

Manuscript ID:
IJRSEAS-2025-020410



Quick Response Code:



Website: <https://eesrd.us>



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DOI: 10.5281/zenodo.19841362

DOI Link:
<https://doi.org/10.5281/zenodo.19841362>

Volume: 2

Issue: 4

Pp. 52-59

Month: August

Year: 2025

E-ISSN: 3066-0637

Submitted: 08 July 2025

Revised: 15 July 2025

Accepted: 12 Aug. 2025

Published: 31 Aug. 2025

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How to cite this article:

Kadam, S., & Patil, P. T. (2025).
An Assessment of Accessibility and
Network Connectivity in Kolhapur
District Using Geospatial
Technology. *International Journal
of Research Studies on
Environment, Earth, and Allied
Sciences*, 2(4), 52-59.
<https://doi.org/10.5281/zenodo.19841362>

An Assessment of Accessibility and Network Connectivity in Kolhapur District Using Geospatial Technology

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Abstract

Urban accessibility and network connectivity are critical determinants of mobility, service delivery, and sustainable urban development. This study evaluates the accessibility and connectivity of 14 municipal councils in the Kolhapur district, Maharashtra, using network analysis metrics, including the Beta Index, node and arc counts, and accessibility scores. Spatial and statistical analyses reveal significant variations, with areas like Ichalkaranji, Kolhapur (Karvir), and Gadhinglaj exhibiting high connectivity and accessibility, while regions such as Hathangale, Ajara, and Peth Vadgaon demonstrate low or tree-like network structures. Correlation between accessibility and connectivity indices highlights the importance of well-connected urban grids in enhancing movement efficiency and equitable access for resources. Graphical representations, including bar charts, histograms, and ranking analyses, support the interpretation of results. The findings provide actionable insights for urban planners to optimise transport networks, prioritise infrastructure interventions, and improve overall urban functionality, contributing to more resilient and accessible urban systems.

Keywords: Accessibility, Connectivity, Beta Index, Urban Network, GIS, Transport Planning etc.

Introduction

Accessibility and network connectivity largely determine regional development, impacting social inclusion, economic productivity, and overall quality of life. While network connection refers to the effectiveness and structure of the transportation and communication networks that facilitate such mobility, accessibility relates to how simple it is for people to access to desired services, activities, and destinations. These ideas work together to shape geographical inequality, particularly in developing countries with unequal infrastructure distribution.

Rapid urbanisation and population growth have increased the need for effective transportation and service delivery infrastructure in nations like India. Nonetheless, there are still significant differences between urban and rural communities, with rural areas frequently having less access to markets, healthcare, and education. The necessity for methodical evaluation techniques that can analyse and enhance spatial accessibility and connectivity is highlighted by this uneven distribution.

Geographic Information Systems (GIS) and remote sensing, in particular, have become a potent tool for studying infrastructure networks and spatial trends. Researchers may model real-world situations and evaluate accessibility using methods like network analysis, buffer analysis, and cost-distance modelling because of GIS's ability to integrate, visualise, and analyse spatial data. These resources enhance evidence-based planning and decision-making and make it easier to identify underserved areas (Longley et al., 2015).

In district-level research, where localised planning changes can have substantial effects, the use of geospatial tools is especially pertinent. The state of Maharashtra's Kolhapur District has a varied topography that includes hilly regions connected to the Western Ghats, rural communities, and metropolitan areas. This variety is a perfect example for geospatial analysis since it frequently leads to spatial differences in connection and accessibility.

This study uses geospatial technologies to measure network connection and accessibility in order to determine infrastructure gaps, assess service distribution, and offer suggestions for better regional planning. In addition to advancing scholarly study, these assessments aid decision-makers in attaining inclusive and balanced growth by providing data-driven insights that can inform policies and initiatives aimed at improving infrastructure and services in underserved areas.

Study Area

The study area is the Kolhapur district, located in the southwestern part of Maharashtra, India. The district is geographically situated between the Western Ghats and the Deccan Plateau and includes a mix of urban, semi-urban, and rural settlements. Major municipal councils such as Kolhapur, Ichalkaranji, Gadhinglaj, and Jaysingpur serve as important administrative, industrial, and commercial centres with well-developed road networks, while towns such as Ajara and Chandgad represent relatively less connected peripheral areas. The district has an extensive road network connecting urban and rural areas, making it suitable for analysing spatial variations in accessibility and connectivity using graph theory and transport network indices.

STUDY AREA : KOLHAPUR DISTRICT

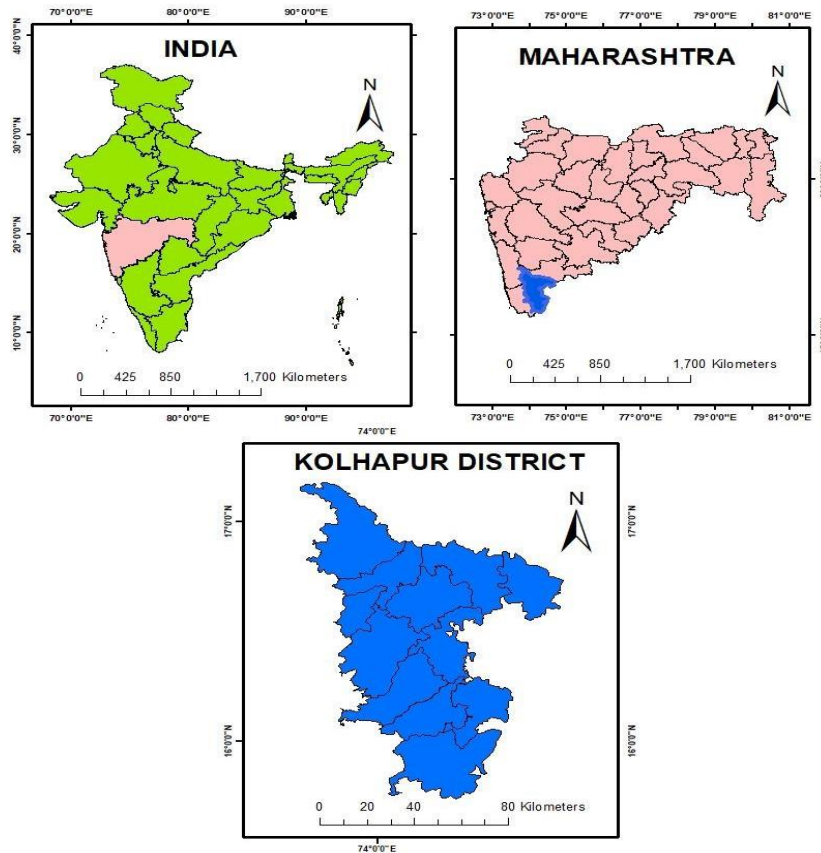


Fig. 1. Location Map

Objective

1. Assess road network connectivity using graph-theoretic indices in Kolhapur's municipal grids.
2. Analyse accessibility patterns to identify high, medium, and low accessibility zones.
3. Examine the relationship between network connectivity and accessibility for planning improvements.

Database and Methodology

The study utilises spatial road network data of Kolhapur district's municipal councils, divided into grids. Each grid's connectivity was quantified using graph-theoretic indices such as the beta index, no. of arcs, and no. of nodes. Accessibility was evaluated by integrating connectivity metrics with population centres and critical service points. Data were collected from municipal GIS maps, OpenStreetMap (OSM), and field surveys for validation. This systematic approach ensures that connectivity and accessibility patterns are clearly quantified and visualised, providing actionable insights for urban planning.

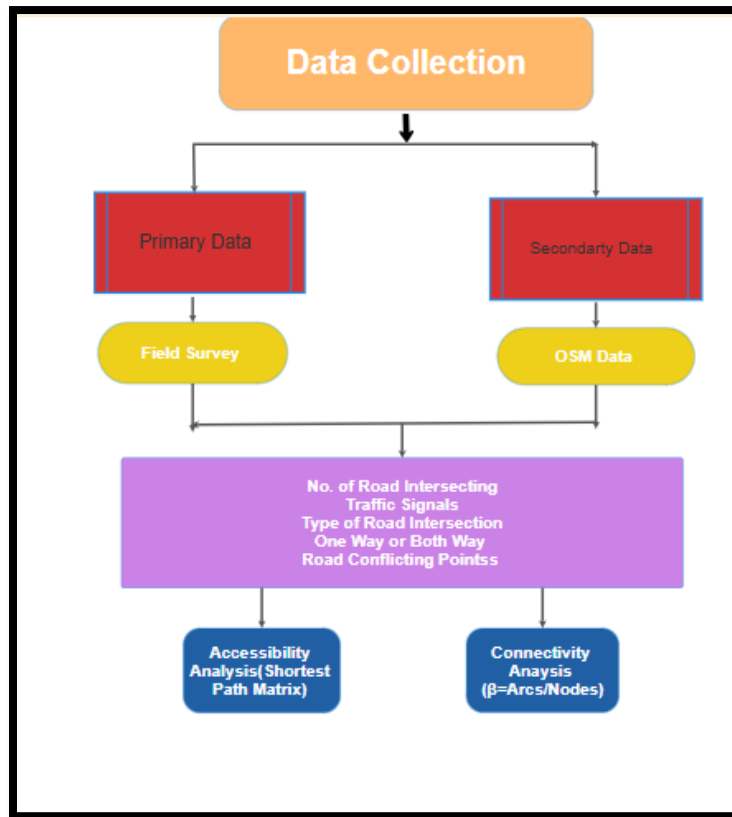


Fig.2 Methodology Flowchart

Results and Discussion

A complicated and spatially varied pattern caused by differences in urbanisation, infrastructure development, and physical limits is shown by evaluating accessibility and network connectivity among municipal councils in Kolhapur District. The study offers a thorough understanding of how transport networks affect accessibility across various locations by utilising graph-theoretic metrics like the Beta Index in conjunction with node and arc analysis.

1. Network Connectivity's Spatial Pattern

Significant differences exist between the 14 municipal councils, according to the connectivity research. A spectrum from incredibly poor to highly established network architecture is represented by the beta index values, which range from 0 to 4.0.

With Beta Index values surpassing 2.5 and occasionally reaching 3.0–4.0, urban hubs like Kolhapur (Karvir), Ichalkaranji, and Panhala demonstrate extremely advantageous connectivity. These regions are distinguished by numerous travel options (arcs), high intersection density (nodes), and dense road networks. For example, grids in Kolhapur City display arc counts above 180–200 and node counts over 100, indicating a well-integrated urban transportation system. High connection facilitates effective car mobility, shortens travel times, and improves accessibility in general.

On the other hand, peripheral municipalities with Beta Index scores near zero, such as Ajara, Hatkangale, and Peth Vadgaon, show extremely poor connection. These regions are characterised by network topologies that resemble trees, with highways branching off of a single main route without creating loops or alternate routes. Sparse infrastructure is indicated by node counts in these grids, which are frequently less than 30–40, and arc counts, which are usually less than 50–60. Movement possibilities are severely limited by such layouts, which also make them more susceptible to disruptions or traffic jams.

With Beta Index values between 1.2 and 1.8, intermediate municipalities like Gadhinglaj, Jaysingpur, and Shirol exhibit moderate connectivity. These regions exhibit partial network development, with gaps in connectivity and some grid-like characteristics. Moderate node and arc counts indicate developing infrastructure that facilitates regional movement but is not as effective as highly connected urban centres.

2. Accessibility Trends in the District

There is a high spatial correlation between network structure and service reach when accessibility analysis is combined with connectivity measures. When compared to low-connectivity zones, high-connectivity zones show noticeably superior accessibility results. High accessibility scores (>75–80%) are found in urban areas like Ichalkaranji and Kolhapur City, suggesting that most people can get necessary services within 5–10 km or 10–15

minutes of travel time. Dense road networks, accessible public transportation, and close proximity to service hubs like hospitals, schools, and marketplaces are all advantages for these communities.

However, accessibility levels are low (<40-50%) in rural and peripheral areas like Chandgad, Ajara, and Hatkangale. To get essential amenities, individuals in these locations frequently have to travel more than 10-15 kilometres or spend 30-60 minutes. Poor road connectivity, a lack of alternative routes, and reduced transportation availability exacerbate these accessibility limitations.

The steady decrease in accessibility from urban centres to rural outskirts is a noteworthy trend that illustrates the impact of infrastructure concentration in economically developed areas. This pattern demonstrates the district's clear urban-rural division.

3. Disparities Within and Between Regions

The analysis shows intra-urban differences within certain municipal councils in addition to inter-municipal heterogeneity. For instance, the city of Kolhapur itself has grids with different degrees of connection, from less developed periphery districts to well-connected commercial zones. Even in metropolitan areas, accessibility is inconsistent due to this internal diversity. Similar mixed connectivity patterns can be seen in towns like Gadhinglaj and Jaysingpur, where certain grids have high beta index values while others are still underdeveloped. Instead of using uniform policy methods, this uneven distribution suggests the need for regional planning initiatives.

4. Geographical and structural factors' influence

Geographical considerations also have an impact on the spatial variance in accessibility and connectivity. Topographical limitations in regions close to the Western Ghats, such as Chandgad and Ajara, restrict the growth of road networks and lower connectivity levels. On the other hand, plains areas and industrial zones like Ichalkaranji have simpler topography and more economic activity, which makes infrastructure construction easier.

Past trends in urban expansion and industrial concentration also influence the network structure. While rural areas continue to rely on inadequate road infrastructure, industrial centers often create more intricate and dense networks to support economic activity.

Network Connectivity Analysis

Table 1. Connectivity Classes of Municipal Council Zone

Municipality	Grid	Beta Index	Connectivity Class
Kolhapur	K27	3	Very High
Panhala	Ph2	4	Very High
Hatkangale	H1	0	Very Low (Tree-like)
Peth Vadgaon	P1	0	Very Low (Tree-like)
Ajara	A1/A2	0	Very Low (Tree-like)

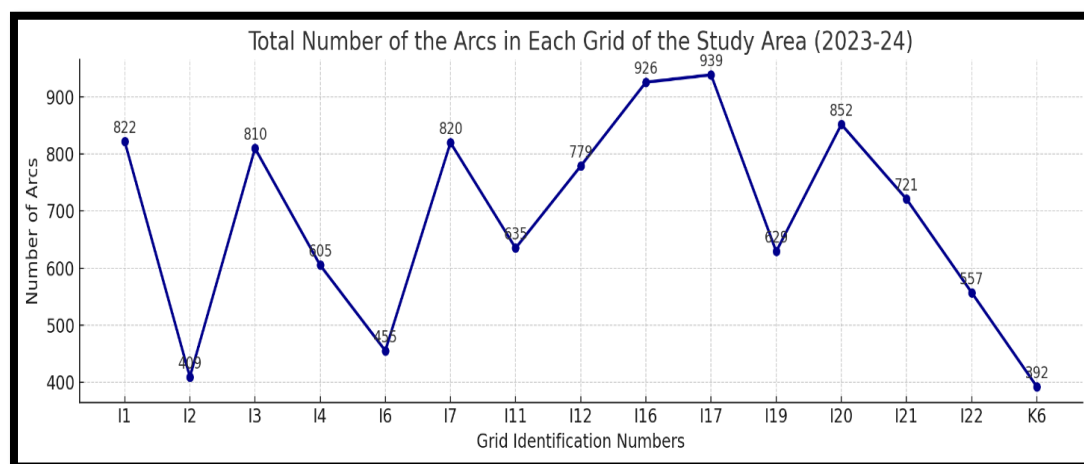


Fig. 3. Total Number of the Arcs in Each Grid of the Study Area. (Source:Based on field survey, 2023-24)

This bar graph illustrates the distribution of arcs, or road segments, among the various municipal grids in the Kolhapur district. Grids in urban areas like Ichalkaranji and Kolhapur (Karvir) show significantly greater arc counts (sometimes exceeding 150-200), indicating dense and well-connected road networks. On the other hand, grids in outlying areas such as Hatkangale and Ajara show low arc values (less than 50), indicating a lack of infrastructure. Spatial differences in network density throughout the district are depicted in the figure.

The Beta Index, calculated for all municipal grids, shows significant variation across Kolhapur's municipalities. Grids such as Kolhapur (Karvir) K27 and Panhala Ph2 exhibit very high connectivity (Beta Index > 2.5), indicating a highly meshed network conducive to efficient movement and accessibility. Conversely, grids like Hatkangale H1, Peth Vadgaon P1, and Ajara A1/A2 have a beta index of 0, indicating tree-like, poorly connected networks with limited route redundancy. This heterogeneity highlights the disparity in connectivity within the district.

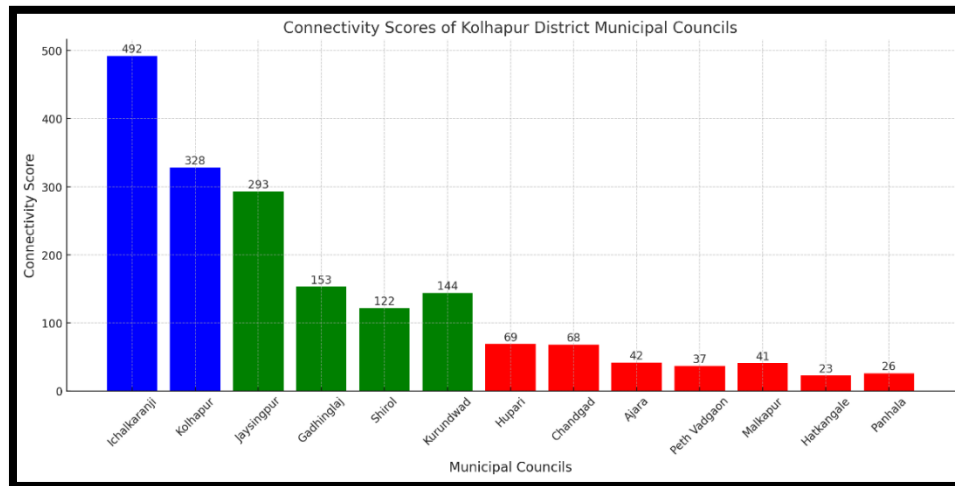


Fig.4. Connectivity Score of Kolhapur District Municipal Councils.
(Source: Based on Field Survey, 2023-24)

Based on the Beta Index and associated graph metrics, this figure displays the overall connectivity scores of various municipal councils. High connectivity ratings are indicative of well-developed and effective transportation networks in urban municipalities like Ichalkaranji and Kolhapur. While low scores in Ajara and Hatkangale indicate poor connection, moderate scores are seen in places like Gadhinglaj and Jaysingpur. The graphic does a good job at comparing differences between municipalities.

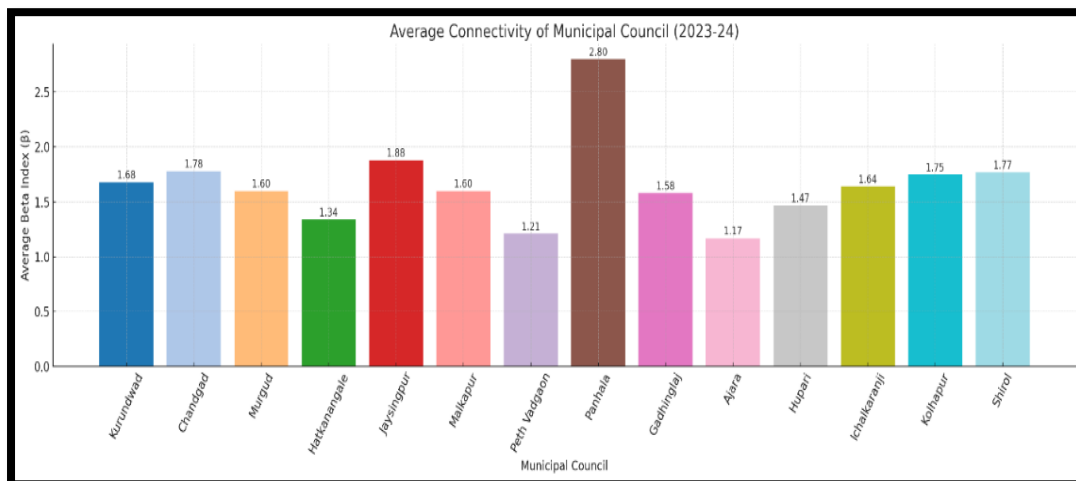


Fig. 5: Average Connectivity of Municipal Council, (2023-24).
(Source: Based on Field Survey, 2023-24)

This graph displays the average connectivity levels among municipal councils. The variation in mean values indicates differences in the overall network structure. Ichalkaranji and Kolhapur exhibit higher average connectivity, indicating a consistent network density throughout their grids. Municipalities like Ajara and Chandgad, on the other hand, show lower averages, suggesting inconsistent or inadequate connectivity. The figure aids in identifying areas in need of infrastructure upgrades.

➤ **Accessibility Assessment**

Accessibility scores, when linked with connectivity metrics, reveal that urbanised areas (e.g., Ichalkaranji I1-I4, Kolhapur K16-K20) have high to very high accessibility, reflecting dense road networks supporting efficient travel. Rural grids (e.g., Chandgad C1-C2, Hatkangale H1/H6) show **low to very low accessibility**, indicating limited infrastructure. This pattern aligns with the expected urban-rural divide, emphasising the importance of targeted infrastructure development in low-accessibility areas.

➤ **Statistical Interpretation**

❖ Mean **beta index** across the district is approximately 1.62, suggesting a moderate overall connectivity.

- ❖ Standard **Deviation (SD)** = 0.56, indicating variability in network connectivity among grids.
- ❖ Correlation **analysis** between the beta index and accessibility shows $r \approx 0.82$, indicating a strong positive relationship; higher connectivity correlates with higher accessibility.

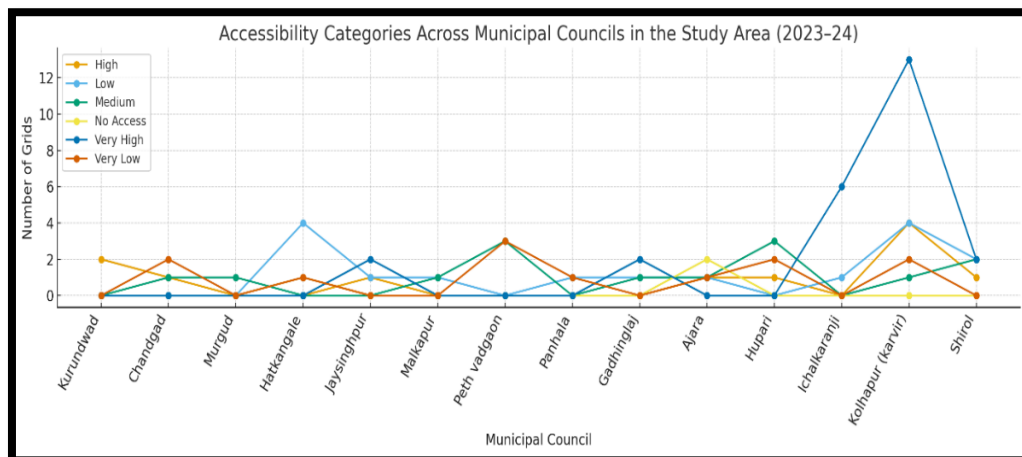


Fig.6. Accessibility Categories Across Municipal Councils in the Study Area (2023-24).

This figure divides municipal grids into high, medium, and low-accessible zones based on service reach and connectivity. High-accessibility areas concentrate in metropolitan regions like Ichalkaranji and Kolhapur, where dense networks facilitate effective mobility. Low-accessibility areas are mostly found in outlying areas like Chandgad and Ajara, whilst medium-accessibility areas are found in towns like Gadhinglaj and Jaysingpur. The figure illustrates the district's accessibility gap between urban and rural areas.

The study demonstrates a strong link between network connectivity and accessibility, corroborating prior studies in urban transport networks (e.g., Rodrigue et al., 2020; Porta et al., 2006). High connectivity in urban centers enhances mobility, reduces travel times, and supports service delivery. Low connectivity in rural grids indicates vulnerability to isolation and inefficient transportation, which can lead to decreased economic opportunities and limited access to essential services for residents.

These findings emphasise the necessity of targeted infrastructural development, particularly in tree-like, low-connectivity grids. Introducing additional road links or upgrading existing routes can improve both accessibility and network robustness, ensuring equitable service access across Kolhapur district.

Conclusion

The current study offers a thorough geographic evaluation of network connection and accessibility throughout Kolhapur District municipal councils. The study reveals notable differences in the district's transport network topology and service reach by combining graph-theoretic indices like the Beta Index with spatial accessibility metrics. With Beta Index values ranging from 0 to 4.0, which show a broad spectrum from minimally connected tree-like systems to extremely complex grid-based metropolitan networks, the results unequivocally show that network connectivity is unevenly distributed. Overall, the mean beta index of 1.62 indicates a considerable degree of connection.

Urban areas with dense road networks, high node and arc densities, and numerous alternate routes, like Ichalkaranji and Kolhapur (Karvir), become high-connectivity hubs. High accessibility levels (>75–80%) in these places provide easy access to markets, healthcare, and education, as well as efficient mobility over short travel distances (usually less than 10 km). Towns with moderate to high connectivity, such as Gadhinglaj and Jaysingpur, facilitate regional movement and serve as secondary growth centres.

On the other side, peripheral and semi-rural municipalities with Beta Index scores near zero, such as Ajara, Chandgad, Hatkangale, and Peth Vadgaon, show extremely poor connectivity. These regions have low accessibility (<40–50%) due to the prevalence of tree-like network architectures, low node density, and fewer arcs. To obtain essential amenities, residents in these areas frequently have to drive significant distances (10–20 km) and endure lengthy travel times (30–60 minutes). These circumstances clearly point to a transportation disadvantage and accessibility limitation.

The statistical analysis further supports these conclusions. Improvements in network topology directly increase service accessibility, as evidenced by the significant positive correlation ($r = 0.82$) between connectivity and accessibility. This connection emphasises how crucial it is to create interconnected transportation networks in order to guarantee effective mobility and fair resource allocation.

The study also shows intra-urban differences, with certain grids showing poorer connection than centre zones even in highly developed municipalities like Kolhapur. This unequal internal distribution implies that localised accessibility gaps have resulted from spatially focused infrastructure development.

Geographic conditions, particularly the presence of the Western Ghats, greatly influence network growth. While plains regions like Ichalkaranji benefit from relatively favourable conditions for infrastructure growth, areas like Chandgad and Ajara have topographical obstacles that restrict road building. Economic activity and industrial

development significantly influence network density, resulting in more intricate and linked road networks in industrial towns.

Overall, the study emphasises that high accessibility, which in turn promotes socioeconomic development, lessens spatial inequality, and enhances quality of life, requires effective network connectivity. The results emphasise the necessity of focused, data-driven planning techniques to alleviate current inequalities and advance equitable regional development in the Kolhapur District.

The connectivity analysis of the 14 municipal councils in the Kolhapur area using the Beta Index reveals a diverse road network layout. With Beta Index values above 1.7 and occasionally above 2.5, urban hubs like Kolhapur (Karvir), Ichalkaranji, Panhala, and Jaysingpur demonstrate high to -extreme connectivity. These locations benefit from strong intersection networks and various alternate routes, which promote effective traffic flow and lower the likelihood of congestion. On the other hand, a number of semi-urban and rural grids show very low or tree-like connectivity (Beta Index ≤ 0), such as Hatkangale (H 1, H 6), Peth Vadgaon (P1, P6), Ajara (A1, A2), and Hupari (H1). Due to the lack of viable routes, these regions are more likely to experience traffic jams, less accessibility, and longer travel times. Certain councils, including Chandgad, Gadhinglaj, and Kolhapur, exhibit a range of very high, high, moderate, and low beta index grids, indicating varied connection patterns. Such variation suggests regional differences in traffic flow efficiency and accessibility. The analysis underscores the importance of maintaining and enhancing existing high connectivity hubs, while also enhancing road network connectivity in areas with low beta index.

Recommendations:

1. To alleviate traffic in the urban heart of Kolhapur (Karvir), ring and bypass roads must be built to improve peripheral connections. Additionally, network mobility and efficiency will be enhanced by the deployment of GIS-based smart traffic control systems, which can optimise traffic flow, reduce congestion, and improve response times for emergency services.
2. To maintain high connectivity in Ichalkaranji, bottlenecks in industrial zones must be reduced and intra-urban road hierarchy must be improved. Additionally, integrated public transportation systems must be created to facilitate population and industrial mobility, which could include options such as bus rapid transit, light rail, and improved scheduling to ensure timely connections.
3. In the case of Gadhinglaj, improving the current road system is essential to enhancing its function as a centre for regional connectivity. To increase accessibility, it's also critical to develop the transportation corridors that connect nearby rural communities.
4. Creating link roads will strengthen Jaysingpur's disjointed road networks to ensure consistent connectivity. Improved interaction with regional transport systems is necessary to strengthen its position as a secondary growth centre, as this will facilitate better access to resources, markets, and services for the local population.
5. To lessen reliance on constrained routes, more road connections must be developed in the case of Shirol. Economic accessibility will increase with better connectivity to adjacent industrial and agricultural areas.
6. To preserve environmental sustainability in Panhala, infrastructure development that is sensitive to topography should be given top priority. Increasing connection for travel would also boost the economy by facilitating trade, improving access to jobs, and attracting investment in the region.
7. To turn Hatkanangale's tree-like network architecture into more cohesive systems, additional connecting roadways must be built. Accessibility gaps will be overcome by enhancing rural transportation services.
8. Peth Vadgaon should raise its road network density by creating alternate routes and improving the current infrastructure. Improving service access requires improved connectivity with Kolhapur city.
9. Ajara should prioritise the development of basic road infrastructure in isolated and hilly locations. To lessen isolation and increase accessibility, dependable transportation services must be implemented.
10. In the case of Chandgad, the Western Ghats' geographical limitations necessitate the development of terrain-adaptive roads. Regional integration will be improved by improving connectivity with large cities.
11. To increase connectivity with neighbouring economic hubs, Hupari's road infrastructure has to be upgraded. Bolstering internal road networks will support local industrial development.
12. To encourage industrial expansion in Kagal, better road connections to highways and logistics hubs are crucial. In order to handle future development, planned network expansion should be implemented.
13. Feeder roads should be built in Murgud to improve rural-urban connectivity. Enhancing access to neighbouring service locations will help meet the needs of the local populace.
14. To increase connectivity with major towns, Gargoti's road infrastructure needs to be strengthened. Improved transportation services will provide shorter travel times and increase accessibility.

Acknowledgment

I would like to express my sincere gratitude to my research guide, Dr. P. T. Patil, Assistant Professor, Department of Geography, Shivaji University, Kolhapur, for his invaluable guidance, constant encouragement, and insightful suggestions throughout the course of this study. His support and expertise greatly contributed to the successful completion of this research work.

Financial support and sponsorship

Nil.

Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

1. Batty, M. (1991). Generating urban forms from diffusive growth. *Environment and Planning A*, 23(4), 511-544.
2. Batty, M. (2004). *Cities and complexity*. MIT Press.
3. Church, R. L., & Murray, A. T. (2009). *Business site selection, location analysis, and GIS*. Wiley.
4. Curl, A., Nelson, J. D., & Anable, J. (2011). Does accessibility planning address transport-related social exclusion? *Journal of Transport Geography*, 19(6), 1130-1137.
5. Curtis, C., & Scheurer, J. (2010). Planning for sustainable accessibility. *Transport Policy*, 17(1), 1-10.
6. Dubuc, S. (2007) conducted a GIS-based accessibility analysis for optimal location models in networks. *Cybergeo: European Journal of Geography*.
7. Feng, Y., Zhang, P., Xiao, G., Ding, L., & Meng, L. (2025). GeoAI for geospatial accessibility analysis: A review. *International Journal of Applied Earth Observation and Geoinformation*.
8. Fotheringham, A. S., & Rogerson, P. (1994). *Spatial analysis and GIS*. Taylor & Francis.
9. Geurs, K. T., & van Wee, B. (2004). Accessibility evaluation of land-use and transport strategies. *Journal of Transport Geography*, 12(2), 127-140.
10. Goodchild, M. F. (1992). Geographical information science. *International Journal of Geographical Information Systems*, 6(1), 31-45.
11. Gorjian, M. (2024). GIS-based analysis of urban inequality and accessibility: A systematic review. *Sustainable Cities and Society*.
12. Han, S. R., Yoon, S., & Cho, S. (2019). Smart accessibility using geospatial data models. *Frontiers in Psychology*, 10, 2951.
13. Handy, S. L., & Niemeier, D. A. (1997). Measuring accessibility: An exploration of issues and alternatives. *Environment and Planning A*, 29(7), 1175-1194.
14. Hansen, W. G. (1959). How accessibility shapes land use. *Journal of the American Institute of Planners*, 25(2), 73-76.
15. Hashtarkhani, S., Schwartz, D. L., & Shaban-Nejad, A. (2022). GIS-based healthcare accessibility analysis: Methods and applications. *International Journal of Environmental Research and Public Health*, 19(3), 1234.
16. Haynes, K. E., & Fotheringham, A. S. (1984). *Gravity and spatial interaction models*. Sage Publications.
17. Hillier, B. (2007). *Space is the machine: A configurational theory of architecture*. Cambridge University Press.
18. Ingram, D. R. (1971). The concept of accessibility involves searching for a practical application. *Regional Studies*, 5(2), 101-107.
19. Jiang, B., & Claramunt, C. (1999). Integration of space syntax into GIS for modelling urban spaces. *Computers, Environment and Urban Systems*, 23(2), 107-126.
20. Kumar, A., & Kumari, P. (2016). GIS-based accessibility analysis of urban green spaces. *Urban Forestry & Urban Greening*, 17, 45-52.
21. Kwan, M. P. (2013). Beyond space: Toward temporally integrated geographies of segregation, health, and accessibility. *Annals of GIS*, 19(3), 147-157.
22. Longley, P. A., & Batty, M. (1996). *Spatial analysis: Modelling in a GIS environment*. Wiley.
23. Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). *Geographic information science and systems* (4th ed.). Wiley.
24. Louz, F., et al. (2025). Regional accessibility is modelled using GIS and spatial analytics. *GeoInformatica*.
25. Morales, J., Flacke, J., & Zevenbergen, J. (2019). Mapping urban accessibility using GIS and space syntax. *GeoJournal*, 84(2), 1-15.
26. Neutens, T. (2015). Accessibility, equity and health care: reviews and research directions. *Social Science & Medicine*, 140, 1-10.
27. Páez, A., Scott, D. M., & Morency, C. (2012). Measuring accessibility: Positive and normative implementations of various accessibility indicators. *Journal of Transport Geography*, 25, 141-153.
28. Park, J., & Goldberg, D. W. (2021). A review of recent spatial accessibility studies using GIS-based methods. *ISPRS International Journal of Geo-Information*, 10(8), 532.
29. Rodrigue, J. P. (2020). *The geography of transport systems* (5th ed.). Routledge.
30. Rodrigue, J. P., Comtois, C., & Slack, B. (2010). *The geography of transport systems*. Routledge.
31. Saha, K., & Khare, R. (2025). Geospatial techniques for inclusive accessibility planning in Indian cities. *ISPRS Archives*.
32. Sahitya, K. S., & Prasad, C. S. R. K. (2021). GIS-based urban road network accessibility modelling. *Transportation Telecommunication Journal*, 22(1), 15-28.
33. Schöttler, S., Yang, Y., Pfister, H., & Bach, B. (2021). Visual analysis of geospatial networks. *IEEE Transactions on Visualisation and Computer Graphics*.
34. Transport Research Studies. (2025). Mobility gaps and spatial inequality analysis. *Journal of Transport Geography*.