as a basis for infrastructure planning, public service provision, resource allocation, and evidence-based local development planning.

Overall, the conceptual framework demonstrates how population data are transformed through analytical procedures into meaningful information that supports planning and development decision-making in the Municipality of Carmen.

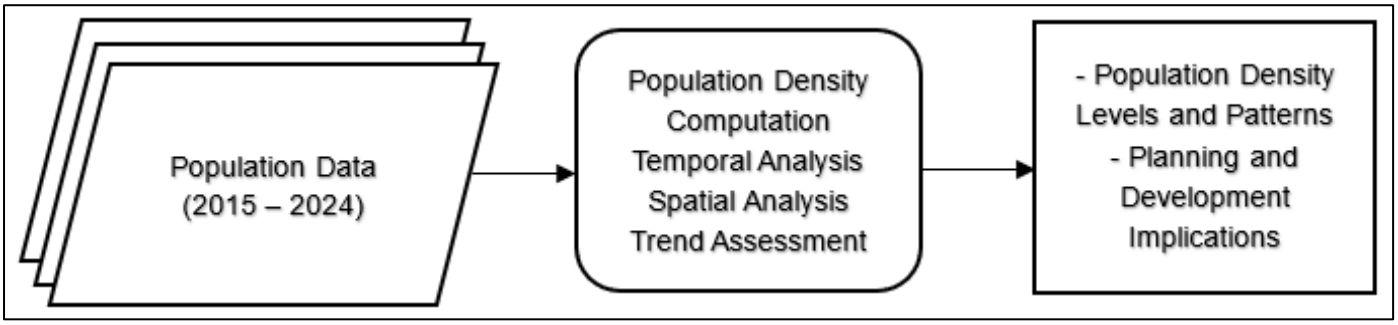

Fig 1 Conceptual Framework of the Study

II. MATERIALS AND METHODS

➢ *Design and Procedure*

This study utilized secondary population and spatial data to analyze the spatiotemporal patterns of population density in the Municipality of Carmen, Davao del Norte, from 2015 to 2024. Population data were obtained from the Philippine Statistics Authority (PSA) and relevant municipal records, while barangay land area data were acquired from official geographic and planning datasets. These data served as the basis for determining population density levels and examining changes in population distribution across the municipality.

Population density was computed for each barangay using the standard population density formula:

Population Density = Population ÷ Land Area

Where population density is expressed in persons per square kilometer (persons/km²), population refers to the total number of inhabitants within a barangay, and land area refers to the total area of the barangay in square kilometers. The computed density values were generated annually from 2015–2024 to facilitate the assessment of temporal changes in population concentration.

After computing population density, spatial analysis was conducted to examine its geographic distribution across the 20 barangays of Carmen. Population density maps were generated using Geographic Information System (GIS) techniques to visualize areas with relatively high and low population concentration. A spatial comparison among barangays was conducted to identify patterns of population clustering and distribution within the municipality.

Temporal analysis was subsequently undertaken to evaluate changes in population density over the ten-year study period. Annual density values were compared to determine trends, increases, decreases, and fluctuations in population concentration among barangays. The analysis enabled the identification of areas experiencing sustained population growth as well as barangays exhibiting relatively stable or declining density levels.

The resulting population density values and spatial outputs were analyzed using descriptive statistics, including minimum, maximum, and mean density values. Trends observed in the spatial and temporal analyses were interpreted

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jun1517

in relation to local planning and development concerns, particularly those related to infrastructure provision, public service delivery, land-use management, and resource allocation. The integrated analysis provided a comprehensive understanding of the spatiotemporal dynamics of population density in the Municipality of Carmen and their implications for future planning initiatives.

➢ *Study Area*

The study was conducted in the Municipality of Carmen, Davao del Norte, Philippines. Carmen is a first-class municipality strategically located within the Davao Region and serves as an important agricultural, commercial, and transportation hub in the province. The municipality is composed of twenty (20) barangays with varying levels of development, accessibility, and settlement concentration, making it a suitable area for examining differences in population density across local communities.

Carmen was selected as the study area because it has experienced continuous population growth and increasing development activities over the years. Its strategic location along major transportation corridors, proximity to urban centers, and expanding economic functions have contributed to changing settlement patterns and population distribution within the municipality. These changes create varying demands for infrastructure, public facilities, housing, transportation services, and other development interventions, all of which are directly influenced by population concentration.

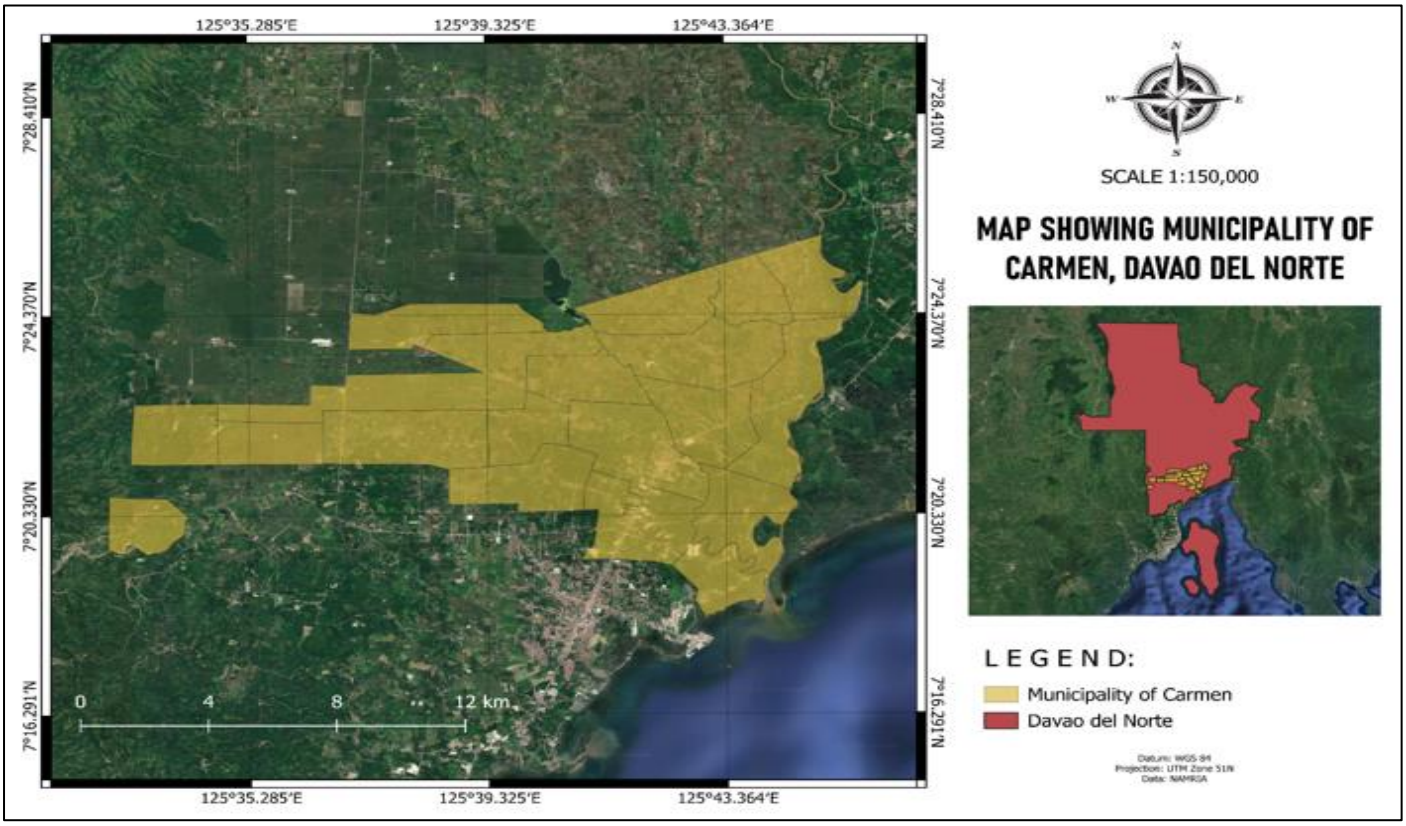

Fig 2 Location of the Study

III. RESULTS AND DISCUSSIONS

➢ *Population Density Levels of Barangays in the Municipality of Carmen (2015–2024)*

Table 1 presents the population density levels of the 20 barangays in the Municipality of Carmen, Davao del Norte, for 2015, 2020, and 2024. Population density, measured as the number of persons per square kilometer, was used to assess population concentration within each barangay.

Table 1 Summary of Population Density Levels and Trends of Barangays in the Municipality of Carmen, Davao del Norte (2015–2024)

Barangay	Population Density (Person per km²)		Change (%)	Pattern
	2015	2024		
Alejal	525.86	539.93	2.68	Increasing
Anibongan	337.64	390.67	15.71	Increasing
Asuncion	397.55	539.98	35.83	Increasing
Cebulano	357.83	521.27	45.67	Increasing

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jun1517

Guadalupe	216.61	295.67	36.50	Increasing
Ising	1198.04	1398.88	16.76	Increasing
La Paz	670.06	511.18	-23.71	Decreasing
Mabaus	236.57	255.48	7.99	Increasing
Mabuhay	815.07	456.45	-43.99	Decreasing
Magsaysay	282.35	302.76	7.23	Increasing
Mangalcal	703.62	860.99	22.37	Increasing
Minda	107.08	127.67	19.23	Increasing
New Camiling	347.47	592.88	70.63	Increasing
Salvacion	156.58	168.20	7.42	Increasing
San Isidro	148.77	171.19	15.07	Increasing
Sto. Niño	1038.72	1140.72	9.82	Increasing
Taba	301.00	303.35	0.78	Fluctuating
Tibulao	418.85	460.01	9.83	Increasing
Tubod	870.61	1093.61	26.61	Increasing
Tuganay	355.74	440.57	23.85	Increasing
Average	**441.71**	**505.26**	**14.38**	**Increasing**

The results indicate an overall increase in the Municipality of Carmen's population density during the study period. The average municipal population density was 441.71 persons/km2 in 2015, 485.12 persons/km2 in 2020, and 505.26 persons/km2 in 2024. This represents a growth of around 14.38 percent over the ten years, showing a trend of increasing population concentration within the municipality. Increased population density is often associated with demographic growth and changing settlement patterns, which influence the spatial distribution of population within local communities (Leyk et al., 2019).

The results showed great variations in population density from barangay to barangay. Barangay Ising had the highest population density in 2024 at 1,398.88 persons/km2, followed by Sto. Niño (1,140.72 persons/km2) and Tubod (1,093.61 persons/km2). These barangays consistently had density levels well above the municipal average throughout the study period, indicating higher population density than in other areas of the municipality. Also, in 2024, Mangalcal (860.99 persons/km²) and Alejal (539.93 persons/km²) had the highest population densities. Similar patterns of population concentration have been found in other locations where demographic growth tends to be clustered rather than evenly spread across space (Wardrop et al., 2018).

On the other hand, the lowest population density in 2024 was recorded in Barangays Minda (127.67 persons/km²), Salvacion (168.20 persons/km²), and San Isidro (171.19 persons/km²). These barangays consistently had lower population density throughout the study period, indicating a more dispersed population distribution. The disparity between barangays with the highest and lowest densities was considerable. In 2024, Ising's population density was nearly eleven times that of Minda's. Such differences indicate the uneven distribution of population within the municipality and suggest varying levels of settlement concentration among the barangays.

Analysis of the density pattern showed that, in most barangays, population growth was generally accompanied by increasing density. The remaining 17 barangays exhibit increasing population density from 2015 to 2024, indicating a general population concentration trend in the municipality. Significant increases were recorded in Tubod, Sto. Niño, Mangalcal, New, and Asuncion, all of which had large increases in density during the period of study. On the other hand, La Paz and Mabuhay showed declining densities, while Taba showed slight fluctuations. Results indicate that population density generally increased in Carmen, but the magnitude and direction of change varied across barangays. Yang et al. (2020) indicated that population growth and changes in density often occur unevenly across space due to differences in local development conditions, accessibility, and settlement dynamics.

Overall, findings indicated that population density in the Municipality of Carmen shows high variation among barangays, with a few areas having high population concentrations and others relatively sparsely populated. The observed differences in density levels are an important basis for understanding the distribution of population within the municipality and a foundation for the analysis of spatial and temporal patterns of population density that follows.

- *Spatial and Temporal Patterns of Population Density in the Municipality of Carmen (2015–2024)*

The spatial distribution of the population density in the Municipality of Carmen in 2015, 2020, and 2024 is shown in Figure 1. The results suggest a high spatial persistence during the study period. Barangays with relatively high population density levels in 2015, especially Ising, Sto. Niño, Tubod, and Mangalcal generally remained in the higher density categories in 2020 and 2024. Similarly, the barangays with low population density, such as Minda, Salvacion, and San Isidro, are in the lower-density classes across all three periods. The patterns indicate that the overall hierarchy of population concentration within the municipality remained relatively stable despite continued population growth.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jun1517

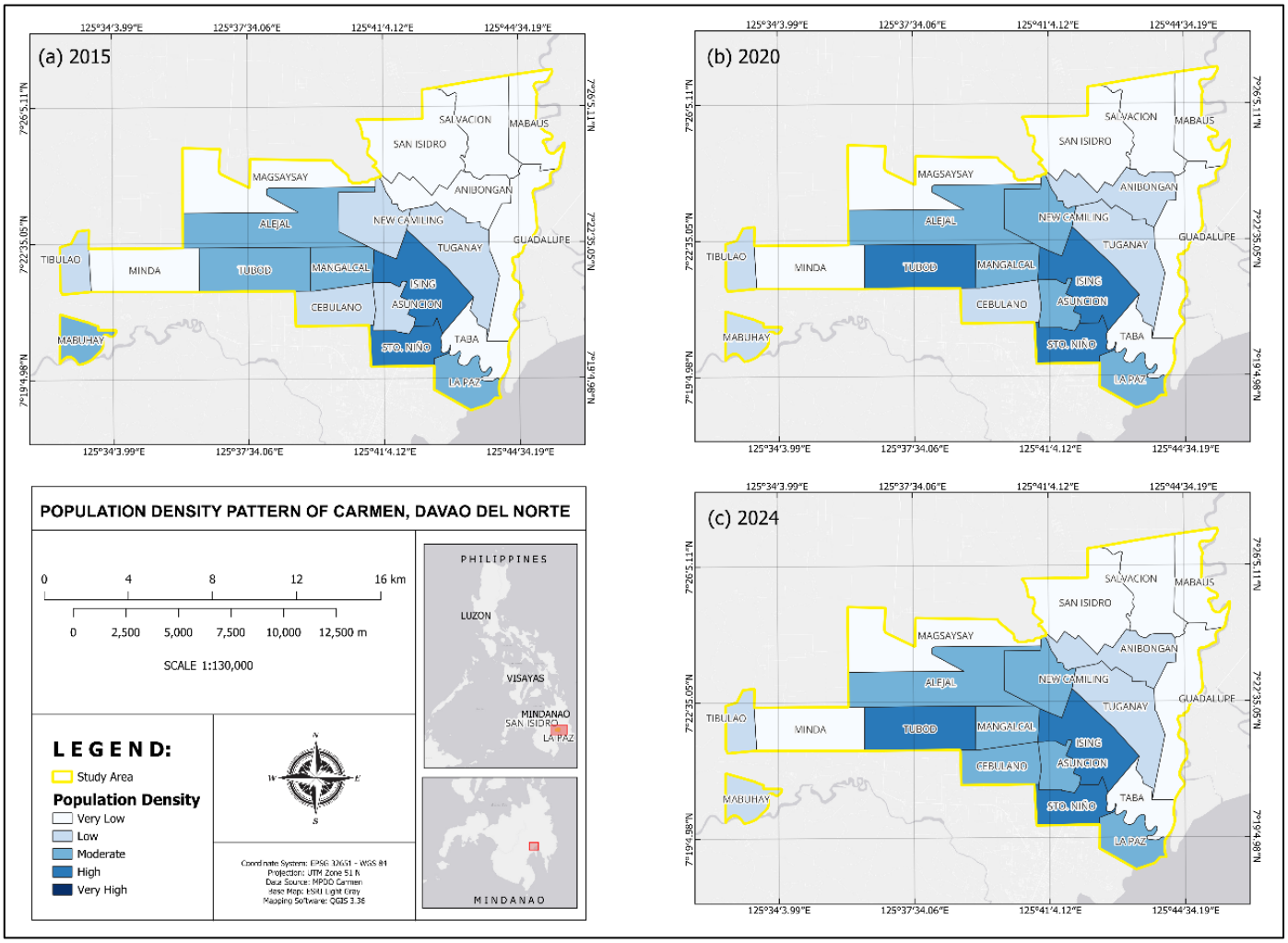

Fig 3 Population Density Pattern of the Municipality of Carmen, Davao del Norte

Temporal changes in population density were characterized largely by intensification rather than spatial reorganization. The spatial distribution of density classes has changed only slightly over time, while the municipality's total population density has increased. Population growth was more likely to reinforce existing centers of concentration than to create new ones. This is observed in barangays like Ising and Sto. Niño, which remained consistently in the highest-density categories throughout the study period. Similar observations have been reported in studies showing that demographic growth often strengthens established settlement structures and existing areas of concentration rather than leading to substantial changes in population distribution (Haase et al., 2018; Angel et al., 2021).

The maps further indicate the emergence of several barangays with increasing demographic significance. Barangays such as New, Cebulano, Guadalupe, and Tuganay exhibited upward shifts in density classifications between 2015 and 2024, suggesting gradual increases in population concentration. However, these changes occurred within the broader context of an already established settlement hierarchy, indicating that demographic growth expanded around existing population centers rather than replacing them. Such patterns are consistent with spatiotemporal studies that describe population growth as a process of density intensification within established settlements (Rith et al., 2020).

The results of the spatiotemporal analysis, in general, showed the persistence, selective intensification, and stability of the settlement structure, characterized by an increase in population density in the Municipality of Carmen. Overall, the municipality's density has increased, but the relative positions of the barangays in the hierarchy of population density remain relatively stable over the ten-year period.

➢ *Planning and Development Implications of Population Density Patterns*

The observed patterns of population density have important implications for local planning and development in the Municipality of Carmen. The municipality's increasing population density and ongoing growth in several barangays indicate a need for infrastructure, public facilities, and basic services. Barangays with consistently high-density levels, especially Ising, Sto. Niño, Tubod, and Mangalcal are likely to face greater pressure on existing infrastructure and community facilities due to population concentration. Local governments should ensure that the provision of essential services is responsive to changing demographic conditions (Arfanuzzaman & Dahiya, 2019).

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jun1517

The spatiotemporal analysis also showed that population growth was mainly due to the intensification of existing population centers, rather than the emergence of new settlement areas. This pattern suggests that future development pressures are likely to be concentrated in already populated areas. Hence, land-use planning strategies should aim to manage growth in such areas to support the efficient use of land resources, ensure adequate service provision, and avoid congestion associated with increasing population density. Population density data can be useful for local development planning and help decision-makers determine where to invest in future infrastructure and service expansions.

At the same time, the persistence of low-density conditions in some barangays underscores the need for balanced territorial development. "Higher density barangays will require more infrastructure capacity, while lower density areas can benefit from improved accessibility, strategic service delivery and development projects that address local development opportunities. This approach can contribute to a more equitable distribution of public resources and to reducing differences in access to basic services throughout the municipality. Research on sustainable urban development indicates that population distribution patterns are critical for guiding resource allocation, service provision, and long-term development planning (McDonald et al., 2023).

In general, the findings suggest that population density can be a valuable planning indicator in understanding settlement dynamics and planning for future development needs. The incorporation of population density analysis into local planning processes may support evidence-based decision-making and contribute to more efficient, sustainable development strategies within the Municipality of Carmen.

IV. CONCLUSION AND RECOMMENDATION

- *Conclusion*

The study analyzed the population density patterns of the Municipality of Carmen, Davao del Norte, from 2015 to 2024 and their implications for local planning and development. The results showed an increase in the municipality's population density, from 441.71 persons/km² in 2015 to 505.26 persons/km² in 2024, indicating continued population growth and greater settlement concentration. However, the population density levels varied greatly between the barangays, with Ising, Sto. Niño and Tubod consistently had the highest density levels, while Minda, Salvacion, and San Isidro had the lowest during the study period.

The spatiotemporal analysis showed that population growth was mainly expressed through the intensification of existing population centers rather than the emergence of new population concentration areas. The barangays with relatively high population density in 2015 were generally found to be in the same positions in the municipal density hierarchy in 2024, indicating a high degree of spatial persistence and stability of settlement patterns. Although most barangays have higher population density, population distribution was uneven throughout the municipality.

The observed density patterns underscore the importance of population density as a planning indicator for understanding settlement dynamics and supporting evidence-based decision-making. The findings suggest that future planning efforts should consider varying degrees of population concentration across barangays to ensure that infrastructure provision, public service delivery, and development interventions are responsive to evolving demographic conditions. In general, the study contributes to spatial and temporal understanding of population distribution, which can support more informed local planning and sustainable development initiatives in the Municipality of Carmen.

- *Recommendations*

The results of the study suggest that the Municipality of Carmen should consider population density analysis in its local planning and development process to support evidence-based decision-making. Regular monitoring of population density trends at the barangay level can help planners identify areas with increasing population density and anticipate future infrastructure and service requirements.

Barangays with consistently high population density, namely Ising, Sto Niño, Tubod, and Mangalcal, should be prioritized in assessing infrastructure capacity and public service provision to ensure that existing facilities are sufficient for current and future population demands. Also, development strategies for lower-density barangays should be focused on improving access and service coverage to promote balanced territorial development in the municipality.

Future research may incorporate additional demographic, socio-economic, and land-use variables to investigate further factors that influence population density patterns and settlement dynamics. The expansion of temporal coverage and comparison with neighboring municipalities can also contribute to a broader understanding of population distribution trends in the province and the region.

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