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Traffic Accidents Analysis and Hotspots Identification Using GIS and Analytical Hierarchy Process: A Case Study of Lahore

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ABSTRACT

Road traffic accidents are a major health and safety problem in the developing regions. The high rate of casualties annually in Lahore, Pakistan needs to be properly risk-assessed and intervened with safety measures. This paper applies QGIS and Multi-Criteria Decision Making to determine the level of accidents in District Lahore. The Analytical Hierarchy Process uses numerical weights, which represent the frequency, severity, road geometry, population density, and land use patterns, and its consistency ratio is 0.076. GIS classifies the levels of severity between 1 (low) and 5 (severe). Ferozepur Road (4.92), GT Road (4.92), and Canal Road (4.008) become the most dangerous streets since they consistently obtain the highest scores in terms of severity. This has largely been attributed to both high volumes of traffic as well as wide land use along these routes. The results suggest that these places have been causing disproportionately to the accident burden of the district with the consequences being very socio-economic and health-threatening to Lahore. As a way of mitigating these risks, the authorities should immediately join force to roll out specific safety measures, focus on mitigating hotspots that have been identified, and keep track of the results of accidents to ensure their effectiveness. GIS and AHP integration in this study, therefore, offer a strong foundation of evidence-based planning to reduce accidents and casualties.

1. Introduction

The ancient South Asian city of Lahore is a long-standing cultural, political and economic center. The high rate of urbanization since 1947 has led to population growth, rise in travel demand and putting pressure on the traffic system. Lahore being the second largest city of Pakistan, attracts millions of daily commuters to its business, education and administrative hubs. Increased numbers of vehicles and uncontrolled growth - in diverse forms, including motorcycles, rickshaws, buses and non-motorized vehicles - cause extreme congestion [1]. Although there are efforts to ease traffic through projects like signal-free corridors and Lahore Ring Road, roadways remain congested during

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rush periods, which increases the risk of traffic accidents. The high rate of accidents caused by overspeeding, careless driving, red-lights, bad road conditions, and lack of enforcement leads to fatalities, injuries, and financial loss. Hotspots are concentrated in the intersections, u-turns and high-speed corridors and so need to be systematically analyzed. High volumes, geometric problems and roadside and pedestrian presence make key roads like Ferozepur, Canal Bank, Multan, GT and Lahore Ring Road high congestion and accident-prone roads [2]. GIS applications, including Kernel Density Estimation, and spatial overlay can show accident trends. There should be safety measures that are oriented towards the factors contributing to high-risk locations through Multi-Criteria Decision Making (MCDM) and Analytical Hierarchy Process (AHP) to rank the interventions and enhance planning. The thesis statement: Lahore needs systematic, data-driven tools, such as GIS and MCDM, to plan its safety.

In Pakistan, road traffic accidents have been a neglected issue whereby little has been done to evaluate the socio-economic effects [3]. This is heightened in the developing nations through the increased use of their own cars that increase congestion and increase the risk of accidents [4]. Thus, to create solutions to smart cities, it is crucial to comprehend the reasons which cause traffic congestion [5] [6]. Although transportation has made the process more comfortable [7], drivers, cyclists, pedestrians and passengers are still at risk of being involved in accidents because of a number of factors [8] [9]. Consequently, collision black spots identification is an important measure in instituting specific interventions to minimize accidents and their effects [10]. People tend to buy cars, which are convenient, fast, comfortable, and private, and such a decision can make people overlook the aspects of safety and security [11]. Following this, one should take into consideration how the larger urban conditions lead to congestion and accidents.

The development of cities and city population is a major cause of urban congestion [12][13]. Moreover, the principal results suggest that the primary causes of road accidents in urban areas are human errors, inappropriate infrastructure, and poor condition of vehicles, and over-speeding, driving on the wrong side and lack of lane discipline are the most common causes [14]. Further, it has been found that the utilization of seat belts, day of the week, and age of the vehicle affects the extent of the accidents [15], particularly in goods vehicle and motorcycles [16][17]. Geospatial analysis is at the centre of enhancing road safety studies to further tackle the complexity of road accidents [18]. GIS can be used to analyze arrest data, blackspots, and to merge data layers to inform interventions [19]. Engineering treatments can be adopted once a Black Spot is detected to minimize accidents [20]. In addition, the volume of traffic per hour, distribution of vehicle types and length queues can be analyzed to identify hotspots and times when congestion is the greatest.

AHP assists in consideration of ecology, topography, soil, climate and socioeconomics during the decision-making process [21]. Dynamic congestion within cities is further described by a mathematical model that takes into consideration service location distances and traffic incidents [22]. Following these analysis plans, sophisticated decision-making models, including Analytic Hierarchy Process (AHP) and GIS, provide a systematic way of ranking road maintenance [23]. More studies emphasize that nature-inspired [24], optimization and multi-criteria decision-making techniques improve the system performance, especially in PV systems [25]. These aspects underscore the pressures of quick urbanization and high vehicle traffic on the world urban roads [26]. The necessity to have good road systems and convenient mobility is evident in cities such as those in Pakistan where the numbers of automobiles [27], buses, rickshaws and pedestrians are growing and consequently the traffic and strain on the infrastructure is also growing [28][29]. Recurring traffic jams in key areas are caused by peak hours and daily travel routines [30][31][32].

Road traffic jams and congestion are among the vital issues in developing countries, especially in a country like Pakistan, where megacities such as Lahore and Karachi have reached intolerable levels, and factors such as congestion hotspots, traffic volumes, and the level of research are considered important [33]. While another study revealed that in Pakistan, the majority of cities are ranked 3 on the scale of road segments, in other words, the cities are ranked 60% on the scale of safety, which is very much below the Sustainable Development Goals (SDGs) for 2020-2030 road safety targets [34]. Studies suggest that Lahore city requires multiple transit options to increase the public ridership and reduce environmental and fog-related issues [35].

1.1 Objectives

This research aims to conduct a systematic investigation and address traffic accidents in Lahore.

1. The first goal is to gather and analyze traffic accident data in Lahore.
2. The second objective is to map the places of accidents and determine their frequency, intensity, and spatial aspects.
3. The third objective is to determine high-priority areas of hotspots for road safety interventions.

1.2. Problem Statement

The high rate of population and increased vehicle traffic has increased congestion in Lahore. As a result, road traffic accidents are on the rise with huge human and economic expenses. Even though a number of agencies collect accident information, there is no complete spatial analysis, and the existing traffic management is reactive. In addition, various factors including road architecture, traffic congestion, land utilization, population agglomeration, and the nature of accidents, affect the risk of accidents but can hardly be resolved through isolated studies. This paper in turn counters this by providing an integrated GIS-MCDM model which, in the first instance in Lahore, is an attempt to synthesize different factors in a spatial framework to objectively identify, rank and weight accident hotspots. This model will facilitate proactive, data-driven road safety planning at Lahore, by empowering stakeholders with precise, actionable intelligence.

2. Methodology

The study employs a quantitative/spatial analysis method to determine the hotspots of traffic accidents in Lahore, in a logical framework guided by the Geographic Information Systems (GIS) and Multi-Criteria Decision Making (MCDM). The methodology includes data collection, preprocessing, and GIS spatial analysis. Criterion weighting is performed using the AHP method, and an accident risk map is generated (Figure 1). Lahore District is selected as the study area due to its large population, diverse land uses, variety of vehicles, and mix of major and minor roads, making it a strong case for studying road accidents and high-risk areas. The analyzed region is shown in Figure 2.

2.1 Data Collection

In this research, several datasets are needed to facilitate research on accidents. The major datasets are cited in Table 1.

Table 1
The adopted datasets to facilitate research on accidents

Dataset	Source
Road Traffic Accidents	Rescue 1122 District Lahore
Road Network	GIS Shapefile (District Lahore)
Population Density Data	PBS Census 2023

2.2 Data Processing
All collected data are processed before analysis to verify their accuracy and compatibility. Geocoding of accident records produces spatial point features. All the spatial layers are mapped into a universal coordinate reference system. Data cleaning is performed to eliminate duplicate, blank, and location-error records. The customary data sets attribute data, hence, support spatial and statistical analysis.

2.2.1 Gis-based spatial analysis
GIS is the platform that is used as the main tool of visualization and spatial analysis. The techniques used are the following:

2.2.2 Kernel density estimation
According to Kernel Density Estimation, statistical clusters of traffic accidents are identified and accident hotspots maps are created. KDE generates a continuous surface where there is high focus of accidents.

2.2.3 Buffer and overlay analysis
Buffer analysis is done in accidents, intersections, and road sections to determine the impact of the surrounding characteristics. The data about accidents are combined with land use, population density, and road network layers by means of spatial overlay techniques.

2.2.4 Gis-based weighted overlay analysis.
The application of a weighted overlay method is done in the GIS environment using the AHP derived weights. The outcome of this process is the map of Accident Risk Index, which puts the study area in high, medium, and low risk of accidents.

2.2.5 Hotspots identification
Identified accident hotspots are ranked. Hotspots are prioritized in terms of their closeness coefficient and the larger the coefficients, the greater the risk of accidents.

2.2.6 Criteria selection for MCDM
Following criteria are selected to assess the accident risks
- Accident Frequency
- Accident Severity
- Road Hierarchy
- Population Density
- Land Use Pattern

2.2.7 Analytical hierarchy process

AHP is the next method used to understand the concept of preference. The relative importance of the selected criteria is determined using the Analytical Hierarchy Process. AHP is a process that involves a pairwise comparison matrix based on expert judgment. Criteria weights are calculated by normalizing the matrix. To assess judgment consistency, a consistency ratio (CR) is calculated, and values below 0.10 are considered acceptable. The resulting weights are subsequently incorporated in a GIS-based weighted overlay analysis. Every criterion is an aspect contributing to the frequency and level of accidents.

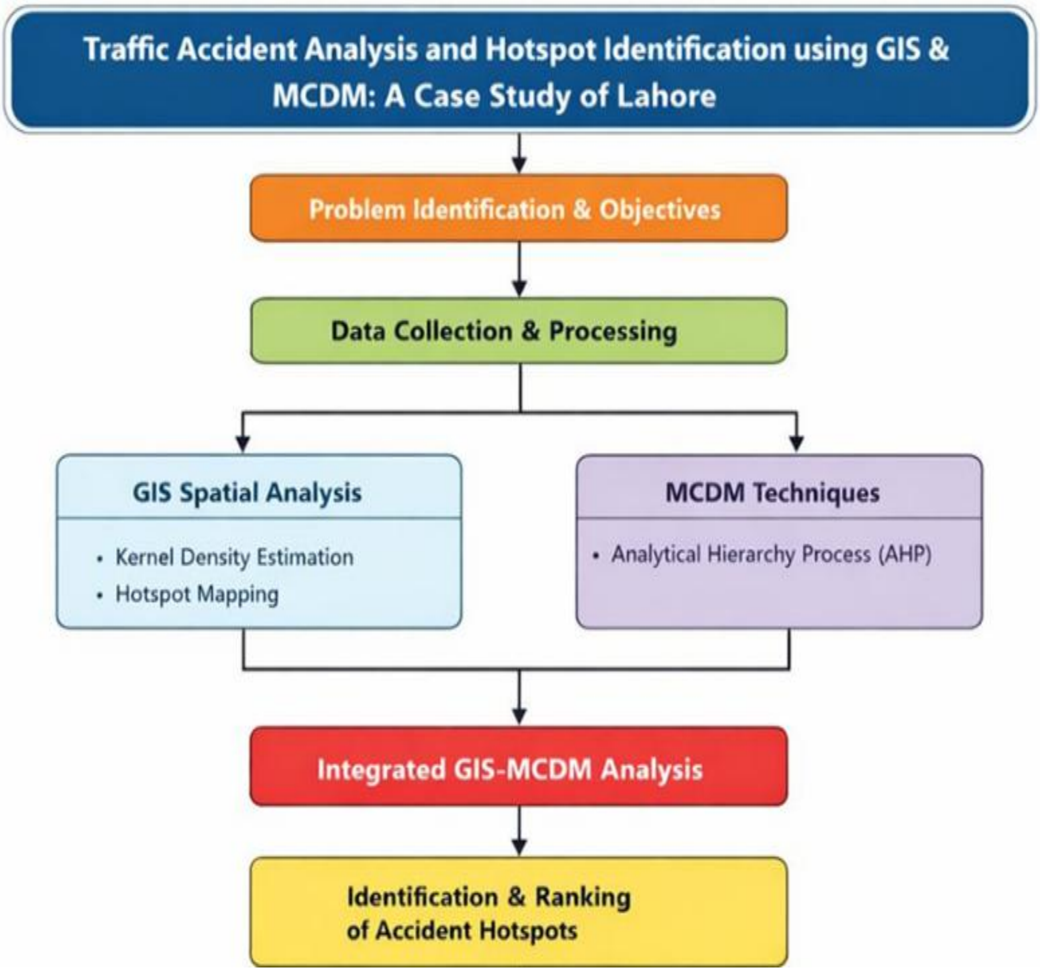

Fig. 1. Research Methodology

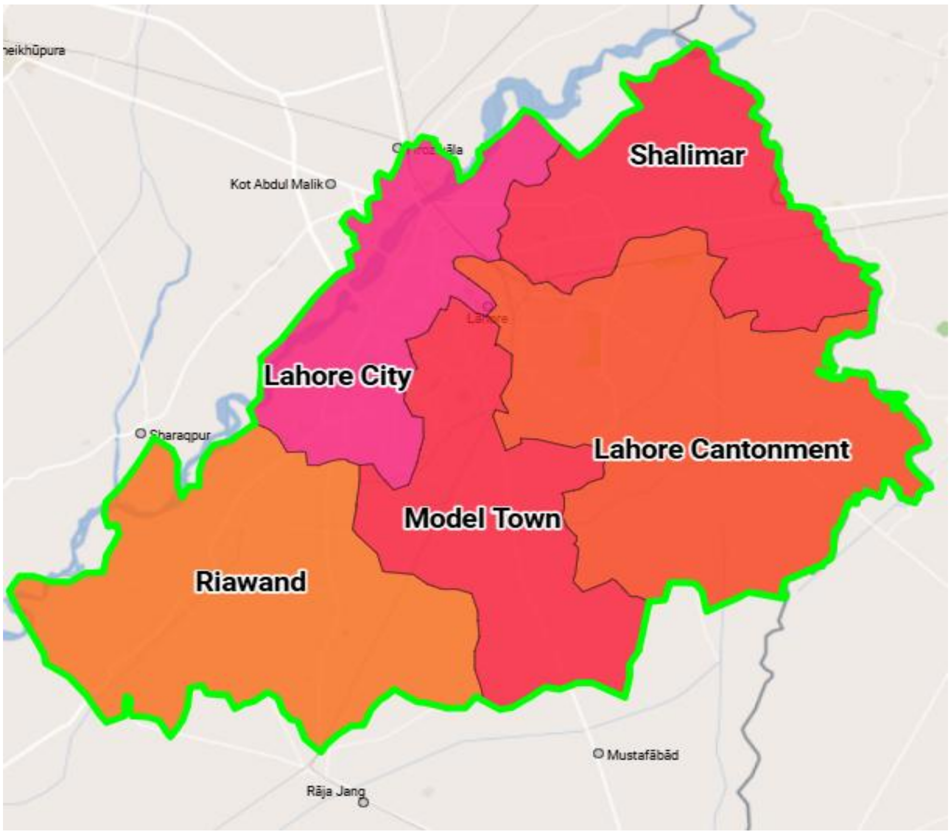

Fig. 2. District Lahore

3. Data Analysis & Results

AHP is the next method used to understand the concept of preference. In this study, the Analytical Hierarchy Process is applied to determine the relative importance of the selected criteria, which later inform the GIS-based analysis. AHP involves constructing a pairwise comparison matrix based on expert judgment, from which criterion weights are calculated by normalizing the matrix. To ensure judgment reliability, a consistency ratio (CR) is calculated; values below 0.10 are considered acceptable. The resulting weights from the AHP process are subsequently used as inputs in the GIS-based weighted overlay analysis.

In this research, the GIS-based spatial analysis is combined with the Analytic Hierarchy Process (AHP) and traffic accidents data. The GIS mapping of accident risk makes use of AHP-derived weights, which produce an Accident Risk Index categorizing the areas as high, medium or low risk. Hotspots of accidents are determined and ranked using the coefficients of closeness, the higher the coefficient, the more risk. The Kernel Density Estimation and weighted overlay analysis are used to visualize the high-risk zones. These findings indicate patterns on where accidents occur, factors affecting risk and spatial concentrations on accidents. The findings are explained within the context of the present-day traffic trends and urban nature of Lahore and the significance of these findings to road safety planning and policy development is addressed.

3.1 Road Accident Data

In this study, two years of accidents data of Rescue 1122 Lahore is used, including place and severity of accidents. Accidents rates are high in Lahore, a fact that indicates that there are long-standing road safety concerns. Accidents are more frequent on major roads, intersections, and high-traffic corridors, which is a manifestation of the influence of the volume of traffic, the geometry of the roads, and mixed conditions. Repeating patterns are indicative of chronic problem areas. No. of accidents are shown in Table No. 02.

Table 2
Road Accident Reported Cases (Rescue 1122 Lahore)

Year	Cases Reported
2024	**113,331**
2025 (As of 15 Nov)	**100,015**
Total	**213,346**

3.2 Population Data

The population data used in this study will be obtained at the Pakistan Bureau of statistics (PBS) which is the official source of demographic data of Lahore. This disequilibrium has a substantial impact on the traffic demand and the risk of accidents. The addition of this information to the GIS-AHP framework allowed a more realistic evaluation of the risk of accidents. Population statistics are shown in Table No. 03 below.

Table 3
District Lahore Population (Census 2023)

District	Tehsils	Area	Population	Density
Lahore	**Lahore Cantonment**	**466**	**1,885,098**	**4045.3**
	Lahore City	**214**	**4,123,354**	**19268**
	Model Town	**353**	**3,244,906**	**9192.4**
	Raiwind	**467**	**1,080,637**	**2314**
	Shalimar	**272**	**2,670,140**	**9816.7**
	District Lahore	**1,772**	**13,004,135**	**7338.7**

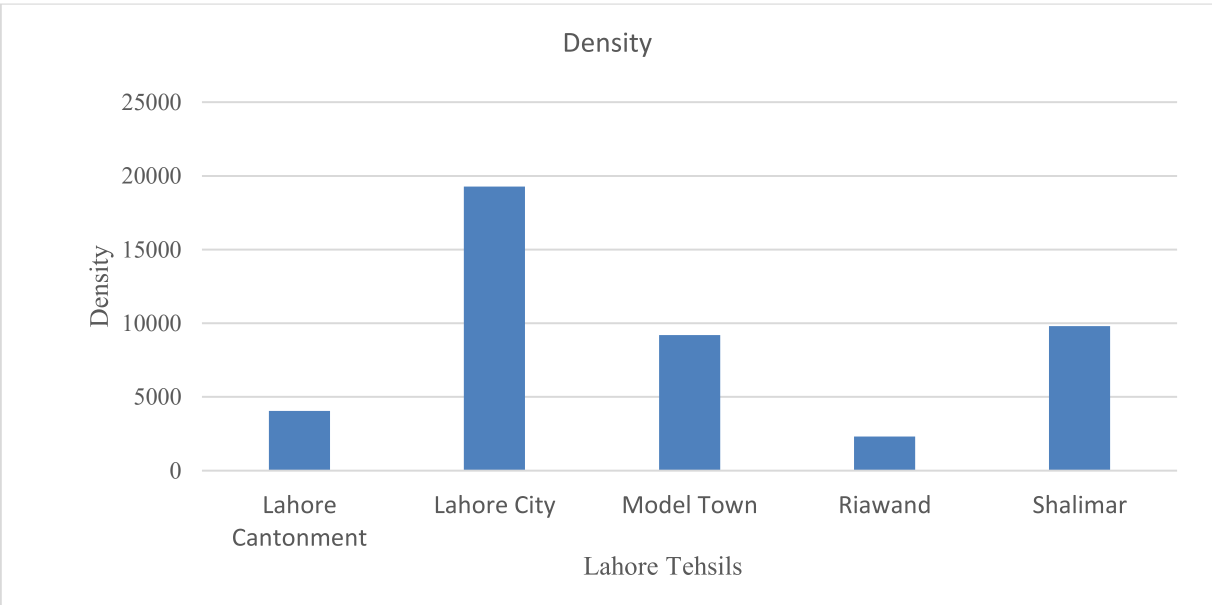

Fig. 1. Lahore Density Chart

3.3 Gis Analysis

Based on this, the Geographic Information System (GIS) tools were applied to examine and determine the hotspots of traffic accidents in Lahore. GIS enabled the processing, analysis and visualization of massive amounts of data on accidents, population, and road networks on a spatial platform. Statistically significant concentrations of accidents were also identified using tools like Kernel Density Estimation (KDE), giving a solid data-driven foundation on effective planning and decision making on traffic safety. The resulting KDE heatmap more graphically showed the accident clusters with high-density areas which represented frequent accidents and lower density areas which represented safe areas as shown in Figure No. 04.

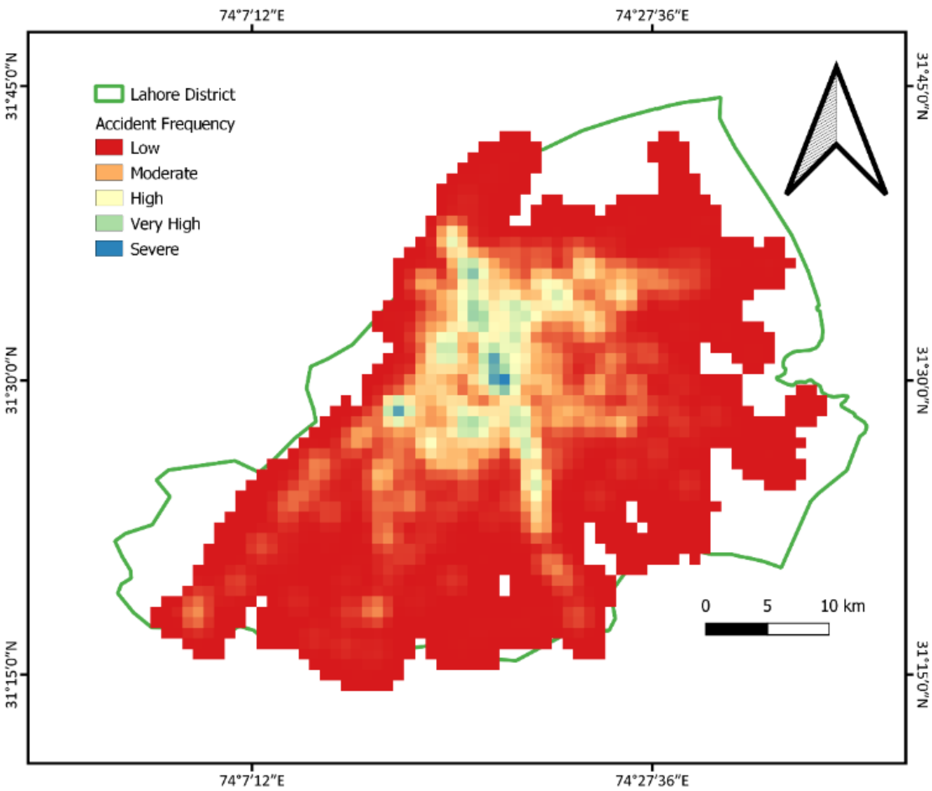

Fig. 4. Density Heatmap (GIS)

3.4 Join Attributes

The non-spatial accident-related data was joined with the spatial data on a common identifier using the attribute joint. This helped in connecting the frequency, severity, and the descriptive characteristics of the accidents to the spatial features hence making it possible to conduct the spatial analysis. Accident Attributes are shown in Figure No. 05.

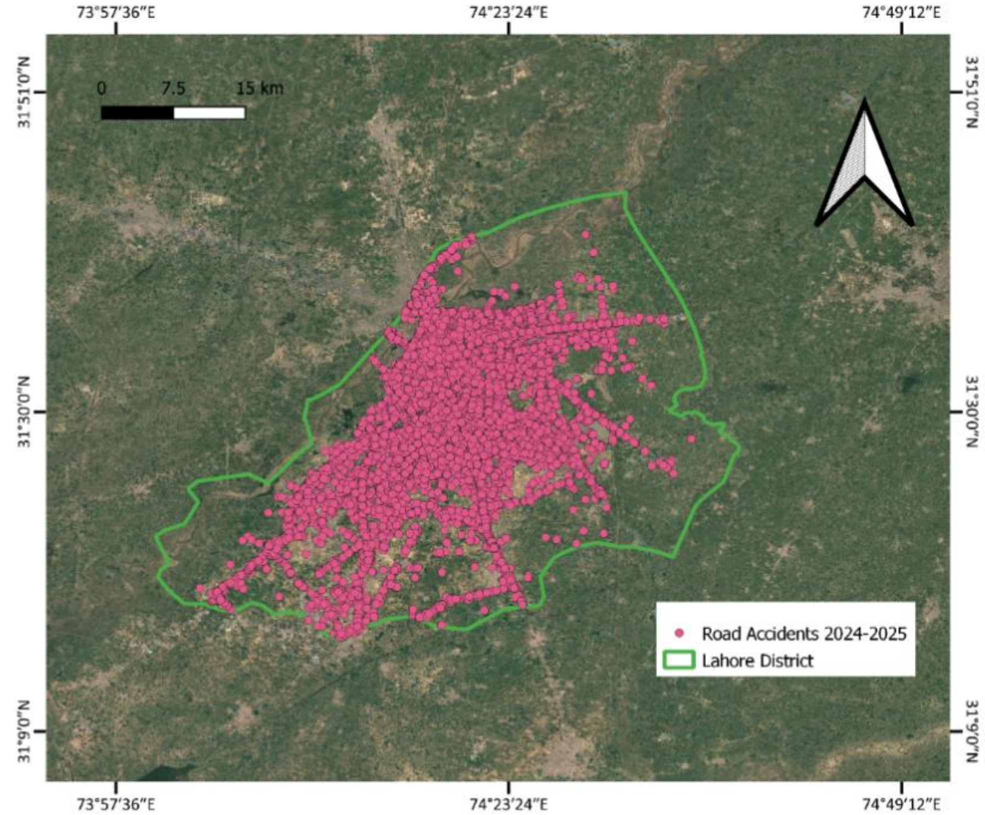

Fig. 5. Accident Attributes (GIS)

3.5 Accident Data

Continuing the developed spatial analysis, traffic accidents were revealed to be rather severe, which is mainly caused by the growth of vehicle traffic and mixed traffic. The trend is especially noticeable on major arterial highways, where the increased volume of traffic, more frequent crossing, and increased pedestrian and business traffic all add to the increased risk of crashing. Interestingly, Ferozepur Road and GT Road are the most sensitive; their greater rates and intensities of accidents, as illustrated in Figure 06, are primarily driven by these factors. The high traffic and business around the Ferozepur Road also create more conflict points, thereby creating more risks of crashing.

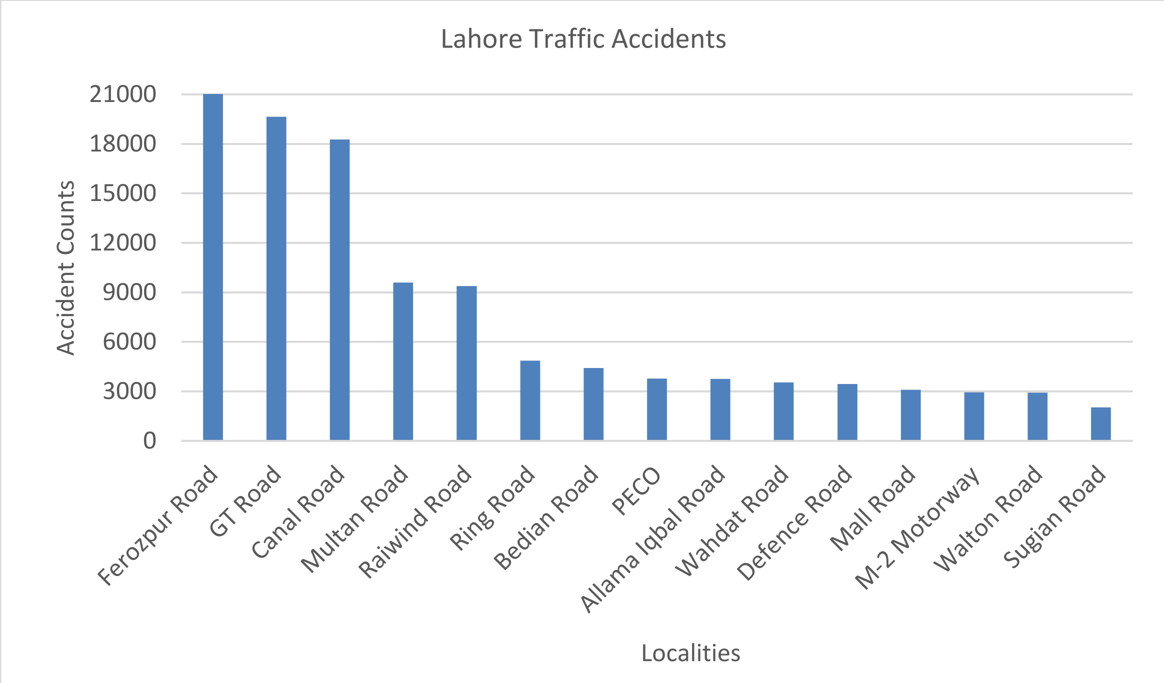

Fig. 2. Reported Accidents

Similarly, GT Road is an important intercity and freight road with high urbanization, with most accidents caused by excessive speed, heavy traffic, and lack of access control. Table 4 displays the number of accidents at different locations.

Table 4
Accidents Reported (Rescue 1122, 2024-2025)

Roads	Accidents
Ferozepur Road	21,563
GT Road	19,653
Canal Road	18,259
Multan Road	9,603
Raiwind Road	9,385
Ring Road	4,857
Bedian Road	4,408
PECO	3,774
Allama Iqbal Road	3,760
Wahdat Road	3,541
Defence Road	3,439
Mall Road	3,098
M-2 Motorway	2,942
Walton Road	2,924
Sugian Road	2,040

Table 5 indicates the spatial distribution of crashes in terms of severity: fatal, serious injury, and minor injury. These areas depict the areas where accidents have more severe outcomes. These locations are often high-speed corridors, complicated intersections, or locations lacking proper safety infrastructure. The most severe ones are fatal accidents due to their irreversible human and social consequences. The way fatal accidents are distributed indicates that the concentration is on the high-speed routes and at major intersections, as observed in Figure 07 and Figure 08. There are also fatalities in places where there are inadequate safety laws. High fatality zones are listed in Table 06.

Table 5
Severity Data (2024-2025)

Severity	Count
Fatal	781
Others	13,689
Severe Injury	67,690
First Aid	131,186

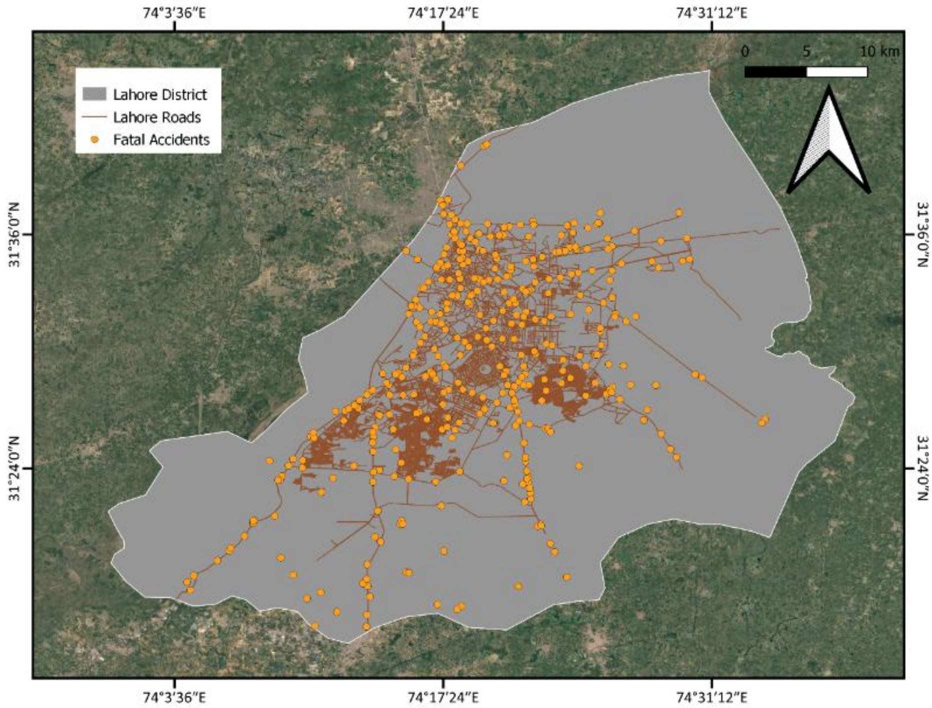

Fig. 3. Fatal Accidents Representation (GIS)

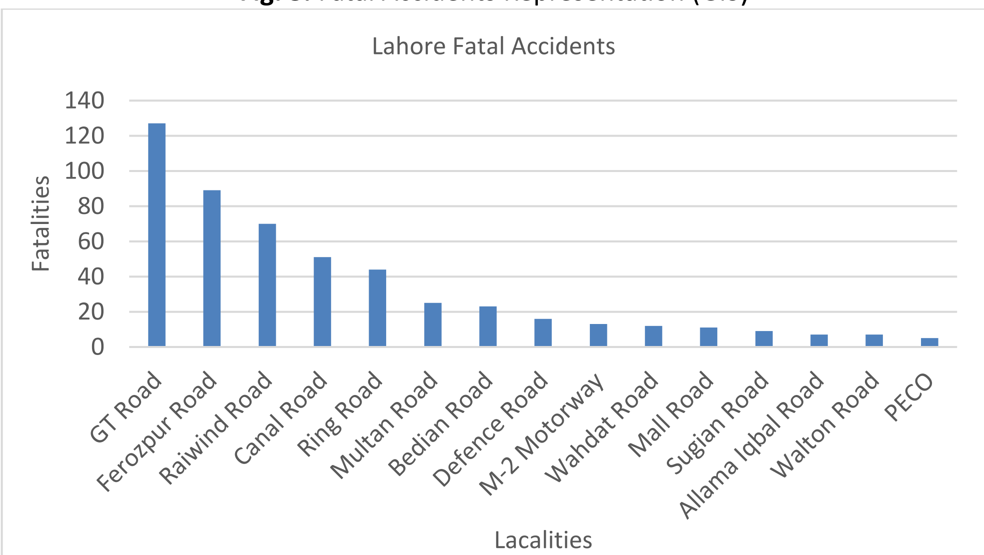

Fig.8. Fatal Accidents (2024-2025)

Table 6
Fatal Accidents (2024-2025)

Roads	Fatalities
GT Road	127
Ferozepur Road	89
Raiwind Road	70
Canal Road	51
Ring Road	44
Multan Road	25
Bedian Road	23
Defence Road	16
M-2 Motorway	13
Wahdat Road	12
Mall Road	11
Sugian Road	9
Allama Iqbal Road	7
Walton Road	7
PECO	5

3.6 Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) was applied to determine the relative weight of five variables, i.e. the frequency of accidents, the severity of accidents, the road geometry, the population density, and the land use pattern (see Tables 07 and 08) in the framework of the risk assessment of traffic accidents. Comparisons of the two revealed that severity of accidents (0.282), frequency (0.282), and population density (0.214) were the most relevant and as such it is evident that the outcome of crashes and the frequency of accidents contribute the most towards the formation of risk. In the meantime, road geometry (0.114) and land use patterns (0.108) had a smaller impact. These findings affirm that AHP is useful in the synthesis of the input of experts and various criteria to guide specific, evidence-based safety interventions. To be clear, Table 09 shows AHP pairwise matrix.
Consistency Ratio 0.1 > 0.076 is OK .

Table 7
Criteria Definition Table

Criterion	Definition	Data Source
Accident Frequency	**Total number of accidents at location**	**Rescue 1122**
Accident Severity	**Fatalities Data**	**Rescue 1122**
Road Geometry	**Number and control type of intersections along the corridor**	**Roads Shapefiles**
Population Density	**Lahore Population**	**PBS**
Land Use Pattern	**Commercial Activities**	**Shapefiles**

Table 8
AHP Priorities

Criteria	Priorities	Rank
Accident Frequency	28%	1
Accident Severity	28%	2
Population Density	21%	3
Road Geometry	11%	4
Land Use Pattern	11%	5

Table 9
The Pairwise Comparison Matrix

Accident Frequency	Accident Severity	Road Geometry	Population Density	Land Use Pattern
1	0.5	2	3	2
2	1	2	1	2
0.5	0.5	1	0.5	1
1/3	1	2	1	3
0.5	0.5	1	1/3	1

3.7 Risk Analysis

Table 10 shows the systematic analysis of hot spot road risk. The process determines decisively and prioritizing segments with high safety issues and employs many contributing factors. The Risk Index is between 1 (Low risk) and 5 (Severe risk) and a 4-5 indicates hotspots. Such problems demand urgent safety measures, such as engineering, increased enforcement, and better traffic control. The next section capitalizes on this prioritization to introduce a model of evaluating the intervention strategies.

Table 10
Risk Index

Roads	Risk Index	Severity
Ferozepur Road	4.92	Severe
GT Road	4.92	Severe
Canal Road	4.008	Severe
Multan Road	2.57	High
Raiwind Road	3.836	Very High
Ring Road	V 2.78	High
Bedian Road	2.078	High
PECO	1.786	Moderate
Allama Iqbal Road	1.686	Moderate
Wahdat Road	1.786	Moderate
Defence Road	2.078	High
Mall Road	1.896	Moderate
M-2 Motorway	1.806	Moderate
Walton Road	1.896	Moderate
Sugian Road	1.304	Moderate

3.8 Alternatives

The AHP hierarchy is a systematic method of risk factors and prioritization of traffic accidents in Lahore to implement specific interventions. Based on this, the other interventions, namely Technological Solutions, Enforcement and Policy Measures, Engineering Solutions, Land-Use Planning and Education and Behavioral Interventions are strictly assessed according to set standards. All options add to a variety of criteria, forming a comprehensive, analytic evaluation. The AHP Hierarchy Diagram is shown in Figure 09.

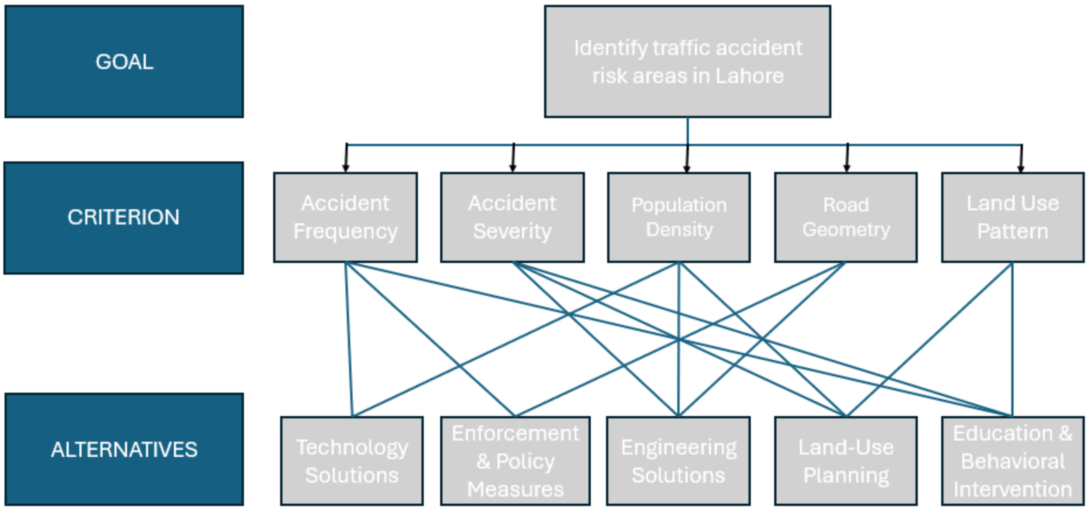

Fig. *9*. The problem Hierarchy Diagram

3.9 Risk Map

The risk map of Figure 10 visually illustrates the risk of road accidents in Lahore. It incorporates Risk Index values- numerical measures of accident probability and intensity, into a Geographic Information System (GIS), special mapping software. The map uses these values to overlay on the road network in Lahore, where there is a risk scale of 1 (Low) to 5 (Severe) to identify the risky routes and hot spots. Areas of high severity are concentrated in large, high-traffic streets, and priorities areas are evident. The map assists in decision-making by helping planners and policymakers to concentrate on safety, enforcement as well as infrastructure improvements according to spatial risk patterns. It also allows close examination by disaggregating the information regarding accidents into individual accidents.

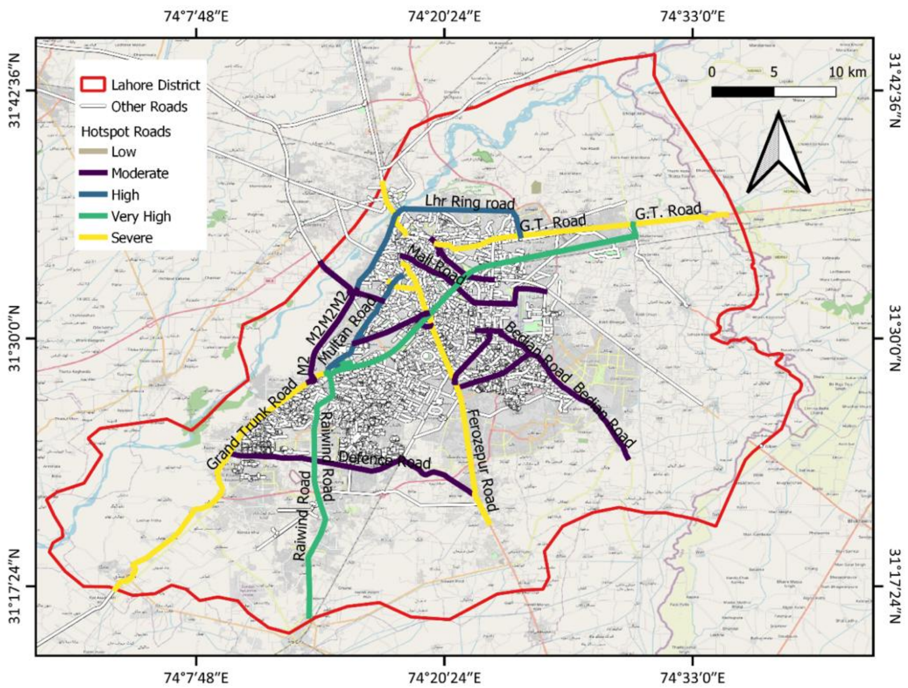

Fig. 10. Black Hotspots Corridors (GIS)

4. Conclusions

- A total of 213,346 reported road accidents and 781 fatalities were recorded, confirming that road accidents constitute the primary transport safety crisis in Lahore.
- Uncontrolled urban sprawl, rapid urbanization, and ineffective transport management collectively amplify accident risk across the city.
- The data exposes severe socio-economic and community health consequences, underscoring the urgent need for data-driven traffic safety planning.
- High traffic volumes, complex intersections, and commercial encroachment were identified as the dominant contributors to elevated accident risk on major corridors.
- AHP provides a transparent, reproducible weighting procedure that removes subjectivity from multi-criteria prioritisation of risk factors.
- Major corridors Ferozepur Road, Grand Trunk Road, and Canal Road emerged as the highest-risk zones due to their traffic load and geometric complexity.
- Wider adoption of this methodology has the potential to reduce accident rates and fatality levels on a national scale.
- The systematic steps outlined in this study provide a replicable blueprint for developing safer and more sustainable urban mobility systems across Pakistan.

5. Recommendations and Future Directions

The current study focuses on infrastructural and spatial criteria, while future studies should focus on driver behaviour, lane displacement, mobile phone use, and determining a holistic risk assessment framework connected to the intelligent transportation system. In addition, the adopted model can be applied in a recent used fuzzy environments [36-41].

Author Contributions

Conceptualization, A.F. and H.Q.; methodology, H.Q.; software, S.N.J. and H.Q.; validation, A.F. and D.F.; formal analysis, H.Q.; investigation, H.Q.; resources, A.F.; writing—original draft preparation, H.Q.; writing—review and editing, A.F.; supervision, A.F.; project administration, D.F. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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