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NETWORK ANALYSIS OF ROAD ACCESSIBILITY IN MADURAI DISTRICT, TAMIL NADU

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ABSTRACT

Road accessibility is a fundamental component of regional development, influencing economic growth, accessibility to healthcare, educational opportunities, and the efficient delivery of public services. This study investigates the spatial distribution of road accessibility across the 13 administrative blocks of Madurai District, Tamil Nadu, using Geographic Information System (GIS)-based buffer analysis and Nearest Neighbour Distance (NND) statistics. Road network datasets comprising National Highways, State Highways, Major District Roads, and village roads were digitized and integrated into a GIS environment to classify accessibility into three categories: high (<1 km), moderate (1–2 km), and low (>2 km). The analysis produced an observed mean nearest neighbour distance of 6.98 km and an expected mean distance of 8.44 km, producing an NNI value of 0.83 with a Z-score of approximately −3.47. These results indicate a statistically significant clustered distribution of road accessibility concentrated around the urban core of Madurai. The findings demonstrate substantial spatial disparities in transportation infrastructure between urban and rural areas of the district. The study provides valuable evidence for prioritizing rural road development, improving emergency healthcare accessibility, strengthening transportation connectivity, and promoting balanced regional development. The integration of GIS spatial analysis with Nearest Neighbour statistics offers an effective framework for infrastructure planning and sustainable transportation management.

KEYWORDS: Road Accessibility; Geographic Information System (GIS); Nearest Neighbour Index; Spatial Analysis; Madurai District; Transportation Planning; Rural Infrastructure.

1. INTRODUCTION

Transportation infrastructure forms the backbone of regional development by facilitating the movement of people, goods, and services. Among the various transportation systems, road networks remain the most important mode of connectivity in developing countries because they directly influence economic productivity, social inclusion, healthcare accessibility, educational opportunities, and overall quality of life. Regions with well-developed road infrastructure generally experience higher levels of economic growth and improved access to public services, whereas inadequate transportation networks contribute to regional disparities and socio-economic exclusion. Accessibility is widely recognised as one of the most important indicators of spatial equity and sustainable regional planning. Hansen (1959) defined accessibility as the potential for interaction between locations, emphasizing the ease with which people can reach desired destinations. Since then, accessibility has evolved into a multidimensional concept that incorporates land-use characteristics, transportation systems, temporal constraints, and individual mobility requirements (Geurs & van Wee, 2004). In recent decades, Geographic Information Systems (GIS) have become indispensable tools for measuring and visualising accessibility due to their capability to integrate spatial data, perform network analyses, and support evidence-based planning. GIS-based accessibility analysis enables researchers to identify well-connected and underserved regions through spatial techniques such as buffer analysis, network analysis, and spatial statistics. Among these methods, Nearest Neighbour Distance (NND) analysis, introduced by Clark and Evans (1954), is widely used to evaluate the spatial arrangement of geographic features. The Nearest Neighbour Index (NNI) compares observed and expected distances between points to determine whether their distribution is clustered, random, or dispersed. When combined with GIS-based road accessibility mapping, NND provides valuable quantitative evidence for identifying infrastructure inequalities and prioritizing transportation investments. Madurai District, situated in the southern part of Tamil Nadu, serves as one of the state's major economic, educational, healthcare, and cultural centres. The district comprises thirteen administrative blocks representing a diverse mix of highly urbanised, peri-urban, and rural environments. While the central urban areas possess an extensive road network connected by National Highways and State Highways, several peripheral blocks continue to experience limited transportation infrastructure. Variations in topography, settlement distribution, and historical investment patterns have resulted in considerable disparities in road accessibility across the district. Previous studies have consistently demonstrated that transportation accessibility strongly influences regional development and social equity. Geurs and van Wee (2004) emphasized that accessibility should be evaluated through an integrated framework incorporating transportation and land-use interactions. Kumar and Banerjee (2016) highlighted the usefulness of GIS techniques in identifying spatial inequalities in transportation infrastructure across India. Rao and Tiwari (2020) reported significant urban-rural disparities in transport accessibility, while Srinivasan (2018) observed that transportation investments in Tamil Nadu have historically favoured urban growth centres over peripheral rural regions. Similarly, Venkatesh and Devi (2019) demonstrated that improved transportation connectivity contributes positively to employment generation, educational attainment, healthcare utilization, and overall socio-economic development. Despite these contributions, comprehensive GIS-based assessments of road accessibility at the block level remain limited for Madurai District (Vinothini et al., 2022,2024,2025). Existing studies primarily focus on urban transportation or regional connectivity without quantitatively evaluating accessibility using spatial statistical techniques (Saravanabavan et al., 2024a,2024b; Vinothini et al.,2024). Furthermore, very few studies have integrated GIS buffer analysis with Nearest Neighbour statistics to investigate the spatial clustering of transportation infrastructure. Addressing this research gap is essential for identifying underserved areas and supporting equitable infrastructure planning. The present study applies an integrated GIS-based methodology to evaluate road accessibility across the thirteen administrative blocks of Madurai District. By combining buffer analysis with Nearest Neighbour Distance statistics, the study quantifies spatial accessibility patterns, identifies highly connected and poorly connected regions, and provides evidence-based recommendations for improving transportation infrastructure and regional equity.

1.1 OBJECTIVES OF THE STUDY

The present study was undertaken with the following objectives:

1. To evaluate the spatial distribution of road accessibility across the thirteen administrative blocks of Madurai District using Geographic Information System (GIS) techniques.
2. To assess the spatial pattern of road accessibility using the Nearest Neighbour Distance (NND) and Nearest Neighbour Index (NNI).

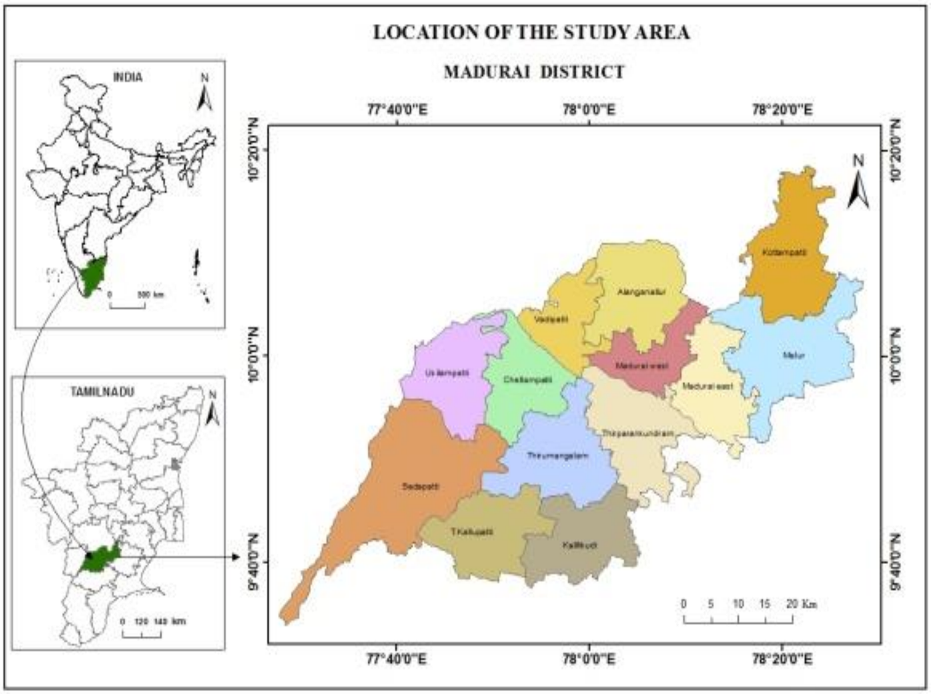

Figure 1 Location of the study area.

2. STUDY AREA

Madurai District is located in the southern part of Tamil Nadu, India, and occupies an area of approximately 3,741.7 km². Geographically, the district lies between 9°30′ and 10°30′ North latitude and 77°00′ and 78°30′ East longitude (Figure 1). It is bounded by Dindigul District to the north, Sivagangai District to the east, Virudhunagar District to the south, and Theni District to the west.

3. MATERIALS AND METHODS

3.1 Research Design

This study employed a Geographic Information System (GIS)-based spatial analytical approach to evaluate road accessibility across the thirteen administrative blocks of Madurai District, Tamil Nadu. The analysis integrated road network mapping, buffer analysis, overlay techniques, and Nearest Neighbour Distance (NND) statistics to examine the spatial distribution of transportation infrastructure. The methodology combined quantitative spatial statistics with cartographic visualization to identify accessibility disparities and prioritize regions requiring infrastructure development.

3.2 Data Sources

Both spatial and non-spatial datasets were collected from government agencies and reliable open-source databases. Administrative boundary maps, road network data, satellite imagery, and supporting geographic information were integrated into a GIS environment for analysis (Table 1).

Table 1. Data sources used in the study.

Data Type	Source	Purpose
Administrative boundaries	Survey of India (SOI); Tamil Nadu State Remote Sensing Agency (TNSRSA)	Delineation of district and block boundaries
Road network	Tamil Nadu Highways Department; OpenStreetMap (OSM)	Mapping of National Highways, State Highways, Major District Roads, and village roads
Satellite imagery	Google Earth	Verification of road alignment and connectivity
Base maps	Survey of India Topographic Sheets	Georeferencing and map preparation
Demographic information	Census of India	Administrative reference
GIS software	ArcGIS 10.8 and QGIS 3.34	Spatial analysis and map generation
Cartographic software	Adobe Illustrator	Final map preparation

3.3 Data Preparation

The collected datasets were converted into a common coordinate reference system (WGS 84 / UTM Zone 43N) to ensure spatial consistency. Road network layers obtained from different sources were integrated into a single geodatabase after removing duplicate segments and correcting topological errors. Administrative boundaries were clipped to the district extent, and all spatial layers were verified using high-resolution satellite imagery to improve positional accuracy.

- National Highways (NH)
- State Highways (SH)
- Major District Roads (MDR)
- Village and local roads

The prepared database formed the basis for all subsequent spatial analyses.

3.4 Techniques

3.4.1 GIS-Based Buffer Analysis

Road accessibility was evaluated using Euclidean buffer analysis. Buffer zones were generated around the entire road network to determine the level of accessibility for different parts of the district. The selected buffer distances represent practical measures of proximity to transportation infrastructure and were classified into three accessibility categories (Table 2).

Table 2. Road accessibility classification.

Buffer Distance	Accessibility Category	Interpretation
< 1 km	High Accessibility	Areas located close to major roads with excellent transportation connectivity
1–2 km	Moderate Accessibility	Areas having reasonable road access but requiring additional feeder roads
> 2 km	Low Accessibility	Remote regions with poor accessibility and limited transportation infrastructure

The generated buffer layers were intersected with administrative block boundaries using overlay analysis. This procedure enabled identification of accessibility levels for each administrative block and facilitated comparison of spatial disparities across the district.

3.4.2 Overlay Analysis

Spatial overlay analysis was performed to integrate the road accessibility buffer with block boundaries. This process enabled the calculation of accessibility characteristics within each administrative unit and identified areas that remained outside the effective road service zone.

Overlay analysis assisted in:

- Identifying highly connected urban regions;
- Locating underserved rural settlements;
- Evaluating spatial variation in transportation infrastructure; and
- Supporting regional planning and infrastructure prioritization.

3.5 Nearest Neighbour Distance Analysis

Nearest Neighbour Distance (NND) analysis was employed to evaluate the spatial arrangement of accessibility nodes across the thirteen administrative blocks. The method proposed by Clark and Evans (1954) was adopted to determine whether the observed spatial distribution exhibited clustering, randomness, or dispersion.

The observed mean nearest neighbour distance (Do) was calculated from the average distance between each block and its nearest neighbouring block. The expected mean distance (De) for a random spatial distribution was computed using:

Observed Mean Distance (Do)

$Do = (\Sigma di)/n$

Expected Mean Distance (De)

$De = 1/[2\sqrt{(n/A)}]$

where: **De** = Expected mean nearest neighbour distance, **n** = Number of spatial points (13 blocks), **A** = Study area (3,741.7 km^2)

The Nearest Neighbour Index (NNI) was then calculated as:

Nearest Neighbour Index (NNI)

$NNI = Do/De$

where: **Do** = Observed mean nearest neighbour distance, **De** = Expected mean nearest neighbour distance

The statistical significance of the spatial pattern was evaluated using the standardized Z-score. Negative Z-score values indicate clustering, whereas positive values indicate dispersion.

Z-score

$Z = (Do - De)/SE$

$SE = 0.26136/\sqrt{(n^2/A)}$

Z = Standardized Z-score, SE = Standard Error, n = Number of spatial points, A = Study area (km^2)

For the present study:

- Number of blocks (n): **13**
- Study area: **3,741.7 km^2**
- Observed mean distance (Do): **6.98 km**
- Expected mean distance (De): **8.44 km**
- Nearest Neighbour Index (NNI): **0.83**
- Z-score: **−3.47**

Since the NNI is less than one and the Z-score is strongly negative, the spatial distribution of road accessibility nodes is interpreted as significantly clustered.

3.6 Accessibility

Based on the observed nearest neighbour distances, the thirteen administrative blocks were classified into three accessibility groups (Table 3).

Table 3. Classification of administrative blocks according to road accessibility.

Accessibility Category	Blocks	Distance Range (km)
Highly Accessible	Madurai East, Madurai West	Approximately 5.2
Moderately Accessible	Thiruparangundram, Tirumangalam, Vadipatti, T. Kallupatti, Kallikudi, Alanganallur	5.7–7.0
Low Accessibility	Melur, Kottampatti, Sedapatti, Usilampatti, Chellampatti	8.2–9.4

This classification facilitated spatial comparison of transportation accessibility and helped identify priority areas for future infrastructure development.

4. RESULTS

4.1 Spatial Pattern of Road Accessibility

The GIS-based road accessibility analysis revealed considerable spatial variation in transportation connectivity across the thirteen administrative blocks of Madurai District. Accessibility was assessed using buffer zones generated around the road network and classified into three categories: high accessibility (<1 km), moderate accessibility (1–2 km), and low accessibility (>2 km). The resulting accessibility map demonstrates a clear concentration of road infrastructure in the central urban region, whereas peripheral rural blocks exhibit relatively poor connectivity.

The highest accessibility was observed in the urban blocks of **Madurai East** and **Madurai West**, where dense road networks and multiple highway corridors provide extensive transportation coverage (Figure 2). These blocks are traversed by major transportation corridors, including National Highways NH-38, NH-85, and NH-744, together with an extensive network of State Highways and urban roads. Consequently, a large proportion of these areas lies within one kilometre of a major road, indicating excellent accessibility to public services, commercial centres, healthcare facilities, and educational institutions. Moderate accessibility was identified in **Thiruparangundram, Tirumangalam, Vadipatti, T. Kallupatti, Kallikudi,** and **Alanganallur**. These peri-urban and semi-rural blocks are connected by major highways but have comparatively lower densities of feeder and village roads. Although transportation connectivity is adequate, several interior settlements remain beyond the immediate service area of the primary road network.

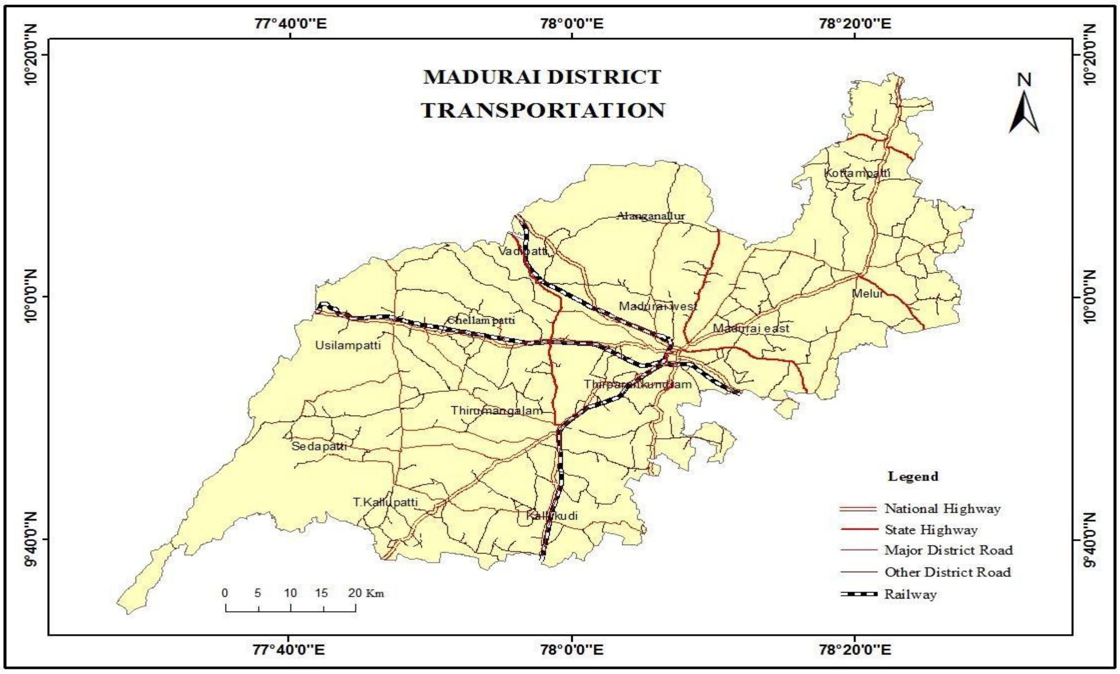

Figure 2 Spatial Pattern of Road Accessibility in Madurai District.

The least accessible regions were observed in **Melur, Kottampatti, Sedapatti, Usilampatti,** and **Chellampatti**, where extensive portions of the landscape occur beyond two kilometres from the nearest major road. These predominantly rural blocks are characterized by dispersed settlements, lower road density, and more complex terrain, resulting in comparatively limited transportation accessibility. Overall, the accessibility map illustrates a pronounced urban–rural gradient, with road infrastructure concentrated around Madurai City and gradually declining toward the western, north-western, and southern parts of the district.

4.2 Nearest Neighbour Distance Analysis

Nearest Neighbour Distance (NND) analysis was performed to evaluate the spatial distribution of accessibility nodes among the thirteen administrative blocks. The observed mean nearest neighbour distance (6.98 km) was substantially lower than the expected distance for a random spatial distribution (8.44 km). Consequently, the calculated Nearest Neighbour Index (NNI) of **0.83** indicates that accessibility nodes are spatially clustered rather than randomly distributed. The calculated Z-score of **−3.47** further confirms that the observed clustering is statistically significant. Therefore, the null hypothesis of random spatial distribution is rejected, demonstrating that road accessibility is concentrated within specific regions of the district, particularly around the urban core.

4.3 Block-wise Nearest Neighbour Distance

The nearest neighbouring block and corresponding distance for each administrative block are presented in **Table 4**.

Table 4. Block-wise nearest neighbour distances.

Sl. No.	Block	Nearest Neighbour	Distance (km)
1	Madurai West	Madurai East	5.2
2	Madurai East	Madurai West	5.2
3	Thiruparangundram	Madurai West	6.1
4	Tirumangalam	Thiruparangundram	7.0
5	Melur	Kottampatti	8.5
6	Sedapatti	Usilampatti	9.4
7	Usilampatti	Sedapatti	9.4
8	Kallikudi	T. Kallupatti	6.3
9	T. Kallupatti	Kallikudi	6.3
10	Vadipatti	Alanganallur	5.7
11	Chellampatti	Usilampatti	8.2
12	Alanganallur	Vadipatti	5.7
13	Kottampatti	Melur	8.5

The shortest nearest neighbour distance (5.2 km) was observed between **Madurai East** and **Madurai West**, reflecting the dense transportation infrastructure within the urban core. Conversely, **Sedapatti** and **Usilampatti** recorded the greatest nearest neighbour distance (9.4 km), indicating relatively isolated transportation networks in the western rural region (Figure 3).

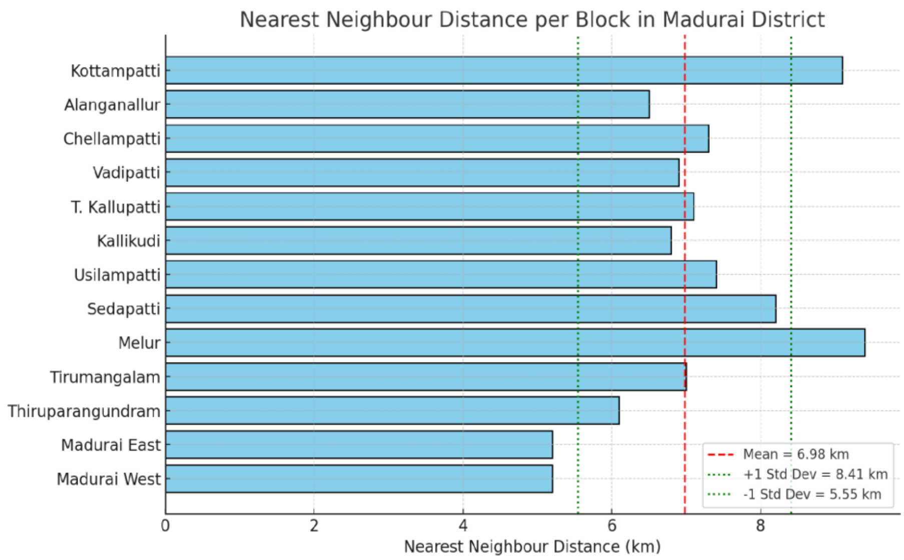

Figure 3. Block-wise Nearest Neighbour Distances among Administrative Blocks.

4.4 Accessibility Classification

Based on nearest neighbour distances, the administrative blocks were classified into three accessibility categories (Table 5).

Table 5. Accessibility classification of administrative blocks.

Accessibility Category	Administrative Blocks	Distance Range (km)
Highly Accessible	Madurai East, Madurai West	Above 5.2
Moderately Accessible	Thiruparangundram, Tirumangalam, Vadipatti, T. Kallupatti, Kallikudi, Alanganallur	5.7–7.0
Low Accessibility	Melur, Kottampatti, Sedapatti, Usilampatti, Chellampatti	8.2–9.4

The classification clearly demonstrates that transportation accessibility decreases progressively from the urban centre toward the peripheral rural blocks.

4.5 Spatial Distribution of Accessibility

4.5.1 Highly Accessible Blocks

Madurai East and Madurai West constitute the most accessible areas of the district. These blocks exhibit the lowest nearest neighbour distances and the greatest concentration of road infrastructure. Extensive National Highways, State Highways, and urban road networks provide efficient transportation, ensuring rapid access to healthcare facilities, educational institutions, markets, and government services. The high density of transportation corridors reflects the economic importance of these urban centres.

4.5.2 Moderately Accessible Blocks

The blocks of Thiruparangundram, Tirumangalam, Vadipatti, Alanganallur, T. Kallupatti, and Kallikudi display moderate levels of accessibility. Although connected to major transportation corridors, these blocks have comparatively lower densities of secondary and feeder roads. Consequently, accessibility declines toward interior rural settlements where transportation options become more limited.

4.5.3 Low Accessibility Blocks

Melur, Kottampatti, Sedapatti, Usilampatti, and Chellampatti exhibit the lowest accessibility across the district. These blocks are characterized by relatively long nearest neighbour distances, sparse transportation infrastructure, and dispersed settlement patterns. The limited availability of all-weather roads increases travel time to essential services and contributes to regional disparities in healthcare, education, and economic opportunities.

4.6 Correlation between Nearest Neighbour Distance and Road Accessibility

The relationship between Nearest Neighbour Distance and the percentage of block area located within one kilometre of a road was examined using scatter plot analysis. The results demonstrate a strong inverse relationship between the two variables, with a Pearson correlation coefficient of approximately **−0.96**.

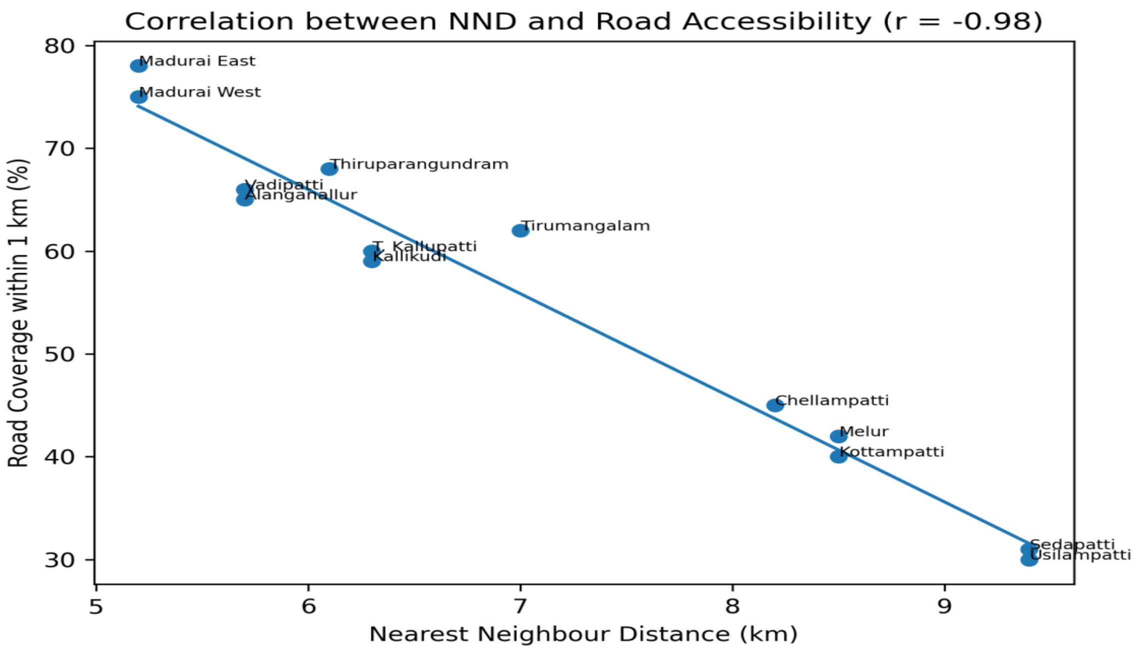

Figure 4 Correlation between Nearest Neighbour Distance and Road Accessibility in Madurai District.

Blocks exhibiting shorter nearest neighbour distances generally possessed substantially greater road coverage. Madurai East and Madurai West recorded the highest levels of accessibility, with more than 70% of their land area located within one kilometre of a major road. In contrast, Sedapatti, Usilampatti, Melur, Kottampatti, and Chellampatti displayed both larger nearest neighbour distances and considerably lower road coverage percentages. The scatter plot (Figure 4) demonstrates a strong inverse relationship between nearest neighbour distance and the percentage of block area located within one kilometre of a road. This finding confirms that nearest neighbour distance provides a reliable indicator for evaluating spatial inequalities in road infrastructure across the district.

4.7 Spatial Connectivity Pattern

The accessibility map reveals a well-defined spatial pattern of transportation connectivity throughout Madurai District. The central and eastern parts of the district exhibit dense transportation networks supported by National Highways and State Highways connecting Madurai with Dindigul, Tiruchirappalli, Theni, Tirunelveli, and neighbouring districts. In contrast, the western and south-western blocks display relatively fragmented transportation networks with fewer secondary roads. Large portions of these regions remain outside the primary road service area, reflecting lower population density, dispersed settlements, and challenging topographic conditions. The spatial clustering identified through Nearest Neighbour analysis corresponds closely with the distribution of transportation infrastructure. Urban blocks form a compact, highly connected cluster, whereas rural blocks remain spatially isolated. This pattern demonstrates the unequal distribution of transportation resources within the district and highlights the need for targeted infrastructure investments in underserved regions.

Overall, the results indicate that transportation accessibility in Madurai District is strongly influenced by the degree of urbanization, road network density, settlement distribution, and geographical characteristics. These findings provide a robust spatial basis for prioritizing future road development, enhancing regional connectivity, and promoting equitable access to essential services.

5. DISCUSSION

The present study employed Geographic Information System (GIS)-based buffer analysis and Nearest Neighbour Distance (NND) statistics to evaluate the spatial distribution of road accessibility across the thirteen administrative blocks of Madurai District. The results reveal a distinct urban–rural disparity in transportation accessibility, with highly connected urban centres surrounded by progressively less accessible peripheral regions. The calculated Nearest Neighbour Index (NNI = 0.83) and the corresponding Z-score (−3.47) indicate a statistically significant clustered distribution of road accessibility, confirming that transportation infrastructure is concentrated around the district's urban core rather than being evenly distributed. The clustering pattern observed in this study is consistent with the theory proposed by Clark and Evans (1954), who demonstrated that spatial point distributions with NNI values less than one indicate clustering rather than random dispersion. Similar findings have been reported in transportation and regional planning studies, where urban areas generally exhibit dense transportation networks due to concentrated population, commercial activities, and public investment (Longley et al., 2015; Rodrigue, 2020). In Madurai District, the concentration of National Highways (NH-38, NH-85, and NH-744), State Highways, and urban road networks around Madurai East and Madurai West has created a highly connected transportation hub that supports efficient movement of people and goods.

The GIS buffer analysis further demonstrated that the central and eastern portions of the district contain a substantially larger proportion of land within one kilometre of a major road compared with the western and southern blocks. This spatial pattern reflects historical infrastructure development, where transportation investments have primarily supported urban growth and regional economic expansion. Consequently, urban residents benefit from shorter travel times, greater employment opportunities, improved healthcare accessibility, and better educational facilities. Conversely, rural blocks such as Sedapatti, Usilampatti, Kottampatti, Melur, and Chellampatti exhibited considerably lower accessibility because of sparse road networks, dispersed settlements, and relatively challenging topography. The greater nearest neighbour distances observed in these areas indicate reduced transportation connectivity, which may limit access to healthcare services, educational institutions, agricultural markets, and employment opportunities. Similar urban–rural accessibility disparities have been documented in other regions of India, where inadequate transportation infrastructure continues to constrain rural development (Rao & Tiwari, 2020).

The strong negative correlation ($r \approx -0.96$) between nearest neighbour distance and road service coverage confirms that transportation accessibility declines as spatial isolation increases. Administrative blocks with shorter nearest neighbour distances consistently exhibited greater road coverage, whereas blocks with larger nearest neighbour distances remained comparatively underserved. This finding demonstrates that Nearest Neighbour Distance provides an effective quantitative indicator for evaluating transportation accessibility and identifying priority areas for infrastructure investment. The combined application of GIS-based buffer analysis and spatial statistical techniques proved highly effective in identifying accessibility inequalities. Buffer analysis clearly delineated the spatial extent of road service coverage, while Nearest Neighbour statistics quantified the degree of clustering. Together, these complementary techniques provide planners with objective evidence for prioritizing transportation infrastructure projects and promoting balanced regional development.

The findings of this study have important implications for transportation planning, regional development, and public service delivery in Madurai District. The western and southern administrative blocks require priority investment in rural transportation infrastructure. Construction and upgrading of Major District Roads and village roads should focus particularly on Sedapatti, Usilampatti, Melur, Kottampatti, and Chellampatti to reduce travel distances and improve regional connectivity. Expanding all-weather road networks would enhance accessibility for rural communities while supporting agricultural marketing and local economic development. Transportation accessibility is directly associated with timely access to healthcare services. Poor road connectivity can delay emergency medical response and reduce healthcare utilization among rural populations. Therefore, improving road infrastructure leading to Primary Health Centres (PHCs), Community Health Centres (CHCs), and district hospitals should be prioritized. Establishing ambulance-friendly road corridors would substantially improve emergency response times in remote villages. Improved transportation connectivity facilitates access to schools, colleges, vocational training centres, and employment opportunities. Upgrading feeder roads in moderately accessible blocks would reduce travel time for students and workers while strengthening economic integration between rural and urban areas. Enhanced connectivity may also encourage investment and support the growth of rural enterprises. The accessibility map developed in this study provides a valuable decision-support tool for district planners and policy makers. Future infrastructure investment should adopt a spatially balanced approach by directing resources toward underserved regions rather than concentrating solely on urban growth centres. Integrating GIS-based accessibility analysis into district development planning can improve transparency, optimize resource allocation, and promote equitable regional development. Future transportation planning should incorporate multimodal accessibility, public transportation networks, travel-time analysis, and socio-economic indicators to provide a more comprehensive assessment of regional connectivity. The integration of network analysis with demographic and economic datasets would further strengthen infrastructure planning and policy formulation.

7. LIMITATIONS OF THE STUDY

Although the present study provides valuable insights into spatial variations in road accessibility, several limitations should be acknowledged. First, the accessibility assessment was based on Euclidean (straight-line) buffer distances rather than actual travel distances along the road network. Incorporating network-based travel-time analysis would provide a more realistic representation of transportation accessibility. Second, the analysis did not account for seasonal variations in road conditions. During the monsoon season, flooding and road damage may significantly alter accessibility, particularly in rural areas. Third, population distribution and traffic volume were not incorporated into the accessibility assessment. Population-weighted accessibility analysis would enable a more accurate evaluation of service availability for residents. Fourth, although selected field verification was conducted, comprehensive ground surveys covering all administrative blocks were beyond the scope of this study. Additional field investigations would improve the accuracy of road network validation. Finally, the study focused exclusively on road transportation. Future research should integrate public transportation services, travel behaviour, and multimodal accessibility to provide a broader understanding of regional mobility.

8. CONCLUSION

This study evaluated road accessibility across the thirteen administrative blocks of Madurai District using Geographic Information System (GIS)-based buffer analysis and Nearest Neighbour Distance (NND) statistics. The results revealed a statistically significant clustered distribution of transportation infrastructure, with accessibility concentrated around the urban core of Madurai City. The calculated Nearest Neighbour Index (0.83) and negative Z-score (−3.47) confirmed that road accessibility is not randomly distributed but instead exhibits strong spatial clustering. The analysis identified Madurai East and Madurai West as highly accessible blocks because of their dense road networks and strategic location along major transportation corridors. In contrast, Melur, Kottampatti, Sedapatti, Usilampatti, and Chellampatti exhibited relatively poor accessibility owing to sparse road infrastructure, dispersed settlements, and geographical constraints. These disparities demonstrate the existence of a pronounced urban–rural transportation divide within the district. The integration of GIS buffer analysis with Nearest Neighbour statistics proved effective for identifying accessibility inequalities and establishing infrastructure development priorities. The accessibility classification generated in this study provides practical guidance for transportation planners, local governments, and policy makers seeking to improve regional connectivity and ensure equitable access to healthcare, education, markets, and public services. Based on the findings, priority should be given to strengthening rural road infrastructure, upgrading feeder roads, improving emergency transportation networks, and incorporating GIS-based accessibility assessments into district-level planning processes. Such interventions would contribute significantly to balanced regional development and help reduce socio-economic disparities between urban and rural communities. Future studies should integrate network-based travel-time modelling, population-weighted accessibility indices, traffic flow analysis, and remote sensing datasets to develop a more comprehensive understanding of transportation accessibility. The methodology presented in this study can also be applied to other districts in Tamil Nadu and elsewhere to support evidence-based transportation planning and sustainable regional development.

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