Geospatial and Earth System Science
An International Triannual Scientific Journal
e-ISSN: 3139-549X | Vol. 1 | No. 1 | Page Nos. 45 - 55 | June 2026
Original Research Paper | https://www.maned.org/journals | Open Access Journal

Spatial Accessibility and Transport Network Structure: A GIS-Based Analysis of Dharmapuri Taluk, Tamil Nadu

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Abbreviation: GESS
Website: www.maned.org/journals

Received: 04-01-2026
Revised: 24-04-2026
Accepted: 07-05-2026

Key Words:

Transportation
Network
Accessibility
GIS Analysis
Social Accessibility
Spatial Inequality
Rural Accessibility
Network Analysis
Dharmapuri Taluk

ABSTRACT

Transportation networks play a vital role in determining spatial accessibility and regional equity, particularly in semi-urban regions where infrastructure distribution is often uneven. This study examines the impact of transportation networks on social accessibility in Dharmapuri Taluk, Tamil Nadu, using a GIS-based network analysis framework. Both primary and secondary data were integrated to develop a spatial database, and analytical techniques such as shortest path analysis, service area mapping, Isotim travel cost analysis, and Shimbel index-based accessibility assessment were employed. The results reveal significant spatial disparities in accessibility across the study area. Central locations, including Dharmapuri town, Annasagaram, Adiyamankottai, and Lakkiampatti, exhibit higher accessibility due to better connectivity, denser road networks, and proximity to essential services. In contrast, peripheral villages such as Akkamanahalli, Andihalli, Kadagathur, Kammampatti, Konangihalli, and Errabaiyanahalli experience lower accessibility, characterized by longer travel distances, higher travel costs, and limited route options. The findings indicate a clear core–periphery pattern, where infrastructure concentration in central areas leads to unequal access to services in outer regions. The study further demonstrates that although the transportation network ensures basic connectivity, it lacks sufficient redundancy and alternative route options in several parts of the taluk, particularly in villages such as Noolahalli, Kondampatti, and Konanginayakkanahalli, which remain dependent on limited road linkages. This reduces network efficiency and increases vulnerability to disruptions. The accessibility patterns also highlight that improved connectivity is closely associated with better access to education, healthcare, and other essential services, while poorly connected villages such as Budanahalli, Dhalavaihalli, and Dokkubodanahalli continue to face accessibility constraints. The findings provide valuable insights for policymakers and planners to design targeted interventions aimed at improving connectivity in underserved villages and promoting balanced regional development.

INTRODUCTION

Transportation networks play a crucial role in shaping regional development by enabling the movement of people, goods, and services across space. In both urban and semi-urban contexts, the efficiency of transport systems directly influences access to essential facilities such as education, healthcare, and markets (van Wee, 2016). Particularly in developing countries like India, where regional disparities are pronounced, transportation infrastructure acts as a key driver in reducing spatial inequalities and promoting balanced development (van Wee, 2016; Neutens, 2015). However, the mere presence of transport infrastructure does not guarantee equitable accessibility; rather, its structure, connectivity, and efficiency determine how effectively different regions benefit from it. From a geographical standpoint, transportation is closely associated with the concept of spatial interaction, which explains the movement between places based on factors such as distance, accessibility, and connectivity. Early geographical studies emphasized that transport systems reflect the functional relationships between regions and are fundamental to understanding patterns of human activity. Over time, accessibility has emerged as a central concept in transport geography, representing the ease with which people can reach desired services and opportunities (Bhat C. et al., 2000). It is now widely recognized that accessibility is not only a physical measure but also a socio-economic indicator that influences quality of life and regional equity (Geurs et al., 2004; Neutens, 2015; van Wee, 2016).

The advancement of geospatial technologies, particularly Geographic Information Systems (GIS), has significantly transformed the analysis of transportation networks. GIS-based network analysis enables the evaluation of route efficiency, service areas, and spatial accessibility with high precision (Weber & Kwan, 2003). Techniques such as shortest path analysis, buffer analysis, and accessibility modeling are widely used to assess how transportation systems function in real-world scenarios and to identify areas with inadequate service provision (Xie et al., 2011). These tools provide a powerful framework for integrating spatial data with analytical methods, thereby supporting evidence-based planning and decision-making (Weber & Kwan, 2003).

In addition to GIS-based approaches, graph theory has been extensively applied to evaluate the structural characteristics of transportation networks. Network indices such as Alpha, Beta, and Gamma offer quantitative measures of connectivity, density, and efficiency within a transport system. These indices help in understanding how well different parts of a network are interconnected and how effectively the network supports movement across regions. A higher level of connectivity generally indicates better accessibility, while fragmented networks often lead to spatial isolation and reduced service reach (Rodrigue et al., 2017).Accessibility, in this context, serves as a critical link between transportation infrastructure and social development. Regions with well-connected transport networks tend to exhibit improved socio-economic conditions, as residents can easily access employment opportunities, educational institutions, and healthcare services (Neutens, 2015; van Wee, 2016). Conversely, areas with poor connectivity often face challenges such as limited mobility, reduced service access, and economic marginalization (Neutens, 2015). Therefore, assessing accessibility through integrated spatial and network-based approaches is essential for identifying inequalities and guiding infrastructure development (Hansen, 1959).

Despite ongoing efforts to improve transportation systems, many regions continue to experience uneven accessibility due to variations in network structure and infrastructure distribution. Dharmapuri Taluk in Tamil Nadu represents a typical semi-urban region where central areas are relatively well connected, while peripheral zones remain less accessible. Such disparities highlight the need for a systematic analysis of transportation networks and their impact on social accessibility. In this context, the present study aims to examine the role of urban transportation networks in shaping social accessibility in Dharmapuri Taluk using GIS-based network analysis and graph theory indices. By integrating spatial techniques with quantitative measures of connectivity and accessibility, the study seeks to identify spatial disparities, evaluate network performance, and suggest planning strategies for improving equitable access to essential services (church, A. et al., 2000).

STUDY AREA

The present study focuses on Dharmapuri Taluk, located in the northwestern part of Tamil Nadu, India. The taluk serves as an important administrative and economic unit within Dharmapuri District and covers an area of approximately 282.60 square kilometres. Geographically, the region occupies a strategic position with significant connectivity through major transport corridors, including National Highways such as NH-44 and NH-844, which link it to major urban centres like Bengaluru, Salem, and Vellore. This locational advantage makes Dharmapuri Taluk a suitable case for examining the relationship between transportation networks and social accessibility. The physical setting of Dharmapuri Taluk is characterized by a mix of undulating terrain, agricultural lands, and scattered rural settlements, interspersed with emerging urban pockets. The region experiences a semi-arid climate, which influences both land use patterns and economic activities. The availability and distribution of transportation infrastructure play a crucial role in shaping the accessibility of these settlements, particularly in areas where physical geography poses constraints to connectivity. The transport network in the study area is predominantly road-based, with an extensive system of national highways, state highways, and rural roads forming the backbone of mobility. The presence of Dharmapuri railway station further enhances regional connectivity by providing access to inter-district and inter-state transportation. In addition, local transport services such as buses, private vehicles, and auto-rickshaws facilitate intra-regional movement. However, despite the presence of major transport routes, the distribution of connectivity is not uniform across the taluk, with peripheral areas often experiencing limited accessibility.

Socio-economically, Dharmapuri Taluk exhibits a mixed rural-urban character. The majority of the population is engaged in agriculture and allied activities, with mango cultivation being a prominent economic activity that has earned the region recognition as part of the "mango belt" of Tamil Nadu.

Alongside agriculture, small-scale industries such as agro-processing, handloom production, and brick manufacturing contribute to the local economy. However, limited industrial development and employment opportunities have led to seasonal migration of labour to nearby urban centres, highlighting the importance of transport connectivity in supporting livelihoods and economic mobility.
The distribution of essential services such as schools, healthcare facilities, and commercial centres is uneven across the taluk. While urban and central areas tend to have better access to such services, rural and peripheral regions often face challenges due to inadequate infrastructure and longer travel distances. This spatial variation in service availability underscores the need to analyze transportation networks in relation to social accessibility, as improved connectivity can significantly enhance access to basic amenities and contribute to regional development (Geurs & van Wee, 2004).

Overall, the combination of diverse physical characteristics, varying levels of transport connectivity, and socio-economic disparities makes Dharmapuri Taluk an appropriate study area for assessing the impact of transportation networks on accessibility. The region provides a representative example of how infrastructure distribution influences spatial equity and highlights the need for integrated planning approaches to ensure balanced development.

DATA AND METHODOLOGY

This study adopts a geospatial and network-based analytical framework to evaluate the impact of transportation networks on social accessibility in Dharmapuri Taluk. The methodology integrates Geographic Information Systems (GIS) techniques with graph theory-based indices to assess connectivity, accessibility, and spatial disparities. The overall approach involves systematic stages of data collection, processing, network modelling, and analytical evaluation.

Systems Data Sources

The study utilizes both primary and secondary data to construct a comprehensive spatial database. Primary data include the geographic locations of essential service facilities such as bus stops, schools, colleges, hospitals, banks, and government offices. These data were collected using field inputs, Google Earth Pro, and publicly available geospatial platforms. Secondary data comprise administrative boundaries, road network data, and proposed infrastructure information obtained from sources such as Tamil Nadu GIS (TNGIS), OpenStreetMap (OSM), Geofabrik, and other government databases. Educational data were sourced from the UDISE portal, while additional spatial layers were derived from publicly accessible GIS repositories.

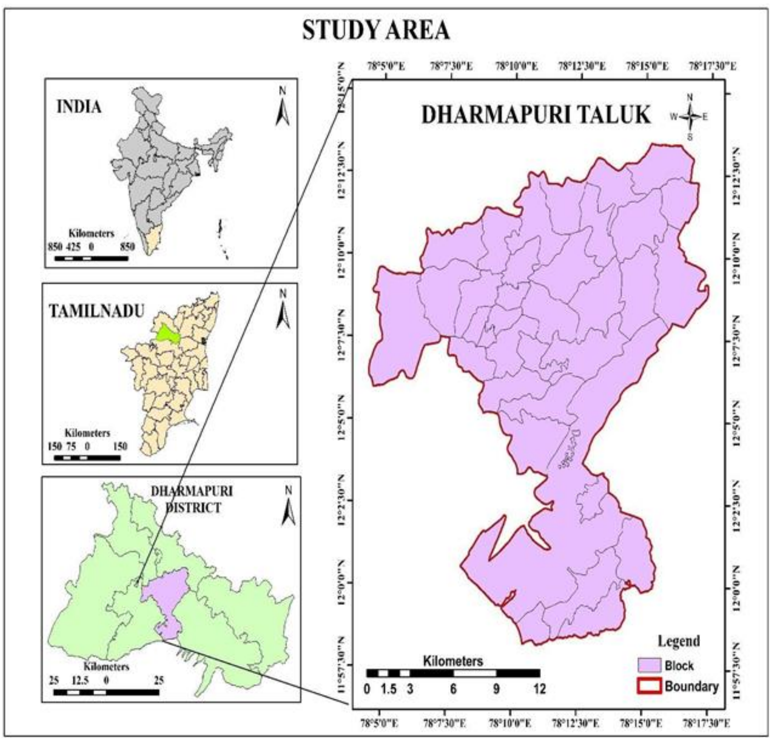

Fig. 1- Study Area Map of Dharmapuri Taluk

Data Processing and Database Creation

The collected datasets were processed and integrated into a GIS environment to develop a structured spatial database. All spatial features were georeferenced and converted into compatible formats for analysis. Road networks were digitized and attributed with relevant parameters such as length, travel distance, and connectivity.

A network dataset was created in ArcGIS by establishing topological relationships between nodes (intersections) and edges (road segments). This enabled the modelling of real-world transport networks for subsequent analysis. Attribute data, including travel cost, distance, and service coverage, were linked to spatial layers to facilitate integrated analysis.

Software and Tools Used

The analysis of transportation networks and accessibility in the present study was carried out using a combination of geospatial and data processing tools. ArcGIS was the primary platform employed for spatial analysis, network modelling, and map generation, enabling the creation of network datasets and execution of various analytical functions such as connectivity, shortest path, and service area analysis (Currie, G. 2010). Google Earth Pro was utilized to identify and verify the geographic locations of key facilities and to assist in georeferencing spatial data through high-resolution satellite imagery. Additionally, Microsoft Excel was used for organizing attribute data, managing coordinate information, and performing preliminary calculations required for network indices. The integration of these tools facilitated an efficient and systematic approach to handling both spatial and non-spatial data within the study.

Analytical Framework

The study employs multiple analytical techniques to evaluate transportation networks and accessibility: Connectivity analysis examines the structural characteristics of the road network by evaluating how nodes are linked through edges. This helps in understanding the completeness and efficiency of the transport system. The shortest path analysis identifies the most efficient routes between origin and destination points based on minimum travel distance or cost. This is particularly useful for evaluating access to critical services such as healthcare facilities. Buffer analysis is used to delineate service areas around key facilities such as schools and hospitals. It helps in identifying served and underserved regions within the study area. Accessibility is assessed by evaluating the ease with which different locations can be reached within the network. This involves the use of indices and spatial modelling techniques to quantify variations in accessibility.

Workflow of Analysis

The methodological workflow of the study follows a systematic sequence of steps designed to ensure a comprehensive evaluation of transportation networks and accessibility patterns. The process begins with the collection of both primary and secondary data related to transport infrastructure and essential service locations. These datasets are then processed and integrated into a GIS environment to create a spatial database, followed by the development of a network dataset representing the road system. Subsequently, various network analyses, including connectivity assessment, shortest path analysis, and service area delineation, are performed to evaluate the functional characteristics of the network. Graph theory indices such as Alpha, Beta, Gamma, and Shimbel are then calculated to quantify connectivity and accessibility levels. The results obtained from these analyses are further examined through spatial interpretation to identify patterns of accessibility and areas of disparity. Finally, the findings are synthesized to support planning recommendations aimed at improving transport efficiency and equitable access to services (El-Geneidy A. et al., 2016).

The use of GIS-based network analysis enhances the reliability and accuracy of the study by enabling precise spatial modelling and quantitative evaluation. The integration of multiple analytical techniques ensures a comprehensive assessment of transportation networks and their impact on accessibility. Such approaches are widely recognized for their effectiveness in transport planning and spatial analysis (Xie et al., 2011; Geurs & van Wee, 2004).

NETWORK ANALYSIS AND ACCESSIBILITY ASSESSMENT

This section presents the results derived from GIS-based network analysis and graph theory indices to evaluate the structure and performance of the transportation network in Dharmapuri Taluk. The analysis focuses on route efficiency, service accessibility, connectivity, and spatial disparities across the study area. The integration of multiple analytical techniques enables a comprehensive understanding of how transportation infrastructure influences accessibility patterns (Geurs & van Wee, 2004; Rodrigue et al., 2017).

Shortest Path and Service Area Analysis

The shortest path analysis was carried out to determine optimal routes between primary healthcare centres and major government hospitals within the study area. The results indicate that the transport network provides relatively efficient connectivity in central regions, where multiple alternative routes are available. However, peripheral areas exhibit limited route options, leading to increased travel time and reduced accessibility to critical services. This spatial variation highlights the uneven distribution of network efficiency across the taluk. The service area (buffer) analysis further reveals disparities in access to educational facilities. The central parts of Dharmapuri Taluk show significant overlap in buffer zones, indicating a higher concentration of schools and better accessibility. In contrast, the northern, southern, and southeastern regions exhibit large unserved areas where access to schools is limited. Such gaps in service coverage suggest the need for improved infrastructure planning and redistribution of facilities (Hansen, 1959; Xie et al., 2011).

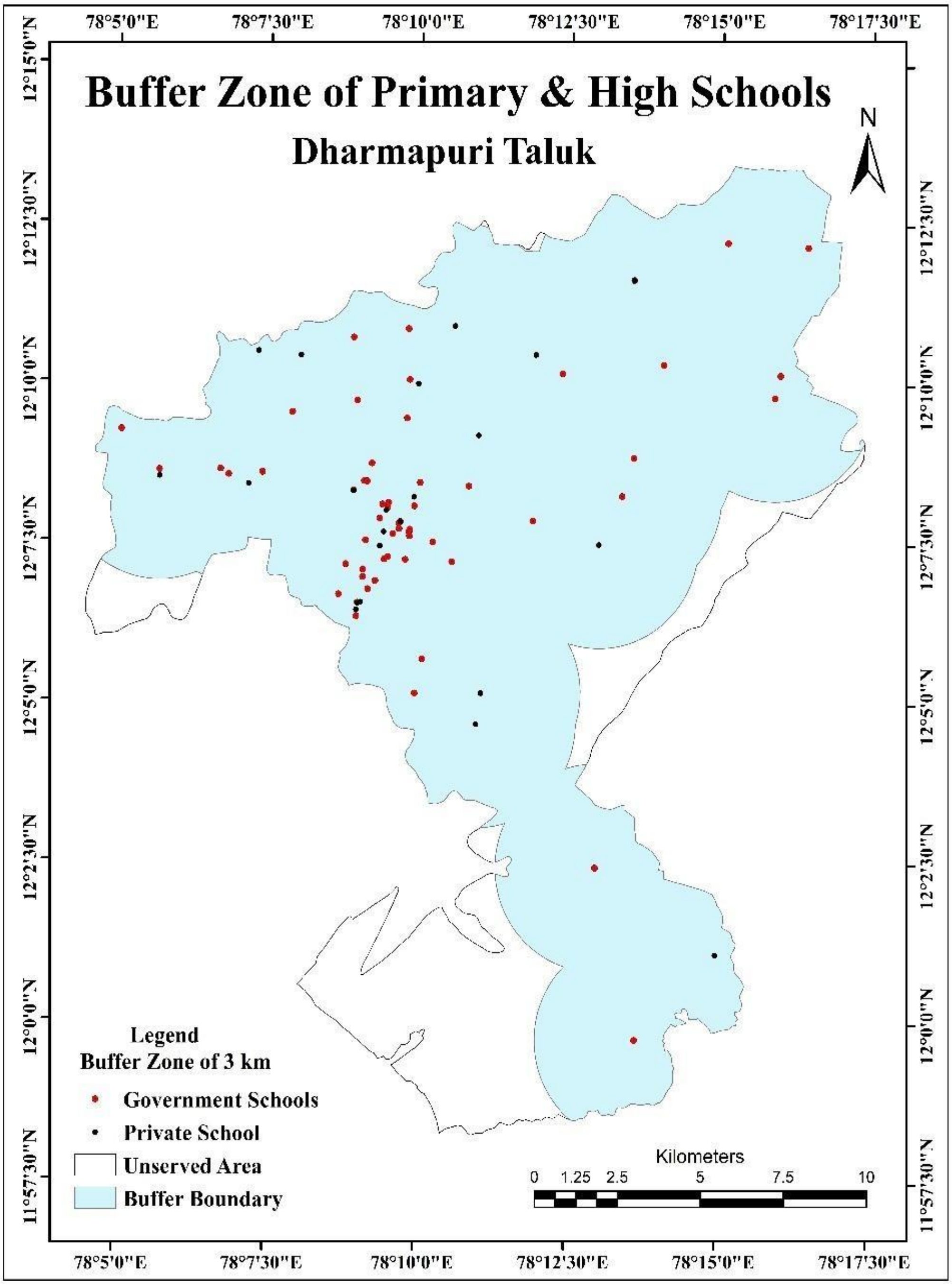

Fig.2: Buffer Map for Schools

Travel Cost and Accessibility (Isotim Analysis)

The Isotim analysis was conducted to evaluate accessibility based on travel cost from the central node, Dharmapuri bus terminal. The results indicate that a significant proportion of the study area falls within moderate travel cost ranges, while areas with higher travel costs are predominantly located in peripheral zones. This pattern reflects the concentration of transport services around central nodes and the gradual decline in accessibility with increasing distance.

The tabulated data shows that nearly 29% of the area falls within a travel cost of 7 units, followed by 25% within a cost of 8 units, indicating that a large portion of the population experiences moderate accessibility. However, only a small percentage of the area lies within higher cost ranges, suggesting limited connectivity in remote regions.

The spatial distribution of travel cost highlights the centralization of transport accessibility and reinforces the existence of a core-periphery structure within the taluk (Geurs et al., 2004).

Table 1: Dharmapuri Taluk Isotim

S.No	Travel Cost in Rupees	Area in %
1	5	5
2	6	10
3	7	29
4	8	25
5	9	12
6	10	7
7	12	3.64
8	13	3.11
9	14	2.76
10	15	0.55
11	16	0.42
12	17	0.61
13	18	0.91

Transport Network Structure (Topological Analysis)

The topological representation of the transportation network provides a foundational understanding of its structural characteristics. The network consists of 115 nodes and 136 edges, with a total route length of approximately 315 km. These parameters indicate a moderately developed network with basic connectivity across the study area. The analysis of nodes and edges suggests that while the network is connected, it lacks sufficient redundancy in certain areas, particularly in peripheral regions. The absence of multiple alternative routes in these areas increases vulnerability to disruptions and limits accessibility. Such structural limitations are common in semi-urban transport networks where infrastructure development is uneven (Rodrigue et al., 2017; Kansky, 1963).

Connectivity Analysis Using Network Indices

The connectivity of the transportation network was evaluated using graph theory indices, including Alpha, Beta, and Gamma. The overall Alpha index value of approximately 0.1 indicates low network connectivity, suggesting minimal circuit formation and limited alternative routes. This reflects a network structure that is relatively simple and less resilient to disruptions.

The Beta index value of 1.03 indicates a basic level of connectivity, where each node is connected to slightly more than one edge on average. This suggests that the network is functional but lacks complexity. The Gamma index value of 0.55 represents moderate network efficiency, indicating that the network achieves just over half of its maximum potential connectivity.

Accessibility Analysis using Shimbel Index

The Shimbel index was used to assess accessibility based on the shortest path between nodes. The results indicate a clear spatial di Moderate accessibility is observed in transitional zones, while low accessibility areas are primarily located in the eastern regions, where connectivity is limited and travel distances are longer. These patterns highlight the influence of network structure on accessibility and reinforce the need for targeted infrastructure development in underserved regions (Geurs & van Wee, 2004).

DISCUSSION

The results of the present study reveal clear spatial disparities in transportation accessibility across Dharmapuri Taluk, which can be better understood when examined in relation to the distribution of settlements and village-level connectivity. The central part of the taluk, including areas such as Dharmapuri town, Annasagaram,

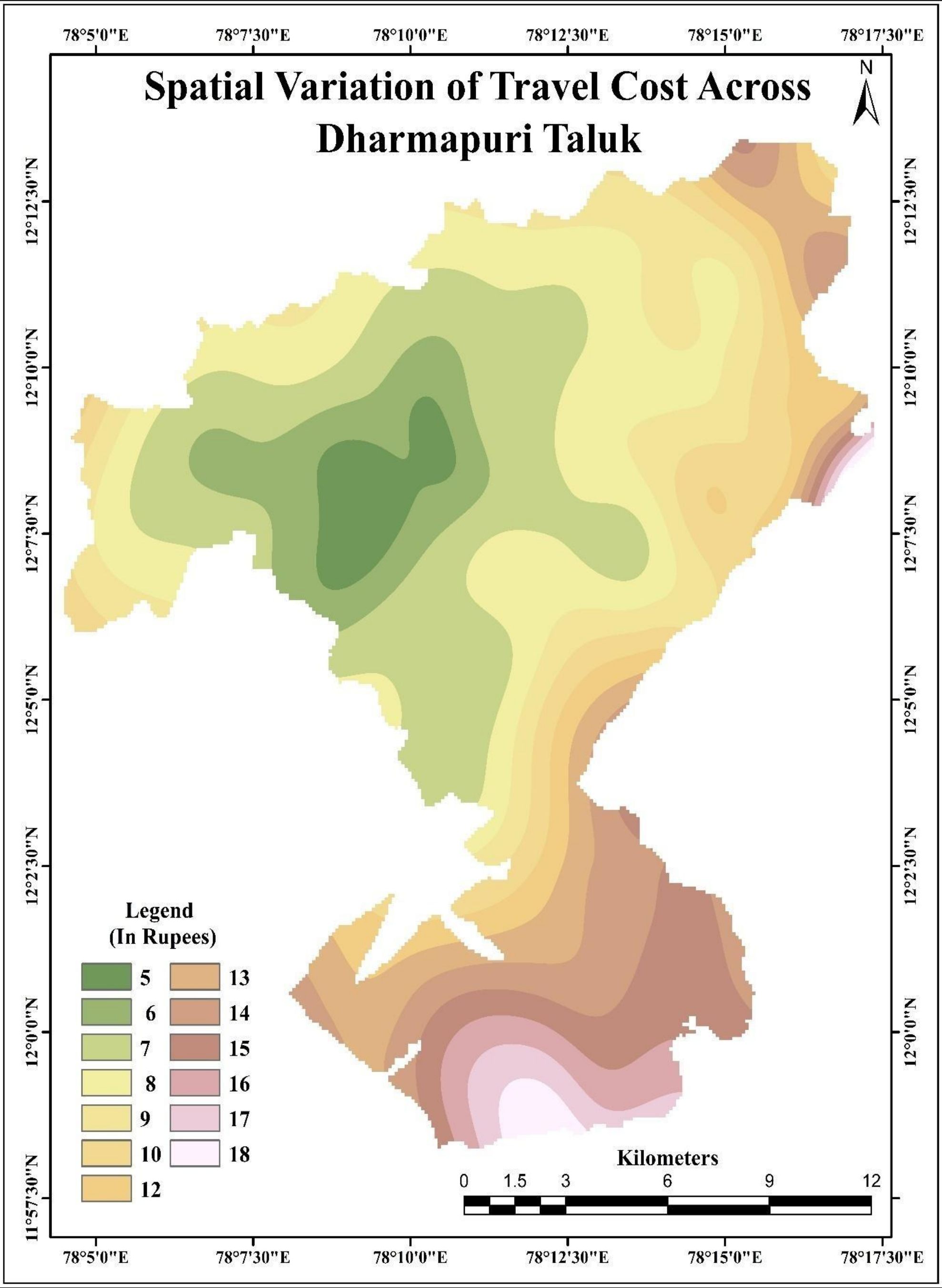

Fig.3: ISOTIM Travel cost

Adiyamankottai, and Lakkiampatti, exhibits relatively high accessibility due to the convergence of major road networks and the concentration of essential services. These areas function as core zones where transport infrastructure is more developed and multiple route options are available, thereby reducing travel distance and time.In contrast, several peripheral villages such as Akkamanahalli, Andihalli, Kadagathur, Konangihalli, Kammampatti, and Errabaiyanahalli experience comparatively lower accessibility. These settlements are located away from major transport corridors and are primarily connected through secondary or rural roads, resulting in limited route choices and increased travel impedance. Such spatial variation reflects a typical core–periphery structure, where accessibility decreases progressively from the centre towards the outer regions.

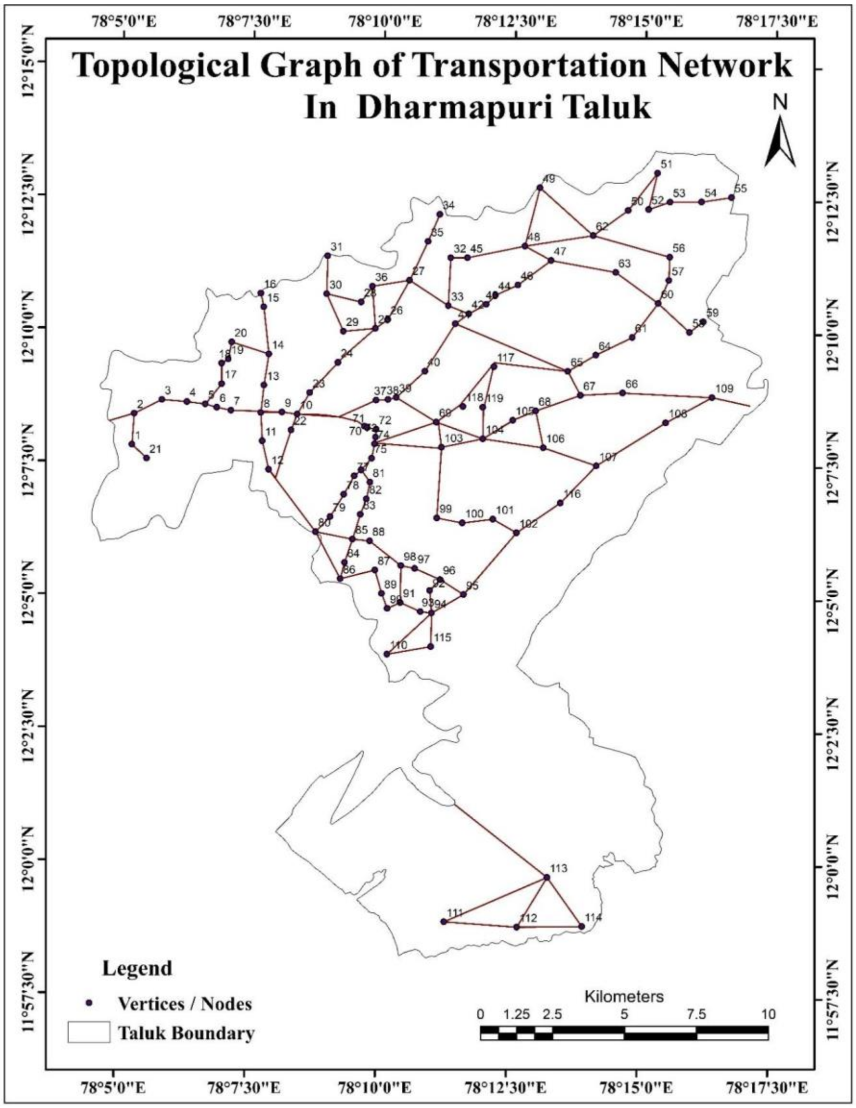

Fig.4: Topological Graph of Transport Network for Dharmapuri Taluk

Table 2: Values of Indices

S. No	INDEX	VALUES	CHARACTERISTSTICS
1	No of Edges	136	-
2	No of Vertices	115	-
3	Alpha	0.1	Minimum connectivity with pattern of Network
4	Beta	1.03	Minimum connectivity
5	Gamma	0.55	Moderate connectivity

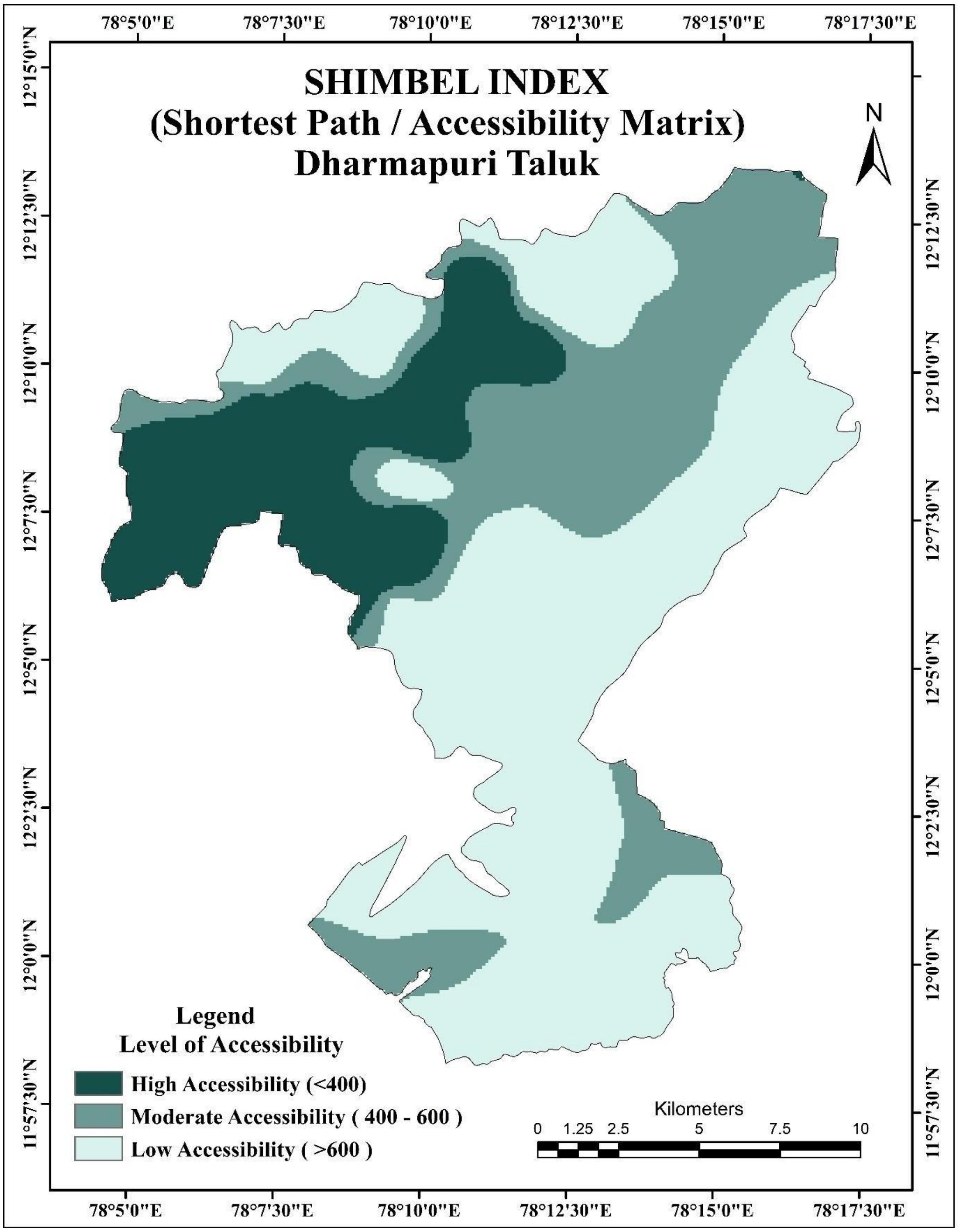

Fig.5: Accessibility Map using Shimbel Index for Dharmapuri Taluk

Similar spatial patterns have been observed in semi-urban regions where infrastructure development is unevenly distributed (Geurs et al., 2004; Páez et al., 2012).

The findings from the service area analysis further reinforce this pattern. Villages such as Annasagaram, Balajangamanhalli, and Boalanahalli fall within well-served zones for educational and healthcare facilities, while settlements like Budanahalli, Dhalavaihalli, and Dokkubodanahalli lie in partially served or underserved regions. This uneven distribution of services indicates that accessibility is not uniform across the taluk and is significantly influenced by proximity to transport nodes and network density. The presence of approximately 60+ villages within the taluk, including settlements such as A. Jettihalli, A. Reddihalli, Adagapadi, and Echanahalli, further emphasizes the need for an integrated transport system that

The Isotim analysis highlights the role of travel cost in shaping accessibility patterns. Villages located closer to Dharmapuri town, such as Adagapadi and Dhinnahalli, fall within lower travel cost zones, indicating better accessibility. On the other hand, villages situated at greater distances, including Elagiri and Errabaiyanahalli, experience higher travel costs, reflecting reduced connectivity. This spatial gradient demonstrates how accessibility declines with increasing distance from central nodes, a phenomenon widely discussed in transport geography (Handy et al., 1997; Litman, 2020).

The topological structure of the transport network also contributes to these disparities. Although the network connects major settlements, the lack of redundancy and alternative routes in several parts of the taluk limits its efficiency. For instance, villages such as Konanginayakkanahalli, Kondampatti, and Noolahalli are connected through limited road links, making them vulnerable to disruptions and reducing overall accessibility. This indicates that while the network is functionally connected, it lacks the structural complexity required to support efficient movement across all regions. Similar findings have been reported in studies where rural transport networks exhibit low redundancy and uneven connectivity (Sreelekha et al., 2016; Levinson & Xie, 2011).

The accessibility patterns observed through the Shimbel index further highlight the spatial inequality within the taluk. High accessibility zones are concentrated around central settlements such as Dharmapuri, Annasagaram, and Adiyamankottai, where nodal connectivity is high and travel distances are relatively short. In contrast, villages located in the eastern and southeastern parts of the taluk, including Kadagathur, Kammampatti, and Konangihalli, show lower accessibility due to longer travel paths and limited connectivity. This clearly demonstrates that accessibility is a function of both network configuration and spatial distribution of settlements, as emphasized in earlier studies (Hansen, 1959; Geurs et al., 2004).

The presence of numerous village panchayats such as Adagapadi, Akkamanahalli, Andihalli, Kuppur, Nallasenahalli, and Puluthikarai within the taluk highlights the complexity of providing equitable transport access across a dispersed settlement system. In such contexts, centralized infrastructure development tends to benefit core areas disproportionately, leaving peripheral regions relatively underserved. This imbalance has important implications for socio-economic development, as limited accessibility can restrict access to education, healthcare, and employment opportunities.

The findings indicate that transportation networks are a key determinant of spatial equity, and that improving connectivity in peripheral villages is essential for achieving balanced regional development. Addressing these disparities requires targeted infrastructure planning, particularly in villages with low accessibility, to ensure that the benefits of transportation networks are distributed more equitably across the region.

CONCLUSION

The present study examined the role of transportation networks in shaping social accessibility in Dharmapuri Taluk using GIS-based network analysis techniques. By integrating shortest path analysis, service area mapping, travel cost evaluation, and accessibility assessment through the Shimbel index, the study provides a comprehensive understanding of how transport infrastructure influences spatial equity within the region. The findings reveal that accessibility within the taluk is highly uneven and largely dependent on the structure and distribution of the transport network. Central areas such as Dharmapuri town and its surrounding settlements exhibit relatively high accessibility due to better connectivity, higher road density, and proximity to essential services. In contrast, peripheral villages experience limited accessibility, characterized by longer travel distances, fewer route alternatives, and higher travel costs. This clear spatial imbalance reflects a core–periphery pattern, where infrastructure development is concentrated in central zones while outer regions remain comparatively underserved.

The results further indicate that while the transportation network ensures basic connectivity across the taluk, it lacks sufficient redundancy and network complexity in several areas. The limited availability of alternative routes in peripheral regions reduces network efficiency and increases vulnerability to disruptions. Additionally, the concentration of transport services around central nodes contributes to disparities in accessibility, particularly affecting rural settlements that depend on secondary and local road networks. The accessibility analysis highlights that improved connectivity is closely associated with better access to education, healthcare, and other essential services. Conversely, areas with poor connectivity are more likely to experience restricted mobility and reduced access to opportunities, which can contribute to socio-economic marginalization. These findings reinforce the importance of transportation planning as a key component of regional development and social inclusion.

Overall, the study demonstrates that transportation networks are a critical determinant of spatial accessibility and regional equity. The application of GIS-based network analysis provides valuable insights into the spatial distribution of accessibility and helps identify areas that require infrastructural improvement. The findings emphasize the need for a more balanced and integrated approach to transport planning, focusing not only on expanding infrastructure but also on improving connectivity in underserved regions.

In conclusion, achieving equitable accessibility in Dharmapuri Taluk requires targeted interventions aimed at strengthening transport linkages in peripheral areas, enhancing network efficiency, and ensuring a more uniform distribution of services. Such efforts will contribute to sustainable regional development and improve the overall quality of life for communities across the taluk.

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