ARUP

The World Bank

Technical Assistance - Improving Resilience and Safety of the Local Roads Transport Network in the Republic of Serbia

Local Roads Transport Network Resilience Methodology for Risk Assessment

Reference:

final | 26 June 2023

Job number 288895-00

Arup d.o.o. Beograd (Vracar)
Kneginje Zorke 77
Belgrade
11000
Serbia
arup.com

ARUP

Document Verification

Project title	Technical Assistance - Improving Resilience and Safety of the Local Roads Transport Network in the Republic of Serbia
Document title	Local Roads Transport Network Resilience Methodology for Risk Assessment
Job number	288895-00
Document ref	
File reference	

Revision	**Date**	**Filename**	2023-01-08 D3_LRTN Methodology for Risk Assessment		
0	08 January 23	**Description**	Deliverable 3 – draft issue		
			Prepared by	**Checked by**	**Approved by**
		Name	Miloš Marjanović, Danijel Vučković	Ivana Stevanović	Aleksandar Bajović
		Signature			
1	24 March 23	**Filename**	2023-03-24 D3_LRTN Methodology for Risk Assessment_v1.0		
		Description	Deliverable 3 – revised after comments received		
			Prepared by	**Checked by**	**Approved by**
		Name	Miloš Marjanović, Danijel Vučković	Ivana Stevanović	Aleksandar Bajović
		Signature			
final	26 June 23	**Filename**	2023-06-26 D3_LRTN Methodology for Risk Assessment_final		
		Description	Deliverable 3 – final, revised after second round of comments received		
			Prepared by	**Checked by**	**Approved by**
		Name	Miloš Marjanović, Danijel Vučković	Ivana Stevanović	Aleksandar Bajović
		Signature			

Issue Document Verification with Document ✓

Contents

Tables

Figures

Appendices

Abbreviations

Abbreviation list	Meaning
AOI	Area Of Interest
Cr	Criticality
DTM	Digital Terrain Model
Eq	Equation
Ex	Exposure
GIS	Geographic Information System
Hz	Hazard
LoR	Local road
LSG	Local self-government
m	Meter
PoI	Points of Interests
Pr	Prioritization
RoA	Road asset
RoL	Road link
RoSL	Road sub-link
ToR	Terms of Reference
Vb	Vulnerability
w	Weighting factor
WB	World Bank

1. Introduction

Resilient road transport infrastructure network can preserve the performance in case of disturbances and quickly recover the original performance level after the disturbances. Improving transport infrastructure resilience relies on the ability to evaluate and understand the direct and indirect impact of the relevant hazards affecting transport infrastructure.

The objective of this methodology is to improve local road transport network and service delivery resilience to natural hazards. The methodology explores how policy makers of Local-Self Government (LSG) can interact and prioritize when shaping investments in road transport infrastructure that affect everyday lives and businesses of local communities. It is developed as part of the World Bank's (WB) assignment Technical Assistance – Improving Resilience and Safety of the Local Road Network in the Republic of Serbia, i.e. according to the Task 1 (Develop Methodology and Guidelines for assessing local transport network resilience and safety) of the Terms of Reference (ToR).

The Methodology assesses local road transport network exposure, vulnerability, risk, and criticality to the selected hazards.

The most challenging part required by the ToR was to ensure transferability of the approach and data collection by the LSG staff. In addition, the subject was limited to local roads (LoR) which commonly cope with poorer data coverage than state-owned roads and lower throughput.

The Methodology was sought to fit the stakeholders operative and technical capabilities, and it was divided into two parts:

- Part 1 - that can be completed by LSG staff (data collection and production of preliminary products)
- Part 2 - which requires expert knowledge (background modelling and final products).

Part 1 is mandatory, and it is understood that it can be organized within the current capacity of the target municipality. On the other hand, Part 2 requires external consultancy which includes hiring spatial modelling experts in the field of geo-hazards, traffic and civil engineering, assuming that such capacities are not likely to be available at the LSGs by default.

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

- Manually developed spreadsheet reports (based on Part 1 as part of manual data collection and spreadsheet prioritization process), and
- Automated map products and spreadsheet reports (based on Part 1 and Part 2 data collection, and as part of automated prioritization process),

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

Based on developed outputs it is possible to create an investment plan, including short-, medium-, and long-term investment measures. In case of lacking capacities and resources to implement Part 2, the outputs from Part 1 are sufficient for investment planning on preliminary level. Ideally, both parts should be implemented for a high confidence decision-making.

To test this Methodology, two pilot areas have been chosen:

- Aleksandrovac Municipality (Serbia), with population of 23,339[1] (2022) and overall local road network of 407.4km[2], as less developed which would expectedly cope with the execution of such task; and
- City of Kraljevo (Serbia), with population of 111,491[1] (2022) and overall local road network of 326.2km[2], as well-developed and experienced in hazard assessment (developed capacities, equipment, procedures, etc.).

Conveniently, pilot areas are adjacent so direct comparisons and other favoring effects are enabled, such as cooperation in bordering zones.

When it comes to the automated process, the Methodology directly influences and overlaps with other tasks and key deliverables, such as:

- Local Road Transport Network Resilience Diagnostic Tool, i.e., mobile and web application for collecting and processing the data and generating various products, and
- Practical Guidelines as an instruction for the end-user how to develop prioritization process manually and also how to use the Diagnostic Tool.

However, the Methodology will hereinafter be presented as a standalone set of procedures, independent of the Tool and the Guidelines.

1.1 Key definitions

To achieve maximum clarity of methodological approach further in the text, the key soft definitions (plain words) to be used with associated abbreviations are presented here:

- Criticality (Cr) – the quantification of relative importance of various mobility related services supported by road infrastructure.
- Exposure (Ex) – the presence of RoA in places and settings that could be adversely affected by Hz over time.
- Hazard (Hz) – a spatial-temporal probability of occurrence of climate-related natural event that may cause loss of life or injury, damage and loss to property, infrastructure and resources.
- Local road (LoR) – a road managed by LSG (state roads excluded)
- Local self-government (LSG) – a party in charge of the management of specified administrative unit (city or municipality), including constructions, reconstruction, maintenance and use of local roads, streets, and other public facilities of the LSG importance.
- Prioritization (Pr) – the ranking of the critical RoL according to their socio-economic importance against the required/recommended climate change adaptation intervention.
- Road asset (RoA) – all parts of the network of roads for transport of passengers and goods that may host other infrastructure (third party utilities, etc.).
- Road link (RoL) – an element of the road network that connects two intersection points of the road network.
- Road sub-link (RoSL) – a generically subsampled RoL into equal length intervals.
- Road accidents (RoAcc) – an event having led to personal injury or damage to property that has taken place in an area intended for public transport, involving at least one vehicle on a road open to public traffic in which at least one person is injured or killed.

[1] https://publikacije.stat.gov.rs/G2022/HtmlL/G20221350.html

[2] https://publikacije.stat.gov.rs/G2022/Pdf/G202213049.pdf

- Score (Sc) – is a numeric value allocated to a layer class or field data entry, assigned by an expert to quantify its local influence within the layer or data group.
- Value of Statistical Life (VoSL) - an economic value used to quantify the benefit of avoiding a fatality.
- Vulnerability (Vb) – the propensity of the RoA to be adversely affected (opposite to its resilience) and the potential impact on society, i.e., the degree of experiencing harm due to exposure to a Hz.
- Weighting factor (w) – is a numeric value allocated to an entire layer or a group of entries by an expert to quantify their overall influence in the model.

2. Rationale

The main feature of this Methodology is its flexibility and adaptability to the limited data and capacity resources, not only for the pilot study areas (Kraljevo and Aleksandrovac), but potentially for any new LSG candidate in the future, who all may vary in terms of data resources and staff qualifications.

The Methodology tends to compensate for all possible shortcomings originating from these shortages, while still providing a certain level of support for LSG decision-makers. As portrayed above, it supports decision-making through two modelling streams (Figure 1), i.e., constitutive parts:

i. Part 1 - automated modelling based on field data (collected by LSG staff)

ii. Part 2 - background modelling based on available spatial data in raster format (by external experts).

The Methodology allows that either (i) or (ii) is missing or being incomplete, while still providing support to a decision-making process.

However, ideally, the LSG will: (i) assign trained staff to collect specific data in the field (about natural hazards that affect the roads, road conditions, consequences to traffic demand and infrastructure, etc.) and (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 available and complete.

According to the Methodology the LSG staff only need 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). Their subsequent combination into a final model is thereby enriching expert-based model with realistic field data.

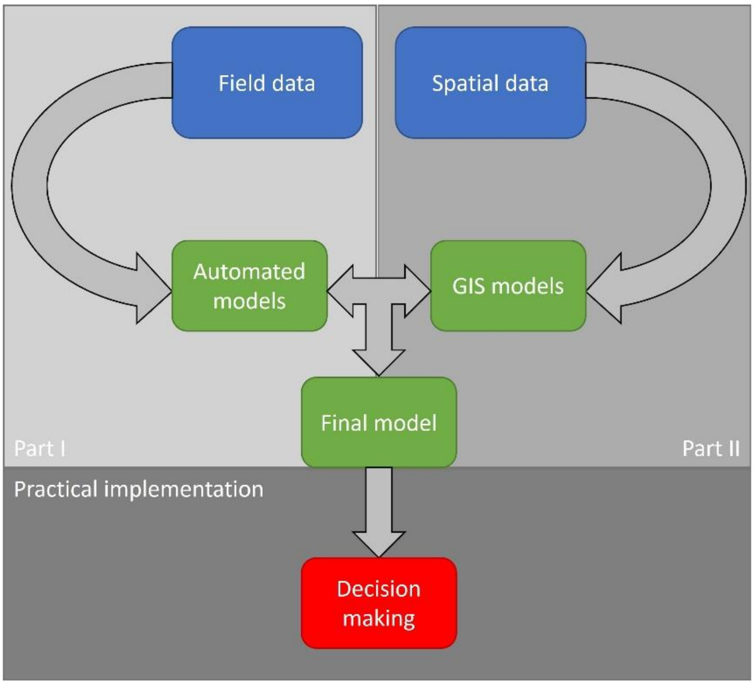


Figure 1 General modelling scheme

Note: Light grey field implies involvement of LSG staff, medium grey is for involvement of external expert roles, while the darkest shade of grey involves decision makers.

The Methodology, especially Part 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.

However, apart from basic level of knowledge on the hazard processes, RoA elements and protection/remediation measures that could be undertaken to resolve the problem at hand, some basic knowledge of handling tablet or smart phone devices, may be required from the LSG staff while using such tool.

The Project Methodology can be principally separated into five interdependent domains (Figure 2) which are subject to overlapping and/or combining (as will be specified later):

- Input data pre-processing
  - Input data 1 (data from field acquisition needed for Automated models)
  - 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 modelling)
  - Input data 3 (climate and climate change parameters in raster format, for baseline, medium ~2050, and long-term ~2100 projections needed for Background modelling)
- Preliminary prioritization
  - Automatization 1 (field-based *Dot map*)
  - Automatization 2 (translating *Dot map* over road links into *Preliminary Priority map*)
- Background spatial modelling
  - Background 1 - Exposure (per road links and sub-links)
  - Background 2 - Criticality (per road links and sub-links)
  - Background 3 - Vulnerability (per road links and sub-links)
  - Background 4 - *Control map*
- Data fusion
  - Final priority map (combining *Control map* and *Preliminary Priority map*)
  - Final spreadsheet report (per link)
- Investment planning
  - Short-term investment plan
  - Medium-term investment plan
  - Long-term investment plan

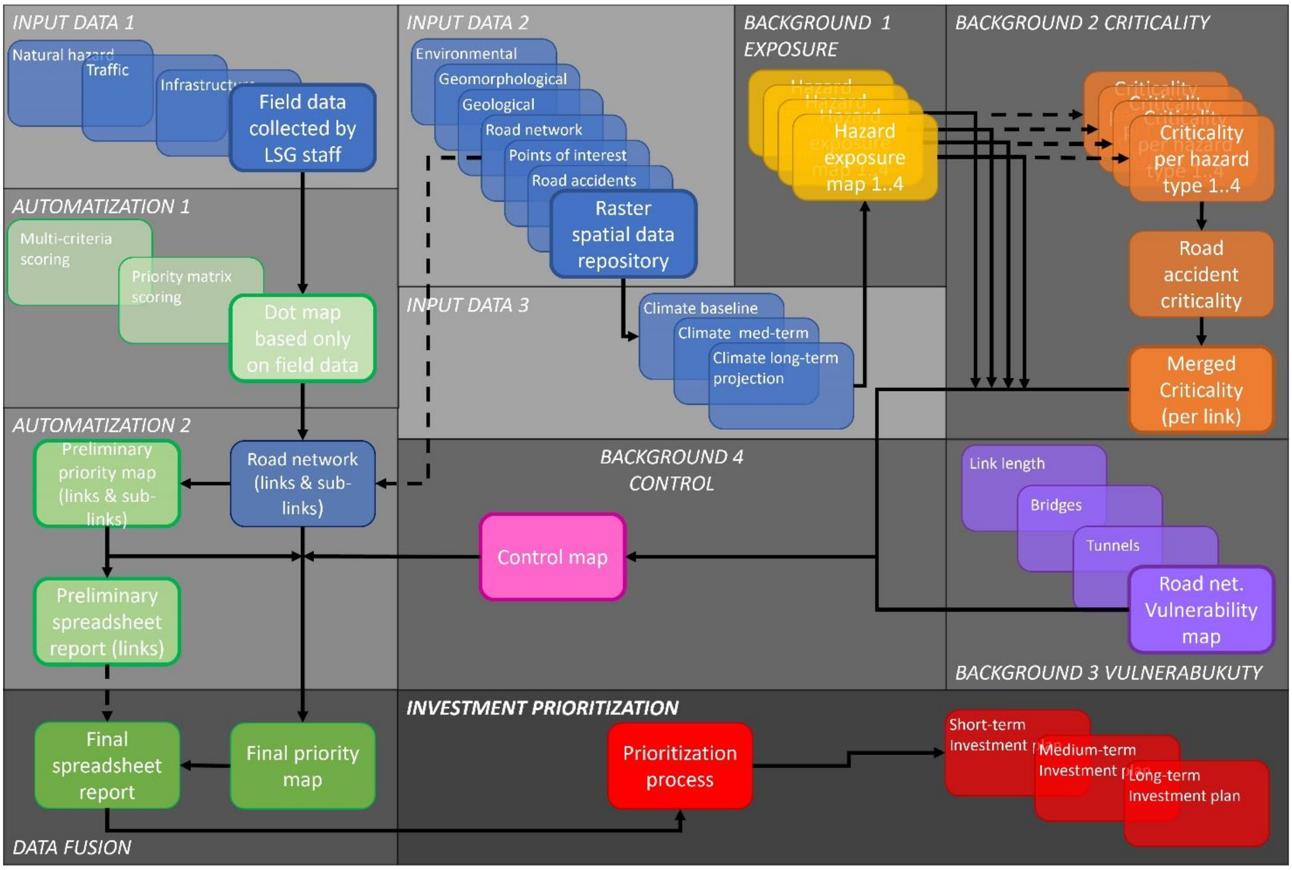


Figure 2 Methodology flow chart

Note: The model elements are color-coded (blue are inputs, green are automated processes, red are prioritization results, and other colors represents different intermediate models); arrows represent the model flow direction; different grey shading indicates larger model blocks (data input very light grey, automation light grey, background modelling medium grey, data outputs dark grey, and the darkest grey is investment).

3. Input data

Given that various types of inputs are used in the model, including field acquisitions, open data repositories, public data, and their derivates, and given that these have their specific role, the inputs are split into classes:

- Field data (Input data 1): collected on the field by LSG staff, trained to report the hazard occurrence and associated criticality and vulnerability of road elements on-site, in vector format. These are collected sequentially and populate the database as events occur in time (interactive and dynamic input). These can be used as both, model building inputs or for model validation.
- Raster spatial data (Input data 2): all existing hazard models of specific hazards such as landslides and floods, or thematic maps in raster format such as Digital Terrain Model, geological, soil, land cover and other maps, that are needed to produce hazard models.
- Unlike field data, these can be collected (downloaded or digitized) beforehand, covering the entire area of interest. In case these are ready-made hazard models, little or no effort is needed to align them with the Methodology through appropriate steps and put them to use. In case that ready-made hazard models (of landslides or floods) are not available for specified area, raster spatial data undergo various processing steps, and eventually, in hands of a skillful GIS expert, become a valid hazard model.
- Climate data (Input data 3): raster maps available for baseline (recent period, e.g., 1981-2010) and future projections (e.g., 2050 and 2100) including various climatic parameters or indices (available for both baseline and projections, in order to be comparable). These are used to add temporal dimension to, otherwise static hazard models, and to incorporate anticipated climate change effects. By default, these raster maps require downscaling from 1-arc minute (~1 km) resolution, common for wider areal coverage, to operative resolution (e.g, 100 m), appropriate for municipality level of detail.

3.1 Input data 1 – Field Data Collection

This chapter (sub-chapters included) is intended for use by both, LSG fieldwork staff and external spatial modelling experts, to get familiarized with types of data, their qualitative and quantitative aspects (Figure 3). The appropriate example is illustrated in Appendix A.

The field work is essential part of this Methodology. It can be potentially treated as a stand-alone process, which, if abundant enough and of satisfying quality, could provide sufficient support for decision making without any further spatial modelling.

However, it is unlikely to expect such scenario for several reasons. Firstly, hazard events seldom occur and have complex spatial patterns. Therefore, one realistically expects uneven amount and distribution of hazard data over the road network. It is also possible that data are not collected with sufficient level of quality, thereby misleading the decision makers to choose priorities which might not be justified.

On the other hand, it is unfeasible to automate or to remotely model the process of an on-site assessment in some specific cases of hazard event impact on the road network, and associated recommendations of the most suitable remediation measures. The primary reasons are (i) lack of reliable and up-to-date event data; (ii) lack of trained staff that can deliver the recommendation; and (iii) uneven quality of data and staff skill in all municipalities.

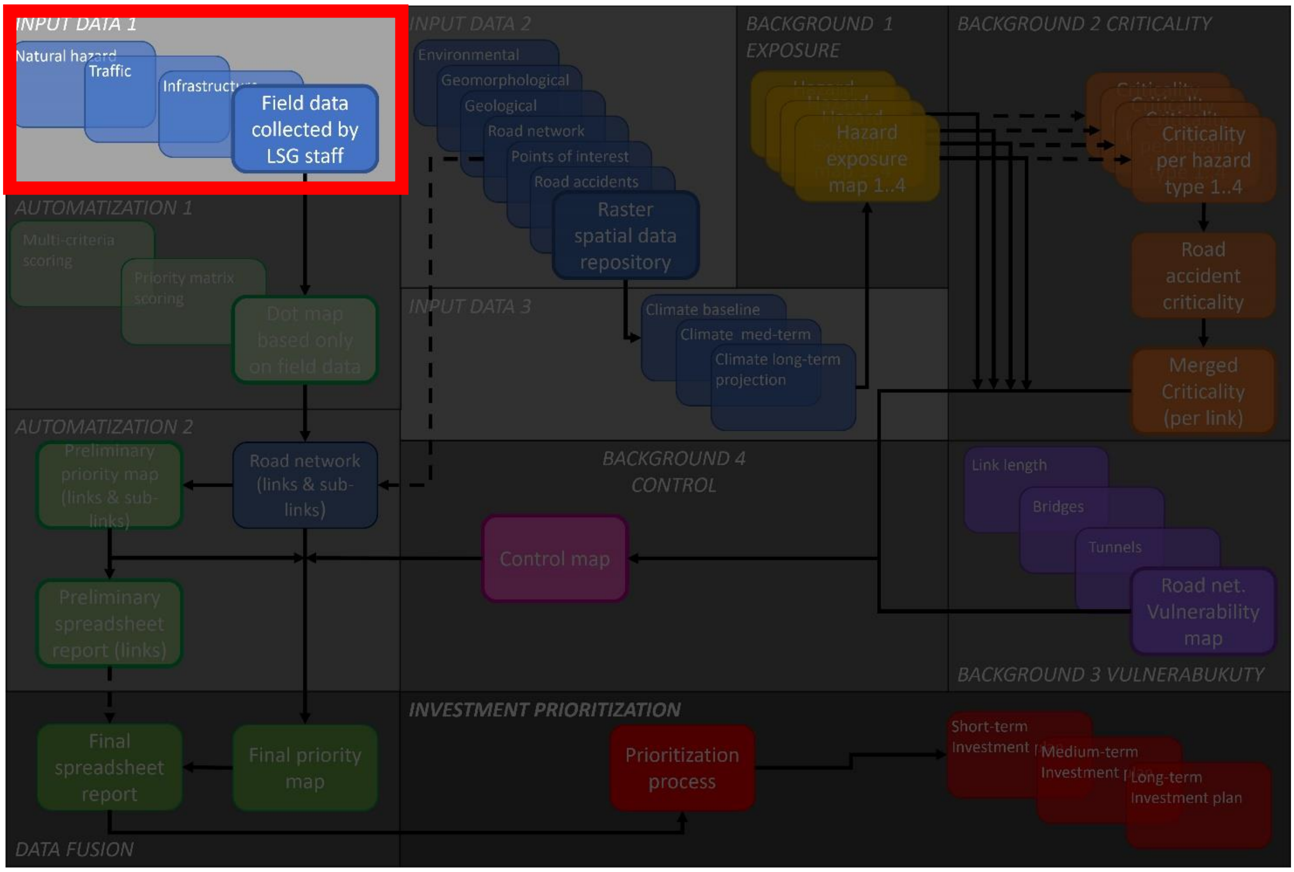


Figure 3 Input data 1 – Field data collection

The fieldwork should be conducted by LSG staff that have previously been subjected to the training process in line with this Methodology and associated Guidelines. Each hazard event (including historical events if applicable, i.e., if their setting can be reconstructed in sufficient level of detail) that affects the RoA should be recorded.

The field data can be thematically separated into three different collections: i) data on hazards, ii) data on traffic and iii) infrastructure data. Each contains specific type of data (numeric, logic or string inputs), that can be further combined (e.g., for calculation of additional inputs, for ruling out illogical observations, etc.), and ultimately, translated into scores and classified as high or low value.

3.1.1 Natural hazard field data

Field collection of hazard data includes primarily selection of the type of hazard at hand (Appendix A - A.1.1). Exceptionally, there can be more than one hazard type present at the same location which is also foreseen in this Methodology. Based on experience from domestic case histories the following four types of hazards are chosen as most harmful to RoA:

- Landslides
- Rockfalls
- Floods
- Flash floods.

They all have their specific influences that can be more or less pronounced from case to case. For instance, landslides are constantly affecting the same location for a longer period, introducing subtle but constant displacements, therefore requiring constant attention. Floods affect long stretches of the road and withdraw completely after some time. On the other hand, rockfalls and flash flood impact is much narrower and requires attention only occasionally (usually just removal of fallen/deposited material) on expected locations.

The following data or parameters are to be collected for each recorded landslide:

- location (can be obtained by using location services of mobile devices)
- dimensions (length, width and depth, area, volume, main scarp height if applicable)
- frequency of occurrence (annually or more/less frequent)
- direct trigger (rainfall, earthquake, snow thaw, erosion, human activity)
- activity status (currently active, dormant, or suspended, in case of which the cost and date of remediation would represent a valuable piece of information).

It is understood that field worker (LSG staff) will introduce at least: the data on the landslide location (while visiting the site and making observation, using mobile device aid for self-location); size (length and width); estimate the frequency of reoccurrence; identify at least one trigger.

The LSG staff should be previously trained to recognize these elements on a real example or ideally, already experienced in this field.

Similarly, for each rockfall the following data or parameters are needed:

- location (can be obtained by using location services of mobile devices)
- dimensions (runout length, release height and block volume if applicable)
- frequency of occurrence (annually or more/less frequent)
- direct trigger (rainfall, earthquake, icing, plant roots, snow thaw, human activity)
- activity status (currently active, dormant, or suspended, in case of which the cost and date of remediation are optionally filled in).

It is required that the user introduces at least the data on the rockfall location (by default, i.e., by visiting the site and entering any observation), runout length, estimate the frequency of reoccurrence, and identify at least one trigger.

The LSG staff should be previously trained to recognize these elements on a realistic example, or ideally, already experienced in this field.

Each flood includes the following data or parameters:

- location (obtained automatically)
- dimensions (floodway and fringe width, level above normal and above/below the road)
- frequency of occurrence (annually or more/less frequent)
- direct cause (rainfall, snow thaw, upstream/downstream breaching/damming, external flood wave)
- flood protection status (no protection installed, damaged protection, regulated, in case of which the cost and date of installation are optionally filled in).

It is required that the user will introduce at least the data on the flood location (by default, i.e., by visiting the site and entering any observation), floodway width and level, estimate the frequency of reoccurrence, identify at least one cause, and estimate the status of the existing protective measures (embankments, channels, drainage, culverts, etc.).

The LSG staff should be previously trained to recognize these elements on a real example, or ideally, already experienced in this field.

Each flash flood contains the following data or parameters:

- location (obtained automatically)

- dimensions (width and runout, level above normal and above/below the road)
- frequency of occurrence (annually or more/less frequent)
- direct cause (rainfall, snow thaw, upstream breaching)
- flash flood protection status (no protection installed, damaged protection, regulated, in case of which the cost and date of installation are optionally filled in).

It is required that the user will introduce at least the data on the flash flood location (by default, i.e., by visiting the site and entering any observation), flash flood width and level, estimate the frequency of reoccurrence, identify at least one cause, and estimate the status of the existing protective measures (embankments, channels, drainage, culverts, etc.).

The LSG staff should be previously trained to recognize these elements on a real example, or ideally, already experienced in this field.

In case that hazard event at hand is not sufficiently described with these categories, the user should make custom comments and append it to each observation.

As mentioned before, a single location could host multiple hazard events, especially those commonly interdependent, such as floods and landslides (flood undercuts the slope which then can initiate a landslide, which can reversely back influence the flood). For this reason, all subsequent scoring procedures consider sum of all scores at specific location. Their further normalization restores the relative 0-1 scale of values, as will be highlighted hereinafter.

3.1.2 Traffic demand field data

It is assumed that every hazard event that requires attention of the LSG affects the traffic flow to a certain extent. To make more precise observation, the following traffic features are considered (Appendix A - A.1.2):

- road function
- interruption type
- traffic flow type
- alternative routes.

Roads are grouped by the character of service they provide. In the transport planning process, which is an integral part of the socio-economic development, functional classification is used to determine how vehicles could be channelized within the road network in an efficient manner. Functional classifications of road define the part that any specific road corridor should use in serving the traffic demand through a road network.

Each observation needs to include the data input on traffic interruption type by specifying whether single or both directions are entirely closed due to hazard event, or there is only speed limit involved, or alternatively, no effect whatsoever is implied.

Additionally, each observation requires specification of the traffic flow type, i.e., presence or absence of the public transport routes.

Finally, it should be specified whether there are suitable alternative routes for bypassing the affected road part, and if so, what is the length of potential detour.

Obviously, the LSG staff does not need special training in this context but needs to be familiar with local conditions (public transport routes, alternative roads, etc.).

3.1.3 Infrastructure field data

Field collection of infrastructure data includes primarily information related to the infrastructure damage. Based on collected information and set scoring, light, medium and heavy infrastructure investment levels are clearly defined.

The following infrastructure feature are to be gathered (Appendix A - A.1.3):

- Road
  - pavement (e.g., damages of asphalt wearing course, asphalt binder course, concrete wearing course, cobbled wearing course, whole pavement structure)
  - embankment damage
  - drainage (damages of roadside channels, gutters, curbs, cleaning of channels, shafts and culverts (box and pipe))
- Structures
  - bridge (e.g., damages of non-structural elements of the bridge such as: pedestrian fence, guardrails, sidewalks, pavement with hydro-isolation, and a like, including damages of parapets and replacement of joints; damages of structural elements such as: superstructure elements (deck slab, deck beams, bridge bearings) and superstructure elements (abutments, wing walls, piers, foundation); completely demolished bridge or with significant defects so construction of a new bridge is required)
  - retaining walls (e.g., damages of the wall that could be repaired; damages of the wall that require replacement of wall sections or the whole wall)
  - drainage (e.g., damages of both box and pipe culverts)
- Other
  - third party utilities (e.g., interruption of power supply, telecommunications, gas pipeline, water supply, sewerage, etc.)
  - earthworks (e.g., cleaning of ground material from the road)
  - scaling (e.g., removal of rock from a slope using hand tools, small explosive charges, pry bars, and other mechanical methods)
  - social infrastructure/impact (e.g., identified roadside households endangered by damaged road; dead or injured people during the occurrence of the road damage).

All three collections of input data are assumed to be acquired through a certain time period (e.g., after a year or so). Eventually, it will happen that specific site becomes revisited once or several times, as hazard event reoccurs at that same place and data starts duplicating. In such case, it is possible that conditions have changed, including hazard event itself, but also the traffic and infrastructure environment. For instance, by implementing the Methodology, or by reacting to emergency, some remediation or protection measures could have taken place in the meanwhile. For this reason, the Methodology considers only the score of the last-known observation date, as will be highlighted hereinafter.

3.2 Input data 2 – Raster spatial data (Hazard data sources & pre-processing)

> This chapter is primarily intended for use by external spatial modelling experts, to get familiarized with types and quality of data required to implement Methodology, as well as where such data can be found. There are also detailed instructions for experienced spatial analysts how to pre-process raw data in GIS environment, and ready it for further modelling steps (Figure 4).

Raster spatial data are needed for implementing the Background Spatial Modelling part, which first starts with hazard assessment. To assess proposed four types of hazards, various modelling techniques are used in practice ranging from multi-criteria analysis to deterministic models. What they all have in common are the basic input data (Figure 4), which are always related to the ground surface and ground conditions (from different aspects) or the environment atop. This practically means that regardless of the modelling approaches that can be applied in the Background Spatial Modelling part, some data are universal and must be acquired.

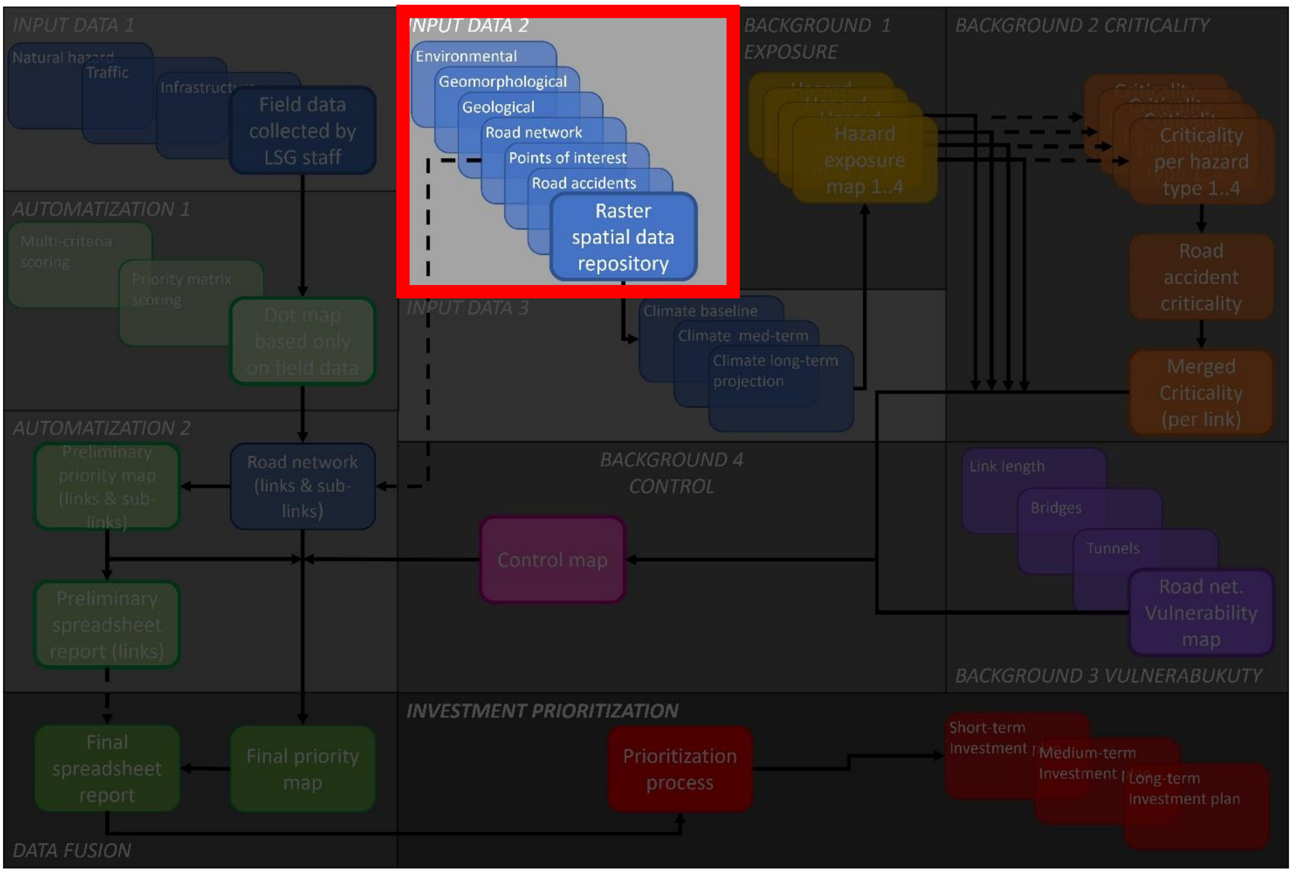


Figure 4 Input data 2 – Hazard data sources and pre-processing

Landslide hazard assessment is commonly modelled using spatial multi-criteria analysis, wherein geomorphological, geological, and environmental factors are involved. The first step is scoring of factors and the second one is weighting. Finally, results are implemented in statistic or heuristic weighting (as will be explained further in the text[3]).

All these factors are represented by appropriate data, commonly in raster format, wherein pixels with assigned values of each spatial factor at each pixel location are arrayed across the Area of Interest (AOI). The required level of detail dictates the pixel size, but it is recommended to use at least 30x30 m pixel resolution for regional scale (municipality or city territory), if possible, for all spatial factors.

Table 1 summarizes the factors, their data sources and necessary pre-processing steps in a Geographic Information System (GIS) environment. The factors or the landslide proxies that should be used to spatially assess landslide Hz via multi-criteria analysis are:

- Geological factor
  - Lithological composition: Soft or weathered rock are more prone to land sliding than their solid and fresh counterparts. Also, rocks with higher content of specific minerals (such as clay or hygroscopic minerals, e.g., olivine) are more prone to host landslides.
  - Structural setting: Tectonized zones, close to various structural features, such as faults and folds, have reduced rock strength in comparison to the rock units sitting away from them. In addition, these

[3] Score is the value allocated for a specific class, so that each class within a layer has a different score. On the other hand, weight is the factor that applies to entire layer, i.e., for all classes equally, and is introduced after scoring.

are the areas where surface and groundwater circulate more easily, thus increasing the strength reduction.

– Depth to bedrock: The soil cover represents the weathered detritus of the solid bedrock underneath, and instabilities such as landslides (especially shallow, translational ones) are commonly developed along the interface between the soil and solid bedrock. Deeper soil indicates possibly landslides of higher magnitude (depth or volume) which makes it a good proxy for their hazard assessment.

Table 1 Landslide hazard assessment proxies, their sources, and their pre-processing for multi-criteria analysis applied in GIS environment

#	Factor	Source	GIS pre-processing
1	Lithological units	Basic geological map 1:100,000 or 1:300,000 scale from Geological Survey of Serbia (https://geoliss.mre.gov.rs/?lang=en)	If unavailable in vector, vectorize the raster map. Engineering geologist should determine the number of representative units (aggregate unis if necessary) and assign their score in respect to land sliding on 0-1 scale (lower score for units less likely to host landslides and vice versa). Convert vector to 30 m raster based on these scores.
2	Distance from structures	Basic geological map 1:100,000 or 1:300,000 scale from Geological Survey of Serbia (https://geoliss.mre.gov.rs/?lang=en)	Structures available on the geological map should be vectorized and spatial buffer should be calculated around them. Subsequently it should be normalized to 0-1 scale and reclassified into 5 classes using quantile intervals technique (equal class distribution).
3	Depth to bedrock	Soil absolute depth (BDTICM_M_250m_ll) to bedrock map (in cm) with 250 m resolution from global resource soilgrid.org (http://globalchange.bnu.edu.cn/research/dtb.jsp)	Resample to 30 m resolution using cubic convolution to smoothen the 250 m raster (alternatively interpolate to 30 m using the pixel centroids). Subsequently normalize to 0-1 range and reclassify to 5 equally distributed classes* (quantile range intervals).
4	Elevation	DTM of at least 30 m freely available at USGS repository (https://earthexplorer.usgs.gov/) or with 12.5 m resolution available at ALOS PALSAR mission portal (https://search.asf.alaska.edu/)	Normalize raw DTM to 0-1 range and reclassify to 5 equally distributed classes (quantile range intervals).
5	Slope	DTM of at least 30 m freely available at USGS repository (https://earthexplorer.usgs.gov/) or with 12.5 m resolution available at ALOS PALSAR mission portal (https://search.asf.alaska.edu/)	Use the DTM to calculate slope inclination in degrees (or % or radians) with standard D8 algorithm in GIS environment. Normalize the resulting raster to 0-1 range and reclassify to 5 equally distributed classes (quantile range intervals).
6	Aspect	DTM of at least 30 m freely available at USGS repository (https://earthexplorer.usgs.gov/) or with 12.5 m resolution available at ALOS PALSAR mission portal (https://search.asf.alaska.edu/)	Use the DTM to calculate slope aspect in respect to N, with standard D8 algorithm in GIS environment. Reclassify to 8 classes (N, NE, E, SE, S, SW, W, NW) based on the values from 0 to 360°. Assign 0-1 values to classes in a logical sequence (0 for S and SW, 1 for N and NE).
7	Curvature	Global DTM of at least 30 m freely available at USGS repository (https://earthexplorer.usgs.gov/) or with 12.5 m resolution available at ALOS PALSAR mission portal (https://search.asf.alaska.edu/)	Use the DTM to calculate slope curvature with standard D8 algorithms in GIS environment. Reclassify to 3 classes (convex or positive, concave or negative, and flat). Assign 0-1 values to classes in a logical sequence (0 for flat, 0.5 for convex, 1 for concave).
8	Land cover	European land cover map with 100 m resolution, available at CORINE portal (https://land.copernicus.eu/pan-european/corine-land-cover)	Resample to 30 m resolution. Engineering geologist should determine the number of representative units (aggregate unis if necessary) and assign their score in respect to land sliding on 0-1 scale (lower score for units less likely to host landslides and vice versa). Reclassify the resampled map based on that score.
9	Landslide hazard map	Preliminary landslide hazard map of Serbia at 100 m resolution, pending at Geological Survey of Serbia portal (https://gzs.gov.rs/doc/portali/inz-geomehanika/2_Karta%20Hazarda%20od%20klizista.pdf)	None (hazard map directly available).

*Quantile range method defines classification intervals in the continuous dataset according to its distribution into samples with equal number of instances (pixels), and in most GIS programs it is routinely processed.

- Geomorphological factor
  - Digital Terrain Model (DTM): DTM is a simplified representation of the ground surface, which is defined by the elevation values at each pixel location. It has a dual role in the landslide Hz assessment, as it can directly imply to areas with higher potential energy difference (larger relative elevation differences over short distances), which are thereby more prone to instabilities, but also, it serves as a base for several derived geomorphological parameters, such as slope, curvature, aspect, flow accumulation, etc.
  - Slope inclination: The angle of the slope is an important factor that indicates unstable slopes, as steeper inclination suggests higher probability of failure and vice versa. It is routinely calculated from DMT using D8 algorithms in GIS environment.
  - Slope aspect: The exposition to the sun can determine subtle influences on the ground condition through moisture. Southern and western slopes are dryer than their opposite sides, and therefore less susceptible to failures and less prone to weathering, and usually less vegetated. It is also derived from DTM using D8 algorithms in GIS environment.
  - Slope curvature: The convexity or concavity of the local topography can also govern moisture distribution and retention of surface water. Obviously, negative curvature provides better conditions for instabilities by accumulating more water from the surface and vice versa. It can be observed parallelly and perpendicularly in respect to the slope. It is also derived from DTM using D8 algorithms in GIS environment.
- Environmental factor
  - Land cover: Different types of material react differently to moisture, which is one of the key conditions for assessing land sliding potential.

    Urban fabric is usually associated with artificial impermeable materials (concrete, asphalt, improved ground, etc.), while drainage and sewer systems control the surface waters discharge. It is safe to assume that urban areas are therefore least susceptible to land sliding.

    On the other hand, this is the area of intense human activity, where undercutting and overloading of slopes is possible. Densely vegetated areas cope better with moisture distribution, and the root systems can fortify the soil additionally, against shallow sliding or surface erosion. Bare soil, agricultural areas, low-vegetation areas commonly host landslides.

It is also important to mention that for the entire Republic of Serbia, a preliminary landslide hazard map exists in raster format with 100-m resolution, which might be sufficient for future stakeholders. It means that instead of building the landslide Hz model, existing one can be used directly.

Rockfall hazard assessment is based on deterministic models of rock propagation under free fall over specified topography. DTM is therefore, essential input, but also, it is necessary to determine from which part of the slope the potential rockfall can be detached.

Therefore, rockfall assessment requires a two-stage approach (as will be elaborated further in the text), i.e., source area selection, and rock block propagation. For the former, it is required to analyse the geological conditions throughout the AOI, as well as the cover type (bare rock). The latter only requires estimated size of the block and DTM surface to place the trajectory simulation onto. Table 2 summarizes required input data, their data sources and necessary pre-processing steps in a GIS environment to narrow down the source areas, and to host rockfall simulations.

- Geological conditions
  - Lithological composition: Obviously, this type of hazard should be reserved only for solid rocks, meaning that all soft rock and soil units can be ruled-out when delineating the source areas. However, some solid rock units can be more susceptible than the others, based on their structure, texture, jointing, weathering and other features, which means that there can be differentiation in the level of

susceptibility to rockfall among the selected solid rock units. It is also needed to estimate general friction properties along discontinuities for selected (rocky) units.

Table 2 Rockfall hazard assessment inputs, their sources, and their pre-processing in GIS environment for two-step modelling procedure (source area & rockfall simulation)

#	Input	Source	GIS pre-processing
1	Lithological units	Basic geological map 1:100,000 or 1:300,000 scale from Geological Survey of Serbia (https://geoliss.mre.gov.rs/?lang=en)	If unavailable in vector, vectorize the raster map. Engineering geologist should determine eligible units (to host rockfall) and assign their score in respect to anticipated rockfall occurrence on 0-1 scale (lower score for units less likely to host rockfalls and vice versa). Convert vector to 30 m raster based on these scores.
2	Aspect	DTM of at least 30 m freely available at USGS repository (https://earthexplorer.usgs.gov/) or with 12.5 m resolution available at ALOS PALSAR mission portal (https://search.asf.alaska.edu/)	Use the DTM to calculate slope aspect in degrees (0-360°) in respect to N, with standard D8 algorithm in GIS environment. No further processing needed.
3	Slope	DTM of at least 30 m freely available at USGS repository (https://earthexplorer.usgs.gov/) or with 12.5 m resolution available at ALOS PALSAR mission portal (https://search.asf.alaska.edu/)	Use the DTM to calculate slope angle in degrees (0-90°), with standard D8 algorithm in GIS environment. No further processing needed.
4	Dip	Basic geological map 1:100,000 or 1:300,000 scale from Geological Survey of Serbia (https://geoliss.mre.gov.rs/?lang=en)	If unavailable in vector, vectorize the raster map so that beddings, joints, foliation, and other discontinuities shown on the map are represented by points containing dip (and azimuth) value copied/measured from the map. Engineering geologist should define domains where same trend of discontinuity dip (and azimuth) are present (if needed, subdivide the lithological units). Calculate the prevalent dip for each domain, using zonal statistics tool (domains vs. mapped dips).
5	Azimuth	Basic geological map 1:100,000 or 1:300,000 scale from Geological Survey of Serbia (https://geoliss.mre.gov.rs/?lang=en)	If unavailable in vector, vectorize the raster map so that beddings, joints, foliation, and other discontinuities shown on the map are represented by points containing azimuth (and dip) value copied/measured from the map. Engineering geologist should define domains where same trend of discontinuity azimuth (and dip) are present (if needed, subdivide the lithological units). Calculate the prevalent azimuth for each domain, using zonal statistics tool (domains vs. mapped azimuths).
6	Friction angle	Basic geological map 1:100,000 or 1:300,000 scale from Geological Survey of Serbia (https://geoliss.mre.gov.rs/?lang=en)	If unavailable in vector, vectorize the raster map. All eligible solid rock units determined at item 1 should be allocated with the residual friction angle estimation in degrees. Convert vector to 30 m raster based on these values.
7	Land cover	European land cover map with 100 m resolution, available at CORINE portal (https://land.copernicus.eu/pan-european/corine-land-cover) Alternatively, Google imagery (https://earth.google.com/web/, https://www.google.com/maps)	Resample CORINE map to 30 m resolution. Use bare rock class as a mask for source area delineation. Alternatively, use Google Earth and Google Maps Street View (where available) to delineate (vectorize) rocky outcrops along the road corridors (especially uphill) with more detail. Convert to raster format (as a binary mask with value 1 and 0).
8	Digital Terrain Model	DTM of at least 30 m freely available at USGS repository (https://earthexplorer.usgs.gov/) or with 12.5 m resolution available at ALOS PALSAR mission portal (https://search.asf.alaska.edu/)	Use as-is to host rockfall trajectory simulation.

  - Kinematic condition: discontinuity planes (observable on geologic map) are defining the rock block shape and geometry, and in order to allow rockfall, they need to have inconvenient position in the slope, i.e., they need to dip steeper than the estimated residual friction angle and less steep than the slope face. Also, if their intersections plunge steeper than the friction angle and less steep than the face the instability condition is met. Indirectly, the following data are needed to spatially analyse kinematic conditions over AOI:
    - Slope aspect (the same as for the landslide hazard case)
    - Slope inclination (the same as for the landslide hazard case)
    - Discontinuity dip
    - Discontinuity azimuth
    - Discontinuity residual friction angle.
- Environmental condition
  - Land cover type: Obviously, bare rock is prerequisite for hosting such phenomena.
- Geomorphological base
  - DTM, as a simplified representation of the ground surface, needs to be detailed enough to provide a reliable geometry for rock trajectory simulation. Due to scale effects, larger scales suffer from non-representative slope angles due to resolution-related errors in sub-pixel domain. With 30 m resolution the slope angles will be unrealistic (gentler than the real) in most cases. With 12.5 m resolution the situation is somewhat better, but only with 1 m or smaller resolution DTMs (generated using LiDAR or SfM technology) it is possible to obtain realistic surfaces. However, in the regional assessment, it is not expected to be accurate to the level of individual rockfall, but to capture the trend and potential.

Flood hazard is based on more or less complex models, ranging from 1D to 3D hydraulic simulations, wherein ground surface, conductivity properties and anticipated rainfall interplay to define weather the natural river channels will sustain simulated (or historical) conditions.

For all main river systems, such models are already available for the entire Europe, including various scenarios (River flood Hz maps for Europe and the Mediterranean Basin region from 1-in-10-years to 1-in-500-years) so no specific input data are needed, and such is the case with the pilot study areas (Kraljevo and Aleksandrovac).

In addition, the Public Water Management Company (PWMC) Srbijavode, in charge of water management in the country in cooperation with PWMC Vode Vojvodine, both coordinated by the Directorate of Water (under the Ministry of agriculture, forestry and water management of Republic of Serbia), have an on-going flood mapping campaign at different watersheds throughout Serbia, also considering various return periods.

However, in an unlikely case that some future stakeholder is interested in implementing this Methodology but has limited catchment extent that does not fit to a continent-wide model, it is possible to create relatively simple model in the GIS environment (which will be elaborated further in the text).

Table 3 summarizes required input data for both cases, their data sources and necessary pre-processing steps in a GIS environment. The data needed for the purpose of simple flood model for smaller catchments are:

- Geomorphological base
  - DTM, as a simplified representation of the ground surface, needs to be detailed enough to provide a reliable geometry for surface water discharge.
- Hydrograph data
  - A historical record of hydrographic level of the target river system (e.g., main river and its primary tributaries) which is required to define the normal, alerting and emergency water levels recorded in the river channel.

Table 3 Flood hazard assessment inputs, their sources, and their pre-processing in GIS environment for simple model generation

#	Input	Source	GIS pre-processing
1	Flood map	River flood hazard maps for Europe and the Mediterranean Basin region for different return periods, 100 m resolution, freely available at European Commission portal (https://data.jrc.ec.europa.eu/dataset).	None (hazard map directly available).
		PWMC Srbijavode, PWMC Vode Vojvodine, authorities on water management, which have archived and on-going repository of flood maps for various scenarios in PDF format (https://www.srbijavode.rs/karte-ugrozenosti-i-karte-rizika-od-poplava.html) and in GIS formats for the largest river catchments (https://www.danubegis.org/ https://www.savagis.org/map).	Digitizing from available PDFs, and other resources or contacting water authority for operable raster files.
2	Digital Terrain Model	DTM of at least 30 m freely available at USGS repository (https://earthexplorer.usgs.gov/) or with 12.5 m resolution available at ALOS PALSAR mission portal (https://search.asf.alaska.edu/)	Use as-is to host water level rise simulation.
3	Hydrographic level	Surface water (analogue) yearbook repository (https://www.hidmet.gov.rs/)	Digitize the target hydrograph stations as point vectors (locations and level values). If needed, append more fake (non-existing) stations for better point density and distribution along the target river system.

Flash flood hazard is also very specific, and generally combines the modelling principles of landslides and rockfalls, i.e., it first requires delineation of susceptible source areas, commonly using the multi-criteria analysis (like in landslides), followed by a deterministic hydrodynamic model that simulates the flow behavior on top of available DTM surface (like in rockfalls).

Table 4 summarizes required input data for both procedures, their data sources and necessary pre-processing steps in a GIS environment. The data needed for delineating flash flood sources via multi-criteria analysis are as follows:

- Precipitation factor
  - Rainfall intensity: Flash floods happen when there is a sudden and intense rainfall, especially in mountainous areas. The amount of rainfall that triggers a flash flood is called the critical precipitation level. Historical rainfall data and the duration and volume of rainstorms are used to estimate the critical precipitation level or rainfall intensity. This level is similar to the water permeability of the rock in the catchment area, which defines how much water can be absorbed. When the critical precipitation level is exceeded, there is a surplus of water that cannot be absorbed and therefore, runs above the surface, causing quick and intensive floods, endangering people and property.
- Geological factor
  - Lithological composition: As indicated above, water permeability is a rock property that determines how much water is absorbed into the ground. Different types of rocks can absorb different amounts of water, so it is important to classify them based on their estimated or measured permeability capacity. The reference for performing such classification is the lithological map, while allocating the class requires additional measurements or expert estimations. As permeability capacity is the volume of water that can pass through a certain amount of ground over a specific period of time, it is directly comparable to the most extreme expected precipitation (which is also measured in terms of water volume over time, e.g., mm of height over a square meter surface per day or hour). By understanding water permeability and expected precipitation, we can better predict how water will behave in different types of rock during storms or thawing events.
  - Hydrogeological function: Permeable rock units (such as granular, jointed, karstic, etc.) allow that superficial discharge happens only when the rock unit is fully saturated (all voids filled). It obviously depends on the previous groundwater condition, i.e., level of saturation at the time of the rainfall

event, but this aspect is too complex for regional scale assessment. On the other hand, presence of impermeable rock units in the local catchment suggests that all precipitated water will be discharged superficially, which is the onset of the flash flood scenario.

- Geomorphological factor
  - Catchment structure: Catchment size, average slope steepness, development of the gully pattern are all parameters that are subjectable to classification against flash flood potential. Smaller steeper catchments with poor drainage are more prone to flash flood development and vice versa.
  - DTM, as a simplified representation of the ground surface, needs to be detailed enough to provide a reliable geometry for surface water discharge.
- Environmental factor
  - Land cover: During a rainfall event, vegetation can help retain some of the water through its root system and evapotranspiration. This means that areas with lots of vegetation, like forests, can absorb enough water to prevent flash floods. However, areas with little or no vegetation, like bare ground, do not have this ability, even under the same geological and morphological conditions and with the same critical rainfall. Land cover maps can show areas with impermeable surfaces like urban areas, and permeable areas like farmland and poorly vegetated areas, forests, etc. This map can be useful as a proxy in assessing flash flood hazard.

Table 4 Flash flood hazard assessment inputs, their sources, and their pre-processing in GIS environment

#	Input	Source	GIS pre-processing
1	Critical precipitation	Weather (analogue) yearbook repository (https://www.hidmet.gov.rs/)	Define relevant weather gauges within or in neighborhood of the AOI. Scope baseline period for intense rainfall extremes using daily data at selected weather gauges and define the threshold. Alternatively, use determined historical extremes, if available.
2	Lithological units	Basic geological map 1:100,000 or 1:300,000 scale from Geological Survey of Serbia (https://geoliss.mre.gov.rs/?lang=en)	If unavailable in vector, vectorize the raster map. Engineering geologist should estimate water conductivity of the unit and define weather the unit is permeable (score 0) or impermeable (score 1) against the critical precipitation threshold. Alternatively, all units can be scored in respect to anticipated permeability on 0-1 scale. Convert vector to 30 m raster based on these scores.
3	Catchment structure stack of raster	DTM of at least 30 m freely available at USGS repository (https://earthexplorer.usgs.gov/) or with 12.5 m resolution available at ALOS PALSAR mission portal (https://search.asf.alaska.edu/)	Use DTM to define sub-catchments and calculate all thereto implied parameters as independent raster, including sub-catchment size, average slope, and drainage network density.
4	Digital Terrain Model	DTM of at least 30 m freely available at USGS repository (https://earthexplorer.usgs.gov/) or with 12.5 m resolution available at ALOS PALSAR mission portal (https://search.asf.alaska.edu/)	Use as-is to host hydrodynamic flow simulation.
5	Land cover	European land cover map with 100 m resolution, available at CORINE portal (https://land.copernicus.eu/pan-european/corine-land-cover)	Resample CORINE map to 30 m resolution. Score land cover classes according to their water permeability potential on 0-1 scale, starting with forest class as 0 and impermeable surfaces as 1.

Road network data are essential input for exposure (Ex) assessment, as it defines the object of the assessment, i.e., RoA. State roads, governed by PE, are freely available in vector format, and contain standardized and harmonized files with all supplementary metadata.

Local roads (LoR), on the other end, governed by local authorities, are rarely available in vector format. One reliable resource of LoR is the Open Street Map (OSM) database, available freely at national level. However, the some intervention in GIS environment is needed to subsample LoR from the original OSM file, as it contains other types of roads and paths.

In the OSM original file, all LoRs can be equalized with the following OSM classes: “living street”; “residential”; and “unclassified” roads. The “living street” + “residential” are usually allocated within urban settlements, while “unclassified” are primarily allocated away from urban fabric and represent various access, service roads, etc.

Other categories in the OSM (primary, secondary, and tertiary roads are in fact the state roads) do not belong to LoR and should be excluded. It is possible to use road vector file from other resources, e.g., provided by the LSG if such is at disposal (e.g., within a detailed Master Plan and other local GIS maps), especially if it turns out to be more accurate than OSM network. In such case, it might be needed to apply the above classification to differentiate:

- Roads within settlements
- Roads outside settlements
  - Access roads
  - Collecting roads
  - Other roads (forest, field, village, etc.)

However, it is recommended to use OSM files, as some standard is therein guaranteed, and unified throughout the entire country, which might not be the case with alternative local sources.

Table 5 Road network input, its source, and pre-processing in GIS environment

#	Input	Source	GIS pre-processing
1	Road network per link	Open Street Map repository with shapefiles on national level (https://download.geofabrik.de/europe/serbia.html)	Download the shapefile and clean from all undesired vector types and contents. Leave only local road network and if applicable reclassify them (roads within and outside settlements, etc.).
2	Road network per sub-link	Open Street Map repository with shapefiles on national level (https://download.geofabrik.de/europe/serbia.html)	Use the road vector (cleaned and reclassified) generated at 1). Break road links into equal length segments, e.g., 500 m.

The link geometry (starting and ending node, link length, number of vertices, etc.) is defined in the OSM vector file. Although it is arbitrary (unknown by which principle it has been defined during digitization) it can be used as reference.

In addition to OSM-defined links vector layer, sub-links should be generated (and saved as a separate vector file), by splitting the network into, e.g., 500 m long segments. This way, a network with links of similar length (500 m or smaller) is generated. The purpose of the sub-link layer is identifying of hot spot locations, with high exposure (Ex) or criticality (Cr) value, whereas the link layer generalizes these values depending on links’ length). Table 5 summarizes sources and pre-processing steps needed for the LoR network definition.

Points of interests (PoI) similarly to road vector represent important input but not related to the hazard processes and not related to automated part of the modelling, but for the background part. These points are essential for defining the social and economic component of Vb of the road network (buffer analysis).

PoI that are included in this Methodology are hospitals, religious places (churches, monasteries and graveyards) and schools (and kindergartens), but other social facilities might be also considered (nursing homes, touristic places, shopping malls, etc.).

The link geometry (starting and ending node, link length, number of vertices, etc.) is defined in the OSM vector file. Although it is arbitrary (unknown by which principle it has been defined during digitization) it can be used as reference.

In addition to OSM-defined links vector layer, sub-links should be generated (and saved as a separate vector file), by splitting the network into, e.g., 500 m long segments. This way, a network with links of similar length (500 m or smaller) is generated. The purpose of the sub-link layer is identifying of hot spot locations, with high exposure (Ex) or criticality (Cr) value, whereas the link layer generalizes these values depending on links' length). Table 5 summarizes sources and pre-processing steps needed for the LoR network definition.

Table 6 Points of interest inputs, their source, and pre-processing in GIS environment

#	Input	Source	GIS pre-processing
1	Hospitals	Open Street Map repository with shapefiles on national level (https://download.geofabrik.de/europe/serbia.html)	Download the shapefile and clean from all undesired vector types and contents (leaving only hospitals). Generate Euclidean buffer around the hospital(s) vector.
2	Schools and kindergartens	Open Street Map repository with shapefiles on national level (https://download.geofabrik.de/europe/serbia.html)	Download the shapefile and clean from all undesired vector types and contents (leaving only schools and kindergartens). Generate Euclidean buffer around the PoI vector.
3	Religious places	Open Street Map repository with shapefiles on national level (https://download.geofabrik.de/europe/serbia.html)	Download the shapefile and clean from all undesired vector types and contents (leaving only religious places, such as churches, graveyards, monasteries). Generate Euclidean buffer around the religious PoI vector.

Road accidents (RoAcc) also represent important information, and they are liked to hazard occurrence. This input is not used for automated modelling but for background modelling. RoAcc are used to represent dangerous sections in terms of road accidents occurred, which might be and is related to the road infrastructure and hazard occurrence. Road accidents included in the methodology are road accidents with fatalities, injuries or material damage.

Table 7 Road accidents inputs, their source, and pre-processing in GIS environment

#	Input	Source	GIS pre-processing
1	Road accidents with fatalities	Open data, Traffic accident data per Police administrative units and Municipalities, excel files containing coordinates. (www.data.gov.rs/) To make modelling more precise, data on the number of fatalities per accident with fatalities could be requested from the Road Traffic Safety Agency (www.abs.gov.rs)	Download the excel files for last 5 years copy all into a single sheet, resave as .csv file. Generate shape file for accident fatalities using the Lon/Lat geographic coordinates (column E and F, i.e., 5 and 6) to convert tables to points, and subsequently to shape file. In generated shapefile add new field (column) as float type data and calculate field value using a condition: *Dim x* *If ([Field7] = "Saobracajna nezgoda sa poginulim") Then* *x=97* *Else* *x=0* *End If*
2	Road accidents with Injured	Open data, Traffic accident data per Police administrative units and Municipalities, excel files containing coordinates. (www.data.gov.rs/) Disaggregation of injuries could be done per severe and light injuries. Additional data could be required from the Road Traffic Safety Agency (www.abs.gov.rs) or taken manually from their integrated road safety database portal (http://bazabs.abs.gov.rs/absPortal/) Also, to make modelling more precise, data on the number of injuries per accident with injuries could	In the shapefile generated in previous step add new field (column) as float type data and calculate field value using a condition: *Dim x* *If ([Field7] = "Saobracajna nezgoda sa povredjenim") Then* *x=13* *Else* *x=0* *End If*

#	Input	Source	GIS pre-processing
		be requested from the Road Traffic Safety Agency (www.abs.gov.rs)	
3	Road accidents with material damage	Open data, Traffic accident data per Police administrative units and Municipalities., excel files containing coordinates. (www.data.gov.rs/)	In the shapefile generated in previous step add new field (column) as float type data and calculate field value using a condition: *Dim x* *If ([Field7] = "Saobracajna nezgoda sa mat.stetom") Then* *x=5* *Else* *x=0* *End If*

3.3 Input data 3 – Climate inputs

This chapter is primarily intended for use by external spatial modelling experts, to get familiarized with types and quality of data required to implement the Methodology, as well as where such data can be found. There are also detailed instructions for experienced spatial analysts how to pre-process raw data in GIS environment, and ready it for further modelling steps (Figure 5).

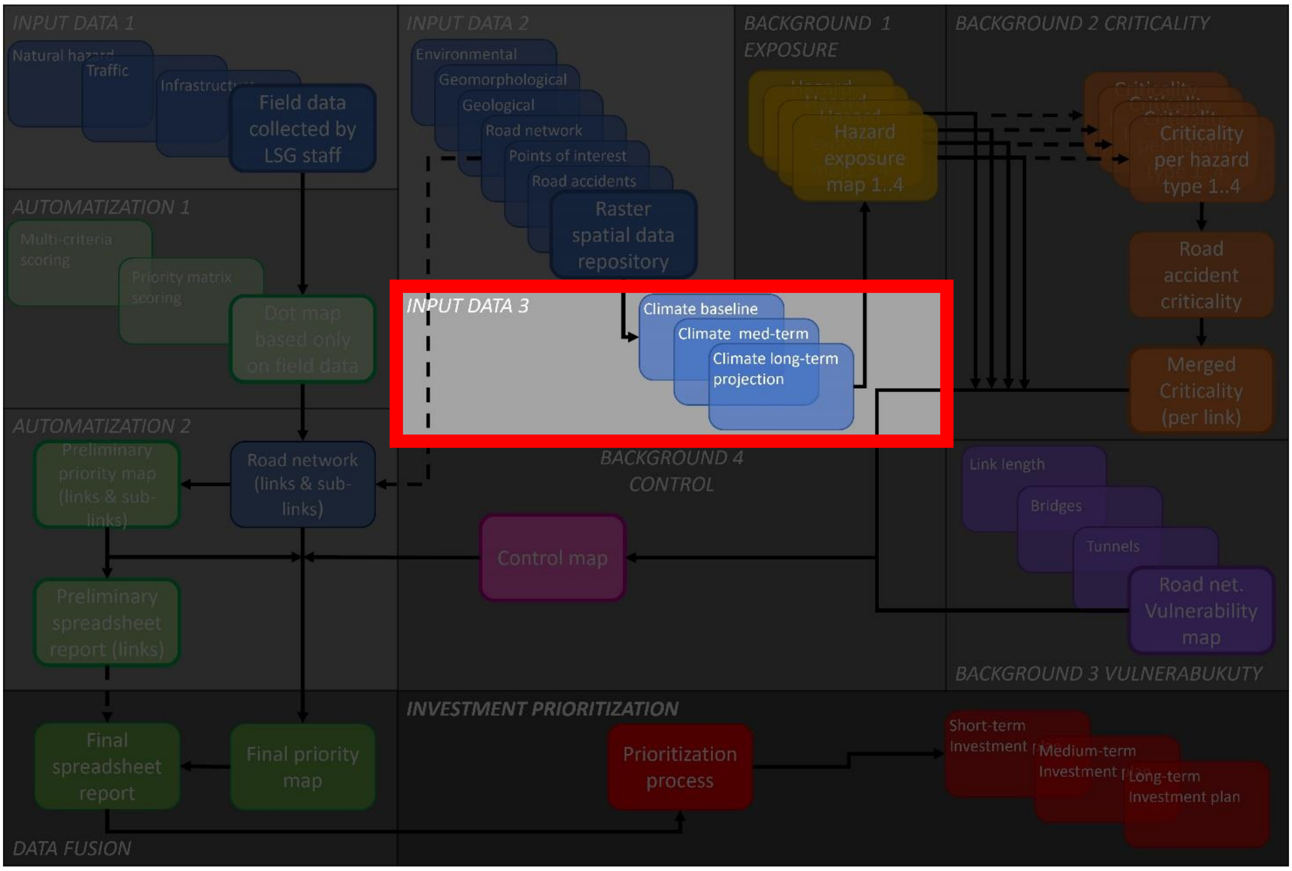


Figure 5 Input data 3 – Climate inputs

The project task implies impact of climate-related hazards along the road network, as of current, but also in the near and far future. Therefore, climate data for the baseline, 2050- and 2100-year projections are required, respectively.

Considering the hazard types involved (gravitational movements and flooding) precipitation is the key data required, but from multiple aspects. For instance, landslides and floods correspond well with annual average precipitation and number of days with intense rainfall, while flash floods are more tightly related to short, intense rainfall events.

As mentioned earlier, flood hazards are available as ready-made models for different return periods, including 10-year, which can match with the baseline, 50-year, which can match the 2050 projection, and 100-year, which can be considered as equivalent for 2100 projection). Of course, they do not match exactly, and the logic here implies that increased precipitation trends and increased frequency of extreme weather events (predicted in all climate change greenhouse gas emission scenarios), would increase temporal probability of occurrence of flooding in future projections to a level that corresponds to at least one magnitude higher return periods.

Alternatively, i.e., in the case of small AOI which are not encompassed by large scale model, the simplified modelling based on water level rise can be conducted arbitrarily but in line with flooding trends exhibited in large scale model for the nearest large river system (proportional reduction or increase of affected surface). Other types of hazards, landslides, rockfalls and flash floods should use the following climate parameters, which are also summarized in Table 8:

- Baseline average annual rainfall intensity: Raster dataset (unbiassed and downscaled to a suitable resolution, e.g., 30x30 m). Determines Hz for landslides, flash floods and subordinately, rockfalls.
- 2050 projection of average annual rainfall intensity: Raster dataset (unbiassed and downscaled to a suitable resolution, e.g., 30x30 m). Determines Hz for landslides, flash floods and subordinately, rockfalls.
- 2100 projection of average annual rainfall intensity: Raster dataset (unbiassed and downscaled to a suitable resolution, e.g., 30x30 m). Determines Hz for landslides, flash floods and subordinately, rockfalls.

Table 8 Climate data inputs, their source, and pre-processing in GIS environment

#	Input	Source	GIS pre-processing
1	Baseline rainfall	Weather (analogue) yearbook repository (https://www.hidmet.gov.rs/) CLIMAPROOF tool for bias-corrected downscale-able climate models for RCP4.5 scenario (https://climaproof.net/icc-obs-tool)	Define relevant weather gauges within or in neighbourhood of the AOI. Create point-based vector file of rain gauges. Append precipitation data (average annual sum) for baseline period. Interpolate (e.g., using Spline function) and generate the raster model with desired resolution (e.g., 30 m). Alternatively, use the ready-made CLIMAPROOF product in raster format (decompose original netCDF format into TIFF). Use only the raster within desired time interval and average them. Normalize to 0-1 range.
2	2050 rainfall	CLIMAPROOF tool for bias-corrected downscale-able climate models for RCP4.5 scenario (https://climaproof.net/icc-obs-tool)	Download projected 2050 precipitation data for Western Balkan Region (limit the search area and time interval). Convert to common raster file. Convert pixel centroids to points. Interpolate (e.g., using Spline) to a raster model with desired resolution (e.g., 30 m). Alternatively, use the ready-made CLIMAPROOF product in raster format (decompose original netCDF format into TIFF). Use only the raster within desired time interval and average them. Normalize to 0-1.
3	2100 rainfall	CLIMAPROOF tool for bias-corrected downscale-able climate models for RCP4.5 scenario (https://climaproof.net/icc-obs-tool)	Download projected 2100 precipitation data for Western Balkan Region (limit the search area and time interval). Convert to common raster file. Convert pixel centroids to points. Interpolate (e.g., using Spline) to a raster model with desired resolution (e.g., 30 m). Alternatively, use the ready-made CLIMAPROOF product in raster format (decompose original netCDF format into TIFF). Use only the raster within desired time interval and average them. Normalize to 0-1.

4. Preliminary prioritization

This chapter is only outlining the automation Methodology and does not necessarily involve external spatial modelling experts, nor the LSG staff, but all parties can be familiarized with the mechanism of the automation presented in this chapter (Figure 6 and Figure 7). The appropriate example is illustrated in Appendix A.

One part of the Methodology is dedicated to automation of the prioritization process, so that the LSG staff and LSG decision makers do not need to perform any modelling, but merely understand and use the automatic outputs generated from all input data.

As presented in preceding Chapter, the field data are collected at specific field locations, meaning that the base for presenting the data are point vectors. After collecting enough points, the information can then be translated onto road elements, i.e., links and sub-links, which are line vectors.

The automation thus, involves generating of both preliminary point and preliminary line maps in vector format (Appendix A - A.1 and A.2). Although it generates respective preliminary products that can be used as stand-alone aids in decision making, it is highly recommended that they are used in combination (fusion) with control map, as will be explained later.

4.1 Automation 1 – per location prioritizing

The Automation 1 is a procedure which requires that all relevant field data inputs, described in Chapter 3.1, are supplied. The procedure can be separated into steps and sub-steps, as follows (Appendix A - A.1.4).

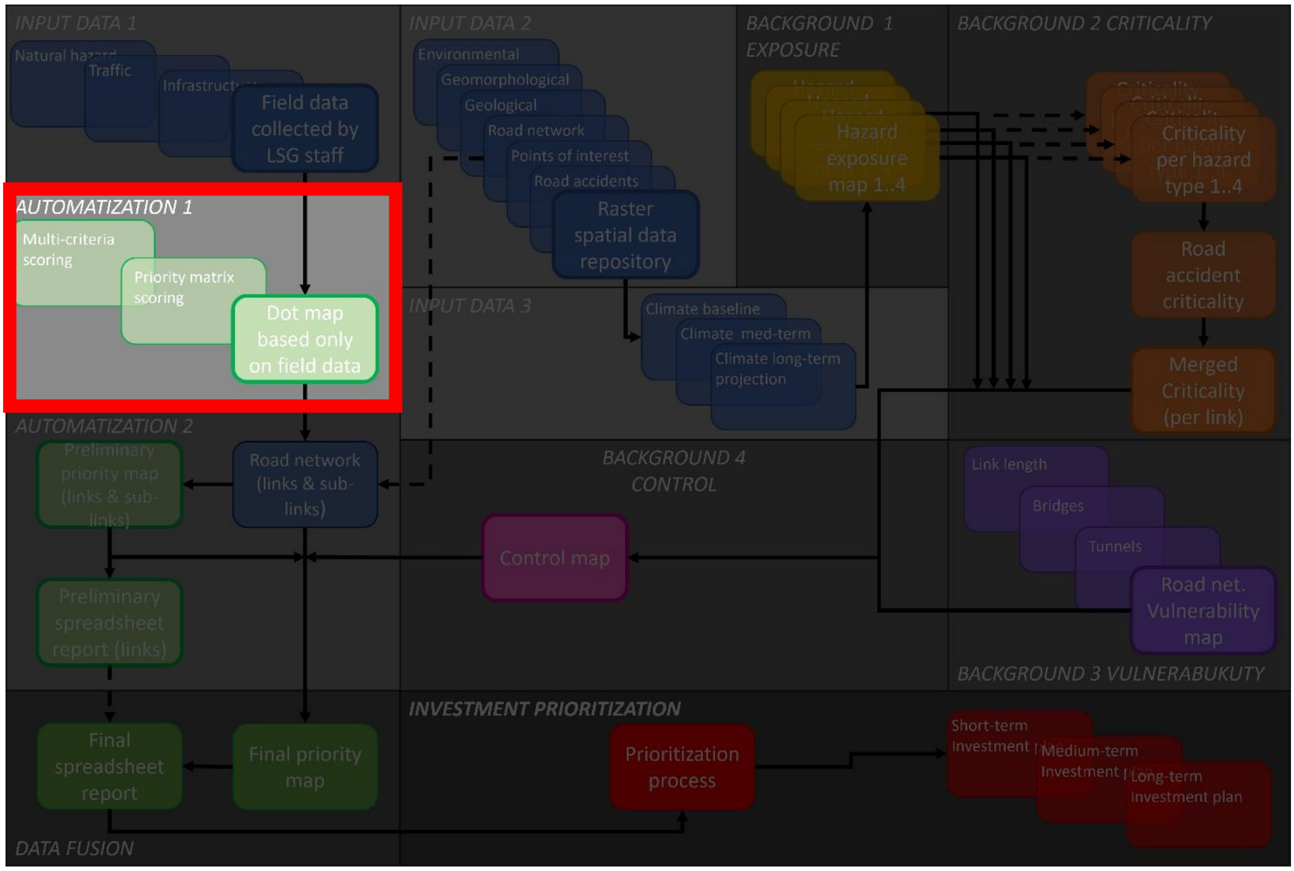


Figure 6 Automation 1 – per location prioritizing

Step 1 – Multi-criteria scoring of the natural hazard processes: The scoring is performed on each piece of input data (parameter), collected by the LSG field worker, including required and optional parameters, as well as automatically generated data (e.g., data that can be automatically generated from previously introduced data, such as surface area from length and width).

It is possible that the same location, where some road damage is observed, contains more than one hazard event, so Step 1 can be segregated into four sub-steps in accordance with four different hazard types.

The scoring is based on a relative scale of values, ranging from 1 to 5, by predefined criteria. For each discrete information within a specific category defined by our expert team, or for each value that falls within a range defined by our expert team, a value (1, 2, 3, 4 or 5) is assigned.

Thereby, LSG staff are automatically assigning score to each piece of information introduced. After completing an observation at the field site, Hz score must be normalized (to keep relative scale throughout) and then multiplied by its weighting factor *w* (also defined by our expert team):

$$fin\_h\_score = w \cdot norm\_h\_score = w \cdot \frac{\sum h\_score - h\_score\_min}{h\_score\_max - h\_score\_min} \qquad [1]$$

wherein: *fin_h_score* is the final hazard score of each individual hazard (landslide, rockfall, flash flood, flood), *w* is the preassigned weighting factor different for each hazard type, *h_score* is the score of each introduced parameter (presented in Tables 8–11), *h_score_min* and *h_score_max* are minimal and maximal possible sum of scores of all parameters, respectively (different for every hazard type).

Sub-step 1.1. Landslide hazard score – Required fields: length, width, scarp visibility, scarp height (conditionally), area (automatic), frequency, trigger, and activity. Table 9 summarizes the scoring system. Landslides gain the highest weight factor (*w*=5) as they represent the process not just events. They commonly appear with high magnitude and are constantly damaging the road until remediated (unlike floods, rockfalls and flash floods), as displacement may be small or large, but constant. The maximum value is 50 and minimal 11.

Sub-step 1.2. Rockfall score – Required fields: runout, frequency, trigger, and activity. Table 10 summarizes the scoring system. Rockfalls gain the lowest factor (*w*=2) since they commonly affect the road for a short time and along small stretches (local events). The maximum value is 30 and minimal 7.

Sub-step 1.3. Flood score – Required fields: floodway width, flood fringe width, water level above normal river level, water level in respect to the road level, frequency, cause, and protection status.
Table 11 summarizes the scoring system. Floods gain the moderate factor (*w*=3) since they appear chronically but retreat after some time and do not affect the road in between. The maximum value is 35 and minimal 8.

Sub-step 1.4. Flash flood score – Required fields: width, runout, water level above ground, water level in respect to the road level, frequency, cause, and protection status. Table 12 summarizes the scoring system. Flash floods gain the higher weight factor than floods (*w*=4) since they are similar to floods in many aspects except, they are usually more violent and extremely rapid and do not allow any time lag (to allow action) like floods (which can be announced days in advance). The maximum value is 30 and minimal 8.

Table 9 Scoring system for landslide hazard process

Parameter	Class interval**					Score				
weighting factor *w*	NA					5				
length [m]	<10	10-50	50-200	200-500	≥ 500	1	2	3	4	5
width [m]	<5	5-10	10-50	50-200	≥ 200	1	2	3	4	5
depth [m]	<5	5-10	10-20	20-30	≥ 30	1	2	3	4	5
visible scarp	no		yes			1		5		
scarp height [m]	<0.5	0.5-1	1-2	2-3	≥ 3	1	2	3	4	5
area [m^2]	<50	50-500	500-10k	10k-100k	≥100k	1	2	3	4	5
volume [m^3]	<250	250-5k	5k-200k	200k-3M	≥3M	1	2	3	4	5
frequency	<1/year	1/year	≥1/year			1	3	5		

Parameter	Class interval**					Score				
trigger	erosion	human	snow thaw	rain	earthquake	1	2	3	4	5
activity	suspended	dormant	active			1	3	5		
remediation date	<1y ago	1y-5y ago	≥5y ago			0.5*	0.75*	1*		
remediation cost [€]	<500k	500k-3M	≥3M			0.5*	0.75*	1*		

*Conditional scores in case a landslide is suspended (scores for both conditional inputs should not exceed dormant landslide score)
** All intervals take the lower bound as inclusive while upper bound is exclusive, e.g., class 5-10 means 5 to 9.99.

Table 10 Scoring system for rockfall hazard process

Parameter	Class interval**					Score				
weighting factor *w*	NA					2				
runout [m]	<50	50-100	100-300	300-1000	≥1000	1	2	3	4	5
release height [m]	<5	5-10	10-50	50-100	≥100	1	2	3	4	5
block volume [m^3]	<0.3	0.3-1	1-5	5-10	≥10	1	2	3	4	5
frequency	<1/year	1/year	≥1/year			1	3	5		
trigger	icing or root	human	snow thaw	rain	earthquake	1	2	3	4	5
activity	suspended	dormant	active			1	3	5		
remediation date	<1y ago	1y-5y ago	≥5y ago			0.5*	0.75*	1*		
remediation cost [€]	<500k	500k-3M	≥3M			0.5*	0.75*	1*		

*Conditional scores in case that the rockfall is suspended (scores for both conditional inputs should not exceed the dormant rockfall score)
** All intervals take the lower bound as inclusive while upper bound is exclusive, e.g., class 5-10 means 5 to 9.99.

Table 11 Scoring system for flood hazard process

Parameter	Class interval**					Score				
weighting factor *w*	NA					3				
floodway width [m]	<10	10-50	≥50			1	3	5		
flood fringe width [m]	<50	50-300	≥300			1	3	5		
level above normal [m]	<2	2-5	≥5			1	3	5		
level above/below the road [m]	<-2	-2-0	≥0			1	3	5		
frequency	<1/year	1/year	≥1/year			1	3	5		
cause	external flood wave	downstream damming	rain	snow thaw	upstream dam breach	1	2	3	4	5
protection status	regulated	damaged	no regulation			1	3	5		
regulation date	<1y ago	1y-5y ago	≥5y ago			0.5*	0.75*	1*		
regulation cost [€]	<500k	500k-3M	≥3M			0.5*	0.75*	1*		

*Conditional scores in case that the flood is regulated, or regulation is damaged by the event (scores for both conditional inputs should not exceed the damaged regulation score, i.e., no regulation score)
** All intervals take the lower bound as inclusive while upper bound is exclusive, e.g., class 5-10 means 5 to 9.99.

As mentioned earlier, a single location (defined within a reasonable distance, such as a stretch of road from a few meters to a few hundred meters long) can experience multiple events of different types, or multiple events of the same type (such as consecutive landslides, rockfalls, or flash floods). In this case, the score should be added together to reflect the total impact of all the events at that location.

The crucial step is to apply the second round of normalization, which preserves the relative relationships between the different locations within the point vector. This relative relationship is crucial because it enables comparisons between locations to determine which one remains the most critical flash flood:

$$fin\_h\_score\_multi = \frac{\sum fin\_h\_score - fin\_h\_score\_min}{fin\_h\_score\_max - fin\_h\_score\_min} \qquad [2]$$

wherein: *fin_h_score_multi* is the multi-hazard score of all individual hazards combined (at specified location), *fin_ h_score* is the final (normalized and weighted) hazard score of individual hazards, *fin_h_score_min* and *fin_h_score_max* are minimal and maximal possible values of *fin_ h_score* (at LSG area level, not at specified location, i.e., min/max of all values within the LSG local road network).

Table 12 Scoring system for flash flood hazard process

Parameter	Class interval**					Score				
weighting factor *w*	NA					4				
width [m]	<50	50-100	≥100			1	3	5		
runout [km]	<0.5	0.5-1	1-3	3-10	≥10	1	2	3	4	5
level above normal [m]	<2	2-5	≥5			1	3	5		
level above/below the road [m]	<-2	-2-0	≥0			1	3	5		
frequency	<1/year	1/year	≥1/year			1	3	5		
cause	rain	snow thaw	upstream dam breach			1	3	5		
protection status	regulated	damaged	no regulation			1	3	5		
regulation date	<1y ago	1y-5y ago	≥5y ago			0.5*	0.75*	1*		
regulation cost [€]	<500k	500k-3M	≥3M			0.5*	0.75*	1*		

*Conditional scores in case that the flash flood is regulated, or regulation is damaged by the event (scores for both conditional inputs should not exceed the damaged regulation score, i.e., no regulation score)
** All intervals take the lower bound as inclusive while upper bound is exclusive, e.g., class 5-10 means 5 to 9.99.

Table 13 Scoring system for road importance

Parameter	Class interval**				Score			
weighting factor *w*	n.a				5			
road function	Urban (other)	Urban (transit)	Rural (transit)	Rural (connecting remote villages/ households)	1	3	4	5
interruption type	None	Reduces velocity	One direction	Both directions	1	3	4	5
traffic flow type	no public transport		with public transport		1		5	
alternative routes	yes		no		1		5	
estimated reroute length [km]	<1	1-5		≥5	1*	2*	3*	

*Conditional scores in case that alternative route exists (scores for conditional input should not exceed the score of no alternative route)
**All intervals take the lower bound as inclusive while upper bound is exclusive, e.g., class 1-5 means 1 to 4.99.

Step 2 – Impact assessment – multi-criteria scoring of the traffic flow importance/interruption: This step simulates what would theoretically be represented as impact or risk scenario analysis. It is herein simplified based on limited information availability and limited user background and skill. Each observation by the user will presumably be conducted at the time or immediately after the event occurs (depending on the event, since some hazard processes are short and fast, while others last for days and weeks).

This allows on-site estimation of the affected traffic demand using very simple, obvious information, which would in general cover all marginal cost needed for economic assessment. All inputs are required or conditionally required (e.g., in the case that there is an alternative road it becomes required to estimate the length of rerouting).

Our expert team defined the scoring system for both, fixed scores, as well as scores defined by the class intervals. This way, scoring gives priority to the socio-economic impact (e.g., travel time, public transport, transit routes). The final traffic score is normalized and then multiplied by its weighting factor *w*. The normalization (Eq. 3) should be calculated similarly as in the case of Hz score. Table 13 summarizes scoring system for the traffic component. The maximum value is 23 and minimal 5.

$$T = fin\_t\_score = w \cdot norm\_t\_score = w \cdot \frac{\sum t\_score - t\_score\_min}{t\_score\_max - t\_score\_min} \qquad [3]$$

wherein: *fin_t_score* is the final traffic score, *norm_ h_score* is the normalized traffic score, *w* is the preassigned weighting factor, *t_score* is the score of each introduced parameter (presented in Table 13), *t_score_min* and *t_score_max* are minimal and maximal possible values of *t_score* (at specified location).

Step 3 – Vulnerability assessment – multi-criteria scoring of the affected infrastructure: This step simulates the simplified road asset vulnerability. Vulnerability is herein based on the presented matrix (Table 14).

All damages are presented as light, medium, and heavy investment. This way, it presents that the most vulnerable infrastructure is those the most affected. The same as in the previous step, this is done based on the limited user background and skills. Each observation by the user will presumably be conducted at the time or immediately after the event occurs (depending on the event, since some hazard processes are short and fast, while others last for days).

This allows on-site estimation of the affected infrastructure using very simple, obvious information, which would represent the road asset vulnerability on one side and the level of investment on the other side as used in the economic assessments.

It contains fixed scores (as of current provisional), assigned by our expert team. If more than one for light/heavy investment is selected, maximal value is assigned. The final infrastructure score is normalized and then multiplied by its weighting factor *w*. The score minimum is equal to 0 as all fields involving some interventions are optional and depend on the on-spot estimation of the user, while the maximum score is 12.

$$I = fin\_i\_score = w \cdot norm\_i\_score = w \cdot \frac{\sum i\_score - i\_score\_min}{i\_score\_max - i\_score\_min} \qquad [4]$$

wherein: *I* or *fin_i_score* is the final infrastructure score, *norm_ i_score* is the normalized infrastructure score, *w* is the preassigned weighting factor, *i_score* is the score of each introduced parameter (presented in Table 14), *i_score_min* and *i_score_max* are minimal and maximal possible values of *i_score* (at specified location).

Table 14 Scoring system for affected infrastructure

<table>
<tr><th>Parameter</th><th colspan="6">Class interval</th><th colspan="5">Score*</th></tr>
<tr><td>weighting factor w</td><td colspan="6">n.a</td><td colspan="5">2</td></tr>
<tr><td>Light investment</td><td colspan="2">Planning not needed – immediate actions</td><td colspan="2">Planning not needed – repair</td><td colspan="2">Planning needed – Repair</td><td>1</td><td>2</td><td>3</td><td></td><td></td></tr>
<tr><td>Medium investment</td><td colspan="6">Planning needed – reconstruction</td><td></td><td></td><td></td><td>4</td><td></td></tr>
<tr><td>Heavy investment</td><td colspan="3">Planning needed – reconstruction</td><td colspan="3">Planning needed – new infrastructure</td><td></td><td></td><td></td><td>4</td><td>5</td></tr>
</table>

*Score will be based on the detailed breakdown of each damage and the total sum of all sub-scores.

These crucial three steps might face another issue in time. As it is expected that after several years of reporting, and due to the nature of the hazard events and their frequency (repetition at same location), LSG staff might revisit locations that have been affected by past events. These records already contain scoring, but for past events, and an update is necessary.

In that context, only the latest observations should enter further calculations, as many thigs can change between two visits (e.g., different characteristics of hazard event, climate change, various protective or remediation measures undertaken meanwhile).

Step 4 – Priority matrix: When all scoring is completed at a single site location, it is necessary to pair the scores of Traffic impact (*T*) and Infrastructure vulnerability (*I*) against hazard exposure scores (*fin_h_score* or *fin_h_score_multi*) for landslides (*L*), rockfalls *(R)*, floods (*F*), and flash floods (*FF*) and define the preliminary priority classes.

Sub-step 4.1 - Beforehand, it is needed to sum up scores of Traffic impact and Infrastructure vulnerability scores (*T*+*I*) and then normalize the sum (using max=2, min=0). Thereby the value will be maintained in the 0-1 range.

Sub-step 4.2 - Repeat the same normalizing procedure for all four Hz scores (*L*+*R*+*F*+*FF*), wherein the sum (max=4, min=0) should range into 0-1 domain after normalization.

Sub-step 4.3 - Next step is to classify summed and normalized scores *T*+*I* on one side, and *L*+*R*+*F*+*FF* on the other side, using the standard equal intervals[4] in the following procedure:

- Very low class < 0.2 ⇒ assign value 0.2
- Low class = 0.2-0.4 ⇒ assign value 0.4
- Moderate class = 0.4-0.6 ⇒ assign value 0.6
- High class = 0.6-0.8 ⇒ assign value 0.8
- Very high class ≥ 0.8 ⇒ assign value 1.0

Sub-step 4.4 - Multiply pairs of scores (*T*+*I*) x (*L*+*R*+*F*+*FF*) to form the preliminary priority matrix (Table 15). For more straightforward visualization and easier later fusion with background model outputs it is convenient to reclassify preliminary matrix values by using 1 – 5 value intervals (Table 16):

- Very low class = 1
- Low class = 2
- Moderate class = 3
- High class = 4
- Very high class = 5

[4] All intervals take the lower bound as inclusive while upper bound is exclusive, e.g., class 0.2-0.4 means 0.2 to 0.399.

Table 15 Preliminary priority matrix derivation

Normalized* (T+I)	Class	Priority matrix				
1	Very high	0.20	0.40	0.60	0.80	1.00
0.8	High	0.16	0.32	0.48	0.64	0.80
0.6	Moderate	0.12	0.24	0.36	0.48	0.60
0.4	Low	0.08	0.16	0.24	0.32	0.40
0.2	Very low	0.04	0.08	0.12	0.16	0.20
	Class	Very low	Low	Moderate	High	Very high
	Normalized* (L+R+F+FF)	0.2	0.4	0.6	0.8	1

* After normalization each score class has been assigned a single value, i.e., the upper bound value
Note: All intervals take the lower bound as inclusive while upper bound is exclusive, e.g., class 0.6-0.8 means 0.6 to 0.79.

Sub-step 4.5 - Classify[5] and color code the priority values using the following intervals:

- Very low class <0.08 ⇒ color code **dark green**
- Low class = 0.08-0.16 ⇒ color code **light green**
- Moderate class = 0.16-0.36 ⇒ color code **yellow**
- High class = 0.36-0.64 ⇒ color code **orange**
- Very high class > 0.64 ⇒ color code **red**

For more straightforward visualization and easier later fusion with background model outputs it is convenient to reclassify preliminary matrix values in the same way as in Sub-step 4.4, I.e., by using 1 – 5 value intervals Table 16):

Table 16 Final (reclassified) priority matrix

(T+I) Class	Priority matrix				
Very high	3	4	4	5	5
High	2	3	4	4	5
Moderate	2	3	3	4	4
Low	1	2	3	3	4
Very low	1	1	2	2	3
(L+R+F+FF) Class	Very low	Low	Moderate	High	Very high

The output, i.e., the preliminary Dot map, can be conveniently presented using the traffic light color coding, from dark green, to red, with simple and understandable scoring scale 1–5. These (observation) points will be superimposed over the OSM in next part to generate per link and per sub-link preliminary map products (Appendix A - A.2).

[5] All intervals take the lower bound as inclusive while upper bound is exclusive, e.g., class 0.08-0.16 means 0.08 to 0.159.

4.2 Automation 2 - road network prioritizing

Instead of visualizing points, decision makers tend to benefit from visualizing stretches of the road that are higher priority in comparison to the other parts of the road. To this end, it is needed to translate previously collected point vector data onto the line vector of the road network, as a new overlay. Road network layer which will be subjected to the spatial overlap with points, should be previously obtained from the OSM and prepared in two variants, with links and sub-links geometry definition, as described in Chapter 3.2.

The procedure implies simple aggregation of point priority values that spatially correspond to the specific RoL (Appendix A - A.1.5). The same procedure applies for both line vectors variants (link and sub-link).

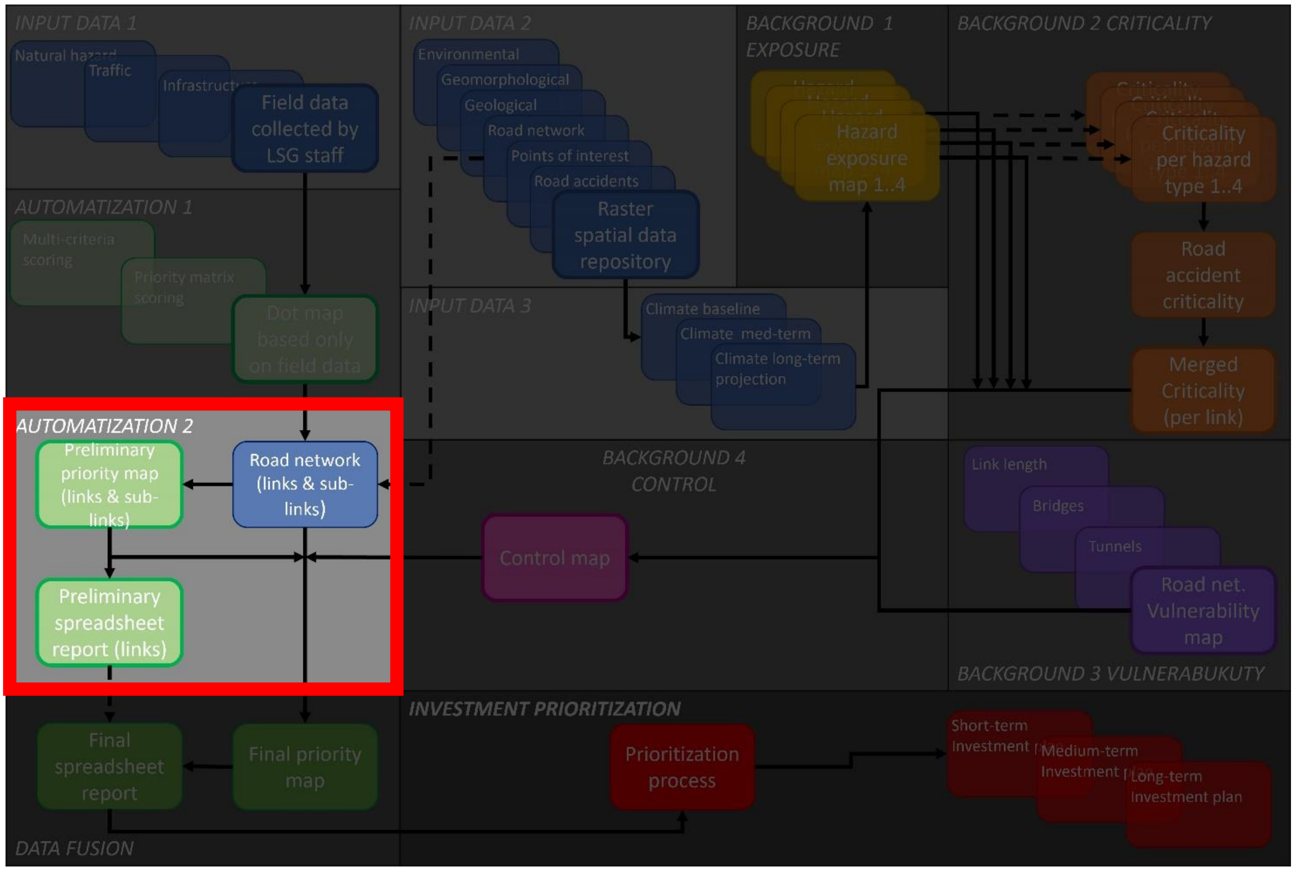


Figure 7 Automation 2 - road network prioritizing

Per link road network is segmented by default topology inherited from the OSM. Each link is thus one line vector feature. Priority value is allocated to each link by spatially overlapping each line feature against the points from the Dot map and aggregating their values (Figure 8).

The aggregation can include various operations such as addition, maximum/minimum value, averaging, etc. but it is most reasonable to use weighted sum for links and maximum value for sub-links. It is recommended to divide the summed score per link by the link length in km to obtain a realistic result. Namely, the longer links have more chances to intersect observation points than short links. A short link with a single high score point might be underestimated, as attention might be deflected towards a long link with many low score points.

Majority of points along the longer link might overcome the value of that single point observed at the short link. All points that intersect or overlap with a link line with some tolerance (e.g., 10-20 m) are included in this calculation. Introducing spatial tolerance is meaningful for several reasons. Firstly, the field data are routinely collected with aid of navigation services available on standard mobile devices, which commonly have location error of several meters in both, horizontal and vertical directions.

Another source of dislocation is the user position while performing the observation. As it is safer and more comfortable to work away from the road (traffic, noise, sunshade, rain shelter, etc.), the resulting location can be significantly off the road line.

Finally, the phenomena at hand might be located uphill or downhill from the road, while still affecting it. Once calculated the aggregated priority value will have arbitrary score intervals. Therefore, normalization should once again take place, so that there is a clear relationship between the link priority values throughout the entire road network. By using the traffic light color coding, high priority links will automatically be highlighted in red. The output of this procedure is per link map of priorities.

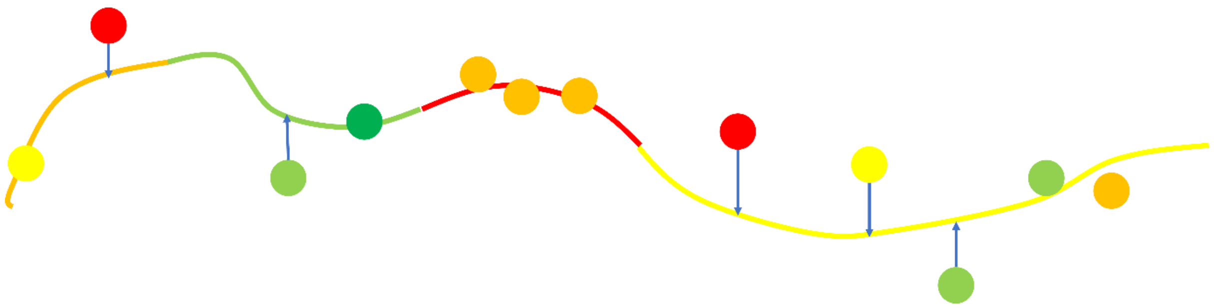


Figure 8 Point aggregating principle for links case

Per sub-link road network is segmented by arbitrary length, so that every vector feature has similar length. It is advisable to use 500 m segment length for sub-links, as it provides good resolution in regional scales and still picking up sufficient level of detail of RoA (curves, bridges, straights, etc.).

This maneuver is commonly used to highlight the priority distribution in greater detail (Figure 9). The length factor that affects per link case is herein absent, as all links are of the similar length (500 m or smaller).

Aggregation is straightforward, i.e., represented by sum or by maximum value. Subsequent normalization is also necessary to distinct the most critical of all sub-links in the network. Traffic light color coding can be used to highlight the highest priority sub-links. It is desirable to reinspect the per link priority map by comparing it to per sub-link map and seek for potential irregularities. The output of this procedure is per sub-link map of priorities.

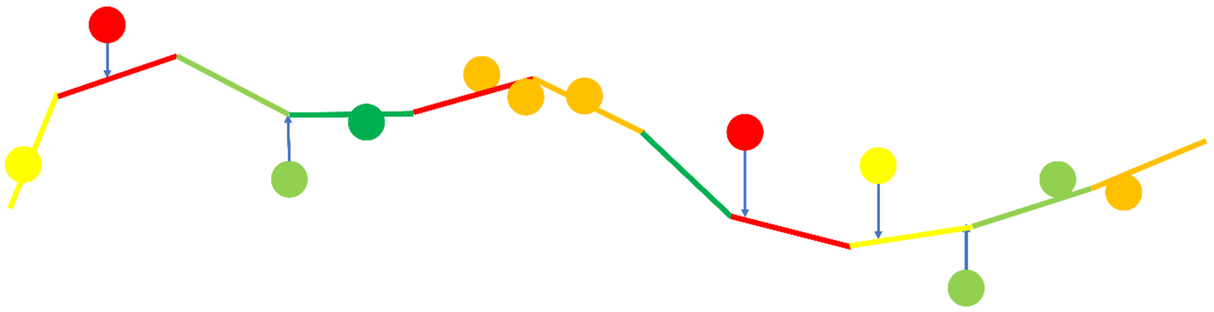


Figure 9 Point aggregating principle for sub-links case

Finally, the automation also includes extraction of desired output data (Hz, Cr, Vb, Pr, etc.) in spreadsheet format. It is more convenient for decision makers to work with longer stretches of road, i.e., links in the network, albeit arbitrarily partitioned (default OSM topology). The simple reason behind it is that the investment of the road repairment cannot be localized to 500 m on one part of the network and then moved to entirely different 500 m sub-link in another part of the network.

In practice, the interventions are usually conveyed along entire sections of the road, connecting adjacent links (and sub-links). For this reason, decision makers might benefit from using spreadsheets generated from Per link priority map. Therein, they can sort the links according to priority, or according to any desired criteria, as all information remains in one place (including all input data and scoring data). For instance, one could be interested in remediating flood impacts only, and accordingly filter the dataset to highlight only eligible locations.

5. Background Spatial Modelling

This chapter is describing the spatial modelling methodology, which does not involve the LSG staff, but instructs the external spatial modelling experts, hired to perform the analysis. The modelling sequence is outlined in Figure 10, Figure 16, Figure 18 and Figure 19.

So far, the Methodology has considered the interactive part which requires user's input. It is further proposed that user's preliminary (automatic) results are not the final ones, even though they may be sufficient. These preliminary results should undergo a correction procedure, which requires a great deal of spatial modelling. This part is therefore to be conducted by respective specialists in the field of natural hazards, traffic and civil engineering via spatial analysis. The LSG user has no need to interact with controlling process, as it is there to ensure reliable results.

It is expectable that the LSG user cannot collect enough data in a short period of time (within one season, or one year). Consequently, preliminary maps and designated priorities can be biased, and control process is there to rectify them. Thematically, this chapter can be split into four segments following the respective themes: Ex, Cr, Vb and final control layer.

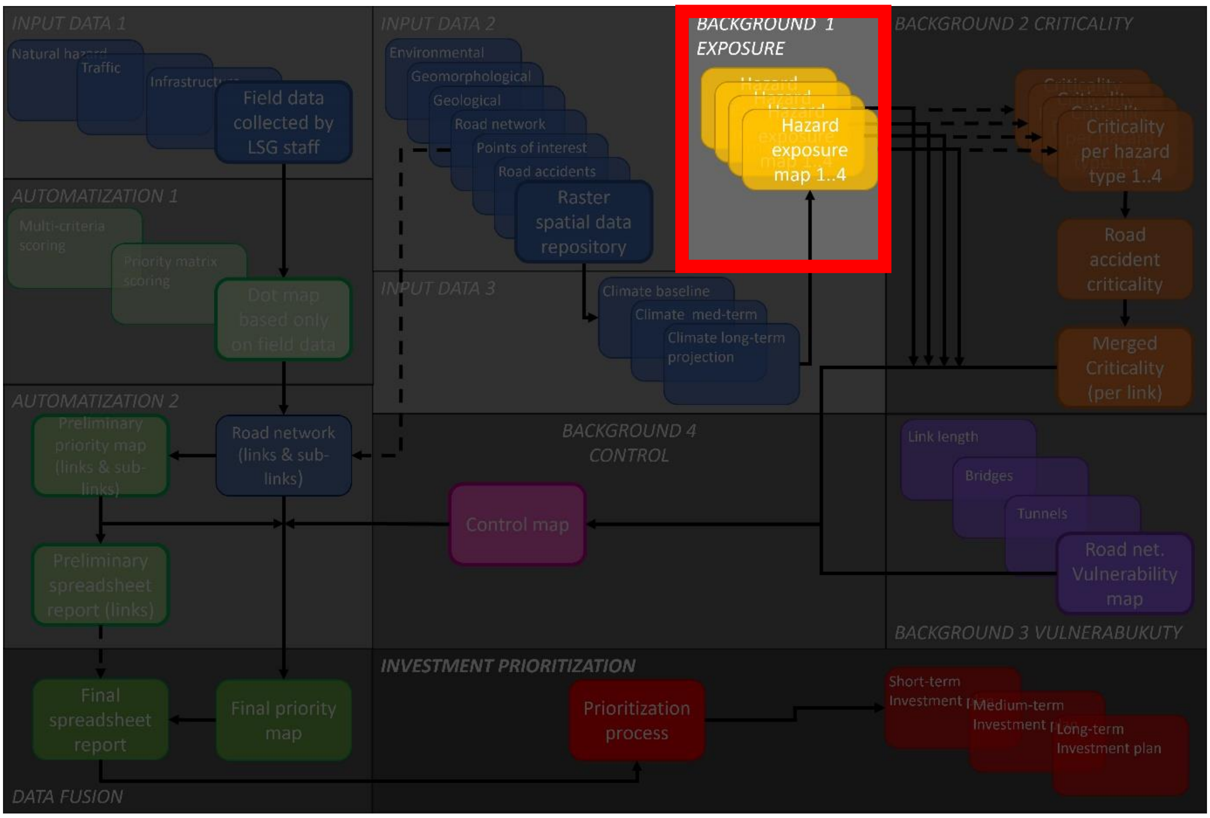


Figure 10 Background 1 - Hazard exposure assessment

5.1 Background 1 - Hazard exposure assessment

In this subchapter, all four types of hazards (landslides, rockfalls, floods and flash floods) involved in road resilience, and their modelling techniques will be described.

As will be shown later in the Report, criticality assessment might be affected differently by different hazard types. It was therefore decided that each Hz has a separate Ex layer without merging them together into a multi-hazard exposure.

Landslides hazard exposure can be assessed with various techniques, ranging from heuristic to statistic, deterministic, machine learning, etc. They mainly require preparation of historic landslide inventory to compare analysis based on relation of landslide proxies with existing landslides, using one of the abovementioned approaches.

Back analysis of existing landslides are especially used in deterministic models, but the same principle applies to all other approaches. Herein, we propose using an even simpler multi-criteria heuristic approach for which only arbitrary expert judgement is needed without the inventory (which is commonly the hardest piece of data to acquire).

However, if the inventory is present, it should be used firstly to calibrate class intervals for input proxies, and secondly, for establishing weight factors of each proxy layer. This procedure has been proven applicable on regional scales throughout the world, with more or less success.

Alternatively, the Preliminary landslide hazard map of Serbia 1:300 000 (Figure 11), which can be found in the Geological Survey of Serbia repository (as indicated in Chapter 3.2), can be used directly even though it remains only in PDF format and requires additional digitizing and georeferencing work.

It is also important to mention that hazard assessment should be separated into two steps, regarding spatial and temporal probabilistic nature of the landslide hazard.

Step 1 – Landslide susceptibility assessment: The simplest way of conducting the susceptibility assessment is by combining the available landslide proxies P_i pre-processed (classified and scored) as instructed in Chapter 3.2. The general hierarchy of their importance, together with proposed percentages of influence or weight factors *w* (which should add up to 100) is as follows:

1.	lithological units (*LU*)	25%
2.	slope (*S*)	20%
3.	depth to bedrock (*DB*)	15%
4.	distance from structures (*DS*)	12%
5.	land cover (*LS*)	10%
6.	curvatuI(*C*)	8%
7.	elevIon (*E*)	6%
8.	aspect (*A*)	4%

A simple additive model for defining landslide susceptibility (*LS*) follows as in the formula:

$$LS = \sum_1^{n=7} w_i \cdot P_i \quad [5]$$

$$LS = 0.25 \cdot LU + 0.2 \cdot S + 0.15 \cdot DB + 0.12 \cdot DS + 0.1 \cdot LC + 0.08 \cdot C + 0.06 \cdot E + 0.04 \cdot A \quad [6]$$

Step 2 – Landslide (quasi) hazard assessment: Once that spatial probability has been determined, the next step involves the introduction of temporal component. For regional scale landslides and scarce landslide inventories, it can become an unfeasible task.

For this reason, it is advisable to use the temporal frequency of their most common trigger, i.e., rainfall. Normalized Baseline average annual rainfall (*BR*) or Baseline average annual rainfall intensity (*BRI*) can be considered representative as temporal factors that are introducing difference in spatial probability pattern due to difference in their temporal frequency over AOI.

For 2050 and 2100 climate projections, these can be downscaled from wide region models as explained earlier. Given all degrees of freedom implied through associated climatic variables and possible GHG emission scenarios, these projections are rather abstract, but the only reference that can be used for such far future predictions. The landslide hazard for baseline and the 2050 and 2100 equivalents thus, become:

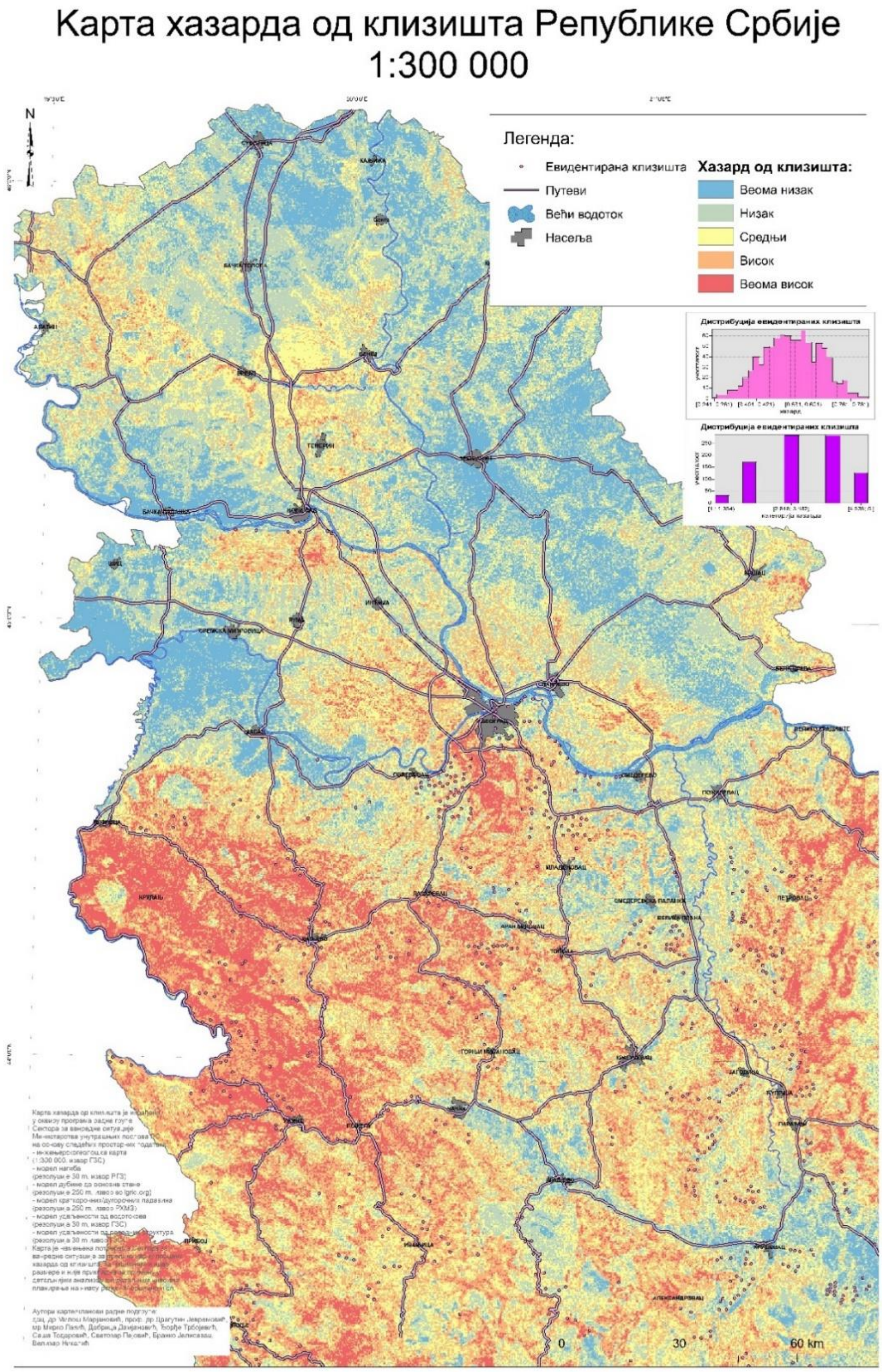


Figure 11 Preliminary landslide hazard map of Serbia[6]

$$LH_{baseline} = LS \cdot BRI_{baseline} \quad [7]$$

$$LH_{2050} = LS \cdot BRI_{2050} \quad [8]$$

$$LH_{2100} = LS \cdot BRI_{2100} \quad [9]$$

6 https://gzs.gov.rs/doc/portali/inz-geomehanika/2_Karta%20Hazarda%20od%20klizista.pdf

Step 3 – Landslide hazard exposure assessment: Apart from hazard model in raster format, exposure assessment requires vector elements (in this case the LoR) that will become affected by specific hazard (in this case *LH* raster).

The assessment procedure involves simple spatial overlap of RoL and RoSL line vectors with *LH* raster and aggregating of values of all intersected pixels vs. corresponding road links or sub-links. The output thus, includes per link and per sub-link landslide Ex. In the former, each link Ex value is calculated as the weighted sum, i.e., the sum of all values of *LH* pixels intersected by RoL divided by the link length (in km).

The weighted sum is applied for the same reason as in prioritization, i.e., for counterbalancing the link length effect. In the latter, simple sum or maximal value can be used instead of weighted sum, because all sub-links have similar lengths. The output contains 6 layers, two of each vector types (link and sub-link) times 3 temporal sequences (baseline, 2050 and 2100).

Rockfall hazard exposure can also be assessed with various more or less complex techniques, that require a two-stage modelling approach. The first one is dedicated to finding potentially detachable blocks, and the second, simulating how such blocks might propagate downslope. These are convenient to be defined as separate Steps.

Step 4 – Outlining source areas: By using the inputs generated in the pre-processing stage (Table 2) it is possible to limit the areas within AOI that satisfy the following condition:

$$(\varphi_r < \alpha < \beta) \cup (\theta = \nu \pm 20°) \qquad [10]$$

wherein, φ_r is the residual friction angle of the sliding plane(s), α is the plane's dip, β is the slope angle, θ is the slope aspect, and ν is the plane's azimuth.

Furthermore, the source areas can be narrowed down by:

- introducing masks that will further limit the area to rocky outcrops only (generated via land cover map or visual delimitation of rocky outcrops using satellite images, Google maps, etc.)
- introducing scores which are based on the lithological units (those that were included in the selection by Eq. 10) – higher scores can be allocated to units that are more susceptible to rockfalls and vice-versa.

Step 5 – Adding temporal dimension through climatic parameters: The sub-selected pixels in the previous Step might be spatially set apart across the AOI, and therefore, characterized by different weather conditions.

An intermediate Step is required to highlight areas that are more likely to detach, as they have a higher frequency or intensity of principal triggers (precipitation and temperature). Accordingly, the baseline average rainfall or rainfall intensity and baseline temperatures should be introduced and multiplied with the outcome of Step 4.

The same should be performed with the 2050 and 2100 projections (thereby generating three hazard variants of source areas). Trigger-filtered source area raster file(s) containing pixels that represent the places from which blocks or wedges can detach from, should be converted to binary format with -1 values for no detachment, and 1 for detachment pixels.

Step 6 – Simulating rockfall trajectory: The simulation requires two inputs: the first one is generated in the previous Step (defines the starting point of the falling rock), while the second input is the DTM (provides the base geometry to host the simulation).

There are a number of software that can be used, but it is recommended to use one of the simplest but still effective solution called CONEFALL (https://wp.unil.ch/risk/software/conefall/). Most importantly, it is free and stand-alone solution that can be combined in any GIS environment via *.asc* files. The software requires only to set up input and output paths, appropriate shade angle of the friction cone (32° is commonly used), and output type, i.e., energy or velocity of the falling block (Figure 12).

The physics behind it simple and relies on gravitational propagation of the block controlled by a single parameter, the angle between the horizontal line and the slope line at the runout point (shade angle). Outputs contain velocity or energy values, which are easily relatable to hazard, but in any case, the Hz component is already introduced in Step 5. In effect, there will be 3 simulations performed, i.e., 3 outputs, one for each timeframe reference (baseline, 2050 and 2100).

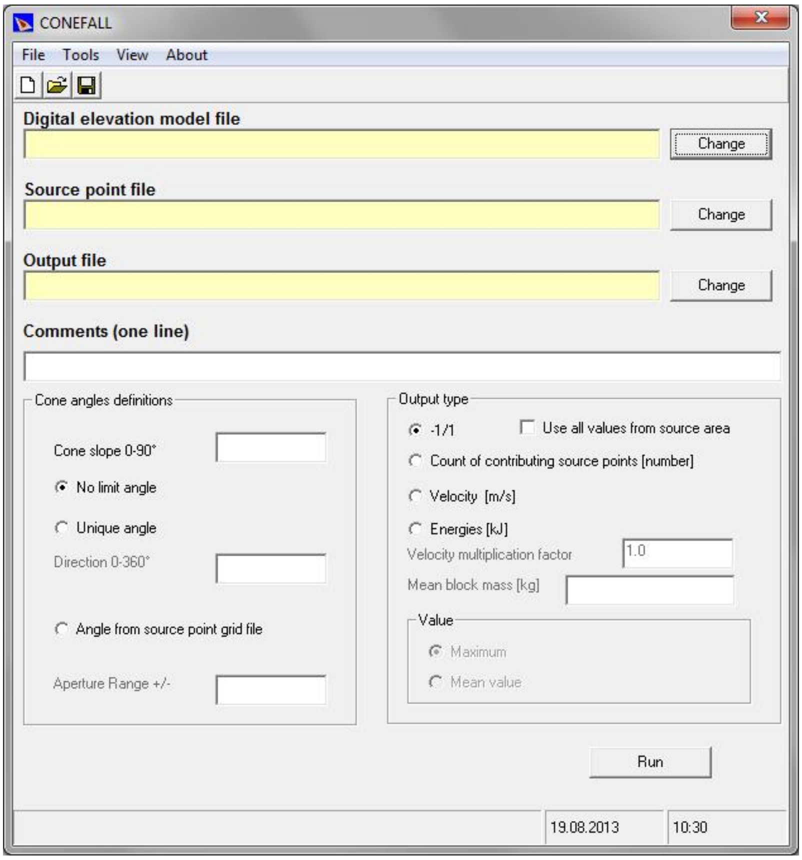


Figure 12 CONEFALL tool interface[7]

Step 7 – Rockfall hazard exposure assessment: Exposure assessment is the same as in the landslide case. The output of spatial overlapping procedure leads to per link and per sub-link rockfall Ex (for all three temporal sequences). In both cases the value is calculated as the averaged sum of all pixels that line vector spatially overlaps with. The output contains 6 layers, two of each vector type (link and sub-link) times 3 temporal sequences (baseline, 2050 and 2100).

Flood hazard exposure, as previously indicated, is the easiest task, because reliable, downscaled models for large river systems already exist for the entire country and beyond (https://data.jrc.ec.europa.eu/dataset).

By using different return periods, the expected global sea level rise and other factors that can influence the river waters can be simulated. Return period of 10 years can be used for the current, baseline state, 50-year for 2050 and 100-year variant for 2100 temporal reference, as explained in Chapter 0. In an unlikely case that the AOI does not correspond to areas covered by the Flood map (e.g., catchment size too small, or dewatered), it is possible to derive a simple flood model based on level rise. Herein it will be introduced in the according Steps marked with suffix *b*, while the likely case of applicability of the available Flood map is marked with suffix *a*. The final Step, i.e., translating flood Ex to road network links and sub-links, considers any of the available variants (*a* or *b* outputs).

Step 8a – Flood map downscaling: The raster maps for different return periods are already at a resolution of 100 meters, which is sufficiently detailed. However, to match the resolution of other models, it is recommended to resample the maps to at least 30 meters, which can be accomplished using standard interpolation tools available in GIS software.

[7] https://wp.unil.ch/risk/software/conefall/

Since it is irrelevant what is the flooding level (which is the primary information contained in the pixels), it is only required to know whether the road will be reached by the flood surface or not. Therefore, it is convenient to reclassify the output raster's as binary 0 and 1values.

Step 8b – Hydrograph analysis: By using available historical hydrograph data obtained from the closest automatic water level gauges, it is possible to establish threshold for normal level, alerted and emergency state (Figure 13). Due to tendencies of global sea level rise and increase of precipitation and weather extremes, established levels for the baseline can be increased for the 2050 and 2100 projections. The degree of rise depends on local factors such as surrounding terrain and channel geometry. However, it is possible to determine the rise threshold for each of the three intervals by using trial-and-error methods or conducting back-analysis, which involves examining historical flood outlines.

Step 9b – Water table interpolation: After defining the thresholds, the next step is to generate water table surfaces that accurately represent the defined thresholds. This can be achieved by introducing auxiliary points along the drainage network, extracting the corresponding values of the Digital Terrain Model (DTM) at these points, and then increasing the extracted value by the threshold value defined in Step 8b. Each of the three threshold variants should be used to interpolate one raster surface, for example, by using Spline interpolation.

Step 10b – Spatial overlap: Once the water table surfaces have been generated, a spatial query can be performed in a GIS environment to identify flooded areas. In this query, any area where the interpolated water surface altitude exceeds the corresponding DTM value represents a flooded area (as shown in Figure 13) and is assigned a value of 1. All other areas are assigned a value of 0.

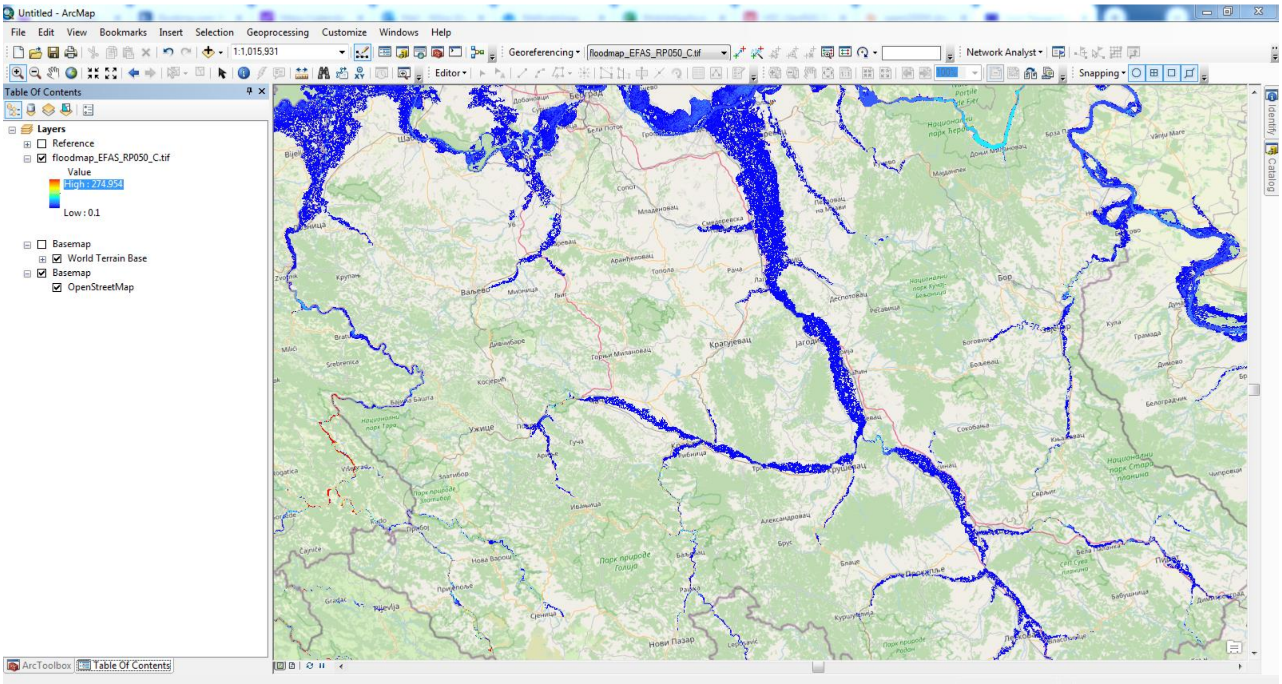


Figure 13 Preview of the Flood map for 50-year return period for Central Serbia[8]

[8] https://data.jrc.ec.europa.eu/dataset

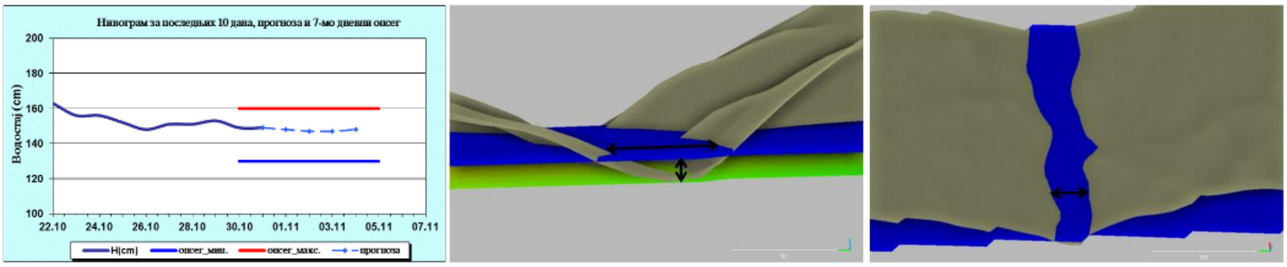


Figure 14 Illustration of water table rise and simulation of the flood (from left to right, establishing the threshold value, raising new water table surface for the threshold value, and comparing against DTM for detecting flooded area indicated in blue color

Step 11 – Flood hazard exposure assessment: The exposure assessment is similar to previous cases, with the exception that all values encountered by the line vector are either 0 or 1. The weighted sum of these values for RoL and the maximum value for RoSL are good proxies of the flood percentage along the link or sub-link, resulting in the flood exposure (Ex) for all three temporal sequences. The output of this process includes six layers: two for each vector type (link and sub-link) and three for each temporal sequences (baseline, 2050 and 2100).

Flash flood hazard exposure modelling is probably the most demanding part. Therefore, a simplified variant is herein introduced, based on similarities to debris flow process. Flash flooding events typically involve not only water, but also a very dense suspension consisting of a significant number of coarse materials such as silt and sand. This means that there is a thin line between categorizing an event as a flash flood instead of a debris flow. By definition, flash floods contain 20-60% coarse suspension, while debris flows contain more than 60%.

There are various commercial and open source (code-based) solutions available to model flash flood specifically, such as HEC-RAC, Flow3D, MIKI FLOOD, openLISEM Hazard, etc. However, flash flood these solutions can be too complicated and would require specialized training, programming skills, and in some cases, procurement of licenses.

The simplified approach involves coupling of multi-criteria analysis for source area delineation, and deterministic model for the flow propagation, very similar to the approach used for rockfall case. This approach can be completed without the need for complex fluid dynamics software. Instead, the entire procedure, using the previously prepared input raster as instructed before (Chapter 3.2), can be completed in free, stand-alone software Flow-R 1.0, which can be downloaded from https://www.flow-r.org/.

Step 12 – delineating source areas/susceptibility to flash floods: Once the extreme rainfall threshold is determined for the baseline period, such as 100 mm/day for the 2014 cyclone in Western Serbia, it is possible to classify lithological units as permeable (0) or impermeable (1), i.e., units which are capable to handle localized threshold, and those that cannot (the surface discharge is inevitable) as explained earlier (Table 4). For example, clay- and silt-rich formations, as well as formations of solid rocks with jointed aquifer type can be considered as impermeable in most extreme rainfall cases, while coarse sediments, limestones, highly jointed solid rock, weathered rock, and other formations can be classified as permeable.

In addition, the catchment analysis involves conducting zonal statistics on relevant parameters such as average slope, average curvature, drainage network density, and surface area. By analysing these parameters, areas that are prone to accumulating water, such as steeper slopes, dense drainage patterns, and larger catchments, can be identified.

Simple addition of normalized raster of chosen catchment parameters forms a stacked catchment model for the AOI. Finally, it is recommended to use land cover data, which contains information on vegetation distribution, as a significant amount of rain can be intercepted by high vegetation or sucked by root systems. All mentioned raster need to be normalized into the 0-1 range.

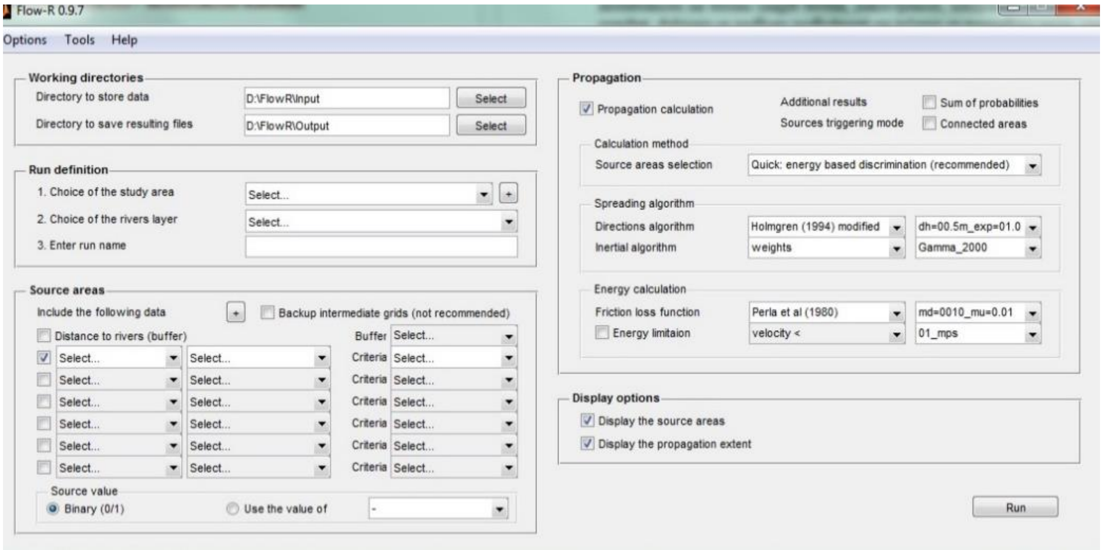


Figure 15 Flow-R 1.0 interface, indicating selection of inputs and outputs, as well as flow propagation parameters.

Step 13 – simulating the flow: The software initially requires surface geometry represented by DTM of sufficient accuracy and level of detail (Figure 15). Subsequently, it requires input of all abovementioned raster that can be used as proxies to source area delineation (elevation, curvature, slope, flow accumulation, etc.).

Once the sources are generated, it is necessary to select the fluid dynamic direction algorithm, and inertial algorithm, as well as friction loss function and velocity. The former two can be selected by default as most algorithms create results that do not differ considerably. The latter two parameters are crucial. Since the tool is used to simulate flash flood instead of the debris flow, it is necessary to fluidize the material as much as possible, leaving the viscosity parameters as low as possible (friction angle and turbulence module).

Finally, debris flows are in fact, faster than the flash floods, due to their higher bulk density, which means that moderate to low velocities should be considered (e.g., less than 20 m/s). The output does not only contour the final reach of the flash flood (runout) but also calculates velocity or kinetic energy. It is necessary to normalize the output into 0-1 range. The entire procedure should be repeated for 2050 and 2100 precipitation projections, which should be introduced at Step 12, but this time with projected values that are in accordance with climate change models.

Step 14 – Flash flood hazard exposure assessment: For exposure assessment in cases of flash floods, a methodology similar to that used for landslides or rockfalls can be applied. The pixel values that intersect the line vector can range between 0 and 1 Ex value. By taking their weighted sum, an approximation of the percentage of the flash flood along the link can be obtained, while the maximum value can serve as a proxy for the sub-links. The output contains six layers, consisting of two layers for each vector type (link and sub-link) multiplied by three 3 temporal sequences (baseline, 2050 and 2100).

5.2 Background 2 - Criticality assessment

This chapter is describing the method for defining criticality per road link and sub-link. It should not concern the LSG staff but provides the external spatial modelling experts with a know-how for completing this step. The modelling sequence is outlined Figure 16.

The criticality is defined by several intrinsic factors, that can act upon a RoL or RoSL.

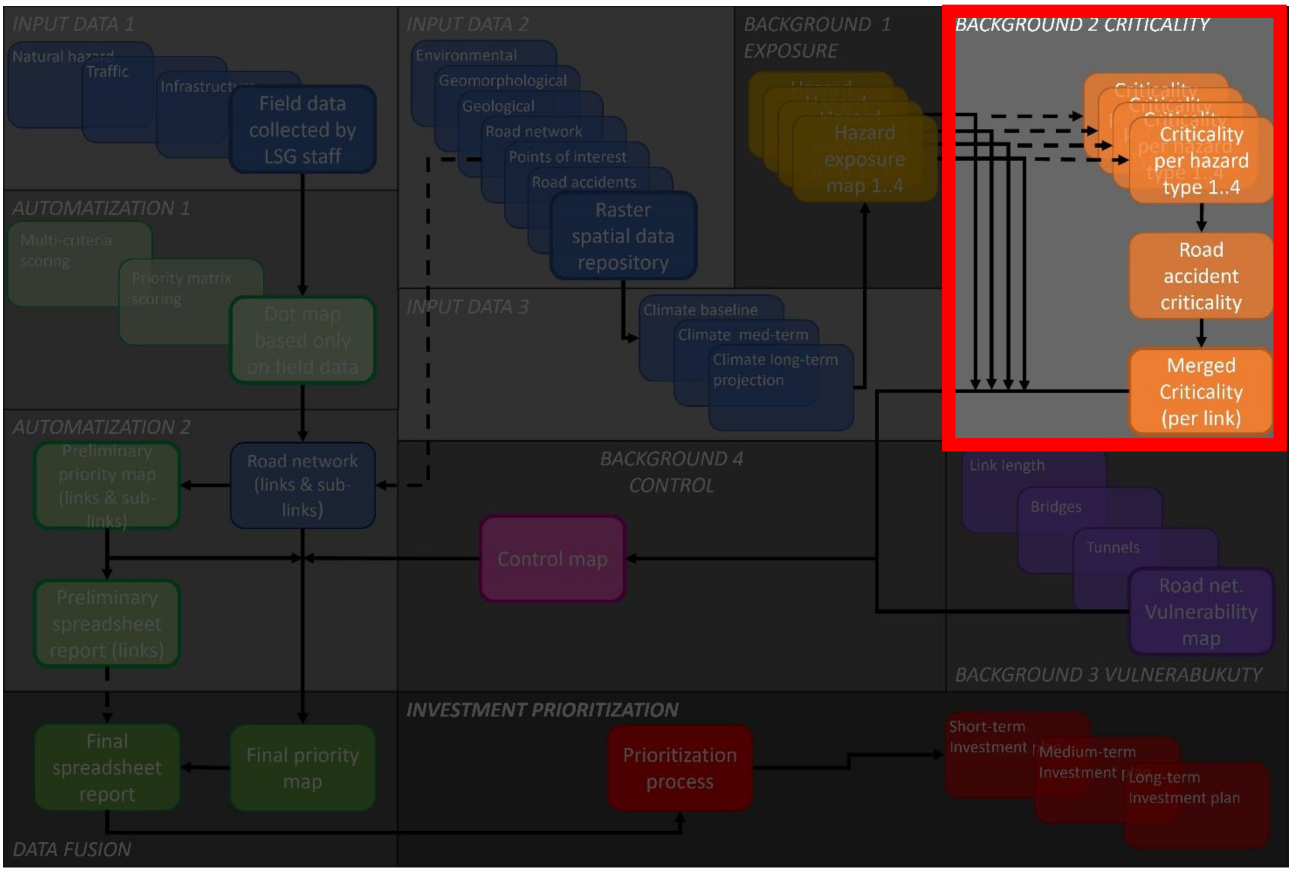


Figure 16 Back–round 2 - Criticality assessment

The main reason for avoiding merging Ex of all four hazard types into a single, multi-hazard exposure is the difference in Cr imposed by different Hz types. Specifically, the length of traffic disruption varies depending on the hazard process. Therefore, it is generally accepted that:

- Rockfalls disrupt the least, as traffic can be re-established once the fallen material is removed mechanically. In most cases they do not destruct the RoA to that level that it requires immediate remediation and closure until stabilization is complete. The interruption can be measured in hours or days. Therefore, assigned fixed score equals 0.4.
- Flash floods are leaving deposited material behind, but more commonly inflict damage that requires emergency procedures (damaged road embankments, bridge foundations, and other constructive elements). The interruption can be measured in days. Assigned fixed score equals 0.6.
- Floods are disrupting the road for a longer period, i.e., until the water withdraws, which only then allows for potential service interventions, which makes it longer than the rockfall and flash floods. In addition, severe damages to different road elements are more common and of greater scale, so repairment lasts longer. The interruption can last for days or weeks. Assigned fixed score equals 0.8.
- Landslides are constantly disturbing the road structure, but occasionally can intensify (due to heavy rain or earthquake for instance), which is when they require immediate intervention and repairment works that usually include new constructions (retaining, draining, earthworks, etc.). For such activities it is first necessary to make design in accordance with the legislation, and then to execute the design, which can take weeks and months. The landslide-related interruptions or limitations of the traffic flow are therefore the longest, i.e., assigned fixed score equals 1.0.

In addition to utilizing fixed scores based on intrinsic features of different hazard types, spatial aspects of criticality that can also be partially modelled by using of Points of Interest (PoI).

Step 15 - Buffering points of interest from the OSM source:

Buffer from schools and kindergartens (*PoI_Factor_Sch*): It is estimated that the influence of each school or kindergarten can be approximated by a surrounding area within which the frequency of road usage is elevated. This task can be simply resolved by calculating a buffer from the school/kindergarten point vector (obtained from OSM and filtered as described earlier) in a GIS environment. It's important to invert and normalize the buffer to ensure that the pixels closest to PoI are assigned the highest value (1).

Buffer from hospital (*PoI_Factor_Hos*): The same principle is implied as above.

Buffer from religion PoI, such as churches, graveyards, monasteries (*PoI_Factor_Rel*): The same principle is implied as above.

At the end of this Step, it is needed to multiply all three normalized PoI rasters, and once again normalize their product:

$$Cr1 = PoI\_Factor\_multi = PoI\_Factor\_Sch \cdot PoI\_Factor\_Hos \cdot PoI\_Factor\_Rel \quad [11]$$

Step 16 - Road accidents

RoAcc criticality per road links is based on the VoSL, cost of injured people and materials damages. The cost of all accidents on one link should be computed using following equation:

$$\begin{aligned} Cr2 \ = \ & No. of\ accidents\ with\ fatalities\ x\ 1.09\ x\ VoSL \\ & + No. of\ accidents\ with\ injured\ people\ x\ 1.5\ x\ cost\ of\ injured\ person \\ & + No. of\ accidents\ with\ material\ damage\ x\ cost\ of\ accdient\ with\ mate. damage \quad [12] \end{aligned}$$

The total number of accidents resulting in fatalities or injuries is estimated based on the average number of fatalities or injuries per incident in Serbia. To improve the accuracy of the modelling, data obtained from the Agency for Road Traffic Safety (upon request) could be utilized to directly estimate the total number of fatalities and injuries.

The number of accidents with fatalities, injuries and material damage needs to be elaborated for the same time horizon. The Cr2 uses point data of RoAcc, meaning that they first need to be converted to raster based on Cr2 value.

Step 17 – Translating Cr to per link and per sub-link road network:

Similarly to Ex, the normalized Cr1 buffer raster *PoI_Facor_multi* as well as Cr2 raster can be overlapped with per link and per sub-link road network vectors. This time, all intersected pixels should be summed up, and links which are the closest to the PoIs will be the most critical and vice-versa (Figure **17**). The same procedure should be performed for RoL and RoSL.

Step 18 – Merge Cr value by using fixed scores:

The final criticality for both per link and per sub-link layers should be calculated using fixed Cr weighting factor per each Hz type (multiplication only applies when particular Ex > 0) and normalized Cr.

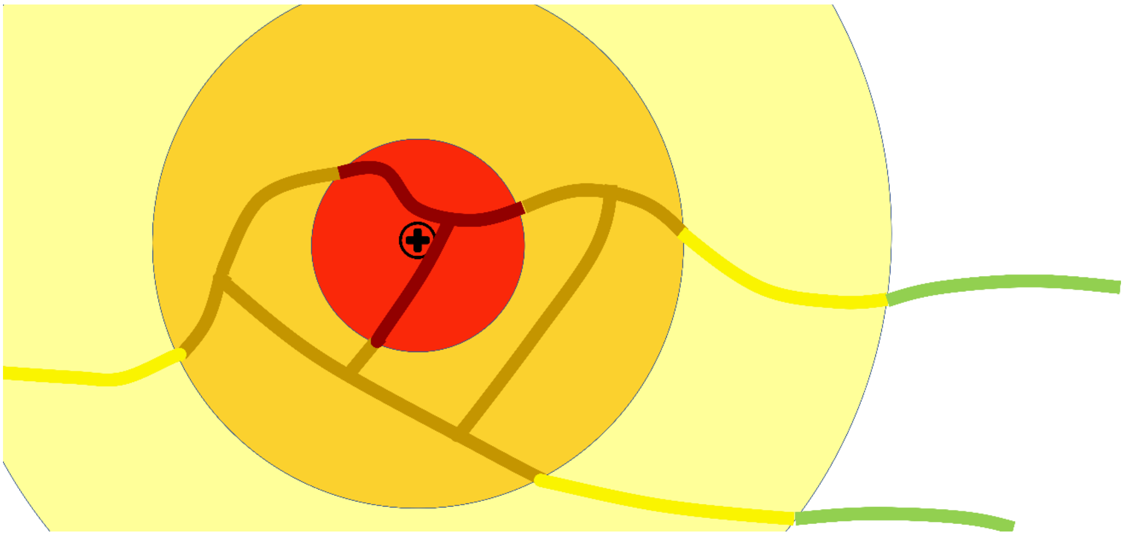


Figure 17 **Illustration of a buffer around hospital (cross mark), and zonation of the road network layer (closer are the higher values, further are lower criticality values)**

5.3 Background 3 - Vulnerability assessment

This chapter is describing very limited vulnerability assessment methodology, which does not concern the LSG staff, but concerns external spatial modelling experts, hired to perform the analysis. The modelling sequence is outlined in Figure 18.

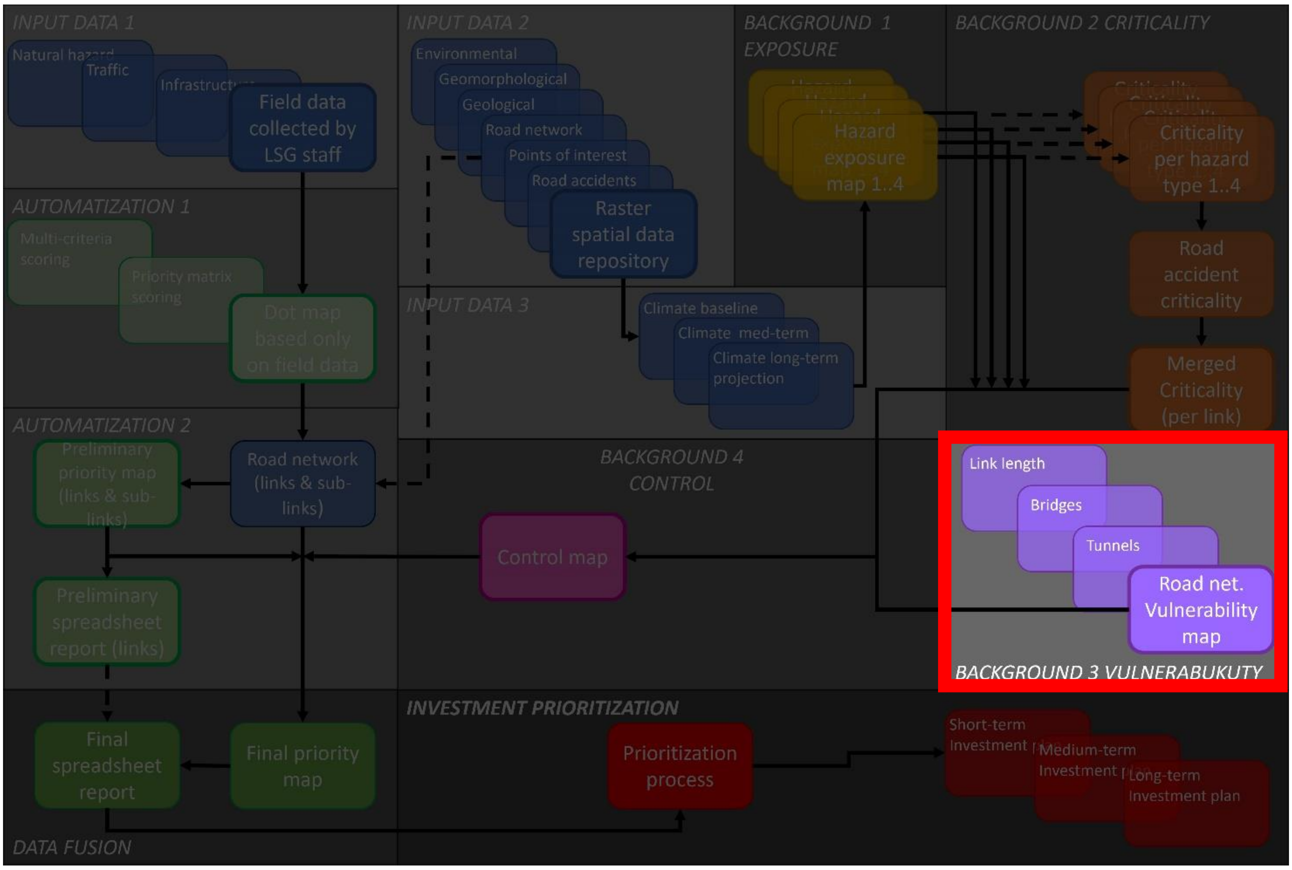


Figure 18 Background 3 - Vulnerability assessment

Local road network does not provide many resources for performing spatial vulnerability assessment, as intrinsic features of the RoA are usually available only for state roads (category, condition, type of pavement, roughness, vehicle count, etc.). Therefore, only few proxies can be used to describe Vb of the road asset.

Step 18 – Quantifying Vb value per link

- Link length (does not apply to sub-link variant, as therein, lengths are similar), normalized to 0-1 range of values

as well as specific Vb scores which are derivable from the OSM (standard metadata in all OSM road files):

- Presence of bridges
  - One-way Vb fixed score equals 1.0
  - Two-way Vb fixed score equals 0.8
- Presence of tunnels
  - One-way Vb fixed score equals 0.9
  - Two-way Vb fixed score equals 0.7
- Default road (no bridges or tunnels)
  - One-way Vb fixed score equals 0.6
  - Two-way Vb fixed score equals 0.5.

The resulting Vb value is calculated by multiplying the normalized length with specific Vb score. It is important to notice that link road network vector is more meaningful for this Step, while per sub-link can be only generically scored via specific Vb scores because it contains the segments of similar lengths). It is understandable that the road sub-link is more useful to localize high exposure, and high criticality areas.

5.4 Background 4 - Prioritization control model

This chapter is describing very simple procedure of generating the Control model., which does not concern the LSG staff, but concerns external spatial modelling experts, hired to perform the analysis, because this is their final output. The modelling sequence is outlined in Figure 19.

The Control model simply represents the addition of merged Cr and road Vb values per link and sub-link, which is subsequently reclassified into five priority intervals based on quantile range (equal class size), from VL to VH, i.e., from 1–5.

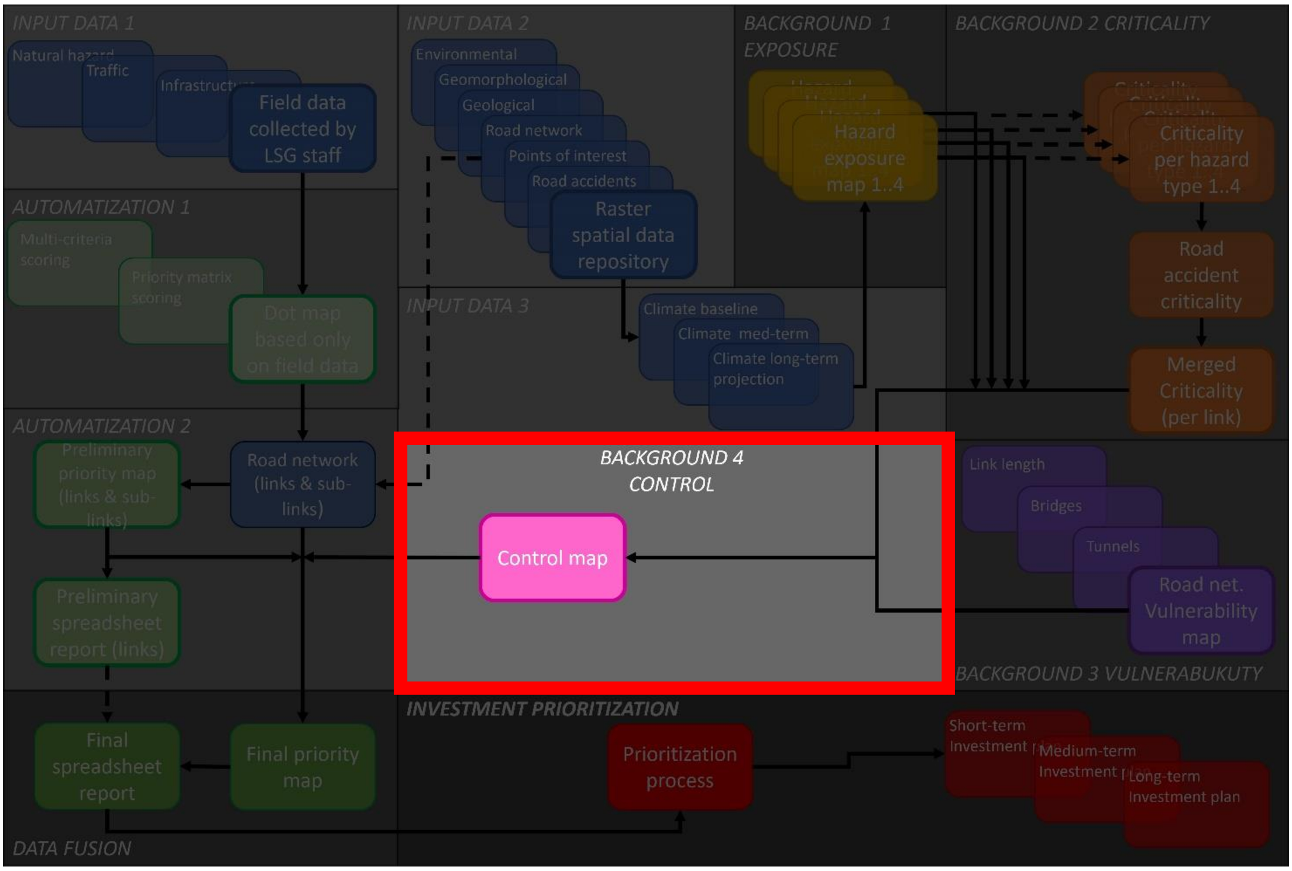


Figure 19 Background 4 - Prioritization control model

6. Data fusion

This Chapter is describing combination of preliminary and control models, while picking the best of both models. The procedure does not involve the LSG staff, nor external spatial modelling experts, but can familiarize them with the further purpose of this step. The merging sequence is outlined in Figure 20.

The final output of the Background modelling is the Control model. Its purpose is to ensure correct distribution of Ex, Cr, and Vb over the AOI, based on spatial data. On the other hand, the final output of the Automatization is the Preliminary priority model, which might not meet the reality due to a number of previously discussed reasons. GIS-based Control map thus, serves as the counterbalance to field-based preliminary map. In fact, these two maps mutually aid each other for reaching higher accuracy and reliability.

These two models are not easy to combine due to applied scales and multiple normalization procedures. However, the relative relationships are the most important when prioritizing within a single LSG area, meaning that it is necessary to know which links and sub-links have the highest, and which the lowest priority. Since both map products result into classes with values in 1–5 range, it is the best to combine these compatible classes and enable highest-lowest prioritizing principle. It is also possible to assign weights to each map, giving for instance, preference to Control map or to Preliminary map, but the equal weight is also viable solution.

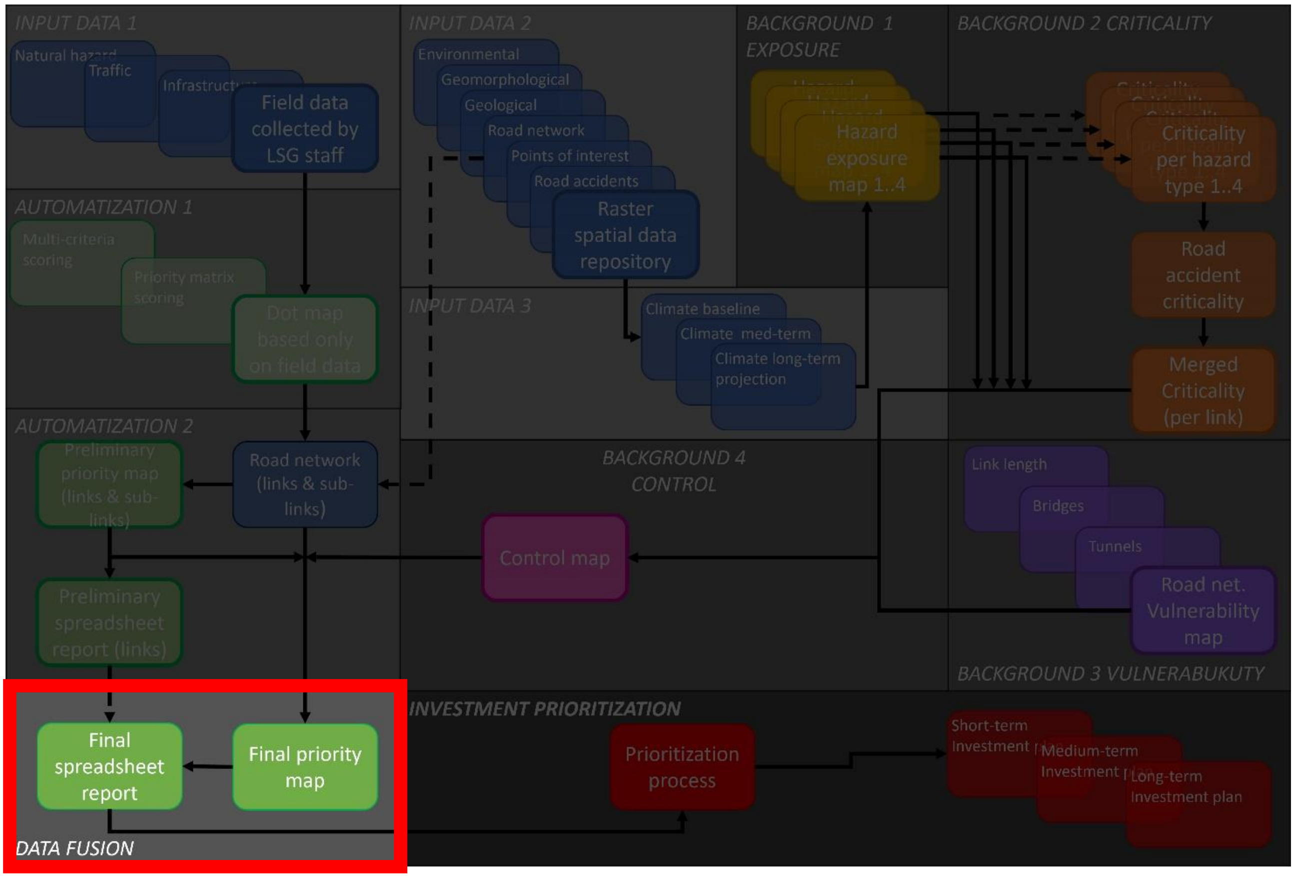


Figure 20 Data fusion (Final prioritization map & Final spreadsheet report)

6.1 Final prioritization map

To produce the final prioritization map, the GIS environment combines the Preliminary link prioritization classes (1–5) and Control map prioritization classes (1–5), using respective weighting factors w_1 and w_2 that add up to 100%, as indicated in the formula below. It is recommended that the weight distribution be either 50-50% or slightly in favour of the Control map at this stage, before extensive field use. However, the distribution may vary depending on the circumstances. Figure 21 illustrates the fusion process and related outputs.

$$Priority\_Map = w_1 \cdot Preliminary\_Map + w_2 \cdot Control\_Map \quad [13]$$

6.2 Final spreadsheet report

The final Priority map is stored in a vector format that includes all necessary data in the attached attribute table from the initial processing stages, such as individual hazard exposure calculation. This format allows for a conversion into a tabular format, such as spreadsheet, which provides further functionality, such as sorting, ranking, filtering, charting, selected data, using green-red color coding to highlight links (or sub-links) which are of interest by specific criterion. On one hand, links can be differentiated by their preliminary criticality score or by scores of individual criteria, as presented in Automation 1 and 2. On the other hand, links (or sub-links) of highest priority, or Cr, or Vb or Ex to all hazards together or to specific type of hazard, etc., can be highlighted and singled out.

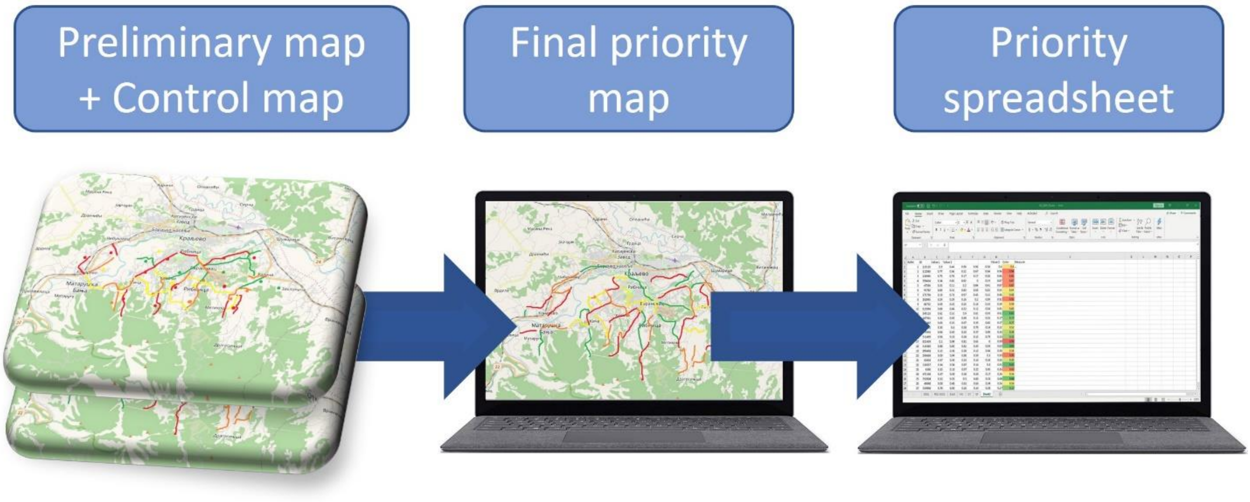


Figure 21 Schematic display of data fusion, i.e., combination of Preliminary and Control map for outputting final Priority map

7. Investment planning

This chapter is describing the investment plans methodology, which involve the LSG staff and external experts (financial and transport economists) hired to perform the analysis. The modelling sequence is outlined in Figure 23. This part of the Methodology is providing instructions for an independent assessment based on the Methodology outputs. It also outlines how the investment planning should be set in the future, and how any necessary changes will be made once it is set.

The LSGs spends considerable budget portions on local road developments but mostly in the absence of thorough and systematic methodology. For the illustrative purposes, Consultant' own calculations based on the sample of 27 municipalities in Serbia (excl. Belgrade) taken from the official website presenting budgets of cities and municipalities in Serbia [9], the average budget of the municipality is over EUR 30 mil., while the average spending on the road infrastructure is around EUR 4.00 mil (13%). In the AOI, budget share allocated for road infrastructure is over the average, in Kraljevo 22.12% (EUR 8,35 mil.) while in Aleksandrovac 32.10% (EUR 2.85 mil.).

Various challenges in LSGs, such as scarcity of funds, lack of technical expertise, weak governance, lack of transparency, geographic conditions, not allowing proper development of investment plans, are the obstacles for proper local road development.

Developments of investment plans for local roads are more and more important in developed countries as it can be a trigger for the socio-economic development of local communities. Such investment plans need to be systematically developed, with the final goal to recover all shortcomings in terms of accessibility, connectivity, and inadequate local road infrastructure.

A high-performing local road network is an essential part of a modern, vibrant, and progressive LSG and its economy. Well-planned and developed local road network, its continued operation, maintenance, and their enhancement is fundamental to the wellbeing of the population and the development of the LSG economy.

Investment planning is one of four key pillars in the development of road investment as presented in the Figure 22 below.

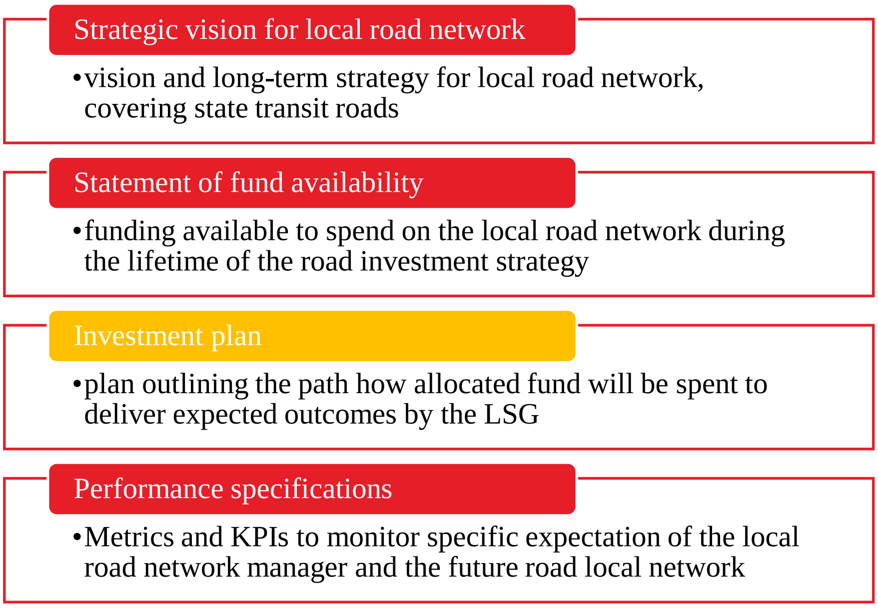


Figure 22 Road investment strategy pillars

Investment plan has to outline how funding will be allocated in red to deliver LSG's vision and outcomes, covering specific expectations for local road network and LSG's key stakeholder (e.g. relevant road

[9] https://budzeti.data.gov.rs/

department/public enterprise or department for investment planning within municipality or Municipality representatives in the absence of those, which is in the case of AOI the Directorate for planning and construction - Kraljevo and Municipality Aleksandrovac) performance including metrics and KPIs.

Investment planning needs to cover the following key considerations: i) why do we need to invest? ii) what is our time horizon? iii) what is the level of costing? and iv) what would be the source of financing? The goal and needs assessment for the investment are known and based on the prioritization process explained above. In order to achieve this goal and cover the needs it is necessary to define the budgets needed and the investment time horizon, as well as the source of financing. In some cases, return expectations must be elaborated in more details.

To undertake planning of required vs available budget, a comprehensive assessment needs to be undertaken, covering: i) review of the existing investment plans (including latest short-, medium-, and long- term plans), ii) climate resilience assessment undertaken as per methodology provided in chapters above, iii) cross-check of already defined priorities (in the existing investment plans) with the Priority Spreadsheet (please see Figure 21 above), iv) assess potential funding opportunities, and iv) undertake the development of the objective investment planning framework though the prioritization.

In absence of the objective prioritization framework, prioritization is done on ad-hoc basis and subjective justifications and judgments of LSG officials. A prioritization framework is needed to justify well construction and maintenance budgets and to direct funds in those areas with the greatest return on investment are. Without this framework, transport infrastructure asset investments are not well regulated or operated efficiently, and maintenance of the network is inefficient, which limits the long-term usefulness of transport assets and undermines investments. Also, as budgets are not efficiently allocated, social benefits are bypassed and neglected.

If possible, at least key local stakeholders have to participate in the prioritization as it should not be a top-down approach, therefore this is why we recommend involvement of the LSGs in the development of the investment plan based on the defined priority maps as presented in previous chapters.

Investment plans will include a list of schemes from the Priority Spreadsheet (please see Figure 21 above) to be funded out of the current statement of funds available, together with funding for any other strategic objectives and outputs based on the LGS's needs.

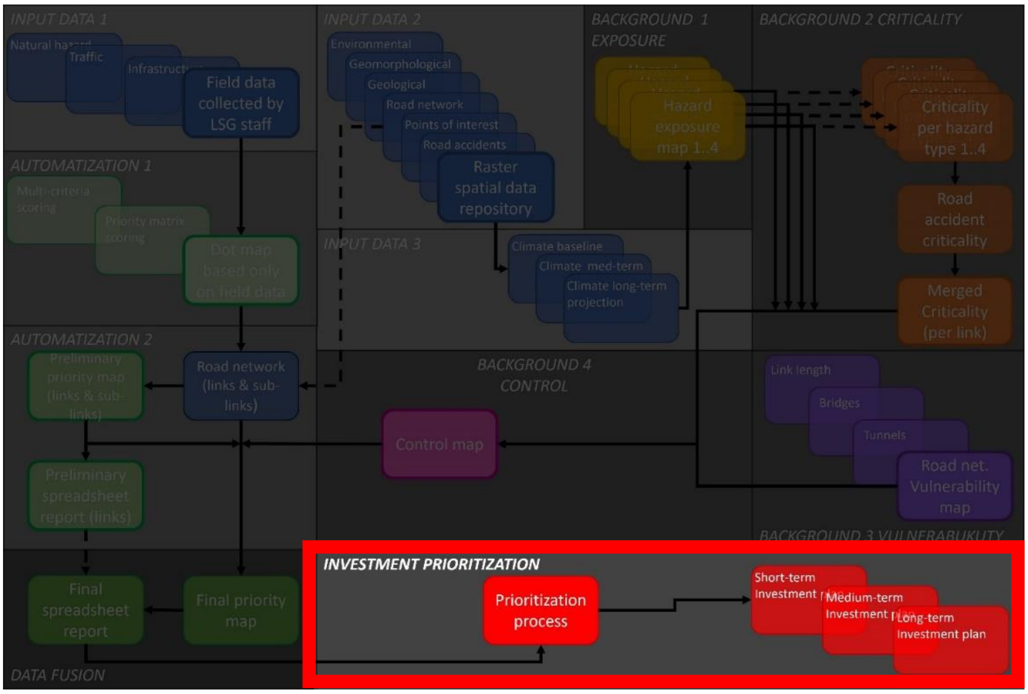


Figure 23 Investment planning (Prioritization process & Investment Plan)

7.1 Prioritization process

Based on the Priority Spreadsheet according to previously described methodology, further prioritization needs to be done to develop appropriate LSG's investment plan, which will cover all stated consideration.

Prioritization will be based on the following matrix (subject to modifications once all details for the two selected LSGs are known) which presents the overview of the short- to long-term investment planning is presented in the table below.

The time horizons for each prioritized activity will be known once the details of the potential schemes are known (e.g. light investment for the repair of bridge could be light surface repair or repair of pedestrian fence, sidewalks, hydro-isolations, etc. which is directly linked with the decision if planning/design is needed or not; or medium investment for repair of bridge structural elements could be short- to long- term measure which depends on the scale of works and maturity of readiness for urgent repair, etc.).

Table 17 Short- Medium- and Long-term prioritization matrix

Investment weight	Type of object	Description	Short-term		Medium-term	Long-term
			Without planning	Needed planning		
Light investment	Bridge	Repair	✓	✓		
	Drainage	Cleaning or repair of light drainage elements	✓	✓		
	Earthworks	Cleaning of ground material from the road and drainage elements (cleaning of channels, shafts and culverts (box and pipe))	✓			
	Pavement	All layers, asphalt layers, concrete layers, cobbled (wearing courses)	✓	✓		
	Scaling	Rock scaling	✓			
Medium investment	Culvert repair	Repair/Reconstruction		✓		
	Retaining walls	Reconstruction		✓	✓	
	Bridge	Reconstruction of structural elements		✓	✓	✓
Heavy investment	Bridge	New		✓	✓	✓
	Embankment	Repair		✓	✓	✓
	Landslide	Repair		✓	✓	✓
	Pavement	All layers		✓	✓	✓
	Retaining wall	New		✓	✓	✓
	Slopes	Stabilization		✓	✓	✓
	Third party utilities	Interruption of the roadside third party utilities (gas pipelines, telecommunication, water supply, etc.)		✓	✓	✓

Light investments are those less than EUR 10,000, medium investments between EUR 10,000 and EUR 100,000 and heavy investments above EUR 100,000. For the purpose of investment planning, all schemes will be distributed to the categories as per prioritization process explained below and short-term, medium-term and long-term plans will be generated (as presented on the Figure 23 above).

7.2 Investment Plan

An Investment Plan provides a link between municipality's/city's strategic vision, their land use and maintenance plans, and their annual budgets. As per the best international practices, already applicable in Serbia, municipal/city fiscal management develops annual exercise of preparing a multiannual investment plan for transport infrastructure. This plan should identify public transport infrastructure investment projects together with the financing approach. It describes the financial ability to manage the investment needs. Investment plans might include fiscal metrics which for example can be a percentage of the annual budget to be committed to the transport infrastructure projects or it can be defined the limit of the total debts.

This plan defined specific public projects for the transport infrastructure and implementation schedule. First year in the investment plan should be included in the first fiscal year, while other years of the investment plan should reflect an estimated value of the fund needs.

Investment Plan should cover:

- capital investments (part of proposed heavy investments),
- periodic maintenance (part of proposed heavy, medium, and light investment), and
- regular maintenance (light investment).

Investment Plan must contain (please see Table 18 below):

- Project name/ Investment filed
- Rational for proposed investment
- Length of the section
- Project cost
- Responsible agency
- Maturity of project documentation
- Expected rate of return
- Funding agency
- Year for implementation
- Monitoring indicators.

For example, the Investment Plan (i.e. program for construction) of the City of Kraljevo developed by Public Enterprise for Construction of the City of Kraljevo[10] contains only partial information of what needs to be presented in the Investment Plan (e.g. Project name/Investment filed, partially covered length/description of the section, project costs are merged for various projects, and source of funding, while all other information miss). The average budget in the last five years was EUR 2,32 mil for maintenance and EUR 1,88 for construction of local roads.

If properly developed and monitored, Investment Plan can enable implementing agencies to increase organizational, asset and network performance, but also to invest the money when the highest benefits are expected for the society.

The timeframe of the municipality's/city's investment plan is a local decision. The investment plan should cover all prioritized links where the needs for investment have been identified. Each project (covering specific location, link or set of links) will be placed into the appropriate time horizons, as follows: i) short-term (< 1 year), ii) medium-term (1 - 3 years) and iii) long-term investment measures (> 3 years). Every 6 months or 1 year, the investment plan itself should be re-assessed in order to:

[10] http://www.direkcijakv.net/wp-content/uploads/2022/03/Program-uredjivanja-gradjevinskog-zemljista-za-2022.-godinu-1.pdf

- take into consideration the changes in the main scheme of the road network (e.g. there are annually 30km of new roads in Kraljevo),
- consider all recent changes on the local road network, and
- incorporate new intervention policies, both in terms of maintenance or major rehabilitation/ reconstruction works.

Multiannual investment plans provide many benefits to the implementing agency and society. First, it promotes effective planning and management of public infrastructure assets. Secondly, it encourages LSGs to consider funding requirements, prioritization and timing and costs of core required investments. And thirdly, it allows LSG to seek an external funding to cover any shortfalls. Heavy investment projects (e.g. large-scale projects) may be implemented in over 10-20 year period. Therefore, not all funds should be accessed up front, so an Investment Plan need to address of when the funds would actually be required, which leads to the effective planning by LSGs and lower transaction costs.

Investment plan options for the selected pilot LSGs will be presented within deliverable 6 of the Project.

Table 18 Investment Plan template

Priority No.	Project Name/Investment filed	Type of investment	Rational for proposed investment	Length of the section (chainage from-to or km)/ Area (m2)	Project cost (local currency)	Rate of return (%)	Maturity of project documentation A. Project documentation not needed B. Spatial planning: B.1 Completed B.2 Needed B.3 Not needed C. Design documentation: C.1 Completed C.2 Needed C.3 Not needed C. Environmental permit: C.1 Issued C.2 Needed C.3 Not needed D. Construction permit: D.1 Issued D.2 Needed D.3 Not needed	Responsible agency for implementation	Funding agency	Year of implementation	Monitoring indicator
1 Priority No.1 as per conducted prioritization process	Project name to cover briefly type of investment, road code/name, location, length/area	Services Supply Goods Works	Brief explanation of the need for proposed investment (e.g. Due to landslide from 2021 this road is still closed and this area requires immediate stabilization)	changes from -to or the total length in km. If it covers more road sections, all should be described. Quantification of area covered is needed if length cannot be presented	Value should include source where it comes from and the year when it was developed. (e.g. RSD 1,000,000; Detailed Design from 207)	For all investments, except for those where Maturity of project documentation is A., calculation of the rate of return is needed to present if the project is economically (and where needed, also financially) viable.	Insert all relevant answers, which will show current level of the design documentation readiness. (e.g. for some light investments/repairs could be A, B3, C3, D3, or for road rehabilitation it could be B3, C1, C3, D2, etc.)	Responsible agency should be set for all needed activities. (e.g. Spatial planning, Design, Supply, Implementation)	If secured, insert name of the agency (all involved agencies to be mentioned) (e.g. for service, supply, works, etc) If there are more funding sources for one project, please list them all and share of their contribution (e.g. State budget 15,6%, World Bank 84,4%) If not secured, please state that funding is not secured yet.	Planned year for implementation of the Type of investment (if there are more types of investment, the year should be stated for all) (e.g. if the road need to be rehabilitated, Works could be tenders in 2025, and guardrails/traffic signalization could be tendered Supply of good in 2026) Phase construction to be mentioned if needed. (e.g 2025: km 3+000 to km 8+000; 2026: km 8+000 to 12+000) Also, when considering year of implementation, procurement procedures need to be considered based on the funding agency procurement procedures, which can require more time than needed as per local procedures.	(e.g. length of improved sections in km, CO2 reduction saved, marginal savings (travel time, vehicle operation costs, maintenance costs), etc.)
2 Priority No.2 as per conducted prioritization process											
…											

8. Concluding remarks

Presented Methodology, although robust, represents a highly adaptable tool that can be easily reapplied to different AOIs, depending on the available staff capacity and data at hand. It has a part which is entirely simplified, to the level of a common LSG staff profile which has no pre-knowledge on hazards, spatial analysis, traffic demand, road management or construction engineering.

Nevertheless, the LSG staff are enabled to generate useful preliminary outputs by simply collecting data (automated process of generating preliminary or provisional products, which can be used as (i) stand-alone or (ii) in combination with professional spatial analysis of hazard exposure, criticality, and vulnerability, which is more recommendable option). We cordially recommend enforcing the latter, because valuable details such as fragile PoIs (hospitals, schools, etc.) and road accidence, climate change, and many other relevant data are only included through (ii).

It also utilizes LSG decision making authority to make appropriate decisions using these automatically generated outputs. To this end, it is required to prepare all spatial data and include various modelling steps (Background 1-4) which is a slow and demanding process and must be performed by skilled experts in associated engineering fields (geological, traffic and civil engineering, supported with appropriate spatial analysis). In this way, decision making is enriched through generating Ex, Cr and Vb models by following step-by-step instructions presented in the Methodology.

For pilot AOIs (Kraljevo and Aleksandrovac) such modelling is performed within the scope of the Project in order to test the Methodology. It is possible that some municipalities that will use this Methodology already have staff profile capable of completing all step, including both Automatization and Background modelling, but according to previous experience and review of current state in Serbia and North Macedonia, conducted under Task 1 of the ToR (which are a subject of a separate report) it is less likely to expect such scenario. Therefore, it is highly recommendable that municipality hires external specialists to perform Background modelling part of the analysis.

The proportion in this respect is very straightforward: more sophisticated the Background modelling is, higher the quality of resulting outputs and associated decisions. In favor of the Background modelling, it is also important to mention that two of the hazards enlisted in this Methodology (landslide and flood hazard), have publicly available models for the entire territory of Serbia. This means that limited effort is required to produce these two particular Background layers and support better decision making at the local level.

It is, finally, important to mention that there are limitations, and probably drawbacks of the Methodology which will be definitively known after implementation in the two AOIs (Kraljevo and Aleksandrovac). Feedback from these case studies will allow slight adjustments and further refinement. Expectedly, the scoring system might encounter slight modifications, as well as weight of particular Background modelling Steps (Background 1-4), as well as the Fusion of Preliminary and Background analysis.

Appendix A

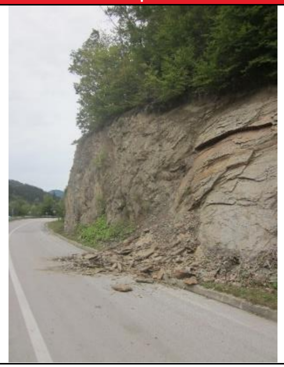
Comparative example of the Methodology implementation with and without the MaPLoRds technical solution

A.1 A step-by-step example of prioritizing road network links and observations

It is possible to register an adverse road event in paper or tabular form by following the list of parameters related to the hazards, traffic and infrastructure features (Table 9 – Table 14). Each parameter score must be filled in manually to allow for the subsequent total and normalized score calculation. Once at the site, it is first needed to locate the event by using some navigational device and to write down relevant coordinates, e.g., lat/lon and assign systematic observation ID and date. Preferably, a photograph or a few should be also included at every observation point, wherein the Photo ID should be written down and assigned to the corresponding observation point. It is sometimes possible that the same location hosts several types of hazards within a short distance (few tens of meters). In such case, these should be all assigned to the same location and their scores superimposed. A hypothetic example of the entire procedure for prioritizing observed locations follows. The emphasis is herein on the part of the procedure which does not require spatial modelling tools. Instead, the example depicts which part of the Methodology is possible to implement in the simplest fashion, using paper form or Excel table.

A.1.1 Registering hazard events and calculating scores

The following parameters and relevant scores can be introduced at a single observation site for hazard event:

ID	Observation coordinates	Observation date	Observation type	Parameter (as per Table 9 – Table 14)	Input value (as per Table 9 – Table 14)	Score (as per Table 9 – Table 14)	Field photo
P001	lat: 43.4433 lon: 21.0719	30.4.2023	Hazard Rockfall 1	Runout distance (m)	10	1	
				Release height (m)	80	4	
				Block volume (m^3)	5	4	
				Frequency	once in a year	3	
				Rockfall trigger	rainfall, snow melt	4	
				Activity	active	5	
					***h_score* =**	**21**	

For illustration, let us suppose that there are for instance three more recorded points, with various hazard types (landslide – L; rockfall – R; flood – F; and flash flood – FF), with score sums as follows:

P002: *h_score* (L) = 22

P003: *h_score* (FF) = 15

P004: *h_score* (F) = 13

By introducing Eq. 1, and *h_score_min* = 13, and *h_score_max* = 22, the normalized value *norm_h_score* becomes:

P001: *norm_h_score* = 0.9

P002: *norm_h_score* = 1.0

P003: *norm_h_score* = 0.2

P004: *norm_h_score* = 0.0

By accepting the weighting factors *w* from tables, the scores are multiplied and final hazard scores *fin_h_score* obtained as follows (note that in the case of multiple hazards the higher weight is introduced):

P001: *fin_h_score* = 2 x 0.9 = 1.8

P002: *fin_h_score* = 5 x 1.0 = 5.0

P003: *fin_h_score* = 4 x 0.2 = 0.8

P004: *fin_h_score* = 3 x 0.0 = 0.0

In case that there are multiple hazards at single site, another round of normalization is needed by using Eq. 2.

A.1.2 Registering affected traffic and calculating scores

The following parameters and relevant scores can be introduced at a single observation site for affected traffic:

ID	Observation coordinates	Observation date	Observation type	Parameter (as per Table 9 – Table 14)	Input value (as per Table 9 – Table 14)	Score (as per Table 9 – Table 14)	Field photo
P001	lat: 43.4433 lon: 21.0719	30.4.2023	Traffic	Road function	Urban - other	1	
				Traffic interruption	both directions	5	
				Traffic flow	public transport included	5	
				Alternative routes	TRUE	1	
				Estimated detour length (km)	15	3	
					***t_score* =**	**15**	

For illustration, let us append abovementioned three hypothetical points P002-P004 with respective traffic scores, as follows:

P002: *t_score* = 8

P003: *t_score* = 13

P004: *t_score* = 18

By introducing Eq. 3, and *t_score_min* = 8, and *t_score_max* = 18, the normalized value *norm_t_score* becomes:

P001: *norm_t_score* = 0.7

P002: *norm_t_score* = 0.0

P003: *norm_t_score* = 0.5

P004: *norm_t_score* = 1.0

By accepting the equal weighting factor *w* = 4, the scores are multiplied and final hazard scores *fin_t_score* or *T* obtained as follows:

P001: *T* = 4 x 0.7 = 2.8

P002: *T* = 4 x 0.0 = 0.0

P003: *T* = 4 x 0.5 = 2.0

P004: *T* = 4 x 1.0 = 4.0

A.1.3 Registering affected road infrastructure and calculating scores

When it comes to affected infrastructure, the procedure is two-fold. It first requires scoring per defined categories of road infrastructure and potential interventions required, and then adopting the highest score class (re-scoring) into designated investment category (light–medium–heavy). As the impact on infrastructure is complex issue that requires very detailed information and commonly, planning and design, the estimation of costs which would confidently categorize investment into light, medium or heavy was not feasible beforehand (at the time of field survey). Instead, the investment categories (light–medium–heavy) are assigned by combining estimation of the future intervention costs (amount and type of work) with currently inflicted damage on the local road network on relative scale.

The first step involves the following parameters and their scoring:

ID	Observation coordinates	Observation date	Category	Object damage or intervention needed	Short description	Class description	Field photo
P001	lat: 43.4433 lon: 21.0719	30.4.2023	Road	pavement	asphalt layer	Planning not needed – repair	
				drainage	culvert cleaning	Planning not needed – repair	
				embankment	NA	NA	
			Structure	bridge	NA	NA	
				retaining wall	wall repair	Planning needed – reconstruction	
				drainage	repair of culverts	Planning needed – reconstruction	
			Other	third party utilities	NA		
				households	NA		
				casualties	NA		
				earthworks	NA		
				scaling	scaling of loose blocks	Planning not needed – repair	

The second step rescores the entry point as follows:

ID	Observation coordinates	Observation date	Observation type	Parameter (as per Table 9 – Table 14)	Input value (as per Table 9 – Table 14)	Score (as per Table 9 – Table 14)
P001	lat: 43.4433 lon: 21.0719	30.4.2023	Infrastructure	Light investment	Planning not needed – repair	2
				Medium investment	Planning needed - reconstruction	4
				Heavy investment	NA	0
					***i_score* =**	6

For illustration, let us append abovementioned three hypothetical points P002-P004 with respective infrastructure scores, as follows:

P002: *i_score* = 2

P003: *i_score* = 9

P004: *i_score* = 4

By introducing Eq. 4, and *t_score_min* = 2, and *t_score_max* = 9, the normalized value *norm_i_score* becomes:

P001: *norm_i_score* = 0.6

P002: *norm_i_score* = 0.0

P003: *norm_i_score* = 1.0

P004: *norm_i_score* = 0.3

By accepting the equal weighting factor *w* = 2, the scores are multiplied and final hazard scores *fin_i_score* or *I* obtained as follows:

P001: *I* = 2 x 0.6 = 1.2

P002: *I* = 2 x 0.0 = 0.0

P003: *I* = 2 x 1.0 = 2.0

P004: *I* = 2 x 0.3 = 0.6

A.1.4 Calculating preliminary prioritization per observation point

Once all parameters are scored and normalized, the preliminary prioritization can take place as proposed in Table 15 and Table 16, preceded by another round of normalization and reclassification.

Normalization of P001 *fin_h_score* = 1.8 in relation to all other *fin_h_score* of P002-P004 is as follows:

*fin_h_score** = (1.8-0)/(5-0) = 0.36

Reclassification of *fin_h_score** is as follows:

*fin_h_score** = 0.36 → 0.4 (class Low)

Summing of *T+I* for P001 is:

T+I = 2.8 + 1.2 = 4.0

Normalization of P001 *T+I* = 4.0 in relation to all other *T+I* of P002-P004 is as follows:

*T+I** = (4-0)/(4.6-0) = 0.86

Reclassification of *T+I** is as follows:

*T+I** = 0.86 → 1.0 (class Very high)

Pair-wising these two classes, i.e., their multiplication according to the Table 15 finally yields:

*fin_h_score** x *T+I** = 0.4 x 1.0 = 0.4 → 4 (class High)

A.1.5 Calculating preliminary and final prioritization per link

According to the Methodology, it is not possible to further the analysis from observations to road links without **distance analysis in GIS environment**, as it requires aggregation of all observation points on the closest road link. Therefore, the manual application of the Methodology without spatial modelling tools stops from this point further. The only possible output from manual implementation of the Methodology is the **list of prioritized observations** in tabular form. However, for illustrative purposes, the procedure will be continued in simplified fashion by overlapping hypothetical points P001-P004 over links L001-L002.

Sum of priority scores per link

L001 aggregates P001 and P002: Σ = 0.4 + 1 = 1.4

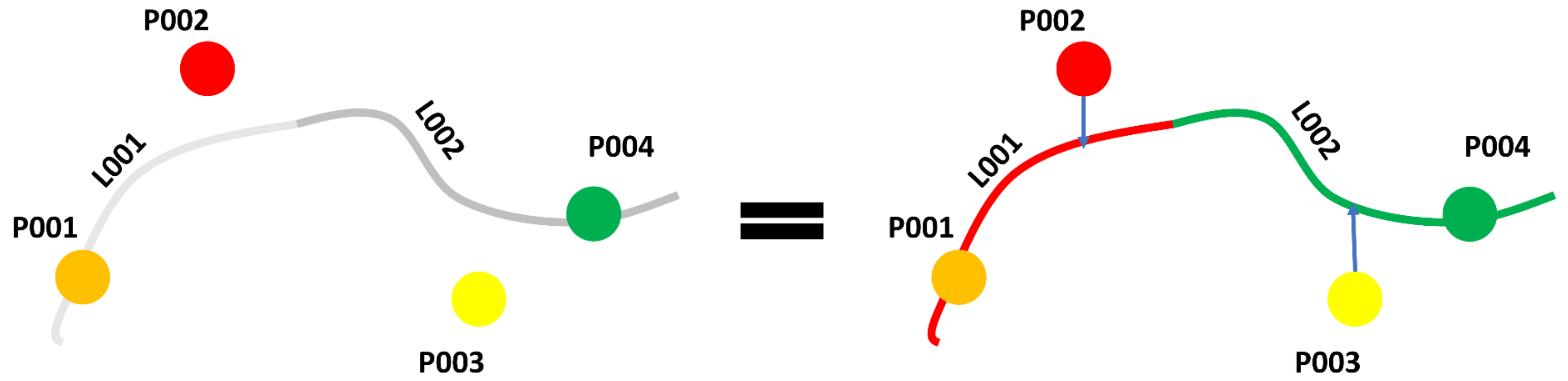
L002 aggregates P003 and P004: Σ = 0.2 + 0 = 0.2

Given that the example contains only two links, their normalization to 0-1 is direct.

Re-classification per link gives preliminary link class:

L001: 1.0 → Very high

L002: 0.0 → Very low



In a likely case that the collected point observations are biased or insufficient (as in this case of hypothetic four points and two links) due to time or other constrains, background models can provide needed support in further decision-making. Let us suppose that the outcome of background modelling yields the following:

Background priority class values per link:

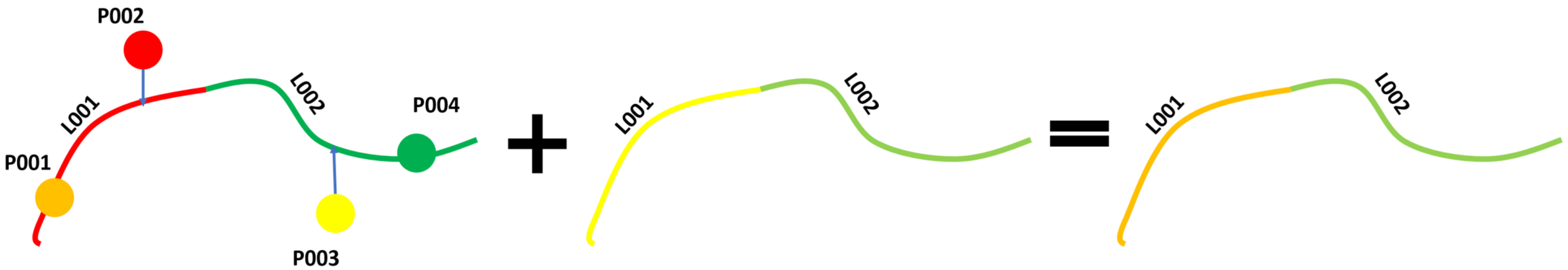
L001: 0.4 → Moderate

L002: 0.3 → Low

Averaging per link:

L001: (0.4 + 1)/2 = 0.7 → High

L002: (0 + 0.3)/2 = 0.15 → Low

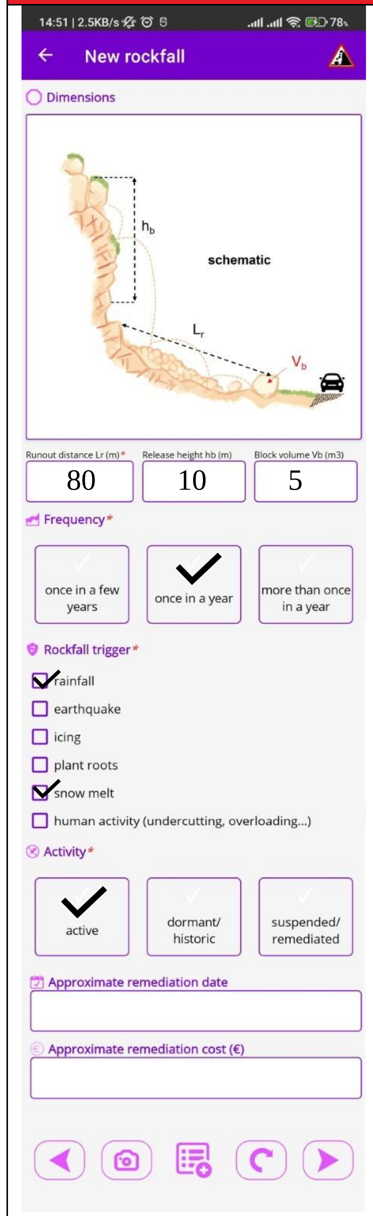
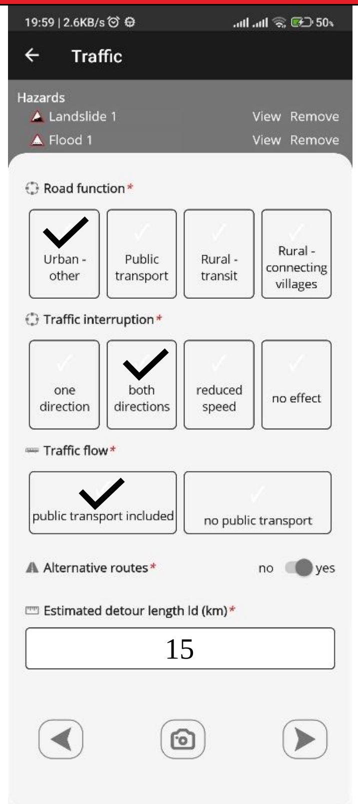
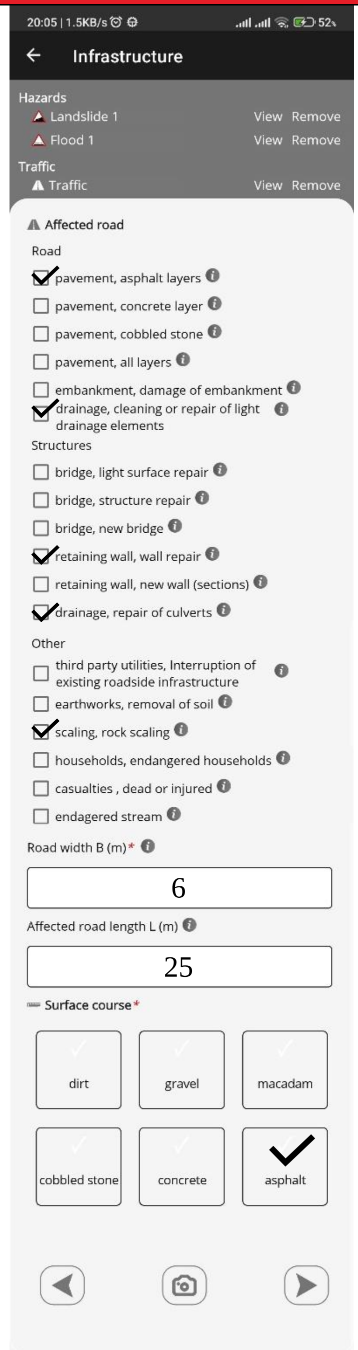


A.2 Registering hazard events and assessing affected road using the MaPLoRds mobile and web tool

The benefit of using specially designed system solution MaPLoRds (mobile and web app) for implementing the Methodology is reflected through a seamless prioritization process for both, preliminary and background modelling. Preliminary priority is entirely automated as soon as the field user inputs the necessary data. The user is not required to score anything, just to select appropriate classes and input appropriate parameter values. The background or model or Control map is prepared beforehand, by GIS specialists (as instructed in the Methodology) and consists of classes which correspond to those of preliminary priority matrix, making it easy to combine the preliminary and background outputs.

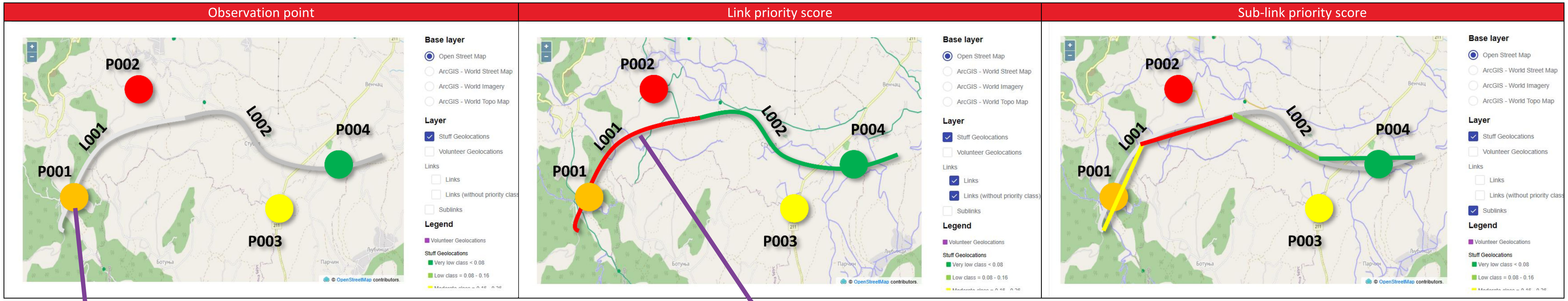
A.2.1 Registering hazard events and calculating scores using the MaPLoRds mobile tool

Using the same hypothetical example with points P001-P004 the mobile app facilitates firstly, data entry, secondly, their automatic scoring, and finally, their visualization.

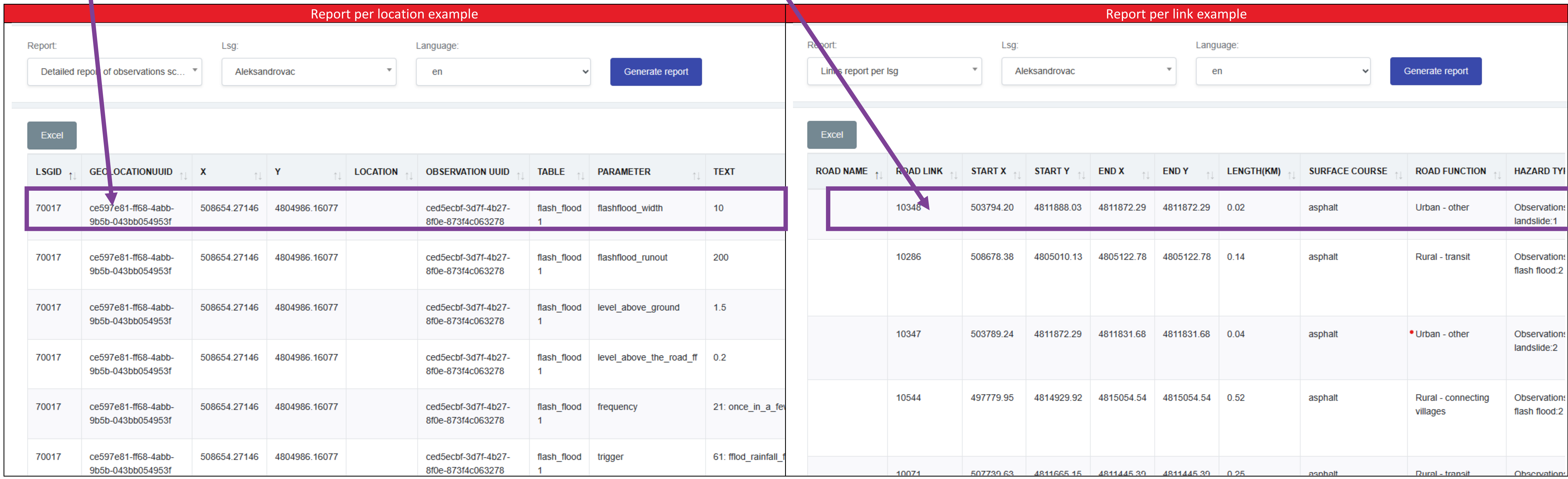
P001 Hazard	P001 Traffic	P001 Infrastructure	Field photo
			

A.2.2 Calculating and visualizing priority scores using the MaPLoRds web tool

Using the same hypothetical example with points P001-P004 the mobile app facilitates firstly, data entry, secondly, their automatic scoring, and finally, their visualization. It is possible to choose among observations, preliminary link priority scores, preliminary sub-link priority scores, and combined link priority scores to visualize on the map which is generated automatically.



It is then possible to obtain tabular (exportable to Excel) reports per each observation or each link in order to rank them by priority score (or any other relevant parameter) and prioritize them (apply more detailed investment plan).



Report per location example

Report: Detailed report of observations sc... Lsg: Aleksandrovac Language: en Generate report

Excel

LSGID	GEOLOCATIONUUID	X	Y	LOCATION	OBSERVATION UUID	TABLE	PARAMETER	TEXT
70017	ce597e81-ff68-4abb-9b5b-043bb054953f	508654.27146	4804986.16077		ced5ecbf-3d7f-4b27-8f0e-873f4c063278	flash_flood 1	flashflood_width	10
70017	ce597e81-ff68-4abb-9b5b-043bb054953f	508654.27146	4804986.16077		ced5ecbf-3d7f-4b27-8f0e-873f4c063278	flash_flood 1	flashflood_runout	200
70017	ce597e81-ff68-4abb-9b5b-043bb054953f	508654.27146	4804986.16077		ced5ecbf-3d7f-4b27-8f0e-873f4c063278	flash_flood 1	level_above_ground	1.5
70017	ce597e81-ff68-4abb-9b5b-043bb054953f	508654.27146	4804986.16077		ced5ecbf-3d7f-4b27-8f0e-873f4c063278	flash_flood 1	level_above_the_road_ff	0.2
70017	ce597e81-ff68-4abb-9b5b-043bb054953f	508654.27146	4804986.16077		ced5ecbf-3d7f-4b27-8f0e-873f4c063278	flash_flood 1	frequency	21: once_in_a_fe
70017	ce597e81-ff68-4abb-9b5b-043bb054953f	508654.27146	4804986.16077		ced5ecbf-3d7f-4b27-8f0e-873f4c063278	flash_flood 1	trigger	61: fflod_rainfall_f

Report per link example

Report: Links report per lsg Lsg: Aleksandrovac Language: en Generate report

Excel

ROAD NAME	ROAD LINK	START X	START Y	END X	END Y	LENGTH(KM)	SURFACE COURSE	ROAD FUNCTION	HAZARD TYI
	10348	503794.20	4811888.03	4811872.29	4811872.29	0.02	asphalt	Urban - other	Observations landslide:1
	10286	508678.38	4805010.13	4805122.78	4805122.78	0.14	asphalt	Rural - transit	Observations flash flood:2
	10347	503789.24	4811872.29	4811831.68	4811831.68	0.04	asphalt	Urban - other	Observations landslide:2
	10544	497779.95	4814929.92	4815054.54	4815054.54	0.52	asphalt	Rural - connecting villages	Observations flash flood:2
	10071	507730.63	4811665.15	4811445.30	4811445.30	0.25	asphalt	Rural - transit	Observations

More details on MaPLoRds tool functionalities can be found in the official project Guidelines.