GIS Application in Urban Road Network Analysis: The Case of Panchkula City, Haryana, India

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Abstract
Urban road networks are crucial for the efficient movement of people and goods. A region's ability to develop has always been directly correlated with the calibre of its transportation infrastructure. Effective and unobstructed road networks are essential in today's world to reduce problems like traffic jams, delays, pollution, higher vehicle operating expenses, and collisions. Panchkula, a rapidly growing city in Haryana, India, faces challenges related to traffic congestion and road network efficiency. Using Geographic Information Systems (GIS), this study examines Panchkula City, Haryana, India's urban road network. The objective of this research is to assess the current condition of Panchkula's road densities, such as major, minor, and lane road density, and short path analysis for the emergency services between the two city points. GIS technique is used to find the shortest path between important city places, providing workable answers to traffic related issues. By employing various connectivity and density indices, the current state of the road network is analysed, and proposals for improvements for better traffic management and urban planning are made. The results show that the major roads density varies from 0.150537 to 3.201378, the minor road density varies from 0.013290 to 1.565590, and the lane density varies from 0.56540 to 3.068603.

Keywords: Connectivity, Geographic Information Systems, Panchkula, Road Network, Traffic Management

1. Introduction

In the evolving landscape of urban planning and development, transportation infrastructure plays a pivotal role in shaping the economic, social, and environmental fabric of a city. The road transport network is fundamental to human settlement [1], and it plays a significant role in determining the urban mobility pattern of any given metropolis. Efficient and well planned road networks are fundamental to the growth and development of urban areas, ensuring connectivity and accessibility, which are crucial for sustainable development. Traditionally, Toposheets were the only tool available in classical GIS for visualizing the transport network [2]. Similarly, in order to identify solutions for routing issues pertaining to accessibility, flow rate, and network connection for the southwest region of Delhi, [3] focused on the network analysis of services like ATMs of various banks and hospitals. Important density and connectivity indices quantify accessibility and connectivity, which improve urban mobility and are crucial for evaluating the effectiveness of the road network [4]. Panchkula, with its strategic location and burgeoning population, faces significant challenges in terms of traffic congestion, road safety, and overall transportation efficiency. The town of Panchkula, one of the newest cities in the nation at less than 50 years old, was once free of annoyances like congested roads, cramped apartments, and dim, narrow streets, but today things have reversed [5]. Their research indicates that ANFIS modelling provides the most accurate explanation of accessibility in terms of network coverage, connectivity, and spatial organization. Another crucial method for demonstrating the relationship between connectivity and spatial pattern is geographically weighted regression (GWR) [6]. The utilization of Geographic Information Systems (GIS) in the research of urban road networks has led to notable improvements in traffic management and urban planning [7]. Accessibility which is closely related to connectivity has a significant impact on the value of property [8]. Network Analyst in GIS make it easier to plan the best routes, which is essential for emergency response and traffic flow [9]. Effective transportation systems have always been essential to the growth of an area [10].

The road network of any urban area acts as the veins of the city's body, facilitating the flow of goods, services, and people, much like blood through the human circulatory system. An efficient road area network is the fundamental infrastructure that expedites development by facilitating trade and investment between underdeveloped regions and fostering connections [11]. This study focuses on the application of GIS in analysing the urban road network of Panchkula City, a rapidly growing urban centre in Haryana, India. The agricultural land that is annexed to the city's built up region has seen the physical expansion of the metropolis of Panchkula [12]. By leveraging GIS technology, this study aims to assess the current state of the road network in Panchkula, identify critical issues, and propose solutions to enhance the overall transportation system. The effective planning, designing, building, maintenance, and administration of the transportation system all depend on information about the transportation network [13]. Connectivity, accessibility, hierarchy, and shape are the fundamental components of any road network. A well connected street system makes it easier to go to your intended locations. An ordered, hierarchical road system facilitates varying vehicle volumes, speeds, and types of transportation [14]. Network analysis, which is based on GIS, is an effective add on that offers network based spatial analysis, such as routing, trip directions, nearest facility, and service area analysis [15]. Numerous methods for observing the characteristics of the transport structure are available when GIS and transportation network analysis are combined [16]. Since efficient road networks save travel times and increase accessibility, they promote socioeconomic development [17].

Although both machine learning (ML) and predictive modeling techniques have become more popular in transportation research for traffic prediction or pattern detection, their application demands large amounts of data and usually concerns prediction accuracy. In contrast, GIS-based network analysis provides a transparent, spatially explicit, and structurally interpretable framework for evaluating road network characteristics such as connectivity, hierarchy, accessibility, and service areas [18].

Considering the rapid metropolitan growth of Panchkula's geographic area and the growing difficulties in transportation, systematic infrastructure analysis on the city's road network shall be significant. Accordingly, this research endeavors to employ GIS-driven network analysis methods to investigate Panchkula's urban road network in the context of its structural efficiency and functional performance. The objective of this research is to apply GIS-based network analysis methods to conduct a detailed evaluation of the urban road network in Panchkula and to assess the structural efficiency and functional performance of this network. In particular, the purpose of this study, therefore, is to investigate the degree of connectivity and accessibility of the current road network, to examine its hierarchical organization and spatial layout, and to identify major deficiencies or spatial imbalances that impair the travel capacity. This study therefore also aims to use the integration of spatial indicators with network analysis tools to develop data-driven strategies to help advance sustainability in transportation and informed decision-making in a growing urban setting. Accordingly, the study is designed to address these following questions:

- With respect to connectivity and accessibility, what level of efficiency does Panchkula's current road network structure provide?
- What are the spatial characteristics of the network's hierarchical structure and configuration?
- Which regions exhibit structural deficiencies or low accessibility?
- In what way can GIS-based analysis help to develop sustainable transportation planning in rapidly developing urban environments?

2. Literature Review

Conducted an ArcGIS network study for Varanasi city in order to determine the best routes for delivering services such as hospitals [19]. Numerous approaches may be used to investigate the relationship between spatial pattern and connectivity. With the aid of multiple linear regression (MLR), artificial neural networks (ANN), and adaptive network based fuzzy inference system (ANFIS) modelling, Sahitya and Prasad have investigated the relationship between connectivity, coverage, accessibility, and spatial pattern [20]. There is more connection and coverage of the Calicut city road network close to the central business district and less at the city's outskirts.

The management of urban infrastructure has been completely transformed by GIS technologies, especially ArcGIS, which offers powerful spatial analysis capabilities [21]. Using Network Analyst tool in ArcGIS software was utilized to assess the network connection indices in the Kasaragod taluk, Kerala study region [22]. They found that the road connectivity in the research area was inadequate. The connectedness, accessibility, and network efficiency of the road network structure in the Chachar district of Assam have been examined [23]. Using connection indices, [24] have examined Mongolia's network structure. Several case studies, such as those from Hyderabad and Guwahati, show

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how effective GIS is at improving urban planning and reducing traffic [25] and [26]. GIS has been widely used in urban road network analysis. Studies such as [27] demonstrated the utility of QGIS in road network analysis in the kernel district. Furthermore, GIS is critical to sustainable transport management, according to government policies [28]. Similarly, the role of GIS in evaluating road network connectivity in Hyderabad has been highlighted [29]. The road network connectivity of the study area in the city of Aurangabad was determined by several researchers [30]. After calculating the fractal dimension of the road network in the Amman metropolitan district, [31] found a significant relationship between the network's layout and the expansion of the built-up area and population. The urban transportation network plays a significant role in forming urban centres since it allows consumers to select a mode of transportation based on their destination and living situation [32]. For this reason, GIS is a vital tool in addressing the issues associated with contemporary urbanization. These studies highlight the importance of GIS in urban transportation planning and network analysis.

Although the concepts of machine learning (ML) and predictive modeling have been increasingly exploited in transportation research for traffic prediction and pattern recognition, its use is often data-intensive, with an emphasis on prediction correctness. On the other hand, GIS-based network analysis delivers an open-interpretable (visually apparent, spatio-physically transparent and structurally intelligible) structure to the assessment of road network characteristics, such as connectivity, hierarchy, accessibility and service areas. Unlike a number of ML algorithms, we can see in GIS-based analysis the spatial relationship easily, so that the planners and the policy-makers can also identify the structural issues within the network.

Moreover, this study does not seek predictive modeling but diagnostic and structural evaluation. Hence, GIS-based network analysis was deemed more suitable to evaluate spatial layout and functional functionality of urban road network in Panchkula. Nonetheless, future studies could combine GIS with machine learning techniques to improve prediction abilities and facilitate more effective urban transport planning. In this experiment, all the geospatial processing and network analysis was conducted using QGIS as the principal GIS software.

The road network data for Panchkula City was harvested from OpenStreetMap (OSM) and passed to QGIS to be pre-processed and fine-tuned. Vector treatment tools were used for dataset sanitization to eliminate geometric irregularities and to check the proper topological relationship between different road segments and intersections. The topology validation and geometry checking tools were employed to manually correct the errors as well as to properly construct node–edge relationships in the network. In network modeling and routing analysis, the Network Analysis package from QGIS was utilized to compute optimal directions for the selected origin–destination points using Dijkstra's shortest path algorithm. The road density and junctions of a project were calculated with spatial analysis functions from the Processing Toolbox, and intersection analysis was performed by means of spatial overlay and point extraction operations.

3. Study Area

Panchkula district is located in the northern part of Haryana, having a locational extent between 32° 27′ and 30°57′ north longitude and 76°48′ and 77° 10′ east longitude (Figure 1). It is bounded by Himachal Pradesh in the north and east, Punjab and the Union Territory of Chandigarh in the west, and by Ambala district in the south and southeast. The district is spread over an area of 898 sq. km with a total population of 5.61 lac as per the 2011 census. Panchkula district has a sub-tropical continental monsoon climate where the seasons are hot summer, cool winter, good monsoon rainfall, and great variation in temperature. In winter, frost sometimes occurs during December and January. The rainfall is mostly received in the summer season during monsoon and also by western disturbances in winter. Morni hills constitute the highest point of the district as well as of Haryana. The Ghaggar is the only main river that originates in Himachal Pradesh and flows through the district up to Hanumangarh district in Rajasthan, where it dries up in the desert. Panchkula city, which is the district headquarters of district Panchkula, is a well-planned city of Haryana.

Panchkula city is a satellite city of the Chandigarh Union Territory and serves as the home to the Indian Western Command's prominent Chandimandir Cantonment Headquarters. The district encompasses five primary towns: Raipur Rani, Panchkula, Barwala, Pinjore, and Kalka. Additionally, it includes Morni, which is the sole hill station in the state of Haryana. According to the 2011 Census, the district recorded a total population of 561,293, consisting of 299,679 males and 261,614 females, respectively. Chandigarh has two satellite cities: Mohali in Punjab and Panchkula in Haryana. Chandigarh Tricity is the aggregate name for these three cities.

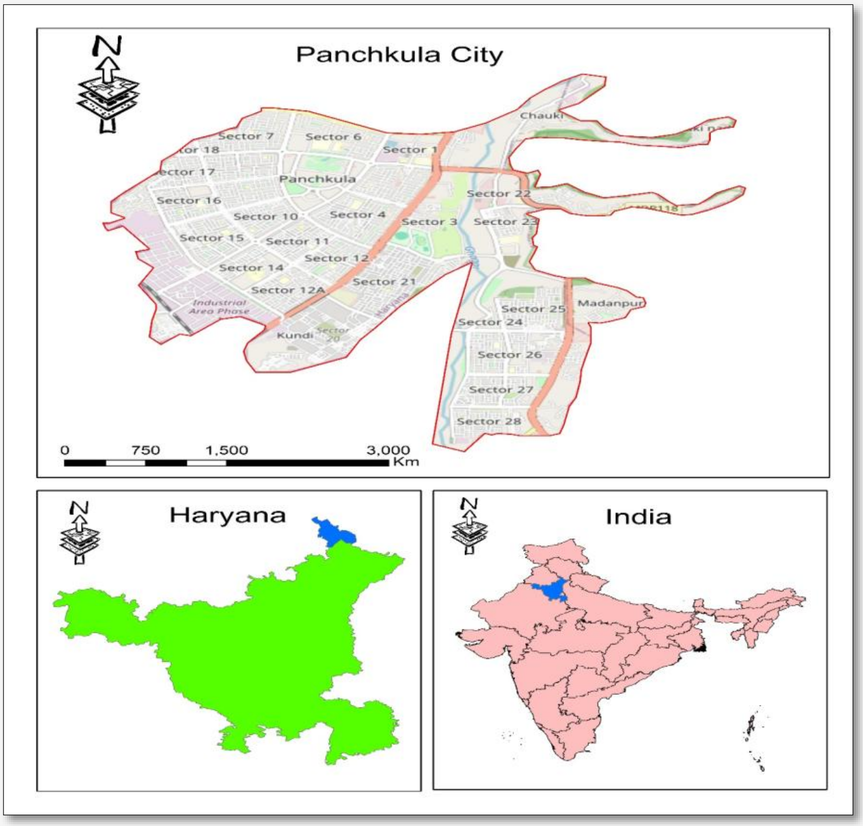

Figure 1: Panchkula city, Harayana, India

Combining the terms panch (five) and kul (canal) results in the word Panchkula, which means "the city of five canals." Possibly alluding to the five irrigation canals that transport the Ghaggar River's water from Nada Sahib to Mata Mansa Devi. Now that the river has damaged the Nada canal, the majority of the kul's pass via Chandimandir's cantonment on their way to Mansa Devi. The canals are a stunning illustration of communal property, and the villages along the route care for them, choosing distribution dates. The canals, which were built by a monarch in the past, follow the natural contours to raise water levels above the river at that location. It is located about 4 km southeast of Chandigarh, 105 km southwest of Shimla, 44 km from Ambala, and 259 km northeast of the nation's capital, New Delhi. It lies within the Greater Chandigarh area, which is the capital of Chandigarh. With a combined population of nearly two million, the Chandigarh-Mohali-Panchkula metropolitan region is unified as the Chandigarh Tricity.

4. Methodology

The study procedure was structured into four key processes. The study's steps are explained in detail below:

4.1 Data Collection

It is an essential step in the study to collect reliable data from the sources and enhance the credibility of the study. The first step of the study was to obtain the sector map of Panchkula city from the Survey of India, then the road network data was extracted from OpenStreetMap (OSM). OSM is a valuable open resource that provides detailed information and data about road networks worldwide, including rural and urban areas. It provides the highways, district roads, sector roads, service roads, and footpaths. City point is identified and extracted within the city to analyse the shortest path, such as major intersections, landmarks, etc.

4.2 Data Preparation

The sector map was used to calculate the area of each sector in Panchkula city, Haryana. Extracted roads from the OSM dataset and calculated the total length of roads within each sector. Calculation of the length of each road and the area of each sector is important to compute the road density in the city.

4.3 Density Calculation

Road Density: It indicates the total length of the road in a given area and is expressed as kilometres and square kilometres. Road density is also important to understand the transportation network accessibility in the city. Higher road density indicates good connectivity and is suitable for movement, supporting development activities, and efficient urban planning. High road density is also associated with a well developed infrastructure and transportation network in the city, while low road density is associated with less developed infrastructure and development [33]. To compute the road density for each sector using the formula:

$$D = \frac{L}{A}$$

Equation 1

Where:

D is a set of Density.
L is a set of the length of roads.
A is a set of the area.

4.4 Network Analysis

Network analysis in GIS plays an important role in analysing and increasing transportation connectivity and functionality. It includes examining roads, pathways, and connected routes to analyse the flow of movement across a network. This analysis is essential for solving complex problems such as finding the shortest path, identifying the most accessible locations, determining service areas around facilities, and evaluating traffic congestion or bottlenecks. This study used road network data to identify edges (roads) and junctions (intersections) and performed network analysis to determine the shortest routes between various city points, along with Dijkstra's algorithm. Dijkstra's algorithm calculates the shortest path between nodes in a graph. The formula can be represented as follows:

$$G = (V, E)$$

Equation 2

Where:

G is defined as the Graph representing the spatial network under study
V is a set of vertices
E is a set of edges.

Dijkstra's algorithm is a fundamental algorithm in computer science used to find the shortest path from a single source node to all other nodes in a weighted graph. It is widely used in network routing, GPS navigation, and many other applications. Dijkstra's algorithm keeps following sets of vertices shown in Table 1.

The basic mode of operation is:

- Initial is *d* and *Pi.*
- Set *S* to empty.
- While there are still vertices in *V-S*.
- Sort the vertices in *V-S* according to the current best estimate of their distance from the source.
- Add u, the closest vertex in *V-S*, to *S*.
- Relax all the vertices still in *V-S* connected to *u*

In this study, the weight assigned to each edge corresponds to travel time. Travel time for each road segment was calculated based on segment length and estimated travel speed using the following relationship:

$$T = \frac{L}{V}$$

Equation 3

Where:

T is travel time.
L is the length of the road segment.
V is the assumed average travel speed.

Road segment lengths were derived directly from the GIS road network dataset, while travel speeds were assigned based on road classification (e.g., primary, secondary, local roads). The resulting travel time values were then used as edge weights in Dijkstra's algorithm. This algorithm efficiently finds the shortest path by iteratively selecting the nearest unvisited vertex, updating the distances to its neighbours, and marking it as visited. The operation of the algorithm maintains a partition of the vertices *V* into two sets: S, the set of vertices whose shortest-path weights from the source have already been determined, and *V - S*, the remaining vertices. At each step, the algorithm selects a vertex u in *V - S* with the minimum distance estimate *D*, adds it to *S*, and relaxes all edges leaving u. During this relaxation, both the distance *D* and the predecessor *Pi* are updated if a shorter path to a neighboring vertex is discovered.

Table 1: Dijkstra's algorithm vertices

Vertices	Explanation
S	The set of vertices whose shortest paths from the source have already been determined.
V-S	The remaining vertices.
D	An array of the best estimates of the shortest path to each vertex
Pi	An array of predecessors for each vertex
U	Represents the specific vertex being extracted from the priority queue V-S in each iteration

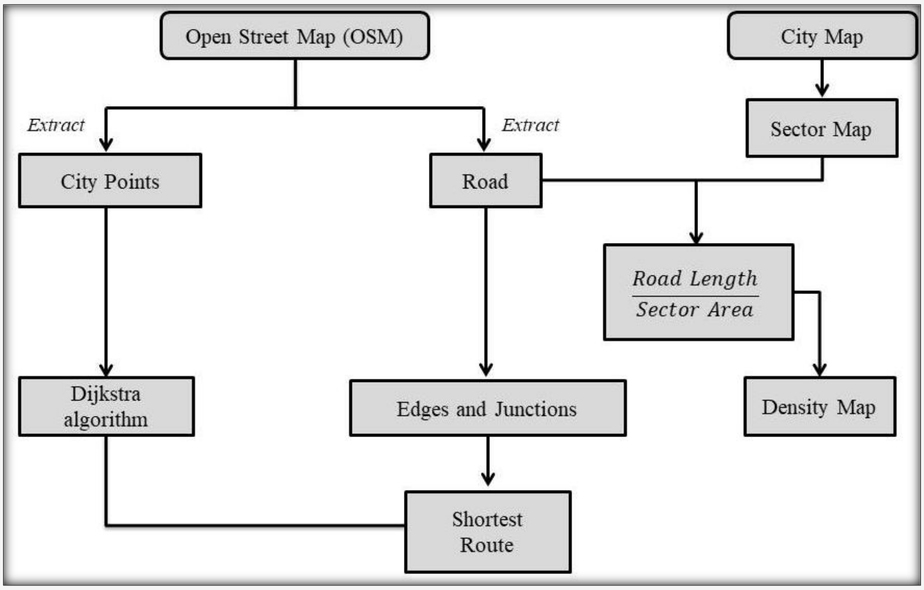

Figure 2: Shortest route methodology

4.5 GIS Tools and Techniques

This study is guided by the core principles of using QGIS as the essential geospatial platform for processing and analyzing networks. Extraction of the road network for Panchkula City was done from OpenStreetMap (OSM) and then a cleaning and refining process was performed in QGIS for data integrity and topological connectivity. The analytical framework contains key GIS techniques that work synergistically. First, a network analysis is done to analyse connectivity of the urban fabric in conjunction with calculating road and junction densities to identify areas of high infrastructure concentration. Next is shortest path analysis to get an approximation of routing efficiency, and intersection analysis to show the complexity of traffic flow in the city. Synthesizing these, it is concluded, a continuous process (Figure 2) the methodology flowchart, which enables the structured and fine-grained study of the urban road network, contributing to better traffic management and urban planning decisions.

This study's methodology is outlined in Figure 2, which shows the process step by step and continuity from data collection to spatial analysis. This procedure starts with two main datasets, ‘City Points’ which are the key city locations, along with ‘Edges and Junctions’ that form the structural framework of the road network taken from OpenStreetMap. The data is then processed through the Dijkstra Algorithm and the above inputs are used as building blocks for the analysis phase. Based on optimization of network topology and edge weights, the algorithm finds the best routes. As a result, the 'Shortest Route' is produced as the final output, which quantitatively describes urban connectivity and can be used to inform traffic management in Panchkula City.

5. Results and Discussion

5.1 Panchkula City Block

The study of Panchkula City involved partitioning it into spatial areas, city blocks so that thorough analyses could be carried out on these road networks. A city block is defined here as a planned urban sector enclosed by arterial or collector roads, designed as a functional unit for residential, commercial, industrial, or mixed land-use activity. Under this division, road network characteristics of different parts of the city can be compared. This division of Panchkula City into 37 city blocks was based on administrative planning boundaries, road network structure, and functional land-use characteristics. Examples include sectors 1 through 32 and 5 more blocks in the Manimajra Development Complex (MDC), namely Industrial Area Phase 1, Industrial Area Phase 2, Kundi, Ramgarh, and Nagalmoginand (Figure 3). Each block is a unique spatial unit with distinct road characteristics and connectivity traits that suggest sectoral categorization. City blocks are used as analytical units, allowing for a more accurate assessment of network density, connectivity, and accessibility. The spatial difference in transportation infrastructure performance can be verified by studying each block independently and, in that case, the targeted urban planning and traffic management can be determined.

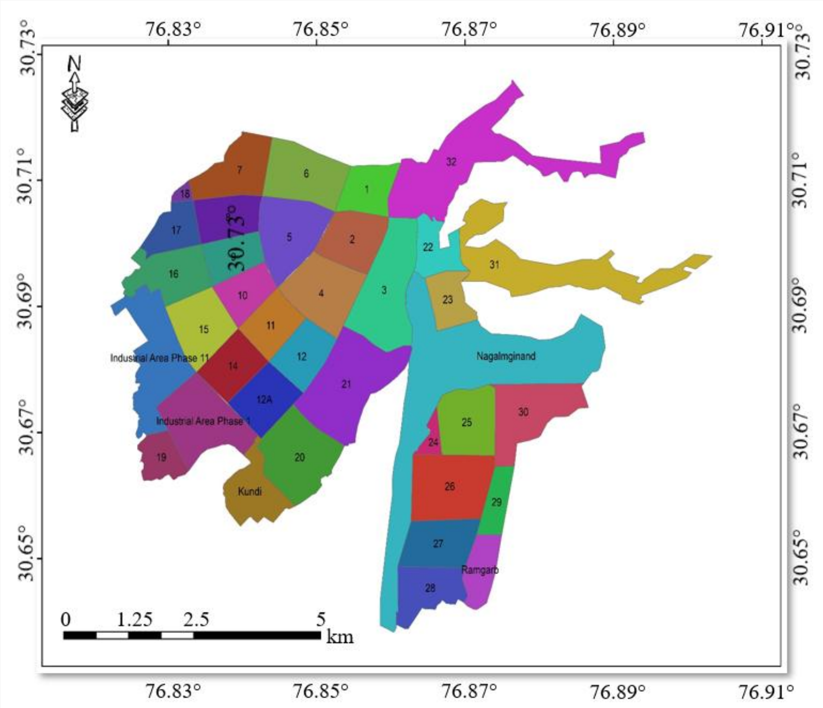

Figure 3: Sector-wise map of Panchkula City

Table 2: Panchkula City: Statistics of major and minor roads, Lanes and local road

No.	Attribute	Numbers	Total length (km)
1	Total no. of major roads	22	87.0553
2	Total no. of minor roads	36	164.187
3	Total no. of lanes and local road	37	445.149

5.2 Road Network of the City

The road network of Panchkula City is a hierarchical one, depicted in Table 2 and graphical in Figure 4. Lanes and by-lanes are the largest parts of the network, measuring 445.149 km. This large spread is evidence of the massive expansion of the urban area and sophisticated transport infrastructure. Particularly, there is a high density of local roads and by-lanes to connect all points of access, ensuring efficient traffic distribution across the city's various sectors.

5.3 Edges and Junctions in the City

The spatial analysis is shown in Figure 5 which shows hierarchical structure of Panchkula City's transportation network as evidenced by the strategic integration of main routes, intersections, and urban edges. Main streets are the platform for inter-sector connectivity, enabling widespread mobility throughout the city. Moreover, the arrangement of major junctions indicates a great extent of accessibility at points of traffic intersection. Its geography is dominated by several administrative and physical boundaries (e.g., the natural corridor of the River Ghaggar in the eastern region). The systemic layout of these infrastructural elements serves a considered urban planning strategy to facilitate intercommunication by merging the built context of the city with its natural geography. This smooth road network illustrates the energyfulness of the city in terms of traffic flow and the durability of its urban environment.

5.4 Major Road Density

These differences are shown in Figure 6 in the spatial distribution of road density among the different districts in Panchkula. District 7 and District 6 have the highest road densities, with 3.201 and 2.671, respectively, suggesting high traffic congestion. Districts such as District 1 and District 25 indicate an urban well-functioning road network but possibly causing congestion. On the other hand, Nagar Mogi Nand and Zone 32 have the lowest densities, indicating that these areas are less developed or have lower traffic volumes.

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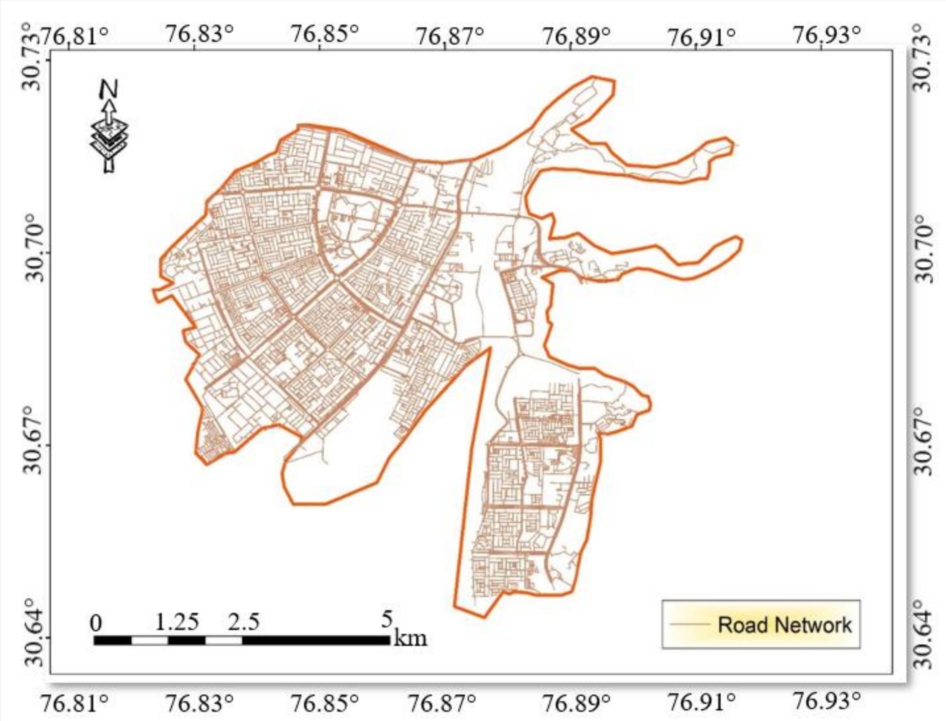

Figure 4: Road network of Panchkula City

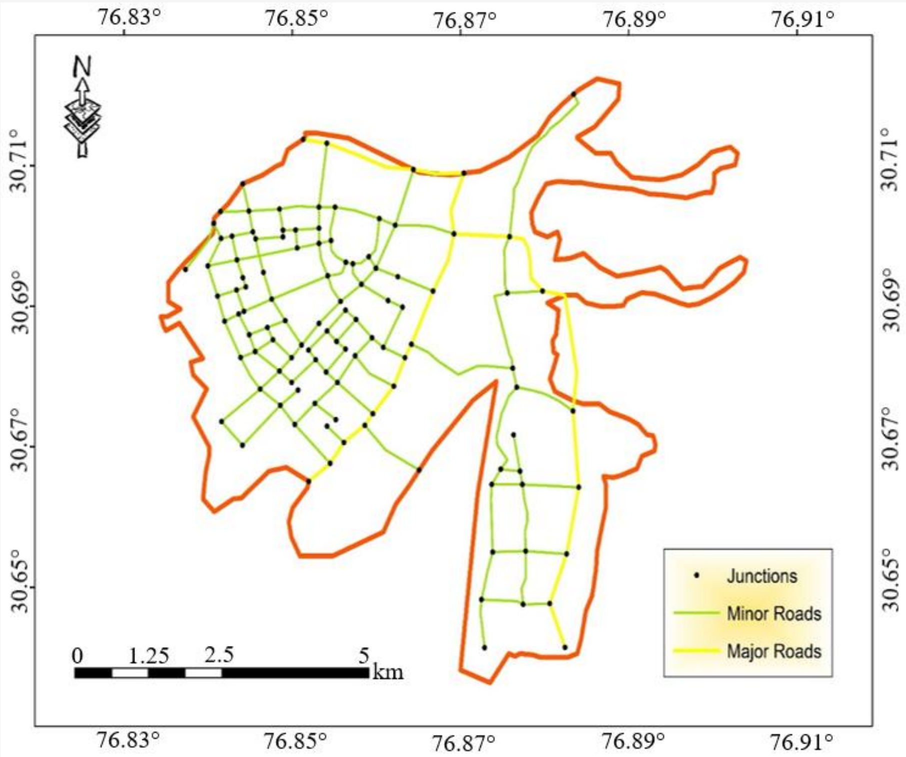

Figure 5: Edges and junctions of Panchkula City

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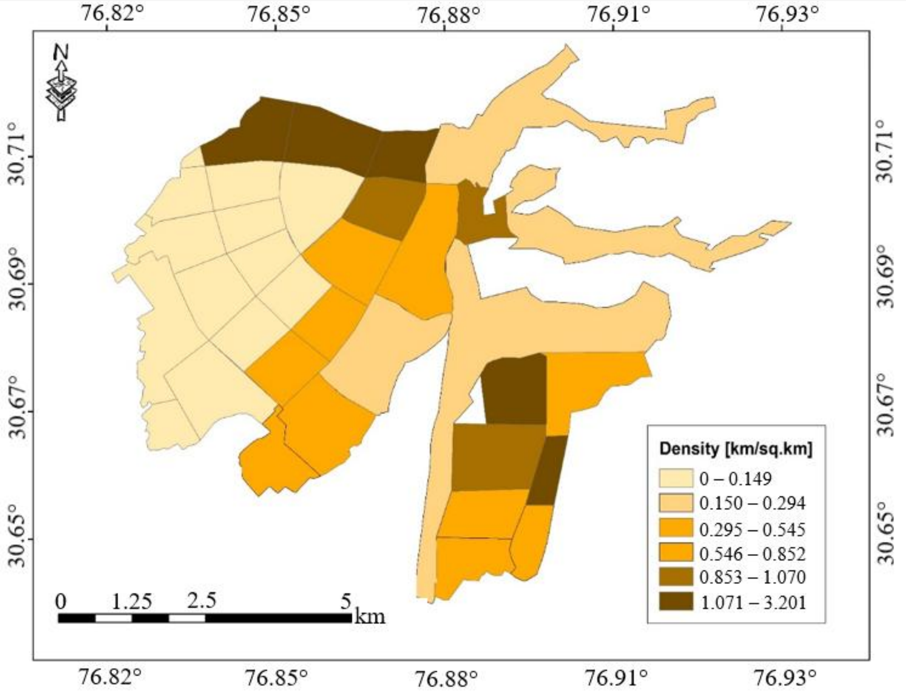

Figure 6: Major road density of Panchkula City

In general, the major density ranges are high, medium, and low level and are consistent with the different levels of infrastructure development and traffic congestion in Panchkula City as a whole. However, most of Panchkula is in the middle to high density, so even though its road network is pretty advanced, it faces some congestion hotspots.

5.5 Minor Road Density

As per the minor road density, Panchkula has a diverse range of road densities across the sectors within Panchkula City. There are low points in Sector 30 as well as in Nagalmoginand, with densities of 0.013 and 0.070 respectively, reflecting a lower degree of development. Neutral density areas (e.g., Sector 4 and Sector 7) exhibit a moderate road network, while medium density sectors (i.e., Sector 11 and Sector 10) have larger infrastructure and manageable traffic density. The high-density regions such as Industrial Area Phase II and Sector 32, with densities of 0.712 km/km2 and 1.069 km/km2 respectively, illustrate large areas of development and congestion. Data on road density also shows that very high-density sections such as Sector 18 (1.566 km/km2) show extreme congestion and intense road usage as indicated in Figure 7. It can be said that Panchkula City has road density of both heavily congested areas and lightly built-up areas.

5.6 Local Road Density

Summary of the major road densities in Panchkula City. The lowest density areas are located at Nagalmoginand and Sector 32 and 31, i.e., they show smaller road congestion and possibly inadequate structure (Figure 8). Sectors like Sector 22, Sector 18 and Sector 24 have the highest road densities suggesting high levels of congestion and a good level of built-up road systems. Moderate densities where some areas such as Industrial Area Phase II, Sector 20 and Sector 21 are observed, indicating balanced development. The distribution in a wider sense shows the different types of infrastructure development in the Panchkula region, which includes those with low, medium, and high density, corresponding to different levels of urbanization and traffic constraints. Though road density was not employed as an impedance in the shortest path analysis, the traffic density served an important as context and interpretation in the network. The computation for the shortest path was mainly made in terms of time spent traveling, at least as a cost factor, but road density variations in spatial dimension correspond to network connectivity, redundancy and accessibility between sectors of Panchkula City. The road density on the part of the locality can often lead to several more route options and hence enhance internal connectivity, which could then help to increase flexibility of emergency response.

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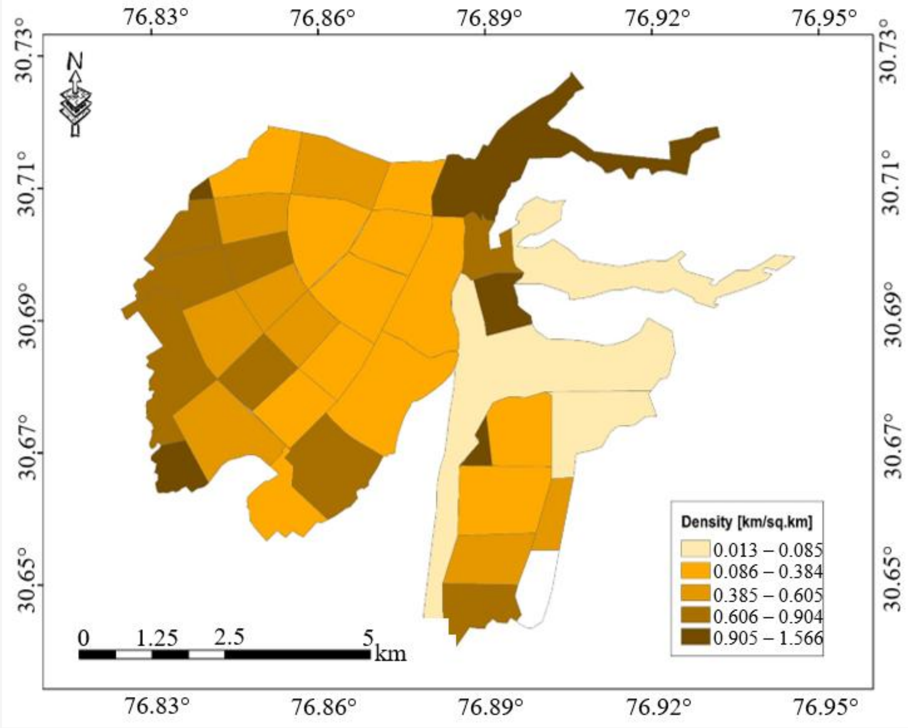

Figure 7: Minor road density of Panchkula City

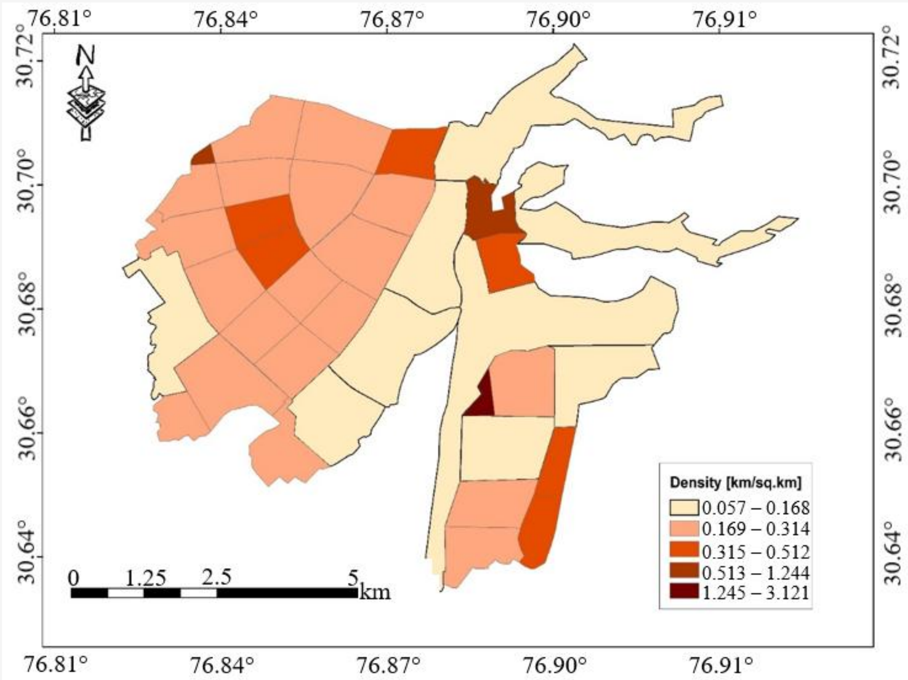

Figure 8: Lane Density of Panchkula City

On the other side, networks are hard to access in low-density areas where only a handful of alternatives exist, and this could make such zones more susceptible in case things go wrong. Thus, the analysis of road density also complements the results of the shortest path as a structural characterization of network capacity and spatial distribution of infrastructure, even as this was not directly present as a weighted variable in the algorithm. There is also some possibility to look at the physical spatial variation in road density in Panchkula City through the lens of underlying socio-economic and planning parameters. Higher road densities are seen in a certain area with urban residents, especially those near city central business district (CBD) and well-established residential sector, because this is where the demand for accessible road space and historical urban development trends dominate. For instance, peripheral or newly developed sectors with an urban development plan typically show lower road densities, which is indicative of planned infrastructure growth and reduced near-term traffic demand. Thus, road density variations are not only technical signals for the distribution of infrastructure, but are also linked to demographic concentration, land use intensity, economic activity and the plans of urban expansion.

5.7 Shortest Path Analysis

The shortest path was evaluated to identify the most efficient routes for emergency services to minimize response time and improve accessibility across the entire network. In this study, travel time was considered as the cost metric (impedance) for the network analysis instead of physical distance. Network analysis using Dijkstra's algorithm (which finds paths with minimum impedance to estimate travel times) was used. Each network edge travel time was determined by dividing the segment length (L) of each edge by the average speed assigned to each edge (e.g., arterial, collector, local roads) based on the data. To enhance accuracy, speed values were given according to local traffic regulations and road hierarchy. Therefore, it is also true that while it may be a shorter route in geography, the travel costs could be elevated because of the lower speed limits or the presence of a network constraint. In contrast, the model will choose the fastest routes of the major arterial roads, which even if they have longer distance, they also have a much shorter trip time. It considers the geometry-related network linkages and allows for a highly realistic estimation of the time of passage for free-flowing traffic, as depicted in Figure 9 and Table 3.

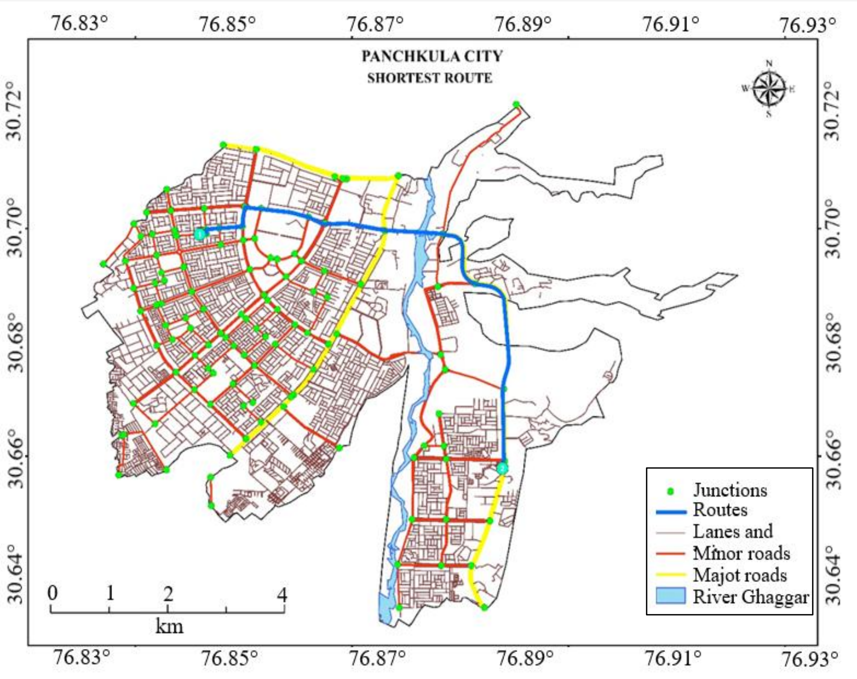

Figure 9: Shortest route analysis b/w Govt Dispensary Sector 8 and Madanpur bus stop

Table 3: Panchkula City: shortest route analysis b/w two points

Starting Point	End point	Major Landmarks	Total Distance (km)	Time (min)
Govt. Dispensary Sector 8	Madanpur Bus Stop.	Sector 8/7 dividing Road and Madanpur Junction	5.41	13
Bharat Petroleum, Industrial Area Phase II	Purana Panchkula Chowk	Main Industrial Road and Panchkula Junction	8.73	16

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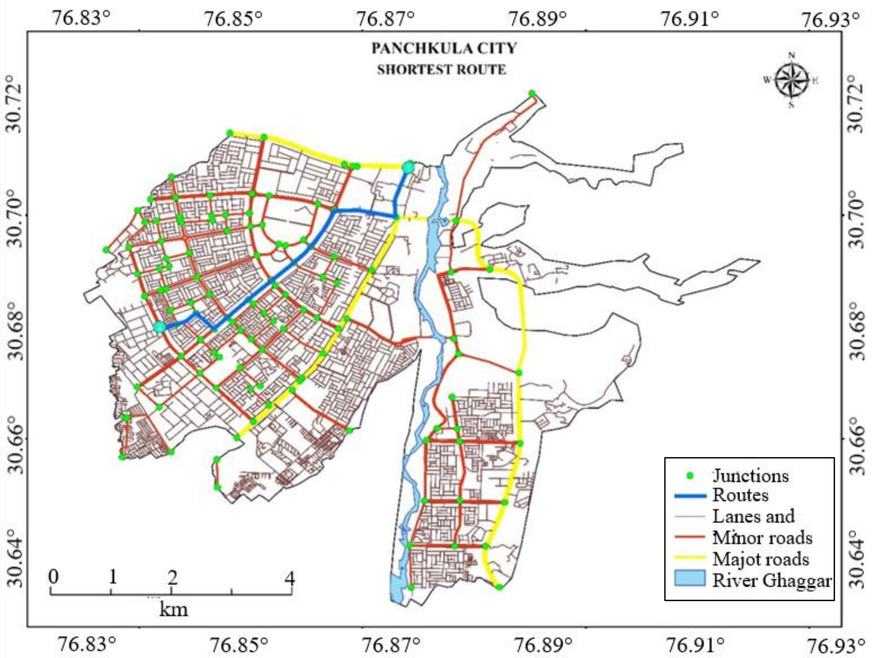

Figure 10: Panchkula City: Shortest Route Analysis b/w Bharat Petroleum, Industrial Area Phase II and Purana Panchkula Chowk

A. Shortest Path Analysis: between Govt. Dispensary Sector 8 to Madanpur Bus Stop

From the District 8 Government Clinic to the Matampur Bus Stop the shortest route is south on the main road turn right onto the District 8/District 7 boundary road continue straight and merge onto the main road leading to Matampur exit the Matampur intersection and to the local roads directly to the bus stop. Thus, taking on about 5.41 kilometers of distance, about 13 minutes to travel; though the actual time is not strictly specified as traffic speed varies. This route has the fewest turns, predominantly uses major thoroughfares for reduced travel time, and does not hit congestion hotspots according to traffic data interpretation.

B. Shortest Path Analysis: between Bharat Petroleum, Industrial Area Phase II, to Purana Panchkula Chowk

Panchkula Chowk on the north-east to south street of Bharat Petroleum Phase II Industrial Estate has the shortest distance at which to travel, which is head north-east using main industrial road turn left on slip road to Panchkula, cross the junction to main road to Panchkula and follow the road to Purana Panchkula junction. The total route is about 8.73 km with a duration of about 16 minutes; the exact time required depends on the traffic. This path reduces the number of trips through the bustling industrial district and utilises the main road for quicker, more direct travel (Figure 10).

The two cases were selected and each of four locations for the shortest path analysis were chosen to fit well with key logistical and public service nodes. The first one (Govt. Dispensary to Madanpur Bus Stop) assesses the accessibility of critical health services to transit hubs. The second case (Bharat Petroleum, Industrial Area to Purana Panchkula Chowk) was also conducted to study the industrial-to-urban connectivity. It is the major fuel supply and industrial point so studying its link with the main junction, such as Purana Panchkula Chowk is crucial to understand how heavy vehicular traffic and emergency fuel logistics engage with the urban road network. Compared with commercial logistics, we see that both high-capacity highways and industrial corridors are integrated into the overall network, which is the net result of these four sites. To assess the credibility of the shortest path results, we utilized a compare and contrast procedure with real-world navigation data. Travel times computed from the Dijkstra-based network model were compared to the ones obtained from Google Maps navigation for the same origin–destination pairs under similar temporal conditions. The comparison was made to compare the modeled free-flow travel times to measurements of observed travel times. To evaluate the precision of the model, the proportion of deviation between travel times predicted from the model and travel times observed was calculated. The deviation values were found to be within an acceptable range, implying that the algorithm can determine an optimal trajectory under the assumed traffic conditions. Minor deviations are caused through dynamic traffic flow, traffic signal delays and temporary congestion, attributes that were not modelled in the static network analysis. This validation improves the reliability of the shortest path analysis and proves that the chosen options are structurally viable routes in the impedance framework described. This study produces a reliable estimate of the fastest route between the start and end points. This is quite useful for emergency services, since it allows for decision making and optimal route selection in a short order, which reduces response times.

These insights are applicable not only to emergency response but also provide actual public gains. These will allow local residents and commuters to map out journeys, where they know when and where to travel by reducing (and not only minimising) time spent travelling across spatial distances. That, for example, means that someone who is travelling between a residential settlement and a central service point may eventually notice that it is going to take them longer to use a main road but by using the main route they will actually save time overall. Moreover, urban planners and local authorities will also be able to use the analytics to identify shortcomings in the transport infrastructure, as well as what priorities to put forward in their work to enhance infrastructure in this area or to improve overall efficiency of transport. This study provides a decision-support framework that improves the commuting facilitation and accessibility of services and makes the study community more convenient for travel in the local context.

Although popular navigation systems, such as Google Maps, give real-time route optimization based on dynamic traffic conditions, their primary objective is operational guidance for individual users. On the other hand, this study is specifically aimed at a structural and sector-based assessment of the urban road network. The GIS-based network approach proposed in this paper is transparent and reproducible and can be explicitly controlled with respect to impedance parameters such as road hierarchy and assigned travel speeds. This structural modeling permits comparative assessment across city blocks and supports scenario-based planning, which is not directly accessible through proprietary navigation systems.

6. Conclusion

Examining the urban road network of Panchkula using Geographic Information Systems (GIS) has been useful to get information on road connectivity, traffic congestion, and infrastructure efficiency. This study has identified several severe congestion hotspots in which significant need exists in enhancing management and urban planning, specifically at the intersections of Sector 20 and the Chirakpur-Panchkula-Kalka Expressway. One of them would like to use GIS to analyze distances travelled or fastest route between places such as Panchkula Bus Terminal and Panchkula IT Park, discovering that GIS would do the job as a practical tool to optimize routes, increase accessibility and shorten the travel time. This study emphasizes the importance of utilizing traffic data and exploring sustainable modes of urban transportation in the face of urbanization. This may be in search of alternative routes or even to avoid crowded routes, like the market in District 5, at peak hours. Combining the information from live traffic, assessing how integrated traffic dynamics work, and the consequences of planned infrastructure projects are necessary contributions in future research, while dedicated bike lanes, transport options, and efficient modes of public transportation can address the mobility needs of the population and crowding along the city's arteries, thereby alleviating congestion. The significance of the study lies in the development of the resilience of traffic control methods and urban planning to deal with challenges such as the urgent need of the hour. New initiatives should aim to integrate real-time data with sustainable transportation options.

This study complements the already available navigation platforms, such as Google Maps, by providing a static, structural, and planning approach to evaluate the performance of the road network. While contemporary navigation tools support travellers in identifying the optimal routes under dynamic traffic, the study presents a transparent analytical framework for assessing sector-level accessibility, infrastructure imbalances, and upcoming planning options. Therefore, the contributions of this study will contribute to the development of strategic decision-making capability for urban planners and policy makers. It enables us to detect systemic vulnerabilities in road networks: areas with low road density inherently restrict accessibility regardless of traffic conditions. And also, this research allows for planners to map Service Areas (Isochrones), providing spatial coverage in the form of institutional (e.g., healthcare) coverage that point-to-point navigation tools cannot have. This study provides a solid technical plan for the development of infrastructure and preparation for emergency service coverage on a long-term basis by establishing road density and connectivity as the underlying variables, and not as optional factors in personal navigation.

7. Recommendations

According to the conclusions of the study of urban road network of Panchkula City under this system, recommendations for improving urban mobility as well as infrastructure efficiency based on the study are:

- The immediate level of structural solutions, such as construction of flyovers or underpasses, should be made in high congested areas at Sector 20 intersection and the Zirakpur-Panchkula-Kalka Highway and on congestion peak nodes, to separate local and transit traffic.
- The local authorities should transition from static planning to a Real-Time GIS Monitoring System.
- planners should encourage high-density development along major transit corridors, supported by the shortest-path GIS models developed in this study to reduce individual vehicle dependency.
- Future urban expansion should require a Traffic Impact Assessment using GIS before new building permits are issued. This ensures that the physical expansion of the city does not exceed the capacity of its "circulatory system.
- Future research may integrate road density as a weighted parameter in network performance evaluation to examine its direct influence on route optimization outcomes.

8. Study Limitations

While this study provides a detailed GIS-based analysis of road densities and shortest path routing in Panchkula, certain limitations should be noted. First, the shortest path analysis was primarily based on spatial distance and road hierarchy, without full integration of real-time traffic volume data or seasonal variations which may affect travel time for emergency services. Second, the study's scope was limited to the urban extent of Panchkula, and while the road density indices provide a robust structural overview, they do not account for pavement quality or infrastructure conditions (e.g., potholes or street lighting). Thirdly, validation of shortest path results – Structural estimates of the shortest paths based on network topology and assigned travel times were given by the current work but were not validated quantitatively with real-world traffic conditions. This is a limitation that will be mitigated in subsequent work by incorporating empirical travel time data to enhance the reliability of the analysis.

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