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Danijel Ivajnšič, David Pintarič, Veno Jaša Grujić, Igor Žiberna

DANIJEL IVAJNŠIČ

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Danijel Ivajnšič[1], David Pintarič[2], Veno Jaša Grujić[3], Igor Žiberna[4]

A spatial decision support system for traffic accident prevention in different weather conditions

ABSTRACT: Natural conditions play an important role as determinants and cocreators of the spatiotemporal road traffic accident Hot Spot footprint; however, none of the modern commercial, or open-source, navigation systems currently provides it for the driver. Our findings, based on a spatiotemporal database recording 11 years of traffic accidents in Slovenia, proved that different weather conditions yield distinct spatial patterns of dangerous road segments. All potentially dangerous road segments were identified and incorporated into a mobile spatial decision support system (SLOCrashInfo), which raises awareness among drivers who are entering or leaving the predefined danger zones on the street network. It is expected that such systems could potentially increase road traffic safety in the future.

KEY WORDS: GIS, mobile application, spatial databases, spatial patterns, traffic safety

Prostorski sistem za podporo odločanju pri preprečevanje prometnih nesreč v različnih vremenskih razmerah

POVZETEK: Vremenske razmere so pomemben dejavnik in soustvarjalec prostorsko-časovnih vzorcev prometnih nesreč. Kljub veliki uporabni vrednosti podatki o prostorskem odtisu prometnih nesreč niso del programske podpore voznikov v sodobnih komercialnih ali odprtokodnih navigacijskih sistemih. Na podlagi baze 11-letnih podatkov o prometnih nesrečah v Sloveniji smo ugotovili, da različne vremenske razmere oblikujejo različne prostorske vzorce nevarnih cestnih odsekov. Potencialno nevarne cestne odseke smo vključili v mobilni prostorski sistem za podporo odločanju (SLOCrashInfo), ki voznike opozori, ko vstopajo ali zapuščajo nevarna območja cestnega omrežja. Pričakujemo, da se bo s tem sistemom povečala varnost v cestnem prometu.

KLJUČNE BESEDE: GIS, mobilna aplikacija, prostorske podatkovne baze, prostorski vzorci, prometna varnost

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[1] University of Maribor, Faculty of natural sciences and mathematics, Maribor, Slovenia; University of Maribor, Faculty of arts, Maribor, Slovenia
dani.ivajnsic@um.si (https://orcid.org/0000-0003-4419-5295)

[2] david.pintaric@gmail.com (https://orcid.org/0000-0002-6021-9851)

[3] University of Maribor, Faculty of natural sciences and mathematics, Maribor, Slovenia; University of Maribor, Faculty of education, Maribor, Slovenia
veno.grujic@um.si

[4] University of Maribor, Faculty of arts, Maribor, Slovenia
igor.ziberna@um.si

1 Introduction

Road transport remains one of the most important human activities. One of the essential components of road transport efficiency is its safety. The latter is the result of the triangle formed by entities like road infrastructure, vehicles and users (Yannis and Karlaftis 2010; Perrels et al. 2015). The interaction between them is especially pronounced by considering the driver's age (Etehad et al. 2015). Physiological (vision, reaction time) and cognitive functions decline with increasing age, thus 40% of fatal road traffic injuries in the European Union are caused by elderly people (65+ years) (Nagata, Uno and Perry 2010; Etehad et al. 2015). The European Commission reported that by 2030 a quarter of all drivers will be aged 65 and above (Internet 1). However, the social, psychological and financial damage caused by road accidents worldwide is still enormous. Road traffic crashes cost most countries 3% of their gross domestic product (Global status report … 2018). Every year the lives of approximately 1.35 million people are cut short as a result of road traffic crashes. Between 20 and 50 million more people suffer non-fatal injuries, with many incurring a disability as a result of their injury, and road traffic injuries are the leading cause of death among children and young adults aged 5–29 years (Global status report … 2018). These numbers are calling time-efficient and cost-effective applicative actions, in conjunction with recent advances in spatial analysis and GIS technology, to identify road traffic accident Hot Spots and increase traffic safety (El-Said et al. 2019). In that regard, the following risk factors should be considered: speeding, inadequate safety distance, driving under the influence of alcohol and other psychoactive substances, nonuse of motorcycle helmets, seat-belts and child restraints, distracted driving (mobile phones, smoking while driving etc.), unsafe road infrastructure, unsafe vehicles, inadequate post-crash care and inadequate law enforcement of traffic laws (Global status report … 2018). In addition, natural conditions, manifested mainly in the geometrical structure of the road and various weather conditions, play an important role as determinants and co-create the spatiotemporal footprint of road accidents. However, Bergel-Hayat et al. (2013) outlined that weather conditions can be considered as a significant driver of traffic accidents, whether on motorways, or on urban or rural road systems. Moreover, the frequency of traffic accidents simultaneously depends on mobility, on which the weather can have either a positive or a negative impact. Fridström et al. (1995) and Hermans, Wets and Van Den Bossche (2006) concluded that weather conditions can explain 5% of the variability in frequency of traffic accidents at the monthly level. Brodsky and Hakkert (1988) have proven that the weather type dominated by rain is the main meteorological explanatory factor for a higher car accident risk. However, rain can have the opposite effect on the frequency of traffic accidents, as well. Yannis and Karlaftis (2010) discovered that, in some places, the number of road accidents decreased during rainy weather, which can be explained by preventive behavior of the drivers, which at the same time reduces exposure to accidents on road networks. Some studies dealing with temporal variability in the effects of precipitation on traffic accidents point out that the influence of rain on the abundance of road accidents is less if it rained the day before (Eisenberg 2004). This positive anomaly is the result of increased care among drivers who adjust to the given situation. Brijs, Karlis and Wets (2008), who proved the connection between the length of drought periods and an increase in road accidents occurring at the reappearance of rain, further confirmed this theory. These facts lead to the conclusion that surveys investigating the impact of weather conditions on the number and spatiotemporal pattern of road accidents are very important for the preparation of appropriate mitigation measures and strategic planning to increase traffic safety.

Understanding the causes, position and time dynamics of road accidents is thus crucial for realizing this goal (Xie and Yan 2008). However, the spatiotemporal pattern of traffic accidents is rarely random. Most often traffic accidents form significant concentrations along a road network, called Hot Spots, Black Spots or Death Spots (Aguero-Valverde and Jovanis 2006). These dangerous sections of the road system usually form because of typical traffic load (Black 1991). Of course, other factors that shape the spatial distribution of these negative events are also important: natural and environmental determinants (steep slopes, sharp turns), weather (rain, snow, wind, fog and black ice), the configuration of the transport network with the number of entry and exit points, defective design and maintenance of roads and motorways, etc. (Xie and Jun 2008). The spatial data analysis known as Point Pattern Analysis has frequently been used by spatial statistics that have developed various methodological approaches to identify hot spots based on point events (Bailey and Gatrell 1995; O'Sullivan and Unwin 2002; Xie and Yan 2008). Often, the kernel density estimation method, now based on road complexity (Okabe, Satoh and Sugihara 2009), is at the forefront and can be traced in numerous studies considering road accident analysis (Anderson 2009), risk analyses for cyclists based on traffic density (Delmelle and Thill 2008), the detection of critical areas for pedestrians (Pulugurtha, Krishnakumar and Nambisan 2007), the analysis of animal collisions (Krisp and Durot 2007; Colino-Rabanal and Peris 2016), or in the analysis of hot spots on the motorway network (Erdogan et al. 2008).

However, there is no doubt that road accident Hot Spots are important spatial information with considerable applicative value (Savas Durduran 2010), but none of the modern commercial or open-source navigation systems provides this for the user or customer. From that perspective, we aimed to reveal the weather-related spatial pattern of the road accidents in Slovenia. In addition to our findings, a mobile application was developed that warns drivers when they enter and leave sections of road that have been identified as significant road accident Hot Spots under various weather conditions. Thus, the following research issues were addressed: (1) which municipalities in Slovenia are most exposed to road traffic accidents and are thus suitable for preventive action implementation; (2) which are the specific characteristics of road traffic accidents in the selected municipalities (study areas); (3) whether the spatial Hot Spot pattern in the study areas differ in different weather situations; and finally, (4) whether those results can be applied in the form of a mobile spatial decision support system that raises driver awareness when entering or leaving predefined danger zones along the street network.

2 Methodes

2.1 Databases

In order to secure the road network vector data, the national public infrastructure database (GJI) was obtained from the web platform of The Surveying and Mapping Authority of the Republic of Slovenia (Internet 2), which operates under the Ministry of the Environment and Spatial Planning. In the next step, the traffic accident data were downloaded from the Slovenian Police website (Internet 3) owned by the Ministry of the Interior. These data were collected by the Police at each reported traffic accident along the existing street network in Slovenia and can be downloaded for 1995 onwards in CSV format. We transformed this database (considering the time window 2006–2017) into a geospatial format in order to identify potential significant road accident Hot Spots along road network segments in the study areas in different weather conditions. All the required information (GPS location, traffic accident type and weather conditions at the events etc.) were provided in the CSV file. To calibrate the potentially identified significant road accident Hot Spots, a third database was obtained. Here, the national OPSI [Slovenia Open Data] platform (Internet 4) was used to obtain traffic load data in the same time period (2006–2017). This is collected at predefined locations but can be interpolated by applying Spatial Analysis along Networks (SANET) tools (Okabe, Okunuki and Shoiode 2006).

2.2 Study area

By analyzing the 2006–2017 time interval of road traffic accidents and its geospatial pattern in Slovenia (Figure 1), we selected the four most prominent municipalities (according to road traffic accident frequency and traffic load data) for detailed analysis and mobile spatial decision support system (SDSS) development, owing to computation capacity limits. All four municipalities (Ljubljana [LJ], Maribor [MB], Celje [CE] and Koper [KP]) are located along the main Slovenian transport corridor axis (A1), which runs from NE to SW (Figure 2). Ljubljana, the capital city, lies right at the intersection with another Slovenian transport corridor running from NW to SE. Maribor, as the second largest urban area in Slovenia, and Celje stand out in road traffic accident frequency, as well. Koper is a special case, especially in the summer months owing to higher traffic load caused by tourism.

2.3 Structure and properties of road traffic accidents in the study areas

To understand the spatial footprint of road traffic accidents in the study areas, all information in the databases (number, time, traffic accident type [death, serious or minor injury or just material damage], road type [highway, high-speed road, primary road, secondary road, tertiary road, town street network, etc.])

and weather conditions (clear sky, cloudy sky, rain, snow, wind and fog) were analyzed. Collision types (rollover, frontal collision, lateral collision, chain collision, pedestrian collision, animal collision, collision with an object and collision with a standing or parked vehicle) were also analyzed. The SPSS statistical toolkit was used to generate the contingency tables and descriptive statistics parameters.

2.4 Road traffic accident spatial pattern analysis

In the next step, all road traffic accidents, along with the outcome death, major or minor injury or material damage between 2006 and 2017 in different weather conditions (sunny, cloudy, rainy, snowy, windy and foggy) in the study areas were combined to develop point input layers for identifying Hot Spots along road network segments based on the network kernel density estimation algorithm (Kernel type = Equal split continuous at nodes, Band width = 300 m) within the SANET tool (Okabe, Okunuki and Shoiode 2006) for ArcGIS. The second input comprised the network dataset built with the corrected (linked) national road vector layer. Additionally, weightings were applied by considering the traffic load data for each study area and weather conditions. These were initially interpolated across road networks in the study areas by applying the Interpolation algorithm within SANET (Interpolation Type = Inverse Distance Weighting, Band width = 300 m). Finally, to compare the identified Hot Spot pattern in each study area and weather conditions, the average Kernel density variable was transformed to raster format and compared with band collection statistics (Pearson's correlation coefficient) in ArcGIS. Thus, the similarity or dissimilarity in the road traffic accident Hot Spot pattern was evaluated.

2.5 SDSS (SLOCrashInfo) development

Identification of significant Hot Spots along road networks in different weather conditions is a highly applicative result. A spatial decision support system for Android mobile devices in the study areas was developed by using the Hot Spot database, Mapbox Maps SDK for Android, SpatiaLite database, GraphHopper Routing Engine, OpenWeatherMap API and Kotlin programming language (Figure 1). The app is also linked to

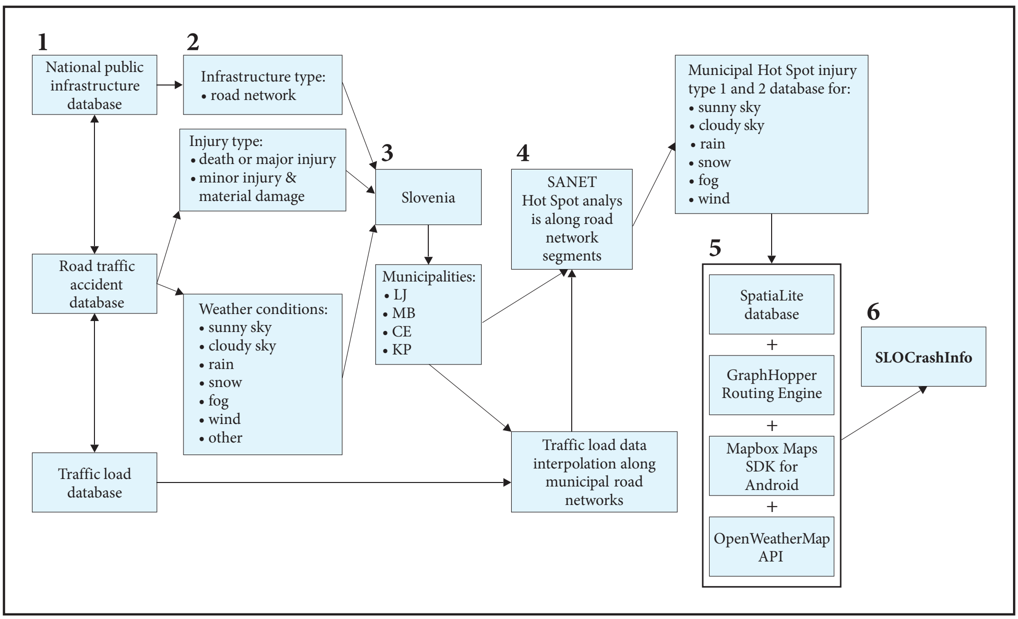


Figure 1: The schematic view of the SDSS development. 1= database integration phase, 2=database filtering phase, 3=spatial extent filtering phase, 4=spatial analysis phase, 5=programing phase and 6=SDSS applying phase.

the weather forecast (utilized OpenWeatherMap API) and thus adjusts the Hot Spot footprint provided for a given study area, depending on the actual weather situation. The SLOCrashInfo app can be downloaded at http://185.164.136.112:21201/slocrashinfo/slocrashinfo.apk.

However, to better visualize the SLOCrashInfo SDSS integrated results in this paper, a hexagon network (diameter = 500 m) was developed across all study areas with the Generate Patterns of Repeating Shapes tool in ArcGIS, since road segments identified as Hot Spots are linear structures, which are barely visible at the municipal level. However, this was done only to prepare Figures 2, 3, 4 and 5. The SDSS app operates with raw vector line data, where each critical road segment is clearly recognizable on the OpenStreetMap road network.

3 Results

3.1 Road traffic accident frequency and distribution in Slovenia

Between 2006 and 2017, 171,119 GPS-recorded road accidents occurred in Slovenia. In 45,493 (26.6%) of these situations, no injuries were recorded; 43,588 ended with major injuries (25.5%), 6202 with serious injuries (3.6%) and 1278 (0.7%) with a fatal outcome. Most accidents occurred on Fridays (17.1%) and Mondays (14.7%), with 25.5% of all traffic accidents occurring over the weekend. The highest share of traffic accidents was recorded in July and August (9.0% of all road accidents), followed by June (8.9%) and May (8.8%). During the day, traffic accidents were concentrated in the afternoon. More than a third (27.0%) of road accidents occurred on regional roads, 17.9% in settlements with a street network system and 17.2% in settlements without an existing street system. In 18.4% of road traffic accidents between 2006 and 2017, speed limits were exceeded; in 17.3%, an incorrect driving side or direction was the main cause of the accident, and in 16.8%, incorrect operation of the vehicle.

Adverse weather conditions were present by 13.8% of all road accidents: most frequent were road traffic accidents in rainy conditions (9.7%), followed by snow conditions (2.7%), fog (1.3%) and high wind situations (0 .1%). The road surface was dry in 70.0% of cases, wet in 22.0% and slippery in 2.8%.

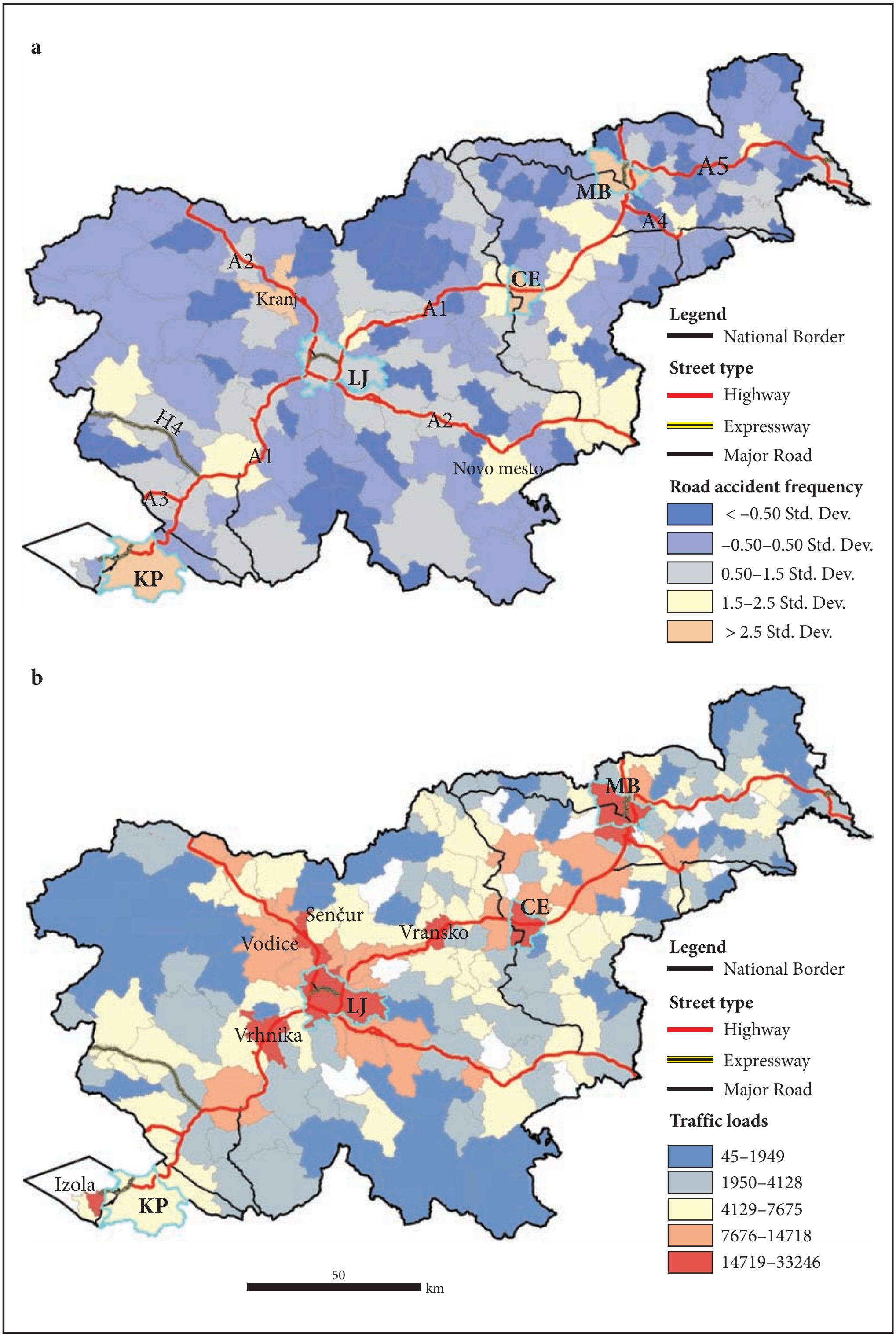
In the next part of the research, we focused on the four most prominent municipalities (LJ, MB, CE and KP), owing to computation capacity limits; the four were selected based on road traffic accident frequency and traffic load between 2006 and 2017 (Figure 2a, b). The spatial frequency pattern of road traffic accidents is correlated with traffic load, since Slovenia is a typical road transit country.

3.2 Road traffic accident characteristics in the study areas

Among the 29,071 traffic accidents that occurred in the four municipalities during the period 2006–2017, the most (13,843) occurred in LJ, followed by MB (7354), CE (4214) and KP (3660). In CE, 32.9% of recorded cases ended with minor and major injuries or with fatal consequences, 31.2% in MB, 26.4% in KP and – surprisingly – in a smaller proportion in LJ (23.3%), despite its having the highest frequency of traffic accidents. The weekly traffic accident regime did not differ significantly between the study areas: the highest proportion of road accidents occurred on Fridays (between 16.4% and 18.8%), but KP stands out, owing to its tourism orientation, by having a clearly higher traffic accident frequency on weekends (Saturday, Sunday). This fact can also be traced by breaking down the monthly regime of road traffic accidents in the study areas. In KP, more records of these unfortunate events were reported in July (11.1%) and August (10.9%) during the summer holidays and the tourist season. By considering the day interval, all study areas had a traffic accident frequency peak between 3pm and 4pm, thus indicating a classic daily employee migration cycle. The minimum (0.9%) was detected between 2am and 4am.

There were 11.4% weather-related traffic accidents in the study areas. The highest share belonged to CE (13.2%) and LJ (11.5%), while MB accounted for 10.9% and KP for only 9.7% (Table 1). Most of the traffic accidents occurred in rainy weather (2,594 or 8.9%), with CE standing out (9.7%). Among the weather situations under consideration, snow-related traffic accidents were frequent in LJ, MB and CE (478 or 1.6%).

Figure 2: Road traffic accident frequency (in SD categories) in Slovenian municipalities (a) and the corresponding average traffic loads (no data in white) between 2006 and 2017 (b). The selected study areas (the municipalities of Ljubljana [LJ], Maribor [MB], Celje [CE] and Koper [KP]) are outlined in turquoise. ➤


a
A5
MB
A4
A2
CE
Kranj
A1
LJ
H4
A2
A1
Novo mesto
A3
KP
Legend
National Border
Street type
Highway
Expressway
Major Road
Road accident frequency
< –0.50 Std. Dev.
–0.50–0.50 Std. Dev.
0.50–1.5 Std. Dev.
1.5–2.5 Std. Dev.
> 2.5 Std. Dev.
b
MB
CE
Senčur
Vransko
Vodice
LJ
Vrhnika
Izola
KP
Legend
National Border
Street type
Highway
Expressway
Major Road
Traffic loads
45–1949
1950–4128
4129–7675
7676–14718
14719–33246
50
km

Here, CE was again in front with 2.6%, while – understandably – this share was the lowest in KP (0.2%), which is characterized by a milder and windy sub-Mediterranean climate. However, if we normalize the absolute frequency of road traffic accidents in each municipality with the corresponding number of days of each weather situation between 2006 and 2017 (Table 1), we can conclude that snowy condonations yielded the highest risk for a traffic accident exactly in KP. Owing to low snow frequency, winter tires are not obligatory there, resulting in chaotic road traffic whenever snow does occur. Moreover, traffic accidents in extreme wind conditions were recorded only in KP (0.3%). Foggy weather conditions are common in LJ and CE, owing to their geographic position in the bottom of relief basins (the Ljubljana basin and the Celje basin); thus, 2% of all traffic accidents in fog happen in those two study areas.

3.3 Road traffic accident spatial patterns and the SLOCrashInfo SDSS

The road traffic accident spatio-temporal database that we developed revealed that these unwanted events appeared on different road segments of the street network in all study areas depending on the given weather situation (Table 2). Most of the identified danger zones or Hot Spots were in accordance with clear and cloudy atmospheric conditions. Clearly, other road traffic accident causes must be playing the major role here. However, the spatial Hot Spot footprint under clear and cloudy conditions is significantly different compared to other weather situations in all study areas and is thus still highly informative for the driver, regardless of its weather-independent origin. In LJ, the highway bypass ring, in particular the entrance and exit segments, is highly susceptible to traffic accidents in clear and cloudy conditions. Most of the deadly outcomes happened on these high-speed roads (Figure 3a, b). Dangerous road segments outside the highway

Table 1: Weather-related road traffic accident numerical summary in the study areas, additionally normalized with total number of days for each considered weather situation between 2006 and 2017.

Weather	Variable	CE	KP	LJ	MB	Total
Sunny sky	F	2402	2563	6930	3997	15892
	%	57	70	50	54	55
	$F_{normalized}$	7	2	16	7	32
	$\%_{normalized}$	76	61	76	70	73
Cloudy sky	F	1118	665	4546	2404	8733
	%	27	18	33	33	30
	$F_{normalized}$	1	1	3	2	7
	$\%_{normalized}$	12	18	15	19	15
Rain	F	407	326	1212	649	2594
	%	10	9	9	9	9
	$F_{normalized}$	0.3	0.2	1	0.4	2
	$\%_{normalized}$	4	7	3	4	4
Snow	F	110	7	235	126	478
	%	3	0.2	2	2	2
	$F_{normalized}$	1	0.4	1	1	3
	$\%_{normalized}$	7	12	5	6	6
Fog	F	40	10	150	30	230
	%	1	0.3	1	0	1
	$F_{normalized}$	0.1	0.1	0.2	0.1	0.4
	$\%_{normalized}$	1	2	1	1	1
Wind	F	0	12	0	0	12
	%	0	0.3	0	0	0
	$F_{normalized}$	0	0.01	0	0	0.01
	$\%_{normalized}$	0	0.2	0	0	0.02
Other	F	137	77	770	148	1132
	%	3	2	6	2	4

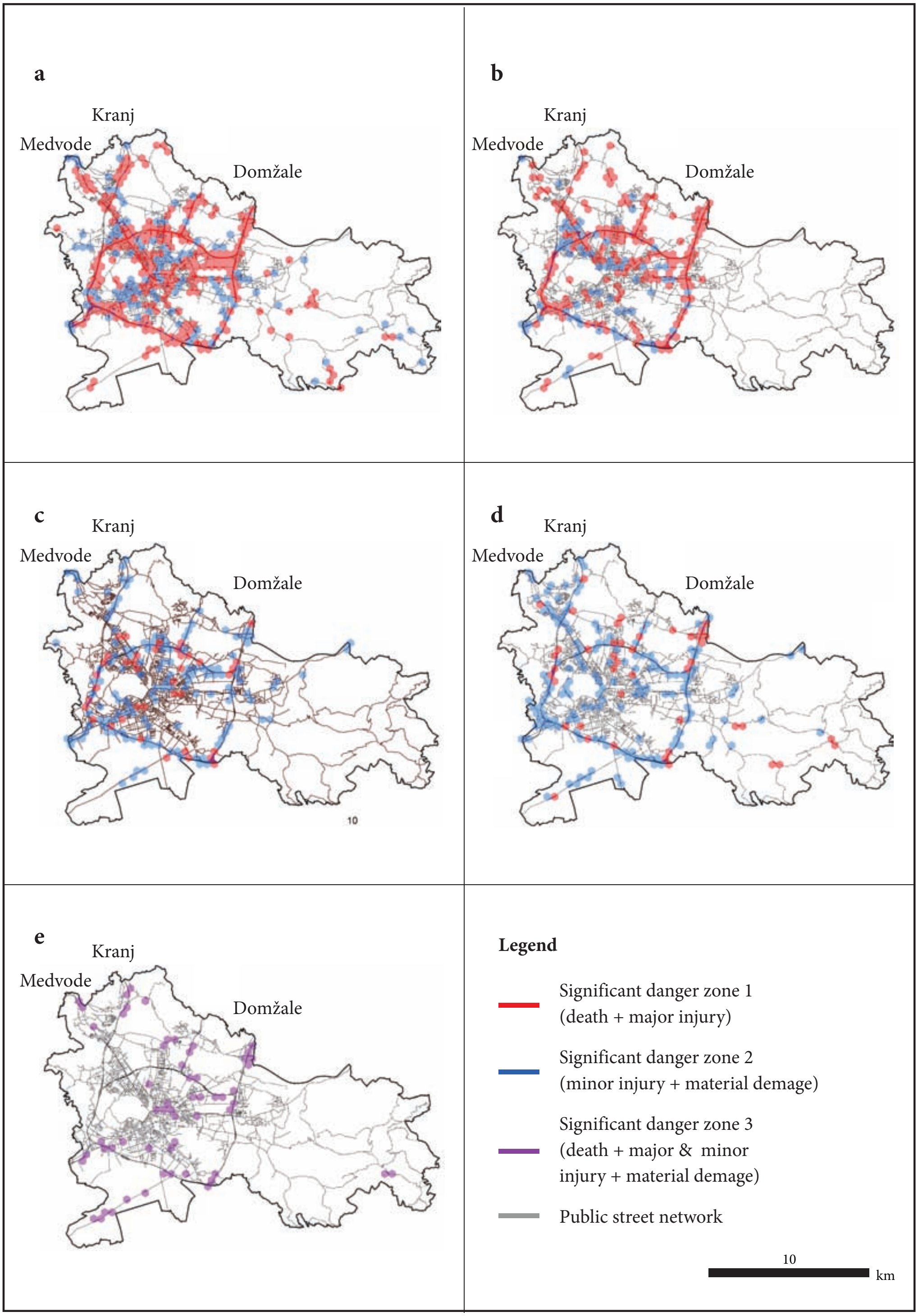


Figure 3: LJ's Hot Spot footprint (general [clear (a) or cloudy sky (b)], rain (c), snow (d), fog (e)).

ring were identified along regional roads 211 via Kranj and 639 via Jože Pučnik airport, and on road 104 to Domžale. Inside the highway ring of LJ, dangerous street segments were mainly identified on three city entrance roads (Celovška street, Šmartinska street and Zaloška street). However, there was a clear difference by comparing the Hot Spots footprint in weather independent (Figure 3a, b) and dependent situations (Figure 3c, d, e). In rain or snow, the junctions between the highway ring surrounding LJ (the highway junctions E and N, E and S, N and W, W and S) experience the most deadly road traffic accidents. In contrast, in foggy weather conditions, streets outside and inside the highway ring are more susceptible at Hot Spots.

In MB, the spatial distribution of Hot Spots in clear or cloudy conditions shows a general footprint where five critical zones can be identified (Figure 4): (1) the H2 road starting with the roundabout in Pesnica and continuing to road 430 (Tržaška street), crossing MB city from N to S; (2) the western entrance from the town of Bresternica to Koroška street; (3) the parallel road on the other side of the river Drava from Limbuš to the roundabout connecting Limbuška and Erjavčeva street; (4) The SE entrance street to Maribor (Ptujska street) and finally, (5) the road segment crossing the river Drava channel in the town of Dogoše (on the SE outskirts of Maribor). As in LJ, the spatial pattern of Hot Spots in rainy, snowy or foggy weather conditions clearly differs from the above-described general situation. Consequently, fewer danger zones were identified in poor weather conditions. Sharp curves, high-speed road entrances and major intersections are typical Hot Spots under these weather conditions in MB. Under heavy fog conditions, dangerous road segments were identified mainly outside the city structure. An individual section of the H2 road stands out here, as well as some curves in the eastern hilly part of the municipality towards the town of Malečnik.

In CE, three zones should receive heightened driver attention: (1) the N-S segment of road 430 from the settlement of Škoflja vas, through Celje city and continuing as road 5 in the direction of the town of Laško, (2) the E-W corridor consisting of roads 107 and 5 from the town of Štore in the direction of the town of Levec, and (3) highway exits across the whole municipality (Figure 5). However, in rainy weather conditions, clusters of Hot Spots are located in the eastern (industrial) part of the municipality, near the town of Štore and at some major road crossings in the city center. Accidents with minor injuries and material damage are linked to the E57 highway and the winding sections of road in the Savinja valley towards the town of Laško. These parts of the road are identified as dangerous in snowy conditions as well. In fog, highway exits in CE are most susceptible to road traffic accidents.

In KP, dangerous sections of road were identified mainly along the H5 and H6 highway and on the roads surrounding the town of Koper (Figure 6). The road network in the rural outskirts of Koper is mostly free of Hot Spots, with a local road exception in rainy weather conditions between the towns of Sočerga and Buzet (in Croatia). However, the frequent Bora wind does leave behind a road accident footprint, which clearly differs from the general or other weather-dependent Hot Spot spatial patterns. In this regard, the area around the town of Črni Kal stands out, owing to its geographic position beneath a high limestone plateau, where these katabatic NE winds gain turbulence and speed.

By comparing the Kernel density variable along the street networks in all study areas, similarities or dissimilarities in Hot Spot footprints for different weather conditions were quantified (Table 2). Clear and cloudy conditions leave behind a similar spatial pattern of Hot Spots. However, the highest variability in road traffic accident spatial patterns was identified in KP and MB. Fog and wind were the two weather conditions with the most unique Hot Spot footprints relative to other weather independent (clear or cloudy sky) or dependent situations (rain and snow).

Figure 7 illustrates the activated SLOCrashInfo app. The identified Hot Spot footprint is linked to the OpenStreetMap basemap and to the weather forecast and is automatically adjusted depending on the GPS position of the mobile device in the study areas. The screen frame of the mobile device turns red (Figure 6a) if the vehicle enters danger zone 1 (death, major injury) and automatically switches color when reaching danger zone 2 (minor injury or material damage) or 3 (death, major injury + minor injury or material damage) (Figure 6b), or turns off when the Hot Spot section of the street network has been left behind. Sound alerts are not integrated because these could disrupt driver's attention and can be annoying while driving. Thus, drivers are informed about the potential danger and can react accordingly by focusing on the speed limit and safety distance to other nearby vehicles at the given momentum.

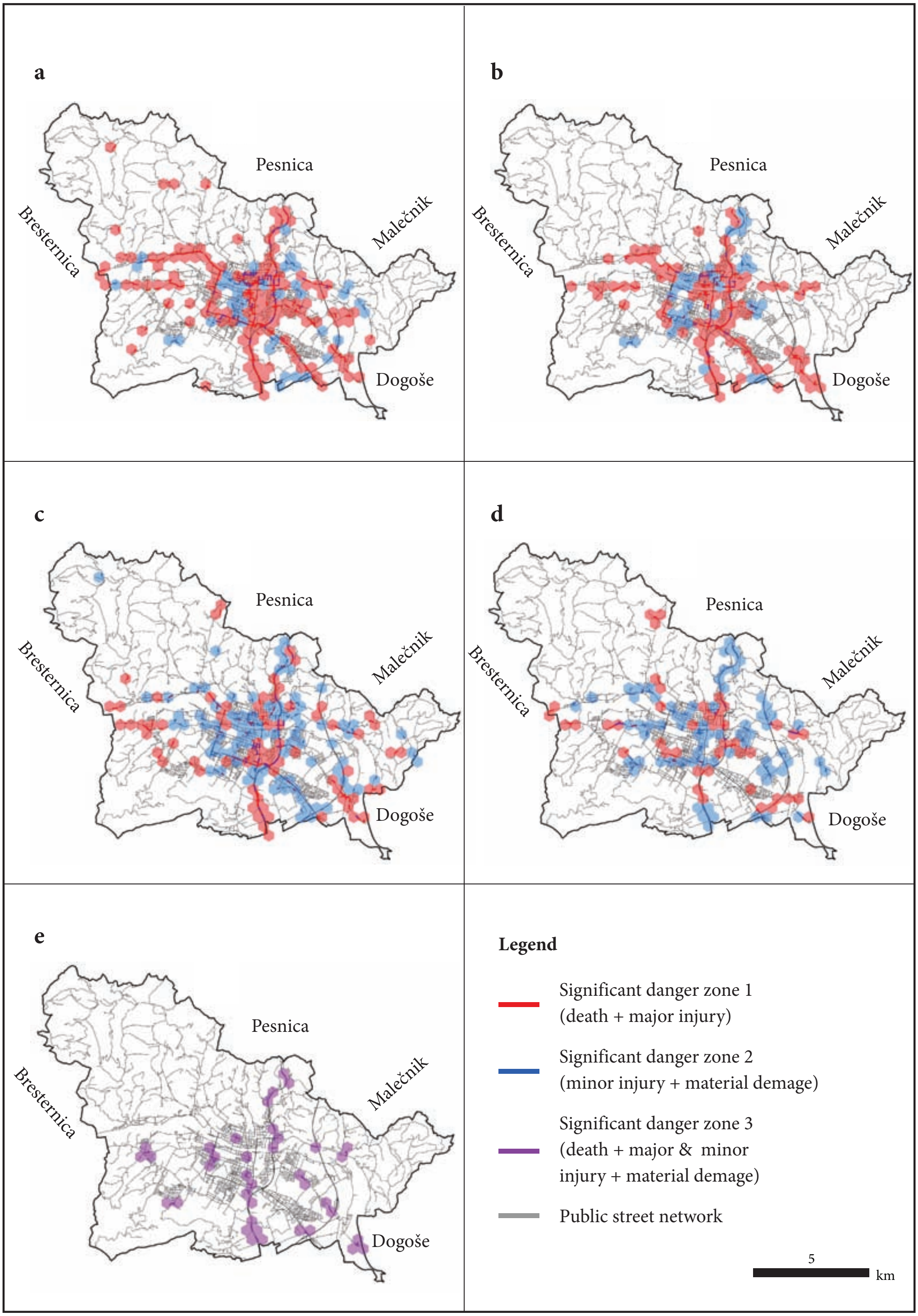


Figure 4: MB's Hot Spot footprint (general [clear (a) or cloudy sky (b)], rain (c), snow (d), fog (e)).

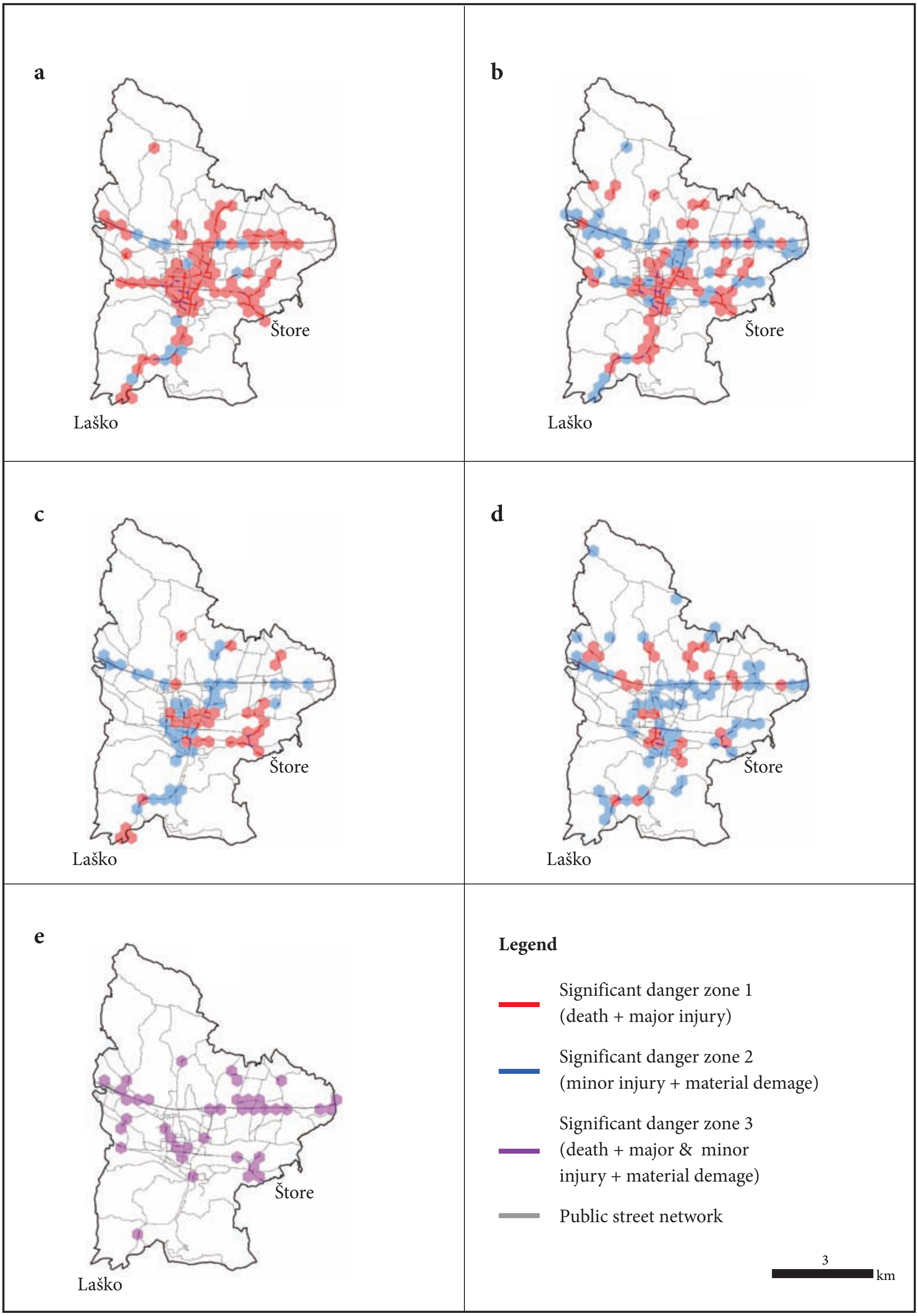


Figure 5: CE's Hot Spot footprint (general [clear (a) or cloudy sky (b)], rain (c), snow (d), fog (e)).

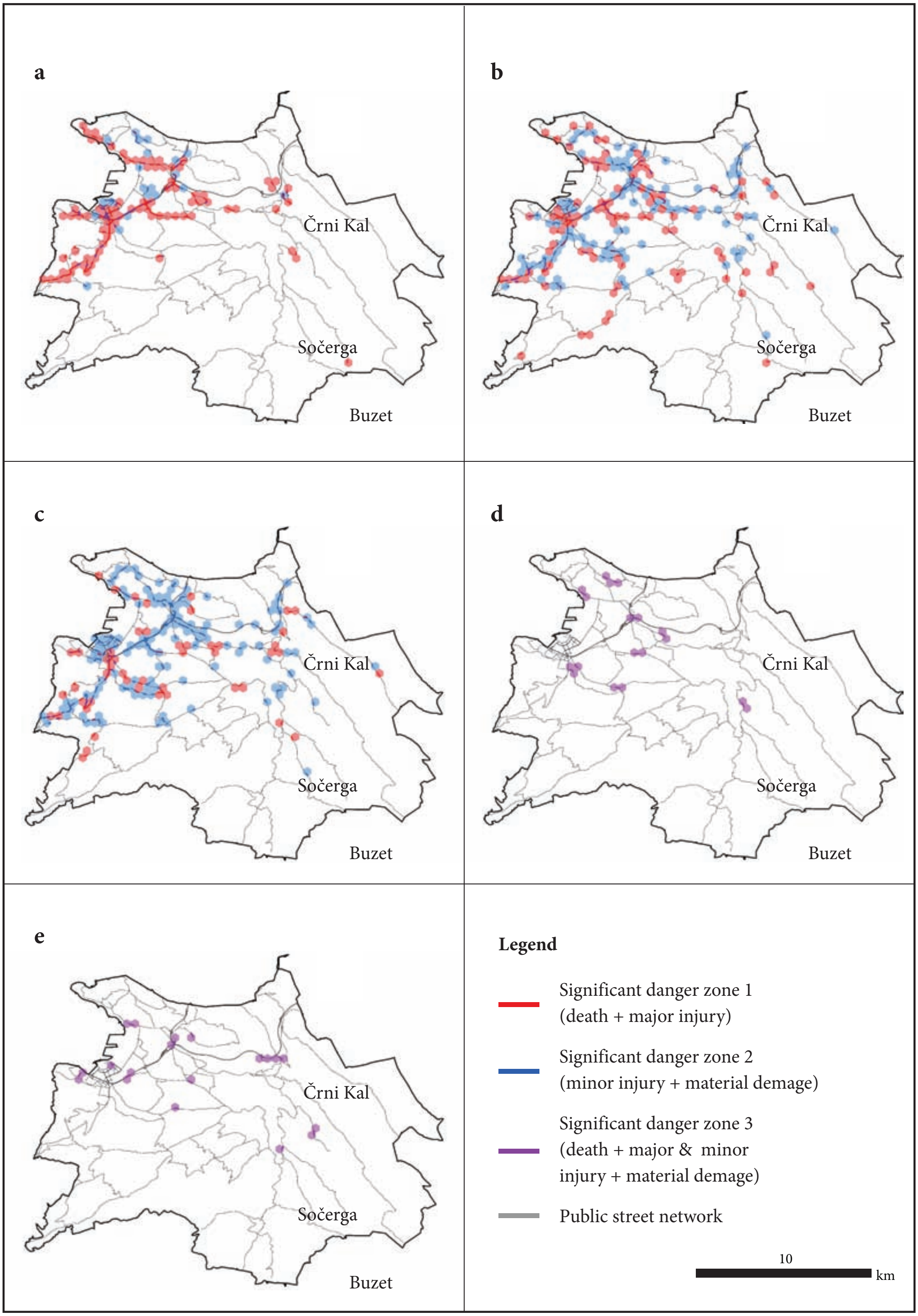


Figure 6: KP's Hot Spot footprint (general [clear (a) or cloudy sky (b)], rain (c), fog (d), wind (e)).

Table 2: Study site- and weather-related correlation matrix (Pearson's correlation coefficient).

Weather condition	Study Area	Clear Sky	Cloudy Sky	Rain	Snow	Fog	Wind
Clear Sky	LJ	1	0.77	0.61	0.47	0.32	
	MB	1	0.87	0.58	0.37	0.24	
	CE	1	0.79	0.52	0.36	0.27	
	KP	1	0.65	0.62		0.05	0.05
Cloudy Sky	LJ	0.77	1	0.76	0.52	0.41	
	MB	0.87	1	0.69	0.35	0.28	
	CE	0.79	1	0.55	0.37	0.29	
	KP	0.65	1	0.87		0.06	0.08
Rain	LJ	0.61	0.76	1	0.42	0.30	
	MB	0.58	0.69	1	0.27	0.23	
	CE	0.52	0.55	1	0.35	0.34	
	KP	0.62	0.87	1		0.03	0.09
Snow	LJ	0.47	0.52	0.42	1	0.28	
	MB	0.37	0.35	0.27	1	0.11	
	CE	0.36	0.37	0.35	1	0.17	
	KP	0.05			1		
Fog	LJ	0.32	0.41	0.30	0.28	1	
	MB	0.24	0.28	0.23	0.11	1	
	CE	0.27	0.29	0.34	0.17	1	
	KP	0.05	0.06	0.03		1	0.01
Wind	LJ						
	MB						
	CE						
	KP	0.05	0.08	0.09		0.01	1

4 Disscusion

Slovenia lies at the conjunction of different climatic zones characterized by differences in air masses and differences in weather phenomena, which further modify traffic safety. When traveling on the NE-SW trajectory, across the Alpine-Dinaric mountain barrier to the Slovenian coast, a driver can experience very diverse weather conditions along the road in only a few hours. However, the Slovenian data show that the frequency of traffic accidents in adverse weather conditions is comparable to that of other European countries (Etehad et al. 2015). Despite improving numbers, road traffic accidents remain one of the main global issues of health and social policy (Goniewicz et al. 2016). In Slovenia, trends in road traffic accident frequency are fortunately clearly negative, as in other European countries, but with significant regional differences. Traffic load plays here an important role, since Slovenia is a typical road transit country. However, studies investigating highway traffic loads (Castillo-Manzano, Castro-Nuño and Fageda 2016) concluded that modern vehicle-to-vehicle communication technologies could support the driver with real-time traffic data and thus prevent road network accidents. Such technology can be seen in the Google Maps navigation system, which is, for now, developed only for the highway network. However, highways tend to be safer than regional, local or urban road systems (Grande et al. 2017). From that perspective, we can highlight some municipalities with larger towns that had higher road traffic accident frequency, although there were some exceptions (municipalities lying within the triangle MB, CE and the city of Novo mesto and along the H4 expressway (Razdrto–Vrtojba) in the SW part of Slovenia). Consequently, the spatial road accident Hot Spot pattern clearly differs in regard to study areas and different weather conditions. Several studies across the Globe (Brodsky and Hakkert 1988; Fridström et al. 1995; Hermans et al. 2006; Brijs, Karlis and Wets 2008; Yannis and Karlaftis 2010; Bergel-Hayat et al. 2013) confirmed the weather dependence (as direct or indirect cause) of road traffic accident, particularly under rainy or snowy conditions. Slovenia is not an exception, rain and snow leave behind the highest share of road traffic accidents in adverse weather but fog and wind were the two weather conditions with the most unique Hot Spots footprints. However, Romano and Jiang (2017) emphasized that road traffic accident Hot Spots should be considered as spatio-temporal events along road networks. In other words, the road accident footprint is changing with time and is influenced by many factors, including weather. The informative power of such geospatial results is highly applicable and these data, not just can, but should be integrated as a driver assistance system in the coming »smart« vehicles. Our study proves that an information system providing the driver with information about potentially dangerous road network segments in varying weather conditions could have a positive influence on the driver's behavior while navigating these routes. Thus, more attention to speed limits, safety distance

Figure 7: The SDSS application SLOCrashInfo in action (in the danger zone) (a). The Data view mode (b). Live mode in the non-danger zones (c) and Live mode in the significant danger zone 1 (d), 2 (e) and 3 (f).

and other vehicles entering and leaving the system can be expected. Uchida et al. (2017) outlined that mobile devices, such as smartphones, have recently become very effective methods that could help prevent or decrease road traffic accident frequency in general if they are used properly. As already mentioned, the ideal solution for this mobile spatial decision support system would be integration with the vehicle's system, so that dangerous road segments could be indicated with a warning symbol, like the slippery road alert if air temperatures drop below 4°C. Another possibility would be integration with the Google Maps navigation system, which provides in-time traffic updates based on mobile device location. This app could be enhanced with the weather-related Hot Spot footprint data and easily projected into the vehicle cockpit via Android Auto technology (if supported). To do so, national road traffic accident databases should be analyzed. With the recent developments Intelligent Transport Systems such as autonomous vehicles or vehicle-to-vehicle communication systems, which will definitely be equipped with smart geospatial information systems, it is expected that traffic accident frequency will be decrease drastically in the near future.

5 Conclusion

Understanding where traffic accidents occur is crucial for improving road safety and proper traffic enforcement allocation. We detected clear regional differences in road traffic accident frequency connected with traffic load, since Slovenia is a typical road transit country. As expected, municipalities with larger towns had higher road traffic accident frequency, although there were some exceptions. However, different weather situations leave behind different spatial footprints of road traffic accidents. Thus, the spatial road accident Hot Spot pattern clearly differs in regard to study areas and different weather conditions. Despite that, the highest weather-related road accident frequency was recorded in rain and snow, fog and wind were the two weather conditions with the most unique Hot Spot footprints. To address the applicability of such geospatial results, we developed a mobile spatial decision support system (SDSS), functioning in the Android environment that have the potential to improve road safety. Moreover, modern commercial car navigation systems provide many valuable spatial data for the driver but none of them visualizes road traffic accident hot-spots (dangerous road segments) related to weather patterns. Owing to computer limits, our SDSS SLOCrashInfo was designed only for most exposed municipalities in Slovenia. Next steps should thus be orientated towards the whole road network in Slovenia or even beyond national borders. The optimal solution would be an automatic integration of such data into the navigation system of all vehicles, where an alert message could be immediately displayed on the cockpit while entering a traffic accident hot-spot road segment. However, it should be emphasized, that such information systems are only suitable (or necessary) for non-autonomous vehicles, where driving decisions are still in human hands.

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