Increasing the Local Road Network Resilience from Natural Hazards in Municipalities in Serbia

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Abstract

This work is exampling a strategy for increasing climate resilience on local roads infrastructure in the Republic of Serbia, under the World Bank project framework. Methodological approach is briefly described as well as related mobile and web applications, labelled MaPLoRDs, which offers sustainable solution for resolving common issues encountered in road management at local, municipality level. It utilizes field and spatial data modelling as separate procedures which can be coupled or produce outputs independently, with minimal interaction with the operating staff. Collected data are translated into scores of exposure to main types of hazard (landslides, rockfalls, floods and flash floods) followed by vulnerability and criticality scores allocated per each road link. Final risk calculation allows ranking of highly impacted links that can be prioritized during subsequent road investment planning, enabling more rational budgeting. The concept is tested on two neighbouring pilot areas, the City of Kraljevo and the Aleksandrovac Municipality in Serbia, which are very different in terms of capacity, equipment and experience in dealing with natural hazards. Initial investment simulations for both pilots imply that MaPLoRds is a powerful tool for undertaking the first steps toward climate resilient roads.

Keywords

Local roads · Natural hazards · Climate resilience · MaPLoRds · Municipalities · Local road network · Natural hazards

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1 Introduction

The Republic of Serbia has experienced extreme climate conditions in the last two decades, especially floods, flash floods and mass movements (Prohaska et al. 2014; Marjanović et al. 2018a; Abolmasov et al. 2021). The frequency and intensity of floods and droughts have increased over the last 50 years, causing great socio-economic and environmental damage such as increased forest fires, desertification, decreased agricultural outputs and other negative consequences. According to the national climate changing projection, it is expected that average temperatures will increase between 1.7 and 2.3 °C in the next 50 years and that overall precipitation will drop, but the frequency of intensive precipitation is expected to be five times higher than in reference period 1981–2010 (Kržić et al. 2011; Rajković et al. 2013; Đurđević et al. 2018).

Roads in Serbia are the backbone of its transportation system and an important part of the European road network (TEN-T). The total length of roads in the country is 44,794 km. They are categorized as national-state roads (total length 13,505 km) and local (municipal) roads (total length approximately 31,289 km). All state roads in Serbia are maintained by the public, nation-wide, road construction company, The Public Enterprise Roads of Serbia (PERS), while local roads are maintained by municipal administration/public companies. Municipal local road networks vary in length and depend on municipality area, population, and number of settlements, as well as local morphological conditions. Only two-thirds of all municipal roads are paved.

More than 150 municipalities (out of 194) have suffered from flash floods, mass movements and riverine flooding in Serbia in the last decade. National road network, local roads, even urban streets, and assets including other roads structures such as bridges and culverts, are constantly threatened by flash floods, riverine floods and landslides. For instance, Serbia was heavily affected in May 2014, by extraordinary rains, which have caused severe flooding/flash flooding/land-

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sliding, unprecedented in the past 120 years. Recovery need assessment analysis done for 24 out of 38 affected municipalities in 2014, suggests that total effect on transport infrastructure was approximately EUR 166.5 million, out of which 96 million was estimated damage and 70.5 million was estimated loss. Rough assessment by PERS suggested that more than 2000 landslides were activated on the state roads and more than 3000 on the local roads (Jotić et al. 2015).

Review of the international practices related to climate resilience in the road sector shows considerable effort given to the national roads level. The methodologies for the inclusion of climate resilience considerations into the national roads transport management have been developed and tested successfully worldwide (Bíl et al. 2015, 2016). However, there is a limited number of methodologies related to the increasing local (municipality) road network resilience from natural hazards. Majority of projects in the World relate to the rehabilitation and construction of the road assets, but a small number of projects analyze the impact of climate change and natural hazards on the local road network (Andrejev et al. 2017; Marjanović et al. 2019).

Previous experience on national road network exposure and vulnerability assessment (Marjanović et al. 2022; Abolmasov et al. 2023b) recognized an urgent need to tackle local road network resilience and management in Serbia. This has been confirmed in practice, since 70 percent (in terms of the road length) of damages on the road transport network from natural hazards occurred at the local level (Jotić et al. 2015; Marjanović et al. 2018b; Marjanović et al. 2019).

Within the scope of the Japan-World Bank Program for Mainstreaming Disaster Risk Management in Developing Countries the World Bank received a grant from the Global Facility for Disaster Reduction and Recovery (GFDRR) for the Project "Improving Resilience and Safety of the Local Road Transport Network in the Republic of Serbia" in 2022. The University of Belgrade, Faculty of Mining and Geology (UBFMG) together with ARUP d.o.o. Belgrade directly contributed to realization of the Project Tasks, which included capacity building for local road network climate change adaptation planning and management within the beneficiary Local Self Governments (LSGs).

The Project activities directly contributed to the obligation of LSGs to prepare their local Disaster Risk Assessments, Protection and Rescue Plans and Disaster Risk Reduction Plans as per stipulations of the Law on Disaster Risk Reduction and Emergency Management adopted at the end of 2018 (Abolmasov et al. 2023a). UBFMG has been supporting activities of the national authorities as well as local authorities in the field of landslides disaster risk reduction and strongly contributes to the Sendai Framework for Disaster Risk Reduction 2015–2030. In this paper, the activities of WCoE on the Project realization on landslide risk reduction on the local road network will be presented.

2 Project Objectives

Due to fundamental differences between local and national road networks' characteristics, it is not possible to simply transfer national level resilience measures to local transport networks. For one, local transport networks are usually much denser than the national, whereas, the quality of the road transportation links on a local level are much lower than that on the national level. Furthermore, local communities have little, if any, capacity to deal with this issue. Consequently, road state monitoring, and availability of related data, are by far poorer for local roads. While basic concepts of resilience from natural hazards are universal for all road networks, the approaches for diagnostics, prioritization, and asset management of the local network are therefore specific, and additionally dependent on country context and local capacities. The methodological solution should cover all basic elements of the local road network resilience but should be simple enough for usage by the local level authorities and local technical staff and adaptive to poorer or limited data input.

The Project comprises of four main sets of tasks: (i) Developing methodology for LSGs to assess local road transport network exposure, vulnerability, risk, and criticality to the specified hazards; (ii) Local Road Transport Network Resilience Diagnostic Tool; (iii) Local Transport Network Resilience and Investment needs Assessment in Pilot LSG and (iv) Capacity building through several practical/field workshops with selected LSGs and local/national authorities.

3 Methodology

The goal of the methodology is focused on the outputs, which will enable LSGs to sustainably prioritize parts of the local road network they plan to invest in, such as: maintenance (routine, periodic and urgent), rehabilitation, or reconstruction. These outputs include:

- manually developed spreadsheet reports (based on manual field data collection and spreadsheet prioritization process), and
- automated map products and spreadsheet reports (based on field and spatial data collection, and as part of automated prioritization process),

both with a purpose to aid and supplement decision making process on the municipality level during the process of planning the investment in local road network. It allows for more efficient, systematic, and economically justified solutions for available budgets and more responsible management in limited budgeting circumstances, and sets course towards higher social benefits.

The Methodology tends to compensate for all possible shortcomings originating from these shortages, while still providing a certain level of support for LSGs decision-makers. As portrayed in Fig. 1, it supports decision-making through two modelling streams:

(i) Part 1 - automated modelling based on field data (collected by LSGs staff)
(ii) Part 2 - background modelling based on available spatial data in raster format (by external experts).

According to the methodology, the LSG staff only needs to collect the data, without knowing the modelling process, as it is automated. It results in a preliminary priority and preliminary report for the needed investments. It can be further combined, with the expert-based model which is generated under (ii). It is an optional, but strongly encouraged part. Their subsequent combination into a final model is thereby enriching expert-based model with realistic field data, and vice-versa, gives the field data theoretical background, which is useful for supporting decisions before the field data is fully acquired (which might be lengthy process).

The LSGs should ideally do both: (i) assign trained staff to collect specific field data (about natural hazards that affect the roads, road conditions, consequences to traffic demand

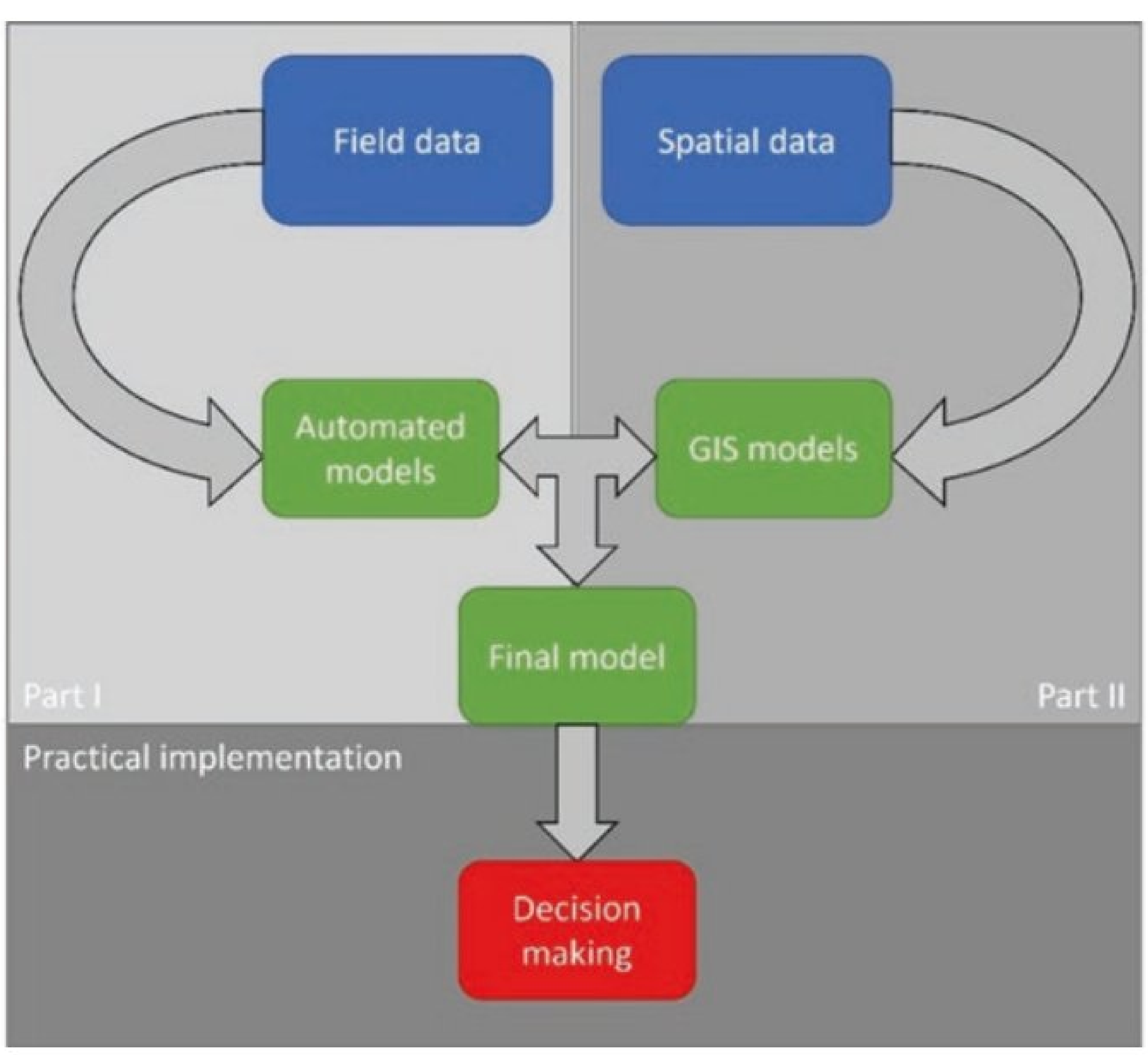

Fig. 1 General modelling scheme; Note: Light grey field implies involvement of LSG staff, medium grey is for involvement of external experts, while the darkest shade of grey involves decision-makers

and infrastructure, etc.); (ii) hire specialists in the field of natural hazards, roads, and traffic (geological, civil, and traffic engineers, etc.) to conduct spatial analysis. Naturally, the support will be more reliable if both (i) and (ii) are undertaken. The methodology allows that either (i) or (ii) is missing or being incomplete, while still providing support to a decision-making process. Apart from basic level of knowledge on the hazard processes, road asset elements and protection/remediation measures that could be undertaken to resolve the problem at hand, some basic knowledge of handling mobile devices, may be required from the LSG staff while using such tool.

The methodology is based on step-by-step procedure for assessment of the road network vulnerability, risk, criticality, and prioritization, which has been already developed in previous projects for national level network, now simplified/automated for LSGs local road networks. The Project Methodology is principally separated into five interdependent domains (Fig. 2) which are subject to overlapping and/or combining:

Input data pre-processing (red box Fig. 2)

1. Input data 1 - data from field acquisition needed for Automated models)
2. Input data 2 - acquisition and pre-processing of various raster datasets, such as terrain model, geological, soil, environmental and other thematic maps needed for background spatial modelling
3. Input data 3 - climate and climate change parameters in raster format, for baseline (reference period), medium (2050y), and long-term (2100y) projections needed for Background modelling

Preliminary prioritization (light blue box Fig. 2)

1. Automatization 1 - field-based *Dot map*
2. Automatization 2 - translating *Dot map* over road links into *Preliminary Priority map*

Background spatial modelling (orange box Fig. 2)

1. Background 1 - Exposure (per road links/sub-links)
2. Background 2 - Criticality (per road links/sub-links)
3. Background 3 - Vulnerability (per road links/sub-links)
4. Background 4 - *Control map* (per road links/sub-links)

Data fusion (blue box Fig. 2)

1. Final priority map (combining *Control map* and *Preliminary Priority map*)
2. Final spreadsheet report (per link)

Investment planning (violet box Fig. 2)

Fig. 2 The methodology flow chart

1. Short-term investment plan
2. Medium-term investment plan
3. Long-term investment plan

4 Local Road Resilience Diagnostic Tool

The Methodology, especially Part 1 (Fig. 1), seems very suitable for mobile implementation. Since fixed scoring criteria are utilized to translate what observer reports on the field into a numerical value (score), a simple, user-friendly mobile application that would support this process seems very reasonable. Mobile application would use the location services of hosting mobile device to enable all foreseen aspects of the Methodology.

Such tool for mobile devices is developed to facilitate the data collection in the field, while web application is developed for further local road network data analysis, resilience and priority assessment based on the methodology (MaPLoRds mobile and web app). The tools are simple to use, intuitive and with user friendly interface for utilization by engineers or technicians in the LSGs' administration.

Collected data are stored first on a mobile device memory and then uploaded to the back-end, central database to be easily accessible to different users. A set of different reports are available for onscreen preview and for export to Excel. This enables authorities to prioritize the activities, review the types of hazards, network, and links vulnerabilities, etc. in the familiar, spreadsheet, environment.

In general, development of information systems includes design of components for data collection, system analysis, requirements gathering, asset data definition and data management processes, levels of GIS service and implementation of basic API-s (Application Programming Interface).

Development of the MaPLoRds mobile application (for Android and iOS) and web GIS application enables users to perform continuous data collection related to occurred road hazards events, upon which priority assessment will be made based on the developed methodology. The workflow overview of the developed system is presented in Fig. 3. The implemented decision support system relies on both up-to-date field data and data obtained through the Background modelling (spatial modelling of specific hazard types, road vulnerability and criticality).

The language of the mobile and web application is Serbian, Latin alphabet by default. Application interface and

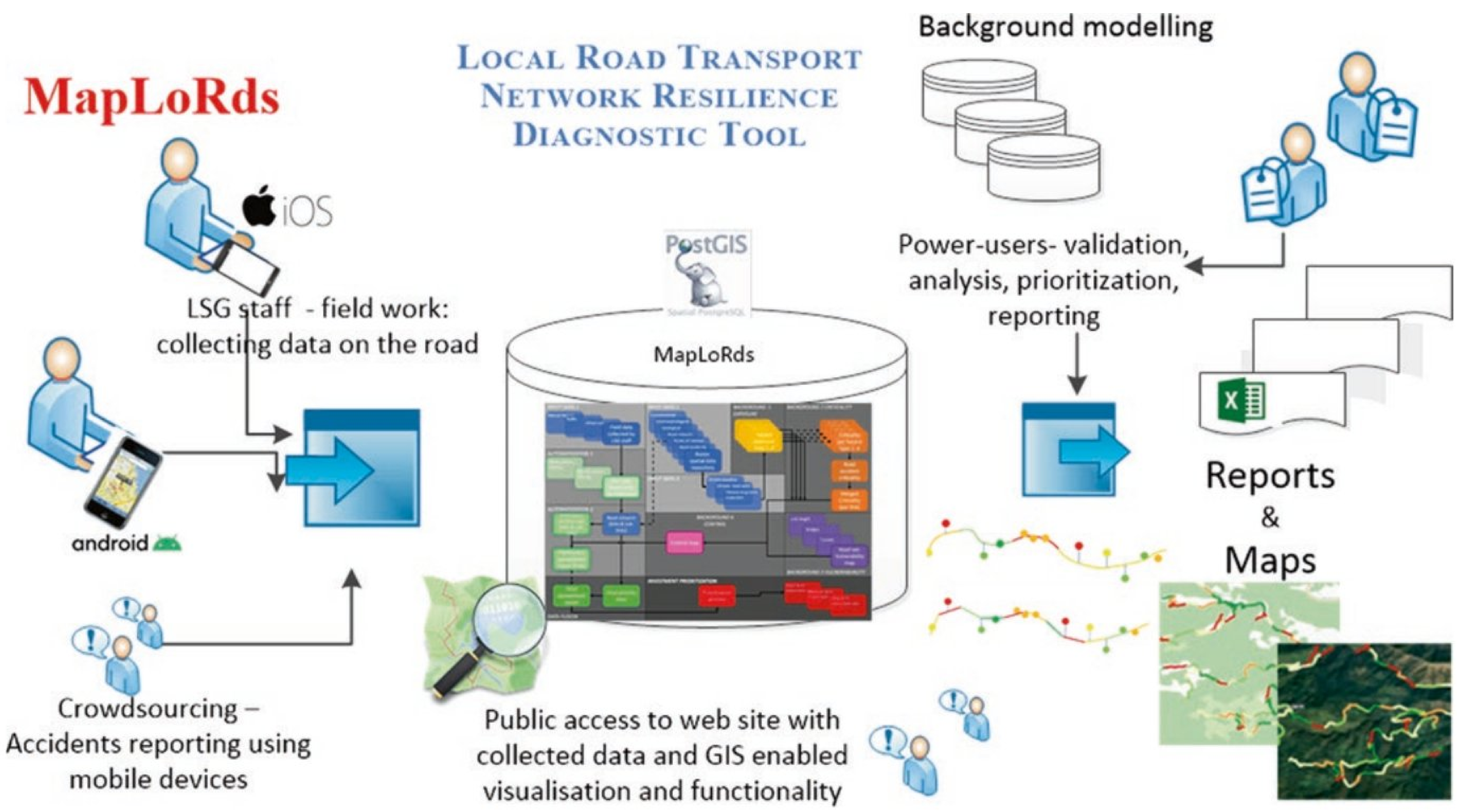

Fig. 3 MaPLoRds system data collection and analysis workflow

data classification labels includes English as well. The bilingual glossary, in Serbian and English, is produced for developed version of the application, introducing key terms and phrases that are required for the MaPLoRds interface, both for mobile and web application. Mobile application is enabled to work in online and offline mode. Since internet connectivity may not be accessible at remote locations, offline mode is needed to enable the collection of necessary field data and its storage on a mobile device. Once an internet connection is re-established, the status or datasets will be updated, transferred, and synchronized with the back-end database (Figs. 4 and 5).

Two pilot areas have been chosen to test the methodology, the Aleksandrovac Municipality and the City of Kraljevo (Fig. 6). The former, less developed pilot was expected to cope more with the execution of the task in comparison to the latter, well developed pilot, experienced in hazard assessment (with developed capacities, equipment, procedures, etc.). Conveniently, pilot areas are adjacent so direct comparisons, and other favoring effects (such as cooperation in bordering zones) are enabled. The selected neighboring LSGs represent communities exhibiting significant differences in population, geography, and economic development aspects. The local road networks within these LSGs serve as vital transportation links for both urban and rural areas. These road networks are vulnerable to a range of hazards, including flooding, landslides, rockfalls, erosion, and extreme weather events. It is imperative to understand and address these hazards to ensure the resilience of the local road infrastructure. A brief comparative overview of the main characteristics of the pilot LSGs is presented in Table 1.

Following the initial visit and the appointment of focal point persons, the project team established a close collaboration with pilot LSGs. This collaboration encompassed ongoing communication and correspondence with the LSGs' representatives. Assigned LSGs' teams diligently collected data and actively worked in close cooperation with the project team to support efficient information exchange.

In addition to the communication channels, workshops and joint fieldwork were conducted to facilitate the project objectives. The workshops and training sessions were specifically designed to provide valuable training to the representatives of the selected LSGs, enabling them to actively participate in diagnostic tool development (debugging), testing and methodology implementation. The primary aim of these workshops was to foster collaboration and ensure that all participants possess the necessary skills and knowledge to contribute meaningfully to the success of the project.

The workshop consisted of two parts. The first part focused on presenting the project and its objectives, as well as the MaPLoRds application. During this session, participants were provided with detailed information about the project goals, target outcomes, and the functionalities of the developed application.

The second part of the workshop enforced participants to focus on implementing the MaPLoRds mobile application in real-world settings. Participants had the opportunity to put

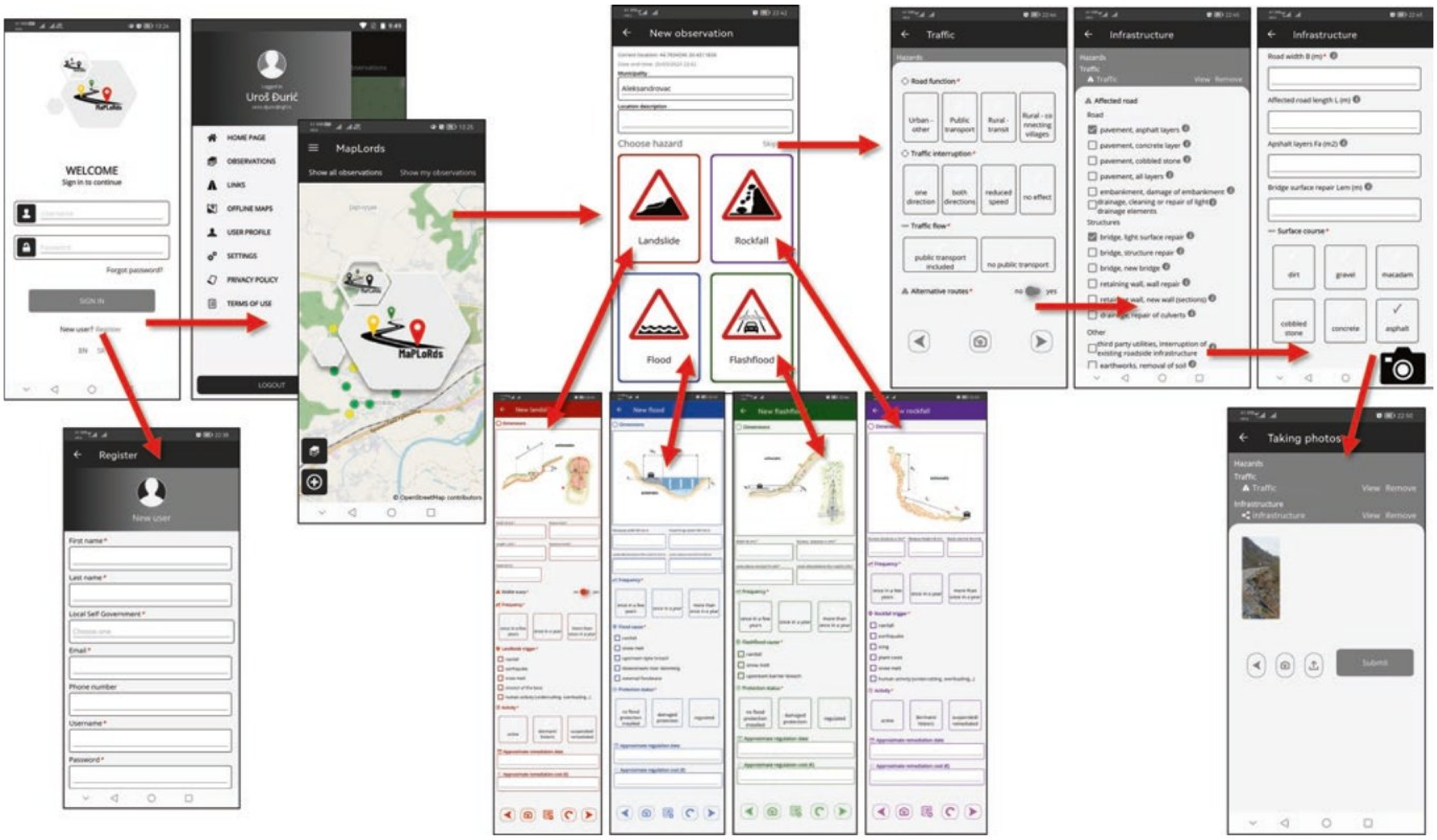

Fig. 4 Overview of the main MaPLoRds mobile app panels with illustrated dataflow

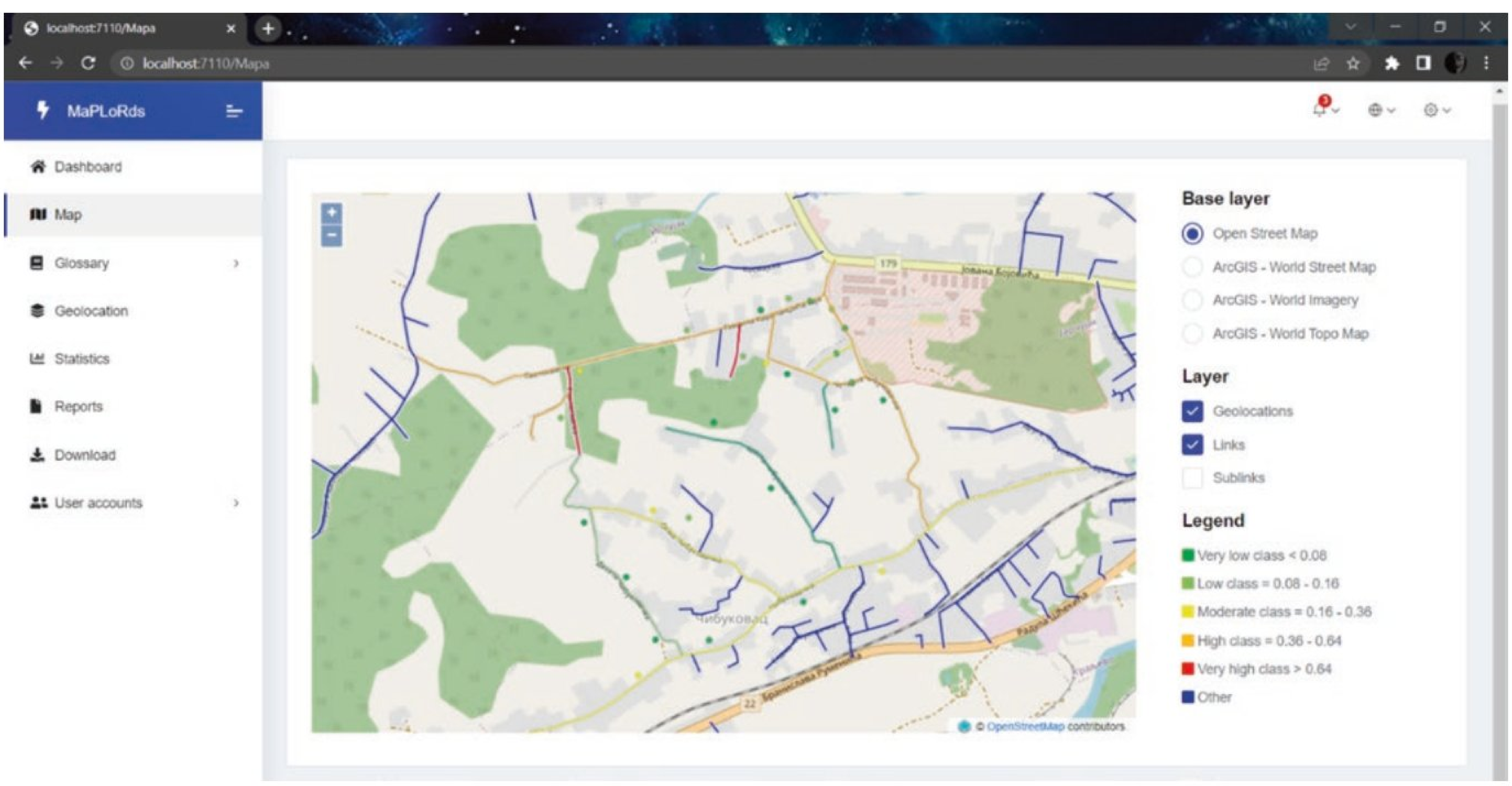

Fig. 5 Web GIS app with illustrated interactive map, hosting point and link view with Open Street base map

their theoretical knowledge into practice by using the application during the fieldwork activities. This hands-on experience allowed them to understand how the application functions in real-world scenarios and provided valuable insights for further improvements or adjustments (versioning of the app). These the two parts of the workshop complemented one another, providing participants with both theoretical knowledge and practical skills to effectively utilize the project application during their fieldwork.

The field visit was targeted to familiarize the users with functionalities of the application and provide guidance on technical aspects. It also served as an opportunity to address

Fig. 6 Position of selected LSGs within Central Serbia; Kraljevo City (red dot, red map) and Aleksandrovac Municipality (violet dot, yellow map)

Table 1 Comparative overview of the main characteristics of the pilot LSGs

Aspect	Kraljevo	Aleksandrovac
Geography	Valley, formed by two main rivers, separates two mountain regions in the north and south	Flanked by Goč, Kopaonik, and Jastrebac mountain ranges
Area	1529 km^2	387 km^2
Population	111,491	22,339
Population density	72.92 people/ km^2	57.72 people/ km^2
Economic activities	Diverse across 11 sectors, with emphasis on trade and manufacturing industries	Specialization in viticulture and fruit-growing industry
Local road network	326.2 km among which 200.2 km (61%) paved	407.4 km among which 218.1 km (53%) paved
Sensitivity to climate change	Vulnerable to floods, flash floods, landslides and rockfalls	Vulnerable to landslides in hilly areas and occasional urban flash floods

Fig. 7 Photos from workshop organized for recruited LSGs staff—Kraljevo and Aleksandrovac

any ongoing technical issues and report any bugs encountered in the mobile application. Establishing direct contact between the field working LSG staff and the project experts responsible for implementing the methodology and developing the MaPLoRds application was of the utmost importance (Fig. 7).

5 Conclusion

The local road transport network is the weakest link in natural disaster emergency situations, especially in climate changing conditions. Improving the national road network resilience is important but without complementary activities on the local level, natural disasters may still impact considerable number of people and services. Particularly vulnerable are people living in remote settlements, which might be completely cut-off during a severe hazard event, which might prevent their timely evacuation, or halt their supply chain and essential services. In such a case, resilient national road nearby is not as useful as it would be if the entire system was to endure the hazard impact. The need to follow resilience standards applied to national road infrastructure therefore must be recognized and implemented at local roads level, as well. The primary obstacle to achieving full (national and local road) climate resilience is understaffed and underequipped authorities that oversee road management. One approach would be to resolve these issues systematically but slowly, by hiring, training and equipping authorities in charge. Alternatively, the problem could be reduced by developing methodologies that offer automated, ready-to-use outputs, requiring minimal interaction with the operative staff. MaPLoRds has shown such capabilities and confirmed them on practical examples for the City of Kraljevo and the Aleksandrovac Municipality. The generated maps and reports were directly used in investment planning simulation, enabling decision makers to identify which road links are of the highest priority, and what type of investment is suitable and cost-effective. It is important to comment that full implementation, coupling both Part 1 and Part 2 procedures, i.e., outputs based on real field data, and outputs based on spatial modelling, respectively, offer much more reliable outputs, although both parts might be used independently. In addition, accounting for climate change impacts is not possible without including spatial modelling procedure.

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