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# CliRtheRoads: An Integrated Approach to Landslide Risk Management on Roads in Serbia

Biljana Abolmasov, Ranka Stanković, Miloš Marjanović, Nikola Vulović, and Uroš Đurić

## Abstract

In the framework of the project “Mainstreaming Climate Resilience in the Road Transportation Management in Serbia (CliRtheRoads)”, a complex mapping tool was developed to support the Government of Serbia and Public Enterprise Roads of Serbia in climate change adaptation planning and management. The software solution comprises of: a web portal for data entry and management for authorised users; a publicly available web-GIS application; a mobile GIS application; and a back-end database. This paper briefly overviews the system, focusing on the landslide data model. Therein, the main system and software solution breakthrough is automatizing the estimation of investment costs of engineering and non-engineering measures recommended at affected locations along the road network. A retrospective on its applicability and user feedback is also included. The objective was to facilitate seamless road management by providing necessary data in a simple, understandable fashion, indicating which locations on the road network have higher priority. The introduced level of automation allows easier decision-making and investment planning.

## Keywords

Landslides database · Mobile app · Road management · Climate change

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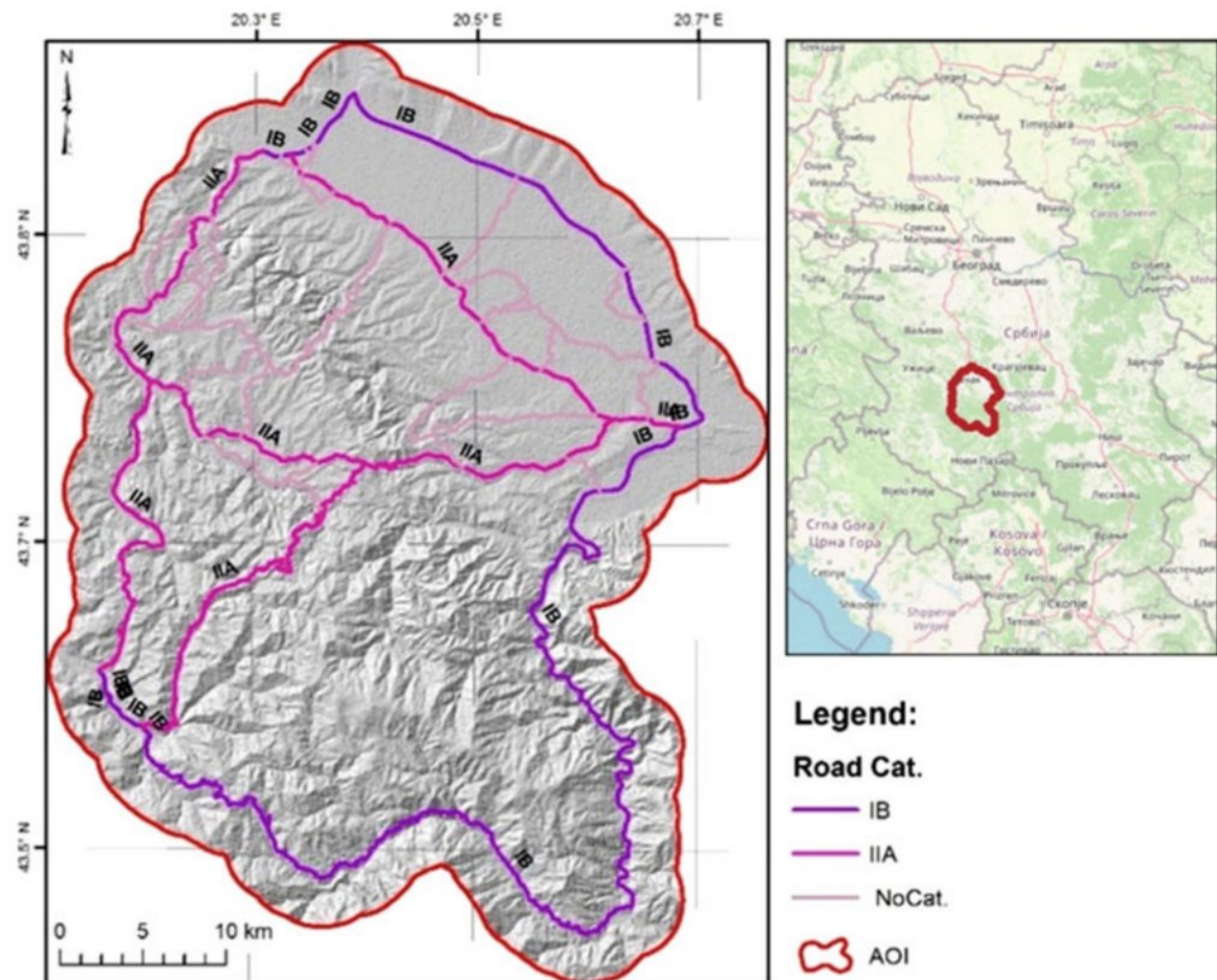
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## 1 Introduction

Since 2016, The World Bank Transport Team has supported the Government of Serbia to mainstream climate resilience in the road transportation sector. The general idea was to connect transportation and natural disaster management after devastating floods and landslides in 2014 (Abolmasov 2019; Đurić et al. 2017; Marjanović et al. 2018a, 2018b). The total negative effect on the transport sector was EUR 166.5 million (RNA Report 2014). Jotić et al. (2015) estimated that approximately more than 2000 landslides were activated on the state roads and more than 3000 on the local roads. Several activities and projects were conducted under the support of The World Bank in recent years, including a project titled “Mainstreaming Climate Resilience in Road Transport Management in Serbia” (CliRtheRoads). The project’s main objectives were to support the Serbian government to mainstream climate resilience in the road transport sector management in Serbia, by enforcing public agencies in charge of roads to follow the climate proofing agenda and include it in day-to-day practice. To that end, the primary step was to develop a practical methodology for assessing the road transport network’s climate-related hazards, vulnerability and risks. It was necessary to improve the capacities of key stakeholders in road network climate resilience planning and set the path for the development of structured and systematic response plans. The agenda included two parts, split into many different tasks, wherein one of them was to test the proposed methodology. The City of Valjevo was selected as a pilot region, followed by other regions. A crucial sub-task was the development of corresponding geographic information systems (GIS) maps for hazard, vulnerability, and risks; and mapping tools to collect the data in the first place. The project was led by IMC Worldwide Ltd. (UK) in partnership with the University of Belgrade, Faculty of Mining and Geology (SER), the Highway Institute Belgrade (SER) and the Acclimatise (UK) in 2017–2018.



**Fig. 1** The study area location and the road network



The second phase of the project was led by the ARUP d.o.o. (SER) as a branch office of the Ove Arup and Partners International Limited (UK) and the University of Belgrade, Faculty of Mining and Geology as a partner. The second phase was finalized in 2020–2021. The testing area was changed to the Kraljevo-Čačak-Ivanjica region (Fig. 1) with an additional task to improve data acquisition by designing an Android application for mobile devices.

The previous research and system development that influenced CliRtheRoads software solution was the project BEWARE, which developed an interactive web-GIS portal (Abolmasov et al. 2021; Abolmasov et al. 2017, 2018). The BEWARE mobile application, as a part of the integrated system, was built for the fieldwork and adapted for quick entry of field data, considering users' experience in local self-governments (LSGs) (Vulović et al. 2017). Similar functionality was envisaged for CliRtheRoads with an additional focus on road management issues, such as cost estimation, automation in staff shortage circumstances, and so on.

The mission of this project and other initiatives was to raise awareness of the natural hazards and climate change within the public enterprise (PE) sector and LSGs and to motivate the legislative authorities to improve design standards in future and take these effects into account. Once the entire decision-making pyramid is updated with climate changing hazard approach, the management of the road network will become more sustainable. In this particular case, public enterprise staff and relevant decision-makers were

supplied with equipment and software, and then trained to use it, thereby allowing to digitize their day-to-day practice, with an emphasis of hazardous events along the road and forward thinking on their mitigation.

## 2 Data Model

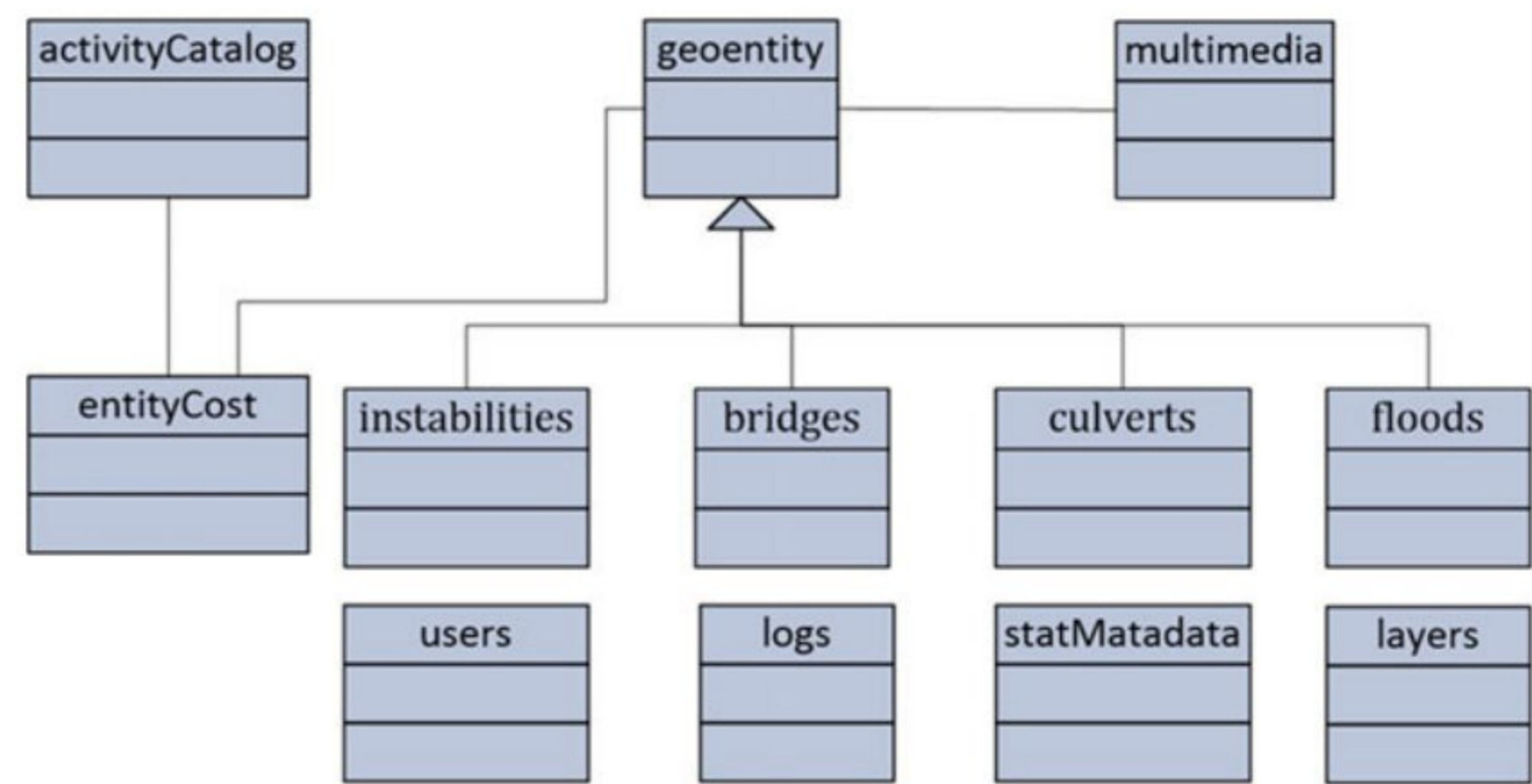
The data model (Fig. 2) behind the CliRtheRoads system includes: (1) main concepts (entity types for instabilities, with detailed data comprising of common and specific attributes); (2) storage of multimedia (photographs from fieldwork); (3) knowledge base with the cost of activities, including catalogue per each entity type with job type and description, unit and total price, maintenance type (regular maintenance, rehabilitation, urgent maintenance), including recommending activities (the system allows users to add specific activities, description and cost of recommended works that is further calculated and aggregated with other data); and (4) secondary data from other sources (other projects, archived data and external resources), or from interpreted data (primarily from existing hazard models).

### 2.1 Main Concepts

Data acquisition was first conceived using analogue data forms to inventory affected road assets. The forms were



**Fig. 2** The data model used for data entry, data editing, and storage of photographs



retrieved from various sources and experiences and simplified to the level of checkboxes and short inputs. Based on the adopted paper form, a digital version was developed with all related data definitions and specifications.

Data fields used for all datatypes included general identification data like: ID, project name, road mark, location (descriptive and geolocation), registration date, responsible researcher, and some metadata related to the user and data status (submitted for verification, pending, verified). Geolocations were recorded as longitude/latitude and chainage (start/end). Additional data may vary depending on the natural hazard at hand.

For instabilities/slope failures (slides, falls, topples, and flows), additional data included: the date of activation or/and reactivation, type of movement, the material involved, water content, the velocity of movement, state of activity, geometry (dimensions), lithological composition, soil thickness, watercourses (permanent or intermittent), hydrogeological causes/triggers of instability, the position of the phenomenon in relation to the road, the threat of the road by the instability, traffic interruption, previous investigation and recommendations of various mitigation activities.

According to recommended activity group (e.g., maintenance, investigation, design, and monitoring), the system allows the users to add specific activities within that group, with their further description and cost that is automatically calculated (in particular, for all maintenance activities, which are calculated per the legislative price list, while for others the cost is estimated by the expert) and aggregated with other data.

## 2.2 Data Storage

The Android mobile application of the CliRtheRoads facilitates the input of all these relevant data interactively in online or offline mode (in remote areas with no internet coverage). The data is locally stored and subsequently

uploaded to the server once the Android device is back on the grid.

A web application of the CliRtheRoads (<http://clirtheroads.rgf.rs/>) was developed in parallel (using PHP) to facilitate data input (by downloading data from the mobile app or by direct web app input). All web forms were standardized, with specified required and optional fields and logical constraints, to help speed up the data digitalization phase and to ensure unified inputs. Data editing and validation were also included. Data filtering and keyword-based searches provided easy access to the data stored in the database.

Once all data was collected, it was stored in the PostgreSQL database using a model adapted to the input data forms. The database developed in the first phase of the project (for the Valjevo area) was modified to include new datasets and to store new data categories (such as floods, culverts, and bridges) and new modules (activity type and cost). Each data entry was assigned a code for the corresponding project: CliRtheRoadS1 (the Valjevo region) or CliRtheRoadS2 (the Kraljevo-Čačak-Ivanjica region).

## 3 Data Management

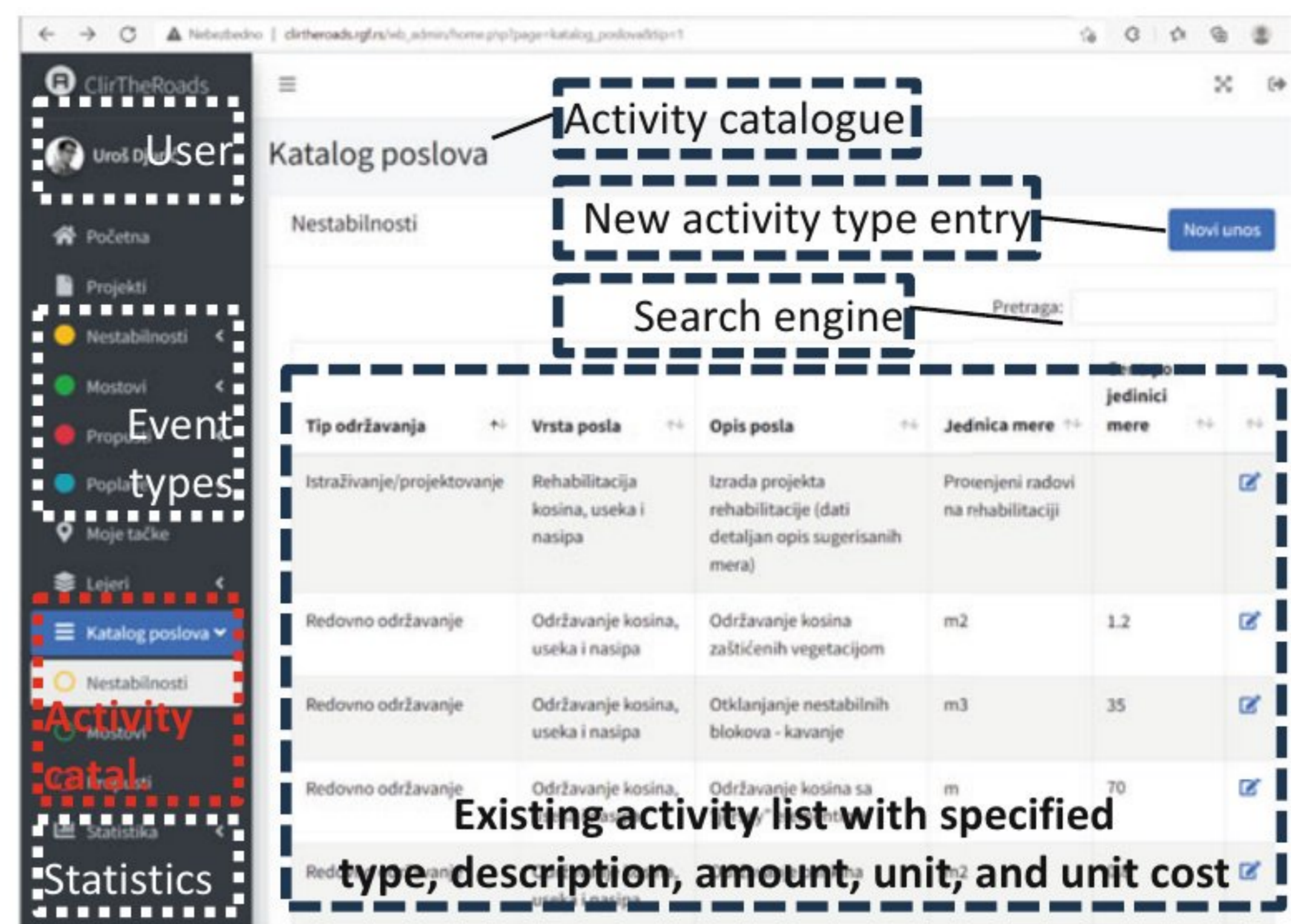
A screenshot from the web application with an overview of the catalogue for mitigation activities is presented in Fig. 3. In contrast, Fig. 4 shows the data entry form for this catalogue.

Once defined in the catalogue, the interventions can be assigned to each observation entry (instabilities, culverts, bridges, floods), wherein all generic intervention costs (such as maintenance and urgent maintenance costs) are automatically calculated, while rehabilitation and design costs have to be additionally estimated by the expert user (as it is a site-specific matter).

Thus, apart from entering instabilities (landslides), culverts, bridges, and floods that users encounter on the field (along the road) and reporting through the mobile or



**Fig. 3** The preview of the main panel with activated (red) Activities catalogue, wherein a list of recommended activities can be defined (<http://clirtheroads.rgf.rs/>)



web app, a completely new cost module was developed, allowing direct estimation of the site mitigation cost. Generic recommended activities (e.g., maintenance) can be entirely customized regarding cost calculation. The catalogues based on data templates for different levels of predefined interventions include: the type of intervention, intervention description, unit, unit price, total price, and maintenance type (regular maintenance, rehabilitation, and urgent maintenance) per each entity type (instabilities, culverts, bridges, floods). They can be edited and changed if, for example, the unit price for specific activity becomes more expensive. A screenshot from the web application with part of the data entry form of recommended activities is presented in Fig. 5.

In the first and the second phase of the project, ten users (field specialists), two application administrators (senior experts) and two database administrators (IT specialists) populated the database using either a web form or a mobile app. However, the tool is intended to be used by field workers from the PE or LSG after being adequately trained to report the event on a road network, recommend its impact

mitigation and estimate the cost of undertaken measures. It is a challenging task and could require a multidisciplinary team comprising different engineering fields, preferably geological, civil engineering, etc. On the other hand, PE, or even more so LSG is expected to cope with the shortage of such staff profiles, another stimulus to improve the staff capacity in this respect.

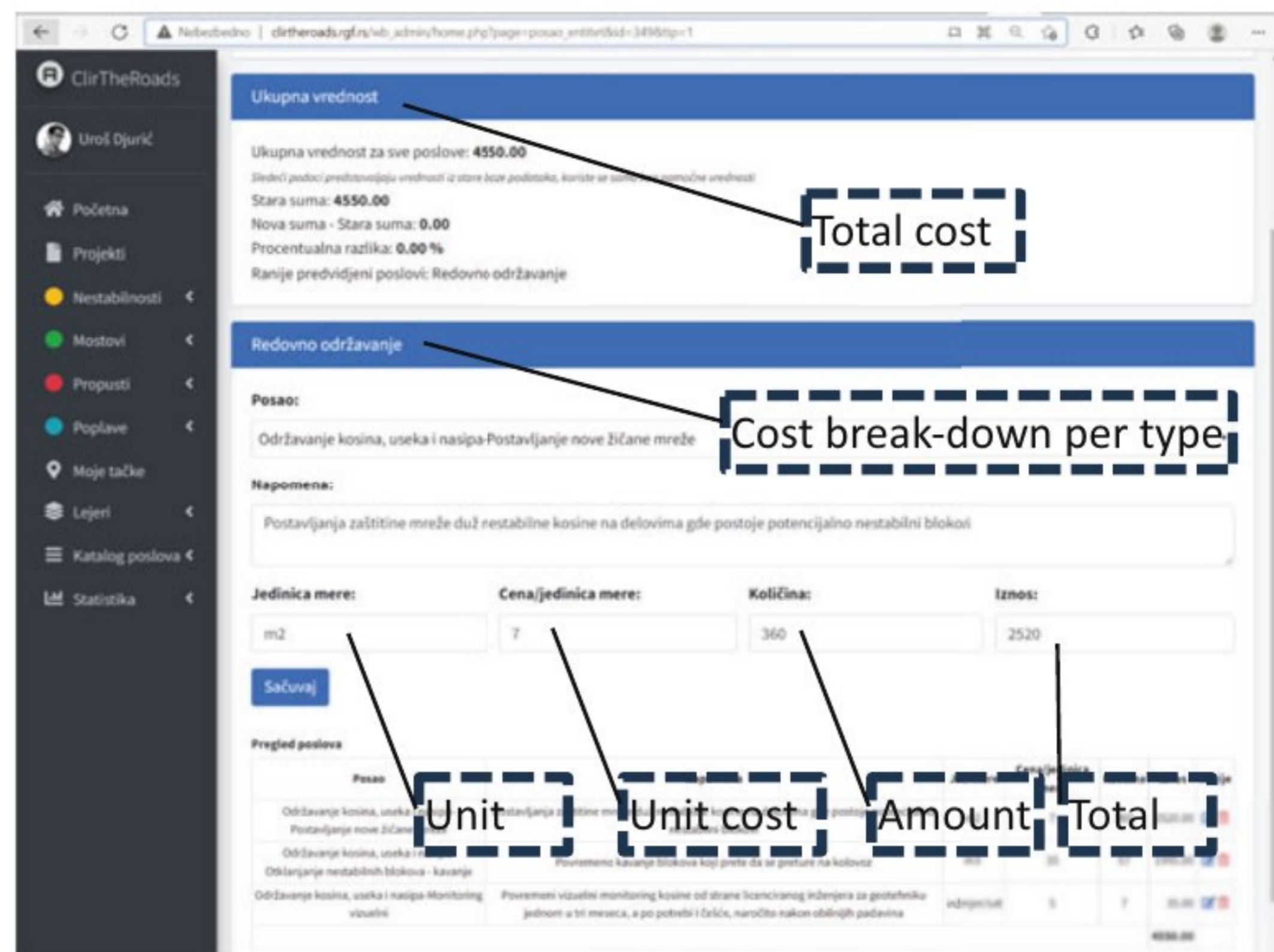
Various statistical analysis with graphical representation has been included in the CliRtheRoads application. An example is given in Fig. 6. Apart from the previous 187 records (CliRtheRoads1), there are 264 new records (CliRtheRoads2) with fully described instabilities, supplemented by numerous photographs from the field. For culverts, 145 records from the first phase were appended, with 190 new records illustrated by several photographs per culvert. For bridges, there were 123 records, while the new dataset included 71 records supported with 3–6 photographs per entry. The flood module is introduced within this project, and it contains ten unique records.

**Fig. 4** An example of recommended activities editing/creating new (from the available list of activities), with the specified group, type of work/intervention, its description, amount (defined by dimension), and unit





**Fig. 5** An example of a completed data entry form for maintenance activity subgroup



A statistical module enabled a comprehensive overview of the data against different classification parameters. This was supported with a graphical preview of charts and tables, with links to appropriate data collections. Data classification can be represented and structured by various attributes, supplemented by basic statistics for road section, hazard process, geologic composition, length, depth, activity, traffic impact, etc. Almost any data category from the web form can be used as a classification parameter, with classes deduced from the database.

#### 4 GIS Component

PostGIS Extension to PostgreSQL Database for hosting GeoServer was used to implement a website with mapping capabilities to provide the demanded geospatial data. To host GeoServer, the PostgreSQL database was extended with PostGIS. With the PostGIS extension, PostgreSQL can be used as a backend spatial database for GIS. GeoServer

provides a set of required functions, such as spatial data entry, management, analysis, and visualization, by sharing and publishing GIS resources on the web as web services. GeoServer is an open-source Java software server. It is used for generating, sharing, and managing geospatial data. Using open standards, GeoServer publishes data from any major spatial data source.

This system consists of the database and the web application. It is also supported by a flexible web-GIS application containing selected data for public and internal use with maps produced by the field acquisition or external GIS processing, as seen in Fig. 7. It provides insight into the current, present, and future zones exposed to target hazards along the road network. A web-GIS application was developed on an open-source spatial database using the PostgreSQL database management system. This is currently one of the most popular open-source spatial databases.

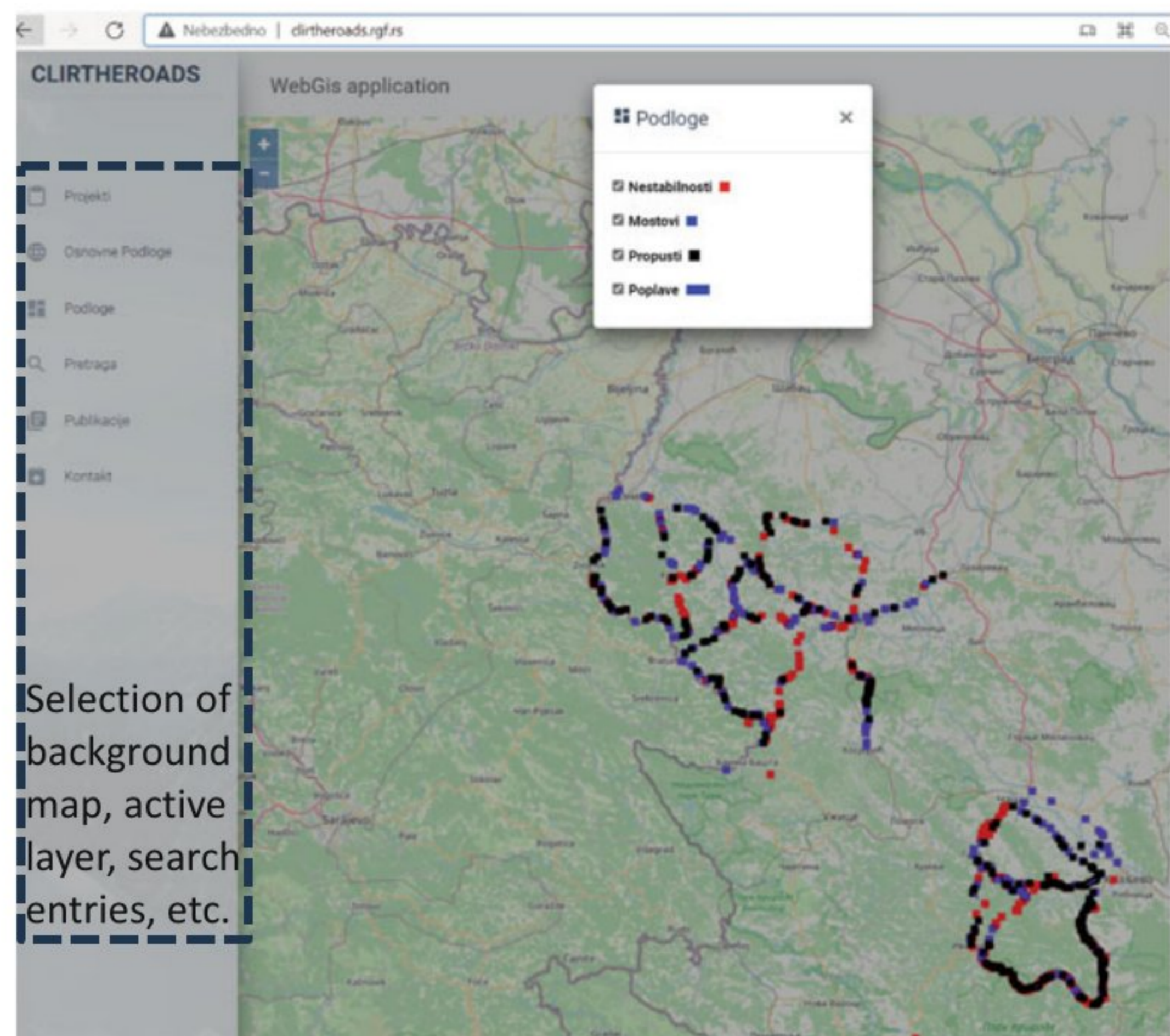
Mobile applications in offline mode manage data in local data storage. In contrast, in connected mode (when the connection via the Internet can be established with the central

**Fig. 6** The example of statistical overview: the landslide data group (in particular, landslides in respect to road alignment: road below the landslide (orange bar); road crossing the landslide middle (blue bar), etc.)





**Fig. 7** Screenshot of the Web-GIS output (entry points with different colours for different types: red—instabilities; blue—bridges; black—culverts; blue section—flood)



server), the data are sent to a central repository. The mobile application supports shorter data sets (e.g., entries completed by filling in only required fields) that can be further complemented (additional photographs can be uploaded, and other comments typed), edited and verified via the web application. The web application can be accessed from mobile phones since the interface is responsive and adaptable to the screen size (phone, tablet, laptop, desktop). The entry can be entirely on the field if there is appropriate internet coverage.

Due to the risk of hazards recurring in the exact location, this inventory will provide planners with a screening tool showing the geographic distribution of known and potentially new occurrences and serving as a helpful decision-making tool that relates directly to road maintenance or remediation requirements.

The main project outputs can be downloaded as open data in various machine-readable formats to enable the reuse of data for other related projects and research.

The following raster outputs are included: hazard maps, the exposure to the hazard of the road network per link, and the hazard of the road network per segment (links split into 500 m intervals). In addition, there are maps representing vulnerability and risk. The GIS maps are available in a raster (.tiff) format with: associated colour maps (to keep the visual appearance of the maps constant regardless of the user system and software preferences), a vector (.shp) format with associated (.lyr) files (compatible with ESRI software only, and also intended for preserving the visualization standards), and in Map Exchange Document (.mxd) files to preserve the symbology, order of appearance, background and layout

settings of the maps, legends, grids, scale bars, etc. (compatible with ESRI software only). There are also map package (.mpk) files available for ESRI software users, prepared in the same fashion (as .mxd format) but more suitable for transfer and sharing.

## 5 Conclusion

In the CLiRtheRoads system, thematic road-related data were managed and stored in a PostgreSQL database. At the same time, mobile and web application developed using PHP programming was used to facilitate data input. Potential users can benefit from the CLiRtheRoads application as the interaction is simplified to the level of advanced field users. The user should be a PE or LSG staff member familiar with the hazard processes (primarily floods, flash floods, rockfalls and slides) and the affected road asset. Ideally, the team for data collection should comprise engineering geologists and civil engineers trained to use the app. The system allows decision-makers to use primary outputs directly per affected location or road link/segment. The system enables decision-makers to act more confidently without knowing in-depth hazard analysis, structural remediation or other components because they are scaled down to estimated risk and cost. Although available for all Android devices, it is recommended to use the app on a tablet of 10' or similar size for better perspective and power autonomy (an Android phone can be used for other purposes during the day and drain the battery). It is also advisable to make entries in paper form in parallel, especially in long field campaigns and if the



field team is large enough (three or more members). In this project, two regions were used to test all functionalities: the Valjevo and the Kraljevo-Čačak-Ivanjica regions. A total of 461 records were collected with fully described instabilities (slides, falls, topples, flows), documented by many photographs from the field. Additionally, every record is supplemented by engineering solutions to support field engineers or decision-makers for better road management in climate changing conditions.

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