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ANALYSIS OF TRAFFIC ACCIDENTS IN NOVI SAD USING GIS TECHNOLOGY

DEJAN DJORDJEVIĆ
Military Geographical Institute - "General Stevan Bosković", Belgrade, dejanjordjevic.vgi@gmail.com

MILOŠ BASARIĆ
Military Geographical Institute - "General Stevan Bosković", Belgrade, m-basaric@protonmail.com

IVAN GARIĆ
Military Geographical Institute - "General Stevan Bosković", Belgrade, ivan.garic@yahoo.com

Abstract: *This paper investigates the spatial and spatio-temporal distribution of traffic accidents in Novi Sad using GIS technology, analyzing open data from 2015 to 2023. Thematic maps, KDE method and k-means cluster analysis were used to identify high-risk areas. The Space-Time Cube tool enabled spatio-temporal analysis, while the Emerging Hot Spot Analysis revealed trends and anomalies in the concentration of accidents. The results contribute to a better understanding of accident dynamics, enabling more efficient planning of safety measures and directing resources to high-risk areas. The findings highlight critical areas and suggest measures to improve traffic safety.*

Keywords: *Traffic accidents, GIS, spatial analysis, high-risk areas, preventive measures.*

1. INTRODUCTION

Traffic accidents (TA) represent one of the most significant problems of modern urban environments, causing serious economic, health and social consequences. In a city like Novi Sad, with a growing population and an increasing number of vehicles, the frequency of traffic accidents is becoming alarming. These accidents result not only in material damage, but also in serious injuries and loss of life, which further burdens the health system and affects the quality of life of residents. Effective traffic management and reducing the number of accidents requires a deep understanding of the spatial patterns of traffic accidents and the factors that influence them. In this context, Geographic Information Systems (GIS) represent a powerful tool for analyzing and visualizing traffic accident data. GIS enables the identification of high-risk areas and the analysis of various factors such as traffic infrastructure, weather conditions, and the behavior of road users.

The aim of this study is the application of GIS technology for the analysis of traffic accidents in Novi Sad, with a special focus on identifying critical points and understanding the key causal factors. The collected data on traffic accidents over a period of eight years (2015-2023) includes information on the location of accidents, type of accident, road conditions and other relevant parameters. This data was analyzed using advanced GIS software, which enabled the creation of thematic maps that visualize the spatial patterns of accidents. In addition to spatial analysis, various statistical methods were used in the study in order to identify the key factors that influence the frequency of traffic accidents. The results of this study provide valuable insights that can be useful for decision makers, urban planners and traffic planners. The identification of high-risk areas enables directing resources to the most critical points, while the analysis of causal factors provides the basis for the development of targeted preventive measures. Recommendations arising from this study include the improvement of traffic infrastructure, installation of additional signage, implementation of educational campaigns and improvement of traffic regulation. In conclusion, this study emphasizes the importance of using GIS technology in the analysis of traffic accidents and provides concrete guidelines for improving traffic safety in Novi Sad. Through accurate mapping and detailed data analysis, it is possible to identify key areas and risk factors, which contributes to the development of more effective strategies to reduce the number of traffic accidents and improve overall traffic safety.

2. TRAFFIC ACCIDENTS AND THEIR ANALYSIS

Traffic accidents represent a significant social problem with a wide range of consequences for safety, economy and health. Analysis of these accidents has a key role in developing strategies to reduce and prevent them. Various methodologies are used in traffic accident research in order to identify the causes, risk factors and forms of their prevention. Descriptive analysis is the basic methodology used to study the characteristics of traffic accidents such as location, time, participants, vehicle types, and traffic conditions. This approach provides basic insights into accident patterns and trends [1].

Corresponding author: D. Đorđević;
E-mail: dejanjordjevic.vgi@gmail.com
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By using GIS technologies, researchers can identify geographical zones with increased risk, as well as analyze the impact of various factors on traffic safety [2]. Statistical analysis is applied to investigate the relationship between different variables and traffic accidents, which includes correlation analyses, regression models and classification analyzes [3]. Qualitative analysis includes detailed analysis of qualitative data such as witness reports, participant testimonies, and police reports. This approach provides additional insights into the causes and circumstances that lead to traffic accidents. Factors that can affect the likelihood and severity of traffic accidents include speed, alcohol and other opiates, bad roads, improper use of mobile devices while driving, lack of safety measures and infrastructure deficiencies. A complex analysis of these factors enables the identification of potential strategies and interventions to reduce the risk and consequences of traffic accidents [4].

In the context of traffic accidents, GIS enables the integration of different types of data in order to better understand the spatial distribution of accidents and identify critical points in traffic flows [5]. The use of GIS technologies allows analysts to visualize the distribution of traffic accidents on maps, which helps identify geographic patterns and locations of increased risk. These analyzes are of essential importance for the development of effective strategies for traffic safety, the planning of infrastructure investments and the application of specific traffic measures at critical locations. The application of GIS technologies represents an important aspect in traffic accident research, providing advanced analytical tools for understanding spatial patterns and the impact of factors on traffic safety. The continuation of the development and application of GIS opens up new opportunities for the improvement of traffic accident prevention strategies and more efficient management of traffic flows.

The use of Geographic Information Systems (GIS) extends beyond civilian applications, as it is also critical in military operations, especially in urban environments where the movement of military vehicles and personnel requires careful planning. In military contexts, traffic accident data, such as the one analyzed in this study, can provide valuable insights into the safest and most efficient routes for troop and equipment transportation. By identifying high-risk areas where accidents are frequent, GIS analysis enables military planners to avoid potential hazards, ensuring that military convoys can move through urban areas with minimal disruption and reduced risk. The same GIS tools that analyze civilian traffic accidents can be applied to simulate the movement of military vehicles, enhancing logistical efficiency and operational safety.

3. DATA AND METHODOLOGY

3.1. Data

Data on traffic accidents were taken from the National Open Data Portal [6], where numerous open data sets in the possession of state authorities of the Republic of Serbia, including state administration authorities, autonomous provinces and local governments, are published. The open data portal is not only a repository but also a platform for interaction with users, allowing them to add supplementary data and examples of data usage. Data on traffic accidents, published by the Ministry of the Interior, includes information by Police Departments and Municipalities, including the unique ID number of the accident, police department, municipality, date and time of the accident, geolocation of the place, type of accident, vehicle number, participant status and detailed description [7].

These data do not include accidents on the territory of Kosovo and Metohija. They are available in the form of tables by year for the period from 2015 to 2024, with an updated situation for the current year 2024. The downloaded Excel spreadsheets were customized by adding a row with column names and a new column showing the time of the accident in a format suitable for later processing, then saved in .csv format for loading into GIS software. All tables are consistent in form, structure and content. Each accident in the tables is marked with geographic coordinates in the WGS 84 projection, which is widely used in GIS applications. The tables were loaded into ArcGIS Pro, where the accidents were visualized according to the coordinates, which resulted in spatial data of point geometry in .shp format. Each accident on the map corresponds to one point that contains all the additional data from the initial table.

A subset of data was used for the territory of the Novi Sad Police Department for the period from 2015 to 2023.

3.2. GIS Methodology

For a deeper understanding of patterns for understanding the occurrence of traffic accidents, various statistical methods were used, including: descriptive statistics and spatial statistical analysis. In this study, ArcGIS Pro software [8], one of the most powerful tools for GIS analysis, was used.

Descriptive statistics provide basic information about the data, such as the number of traffic accidents, the average number of accidents by time period, and variations in the frequency and severity of accidents. This step is crucial because it allows us to identify the underlying characteristics of the data and to determine if there are significant anomalies or patterns that require further investigation. Before embarking on a more detailed spatial and temporal analysis, the presentation of descriptive statistics will provide us with the necessary context and enable a better understanding of the complexity and dynamics of traffic accidents. The Summary Statistics tool generated tables with different summarized data based on individual categories of data in the attribute table. This tool provides a number of statistical measures such as sum, average, minimum, maximum and standard deviation for given categories.

Geographic Information System (GIS) is the key tool used in this study to analyze and visualize traffic accident data. GIS enables the integration and analysis of spatially referenced data, which is essential for identifying patterns and trends.

The first step in the GIS analysis was the creation of a spatial database with information on all accidents. Each accident is represented as a point on the map, with associated attributes (date, time, type of accident, etc.). After that, various GIS functions were used to analyze the spatial distribution of accidents. Spatial analysis included the following steps:

1. *Data visualization* - Thematic maps were created that show the spatial distribution of accidents by year, types of accidents, and other relevant criteria. These maps provide a visual insight into accident concentrations and help identify high-risk areas.
2. *Density analysis* - The kernel density estimation (KDE) method was used to estimate the density of traffic accidents in space. KDE enables the identification of "hot spots" where the concentration of accidents is the highest, which is crucial for directing preventive measures and resources.
3. *Cluster analysis* - K-means cluster analysis was used to group accidents into clusters based on their spatial and attribute characteristics. This enabled the identification of similar groups of accidents and a better understanding of their common characteristics.
4. *Spatio-temporal analysis* - Spatio-temporal analysis of traffic accidents using the tool identifies trends and anomalies over time, discovering new hot spots and changes in the concentration of accidents.

The results of GIS and statistical analysis were integrated in order to obtain a comprehensive picture of the spatial and causal factors of traffic accidents in Novi Sad. The spatial patterns identified through the GIS analysis were correlated with the results of the statistical analysis in order to better understand the factors that contribute to the occurrence of accidents.

4. RESULTS AND DISCUSSION

4.1. Display of descriptive statistics

The display of descriptive traffic accident statistics provides basic information on data such as the number of traffic accidents, the average number of accidents by time period, as well as variations in the frequency and severity of accidents. In this way, we gain insight into the basic characteristics of the data and identify significant patterns that require further analysis.

The results shown in Table 1 show significant variations in the number of traffic accidents by year. The highest number of accidents was recorded in 2019 (4728), while the lowest number was recorded in 2015 (904). Most of the accidents resulted in material damage (52.5%), while accidents with injured persons made up a significant part (46.7%), and accidents with dead persons were relatively rare (0.8%).

Table 1. Number of TAs according to the outcomes by years

Year	Outcome	Number of TAs	
		by outcome	by year
2015	damage material	282 (31.2%)	904
	fatalities	6 (0.7%)	
	injuries	616 (68.1%)	
2016	damage material	2414 (54.3%)	4448
	fatalities	32 (0.7%)	
	injuries	2002 (45%)	
2017	damage material	2426 (52.1%)	4656
	fatalities	16 (0.3%)	
	injuries	2214 (47.6%)	
2018	damage material	2304 (53.7%)	4292
	fatalities	42 (1%)	
	injuries	1946 (45.3%)	
2019	damage material	2432 (51.4%)	4728
	fatalities	42 (0.9%)	
	injuries	2254 (47.7%)	
2020	damage material	2148 (52.4%)	4096
	fatalities	42 (1%)	
	injuries	1906 (46.5%)	
2021	damage material	2360 (53.8%)	4390
	fatalities	42 (1%)	
	injuries	1988 (45.3%)	
2022	damage material	1164 (54.1%)	2150
	fatalities	14 (0.7%)	
	injuries	972 (45.2%)	
2023	damage material	2322 (53.7%)	4326
	fatalities	24 (0.6%)	
	injuries	1980 (45.8%)	

The distribution of traffic accidents by time periods of the day shows that most accidents occur between 08:00 and 20:00, with the peak between 12:00 and 16:00. The results are shown in Table 2.

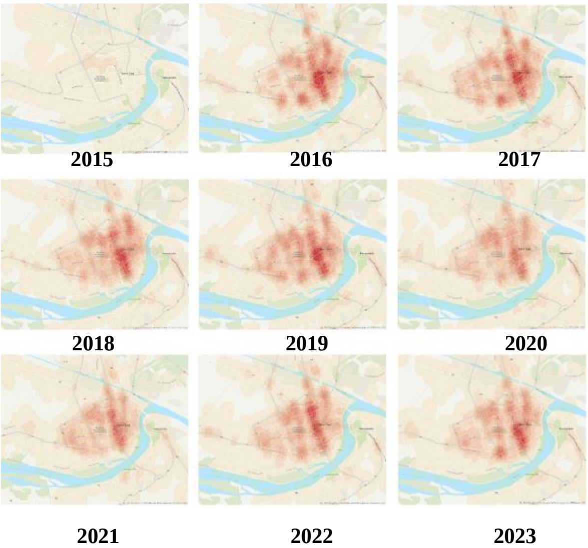
Table 2. Distribution of TAs according to time windows by years

	Time window						Mean time
Year	00-04	04-08	08-12	12-16	16-20	20-24	
2015	54	92	186	224	236	112	13:33
2016	260	408	990	1204	1020	566	13:31
2017	200	430	996	1278	1114	638	13:53
2018	254	424	934	1188	962	530	13:24
2019	302	398	968	1322	1124	614	13:38
2020	202	352	850	1186	1012	494	13:47
2021	258	392	890	1206	1068	576	13:45
2022	129	200	425	589	509	298	13:02
2023	206	356	948	1180	1030	606	13:53

4.2. Spatial analyzes and distribution of accidents

Spatial data visualization is crucial when dealing with large datasets. Vector point representation is not an effective approach for thousands of traffic accidents per year, so it is necessary to use raster data forms. Heatmaps, generated by the Kernel Density method, allow easy identification of patterns and clusters through color gradation, which facilitates the interpretation of density and concentration of events.

Figure 1 shows the results of the analysis of the density of traffic accidents in Novi Sad, where the dark red areas indicated the highest density of accidents. This enables quick identification of critical areas that require additional attention and analysis.



Figures 1. Heatmaps of TAs by years

The analysis showed that certain parts of the city are more prone to more accidents, which may be related to traffic junctions, intensive traffic or specific infrastructural characteristics. To identify the geographic center or center of concentration of traffic accidents, the Mean Center tool was applied. This tool calculates the average X and Y coordinates of all crash points, placing a new point on the map that represents the midpoint for the given data set. This analysis can be performed in an alternative way by focusing on specific cases within the attribute table (Case Field), which enables the identification of central points related to certain phenomena. Figure 2 shows the central points over the years in relation to the outcomes of traffic accidents.

Figures 2. Mean center points by outcomes and years

It is noticeable that the center points are grouped when it comes to outcomes with material damage and injuries, except for 2015, when the mean center point deviated significantly from the others. In contrast, the central points related to fatal traffic accidents vary spatially. This indicates a lack of consistent spatial pattern for these accidents, meaning they may occur in different locations each year. The lack of clearly defined "hot spots" for fatal accidents can make predictive analysis and application of preventive measures difficult.

After that, the Cluster and Outlier Analysis (Anselin Local Moran's I) statistical method was applied, which identifies spatial clusters of high and low values, as well as isolated locations in the data [9]. Figure 3 shows the results of this analysis for the year 2023, which showed that high values are clustered in the city core, while low values are identified along the periphery, especially along the road infrastructure.

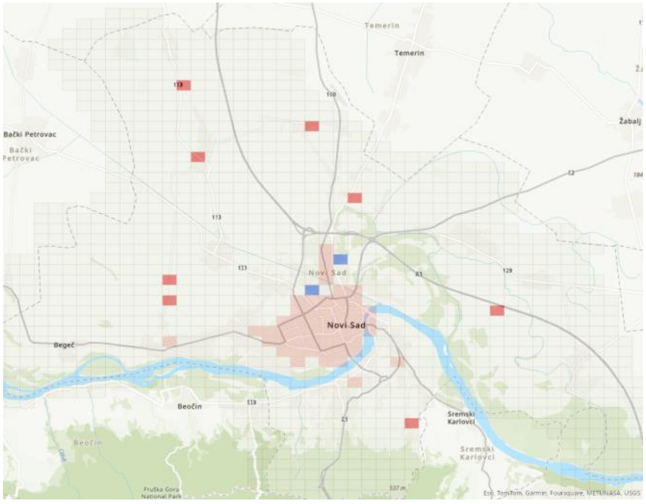


Figure 3. Cluster analysis for 2023

Figure 4 shows a legend for understanding the results shown in Figure 3. Cluster analyzes indicate the sporadic occurrence of fatal traffic accidents in the peripheral parts of the city, while clearly defined hotspots are not observed.

Symbol	Clasters type	Description
	High-High (HH) cluster	High values surrounded by high values.
	High-Low (HL) outlier	High value surrounded by low values (isolated high value).
	Low-High (LH) outlier	Low value surrounded by high values (isolated low value).
	Low-Low (LL) cluster	Low values surrounded by low values.
	Not Significant	These characteristics are not statistically significant.

Figures 4. Cluster analysis legend

These results suggest that traffic density in the city center is associated with a higher number of traffic accidents, while in the periphery the number of traffic accidents is relatively smaller and evenly distributed. This analysis provides important insights for local planners and decision makers in understanding the distribution of traffic incidents in the city.

4.3. Spatio-temporal analysis of traffic accidents

Spatio-temporal analysis of traffic accidents represents an integrative approach that enables a detailed examination and understanding of how traffic accidents are distributed and changed in space and time. This analysis uses geographic information along with weather data to identify patterns and trends that may be invisible in simpler analyses.

Space-Time Cube (STC) is an advanced analytical format that enables the integration and analysis of spatial and temporal data. Data on events that occur at specific time intervals and at specific locations are converted into a three-dimensional cube where two dimensions are spatial (x and y coordinates), and the third dimension represents time. This approach enables the identification of trends in the occurrence of traffic accidents over time [10].

Emerging Hot Spot Analysis is a spatio-temporal analysis based on STC. It is used to identify trends in geographic data, focusing on changes in the spatial and temporal patterns of traffic accident hotspots. This analysis detects new and unexpected areas with a significant increase or decrease in accident concentration over time. STC divides the data into time bins or increments (a period of 3 months was used in this paper), enabling a detailed analysis of trends and anomalies. Figure 5 shows the summarized result of this analysis, identifying the key hot spots in Novi Sad in the period from 2015 to 2023.

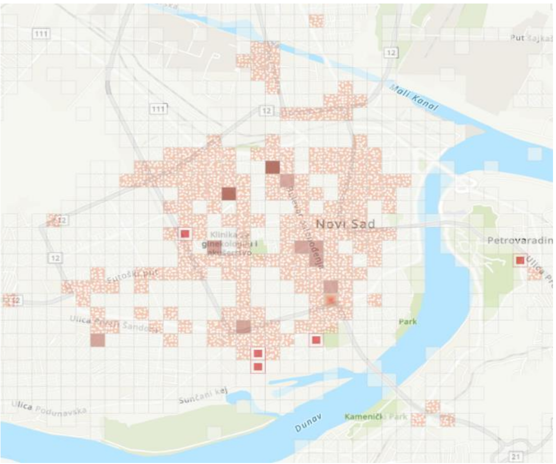


Figure 5. Emerging hot spot analysis results

Figure 6 shows part of the legend that is represented when displaying the results in this analysis with additional descriptions.

Symbol	Name	Description
	New Hot Spot	Statistically significant hot spot only for the most recent time step.
	Consecutive Hot Spot	Series of statistically significant hot spots in the most recent time steps.
	Intensifying Hot Spot	Location that is consistently hot and becoming hotter.
	Persistent Hot Spot	Location that is consistently hot (90% of bins are statistically significant hot spots).
	Diminishing Hot Spot	Location that is consistently hot but cooling down.
	Sporadic Hot Spot	Location that is intermittently hot and not hot.

Figure 6. Emerging hot spot analysis legend

What can be noticed is the appearance of new hot spots in certain parts of the city, with an accent on the group of these hot spots at Liman 4 area, as well as intensifying hot spots at the intersection of Bulevar Oslobođenja and Bulevar Cara Lazar streets. Also, we see that most of the city center is characterized by sporadic hot spots, while persistent hot spots and consecutive hot spots are visible in places that were previously identified as places with the highest incidence of traffic accidents (Bulevar Oslobođenja street, Sajmište area, Detelinara area, corner of Bulevar Europa street and Bulevar Cara Lazar street).

4.4. Discussion

The results of the analysis of traffic accidents in Novi Sad in the period from 2015 to 2023 provide a comprehensive insight into the temporal and spatial patterns of these events. Through descriptive statistics, spatial analysis and the use of advanced GIS tools, significant insights have been obtained that can help improve traffic safety and infrastructure planning.

Analysis of the number of traffic accidents by year shows significant variations. The number of accidents increased sharply between 2015 and 2016, after which it remained relatively stable until 2023. The highest number of accidents was recorded in 2019 (4728), while the lowest number was in 2015 (904). The average time of accidents is around 13:30, which indicates a high frequency of accidents in the early afternoon. These data are crucial for planning traffic controls and interventions during the most critical periods of the day.

Spatial distribution of traffic accidents is shown using raster maps and the Kernel method. The results indicate a high concentration of accidents along the main roads. These areas have been identified as critical zones that require special attention and interventions. Application of the Mean Center tool provided additional insights into changes in the spatial distribution of accidents over the years. Mean Center analysis showed that the mean points of traffic accidents were consistent for accidents with material damage and injured persons, while the mean points for accidents with fatal outcome varied, which indicates the unpredictability of these events.

Cluster and Outlier Analysis (Anselin Local Moran's I) identified spatial clusters and extreme values. The results for 2023 showed that clusters of high accident values are concentrated in the city core, while clusters of low values are located on the outskirts of the city. These findings indicate a higher density of traffic accidents in the central parts of the city, which is expected due to the higher traffic density.

The analysis of traffic accidents in Novi Sad shows significant spatial and temporal variability in the frequency and severity of accidents. The high concentration of accidents along the main roads and in urban centers indicates the need for targeted interventions. It is recommended to improve infrastructure, increase traffic controls in critical periods and at designated places where a large number of TAs are connected, driver education and continuous analysis of data on traffic accidents in order to identify new trends and causes of changes.

The findings from the GIS analysis of traffic accidents in Novi Sad can have broader implications, particularly in military applications. The identification of high-density accident zones and spatial clusters is not only useful for improving civilian traffic safety but also for optimizing military convoy routes and logistics planning. In military operations, the ability to avoid accident-prone areas and to predict traffic patterns can be crucial for the success of missions, especially in urban environments. GIS tools allow military planners to simulate various scenarios, ensuring that routes are both safe and efficient. Additionally, the integration of spatial and temporal data through GIS can improve decision-making processes in emergency situations, enabling faster and more secure deployment of military resources.

5. CONCLUSION

This paper focuses on the analysis of traffic accidents in Novi Sad using GIS technologies and geostatistical methods. The aim of the research is to identify the spatio-temporal patterns of accidents and the factors that influence their occurrence. The application of GIS technologies enables the visualization and analysis of spatial data in a new way, which is of great importance for understanding the causes and dynamics of traffic accidents.

The research results confirmed the existence of defined accident patterns that suggest different influences such as infrastructure, road conditions and traffic density. The analysis of public data from the National Open Data Portal proved their usefulness and usability for various spatio-temporal analyses.

The research applied specific methods for geostatistical analysis and spatial modeling, which led to the identification of the main hotspots with a high number of accidents. This significantly improved the understanding of the causes of traffic accidents at the local level and highlighted the importance of applying GIS technologies for traffic safety management.

This research represents significant progress in the analysis and management of traffic safety, demonstrating that GIS technologies and geostatistical methods can be successfully applied in other locations in Serbia and beyond.

In addition to civilian traffic safety applications, GIS technology plays a crucial role in military logistics and operations, providing critical insights for route optimization and risk management. The findings from this study could be applied to enhance military transport strategies, ensuring safer and more efficient movement of troops and equipment through urban environments by avoiding high-risk areas identified in the analysis.

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