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Identifying Influencing Factors of Road Accidents in Emerging Road Accident Black spots

Mehdi Gheisari[1]

[1]Young Researchers and Elite Club, Islamic Azad University, Parand, Iran

Abstract

This paper deals with identifying the accident black spots and the influencing factors causing accidents using factored analysis in the medium-sized city (Tirunelveli) in India. From the literature review, the geospatial technique to identify the black spots and the factors causing accidents was used for analysis. The most influencing factors driving the accident were identified and ranked based on the repetitive occurrence of accidents in the black spot area. The spearman ranking system obtained the correlation among the factors causing accidents. The factor analysis technique was utilized to identify the key factors driving the repetitive accidents and group them. This study will help transportation planners to understand the factors causing accidents and take appropriate measures to reduce the casualties in the road construction planning stage and existing conditions.

Key Words: *Road*, *Accidents*, *Black spots*, *spatial analysis*, *Factor analysis*

1. Introduction

Worldwide, among the total road accidents occurrence, nearly 1.3 million account to be fatal accidents, among which 90% of the fatal accidents occur in low-income people, such as the countries in Africa, and nearly 20 to 50 million nonfatal accidents contribute to disabilities [1]. From the statistical data obtained, it was observed that low and middle-income people all over the world have a high contribution to the occurrence of road accidents, and it was found that the total cost of accidents was found to be nearly 3 percent of the global gross domestic product [2]. The vulnerable road accident causers are cyclists, motorcyclists, and pedestrians. Road traffic accidents cost shares 3% of total gross domestic product. It was noted that there was a continuous increase in fatal accidents from 1.15 million to 1.35 million during the period from 2000 to 2018. [3]. Traffic accidents are a big issue all around the world. Negative driving behavior, which is inherently influenced by traffic circumstances and infrastructure, among other factors, is one of the leading causes of traffic accidents [4,5].

In 2019 nearly 4.37 lakhs of road accidents were recorded on Indian roads, among which 1.54 lakhs of accidents were fatal, and 4.39 lakhs of accidents were nonfatal but resulted in significant injuries, rendering people incapacitated. Two-

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wheelers caused the deadliest road accidents in 2019 (58,747 deaths), accounting for 38.0 percent of all road fatalities, followed by trucks/lorries (22,637 deaths) (14.6 percent), cars (21,196 deaths) (13.7 percent), and buses (9,192 deaths) (5.9 percent). In India, road accident death has a share of 44 % of total accident deaths, and the remaining percentage of accidents deaths are due to suicide, forces of nature such as floods, Landslide, Cyclone, exposure to cold, Torrential Rain, forest fire, and lightning, etc. In 2019, nearly 57,228 thousand accidents were recorded in the state of Tamil Nadu in, and India stands in an alarming zone. Hence it is necessary to identify the causes of accidents and to take appropriate mitigating measures in the road construction planning stage and for the existing condition [6, 7, 8, 9].

. Road networks are complex, dynamic, and uncertain systems that are influenced by human, technological, and environmental elements, which results in road accidents [10]. It was found that there was a strong relationship between the road accident and the geometrical characteristics of the road, such as sight distance, the radius of curvature and slope, etc. [11,12]. The number of accidents increases with tangent length, peak hour volume, and longitudinal pitch but decreases with the radius of the curve [13]. Furthermore, the efficiency causes are the relationship between speed fluctuations with longitudinal gradient and, as a result, traffic congestion, safety reduction, and the risk of an accident occurring [14]. It impacts driving site distance and driver behavior, such as passing other vehicles. The effects of longitudinal surface friction and pavement are amplified in the plunging slope, increasing the likelihood of occurrence [15]. The following human factors, such as the health condition of the driver and pedestrian, alcohol consumption, use of mobile phone while driving, distraction due to roadside advertisements and age of driver, etc., will have a more significant influence on the occurrence of road accidents [5]. Environmental factors associated with the road accidents, such as fog, ice rain, and rain, will have higher relevance for the occurrence of road crashes [16, 17, 18, 19, 20]. Accident analysis based on the type of road based on environmental exposure revealed high significance for road accidents in poor weather conditions [6]. It was revealed in the research that the road surface condition texture depth and the corresponding skid resistance value have a more significant impact on the occurrence of the accident [7].

Accident prediction methodologies have been extensively researched in the past, especially with the collected statistical data such as spot map method, accident frequency method, rate quality control method, and accident rate method in which the following characteristics such as spatial features, vehicle features, and human behaviors are not considered[21]. In in-depth accident analysis, driver information, vehicle information, and road-environment information are collected for conditions such as pre-crash, In-crash data, and post-crash [22]. However, such systems rely

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heavily on traffic flow data, such as average daily traffic and data gathered by traffic cops at accident locations. However, traffic flow data is rarely accessible insufficient amounts or with sufficient precision to support these regression methods. Furthermore, the traffic police may not be able to acquire all the essential data to do the analysis. Considering all of the aforementioned criteria, it is required to create a model that may aid in predicting risk zones on a specific road network. Using Kernel and overlay analysis in geographic information system (GIS). This study outlines a model created to recognize black spots on highways. GIS analyses both spatial and non-spatial data. As a result, a model for determining the position of accident spots on roads may be simply incorporated using GIS [23,24,25,26].

2. Literature Review

In recent years, research has revealed that road crashes causing severe injuries are identified as a significant public health issue. Hence stringier countermeasures should be initiated to reduce the road crashes causing severe injuries in short-term and long-term improved outcomes [27]. In a study in Toronto, the statistical accident analysis shows that fatal accident is due to the following factors: harsh driving, lack of concentration while driving, and overspeeding. It was found that the harsh driving, speeding, and red light and their corresponding percentage of fatal accidents are 62.9 %, 21.4% .and 10.4%. The cluster analysis was used to find attributes responsible for road accidents for final modeling. However, the results are not highly significant, which may reverse the cause[28]. In a study, the accident data related to vulnerable road users, such as pedestrians and cyclists, were collected from 2012 to 2015 from Aveiro, Portugal, to perform statistical accident analysis to identify the severity of vulnerable road users involved in road accidents. The risk factors considered for this study are profile, meteorological data, location, gender, and weather condition. it was found that considering vulnerable road users, the probability of pedestrians being involved in road accidents increases by 2.7 times on urban roads and 10.6 times for pedestrians[29]. The road accident severity crash was estimated from the accident data collected for the 14 districts of Kerala, India, for six years from 2014 to 2019. The following road partner considered are national highways, state highways, and other roads and found that numerous accidents are occurring, especially in the hilly regions and the intersection of the road geometry. The final results revealed that most road accidents are caused due to vehicle drivers, and other causes, such as pedestrians and vehicle failure, lead to fatal accidents [30]. The researcher developed a regression model to predict the occurrence of a fatal accident in Ahmedabad city with statistical analysis by collecting the fatal accident data and traffic volume per lane for Place Shahibaug and Karanj Bhadra, Ahmedabad, for the period of six years from 2005 to 2010. The regression model developed was found to be satisfactory with the goodness of fit and with a successful

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prediction rate [31]. In order to have an organized city, at the planning stage itself, we have to give special attention to vulnerable road users such as pedestrians and cyclists to reduce road accidents. The cluster analysis technique was done to identify the relevant common factors causing the different types of the road accident. It gives better knowledge for transportation planners to know the factors causing the accident for the development of mathematical models to predict the accidents and to take appropriate measures in the planning stage itself [32]. In order to predict the road accident injury severity and accident prediction model in the United Kingdom, the analytical method of data analysis was used on the accident data collected for the period of 4 years from the period of 2005 to 2019. In this analysis, 63 attributes were considered obtained from three different sources of data found to be influencing the accident severity. The machine learning technique, XGBoost algorithm, was used and compared with other conventional statistical analyses such as the severity index method, GIS method, and cluster analysis. It was found that this technique out layered the conventional method by accuracy even with imbalanced data [33]. The GIS-based accident analysis using the k-function to find out the distribution of road accident crashes is highly informative. In order to find out the accident-prone location, kernel density estimation was utilized, and to ensure the existence of a cluster, the k-function and nearest distance analysis were performed. Thus the blackspots are identified. This method was found to be specialized in performing spatial analysis, and display clearly is an advantage over the other methods of road accident analysis. Based on the results obtained, the budgets allotted to take action to reduce the occurrence of future road accidents [34]. From the research, it concluded that the systematic analysis of accident scenarios with the available data and implementation the countermeasures such as improved road geometric design, traffic control measures, and effective enforcement could reduce the occurrence of road crashes considerably. However, adding the geospatial analysis to the conventional accident analysis has a greater outcome than the conventional accident analysis without using geospatial technologies [35, 36, 37, and 38]. Ultimately, people's mobility is severely harmed by traffic congestion and accidents. Accidents are a drain on the national economy because they can result in disability, death, health and property damage, social suffering, and environmental degradation. In all the above, none of the methods identifies the most influential factor causing the accident. In this research, the accident analysis was done by combining the GIS to identify the black spots, and factor analysis was used to identify the most influential factors causing the accidents and rank; hence future accidents can be reduced by concentrating our research and remedial measures on the most influential factors causing the accidents

3. Objectives of the Study

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The objectives of the study are listed below:

1. To identify the emerging black spots in Tirunelveli city using the geospatial analysis.
2. To identify and rank the road accident-causing factors and classify the influencing factors into groups based on characteristics causing accidents by factor analysis in Indian cities.

4. Study Area

The study area considered for this research is Tirunelveli city in the state of Tamil Nadu in India. It is the sixth largest district in the city. Palayamkottai is the central business center located on the eastern bank of the Thamirabarani River. The town has a number of educational institutions and administrative offices like District police headquarters, medical colleges, commercial shops, and hospitals, attracting more traffic from the outskirts of the city, causing high traffic flow in the city [50-69]. The Municipal Corporation Act of 1994 established a municipal corporation to operate Tirunelveli. The city has a population of 473,637 people and occupies an area of 169.9 km2, as shown in Figure 1. Tirunelveli is well connected to the rest of Tamil Nadu by road and rail. The split of road length is shown in Table 1. Nellaiyappar Temple and other textile shopping malls, retail stores, markets, educational institutions, hospitals, railway junctions, and other tourist attractions are all located in the study area. It draws a more significant number of visitors and daily shopping to the Tirunelveli district, causing traffic congestion, accidents, and unwelcome delays. Hence it demands access to the trend of road accidents and recommends preventative steps to avoid an accident in engineering aspects.

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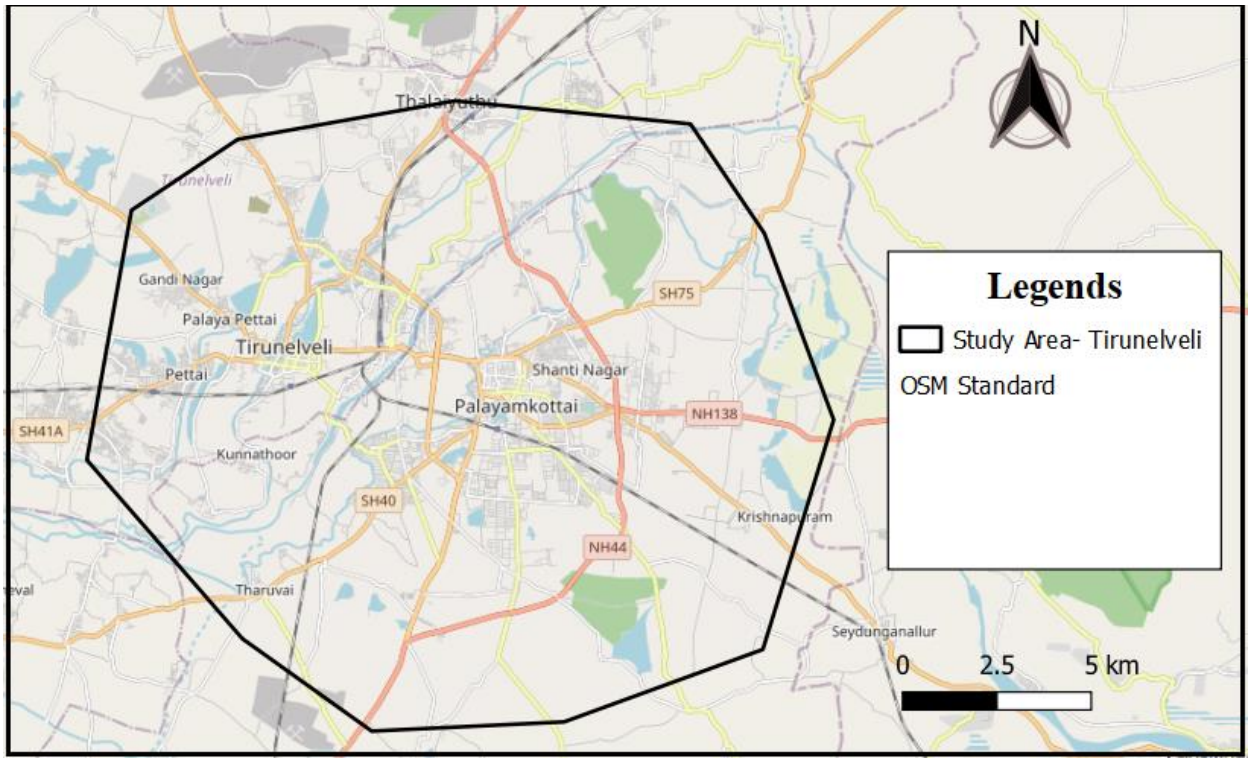

Figure 1 Location of Study Area

Table 1 Classification of roads and their length in Tirunelveli City

S.No	Classification of Roads	Length(Km)
1	National highways	174.824
2	State highways	442.839
3	Municipalities Roads	1,001.54
4	Panchayat Union	1,254.10
5	Panchayat Road	1,658.35
6	City Roads	840.399
7	Other roads	114.450

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5. Data and Methods

5.1Data Collection

In order to perform the accident identification of black spot using geospatial technique and to perform factor analysis, the road crashes data such as Geometric characteristics and human and environmental factors were collected from the Tirunelveli traffic police headquarters. For the last three years, covering all months from 2018 to 2020, total collision accidents of 3693 comprise fatal accidents, unfortunate injury accidents, minor injury accidents, and non-injury accidents, as given in table 2. To even out random variances, three years of data were employed. Aside from that, three years is a good compromise between a lengthy period of forgetting many mishaps and a short period of not changing the location too often. The police department provided information such as the time, Place, type of collision, and other details such as the automobiles involved in the accident. Trimble geo explorer 2008 series handheld receiver was used to obtain the coordinates of all accident locations. It was accurate to within 3-5 meters. They were moved to a GIS database after getting all of the secondary data. The following concerns were identified during the collection of secondary data to obtain a considerable number of road crash data in a limited time period. So that the location is not significantly altered and Effective mapping of all the incidents was possible with a little deviation of 3-5m from the actual position, as shown in Figure 2.

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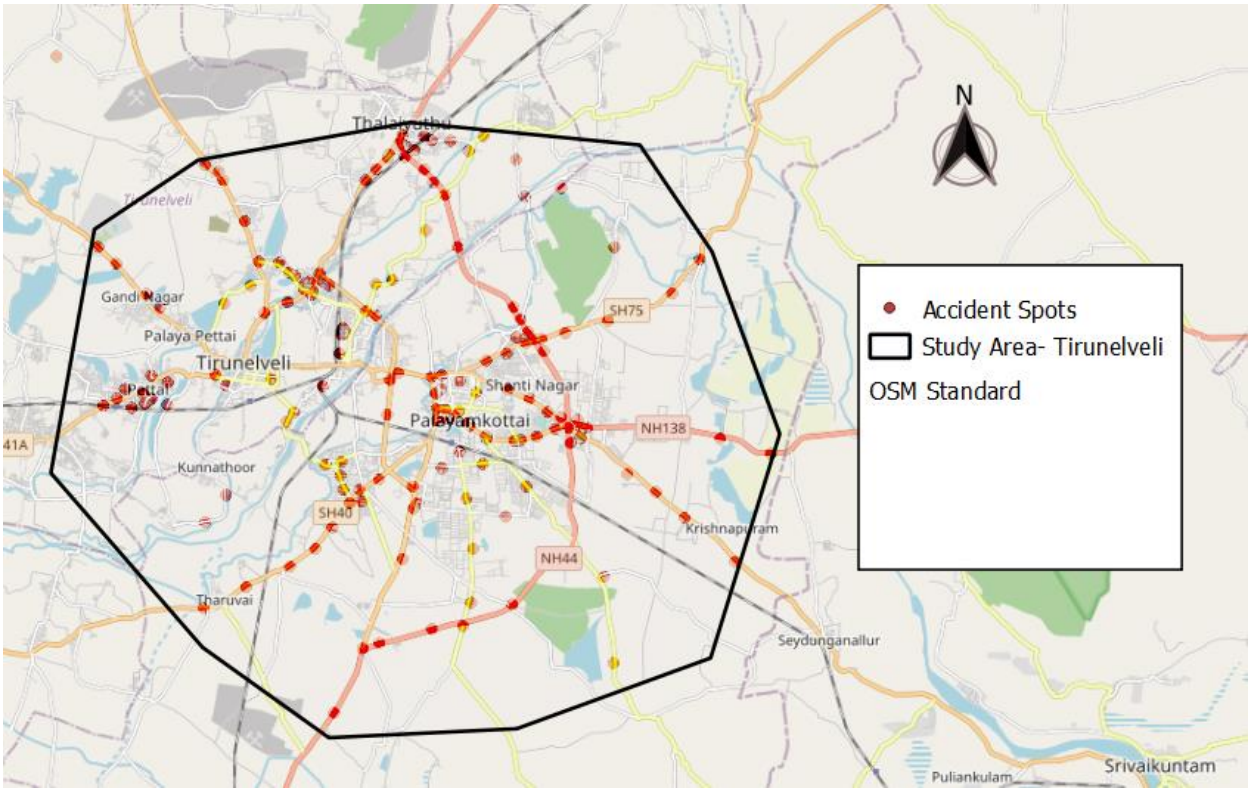

Figure 2 Map showing Geo-referenced Accident Data (Fatal, Grievous, Minor, and Non-injury accidents-Tirunelveli city)

The road inventory survey conducted on the highway to analyzing numerous elements that may directly or indirectly contribute to the causes of accidents is the primary data for the method of prioritization. The following are the main variables to consider. Based on a research review and personal experience, the number of lanes in each direction, as well as the presence of traffic signs and road markings, are all factors to consider. Conditions of drainage, Pedestrian crossings are readily available and the impact of traffic merging and converging.

The collected accident data locations were geo-coded as x and y coordinates using a handheld GPS. In addition to that, the road information such as the texture depth, geometric characteristics, abstraction, road marking, road signs, sight distance, etc., and other information such as year, month, date, time, vehicle type, cause, fatality, and so on. In addition, the road network is digitized from the toposheets. On the digitized road network, the GPS location data merged with the road map.

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Table 2 Accident data for Tirunelveli City

Year	Fatal Accident	Grievous Accident	Minor Accident	Non Injury Accident	Total Accident
2018	282	180	709	44	1214
2019	282	162	759	49	1256
2020	290	190	704	56	1223

6. Methodology

In this research importance of accident, analysis was confirmed by the accident severity index value, which is 24.5, followed by the identification of black spots using the geospatial analysis, and corresponding factors causing the road accidents were identified and ranked using factor analysis. This research paper focused on macro level, the micro level factors such factors such as Volume to capacity ratio, collision rate etc ignored.

6.1 Accident Severity Index

The accident severity index takes into account the seriousness of the accidents as well as the availability of medical services in the area. The number of individuals killed in 100 accidents is the accident severity index. [39,40]. Figure 3 depicts the Tirunelveli district's accident severity index, which is relatively high. The accident severity index in 2018 was 20.6; in 2019, the accident severity index was raised to 24.5. This indicates that the number of people who died per 100 accidents has been rising year after year. In addition, the accident severity index of 24.5 is a significantly higher rate. Furthermore, the high level of accident severity index could be due to insufficient data collection and reporting. Hence the identification of black spots and corresponding influencing factors should be identified and ranked to reduce further accidents in the road planning stage and existing conditions.

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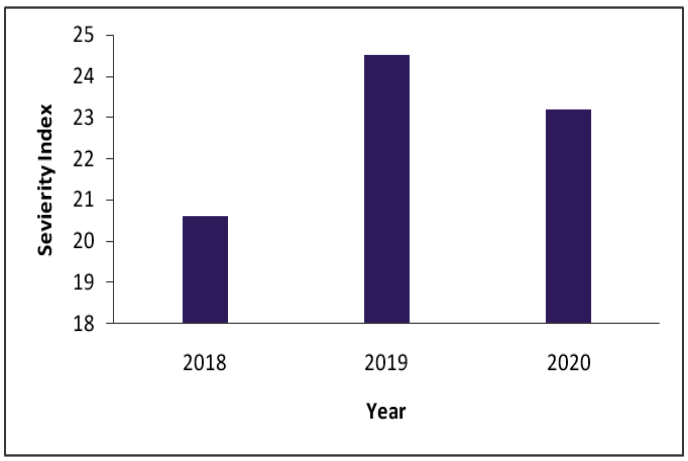

Fig.3 Severity Index and the corresponding Year

6.2 Identifying Black Spot

On a national and worldwide level, research on traffic accident analysis has been ongoing. The main objective of the study was to identify the cause of the accident and the appropriate remedial measures to minimize the occurrence of road crashes. As a result, the first step must be to identify hazardous locations, sometimes known as black spots [41]. Earlier conventional methods were used to find the black spot locality in which only the number of accidents is considered. In most of the traditional methods, they used the statistical Poisson distribution, and the Empirical Bayes technique was utilized [42, 55-69]. The goal of the identification procedure is to pick a few sites from a vast number of possibilities in order to increase safety. The justification for the identification procedure should meet the following criteria: economic efficiency, road user justice, and professional accountability [43]. Developed countries, like the United States, Canada, and European Union, have developed area-specific guidelines to identify and manage the black spots [44].

6.3 Spatial Accident Data Analysis

The researcher should have a clear understanding of spatial and temporal incidents that caused the accident to undergo statistical mapping and modeling using unique data [45, 46, 47]. In this research, the software Arc GIS was used to analyze the accident spots. The relevant data used were field verified to have high-level accuracy. In order to perform the black spot analysis, the Emerging Hotspot Analysis (EHA) methods were utilized in ArcGIS software. In this research, x and y identify the location of transactions, and z is the time of registered property transactions in that location or area of the city[48].

In order to identify the blackspots, the three-step kernel tool consists of a kernel density estimator, kernel function and bandwidth were utilized for density estimation, provided with mapping of cluster and collection of events was done

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using Getis-Ord GI* function given in equation 1. The collect event function was utilized to perform the operation, which produces the new output containing the weighted point feature class with field count expressing the summation of a number of accidents in a specified geographical location. Getis-Ord GI* hot spot function utilizes the weighted point feature as an input parameter to cluster the accuracy of blackspots in the research area [49,50,51]. In order to find out the Gi* value, the following equation given below was utilized.

$$Gi*(d) = \frac{W_{ij}(d)X_j - W_{ix*}}{S^*((nS^*1i) - W_i^{*2}/(n-1))^{1/2}} \text{ --------- (1)}$$

Where,

$W_{ij}(d)$ - Values for j within d of target cell i

W_i^* - Summation of all weights

S_{1i}^* - Summation of all squared weights

S^* - standard deviation in cell data

In the Gi* statistical analysis, the z score was calculated. Based on the GiZScore, the kernel density blackspots were identified, and produced the raster file showing the accident clusters with low or high intensity [52, 53]. This investigation yielded primarily Geo-databases, Queries, and Density Maps based on a variety of parameters. The GIS analysis helped to identify the blackspots in Tirunelveli. A method of heat map plug-in of QGIS was utilized to locate accident black spots. Point data is examined in this manner to build an interpolated surface depicting the density of occurrence. Each raster cell was assigned a density value, and the entire layer was represented using a gradient. The final visualization, which influences how the viewer interprets the data, is subjective. The final interpretation may differ depending on the number of classes and cell ranges used to create the gradient. Five different categories were evaluated for constructing the heat map, with a cell range of 200m, as shown in Fig 4

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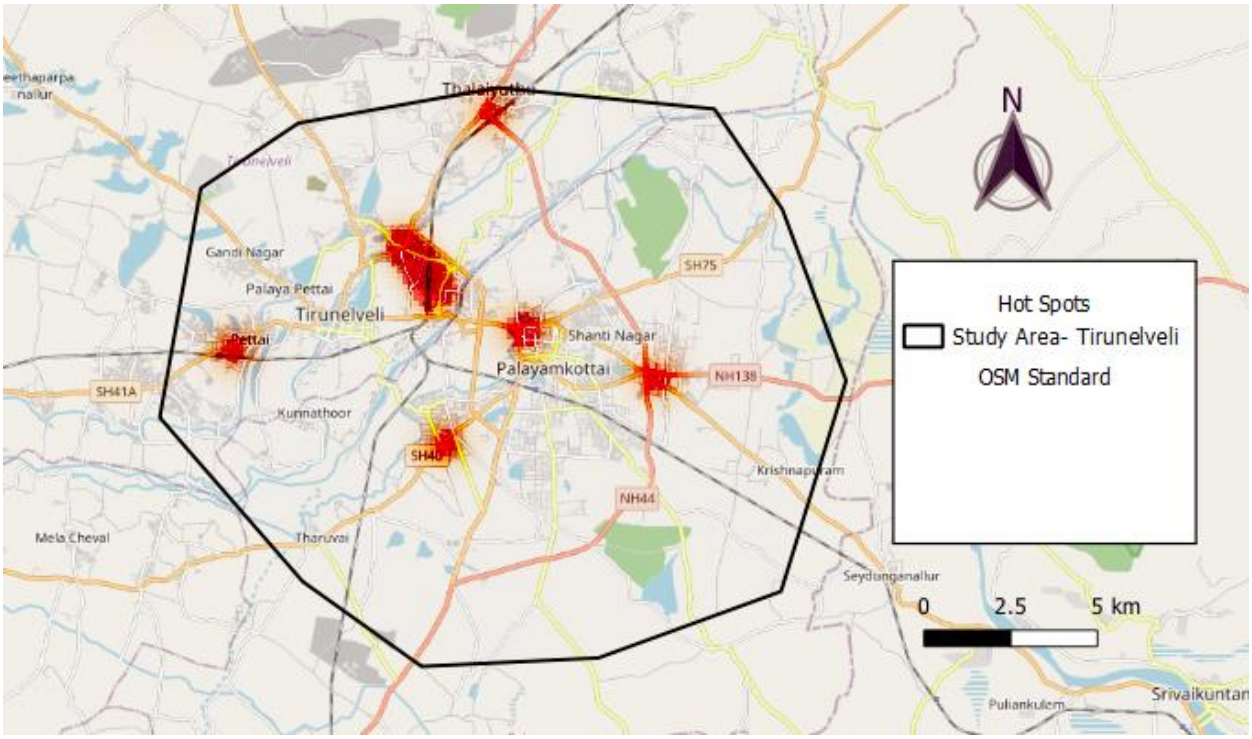

Figure 4 Density map showing the accident. Black spots

For mapping, free available geo-referenced IRS P-6 LISS-III (Indian Remote-Sensing Satellite-P6 A linear imaging self-scanner)was utilized and obtained from the 'Bhuvan India portal. The data obtained are listed below. A heat map is created with five classes using the QGIS Heat map plug-in. As illustrated in the density map shown in Figure 4, black spots are formed in relation to the classes. From the density map, five accident blackspots were identified, as shown in Table 3.

Table 3 Black spot location and number of accidents

Black Spots Location	Total Number of Accidents 2018-2020
Two-tier bridge (Tirunelveli Junction)	23
In front of Tirunelveli Court	16
Vannerpettai Junction	24
Samathanapuram Junction	31
Thatchanallur (bypass road junction)	26

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6.4 Black spot location causes and remedial measures

Two-tier bridge (Tirunelveli Junction)

The cause was due to the road width getting narrowed due to the roadside market and lack of pedestrian footpath, road marking, Improper lighting, sight distance at the junction, Over speeding, pedestrian crossing, and improper geometric characteristics. Roadside shops should get removed, and geometric features get rectified.

In front of Tirunelveli Court

The cause was due to the movement of pedestrians from the court to opposite side hotels and shops, leading to heavy pedestrian and motorcyclist crossing.

Vannerpettai Junction

The cause was due to the Hospitals, textile shops, and hotels being located, leading to heavy pedestrian flow and vehicle movement and PCU higher than the actual capacity during festival time and parking of vehicles on the roadside. The following remedial measures involve the Construction of a subway for pedestrians and provision of footpaths on either side of roads, and the Construction of a median.

Samathanapuram Junction

The cause was due to the roadside occupied by shops, lack of road marking and lighting improper geometric characteristics, and the remedial measures such as geometric characters such as channelization, the smooth radius at the curve, median, and island to reduce the conflicts.

Thatchanallur (bypass road junction)

The cause was due to the national highway passing through this Place having high pedestrian movement on either side of road and crossing of pedestrians from the one side of the road to the other vice-versa having higher design speed and the remedial measures are Construction of subway for catering the pedestrian moving on that Place.

Data Analysis in Black spots

The factors that caused accident crash was recorded, such as traffic characteristics, geometrical characteristics, human behavior, and vehicle characteristics shown in table 4 given below was utilized for data analysis to rank the most influential factor causing the accident using the factor analysis in the Statistical Package for the Social Sciences software. The fitness of data suitable for the factor analysis was checked by Bartlett's test. And to confirm the adequacy of information was studied using the Kaiser–Meyer–Olkin test for factor analysis [54].

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Table 4 Accident causing factors, Frequency Index, and Ranking

S.No	Characteristics	Factors	Frequency Index	Ranking
1	Traffic	V/C Ratio	0.72	8
2	Road Geometry	Ununiform width of the carriageway	0.69	12
		Lack of sight distance	0.75	6
		Radius of curvature	0.63	16
		gradient	0.21	27
		Superelevation	0.45	22
		Controlled intersection	0.32	24
		Uncontrolled intersection	0.89	3
		Lack of auxiliary lanes at the intersection	0.21	28
		Bridge approach	0.53	19
		Lack of footpath	0.83	4
3	Road characteristics	Skid resistance	0.72	9
		Roughness	0.43	23
		PSI	0.64	15
4	Street furniture	Traffic signs	0.59	18
		Road marking	0.53	20
5	Human Factors	age	0.69	13
		male	0.72	10

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S.No	Characteristics	Factors	Frequency Index	Ranking
		Female	0.32	25
		Drunk and driving	0.943	1
		Over speeding	0.92	2
6	Environmental factors	Rainy	0.68	14
		Sunny	0.52	21
		Day time	0.63	17
		Night time	0.74	7
7	Vehicle factors	Low-performance vehicle	0.72	11
		High-performance vehicle	0.12	29
		Brake failure	0.23	5
		Passenger vehicle	0.82	30
		Cargo vehicle	0.32	26

6.5 Ranking of factors

Statistical Package for the Social Sciences software (SPSS) was utilized to analyze the data collected. The data collected at the accident spot were road geometry, road characteristics, street furniture, human behavior, environmental factor, and vehicle characteristics. The data for the analysis was collected from all 120 accident spots comprising fatal, grievous injury, minor injury, and non-injury for all the identified factors causing accidents in the black spots. The frequency index (F.I.) was calculated and ranked as shown in the table, and its ranking for each category was calculated for each factor and is given in Table 4. Table 5 shows the leading ten factors causing the accident, covering all group each groups except the street furniture characteristics. From the observation obtained, it was noted that the features such as human factors stand first in an accident-causing factor, followed by vehicle factors stand second and geometrical factors in the third position.

Table 5 Leading Factors

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Characteristics	Factors	Frequency Index	Average Frequency Index	Ranking
Traffic	V/C Ratio	0.72	0.720	6
Road Geometry	Lack of sight distance	0.75	0.750	3
	Uncontrolled intersection	0.89		
	Bridge approach	0.53		
	Lack of footpath	0.83		
Road characteristics	Skid resistance	0.72	0.730	5
Human Factors	Male drivers	0.72	0.861	1
	Drunk and driving	0.943		
	Over speeding	0.92		
Environmental factors	Night time	0.74	0.740	4
Vehicle factors	Passenger Vehicle	0.82	0.820	2

7. Scope of the research

This research identifies the most influencing factor causing the accident among the n-number of factors driving the road accident and a limited number of accidents spots in the study area; thus, the severity index obtained in holistic

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manner. Hence, it is suggested that intersections and road sections should be examined separately in future studies. Thus, it gives an idea for the transport planners to take appropriate action to reduce the accident in the short term and in the long time.

8. Limitations of the study

The following limitations of the study are the micro-level factors causing the accidents, such as driver behavior, angle of collision, type of collision, volume to capacity ratio, level of service, etc., are ignored.

9. Conclusion

In the past research, the accident data were analyzed by statistical analysis, machine learning, cluster analysis, and GIS-based have utilized all the factors causing the road crashes, but the highly influenced factors causing road crashes are not identified and ranked. The statistical methods are generalized in nature, where the GIS-based analysis shows the distribution of accidents in specified areas along with the spatial data. This research utilized statistical analysis, which is based on the severity index the accident studies were carried out in the particular area, identification of black spots in that area, and identifying the most influencing accident causing factors, especially in the black spots in that area. The 30 accident-causing factors were identified and ranked. The top 10 factors influencing the cause of accidents are (1) volume to capacity ratio, (2) lack of sight distance, (3) uncontrolled intersection, (4) bridge approach, (5) lack of footpath, (6) skid resistance (7) male drivers (8) drunk and driving (9) over speeding (10) passenger vehicle. This study reveals that the identification of accident-causing factors is a very complex process in India and requires proactive decisions to reduce the accidents on the road systematically so that road accidents could effectively be reduced drastically in the future.

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