ISSN 1339-3189 4/2026

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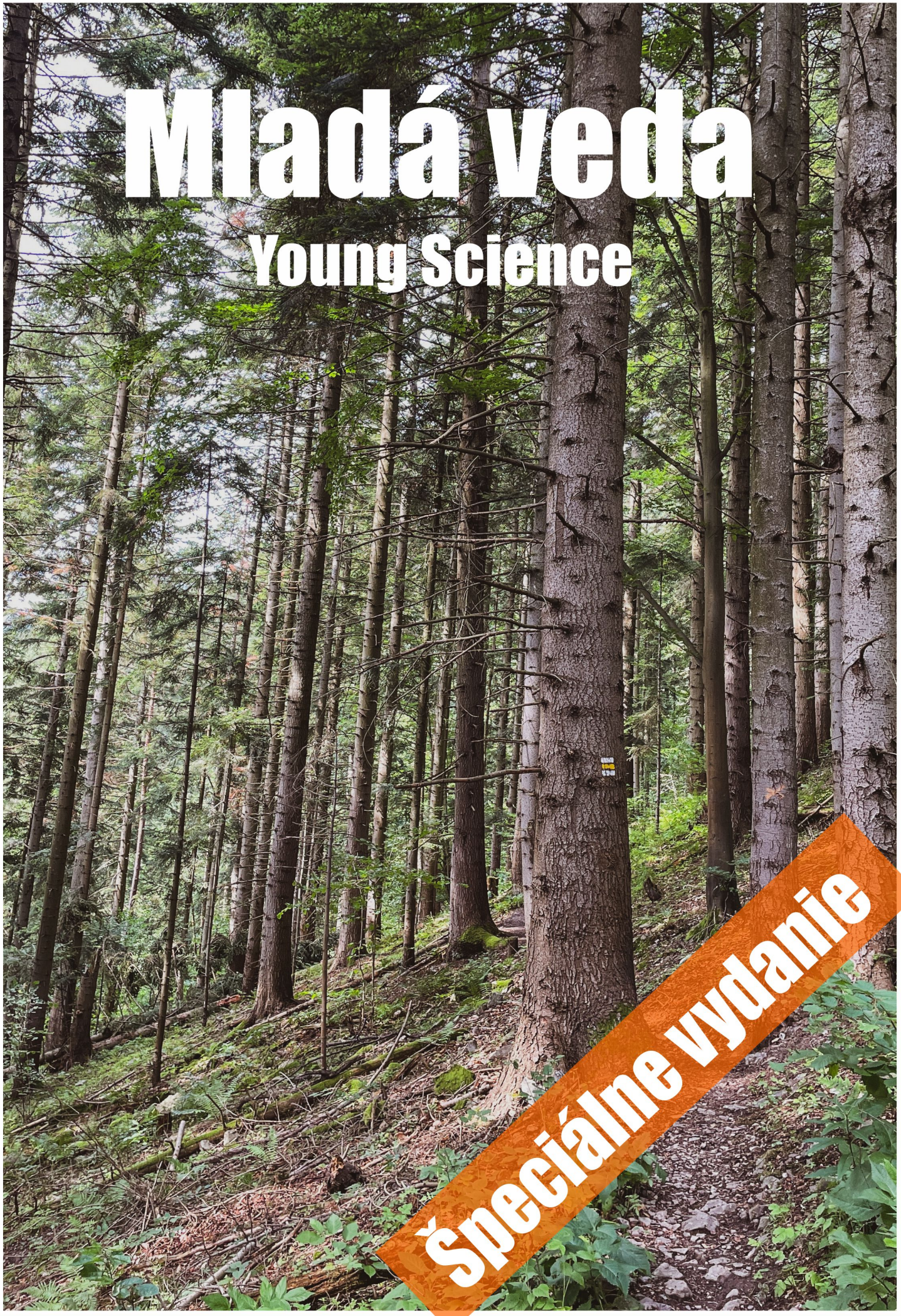

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MEDZINÁRODNÝ VEDECKÝ ČASOPIS MLADÁ VEDA / YOUNG SCIENCE
Číslo 4, ročník 14., špeciálne číslo vydané v auguste 2026
ISSN 1339-3189, EV 167/23/EPP
Kontakt: info@mladaveda.sk, tel.: +421 908 546 716, www.mladaveda.sk
Fotografia na obálke: V lese. © Branislav A. Švorc, foto.branisko.at

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v spolupráci s vydavateľstvom UNIVERSUM-EU, spol. s r. o.

Mladá veda
Young Science
ISSN 1339-3189

Vol. 14 (4), pp. 57-69

GEOSPATIAL EPIDEMIOLOGY OF INJURY-RELATED DEATHS ATTENDED BY EMERGENCY MEDICAL SERVICES IN SLOVAKIA, 2018-2023

GEOPRIESTOROVÁ EPIDEMIOLÓGIA ÚMRTÍ SÚVISIACICH S ÚRAZMI, PRI KTORÝCH ZASAHOVALA ZÁCHRANNÁ ZDRAVOTNÁ SLUŽBA NA SLOVENSKU V ROKOCH 2018-2023

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Autori pôsobia na univerzitných pracoviskách v oblasti verejného zdravotníctva, epidemiológie, geografie a geoinformatiky. Tomáš Dudich je doktorandom v odbore verejné zdravotníctvo na Vysokej škole zdravotníctva a sociálnej práce sv. Alžbety v Bratislave a študentom Fakulty zdravotníckych vied Univerzity v Pécsi. Oldřich Rypl pôsobí na Katedre geografie Technickej univerzity v Liberci a na Katedre geoinformatiky Univerzity Palackého v Olomouci. Anna Horňáková pôsobí na Ústave hygieny a epidemiológie 1. lekárskej fakulty Univerzity Karlovej v Prahe. Andrea Bratová sa vo svojej odbornej a výskumnej činnosti venuje ošetrovateľstvu, anestéziológii a intenzívnej starostlivosti, prvej pomoci, kvalite a bezpečnosti zdravotnej starostlivosti. Spoločný výskum autorov sa zameriava na prednemocničnú zdravotnú starostlivosť, priestorové analýzy zdravotných udalostí a epidemiológiu úrazov.

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Abstract

Injury mortality has a pronounced spatial component because exposure, population distribution, emergency medical service (EMS) demand and access to definitive care vary geographically. To describe the district-level distribution of injury-related fatal EMS attendances in Slovakia and to assess the correspondence between the operational database and the published cartographic representation. A nationwide retrospective observational study used 452,921 injury-related EMS records. Fatal cases were included when the outcome indicated death, at least one diagnosis field contained ICD-10 R96-R99, and at least one concurrent diagnosis represented injury, poisoning or an external cause (S00-T98 or V01-Y98). Map-level operational records were retained for cartographic validation, while a deterministic linkage key was used for a patient-level sensitivity cohort. Results: The case definition identified 2,236 qualifying operational records and 1,798 deduplicated fatal cases. In the patient-level cohort, 1,562 deaths (86.9%) occurred at the scene and 236 (13.1%) were transport-related. Males accounted for 79.7% of cases with known sex, and the median age was 50 years (IQR 36-64). The map contained 1,986 at-scene operational records; Bratislava had the largest district count (n=178), followed by Žilina (n=69), Košice (n=64), Nové Zámky (n=61) and Komárno (n=58). At regional level, the largest counts were observed in the Košice (n=321), Nitra (n=304) and Žilina (n=289) regions. District-level scene fatalities were strongly correlated with the total volume of injury-related EMS attendances (Pearson r=0.910; Spearman rho=0.880; both $p<0.001$). Twenty-eight deduplicated inter-district transport deaths were identified; the largest route was Nové Zámky-Nitra (n=3). Injury-related fatal EMS attendances in Slovakia were spatially concentrated, but absolute hotspots primarily reflected the volume of EMS-treated injuries. Relative burden measures identified additional non-metropolitan districts. The findings support routine geospatial surveillance, standardized destination coding and patient-level identifiers in EMS information systems.

Key words: emergency medical services, geospatial epidemiology, injury mortality, prehospital care, spatial distribution, Slovakia

Abstrakt

Úmrtnosť súvisiaca s úrazmi má výraznú priestorovú dimenziu, keďže expozícia riziku, rozloženie obyvateľstva, dopyt po záchrannej zdravotnej službe (ZZS) a dostupnosť definitívnej starostlivosti sa geograficky líšia. Opísať rozloženie smrteľných prípadov súvisiacich s úrazmi, pri ktorých zasahovala ZZS, na úrovni okresov Slovenska a overiť zhodu operačnej databázy s kartografickým zobrazením. Retrospektívna observačná štúdia využila 452 921 záznamov ZZS súvisiacich s úrazmi. Zaradené boli prípady s výsledkom zásahu

označujúcim úmrtie, diagnózou R96-R99 a súčasne prítomným kódom poranenia, otravy alebo vonkajšej príčiny (S00-T98 alebo V01-Y98). Na validáciu mapy sa zachovali operačné záznamy, pričom pre senzitivnú analýzu bol vytvorený deduplikovaný súbor pacientov. Kritériá splnilo 2 236 operačných záznamov a 1 798 deduplikovaných smrteľných prípadov. V pacientskom súbore nastalo 1 562 úmrtí (86,9 %) na mieste udalosti a 236 (13,1 %) súviselo s transportom. Muži tvorili 79,7 % prípadov so známym pohlavím a medián veku bol 50 rokov (IQR 36-64). Mapa obsahovala 1 986 operačných záznamov úmrtí na mieste; najvyšší počet bol v Bratislave (n=178), nasledovali Žilina (n=69), Košice (n=64), Nové Zámky (n=61) a Komárno (n=58). Počty na úrovni okresov silno korelovali s celkovým objemom úrazových zásahov ZZS (Pearsonovo r=0,910; Spearmanovo rho=0,880; obe p<0,001). Identifikovaných bolo 28 deduplikovaných úmrtí počas medziokresného transportu; najčastejšou trasou boli Nové Zámky-Nitra (n=3). Smrteľné prípady súvisiace s úrazmi boli priestorovo koncentrované, pričom absolútne ohniská do veľkej miery odrážali objem úrazových zásahov ZZS. Relatívne ukazovatele poukázali aj na zvýšenú záťaž v niektorých nemetropolitných okresoch. Výsledky podporujú rutinný geopriestorový dohľad, štandardizované zaznamenávanie cieľového zdravotníckeho zariadenia a používanie jednoznačných identifikátorov pacientov v informačných systémoch ZZS.
Kľúčové slová: epidemiológia úrazov, geopriestorová epidemiológia, prednemocničná starostlivosť, priestorové rozloženie, Slovensko, záchranná zdravotná služba

Introduction

Injuries and violence account for approximately 4.4 million deaths annually, representing nearly 8% of global mortality. Their distribution is unequal both between and within countries, and the organization of emergency and trauma care can modify the consequences of severe injury (World Health Organization, 2024). In Europe, substantial differences remain across subregions and countries. The Global Burden of Disease 2019 analysis estimated 38 injury deaths per 100,000 population in Central Europe in 2019, compared with 27 per 100,000 in Western Europe, while mortality and disability burdens were consistently higher among males (Haagsma et al., 2022).

Geospatial epidemiology adds information that is not available from national totals. Mapping the location of fatal events can reveal concentrations associated with population density, transport corridors, socioeconomic conditions, mechanisms of injury and geographic access to specialized care. A systematic review found that trauma death and disability are repeatedly associated with travel time, rurality, socioeconomic deprivation and the spatial distribution of trauma resources, although the direction and magnitude of these associations vary by setting and methodology (Hwang, Jeong and Jo, 2023). Studies from the United States, Canada, Australia and the United Kingdom have shown that geocoded injury data can identify high-risk environments, changing spatial patterns and areas with less favorable access to advanced prehospital or hospital care (Jarman et al., 2018; Tansley et al., 2019; Beck et al., 2022; Byrne et al., 2022; McHenry and Smith, 2023).

Prehospital mortality is epidemiologically distinct from in-hospital mortality. It includes patients with unsurvivable injuries, delayed discovery, limited access to care and rapidly progressive physiological deterioration. International evidence suggests that prehospital deaths

frequently differ from hospital deaths in age, mechanism and injury pattern, and that their exclusion can substantially underestimate the population burden of fatal trauma (Purcell et al., 2020; Mulima et al., 2021). EMS operational data therefore offer a valuable, although methodologically challenging, source for injury surveillance.

The Slovak EMS system records dispatch information, patient characteristics, diagnosis codes, event location, transport and outcome. These records can support nationwide spatial analysis at district level. However, operational datasets may contain multiple records for a single patient when several response units attend the same event, and the terminal codes R96-R99 are classified by ICD-10 as ill-defined or unknown causes of mortality rather than as injury diagnoses. Consequently, a valid injury-related case definition requires the simultaneous presence of an injury, poisoning or external-cause code (World Health Organization, 2015).

The aim of this study was to characterize the geospatial epidemiology of injury-related deaths attended by EMS in Slovakia from 2018 to 2023. The specific objectives were to: (1) construct a reproducible injury-associated fatality definition; (2) describe demographic and diagnostic characteristics; (3) quantify district and regional concentration of deaths at the scene; (4) describe fatal transport patterns; and (5) validate the published English-language map against the source database and a patient-level sensitivity analysis.

Material and methods

Study design and data source

A retrospective nationwide observational study was conducted using an anonymized operational database of EMS attendances in Slovakia. The source workbook contained 452,921 records classified as injury-related and included event date, dispatch priority and diagnosis, sex, age, crew type, outcome, up to four crew-assigned diagnoses, region, district, municipality, geographic coordinates, intervention variables, destination hospital and operational timestamps. The available fatality subset extended from 3 August 2018 to 30 August 2023. Because 2018 and 2023 represented partial years, annual counts were reported descriptively and were not interpreted as complete-year trends.

Case definition

A record was eligible when all three conditions were met: (1) the EMS outcome was recorded as Exitus, Exitus at the address, or Exitus during transport; (2) at least one of the four crew diagnosis fields contained R96, R98 or R99; and (3) at least one diagnosis field simultaneously contained an injury, poisoning or external-cause code within S00-T98 or V01-Y98. R96-R99 were used as terminal mortality descriptors and not as stand-alone evidence of injury causation. The concurrent injury/external-cause criterion was required because ICD-10 categorizes R96-R99 among ill-defined and unknown causes of mortality (World Health Organization, 2015).

The map-level analysis retained operational records to reproduce the original cartographic counts. Deaths at the scene included records coded as Exitus at the address and records coded as Exitus without transport evidence. Transport-related records were identified from the explicit outcome Exitus during transport or from transport timestamps indicating departure from the scene or arrival at hospital. Raw operational layers were allowed to reflect the source information system; they were not assumed to represent unique patients.

Patient-level linkage and transport classification

For sensitivity analysis, repeated operational records were deterministically linked using the combination of emergency-call receipt time, district, geographic coordinates, sex, age and the sorted set of diagnosis codes. Records with the same key were treated as one patient episode. A transport-related episode took precedence over an at-scene classification when linked records contained transport evidence. Destination district was inferred from the standardized leading token in the hospital field. Episodes with a known destination different from the origin district were classified as inter-district transports; episodes with an identical origin and destination were confirmed within-district transports.

Destination information could not be interpreted for 194 of 236 deduplicated transport-related deaths. To preserve agreement with the existing map, these episodes were represented by an origin-anchored orange symbol together with confirmed within-district cases. Thus, the orange layer should be interpreted as transport deaths assigned to their origin district, not as independently confirmed within-district transport in every case. Inter-district arrows were restricted to episodes with an interpretable destination.

Spatial units and statistical analysis

District abbreviations in the operational data were used as spatial identifiers. Bratislava city districts were aggregated as BA and Košice city districts as KE, resulting in 72 observed analytic district units. Regional totals were calculated for the eight self-governing regions. Absolute scene fatality counts were compared with the total number of injury-related EMS records in each district. Because official population denominators linked to the same time intervals were not included in the source workbook, the study did not calculate population incidence. Instead, an operational fatality ratio was expressed as scene fatality records per 1,000 injury-related EMS records.

Categorical variables are presented as counts and percentages. Age is summarized by mean and standard deviation and by median and interquartile range (IQR). Differences in age between at-scene and transport-related fatal episodes were assessed using the Mann-Whitney U test; sex distribution was compared by chi-square test. Spatial concentration was summarized using the Gini coefficient. Pearson correlation assessed the association between absolute district scene deaths and total injury-related EMS volume; Spearman rank correlation assessed monotonic association and the agreement between raw operational and deduplicated district rankings. Statistical significance was defined as $p<0.05$, two-sided.

Ethical considerations

The analysis used anonymized retrospective operational data and involved no intervention or direct contact with patients. The final manuscript must include the decision of the responsible ethics committee or a formal statement that ethical review was waived under applicable institutional rules.

Results

Cohort identification and validation

The case definition identified 2,236 qualifying operational records. Of these, 1,986 met the cartographic rule for a death at the scene, while 261 records contained evidence of transport. Eleven raw records fulfilled both operational layer rules because outcome and timestamp fields were not fully consistent. Deterministic linkage produced 1,798 unique fatal patient episodes: 1,562 (86.9%) at the scene and 236 (13.1%) transport-related. The district ranking based on raw map records was almost identical to the ranking based on deduplicated scene episodes (Spearman rho=0.987, p<0.001), supporting the robustness of the spatial pattern despite multi-unit duplicate records.

Characteristic	n / value	% or unit
Death at the scene	1,562	86.9
Transport-related death	236	13.1
Male sex	1,408	79.7 of known sex
Female sex	359	20.3 of known sex
Age, median (IQR)	50 (36-64)	years
Age, mean (SD)	50.4 (18.9)	years
Age <15 years	24	1.4
Age 15-24 years	148	8.6
Age 25-44 years	473	27.4
Age 45-64 years	660	38.2
Age 65-79 years	304	17.6
Age >=80 years	119	6.9

Table 1 - Characteristics of the injury-related fatal EMS cohort, Slovakia, 2018-2023
Source: Authors' analysis of the national EMS operational dataset

Demographic and diagnostic profile

Among 1,767 episodes with known sex, 1,408 (79.7%) involved males and 359 (20.3%) females (p<0.001 compared with an equal distribution). Age was available for 1,728 episodes. The median age was 50 years (IQR 36-64), the mean age was 50.4 years (SD 18.9), and the range was 0-99 years. Adults aged 45-64 years formed the largest age group (n=660; 38.2% of episodes with known age), followed by those aged 25-44 years (n=473; 27.4%). Transport-related deaths involved younger patients than deaths at the scene: median 48 years (IQR 29-58) versus 51 years (IQR 37-65), respectively (Mann-Whitney p<0.001). Sex distribution did not differ significantly by transport status (p=0.311).

R96 was present in 819 deduplicated episodes, R98 in 516 and R99 in 513; categories were not mutually exclusive. Injury and external-cause patterns were likewise non-exclusive. Intentional self-harm codes were recorded in 520 episodes, multiple or unspecified injuries (T00-T07) in 454, transport injury codes (V01-V99) in 423, head injuries (S00-S09) in 236, undetermined intent (Y10-Y34) in 139, poisoning or toxic effects in 31, assault in 23, falls in

40 and drowning in one episode. Six hundred episodes contained an injury diagnosis without a sufficiently specific external-cause code to assign a mechanism category.

Code group	n	% of episodes
Intentional self-harm (X60-X84)	520	28.9
Multiple/unspecified injuries (T00-T07)	454	25.3
Transport injury (V01-V99)	423	23.5
Head injury (S00-S09)	236	13.1
Undetermined intent (Y10-Y34)	139	7.7
Falls (W00-W19)	40	2.2
Poisoning/toxic effects	31	1.7
Assault (X85-Y09)	23	1.3
Drowning/submersion (W65-W74)	1	0.1

Table 2 - Selected injury and external-cause code groups in the deduplicated fatal cohort
Source: Authors' analysis.

Geographic distribution of deaths at the scene

The map-level dataset contained 1,986 at-scene operational records, of which 1,945 had a valid district code and 41 lacked district information. The ten districts with the largest counts accounted for 35.5% of all valid district-coded scene records. Bratislava had 178 records, representing 9.2% of the valid total and the maximum displayed in the map. It was followed by Žilina (n=69), Košice (n=64), Nové Zámky (n=61), Komárno (n=58), Levice (n=54), Nitra (n=53), Košice-okolie (n=52), Malacky (n=51) and Prievidza (n=50). The Gini coefficient for scene fatality counts across observed districts was 0.410, indicating moderate spatial concentration.

At regional level, the highest absolute number of scene records was observed in the Košice Region (n=321), followed by the Nitra (n=304), Žilina (n=289), Bratislava (n=269), Banská Bystrica (n=223), Trenčín (n=218), Prešov (n=204) and Trnava (n=146) regions. When standardized to the volume of injury-related EMS records, the highest regional operational ratio occurred in the Nitra Region (6.49 scene fatality records per 1,000 injury attendances), followed by Žilina (5.11), Trenčín (4.68), Košice (4.41), Banská Bystrica (4.26), Bratislava (4.08), Trnava (3.43) and Prešov (2.98).

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ISSN 1339-3189

Vol. 14 (4), pp. 57-69

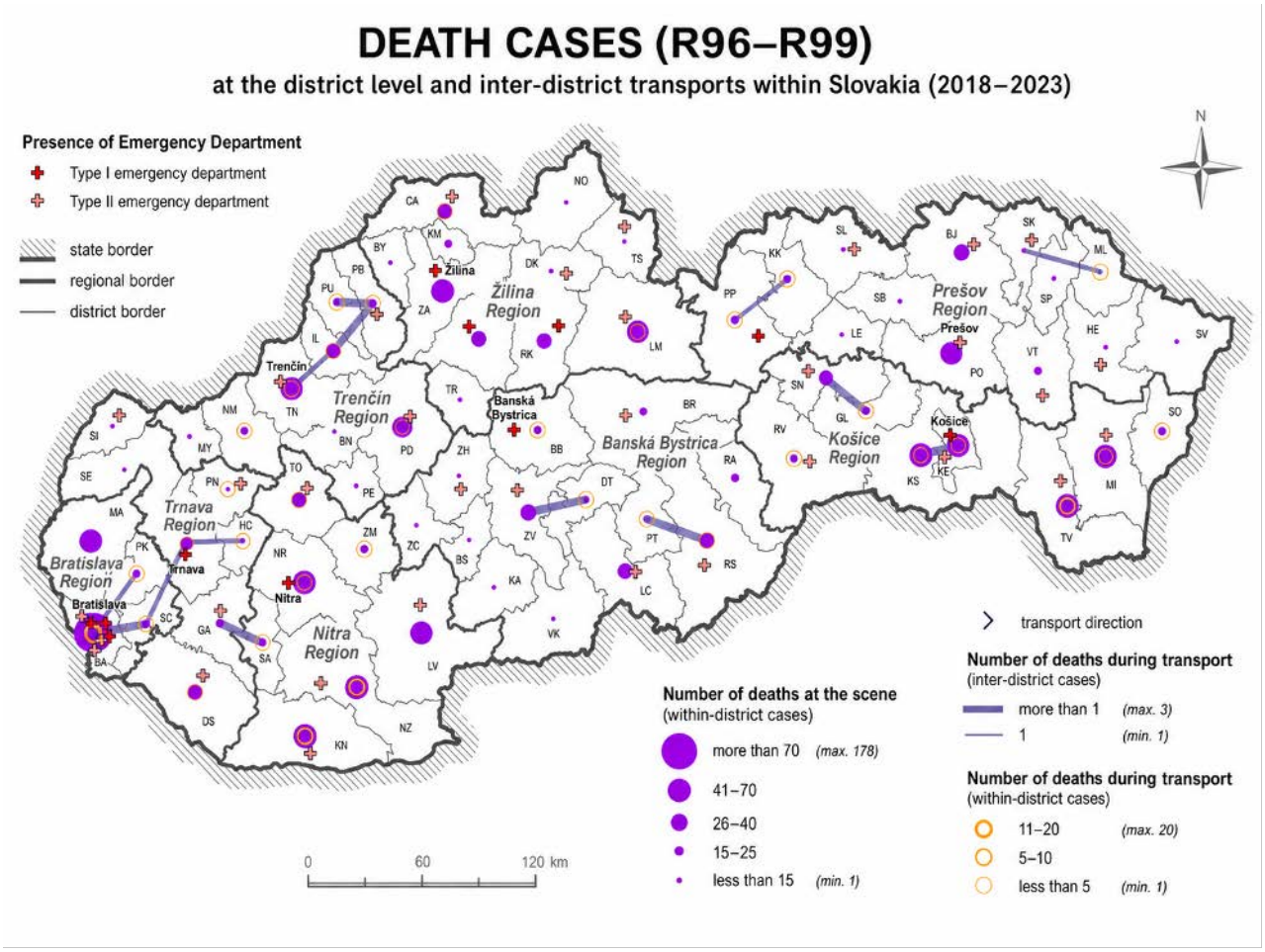

Figure 1 - Injury-related death cases attended by EMS at district level
and inter-district transports in Slovakia, 2018-2023
Source: Authors' cartographic processing of the national EMS operational dataset.
Purple symbols show at-scene operational records; orange symbols show origin-anchored transport deaths, including records with unknown destination; arrows represent deduplicated transports with known destination district

Relationship with EMS injury volume

Absolute scene fatality counts were strongly associated with the total volume of injury-related EMS records at district level (Pearson r=0.910, p<0.001; Spearman rho=0.880, p<0.001). This indicates that the largest circles on the map primarily identify areas with high exposure and high EMS activity rather than an independently elevated fatality risk. The absolute and relative perspectives were not identical. Bratislava had the highest count but an operational ratio of 3.86 per 1,000 injury records. The highest ratios were observed in Sobrance (9.68), Komárno (7.89), Malacky (7.49), Revúca (7.45), Žiar nad Hronom (7.40), Spišská Nová Ves (7.28), Nové Zámky (7.21), Tvrdošín (6.99), Kysucké Nové Mesto (6.83) and Levice (6.73). These ratios require cautious interpretation because they were not adjusted for age, population size, injury severity, mechanism or case ascertainment.

Deaths related to transport

The patient-level cohort included 236 transport-related fatal episodes. Destination evidence yielded 17 same-district designations and 28 inter-district designations across linked records;

three episodes contained duplicate or discordant destination information and were resolved through the linkage hierarchy. Destination was unavailable or not interpretable for 194 episodes. When confirmed within-district and origin-only episodes were combined for compatibility with the map, Bratislava had the highest origin-anchored transport count (n=20), followed by Prešov and Liptovský Mikuláš (n=13 each), Košice-okolie (n=8), Trenčín and Nitra (n=7 each), and Bardejov and Michalovce (n=6 each).

The largest confirmed inter-district route was Nové Zámky to Nitra (n=3). Five routes contained two deaths each: Ilava-Trenčín, Nové Mesto nad Váhom-Trenčín, Michalovce-Košice, Trebišov-Košice and Považská Bystrica-Trenčín. Remaining confirmed routes contained one episode each and predominantly converged on regional centres with emergency departments, including Bratislava, Banská Bystrica, Košice, Prešov, Trenčín and Trnava. The maximum inter-district route count of three and the maximum origin-anchored transport count of 20 exactly reproduced the map legend.

Origin district	Destination district	n
Nové Zámky (NZ)	Nitra (NR)	3
Ilava (IL)	Trenčín (TN)	2
Nové Mesto nad Váhom (NM)	Trenčín (TN)	2
Michalovce (MI)	Košice (KE)	2
Trebišov (TV)	Košice (KE)	2
Považská Bystrica (PB)	Trenčín (TN)	2
Other confirmed routes	Regional destination	15

Table 3 - Confirmed inter-district fatal transport flows
Source: Authors' analysis of deduplicated episodes with an interpretable destination

Discussion

Principal findings

This study provides a nationwide district-level description of injury-related fatal EMS attendances in Slovakia and demonstrates a reproducible method for linking a cartographic product to its source operational database. Three findings are central. First, most deduplicated fatal episodes occurred before transport, with 86.9% classified at the scene. Second, absolute scene-death hotspots were strongly associated with the overall volume of injury-related EMS activity. Third, relative operational burden highlighted a different set of districts, including Sobrance, Komárno, Revúca and Tvrdošín, that were not dominant on the absolute-count map. These findings show why spatial surveillance should present absolute counts together with an appropriate denominator.

Spatial concentration and the interpretation of urban hotspots

The highest absolute count was observed in Bratislava, and large counts also occurred in other regional centres and densely used districts. This pattern is epidemiologically plausible because metropolitan and regional centres combine larger resident and daytime populations, transport infrastructure, employment, tourism and higher EMS utilization. Similar studies have shown that trauma mortality clusters are shaped by both individual characteristics and the built and

socioeconomic environment (Jarman et al., 2018). Spatiotemporal mapping in Victoria also demonstrated that major-trauma risk varies by mechanism and location, and that maps based only on counts can obscure changing area-specific risk (Beck et al., 2022).

In the Slovak data, the correlation between scene deaths and total injury attendances was very strong. Therefore, a large symbol should not be interpreted as evidence that EMS performance is worse in that district. It primarily signals a high volume of severe and fatal events reaching the EMS system. Bratislava illustrates this distinction: it had by far the highest count, yet its fatality-to-injury-attendance ratio was lower than in several smaller districts. Conversely, Sobrance had a modest absolute count but the largest operational ratio. This could reflect case mix, small denominators, longer discovery or response pathways, coding practices, or true differences in injury severity. The available data cannot distinguish these explanations.

Predominance of death at the scene

The predominance of at-scene deaths is consistent with the conceptual distinction between prehospital and in-hospital trauma mortality. Studies from Malawi found that prehospital deaths differed markedly from in-hospital deaths and were frequently associated with severe head injury, road traffic injury and mechanisms causing rapid death (Purcell et al., 2020; Mulima et al., 2021). Direct numeric comparison is limited by differences in trauma systems, case definitions and data sources, but the international evidence supports the inclusion of deaths occurring before hospital arrival in injury surveillance. A registry restricted to admitted patients would miss the majority of fatal cases identified in the present EMS cohort.

The high male proportion and the concentration in middle-aged adults also align with established injury epidemiology. WHO reports that injury mortality is approximately twice as high among males globally, with road traffic injury, homicide and suicide prominent among male deaths (World Health Organization, 2024). In the present cohort, almost four in five episodes with known sex involved males, and self-harm and transport codes were common. This demographic structure suggests that prevention must extend beyond clinical response to road safety, occupational safety, alcohol and substance risk, violence prevention and suicide prevention. When prevention is planned for older population groups, clinical measures should be complemented by an ethical and psychosocial approach that respects the specific needs of older people (Zacharová, Magyaricsová and Repiská, 2020). For long-lived older adults, prevention and follow-up should also take into account the specific problems associated with home-care settings and the complexity of their care needs (Zrubáková, Magerčiaková, Šarkoziová and Repiská, 2026).

Geographic access and transport patterns

Fatal transport events were uncommon relative to deaths at the scene, and confirmed inter-district flows were small. Nevertheless, their direction was informative: routes generally converged on regional centres. This is compatible with the hub-and-spoke organization of emergency and specialized care. International research has linked longer predicted travel time and reduced geographic access to trauma care with higher mortality in selected populations, although effects depend on geography, case severity and statistical model (Tansley et al., 2019; Byrne et al., 2022; Hwang, Jeong and Jo, 2023). McHenry and Smith (2023) further showed

that geographic isolation affected the likelihood of a prehospital critical-care response in major trauma in northern England.

The Slovak transport layer should not be interpreted as a direct test of travel-time effects. Destination was missing in most transport-related episodes, route geometry represented district centroids or operational flows rather than road-network travel time, and the dataset did not contain a validated injury-severity adjustment. The map is best used to identify recurrent referral directions and data-quality priorities. Standardized destination codes and automatic capture of origin, route and hospital arrival would permit future network analysis, isochrone modelling and evaluation of equity in access to trauma-capable facilities.

Interpretation of R96-R99 in an injury study

A major methodological issue is the role of R96-R99. These codes describe other sudden death, unattended death and other ill-defined or unspecified causes of mortality; they are not external-cause injury codes (World Health Organization, 2015). Their presence in an EMS record may reflect the terminal condition observed by the crew rather than the underlying cause established after forensic or hospital investigation. The present study therefore required a concurrent S, T, V, W, X or Y code. All 2,236 included operational records met that combined criterion. The results should nevertheless be described as injury-related or injury-associated fatal EMS attendances, not as certified underlying causes of death. Linkage with forensic and national cause-of-death registers would be required for etiological mortality estimates.

Implications for EMS planning and public health

The map and analyses can support planning at several levels. Absolute counts identify where fatal workload and exposure are greatest, which is relevant for staffing, equipment, training and coordination with emergency departments. Operational ratios may identify districts requiring audit of case mix, response intervals, dispatch accuracy or access pathways. At the organizational level, structured risk-analysis methods such as FMEA can support the systematic identification and prioritization of weaknesses in care processes (Šulcová and Nemčíková, 2025). Inter-district routes identify regional referral connections that should be considered in capacity planning and mass-casualty preparedness. Geospatial outputs can also guide targeted injury-prevention partnerships with road authorities, municipalities, employers and public-health agencies.

For surveillance, the most important improvement would be a stable patient and event identifier shared across dispatch, ambulance crews and receiving facilities. The near-perfect rank correlation between raw and deduplicated district patterns suggests that the current map is spatially robust, but duplicate records inflate absolute totals and complicate comparisons. A standardized minimum dataset should also include injury severity, mechanism, vital signs, response interval, on-scene time, exact destination code, return of spontaneous circulation where relevant, forensic confirmation and linkage to final cause of death. Population-based age-standardized rates could then complement workload-based indicators, as recommended by broader European injury-burden research (Haagsma et al., 2022).

Strengths and limitations

The main strengths are nationwide coverage, the use of event-level spatial identifiers, explicit reproduction of map maxima, transparent injury-associated inclusion criteria and a patient-level sensitivity analysis. The analysis also distinguishes absolute spatial burden from a denominator based on EMS injury volume, reducing the risk of interpreting high-population districts as high-risk areas solely because of their size.

Several limitations must be considered. First, this was an operational EMS database rather than a mortality registry, and diagnosis codes represent prehospital documentation rather than certified underlying causes. Second, multiple-unit responses generated duplicate records; deterministic linkage can reduce but not completely eliminate over- or under-linkage. Third, 41 scene records lacked district information. Fourth, destination was unavailable or uninterpretable for 194 of 236 transport-related episodes, so most orange symbols were assigned by origin district rather than confirmed as within-district transports. Fifth, the study lacked population denominators, injury severity and socioeconomic covariates, and the ratio per 1,000 injury attendances is not incidence or a risk-adjusted quality measure. Sixth, the dataset covered partial years in 2018 and 2023, precluding valid annual trend inference. Finally, ecological district-level associations cannot be used to infer individual causal effects.

Conclusion

Injury-related fatal EMS attendances in Slovakia from 2018 to 2023 showed a clear but nuanced geographic pattern. Bratislava and several regional centres had the highest absolute scene-death counts, while smaller districts emerged when fatalities were related to total injury EMS workload. Most deaths occurred before transport, and confirmed inter-district fatal transports were rare and directed mainly toward regional centres. The map was quantitatively validated against the source database: the maxima of 178 scene records, 20 origin-anchored transport deaths and three deaths on a single inter-district route were reproduced, and raw and deduplicated district rankings were almost identical. Future surveillance should combine population-standardized rates, patient-level linkage, injury severity, response-time measures and certified causes of death to distinguish exposure, access and system performance.

This article was recommended for publication in the scientific journal Young Science by:
doc. PhDr. Katarína Zrubáková, PhD.

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Mladá veda

Young Science

ISSN 1339-3189