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ANALYSIS OF THE COMPONENT ELEMENTS OF TRAFFIC SAFETY USING GEOSPATIAL TOOLS

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Abstract

The primary motivation for undertaking this study was the challenge of highlighting and effectively integrating new digital mechanisms into efforts aimed at improving traffic safety across the road network. The adopted working strategy is based on the fundamental principle that any dataset containing a known reference position, regardless of its nature, can be spatially represented on a map and transformed into an overview that is significantly easier to visualize and interpret. This approach facilitates understanding among all stakeholders involved, irrespective of their level of specialization in traffic safety. By applying this strategy, the ultimate objective is to transform the manner in which specialists access and analyze decision-support information, enabling rapid—sometimes near real-time—assessment from any internet-connected device.

Keywords: GIS, geospatial, interconnectivity, geostatistics

1. INTRODUCTION

The field of traffic safety can be seen as one of those areas of activity that must constantly maintain a balance between the effectiveness of investment and the level of safety in its operation. A road cannot be built with just asphalt, without any traffic restrictions or protective measures for those who use it, even if, hypothetically, a road without restrictions is faster and more efficient to use.

Thus, traffic safety aims to add the necessary active or passive elements that contribute to optimal travel from origin to destination, regardless of the type of vehicle used, travel that is not penalised more than is strictly necessary to maintain the lowest possible level of risk, up to the point where risk reduction could mean a drastic decrease in the economic efficiency and/or profitability of using that road.

Practical experience has shown that the main common element between all components of traffic safety is position, i.e. the parameter that indicates where objects are located, regardless of their geometric shape (point, line, polygon), where phenomena occur or where the effects of a phenomenon that has just occurred are distributed – specific case: understanding and positioning the dynamics of the increase in the number of vehicles stationary following a road incident.

At the same time, noting that geospatial technologies could become the main display and reporting tool for data collected in the field, I chose this theme in order to highlight methods and workflows that can lead to a better understanding of phenomena and processes in the field and, implicitly, to an increase in the level of knowledge of the mathematical reality in the field before making decisions with medium- and long-term impact and long term.

The application of digital and spatially enabled technologies has become central to modern traffic safety analysis and decision support. Geographic Information Systems (GIS) are widely recognized as foundational tools for integrating heterogeneous datasets through a shared spatial reference, enabling the analysis and visualization of traffic safety information at multiple scales [1,2]. Research demonstrates that GIS-based visualization significantly improves the interpretation of complex traffic and infrastructure data, facilitating communication and understanding among both specialists and non-specialist stakeholders [3].

Recent studies highlight the growing role of big data and web-based GIS platforms in traffic safety management. The integration of large-scale traffic, infrastructure, and environmental datasets within digital platforms has been shown to support more comprehensive safety analyses and enhance the identification of high-risk locations and patterns [4,5]. Web-based and cloud-supported GIS solutions further improve accessibility by enabling users to interact with spatial data through internet-connected devices, supporting collaborative and near real-time decision-making processes [6].

The shift toward data-driven safety management is also reflected in methodological frameworks promoted by road authorities, which emphasize evidence-based analysis, transparency, and systematic evaluation of safety measures [7]. Studies on traffic congestion and crash analysis indicate that integrating spatial data with analytical models improves the understanding of relationships between traffic conditions, infrastructure characteristics, and safety outcomes [8,9]. Additionally, advances in volunteered geographic information and crowdsourced data further expand the potential for real-time safety monitoring and public engagement in traffic safety initiatives [10].

Overall, the literature supports the conclusion that spatially enabled digital mechanisms—combining GIS, big data analytics, and web-based visualization—represent an effective approach to transforming complex traffic safety data into actionable decision-support tools. These approaches enhance accessibility, improve situational awareness, and enable faster and more informed safety-related decisions across diverse user groups.

1.1EVOLUTION OF THE CONCEPT OF TRAFFIC SAFETY

At the international level, there are numerous studies and research projects that provide both theoretical and mathematical foundations for the concept of road safety and traffic safety, all of which focus on increasing the level of direct and indirect protection for active and passive traffic participants.

Among the authorities with the highest number of studies in the field of road safety, the United States Department of Transportation, an entity that brings together most of the institutions responsible for this field in all states together with their partners, should definitely be mentioned.

At the research level, concepts in the field of traffic safety, specifically road safety, have evolved and are constantly developing towards the interconnectivity of vehicles that use the road infrastructure at the same time. In addition, after much multidisciplinary research, the US Federal Highway Administration is placing increasing emphasis on the notion of road safety audits and is attempting to define the concept of *"road safety"* as accurately as possible [11].

Thus, the very notion of safety has been defined as *"the absence of risk or danger"*[i] and by associating this definition with road transport, road safety, or more precisely road security, has been characterized by the ideal situation in which *"a person's ability to travel freely without injury or death"* is ensured [12].

Continuing this line of reasoning, it was concluded that the issue of traffic safety, regardless of how it is referred to, belongs to and must be managed by a multidisciplinary group of accredited specialists. It was concluded that a road safety audit is defined as *"a proactive, formal examination of the safety performance of an existing or future road by an independent, multidisciplinary team"*[13].

After evaluating the implementation of several such audits, it was found that this type of organization and the impartial conduct of the audits led to a reduction of between 10% and 60% in the total number of road accidents.

From a conceptual point of view, while traditional research follows certain patterns, road safety audits will always be unique and their design will always take into account all road users. Direct benefits highlighted by the application of road safety audits:

a. Reduction in the number of serious accidents due to design with a greater focus on safety
b. Reduced costs resulting from the identification and rectification of safety issues prior to the construction/implementation of projects
c. Increased awareness of good design practices for improving safety
d. Increased opportunities for integrating multimodal safety strategies and proven safety measures
e. Expanding the ability to consider the human factor at all stages of the project

1.2COMPONENTS AND OBJECTIVES OF THE FIELD OF STUDY TRAFFIC SAFETY

According to the approach adopted by PIARC in the Road Safety Manual framework document published in 2003, the factors that influence road safety are classified into three main categories:

a. the human factor
b. the environment in which travel takes place – this refers to the road and its surroundings
c. Vehicles and their safety equipment

All three of these major groups of factors have been broken down into sub-components, resulting in a structure that must also take into account the temporal criterion when referring to road accidents, which emphasizes the moment before the road accident, the moment during the road accident and the period after the road accident.

From the perspective of the proposed objectives and guiding principles of the study, based on the documents reviewed during the documentation stage, several objectives were identified, without any concern for dividing them into classes and levels. Some of these principles, which in some cases can also be considered objectives, are:

- *"continuous improvement of legislation in the field of transport and road safety, as well as monitoring compliance with it;*
- *identifying financing solutions for road safety activities from legally constituted sources;*
- *improving communication on road safety through better coordination and increased presence of experts in the field in the public sphere;*

- *making the detection of violations of specific road traffic laws more efficient by implementing automated technical systems for detecting, processing and penalising offences;*
- *using technology for prevention, monitoring and intervention;*
- *ensuring safe mobility for all road users by implementing automated traffic management systems.*

2. METHODOLOGY

Emphasizing the importance of analyzing the integral components of road safety from as many perspectives as possible, multiple data sets were used, grouped into several types and categories from a structural point of view. When referring to the basic structure of the data, it is important to specify that we are referring strictly to their IT component and the method of management/display in appropriate geospatial analysis platforms.

Thus, the data used are predominantly static data, both vector and raster, but the numerous advantages offered by dynamic data sets were considered, these being used mainly to consolidate the base maps used in the study.

At the same time, the data sets will be presented in groups, depending on the component for which their use was decided. For a clearer picture of all the elements and categories of information, the databases are explained in a detailed and transparent manner, taking advantage of the possibility of this extremely useful association between tabular data and map geometries.

This study, which focuses on the spatial distribution of road incidents at national level, is based on tabular information provided by the General Inspectorate of the Romanian Police, which also included coordinates associated with each incident, in a specific form, other than the format currently used at national and international level. Table 1 shows the conversion of the coordinate sets from the "lat" and "long" columns to the format of the "lat_gis" and "long_gis" columns. It should be noted that the resulting coordinate sets were additionally verified to ensure that they are in the WGS84 international geographic projection, EPSG 4326.

Table 1. Example of parallelism between the original coordinate format received and the resulting geographic coordinate sets.

No.	lat	long	lat_gis	long_gis
1	023E35.6199	46N04.1138	46.041138	23.356199
2	023E45.8023	46N04.2462	46.042462	23.458023
3	023E32.9858	46N01.7410	46.01741	23.329858
4	023E35.7443	46N04.2673	46.042673	23.357443
5	023E34.1798	46N03.0761	46.030761	23.341798
6	023E35.7504	46N04.2648	46.042648	23.357504

In order to perform the most accurate analysis possible of the phenomenon generated by the existence of road incidents, a series of clear steps were established for the statistical analysis of the data and their transposition into cartographic format. Following the coordinate conversion, the entire content of the tables was transposed onto the map using specialized software, using the lat_gis and long_gis columns for correct positioning. This was a consolidated data set containing road incidents from 2022. An overview of their distribution on DN 1–7 can be seen in the figure 1.

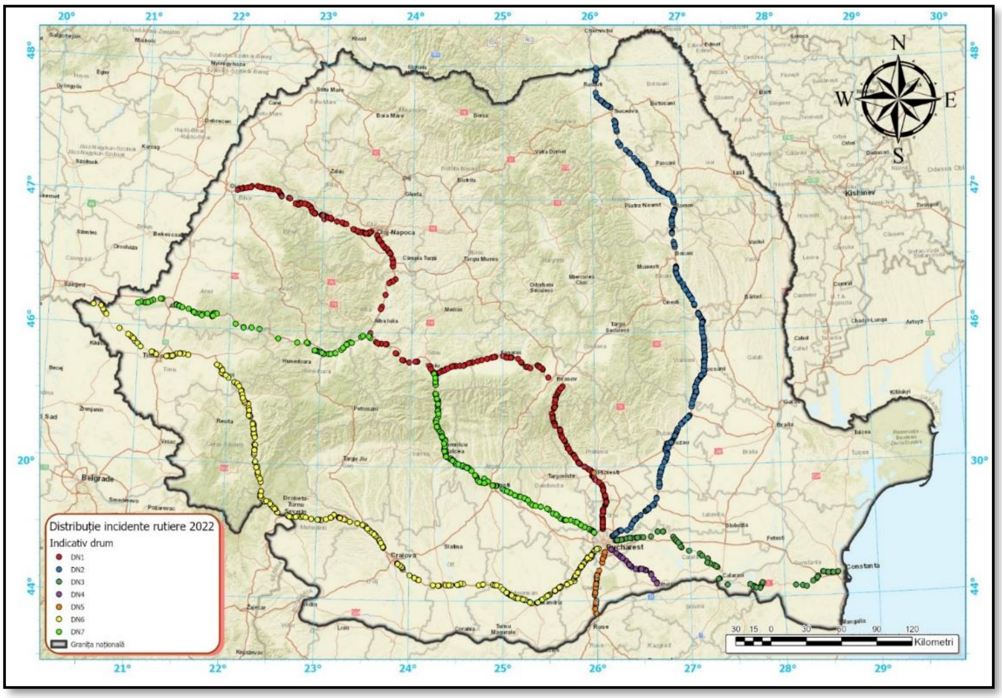

Figure 1. Spatial distribution of road incidents in 2022 on DN 1-7

When talking about natural phenomena that have the potential to cause damage in a geographical area, the term hazard is often used. According to the explanatory dictionary of the Romanian language, the term hazard is defined as "a circumstance or combination of circumstances (favorable or unfavorable) whose cause remains generally unknown". Thus, extrapolating the definition, we can consider that natural hazards can be particularly beneficial when the combination of circumstances is favorable to the proposed objective, or negative natural hazards when the combination of circumstances causes a situation with a negative impact on the geographical area where the hazard occurs.

We will further establish, as negative natural hazards included in this paper, land movements resulting from a set of natural phenomena occurring simultaneously with all the circumstances that cause sudden accumulations of water. Thus, for the areas in the vicinity of DN 1-7, with a direct and/or potential influence on the occurrence of natural hazards, elements of the natural environment will be analyzed, together with multiple scenarios, thus highlighting complex geospatial analyses related to the occurrence and development of the above-mentioned hazards.

Highlighting the areas at risk in terms of flash floods and water accumulation required a series of processing steps, carried out in a sequence in which each processing step builds on the previous one.

Thus, to begin with, the three-dimensional representation of the hypsometric map was taken as a reference, based on the processing of contour lines with an equidistance of 5 meters, resulting in the Digital Terrain Model (DTM), available in this paper in Figure 10, on which the following processing stages were based.

Next, it will be detailed each stage that was completed to obtain the watercourses, regardless of their permanent or temporary nature, thus managing to obtain a current picture of the dynamics of runoff due to precipitation. The stages of processing were as follows:

- Creating a false filling effect in the case of the Digital Terrain Model
- Determining the direction of water runoff on the slope
- Determining the water accumulation beds
- Creating conditionality rules for classifying the resulting pixels
- Converting raster information into vector format

The vector format basically represents the generation of a line-type geometry based on the pixels of the raster dataset that have approximately the same value. Basically, following these processing sequences, we have, from a geometric point of view, an overview of the confluence of runoff on the slope, allowing us to observe the risk areas for the built-up geographical area for both floods and water accumulation in the plain area. The areas most at risk from flooding were identified at the confluence of at least two valleys for the hill area, with the flood subsiding as it advanced towards the plain area.

3. ANALYSIS OF ROAD ACCIDENTS IN 2022

The centralised analysis of road accidents over an entire calendar year is one of the ways in which decision-makers can understand, in practical terms, the dynamics of road accidents, their causes, locations with contributing factors, and other elements that contribute to an increase in the frequency of road accidents in a given environment.

Thus, for a natural transition between technical language and an easier understanding of the phenomenon, maps were used as the main tool for analyzing and distributing the results in an intuitive way. In addition, representative diagrams were used together with tables containing quantifications and hierarchies for the information that could be standardized.

Detailing the spatial distribution of road incidents plays an important role in providing an overview of the location(s) where road incidents occurred. For easier representation, map sheets dedicated to each road have been created and can be viewed below, showing the official locations of road incidents recorded by the IGPR – Traffic Police in the form of a heat map or hotspot. All the figures presented in this subchapter were created in-house, with the data source mentioned.

Analyzing the cartographic representation of road incidents on National Road DN 1, we can see how the density of road events is higher. Thus, the highest density of road incidents is recorded in the area of Cluj Napoca, but most occur between Bucharest and the metropolitan area of Ploiești, followed by the high mountain area of Prahova Valley and the metropolitan area of Zalău.

Another important perspective is the identification of the administrative-territorial units within which road incidents occur. In the case of National Road DN 1, this spatial analysis can be seen in the following figure, which shows the names of the administrative-territorial units within which more than 13 road incidents were recorded in 2022.

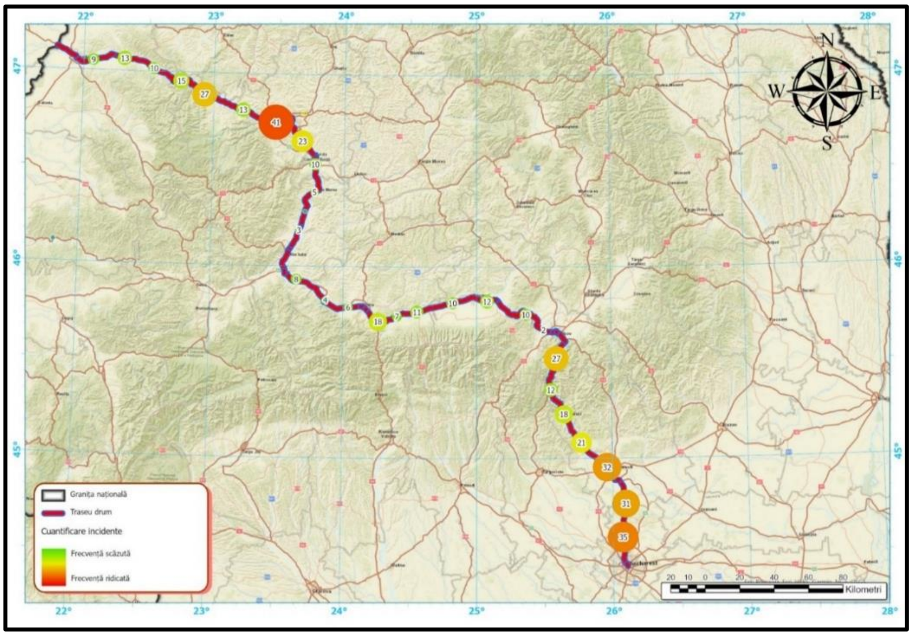

Figure 2. Distribution of road incidents on DN1

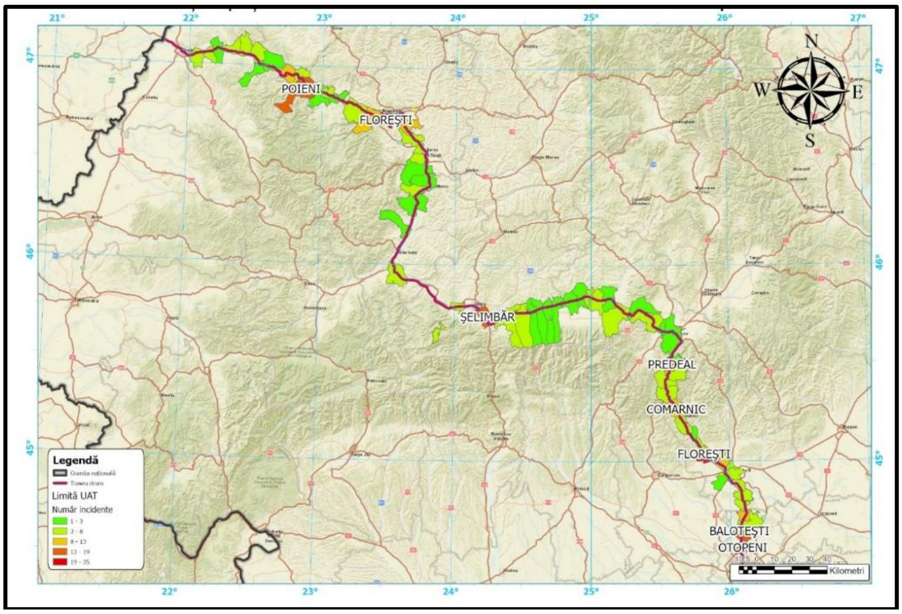

Figure 3. Spatial distribution of road incidents in administrative-territorial units in 2022 on DN1

The last but equally important perspective for understanding the phenomenon as a whole is the graphical representation of road incidents with at least one fatality recorded. Thus, it can be seen that DN1 has different characteristics in terms of fatalities compared to the other roads analyzed graphically according to the same representation criteria.

This graphical perspective, illustrated in the following figure, shows us that in the case of national road DN1, there is a concentration of deaths in two areas that are sufficiently well defined to allow for a subsequent analysis in detail of the areas with clusters of deaths resulting from road accidents.

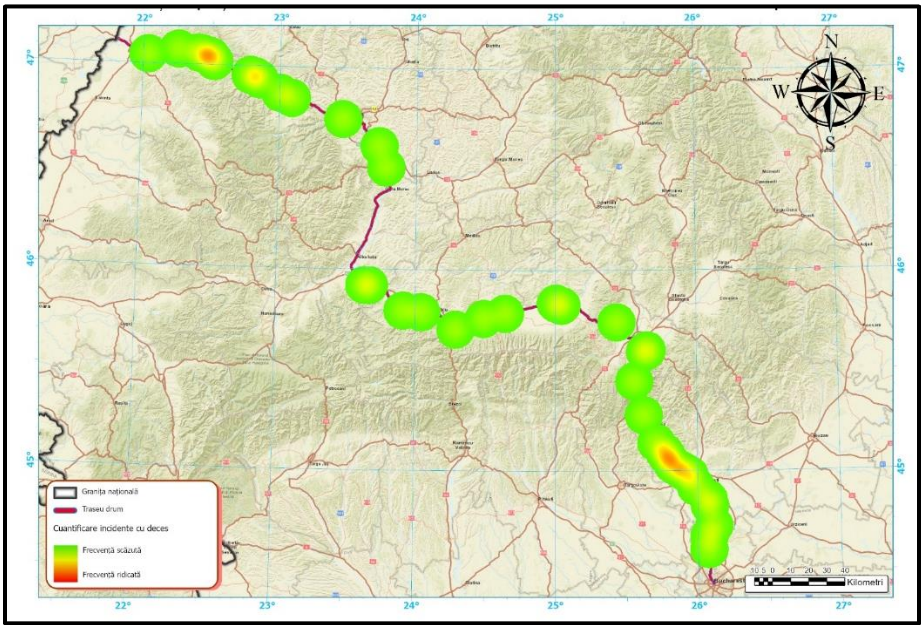

Figure 4. Spatial distribution of road accidents with at least one death in 2022 on DN1

For a clearer understanding, it was decided that for National Road DN 1, a summary table would be presented with all the related figures based on the indicator, followed by a suggestive graph without additional comments showing the calculated percentages.

Table 2. Quantification of road incidents at the UAT level on DN1

UAT name	Number of incidents
Floresti	37
Otopeni	16
Poieni	16
Balotesti	15
Comarnic	13
Negreni	12
Baicoi	11
Ploiesti	10
Paulesti	10
Ciolpani	10
Gilau	10
Vestem	10
Huedin	9
Barcanesti	8
Cornu	7
Feleacu	7
Mihai Viteazu	7
Osorhei	7
Sinaia	7
Azuga	7
Timisu de Jos	7
Gorgota	7
Tureni	7
Vladeni	6
Tincabesti	6
Capusu Mare	6
Cristian	6
Fagaras	6
Timisu de Sus	6
Copaceni	5
Scoreiu	5
Porumbacu de Jos	5
Bradu	5
Busteni	5
Banesti	5
Predeal	4
Alesd	4
Breaza	4
Tileagd	4
Puchenii Mari	4
Moldovenesti	3
Avrig	3
Rahau	3
Borod	3
Brasov	3
Saftica	3
Persani	3
Sercaia	3
Beclean	3
Blejoi	3
Miraslau	3
Codlea	3
Cirta	2
Cilnic	2
Topa de Cris	2
Auseu	2
Urvind	2
Cunta	2
Teius	2
Sandulesti	2
Ciucea	2
Bucea	2
Dridif	2
Selimbar	2
Apoldu de Sus	2
Voila	2
Lugasu de Jos	2
Gheghie	2
Ghimbav	2
Izvoru Crisului	2
Galda de Jos	1
Vilcele	1
Uileacu de Cris	1
Mohu	1
Tinaud	1
Saliste	1
Ucea	1
Decea	1
Bologa	1
Saula	1
Sacadate	1
Ciofliceni	1
Martinesti	1
Oltet	1
Mindra	1
Dumbrava	1
Ucea de Jos	1
Grosi	1
Unirea	1
Arpasu de Sus	1
Sabolciu	1
Campina	1
Vistea de Sus	1
Aiud	1
Sacel	1
Bors	1
Lancram	1
Total incidents	**43**

A standardized understanding of the conditions in which road events took place, together with an overall cartographic analysis of the entire phenomenon, is one of the interdisciplinary approaches that can lead to a set of fully informed measures, along with an increase in the efficiency of their implementation.

Some of the conditions under which road events occurred on the national road will be presented, with a focus on the following parameters, as follows:

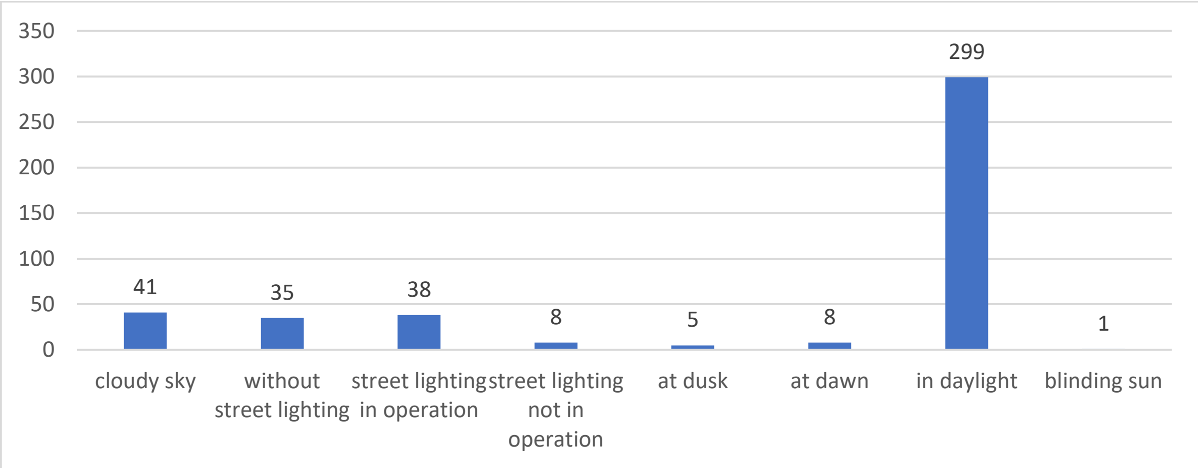

Figure 5. Graphical representation of the number of incidents according to the type of brightness

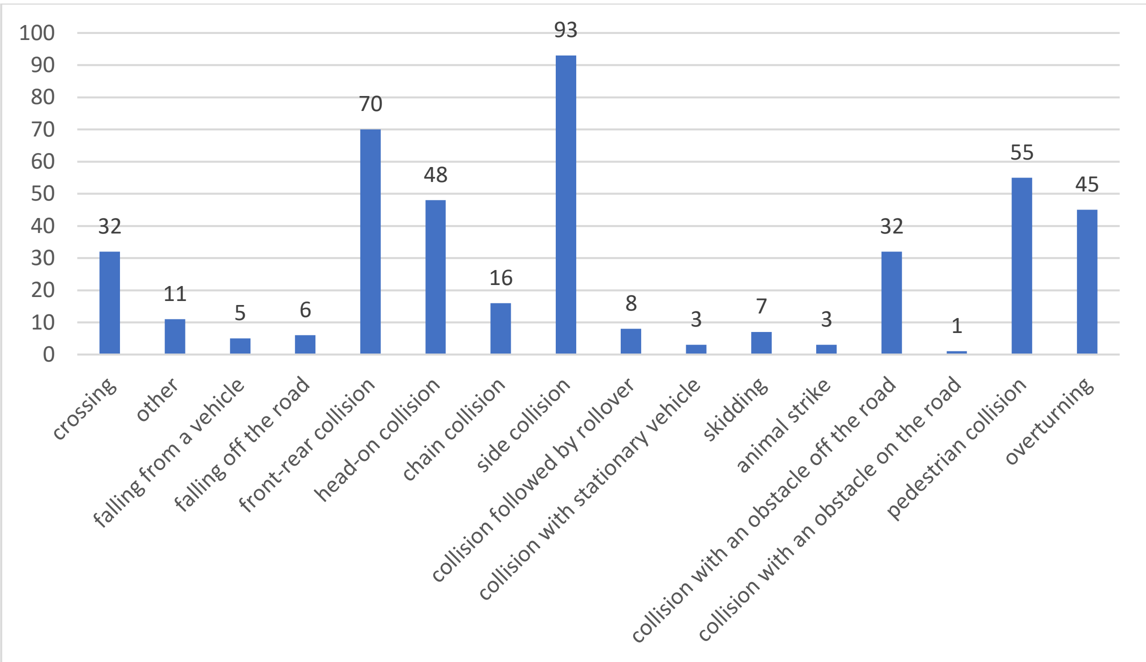

Figure 6. Graphical representation of road incident quantification according to the mode of occurrence

Temporary surface runoff is that part of hydrological phenomena that does not occur and does not produce constant effects over time but which, unplanned and considered in a probabilistic form, will have a significant negative influence in the medium and long term.

In practice, this phenomenon, which can be considered hydrological but also has a strong geomorphological component, actively and passively contributes to maintaining a sustainable and safe infrastructure over time, which will comply with a high percentage of the design specifications and maintain its safe use characteristics.

It has been possible to identify the areas of direct influence of temporary runoff along the entire route of National Road 1.

It all starts with the correct creation of a numerical model of the terrain along the entire length of National Road 1, considering the altimetric variations of the relief as a priority. The result of this processing stage described earlier in this study can be seen in the following figure:

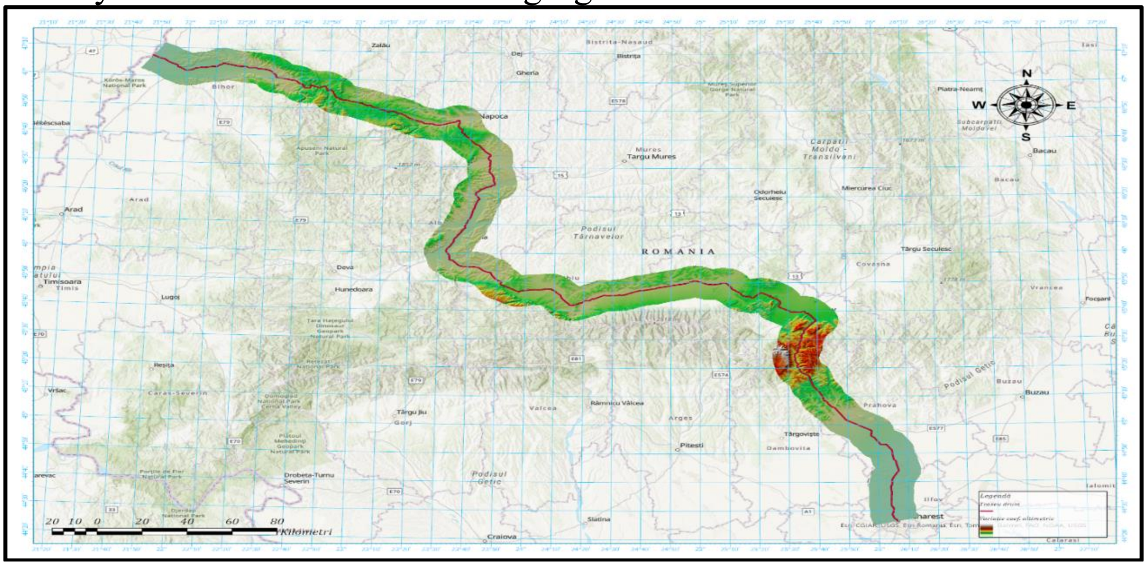

Figure 7. Graphical representation of the relief crossed by DN1

Subsequently, by applying the code sequence necessary for fragmenting the 3D terrain model and calculating the direction of water runoff, a general map was generated showing the runoff directions of the slopes along the entire route of the road, which can be studied below.

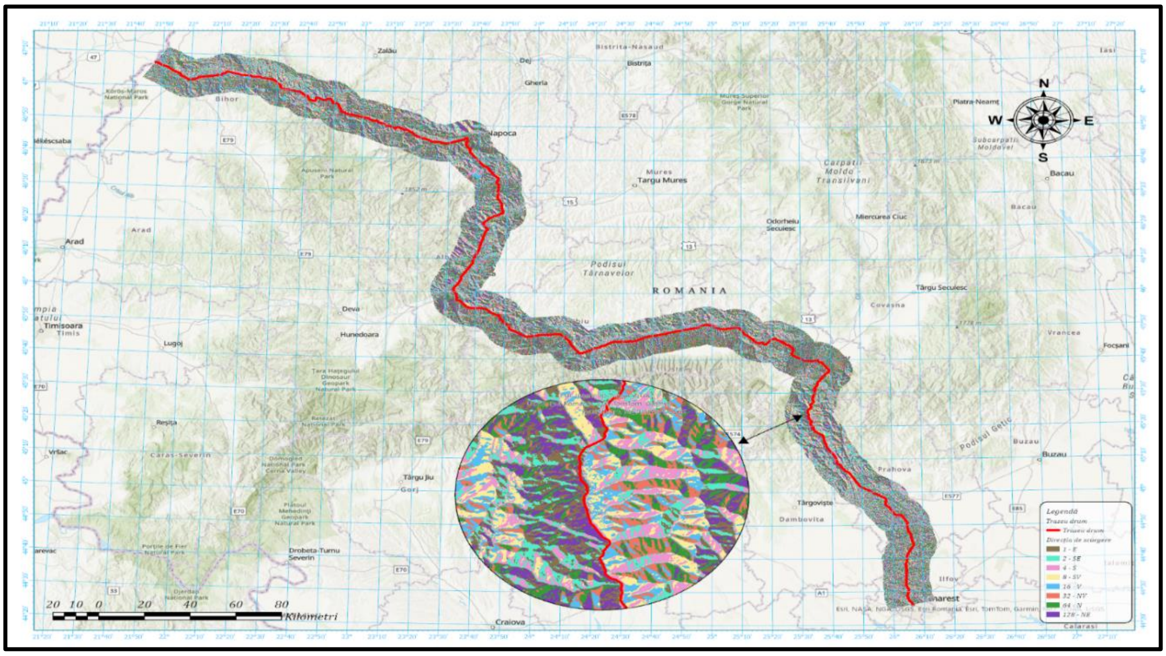

Figure 8. Highlighting the water drainage slopes according to the cardinal direction in the area adjacent to DN1

The exposure of the slopes provides essential information and parameters for understanding the phenomenon of surface water accumulation resulting from point precipitation. Thus, the calculation algorithms distribute the volumes of precipitation falling on a given surface to accumulation areas and then generate the general directions of temporary surface water runoff.

This environmental parameter does not have a direct influence on road incidents, but it negatively affects the quality/service level of the road network, as its degradation results in increased probabilities of a road incident occurring, based on the psychological component of the road user, as follows in a hypothetical example:

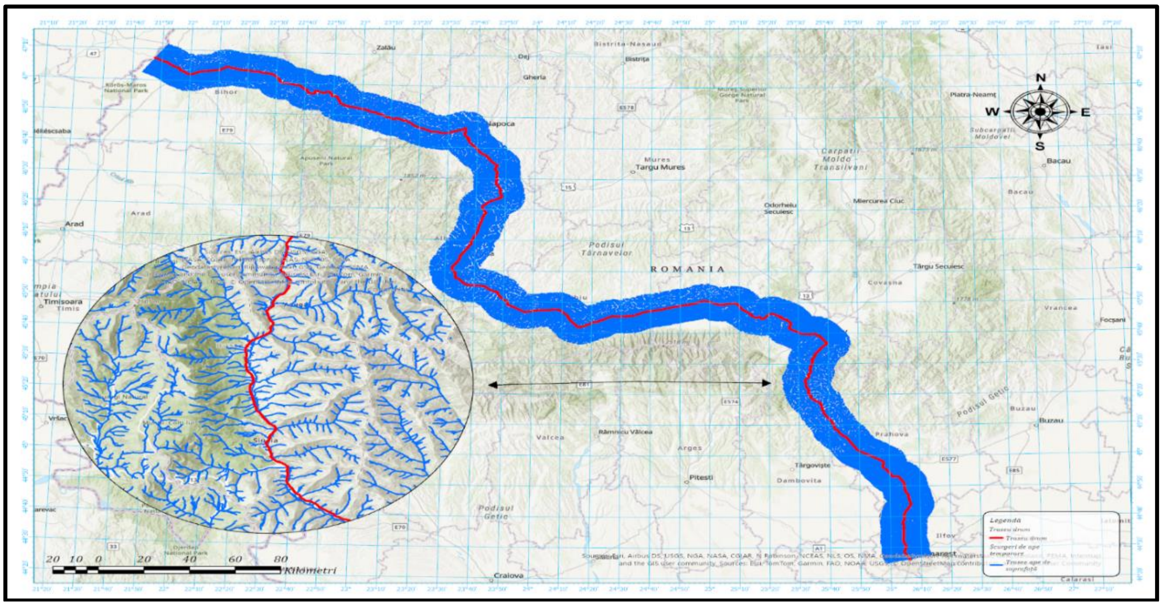

Figure 9. Centralization of temporary surface water runoff from the area adjacent to DN1

By superimposing layers of information, it was possible to highlight most of the areas where torrents and heavy runoff form, showing the need to provide water collection and drainage systems, underground crossings and/or the configuration of multiple erosion protection zones.

It should be taken into account that a factor contributing to the accelerated deterioration of asphalt pavements is the presence of debris on the road surface (gravel, sand, tree debris) which, under the pressure of the axles using the road, has an uneven and unevenly distributed transfer effect on the road layers, especially the asphalt considered to be wear.

Thus, using geospatial tools, it is possible to quickly understand the dynamics of the terrain along with certain parts that have a direct and indirect influence on the number of road events.

In any spatial analysis, part of the road network audit process must consider the capacity of traffic flows, regardless of their distribution by vehicle category, to affect and negatively influence the population in the vicinity of the road in operation.

The main analysis tool remains the method of observation on orthorectified aerial images in order to obtain a perspective view of the potential propagation of effects. This method has been substantially improved by using algorithms derived from the field of artificial intelligence to automatically identify buildings in the vicinity of the road and highlight them in the form of irregular polygons.

After a long stage of processing the aerial images, this method allowed the creation of a geometric perspective that can be used to directly determine cause-and-effect relationships between road incidents and the residential space built near the road. Image clarity was a determining factor in terms of the accuracy of the results obtained, but also in terms of the processing power required.

By applying the semi-automated processing sequences, the contours of roofs located up to 500 meters from the road axis were generated with a high degree of accuracy.

Overlaying the officially recorded road incidents will result in the complete map shown in the following image:

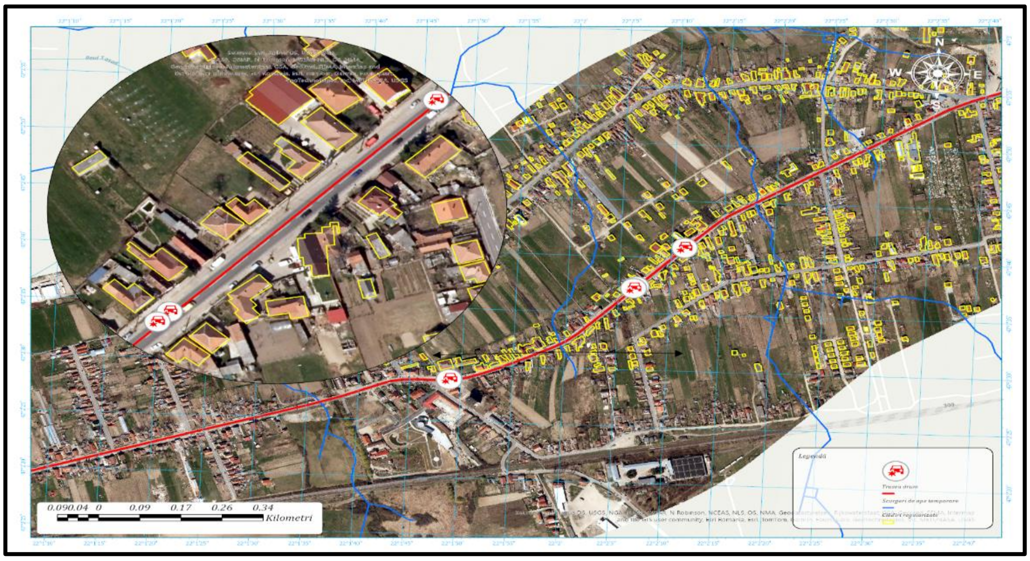

Figure 10. Location of road incidents in context

These two easy-to-understand examples for analyzing parameters that influence road accidents show the clear advantages of using geospatial processing tools and the increased level of simplification in delivering information according to user preferences and other decision-making factors.

4. CONCLUSIONS

Reviewing all the stages of study, analysis and presentation of the results presented in this paper, we can say with certainty that we have succeeded in clearly identifying clearly defined components which, when combined, make up parts of the field of traffic safety.

The general conclusion that emerges from the detailed analysis of road incidents on the DN1 in 2022 is that most of them occurred without aggravating environmental conditions, with behavior remaining the main factor. However, with a good psychological understanding and some additional measures to ensure that the road offers passive protection in the event of a road accident, fewer serious injuries or deaths could be caused.

The study of road incidents has proven to be the central element around which public traffic safety policies are built, and the use of intuitive tools for analysis and cartographic reporting opens up real prospects for transforming tabular information into information that significantly accelerates the analytical and decision-making process.

This research topic will be continued, considering the ongoing shift of digital tools from local equipment to real-time cloud platforms, with high-frequency geostatistical analysis modules and clear rules for accessing and using products and services.

In conclusion, it should be emphasized that significant academic progress with results transferred to the end user of the road network cannot be achieved without extensive interconnection between several curricular areas of study through the use of digital tools with similar data transfer formats.

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