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Identifying spatiotemporal variability of traffic accident mortality. Evidence from the City of Belgrade, Serbia

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Abstract: Traffic accident mortality (TAM) is a significant global problem and part of the sustainable development goals strategy. In Serbia, a decline in the number of deaths in traffic accidents is evident, but in certain time intervals and areas, the number of deaths is higher than in others. This paper adopted Joinpoint regression analysis and a geospatial approach to assessing spatial, temporal, and spatiotemporal mortality variability due to traffic accidents in Belgrade from 2016 to 2021. Results suggested statistically significant change during each year and spatial clustering of higher values of deaths in central Belgrade municipalities. Spatiotemporal analysis of traffic accidents data indicated a change in spatial clusters over time, pointing out two types of hotspots for traffic accident mortality–Sporadic - and New hotspots along the international highway, main, and local roads, in the broader area of the city. The main findings of this paper pointed to the areas in Belgrade where the population is more endangered in traffic compared to other areas. The results and conclusions can serve traffic managers and decision-makers as a basis for more detailed research and local-specific traffic safety strategies.

Key words: Traffic Accident Mortality, Joinpoint Regression Analysis, Optimized Hotspot Analysis, Space-Time Mining Pattern Analytics, Belgrade, Serbia.

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1. INTRODUCTION

Traffic accident mortality (TAM) is a significant global problem. Around 1.3 million people died from a road traffic crash, costing most countries 3% of their gross domestic product [1]. The number of deaths in traffic accidents at a global level in the period from 2000 (19,099 per 100,000 inhabitants) to 2019 (16,714 per 100,000 inhabitants) slightly decreased to more than 12% [2]. This problem is integral to the Sustainable Development Goals (SDG) strategy. By SDG Target 3.6, the number of global deaths and injuries from road traffic accidents should be halved [3]. The extent of this problem can be seen in the fact that this target still needs to be met.

Serbia and other countries of the Balkan Peninsula face the same problem. The decline in the number of deaths caused by traffic accidents began in the last decade of the 20th century due to the stabilization of the economic situation in the country, increasing living standards, tightening the penal policy for traffic violations, etc. [4]. This trend continued at the beginning of the 21st century, which was greatly influenced by the adoption of the Law on Traffic Safety on Roads [5] as well as an intensive media campaign on the behavior of road users [6]. Despite the downward trend in the number of fatalities and number of deaths, Serbia is far from achieving the SDG target.

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In Serbia, the City of Belgrade has the highest number of traffic accident deaths [7]. Belgrade is a crossroads of national and international roads, so it is characterized by a high degree of daily mobility of the population. A total of 766,275 vehicles were registered in Belgrade in 2021, which is slightly less than one-third (28.5%) of all registered vehicles in Serbia [8]. Given that, identifying the areas where a higher number of fatal traffic accidents occurs and monitoring the change in trend in Belgrade is required to reduce the number of deaths.

The assessment of spatial and spatiotemporal patterns is achievable using spatial analysis [9] while significant temporal trend changes can be detected using Joinpoint regression analysis [10]. The data on the number of dead in traffic accidents in Serbia are georeferenced and are grateful material for detecting micro-locations where the highest number of dead was recorded. Since data also contain a time component, it is possible to determine the nature of the temporal trend and whether statistically significant changes in the trend exist.

This study aims to assess the spatial, temporal, and spatiotemporal patterns of the TAM in the City of Belgrade from 2016 to 2021 to identify the areas where the population is the most endangered by adopting a geospatial approach. Yet, this methodological approach has not been applied to study TAM in Belgrade and Serbia. Targeting the area where most people die and when it happens is the initial step towards reducing the number of deaths. Accordingly, three main research questions are:

– What are the temporal dynamics of TAM in Belgrade? And are there statistically significant changes in the studied period, from 2016 to 2021?

– Are spatial, temporal, and spatiotemporal mortality patterns due to traffic accidents noticeable?

– Are TAM patterns constant over space and time or only characterized by temporal variability?

2. LITERATURE REVIEW

TAM is a problem equally represented in underdeveloped [11], developed [12], as well as in developing countries [13]. The change in the number of deaths can be indirectly linked to economic growth. Thus, a study conducted in Nigeria showed that economic development, observed through GDP growth, has conditioned a long-term decrease in crashes and fatalities [14]. Directly, it can be related to the consumption of alcohol [15], drugs [16], etc. TAM is a significant factor in public health problems and a society's economic and social development [17]. Therefore, identifying high-risk crash spots is vital [18].

Recent findings suggest that mortality due to traffic accidents is not random but clustered in space [19,20] and time variable [21,22]. Spatial variations of TAM are noticeable within the state; in Italy are directly associated with disparities in employment rate and alcohol use [23], and in the Netherlands, with per capita income, traffic density, and the availability of advanced trauma care [24]. In Iran, for example, the deaths caused by traffic accidents are spatially diverse and clustered, conditioned by population density differences, traffic volume, highway length, land use, etc. [25]. A study conducted in Japan showed that the spatial variability of TAM can be linked to different socioeconomic characteristics of the population [20]. Some studies indicate that the number of deaths in traffic accidents varies over time and that changes in the trend (increasing or decreasing) are conditioned by the economic crisis [22], in addition to various targeted prevention measures [26].

A review of past studies showed that the researchers successfully applied geospatial approaches to investigating traffic accident data [27] and detecting the areas with the higher concentration of events. A study by Wang et al. [28] suggests Kernel density (KD) analysis for identifying road traffic risk locations, i.e., locations with the highest concentration of incidents. Another study supports that the KD analysis is a practical approach to indicating the distribution according to a pattern; the authors also suggest that this analysis does not provide statistical significance [29]. To overcome this gap, the same study proposes the use of hotspot analysis. Given that the output of hotspot analysis can reveal statistically significant patterns, it is successfully applied for the identification of spatial grouping of traffic accidents [30] and their spatial grouping based on severity [31]. Pljakić et al. [32] employed this method to assess the high frequency of the total number of accidents and pedestrians, and Vaz et al. [33] to identify hotspots and coldspots of road traffic injuries. The study of Kang et al. [29] revealed areas with a high concentration of traffic accidents with the elderly population using hotspot analysis. Finally, numerous studies have implemented space-time mining pattern analytics for spatiotemporal analysis of traffic accidents [29,34], emphasizing their significance to the sustainable development of the studied area [35].

However, relatively few studies connect these two phenomena regarding the application of spatial analysis in TAM research Erdogan [19] investigated the degree of a spatial grouping of high road mortality rates using global and local spatial autocorrelation analyses. The same author successfully applied a geographically weighted regression model to predict death rates. For detecting spatiotemporal variability of hotspots/coldspots and trends of road traffic accident fatalities in Bangladesh between January 2013 and June 2016, Rahman, Crawford, and Schmidlin [36] utilize KD estimation, space-time cube, and emerging hotspot analysis. These methods had satisfactory results and potential for use in other case studies. Given that a significant number of deaths among motorcyclists have been reported in Iran, Saadat et al. [25] utilized the Moran's I index for assessing spatial clustering of these events, Getis-Ord G* statistics to identify hotspots, and geographically weighted regression to determine the spatially varying relationship between environmental factors (population density, level of development, traffic volume, length of highways, etc.) and the number of deaths. These spatial analyses allow identifying the most dangerous places for motorcyclists and the factors that affect their vulnerability. Yoon and Lee [34] investigated the dynamics of changes in the number of pedestrian deaths, comparing the areas where environmental enhancement projects for pedestrians were implemented with those that did not. A declining trend (different variations of coldspots) has been observed in areas where prevention measures come into force. They concluded that the space-time mining pattern is an efficient tool for assessing pedestrian safety.

Previous studies showed that Joinpoint regression analysis is a valuable tool for investigating the time trend of mortality due to traffic accidents and identifying the moment when a statistically significant change occurred. This method helps identify time trends and statistically significant changes in time-series data [9]. Thus, studies conducted in the Slovak Republic [21] and a region in Span – Comunitat Valenciana [22] showed a declining trend after adopting new road safety measures. Bandi, Silver, Mijanovich, and Macinko [37] explored the temporal trend in motor vehicle fatalities in the United States for 42 years for different age groups and genders and concluded that the declining trend followed the entry into force of policies targeting risky behaviors related to motor vehicles. Other studies have also successfully used Joinpoint regression analysis to evaluate policies aimed at increasing traffic safety and reducing mortality based on an assessment of the changing trend in the number of deaths after their adoption [38,39].

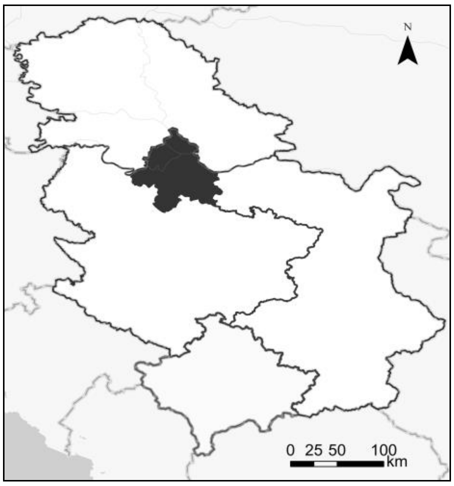
In Serbia, most previous studies on TAM were primarily focused on analyzing the gender and age structure of deaths in traffic accidents, the causes of fatal traffic accidents, and the type of vehicle that participated in the accidents [40]. The factors that influenced the fatal outcome of traffic accidents [41] and changes in the number of deaths in traffic accidents based on demographic characteristics [42] were also investigated. Simić et al. [43] have studied the impact of an economic crisis and transition on the health status of the population of Serbia based on mortality rates of various diseases, encompassing TAM. A group of authors [17] examined road traffic fatalities in Serbia from 1999 to 2014 using Joinpoint regression analysis, and they concluded that the number of fatal injuries significantly decreased, starting in 2008 when a strong media campaign was implemented and in 2009 when the new Law of the Traffic Safety in Serbia entered into force.

The evaluation of the studies to date showed that spatial, temporal, and spatiotemporal analyses are useful for detecting TAM patterns and areas where the population is most endangered. The literature examining this issue in Serbia and in its immediate surroundings is very limited. Traffic accidents and their fatal outcomes are differently distributed in space and time, depending on many factors. Therefore, it is necessary to identify their spatiotemporal patterns, especially there areas where the number of deaths increases over time. The use of open data and spatial analysis makes it possible to identify areas where the concentration of TAM is increased in space and time, creating a base for more detailed research with a focus on dangerous locations.

3. METHODS AND DATA

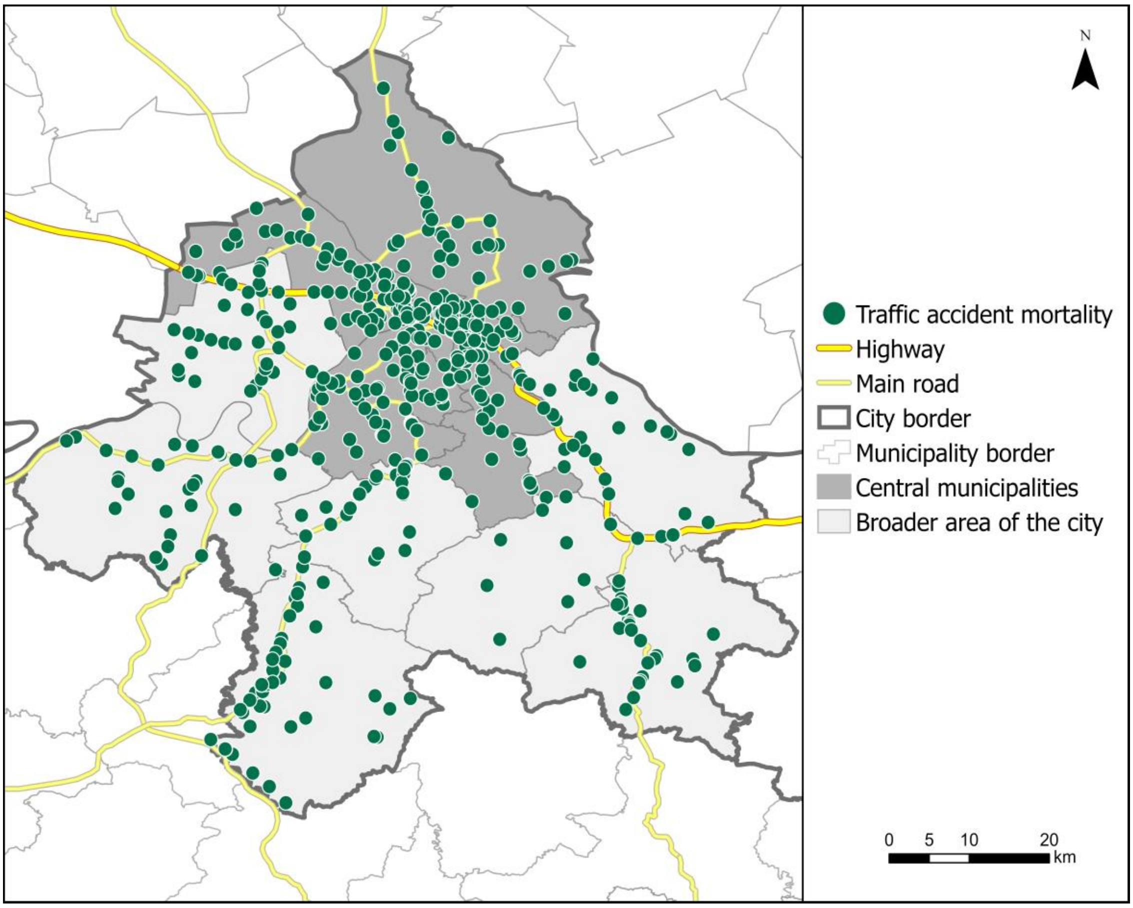
3.1. Study area

Belgrade is the capital of Serbia and its most populous city, with a population of 1,692,768 (523.4 inhabitants/km^2) and an area of 3,234 km^2 [44,45] (Figure 1a). It is a separate territorial unit and is administratively divided into 17 municipalities (Figure 1b). Ten municipalities, with 78.8% of the population (1,333,486), belong to the central urban city core. Central Belgrade municipalities are Čukarica, Novi Beograd, Palilula, Rakovica, Savski Venac, Stari Grad, Voždovac, Vračar, Zemun, and Zvezdara. In comparison, seven municipalities (Barajevo, Grocka, Lazarevac, Mladenovac, Obrenovac, Sopot, and Surčin) make up the broader territory of the city. All these municipalities belong to the Belgrade Police Administration. International Corridor 10 (highway) passes through the territory of Belgrade and is also a crossroads of important state roads (Figure 1c).



(**a**)

(**b**)



(**c**)

Figure 1. Study area (**a**) Position of the City of Belgrade in Serbia, (**b**) Municipalities of the City of Belgrade, (**c**) Location of traffic accidents with a fatal outcome for the period 2016–2021.

Note. The data in Figure 1 are visualized based on data obtained from Data on traffic accidents by police administrations and municipalities [Data set], by Open Data portal, 2022 (https://data.gov.rs/sr/datasets/podatsi-o-saobratshajnim-nezgodama-po-politsijskim-upravama-i-opshtinama/). In the public domain.

Belgrade is the country's administrative, health, political, educational, and cultural center. Economically, it is the most developed part of the country [46], with a high proportion of the value of the national gross domestic product [47]. A significant circulation of the population characterizes Belgrade, which records a continuously positive internal migration balance in the 21st century [48]. Slightly more than 15,000 (15,366) traffic accidents were recorded in Belgrade in 2021 (44.2%) out of a total of 34,751 in Serbia [49], Figure 1c. According to RTSA data [50], the Police Administration of Belgrade belongs to the group of administrations with a very high percentage of drivers in traffic under the influence of alcohol in the settlement in 2020 (1.3%).

3.2. Data

Data on TAM (incidents) for the Police Administration of Belgrade were obtained from the Open Data portal of the Republic of Serbia [49]. Accumulated data on traffic accidents by police administrations and municipalities from 2016 to 2021 were used (Figure 1c). The data contain a unique accident ID number, information on the police administration, municipality, and geolocation (X and Y coordinates). TAM data are also time-determined (date and time). Each recorded traffic accident was attributed to the type of traffic accident (with material damage, with the injured, and with the dead), the description of participants, and a detailed description of the traffic accident.

3.3. Methodology

After the introductory analysis of the quantification of traffic accidents, the temporal dynamics of TAM were analyzed over hours, days, months, and years within the studied period. We utilised a Joinpoint regression analysis, a widely used method for the study of temporal dynamics, to determine a certain moment, specifically a month during the year (from 2016 to 2021), when a statistically significant change in TAM in Belgrade occurs. The study is conducted in Joinpoint Trend Analysis Software, Version 4.9.0.0 [51]. A positive slope value indicates increasing while a negative slope indicates decreasing trend. A statistically significant change in trend is denoted with joinpoint, and the numerical expression of the change is determined using the Monthly Percentage Change (MPC) since monthly data were used [52].

This paper adopted Optimized hotspot analysis to assess whether mortality due to traffic accidents on the territory of Belgrade is clustered or randomly distributed in space. This analysis is suitable for incidence point data. They are aggregated into polygons using the Collect events option. Optimized hotspot analysis executes Hotspot analysis based on Getis-Ord Gi* statistic [53]. The formula can be written as follows:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \bar{X} \sum_{j=1}^{n} w_{i,j}}{S \sqrt{\frac{\left[n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j} \right)^2 \right]}{n-1}}} z \tag{1}$$

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n} \tag{2}$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - \bar{X}^2} \tag{3}$$

where: x_j denotes the value of $\bar{X}$ at location j, $w_{i,j}$ is the weight between i and j, and n is the total number of TAM [54].

This analysis enables the identification of statistically significant clusters of high and low values of TAM in space. The outputs of the analysis are *Z*-score (standard deviation) and *p*-value (probability), which indicate spatial dependence. High values of *Z*-score and low *p*-value indicate a statistically significant hotspot (clustering of high values). The higher value of the positive *Z*-score, the more intense hotspot. Low negative values of *Z*-score and low *p*-value suggest coldspot (clustering of the low values). The lower value of the negative *Z*-score specifies a more intense coldspot. Three confidence levels (90%, 95%, and 99%) are possible. For values of *Z*-score near zero, no spatial clustering is detected (not significant).

The next step involved the utilization of space-time mining pattern analytics, including the space-time cube model and emerging hotspot analysis. Hotspot analysis enables the study of spatial patterns of TAM but not their temporal evolution in space. Incorporating the time dimension in spatial analysis provides insight into spatiotemporal patterns, i.e., how incident patterns of TAM in Belgrade change in space from 2016 to 2021. A space-time cube is a powerful form of three-dimensional (3D) modeling that generates spatiotemporal data in a cube. The cube consists of bins whose spatial dimension is defined by the x- and y-axis, while the z-axis determines time. Bin's position in space (x and y) and time (z) is fixed [55, 56]. Horizontal bins make time slices (the rows that share a temporal extent), while vertical makes time series (columns with the same spatial extent).

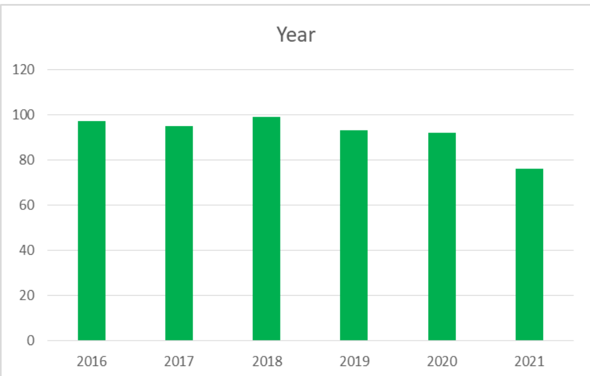
Since the data are represented with points and time-stamped for this study, we used the tool space-time cube by aggregating points. Based on their spatial and temporal determinants, the incidents are structured in bins, and summary Field statistics are calculated. In contrast, the trend for bin values over time at a given location is measured with the Mann-Kendall statistic [57]. The results are saved in a net CDF format compatible with various programs.

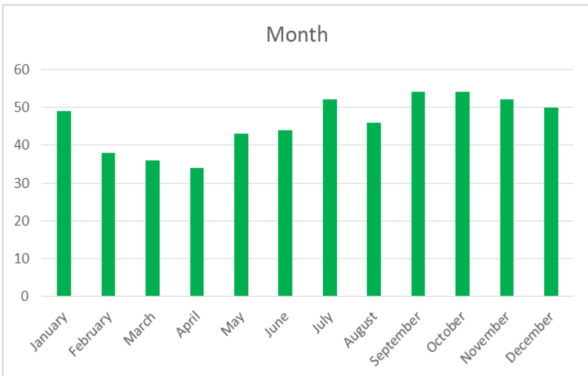
The results of space-time cube analysis are visualized using the 2D tool emerging hotspot analysis due to the simple presentation of the results, allowing an accurate interpretation. This analysis allows observing the temporal trends of hot and coldspots. It is also based on Getis-Ord Gi* statistic, which in this case, is calculated for each bean. The output categorizes the location of interest in one of 17 categories that describe the nature of hot-and coldspots [58]. All spatial analyses were conducted in Version 2.5 of ArcGIS Pro [59].

4. RESULTS

4.1. Temporal trend of TAM

In the past six years, from 2016 to 2021, 552 people died in traffic accidents in Belgrade. The highest number of deaths (99) was recorded in 2018, and the lowest was in 2021 (76). A deeper analysis of the time dynamics of TAM shows that the largest population died on average in September and October (56). When the hours during the day are analyzed, the highest number of deaths is recorded at 4 pm (37) when traffic frequency is increased due to employees returning from work. Observed by days of the week, the highest number of deaths occurred on Friday and Saturday (Figure 2).





(a) **(b)**

(c) **(d)**

Figure 2. Temporal distribution of TAM in Belgrade (2016–2021) by (**a**) years, (**b**) months, (**c**) days, and (**d**) hours. *Note.* Data in the graph are calculated based on Traffic accidents by police administrations and municipalities [Data set], by Open Data portal, 2022 (https://data.gov.rs/sr/datasets/podatsi-o-saobratshajnim-nezgodama-po-politsijskim-upravama-i-opshtinama/). In the public domain.

The results of the Joinpoint regression analysis provided insight into the TAM trends and their statistically significant changes over the months for each of the six analyzed years. One joinpoint, i.e., the month during the year when a statistically significant difference in the number of deaths in traffic accidents was indicated, is detected for each year (Figure 3).

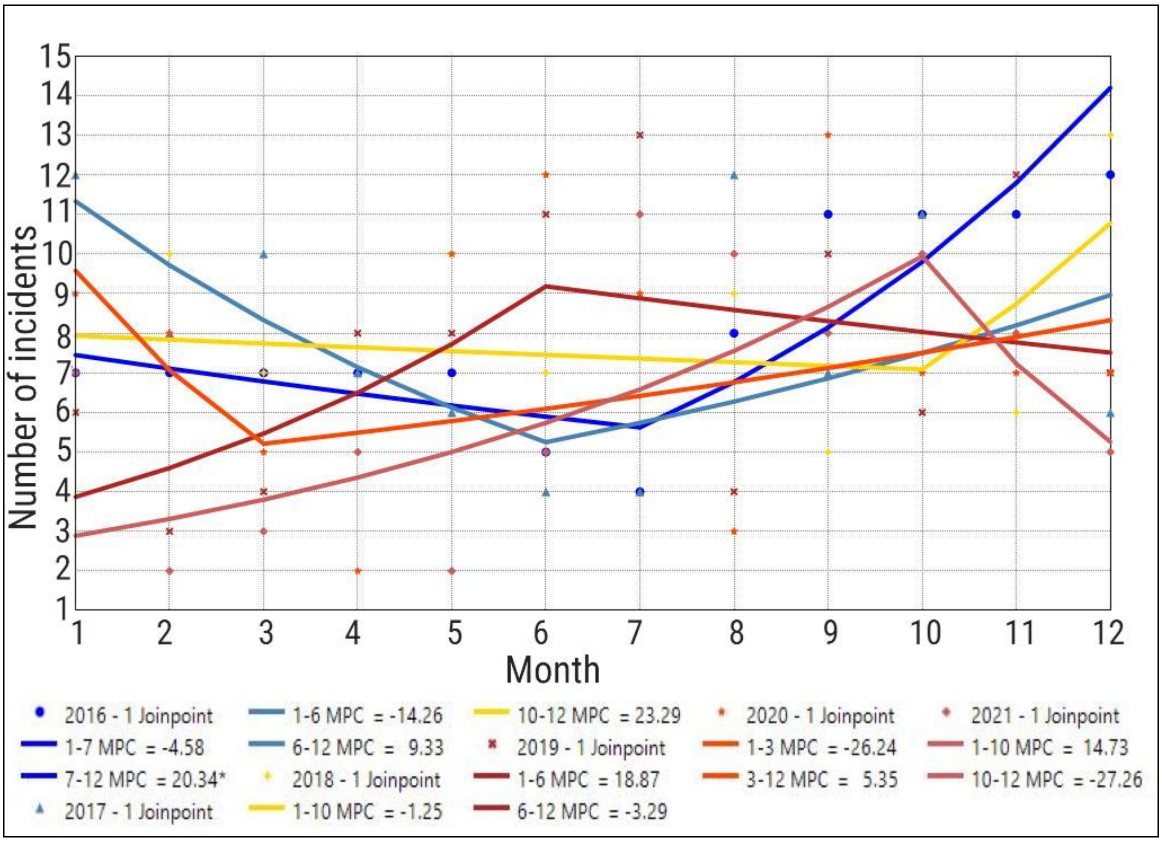


Figure 3. Joinpoint regression analysis of TAM in Belgrade by months, 2016–2021.
Note. Data in the graph are calculated based on Data on traffic accidents by police administrations and municipalities [Data set], by Open Data portal, 2022 (https://data.gov.rs/sr/datasets/podatsi-o-saobratshajnim-nezgodama-po-politsijskim-upravama-i-opshtinama/). In the public domain.

The nature of annual trends is different from the monthly trend when statistically significant change occurs. Thus, in 2016, 2017, 2018, and 2020, decreasing and then increasing trends in TAM were recorded. The months that indicate statistically significant changes marked as turning points are July, June, October, and March, respectively. The two years when the increasing and then decreasing trend was recorded were 2019 and 2021. The monthly percentage change, decreasing or increasing, differs in all analyzed years. The most significant increase was recorded in 2018, when the MPC was 23.29. Specifically, in two months (from October, when there was a statistically significant change, to December), TAM increased by slightly less than 25%. The highest decreasing rate was recorded in 2021 and amounted to –27.26. Mortality due to traffic accidents in the two months (from October to December) was reduced by slightly less than 30%.

4.2. Spatial and spatiotemporal analysis

The result of the optimized hotspot analysis of TAM is displayed in Figure 4. Only hotspots (shades of red), indicating an increased frequency of deaths at given locations, were detected. A strong statistically significant cluster of incidents hotspots with a confidence level of 99% (the darkest shade of red) covers the territories of all seven central Belgrade municipalities. It completely covers the territories of the municipalities of Stari Grad, Savski Venac, and Vračar. As for the other municipalities, the cluster covers peripheral parts towards these three municipalities. Only one hotspot was detected on the border between the central city municipality of Zemun and the municipality of Surčin, which belongs to the broader area of the city. Coldspots that point to locations with a low frequency of deaths were not detected. Statistical grouping of TAM was not detected in the municipalities belonging to the broader area of the city.

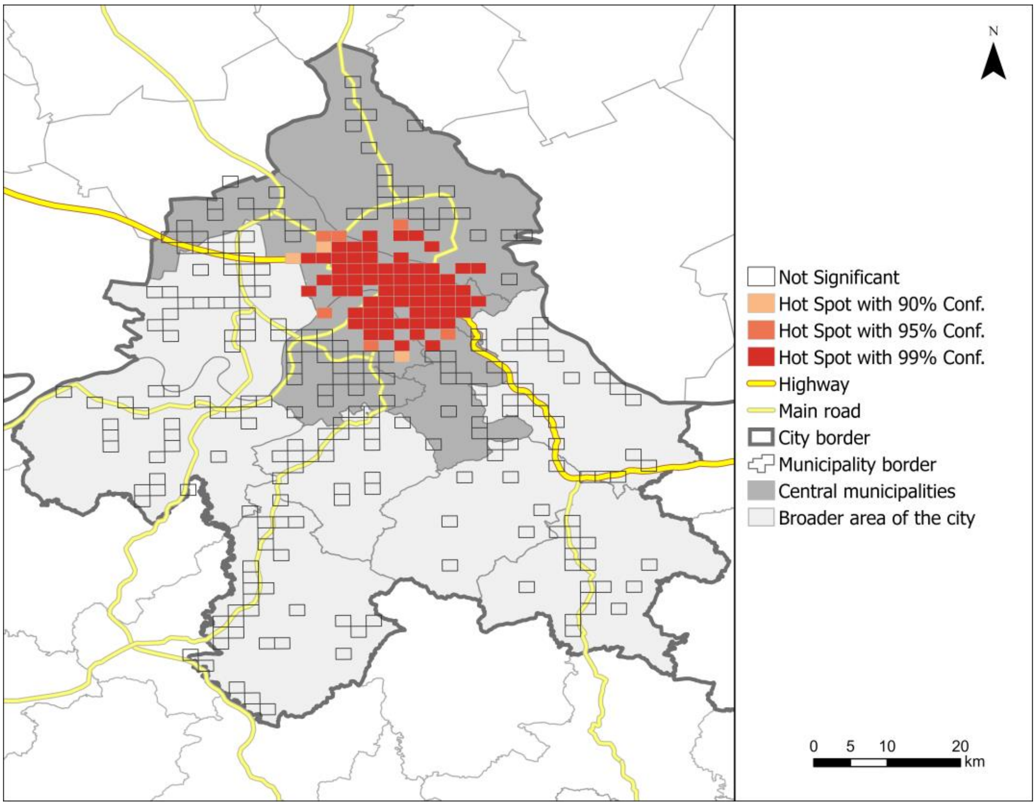
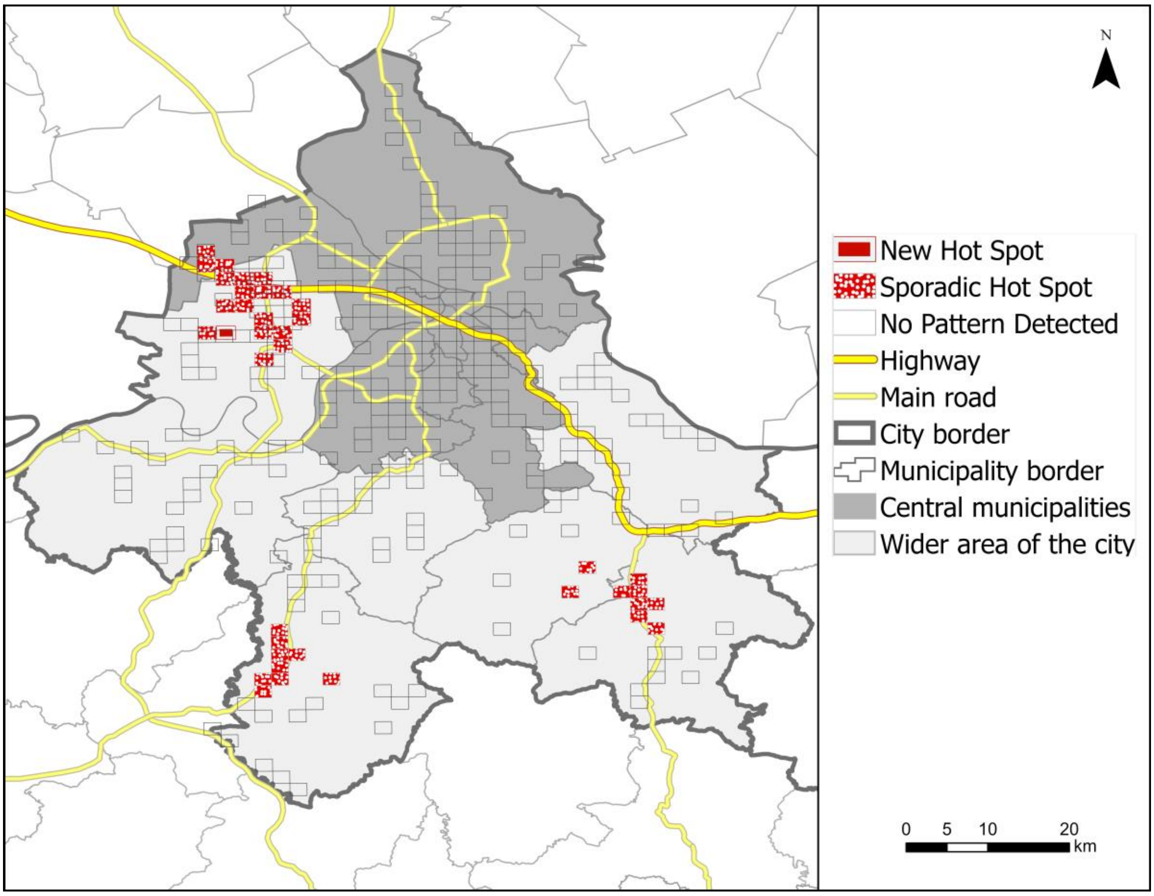
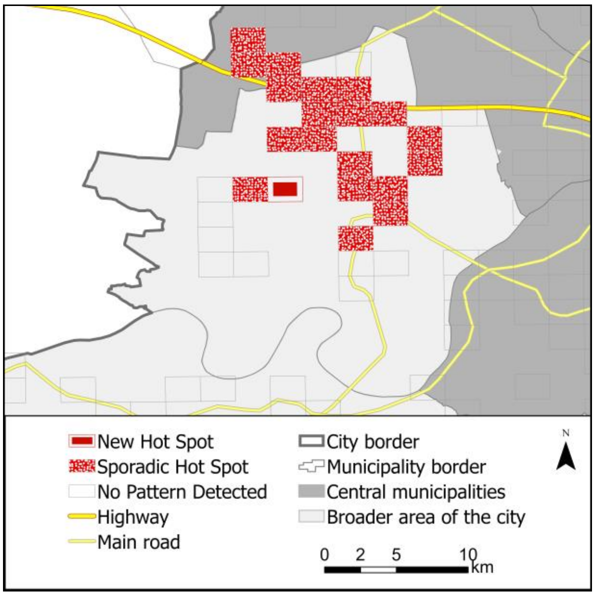


Figure 4. Optimized hotspot analysis of TAM.

Emerging hotspot analysis results indicated two (out of 17) types of hotspots of TAM—Sporadic hotspots and New hotspot, at the different locations (Figure 5a). A significantly higher number of sporadic hotspots, indicating locations marked as hotspots in most cases over time but never as coldspots, can be noticed. Sporadic hotspots have been identified in the municipalities of Surčin, along the international highway and main roads, and in the border part of the municipality of Zemun (central municipality) with the municipality of Surčin, also near the highway (Figure 5b). In the municipalities of Lazarevac (Figure 5c) and Mladenovac (Figure 5d), sporadic hotspots have been identified along the main roads. In contrast, in the municipality of Sopot (Figure 5d), two locations near local roads have been identified as sporadic hotspots. The results of the analysis indicated only one New hotspot (a location marked as a statistically significant hotspot at the end of the studied period, while in the earlier time step, it was not). It was detected in the central part of the municipality of Surčin (Figure 5b).



(a)



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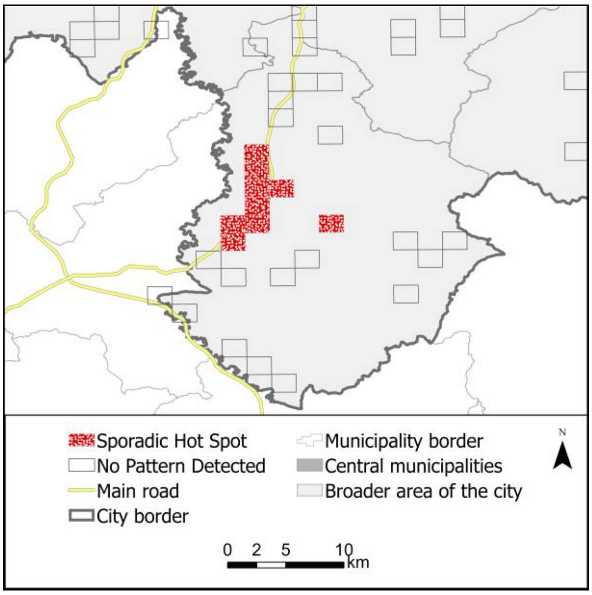

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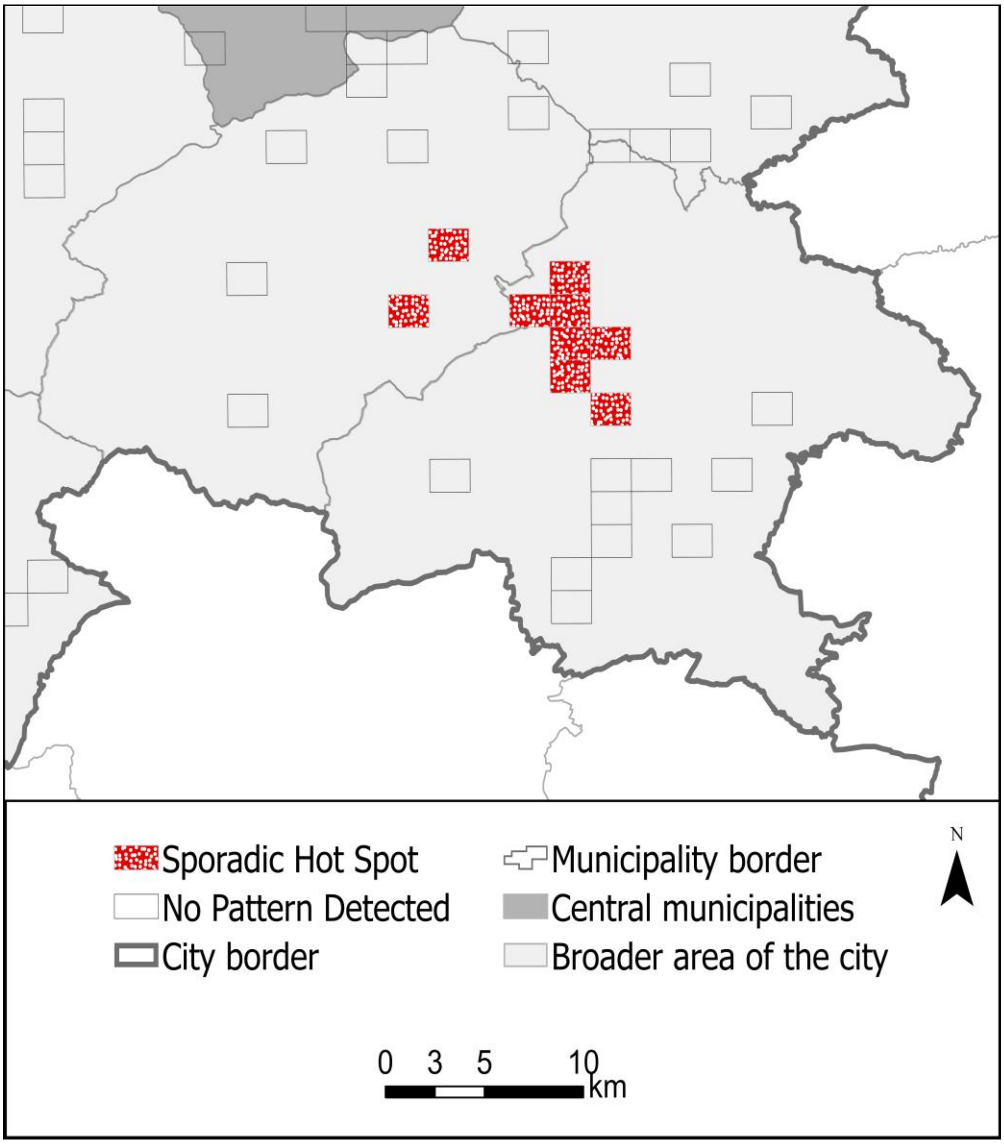

(d)

Figure 5. Space-time cube analysis of TAM for the period 2016–2021, **(a)** The City of Belgrade, **(b)** The municipalities of Surčin and Zemun, **(c)** The municipality of Lazarevac, and **(d)** The municipalities of Sopot and Mladenovac.

5. DISSCUSSION

This study provides a comprehensive assessment of the temporal, spatial, and spatiotemporal variability of TAM in Belgrade, from 2016 to 2021. The variation of the temporal trend by months is achieved through the use of Joinpoint regression analysis, identification of statistically significant hotspots using optimized hotspot analysis, and space-time cube and emerging hotspot analysis are adopted to assess whether hot- and coldspots vary in space over time.

Our findings highlight that the number of deaths during each of the analyzed years differs, as well as during the hours of the day, the day of the week, and the months of the year. Joinpoint regression analysis revealed a statistically significant change in the trend in the number of TAM during the months of the year. In addition, no unique trend was observed for each analyzed year – during the four analyzed years (2016, 2017, 2018, and 2020), the decreasing trend was replaced by an increasing trend. In 2019 and 2021, the opposite change was recorded; the decreasing trend replaced the increasing trend.

The study has also found that a statistically significant spatial concentration of TAM was evident in the study period. A similar study [25] found that deaths caused by driving accidents are spatially grouped in the space, i.e., the distribution of high-risk points is statistically significant. A statistically significant cluster of hotspots of TAM can be found in the central municipalities of Belgrade. The cluster completely covers the territories of the municipalities of Savski Venac, Stari Grad, and Vračar (Figures 1B and Figure 4). These municipalities are characterized by the continuity of built-up urban areas [60], the highest values of in-migration and out-migrations in recent years [48], and according to current data, a high share of daily migrants among employees is presented [61]. According to the same author, the share of daily migrants in the municipality of Vračar was 80.8%, in the municipality of Stari Grad 88.6%, and the municipality of Savski Venac 92.2%, in 2011. The city core is the place that records the highest concentration of tourist attractions [62]. Besides, the central part of Belgrade is the place with the highest concentration of population and activities [63] and entertainment events [60]. Filipović et al. [64] state that Belgrade is the central part of Serbia's most important daily urban system. These conditions initiate a high daily frequency of people, contributing to the formation of a statistically significant cluster of hotspots on the territory of central Belgrade municipalities. At the same time, optimized hotspot analysis did not indicate any coldspots. Another study analyzing traffic fatalities in Dhaka using spatial analysis also revealed a concentration of hotspots in the core of the city [65].

Finally, the utilization of space-time cube and emerging hotspot analysis pointed to specific temporal variability in the spatial grouping of TAM in the period from 2016 to 2021, which could not be detected by optimized hotspot analysis. By incorporating the temporal dimension, spatiotemporal patterns were obtained. This study has revealed that an increase in the number of deaths over time is evident in municipalities (Lazarevac, Mladenovac, Sopot, and Surčin) belonging to the broader area of Belgrade. Based on the report of the RTSA on the values of public weighted risk of road deaths for 2020 (data on the number of mildly and severely injured and killed were used), the municipality of Sopot is characterized by low [66], the municipality of Mladenovac by medium [67], the municipality of Lazarevac by high [68], and the municipality of Surčin by a very high value of risk [69]. According to the same sources, the municipalities of Mladenovac and Surčin recorded an increase in risk in 2020 compared to the previous year, while the municipalities of Lazarevac and Sopot recorded a decrease. Part of State Road 22, known as Ibarska magistrala, passes through the municipality of Lazarevac. Most of this road is highly risky for road users, and several "black spots" have been identified [70]. A decrease in risk in 2020 can be linked to redirecting part of the traffic to the A2 (Miloš the Great) motorway. This motorway was opened for traffic in 2019, has separate traffic lanes in opposite directions, and enables bypassing the dangerous part of the Ibarska magistrala through the municipality of Lazarevac.

Another spatial characteristic of these hotspots is their concentration along the highway and main roads (Figure 5). This finding is somehow similar to previous studies. Thus, a study conducted by Cheng et al. [35], with the main goal of sustainable development, points out that hotspots are concentrated along main roads and urban road intersections. Analyzing the TAM of motorcyclists Saadat et al. [25] concluded that the highest number of TAM was recorded on the highways. Namely, the part of the International European route, international highway E75 (Corridor 10), passes through the municipality of Surčin. The high frequency of traffic, especially on weekends and holidays, causes an increasing number of traffic accidents, some of which are fatal. The construction of the Belgrade Bypass, which is underway, will enable bypassing of the central Belgrade municipalities and a part of the Surčin municipality. By redirecting traffic, multiple benefits are expected, such as a reduction in noise levels, emissions of toxic gases, traffic frequency, and traffic accidents on the core network of urban roads [71].

Distinct spatial differentiation of hotspots obtained utilizing a geospatial approach indicates spatial disparities of TAM between the urban city core (central municipalities) and the peripheral part of Belgrade (broader city area). Different characteristics of the space, such as land cover, the category of roads, population density, and the different frequencies of the population condition. Accordingly, it is necessary to establish territorial-specific prevention programs to reduce the number of deaths in critical locations. Some measures, like installing cameras and traffic signals and increased control, have already been in force in certain areas with high traffic accidents. Education of younger children also produces significant results [72]. Considering that these measures have given satisfactory results, they can be applied in high-risk areas identified in this study.

6. CONCLUSION

This study is conducted to fill the knowledge gap concerning TAM's temporal, spatial, and spatiotemporal patterns using the potential of Joinpoint regression analysis and geospatial approach to identify the areas with the highest number of deaths to reduce the number of deaths in traffic accidents and bring them closer to achieving the Target 3.6. Furthermore, a review of the existing literature and obtaining the results of this research showed that implementing prevention measures positively reduces the number of deaths in traffic accidents. In that sense, the results of this study can be a starting point for identifying areas in Belgrade where the adoption of targeted measures to prevent future accidents with fatal outcomes is necessary. Hence, this study represents a significant contribution to the sustainable development of Belgrade and Serbia.

The methodological apparatus used in this study can be applied to other police administrations in Serbia, given the availability of data, but also in other countries where data on traffic accidents and their outcomes are also spatially and temporally determined. The special significance of applying these methods is that they provide insight into the spatiotemporal distribution of the investigated phenomenon at the local level. The obtained results and the conclusions have a practical application because they unequivocally indicate points of interest, i.e., potentially dangerous areas to the population. At the same time, these areas require special targeted policies to reduce TAM in the future.

The limitation of this study is the availability of the data. Namely, due to the incomplete coverage of data from 2015, as the starting year in time-series data, this study adopted 2016. The data available from an earlier period would allow authors to focus further research on a much more extended period.

In addition, it is necessary to analyze the variability concerning different road users, such as pedestrians and motorcyclists, to indicate potentially dangerous areas for each of the studied categories, but also variability among different age groups and genders. Using additional data sources (e.g., digital elevation method) and analysis, such as Viewshed analysis, will contribute to obtaining more complete conclusions to improve traffic safety for the population. Since the portal contains data for all municipalities and police administrations, future research will focus on detecting vulnerable areas in other parts of Serbia.

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