



# Leveraging Overture Maps for Micro-Level Road Network Connectivity Assessment: A Comparative Analysis across Urban, Suburban, and Rural Areas

Wening Aisyah Fauziana Koman<sup>1\*</sup>, S R Bening Pratiwi K<sup>1</sup>, Maylan Iga Prastika<sup>1</sup>,  
Dewa Ayu Gita Karunia Putri Aryani<sup>1</sup>, Arzaq Dhuha Abdullah<sup>1</sup>, Tuhfatul Atiqoh<sup>1</sup>

<sup>1</sup>Universitas Pembangunan Nasional Veteran Yogyakarta, Indonesia

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## Abstract

Road-network connectivity is an important component of spatial structure, but road density does not necessarily reflect network topology. This study assesses road-network connectivity across urban, suburban, and rural contexts using Overture Maps and graph-theoretic indices, and examines its relationship with population and built-environment density. Three areas in Yogyakarta, Indonesia, were selected: Gondokusuman as urban, Wedomartani as suburban, and Girisubo as rural area. Overture Maps Roads Transportation data were used to construct road networks from segments and connectors, while building data, BPS population data, and Ina-Geoportal boundaries were used to calculate density indicators. Connectivity was evaluated using the Beta ( $\beta$ ), Alpha ( $\alpha$ ), and Gamma ( $\gamma$ ) indices. To provide a broader interpretation of network characteristics, those parameters were examined and compared. These findings indicate that higher road and settlement density does not necessarily correspond to higher topological connectivity.

**Keywords** *Road Connectivity, Road Density, Overture Maps, Settlement Density*

## INTRODUCTION

Road networks are a fundamental structural system of cities, determining connectivity between urban areas and providing a physical framework for population distribution, building development, and mobility. Consequently, road-network connectivity has become an important dimension in urban form and transportation system analysis. Graph theory provides a well-established framework for representing transportation networks, where a road system can be represented as a graph  $G = (V, E)$  with nodes representing intersections and edges representing road segments. The resulting graph structure can be evaluated using topological measures such as the Beta, Alpha, and Gamma indices (Kansky, 1963; Haggett & Chorley, 1969; Rodrigue et al., 2006). These classical indices provide complementary information about network connectivity, circuitry, and complexity, enabling systematic comparison across spatial contexts. Recent research shows that street-network structure influences urban development, not merely transportation. Ashik, Barrington-Leigh, and Manaugh (2025) found that street-network connectivity affects subsequent densification in Canadian cities, where disconnected structures may constrain future population growth.

Despite the established importance of network connectivity, comparative urban network studies remain dependent on the availability and consistency of geospatial road data. Conventional datasets often differ in spatial coverage, classification, update frequency, licensing, and accessibility, limiting reproducibility and comparability across studies. These limitations become particularly important when comparing road-network characteristics across geographically

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Corresponding author's email: [weningaisyahfauziana.koman@upnyk.ac.id](mailto:weningaisyahfauziana.koman@upnyk.ac.id)

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separated regions. Overture Maps offers a new opportunity in this context as an open global geospatial data infrastructure containing standardized Transportation and Buildings themes ([Overture Maps Foundation, 2026a, 2026b](#)). The Transportation theme suits graph construction because it explicitly represents segment–connector relationships, enabling direct graph conversion. The Buildings theme provides footprints for deriving building count and footprint-based density measures.

The Special Region of Yogyakarta provides an appropriate setting for examining road-network connectivity across contrasting urbanization contexts, from highly urbanized to suburban and rural areas. However, road density, although commonly used as an indicator of road infrastructure, does not necessarily represent topological connectivity. Previous research has therefore combined road density with network measures such as closeness and betweenness centrality to capture different dimensions of connectivity ([Lambert et al., 2025](#)). This study addresses the following research question: Does greater road and settlement density correspond to higher topological road-network connectivity across urban, suburban, and rural contexts? To answer this question, the study assesses and compares road-network connectivity using Overture Maps and graph-theoretic measures in Gondokusuman (urban), Wedomartani (suburban), and Girisubo (rural). Specifically, it calculates Beta, Alpha, and Gamma indices and examines their relationship with road density, population density, building count density, and building footprint coverage. The study contributes a reproducible framework that integrates Overture Maps with graph-theoretic and settlement-density measures beyond administrative hierarchy.

## LITERATURE REVIEW

### Road Network Connectivity and Graph Theory

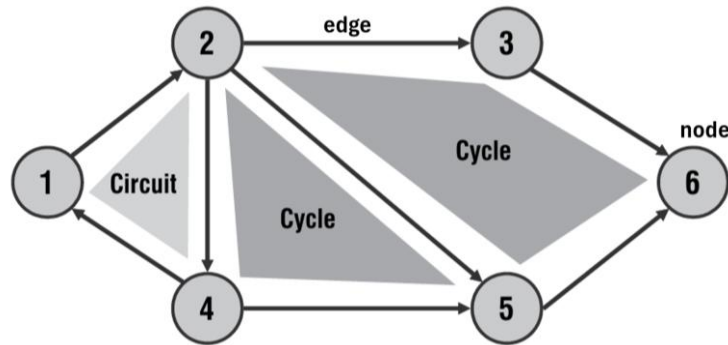
Transportation networks can be represented as graphs consisting of vertices (or nodes) and edges. In a primal representation, intersections are nodes, while road segments are edges. [Kansky \(1963\)](#) laid an important foundation for quantitatively analyzing transportation-network structure by linking graph characteristics to regional properties. [Haggett and Chorley \(1969\)](#) subsequently developed network analysis within geographical research, emphasizing the importance of topology and network structure. In transport geography, [Rodrigue et al. \(2006\)](#) highlight graph theory as a core methodological approach for characterizing transportation networks, particularly through connectivity measures and structural indices. At the urban scale, [Haque and Alam \(2020\)](#) applied structural analysis and graph theory to examine road connectivity at the ward level in the Kolkata Municipal Corporation, using intersections, connected links, and road density to identify spatial variations in network structure.

Several classical graph-theoretic indices are commonly employed to assess the connectivity of transportation networks: Beta, Alpha, and Gamma. The Beta index represents the ratio between edges and vertices, the Alpha index measures the degree of circuit development (cyclomatic number) in a planar graph, and the Gamma index expresses the ratio of observed connectivity to the theoretical maximum for a planar network. Equations (1), (2), and (3) present the Beta, Alpha, and Gamma indices, respectively, where  $E$  denotes the number of edges and  $V$  denotes the number of vertices. Figure 1 illustrates the concepts of a graph.

$$\beta = \frac{E}{V} \quad (1)$$

$$\alpha = \frac{E-V+1}{2V-5} \quad (2)$$

$$\gamma = \frac{E}{3(V-2)} \quad (3)$$



**Figure 1.** Graph concept ([Rodrigue et al., 2006](#))

Road network structure is closely related to settlement form, but urban intensity does not necessarily correspond to higher network connectivity. A dense area may contain more roads while still having dead ends, hierarchical layouts, or limited alternative routes ([Boeing, 2017](#); [Levinson, 2012](#)). Thus, road density and topological connectivity represent different dimensions of the built environment: the former measures infrastructure quantity per unit area, while the latter describes how road elements are structurally connected. Previous studies have linked street connectivity with population density and urban development ([Ewing & Cervero, 2010](#); [Ashik, Barrington-Leigh, and Manaugh, 2025](#)), while [Putri and Indradjati \(2022\)](#) highlighted the relevance of street connectivity and population-related urban-form characteristics in the Indonesian context. Accordingly, this study treats road density and graph-theoretic connectivity as complementary indicators when comparing urban, suburban, and rural areas.

### Population Density, Building Density, and the Built Environment

The built environment's relationship with travel behavior is conceptualized through the "D-Variables" framework—density, diversity, and design ([Cervero & Kockelman, 1997](#))—later expanded to include destination accessibility, transit distance, and demographics. [Ewing and Cervero \(2010\)](#) demonstrated that destination accessibility is the strongest predictor of reduced vehicle travel, followed by street-network design variables, while walking is most associated with land-use diversity and destination proximity. Crucially, population and employment densities are only weakly associated with travel behavior once other spatial design variables are controlled, suggesting density functions as an intermediate variable representing more direct attributes like mixed-use layouts and interconnected blocks.

Beyond travel behavior, street networks function as a semi-permanent urban "skeleton" that constrains spatial development for decades, leading to a theoretical shift in which population density and long-term urban form are governed by initial network connectivity rather than the reverse. [Ashik et al. \(2025\)](#) empirically demonstrated this mechanism in Canadian neighborhoods, showing that low-connectivity layouts (e.g., cul-de-sacs) structurally limit densification, while highly connected gridded networks promote multi-family housing and establish threshold densities for transit and commercial services. In the Indonesian context, [Putri and Indradjati \(2022\)](#) found that transportation energy consumption per capita is negatively correlated with both population density (-0.190) and street connectivity (-0.176). When integrated as "urban form compactness," high-compactness villages showed significantly lower energy consumption, reinforcing that transportation energy is heavily influenced by the synergistic effects of compactness rather than individual built-environment elements.

### Overture Maps as an Open Geospatial Data Source

Open geospatial data is essential for reproducible transportation research, yet

conventional studies often rely on proprietary datasets that limit comparability (Goodchild, 2007). Overture Maps addresses this through a standardized framework with Transportation and Buildings themes. Its Transportation theme explicitly represents connectivity through segment-connector relationships, enabling direct graph construction to compute Beta, Alpha, and Gamma indices (Kansky, 1963). The Buildings theme provides standardized footprints from multiple open sources. Overture's key contribution is its open accessibility, standardized schema, explicit topology, and global coverage, which support transparent analysis. These characteristics enable consistent assessment of road-network topology and building morphology across urban (Gondokusuman), suburban (Wedomartani), and rural (Girisubo) contexts in Yogyakarta.

### **Urban-Suburban-Rural Context and Research Gap**

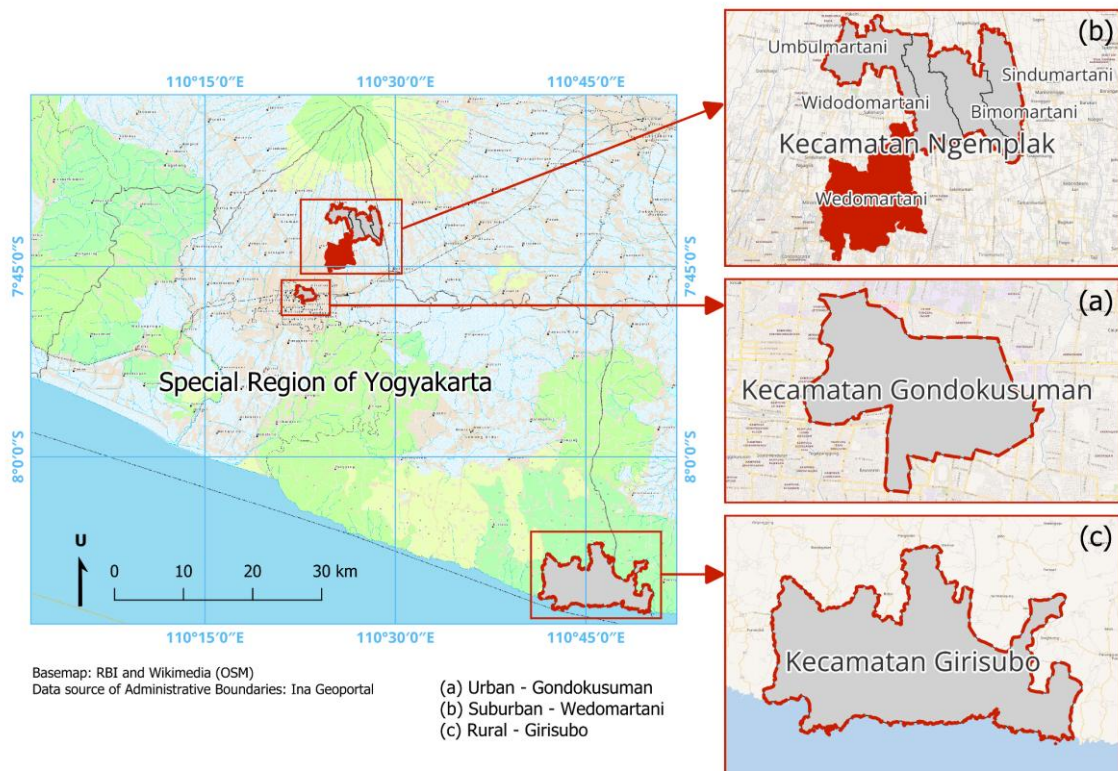
Urbanization creates spatial differences in population concentration, built-up intensity, and infrastructure development. In the Yogyakarta urban region, peri-urbanization has produced transitional areas between established urban and rural environments, as identified by Hidayat et al. (2025). In contrast, Girisubo represents a rural context characterized by karst landscapes and dryland agriculture (Antriyandarti et al., 2023). Despite extensive research on transportation networks, urban form, and density, limited studies have integrated open geospatial network topology with built-environment indicators across contrasting settlement contexts. This study addresses this gap by combining graph-theoretic connectivity, road density, population density, and building-density indicators using Overture Maps to compare urban, suburban, and rural environments.

### **RESEARCH METHOD**

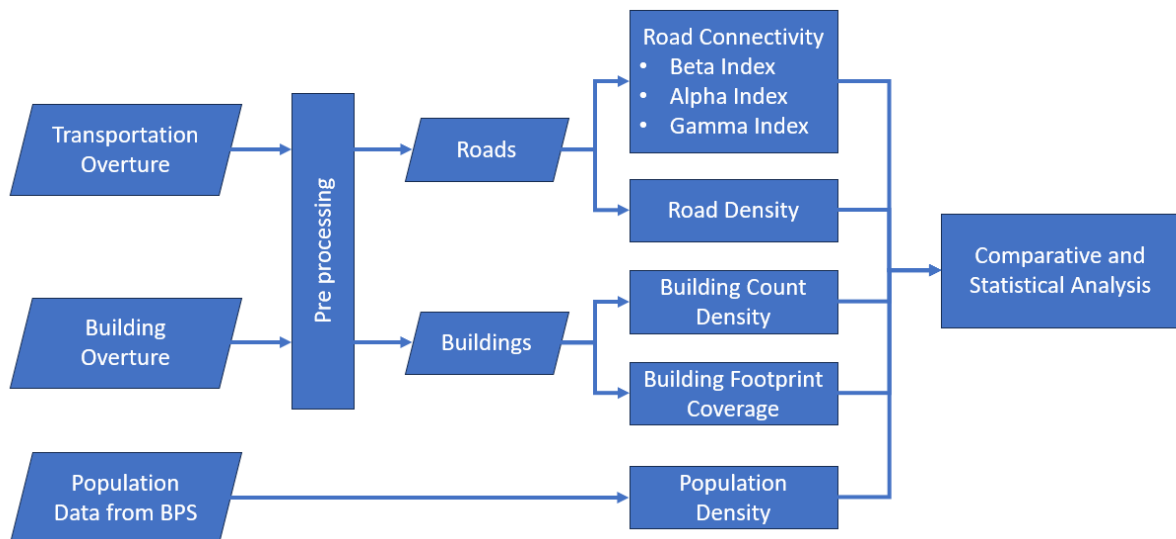
Three areas representing contrasting urban typologies were selected: Gondokusuman (urban), Wedomartani (suburban/peri-urban), and Girisubo (rural), as presented in Figure 2. Gondokusuman represents a densely developed urban environment within Yogyakarta City. Wedomartani was selected based on Hidayat et al. (2025) 's peri-urban classification, while Girisubo represents a rural context characterized by karst landscapes and dryland agriculture (Antriyandarti et al., 2023). These three areas represent different urbanization levels and settlement intensities, providing the conceptual basis for examining how road-network connectivity varies across contrasting settlement environments.

The study integrates Overture Maps Transportation and Buildings theme, population density (PD) data from BPS-Statistics Indonesia (2025, 2026a, 2026b), and administrative boundaries from Ina-Geoportal. As shown in Figure 3, the workflow included data acquisition, preprocessing (format conversion, coordinate transformation, and spatial filtering), network construction, indicator calculation, and comparative analysis. Overture Transportation data were obtained in GeoParquet format and processed in QGIS, where the data were converted to GeoPackage and reprojected to UTM Zone 49S for spatial analysis. The Overture Transportation theme contains road, rail, and water subtypes; this study selected features classified as road and excluded non-road segments. The resulting network was represented as a graph of nodes and edges, following established approaches in street-network analysis (Boeing, 2017). Beta ( $\beta$ ), Alpha ( $\alpha$ ), and Gamma ( $\gamma$ ) indices were then calculated following classical transportation-network analysis (Kansky, 1963; Haggett & Chorley, 1969), while road density (RD) was derived from total road-segment length relative to the administrative area. Building data were processed using the same spatial boundaries; building count density (BCD) was calculated from footprints whose centroids fell within each study area, while building footprint coverage (BFC) was calculated from the total footprint area within the boundary, with boundary-crossing footprints clipped accordingly. Finally, all density indicators and connectivity indices were compared descriptively

across the three study areas.



**Figure 2.** Research Locations

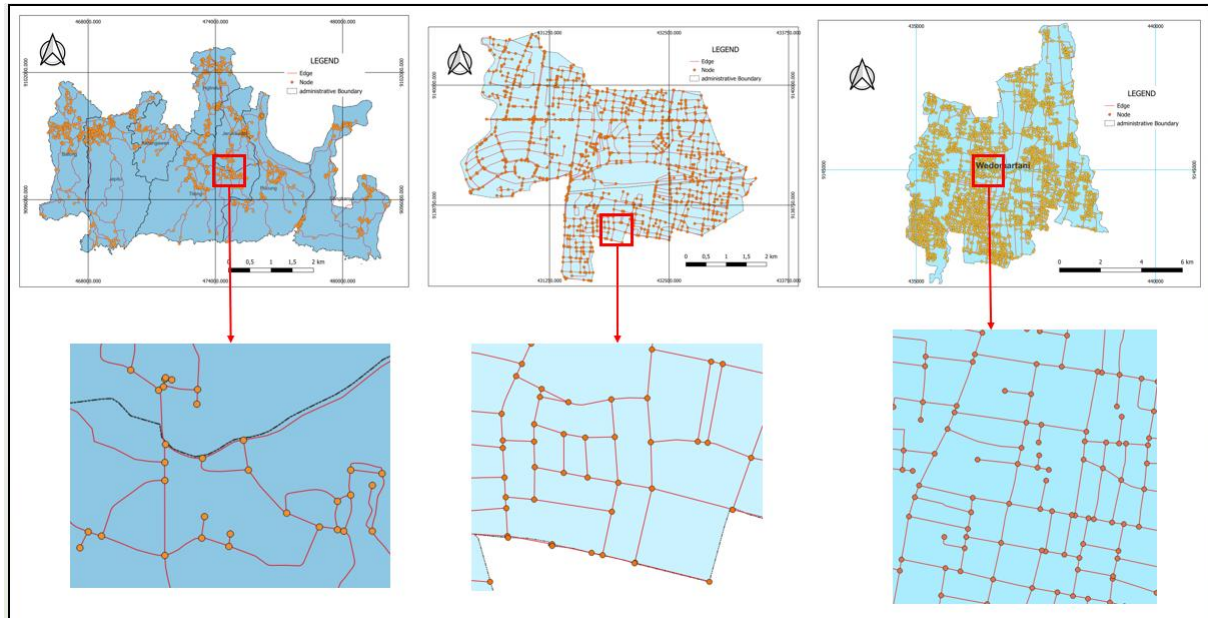


**Figure 3.** Data processing workflow

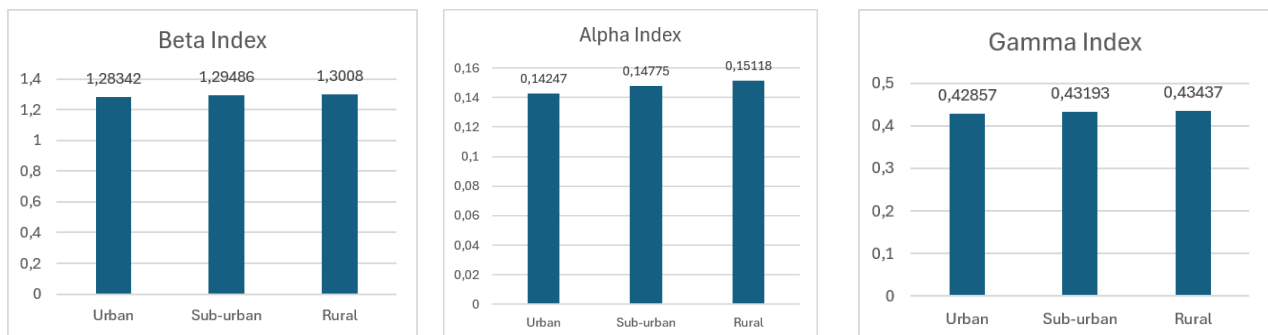
## FINDINGS AND DISCUSSION

Figure 4 presents the spatial visualization of road-network edges and nodes across the three study areas. The visualization illustrates the structural configuration of the road networks

and spatially represents the network elements used in the graph-theoretic analysis. Edges represent road segments, while nodes represent physical connection points between segments. The comparison of Gondokusuman, Wedomartani, and Girisubo provides an overview of how road-network structure varies across urban, suburban, and rural contexts and complements the quantitative results of the Beta, Alpha, and Gamma indices presented in Figure 5.



**Figure 4.** Graph representation of Overture Maps road networks across the study area



**Figure 5.** Comparison of road network connectivity across different urbanization typologies

Table 1 summarizes the calculated density indicators for the urban, suburban, and rural study areas, providing a basis for comparing settlement intensity with road-network structure. The results demonstrate a clear gradient of settlement intensity across the three study areas, while road-network connectivity does not follow the same pattern. Gondokusuman, representing the urban context, has the highest population density, followed by Wedomartani and Girisubo. A similar gradient is observed for road density, building count density, and building footprint coverage. Road density decreases from 20.70 km/km<sup>2</sup> in Gondokusuman to 16.16 km/km<sup>2</sup> in Wedomartani and 2.85 km/km<sup>2</sup> in Girisubo. Building count density decreases from 3,871.54 to 1,734.19 and 127.67 buildings/km<sup>2</sup>, respectively, while building footprint coverage declines from 42.89% to 15.81% and 1.17%. These results indicate strong differentiation in demographic and built-environment intensity across urban, suburban, and rural contexts.

**Table 1.** Edges, vertices or nodes, and density indicators by study area

| Parameter                               | Urban –<br>Gondokusuman | Suburban –<br>Wedomartani | Rural – Girisubo |
|-----------------------------------------|-------------------------|---------------------------|------------------|
| E                                       | 1,440                   | 3,579                     | 1,466            |
| V                                       | 1,122                   | 2,764                     | 1,127            |
| Area (km <sup>2</sup> ) – Ina Geoportal | 4.055                   | 12.415                    | 91.235           |
| PD (people/km <sup>2</sup> ) – BPS      | 10,854.00               | 2,561.41                  | 260.55           |
| RD (km/km <sup>2</sup> )                | 20.7014                 | 16.1603                   | 2.8504           |
| BCD (buildings/km <sup>2</sup> )        | 3,871.536               | 1,734.194                 | 127.670          |
| BFC (%)                                 | 42.89                   | 15.81                     | 1.17             |

The higher densities in Gondokusuman align with the general relationship between urban development and the concentration of population and built infrastructure. Population density, building concentration, and transportation infrastructure are interconnected dimensions of urban form (Ewing & Cervero, 2010). Previous Indonesian research has also shown the relevance of population density and street connectivity as components of urban form, particularly in relation to transportation characteristics (Putri & Indradjati, 2022). In this study, the simultaneous decline in PD, RD, BCD, and BFC from Gondokusuman to Girisubo provides empirical evidence of an urbanization gradient.

However, graph-theoretic connectivity shows a different pattern. The Beta Index increases from 1.283 in Gondokusuman to 1.295 in Wedomartani and 1.301 in Girisubo. The Alpha Index rises from 0.142 to 0.148 and 0.151, while the Gamma Index increases from 0.429 to 0.432 and 0.434. Thus, all three measures consistently indicate slightly higher topological connectivity in the rural area than in the urban area. The differences are small, suggesting that the three networks have broadly comparable structural connectivity despite substantial differences in road and settlement density.

This finding is important because road density and network connectivity represent different dimensions of the transportation system. Road density measures the amount of road infrastructure relative to land area, whereas Beta, Alpha, and Gamma describe the structural relationship between nodes and links within the network (Kansky, 1963). Gondokusuman has about seven times the road density of Girisubo, yet its connectivity indices are slightly lower. More road infrastructure therefore does not necessarily produce a proportionally more connected network. Urban networks may contain hierarchical roads, access roads, and dead-end configurations that increase total road length without equivalent increases in alternative connections. Conversely, a less dense rural network can retain a relatively simple but interconnected structure.

The results differ from Levinson (2012), who found that larger U.S. metropolitan areas tended to have more interconnected and less dendritic transportation networks, with connectivity increasing with population, network size, and road density. This difference may reflect contrasting spatial scales and network contexts. Levinson (2012) examined metropolitan transportation systems across major U.S. cities, whereas this study compares three relatively small and geographically distinct settlement contexts in Yogyakarta using graph-theoretic indices. The results should not be interpreted as evidence that rural networks are universally more connected than urban networks. Rather, they show that the relationship between urban intensity and network topology is context-dependent and should be empirically evaluated.

The relatively small differences among the Beta, Alpha, and Gamma values also suggest that

the main distinction among the three areas lies more in network and settlement intensity than in network topology. Gondokusuman has the highest population and building densities and the greatest road density, indicating a highly developed and spatially intensive environment. Wedomartani occupies an intermediate position, consistent with its suburban or peri-urban character. Girisubo has substantially lower population density, road density, building density, and building footprint coverage, reflecting a more dispersed rural settlement structure. Nevertheless, its road network maintains comparable, and slightly higher, topological connectivity. This contrast supports assessing the physical quantity of infrastructure separately from its structural organization.

The finding is also relevant to recent research on street networks and urban density. [Ashik, Barrington-Leigh, and Manaugh \(2025\)](#) found that street-network connectivity can influence subsequent population-density growth, suggesting that street structure can form a persistent framework for urban development. Their findings imply an important relationship between connectivity and density, but this study shows that the relationship should not be reduced to a cross-sectional assumption that denser areas always have higher connectivity. The analysis identifies a different pattern: population and built-environment density differ strongly across settlement types, while topological connectivity varies only slightly. Moreover, because this study uses cross-sectional observations, the observed relationships should be interpreted as spatial associations rather than causal effects.

Overall, urbanization intensity and road-network connectivity do not necessarily increase in parallel. Population density, road density, building count density, and building footprint coverage show a strong and consistent urban–suburban–rural gradient, whereas Beta, Alpha, and Gamma show only modest variation and a slightly increasing pattern toward the rural area. The results therefore support using both density-based and graph-theoretic indicators in comparative road-network studies. Rather than treating a dense road network as synonymous with a highly connected network, the findings suggest treating network quantity, settlement intensity, and network topology as complementary dimensions of spatial structure.

## CONCLUSIONS

The comparison reveals distinct network and spatial profiles among the three study areas. Gondokusuman is characterized by the highest development intensity, with the highest density indicators. However, its Beta, Alpha, and Gamma indices are slightly lower than those of Wedomartani and Girisubo. In contrast, Girisubo has substantially lower densities, but relatively higher connectivity indices. These findings indicate that greater settlement and road density do not necessarily correspond to higher topological road-network connectivity, thereby answering the research question. The results also meet the study objectives by using Overture Maps Transportation data to construct road networks and calculate graph-theoretic connectivity indices, while Overture Maps Buildings, BPS population data, and administrative boundaries were used to quantify settlement-density indicators. Overall, the findings confirm that spatial density and topological connectivity capture different dimensions of road-network structure: the former reflects infrastructure and settlement intensity, whereas the latter depends on structural relationships among network nodes and edges.

## LIMITATIONS & FURTHER RESEARCH

This study has several limitations. The analysis is based on only three aggregate study areas, with one area representing each urbanization context; therefore, the results are descriptive and cannot be interpreted as statistically generalizable or causal. In addition, the Beta, Alpha, and Gamma indices describe overall network topology but do not capture other dimensions of

accessibility, such as travel distance, travel time, road hierarchy, or route impedance. The results also depend on the completeness and classification of Overture Maps data. Future research should therefore employ multiple spatial units, such as regular grids or smaller administrative areas, and incorporate additional network and spatial-statistical measures to test the robustness and generalizability of these findings.

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