GIS-Based Evaluation of Road Network Development and Regional Connectivity

Ayush Devendra
M. Tech. in Transportation Engineering, Sat Kabir Institute of Technology and Management, Haryana.

Sumit Ruhil
A.P Civil Department, Sat Kabir Institute of Technology and Management, Haryana.

ABSTRACT

The present study focuses on GIS-based spatial analysis of transportation infrastructure development and regional accessibility. Transportation networks such as roads, highways, railways, and public transport routes play an important role in connecting settlements with markets, hospitals, schools, administrative centres, and employment areas. GIS techniques help in mapping transport networks, measuring road density, identifying accessibility zones, and analysing spatial differences in regional connectivity. The result shows that areas with high road density and shorter distance from main roads have better accessibility, lower travel time, and greater development opportunities. In contrast, remote and poorly connected regions show low accessibility and limited socio-economic growth. Therefore, GIS-based analysis is an effective tool for transport planning, regional development, and reducing spatial inequality.

Keywords: *GIS, Transportation Infrastructure, Regional Accessibility, Spatial Analysis, Road Network.*

I. INTRODUCTION

Transportation infrastructure plays a vital role in the social, economic, and spatial development of any region. Roads, railways, highways, bridges, terminals, and public transport networks act as the basic physical framework through which people, goods, services, and information move from one place to another. A well-developed transportation system improves regional connectivity, reduces travel time, strengthens trade, promotes industrial growth, supports access to education and healthcare, and encourages balanced regional development. However, transportation development is not always evenly distributed across all areas. Some regions enjoy dense road and rail connectivity, while others remain isolated due to difficult terrain, poor planning, low investment, or geographical barriers. This uneven distribution creates differences in accessibility, where some communities can easily reach markets, hospitals, schools, administrative centers, and employment opportunities, while others face long travel distances and limited mobility. Therefore, the study of transportation infrastructure and regional accessibility has become an important area of geographical and planning research.

Geographic Information System, commonly known as GIS, provides an effective scientific approach for analyzing transportation networks and their spatial relationship with regional development. GIS helps in collecting, storing, mapping, and analyzing location-based data related to roads, settlements, land use, population distribution, service centers, travel routes, and administrative boundaries. Through GIS-based spatial analysis, researchers can identify areas with strong connectivity as well as regions suffering from poor accessibility. Techniques such as network analysis, buffer analysis, overlay analysis, shortest path analysis, service area mapping, and accessibility index calculation allow a detailed understanding of how transportation infrastructure influences movement and development patterns. For example, GIS can show which villages are located within a certain distance from a major road, how much time is required to reach a hospital or market, which routes are most efficient, and which areas require new road development. In this way, GIS transforms transportation planning from a simple descriptive process into a data-driven and visual decision-making system.

Regional accessibility refers to the ease with which people from one location can reach important destinations, services, and opportunities. It is not only dependent on the physical presence of roads or railways but also on their quality, distance, travel time, connectivity, and integration with other transport modes. A region may have roads, but if those roads are poorly maintained, disconnected, or far from settlements, actual accessibility remains weak. Similarly, areas located near highways or railway stations usually experience better economic growth because they are more connected to markets and service centers. Accessibility is therefore closely related to regional equity, economic opportunity, social inclusion, and quality of life. GIS-based accessibility analysis helps planners understand where development gaps exist and how transport investment can reduce spatial inequality.

The development of transportation infrastructure also has a strong relationship with land use change and regional growth. Improved roads and transport networks often lead to the expansion of urban areas, growth of commercial zones, development of industrial corridors, increase in land value, and better movement of agricultural products. At the same time, unplanned transportation development may create environmental pressure, traffic congestion, displacement, and unequal growth. Therefore, it is necessary to assess transportation infrastructure in a spatial manner so that planning decisions can be more sustainable and inclusive. GIS enables planners to compare transportation networks with population density, settlement patterns, economic activities, topography, and public service locations. Such analysis provides a clear picture of whether transport development is supporting the needs of the population or whether certain regions are being left behind.

In the context of regional planning, GIS-based spatial analysis is especially useful because it supports evidence-based decision-making. Traditional transportation studies often depend on field surveys, manual maps, and statistical data, which may not fully represent spatial patterns. GIS, on the other hand, integrates maps and data together, making it possible to visualize complex relationships between infrastructure and accessibility. It can help government agencies, urban planners, transport engineers, and policymakers identify priority areas for road improvement, new route development, public transport expansion, and rural connectivity schemes. By using GIS tools, decision-makers can allocate resources more effectively and ensure that infrastructure development benefits both urban and rural populations.

Thus, the topic “GIS-Based Spatial Analysis of Transportation Infrastructure Development and Regional Accessibility” is highly significant in modern planning and development studies. It focuses on understanding how transport networks are distributed across a region, how they affect accessibility, and how GIS techniques can be used to identify connectivity gaps. The study is important because transportation is not merely a physical facility; it is a key factor that determines regional progress, social mobility, economic participation, and access to essential services. A GIS-based approach provides a systematic, accurate, and visual method to evaluate transportation infrastructure and its impact on regional accessibility. Such analysis can contribute to better planning, balanced development, improved connectivity, and more inclusive regional growth.

II. RESEARCH BACKGROUND

Yalcin et al. (2026) examined the spatial and temporal distribution of traffic accidents occurring between 2017 and 2021 and explored their underlying causes. Antalya, Turkey, was selected as the study area due to its notable seasonal population fluctuations, which were considered to influence traffic patterns. Geographic Information Systems (GIS) were utilized to analyze the spatial and temporal interactions of accident-related factors, which were categorized into internal factors, such as driver age and driver errors, and external factors, including road density, holiday periods, and the impacts of the COVID-19 pandemic. Accidents were classified into categories such as fatal and injury-related cases to identify critical intervention zones. The Kernel Density Estimation method was applied to detect accident hotspots, while driver characteristics and age distributions were systematically assessed. The findings indicated that drivers aged 20–39 years were predominantly involved in accidents, mainly due to negligence and inappropriate speed adaptation. Seasonal and holiday variations were also found to significantly affect accident distribution patterns.

Valjarević et al. (2026) examined the role of railway transport in promoting sustainable and low-carbon mobility while highlighting the increasing challenges to safety and resilience caused by aging infrastructure, spatial inequality, and climate extremes. The study focused on Serbia, where it was observed that rural and peripheral railway stations lacked adequate safety infrastructure, accessibility, and climate-adaptive design, disproportionately affecting women and vulnerable groups. The authors aimed to develop a GIS-based spatial framework to assess gender-sensitive railway safety under combined socio-spatial and environmental pressures. Multiple geo-information sources, including infrastructure data, passenger statistics, safety incidents, and climate hazard indicators, were integrated. GIS techniques such as kernel density estimation, buffer analysis, zonal statistics, spatial interpolation, and regression were applied. The findings indicated significant regional disparities, with southern and eastern Serbia identified as highly vulnerable. The study recommended improved lighting, surveillance, digital connectivity, and climate-resilient infrastructure planning strategies.

Alemdar (2025) examined urban resilience by emphasizing transportation networks as critical functional systems that supported routine operations and emergency responses. It was noted that the integration and structural integrity of these networks were highly vulnerable to disruptions caused by earthquakes, thereby highlighting their importance in urban risk management. The study was based on the application of the PROMETHEE and VIKOR multi-criteria decision-making methods, which were integrated into a Geographic Information System (GIS) framework using the Analytical Hierarchy Process (AHP). A total of 15 vulnerability criteria and 9 earthquake scenario criteria were considered to assess the earthquake risk of road networks in Istanbul. The findings indicated that the southeastern part of the European side and the eastern part of the Asian side exhibited the highest risk levels. It was further observed that approximately 9% of the city’s area and one-fifth of its road networks were classified as high-risk zones.

Abuzwidah et al. (2024) examined the impacts of climate change on flood risk, emphasizing the increasing frequency and intensity of floods and their implications for human populations and transportation infrastructure. The authors reported that assessing flood risk under changing climatic conditions was complex due to uncertainties in climate projections and the interaction of multiple influencing factors. It was highlighted that Geographic Information Systems (GIS) served as an effective tool for integrating diverse datasets to generate detailed flood risk maps. The study aimed to develop a comprehensive GIS-based flood risk map using climate scenarios derived from CMIP6 models, incorporating the Analytic Hierarchy Process (AHP) for analysis. The findings indicated that northern and coastal regions of the UAE were at higher flood risk. Furthermore, it was observed that flood risks would intensify under the SSP585 scenario compared to SSP245, suggesting severe implications for infrastructure and sustainable planning.

Arango et al. (2024) reported that climate change had been contributing to an increase in the frequency and intensity of wildfires, thereby highlighting the inadequacy of existing response mechanisms. The authors argued that wildfire management policies, practices, and decision-support tools needed to be reconsidered beyond conventional emergency measures. It was presented that the study had extended a GIS-based methodology for fire analysis, which was intended to support decision-making in the formulation and implementation of fire-related policies for road transportation infrastructure. The study was described as a novel contribution that facilitated the transition toward proactive wildfire management strategies. Furthermore, it was demonstrated that the proposed framework supported informed decision-making by addressing both reactive actions, such as emergency response, and proactive adaptation measures at a system level. The findings suggested that landscape management policies played a significant role in enhancing the resilience of road networks to wildfire impacts.

Alamri et al. (2023) examined the role of public transport systems in facilitating efficient and economical mobility within urban environments and emphasized the need for well-organized networks that could cover a larger proportion of the population while supporting urban growth. It was noted that Melbourne, as one of Australia's rapidly expanding capital cities, had experienced significant metropolitan growth due to population increase and rising urban activities. The authors observed that limited research had been conducted on assessing public transport accessibility and adequacy by considering factors such as service gaps, availability of transport options, and population density. In their study, a new measurement model was developed to evaluate accessibility across residential areas within various local government areas. The findings indicated that blank spots decreased with increasing population density, while lower-density areas experienced reduced accessibility, with no clear improvement in service levels in high-density regions.

Droj et al. (2022) examined the impact of traffic on local and regional economies, pollution levels, and public discomfort caused by congestion, accidents, and road disruptions. It was observed that urban congestion had become a common phenomenon, particularly during peak hours and under additional constraints such as road works and accidents. The study indicated that certain road segments were more prone to congestion than others as traffic volume increased. It was further highlighted that congestion patterns were influenced by multiple factors represented through complex geospatial data and their spatial interrelationships. The authors integrated mathematical models with real-time traffic data, network analysis, and simulation techniques to analyze public transportation in Oradea. A mathematical model was adapted to simulate travel behavior of urban and surrounding populations. The findings suggested that traffic congestion could be mitigated by enhancing public transport density and accessibility.

Capodici et al. (2021) examined the growing emphasis on sustainable mobility across municipalities, highlighting the significant role of bicycles in reducing dependence on private cars and promoting eco-friendly transportation. It was reported that both private and shared bicycles could function effectively as feeder systems, addressing first- and last-mile connectivity issues. The study employed Geographic Information System (GIS) tools to evaluate the effectiveness of cycling infrastructure in influencing users' modal choices. An accessibility analysis integrating cycling and rail transport services was conducted to estimate potential mobility demand and assess multimodal integration. Furthermore, a modal choice model calibrated for high school students was utilized to determine their willingness to adopt such solutions for daily commuting. The findings indicated that nearly half of the active population might shift from private cars to bicycles combined with public transport. Additionally, student participation increased significantly, demonstrating the effectiveness of GIS-based multimodal transport planning.

Le et al. (2020) investigated the influence of the Accident Severity Index (SI) on the temporal–spatial distribution of road traffic accident hotspots using GIS-based statistical techniques. The study utilized three years of Road Traffic Accident (RTA) data (2015–2017) from Hanoi, Vietnam. It was reported that the data were categorized into four seasons based on local weather conditions and further divided into specific time intervals such as daytime, nighttime, and peak hours. The Kernel Density Estimation (KDE) method was applied to identify accident hotspots across different temporal scales. The results were visualized using the comap technique. The study examined hotspot patterns both with and without incorporating SI. It was observed that although similar hotspot locations were identified, their rankings varied significantly when SI was considered. The findings suggested that incorporating SI improved the precision and prioritization of accident hotspots, thereby aiding traffic authorities in making more effective, resource-efficient decisions.

Nistor et al. (2020) examined the variation of tourism flow and its spatial representation, emphasizing its importance for transport companies, accommodation providers, and future estimations of international arrivals. It was highlighted that tourism flow mapping was significantly influenced by factors such as tourists' country of origin, their financial capacity, and the availability of statistical databases. The study suggested that the representation of tourism flows, particularly through lines and density mapping, should be aligned with the spatial characteristics of the data. A database of international tourist arrivals across various cities in Romania was utilized as a case example. GIS-based Kernel Density analysis was proposed to map tourist flows, using data from 33 countries between 2015 and 2017. The findings indicated a substantial increase in tourist density from European countries, along with a gradual expansion in mapped density areas, demonstrating the effectiveness of the proposed spatial methods.

Bhuyan et al. (2019) examined the growing adoption of bike-share systems across cities and highlighted emerging concerns related to equity, accessibility, expansion, and bikability. It was reported that Baltimore City had implemented a bike-share program in 2016, with plans to expand it to 57 stations. The study introduced a novel methodology for conducting equity-based planning analysis, which was intended to reduce segregation and marginalization in urban transportation planning. It was further explained that the proposed geographic approach incorporated a modified population density-based bike equity index. Additionally, a level of traffic stress index was developed to assess and prioritize areas requiring improved bikeshare infrastructure. The findings suggested that the study provided a parallel prioritization framework for both the implementation of bikeshare systems and the development of supportive cycling infrastructure, thereby promoting more inclusive and efficient urban mobility planning.

III. METHODOLOGY

The study employed a Geographic Information System (GIS)-based spatial analysis to examine transportation infrastructure development and its influence on regional accessibility. Data on road networks, highways, railway lines, transport junctions, and settlement locations were collected from government transport departments, satellite imagery, and field surveys. The data were processed and integrated into GIS software to create digital maps representing the spatial distribution of transportation infrastructure across the study area. Road density, distance to main roads, and travel times to essential service centers—such as markets, schools, hospitals, and administrative offices—were computed to quantify accessibility levels.

Buffer and network analyses were employed to determine zones of varying accessibility. Buffers of 0–2 km, 2–5 km, and beyond 5 km from primary transport corridors were defined to assess the benefits accrued to nearby settlements. Network analysis techniques, including shortest-path and route-efficiency calculations, were applied to evaluate travel times, distances, and alternative route availability. Accessibility indices were calculated for each settlement, integrating road density, average distance to main roads, and travel time to service centers, allowing classification into high, medium, low, and very low accessibility zones.

Further, the spatial patterns of accessibility were analyzed in relation to urban centers, commercial corridors, and peripheral regions to identify disparities. GIS-based mapping facilitated visualization of poorly connected areas, highlighting gaps in transport provision. The methodology also included comparative assessment of travel efficiency and resilience, considering areas with direct, well-maintained roads versus those dependent on indirect or poorly maintained routes. This systematic approach enabled identification of regional inequalities, prioritization of infrastructure improvement, and provision of evidence-based recommendations for enhancing connectivity, service access, and socio-economic development. The GIS framework thus provided a comprehensive, quantitative, and spatially explicit tool for transportation planning and regional development evaluation.

IV. RESULT AND DISCUSSION

The GIS-based spatial analysis of transportation infrastructure development and regional accessibility shows that transport networks play a major role in shaping the movement pattern, service access, and development level of a region. The analysis indicates that areas located near major roads, highways, railway stations, and transport junctions have better accessibility than interior or remote areas. These well-connected zones show shorter travel time to markets, hospitals, schools, administrative centers, and employment locations. In contrast, settlements situated far from main transport corridors experience poor accessibility due to longer travel distance, weak road density, limited public transport availability, and poor network integration. This uneven distribution of transport facilities creates regional imbalance and affects the socio-economic development of less connected areas.

The spatial distribution of transportation infrastructure reveals that road and rail networks are generally concentrated around urban centers, commercial areas, and economically active corridors. These locations have higher connectivity because they support trade, daily commuting, industrial movement, and public service delivery. GIS mapping shows that settlements within close distance of main roads have stronger physical connectivity and better access to essential facilities. Buffer analysis further indicates that villages and towns located within the first accessibility zone, such as 0–2 km from major roads, receive higher benefits from transportation development. However, settlements beyond 5 km from major transport routes face comparatively low accessibility, especially where feeder roads are weak or seasonal. This shows that the mere presence of a highway or railway line is not enough; local road links are equally important for improving regional accessibility.

Network analysis also highlights differences in travel efficiency across the region. Areas connected through direct and well-maintained roads show lower travel time and better route efficiency, while areas dependent on indirect, narrow, or poorly maintained routes show higher travel cost and delay. The shortest path analysis suggests that transportation infrastructure strongly influences accessibility to service centers. Regions with multiple road intersections and alternative routes have better resilience because people can choose different paths during congestion, road damage, or seasonal disruption. On the other hand, regions with single-route dependency remain highly vulnerable. This condition is common in rural, hilly, forested, or riverine areas where geographical barriers limit transport expansion.

The accessibility index prepared through GIS analysis shows clear spatial variation between high, medium, and low accessibility zones. High accessibility zones are mainly found around urban settlements, highways, railway corridors, and market centers. These areas have better opportunities for education, healthcare, business, and employment because travel time and transportation costs are comparatively low. Medium accessibility zones are generally found in semi-urban and peri-urban areas where transport infrastructure is available but not fully integrated. Low accessibility zones are mostly located in peripheral, rural, or physically isolated areas where road density is low and public transport services are irregular. Such areas require priority attention in transport planning because weak accessibility directly affects quality of life and regional development.

The study also shows that transportation infrastructure development has a strong relationship with regional growth. Areas with improved connectivity show expansion of settlements, growth of commercial activities, better land value, and increased movement of goods and people. Farmers and small traders in well-connected areas can transport products to markets more easily, while students and patients can reach schools and hospitals with less difficulty. In contrast, poorly connected regions remain dependent on limited local services and face difficulties in participating in wider economic activities. This proves that transport accessibility is not only a technical issue but also a social and economic development indicator.

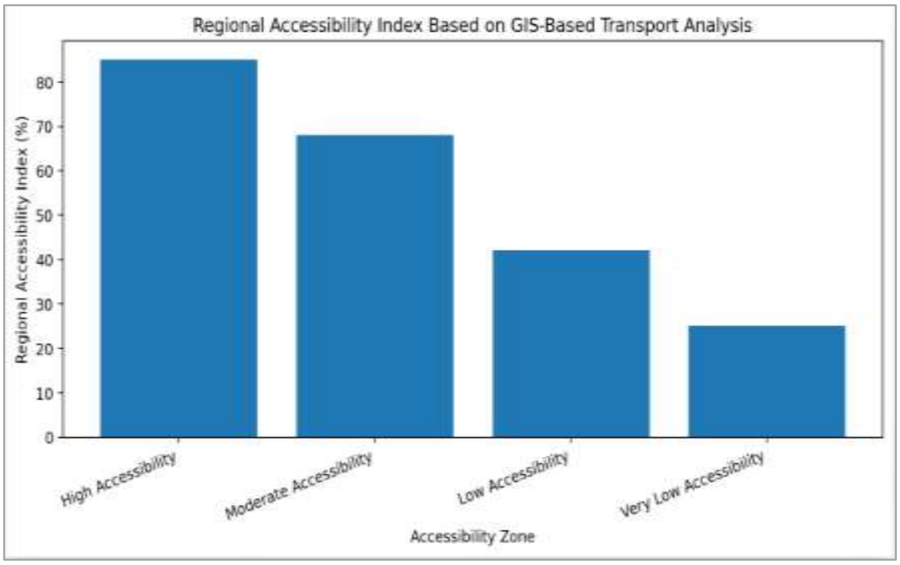
From the discussion, it is clear that GIS is an effective tool for identifying transport-related spatial inequalities. It helps in visualizing gaps in connectivity, measuring distance and travel time, locating underserved settlements, and suggesting priority areas for infrastructure improvement. The results suggest that future transportation planning should focus not only on constructing major roads and highways but also on improving rural roads, feeder links, last-mile connectivity, and public transport availability. Balanced regional accessibility can be achieved only when transportation development reaches both central and peripheral areas.

Overall, the result indicates that regions with dense and integrated transport networks experience higher accessibility and stronger development potential, while areas with weak connectivity remain spatially and economically disadvantaged. Therefore, GIS-based spatial analysis can support planners, engineers, and policymakers in preparing more inclusive, efficient, and sustainable transportation development plans. It provides a scientific base for reducing regional disparities, improving service access, and promoting balanced growth across the study area.

Table 1: GIS-Based Transportation Accessibility Indicators

Accessibility Zone	Road Density (km/sq.km)	Average Distance to Main Road (km)	Average Travel Time to Service Centre (min)	Regional Accessibility Index (%)
High Accessibility	2.8	1.2	15	85
Moderate Accessibility	1.9	3.4	28	68
Low Accessibility	1.1	6.8	45	42
Very Low Accessibility	0.5	10.5	65	25

Bar Graph



Regional Accessibility Index Based on GIS-Based Transportation Infrastructure Analysis

The table and graph show that regional accessibility is strongly influenced by the density and quality of transportation infrastructure. Areas classified under high accessibility have the highest road density of 2.8 km/sq.km, the shortest average distance to the main road at 1.2 km, and the lowest travel time to service centres at 15 minutes. As a result, these areas achieve the highest regional accessibility index of 85%. This indicates that well-connected regions provide better access to markets, hospitals, schools, administrative centres, and employment opportunities.

In contrast, the very low accessibility zone records only 0.5 km/sq.km road density, an average distance of 10.5 km from the main road, and 65 minutes average travel time to service centres. Its accessibility index is only 25%, showing poor connectivity and limited regional development opportunities. The graph clearly shows a gradual decline in accessibility from high to very low zones. This proves that transportation infrastructure development directly affects regional accessibility, mobility, and socio-economic growth. Therefore, GIS-based spatial analysis is useful for identifying poorly connected areas and planning future road development, feeder routes, and public transport improvements.

V. CONCLUSION

The study concludes that transportation infrastructure development has a direct impact on regional accessibility and overall socio-economic growth. Areas with dense and well-connected transport networks show better access to essential services such as education, healthcare, markets, administrative offices, and employment centres. The analysis indicates that high accessibility zones have better road density, shorter travel distance, and lower travel time, while low and very low accessibility zones suffer from weak connectivity and longer travel duration. This creates regional imbalance and affects the quality of life of people living in remote areas.

GIS-based spatial analysis proves to be a useful method for identifying transport gaps and accessibility differences across a region. Through tools such as network analysis, buffer analysis, distance measurement, and accessibility mapping, GIS helps planners understand which areas require priority attention. The study suggests that future transportation planning should focus not only on major highways and urban roads but also on rural roads, feeder routes, last-mile connectivity, and public transport facilities. Improving these elements can reduce regional inequality and promote balanced development. Overall, GIS provides a scientific and visual approach for sustainable transportation planning and better regional accessibility.

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