https://doi.org/10.18485/resylab.2024.6.ch29

Landslide impact on road infrastructure in the Western Balkans

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Abstract Landslides stand among the most common road-related disruptions throughout the Western Balkans Region, especially in the last couple of decades that have been witnessing severe weather anomalies, likely related to climate change. It is therefore inferred that landslides will become even more prominent in near future. Their assessment is, therefore, crucial for all further road planning, design, and management entailed. By fitting into EU frameworks, the Western Balkan countries are lately taking actions to pinpoint landslide and otherwise hotspot areas along the road networks and prioritize future investments accordingly. Herein, an example of landslide assessment along the road network and its impact is presented, with an adjusted methodology for large-scale frameworks, such as Western Bakan. The results show that roads are significantly affected by landslides in the Region to a level that it is difficult to discern areas of higher priority, thereby highlighting the need for developing sophisticated methodologies for their impact assessment. Landslides are confirmed as one of the topmost natural hazard types that cause road network disruption. When it comes to climate change, anticipated for the near and far future, it has been indicated that there are zones where the landslide hazard and their impact are expected to increase locally, but also zones where it will stagnate or drop. It has been demonstrated that such large-scale assessment can be very useful for public enterprises and governmental entities in their further decision-making and financing the road network maintenance, reconstruction, and extension.

Keywords landslide hazard, road network, climate change, the Western Balkans

Introduction

Resilience to climate-related natural hazards which are affecting road networks are emphasized in many agendas (Global Agenda 2030, EU Green Deal) linked to the Western Balkans Region (Albania, Bosnia and Herzegovina, Kosovo*[1], North Macedonia, Montenegro, and Serbia). To ensure that future investments are wisely spent, various frameworks and action plans, targeted at engaging road sector governmental and public enterprise entities, are launched and all include improving climate resilience strategies (Corporate Authors, 2021). Such is the case with Trans-European Transport Network (TEN-T), which includes 5,287 km of roads (existing and planned) throughout the Western Balkan Region (Fig. 1).

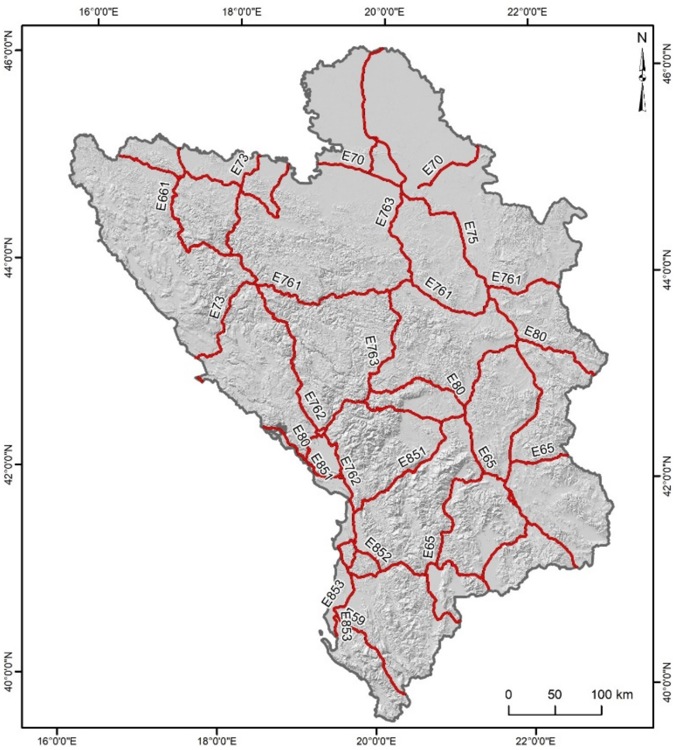

Figure 1. Indicative TEN-T core and comprehensive road network of the target Western Balkans area for 2050.

Among the natural phenomena that are recognized as climate-sensitive, landslide stand hand-in-hand with floods as the most damaging to road and railway networks in this area (Delforge et al, 2023, Marjanović et al, 2019). Other natural hazard types (sea surge, wildfire, snowdrift, drought) are not as damaging and more localized (e.g. to coastal areas, or high mountains). It is also important to note that the landslides are herein defined according to the internationally adopted classification (Hungr et al.

[1] In line with UNSCR 1244 (1999) and the ICJ Opinion on the Kosovo status.

2014), and include various types of mass movements, such as rockfalls, debris-flows, slumps etc. Hence, there are zones highly susceptible to landslides throughout the Region and zones which are landslide-free. Road networks cross-areas with landslide susceptible zones and it is a principal step to determine these stretches of the road network and define to which extent are they affected, and ultimately pick the most vulnerable hotspots.

The principal idea of this work was implemented in the project *Improving climate resilience and adaptation measures in the indicative extension of TEN-T road and rail networks in Western Balkans*, executed by Arup d.o.o. Beograd in 2023 (Transport Community, 2023). This work briefly overviews only the landslide hazard and only mid-term time split of 2050, although other hazard types and other time splits are included in the original project.

Methodology

Techniques available for landslide susceptibility assessment at regional scales are becoming countless (Pourghasemi et al. 2018), ranging from simple heuristics to statistical, deterministic and machine learning-based approaches. Regardless of the technique, determining the zones susceptible to landslides (spatial probability), and then highlighting those where landslide events are repetitive, i.e. hazardous (spatio-temporal probability), it requires two types of input data (Tab. 1):

- static morphological, geological, geotechnical and environmental features for determining where their combination is likely to cause landslides;
- dynamic triggering feature (rainfall, earthquake or other data) which changes over time;

In addition, a landslide inventory is needed to provide existing cases of landslide events during model calibration, as well as to validate its accuracy afterwards. Throughout the Western Balkans, there are differences regarding the data enlisted above. These data are prone to the level of detail and quality differences, which makes it unfeasible to generate a landslide hazard map of the entire Region by integrating the national level data. Such patchwork would cause inaccuracy of comparison of one part of the Region against another. Since consistency is essential in deciding which landslide hotspots are priorities, a downscaling approach is proposed instead.

Table 1 List of used datasets.

Dataset	Source	Resolution
Digital Ter. Model (DTM)	SRTM https://earthexplorer.usgs.gov/	30 m
Landslide suscept. map	EUROPEAN COMISSION JRC ESDAC https://esdac.jrc.ec.europa.eu/	200 m
Precipitation RCP4.5 map	Climate Change Centre Austria https://data.ccca.ac.at/	1 km
Landslide inventory	Western Balkan stakeholders (national public road enterprises)	NA
TEN-T road network	TCT https://todis.transport-community.org/TODIS-APP/	NA

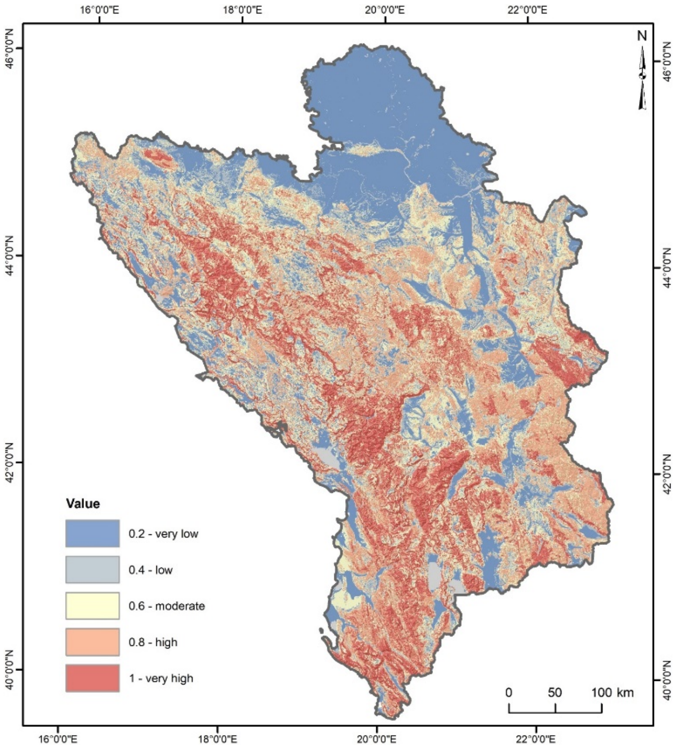

Figure 2. ELSUS2 landslide susceptibility map of the Western Balkans (source: https://esdac.jrc.ec.europa.eu/).

Downscaling the landslide data

Although coarser in resolution and more general in methodology, large-scale landslide susceptibility models provide the consistency needed for this task. The zones that are classified into five intervals, ranging from very low to very high landslide susceptibility are modelled (ELSUS2) for the entire Europe at 200 m resolution (Wilde et al, 2018). When downscaled to the extent of the Western Balkan, reclassified to 0-1 scale of values, and resampled to 30 m resolution using spline interpolation (Fig. 2) the ELSUS 2 model becomes a foreground for further modelling.

Downscaling the rainfall data

Rainfall data, especially those acquired from satellites such as TRMM mission and its successors, even more gravely suffer from coarse resolution (e.g., 1 km or larger pixel size). Their downscaling from to finer pixels is more complex interpolation problem, which requires not only adjacent pixels, but also time series analysis, as it is a dynamic dataset. Due to a vast database with countless climate indices provided especially for the Western Balkans, alongside with the spatio-temporal interpolation tools (in particular patch resampling), the precipitation data for RCP4.5 climate scenario is obtained and processed for 2050 time split, using the ClimaProof project tools (Tab. 1). Once downscaled, from 11 km to 30 m resolution (which now matches downscaled landslide susceptibility map), the precipitation map was normalized to 0-1 range to depict the relative distribution of rainfall throughout the area (Fig. 3).

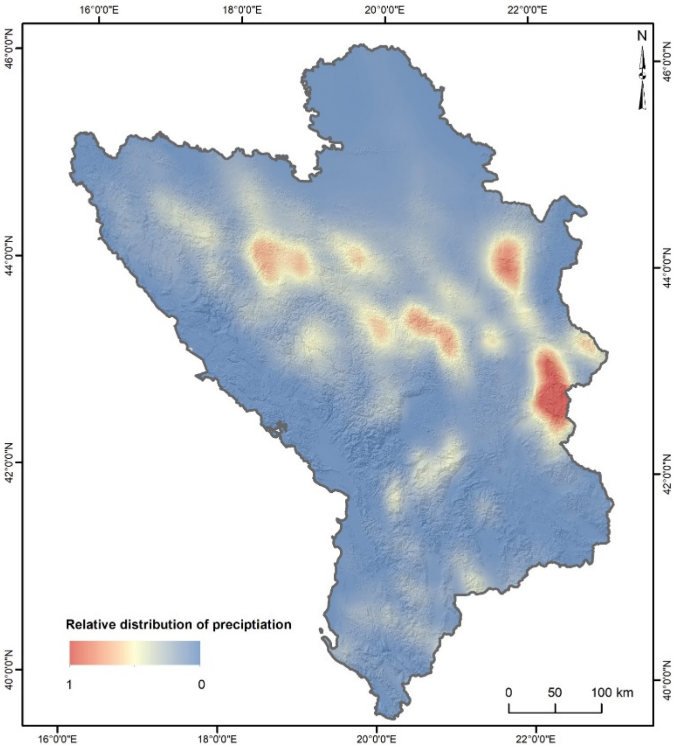

Figure 3. The downscaled original precipitation model (labelled pr_MPI-M-MPI-ESM-LR_rcp45_r1i1p1_SMHI-RCA4_v1a_2011-2100) for 2050 time split (source: https://data.ccca.ac.at/).

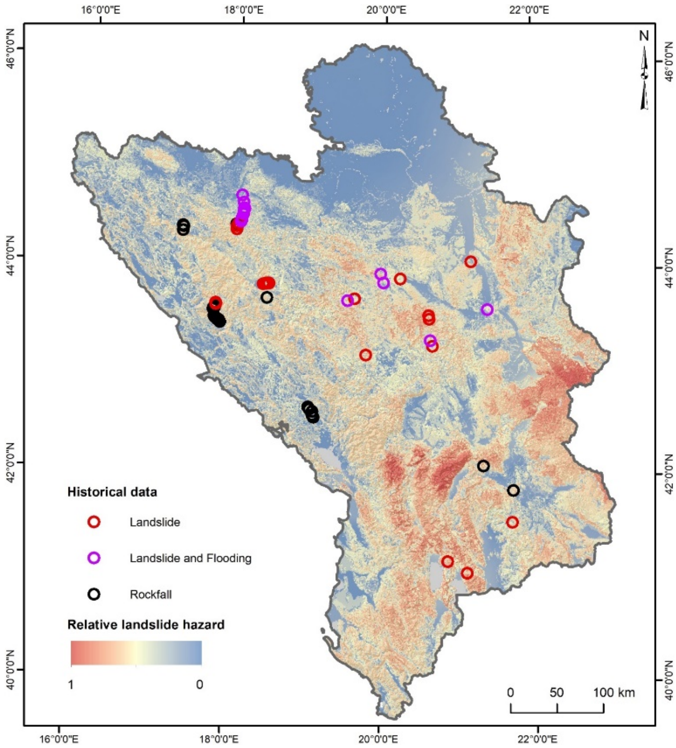

Figure 4. Landslide hazard map of the Western Balkans for the 2050 against the landslide inventory and alike mass movements.

Landslide hazard map

It was further required to append dynamic trigger data, in this case rainfall, which would reflect not only the local anomalies in rainfall in the past, but also rainfall distribution in the future for 2050 time split (under RCP4.5 scenario). This is performed by multiplying the landslide susceptibility and rainfall map (now both downscaled), thereby highlighting the zones where the landslides are likely to occure, and occure more frequently than in other areas (Fig. 4).

The validity of this map was checked using a limited landslide inventory obtained from regional stakeholders in charge of the road sector in the Western Balkans (Tab. 1).

Road network exposure

Road network elements of the TEN-T network are introduced as vectors represented by links and nodes. Given a large extent of the network (some links are tens and hundreds of km long while others are very short), a version of the network vector wherein all links are segmented into 1 km sub-links is also introduced. The latter version turned out to be more useful for network exposure assessment. When overlapping the previously created landslide hazard map, the road segments (links and sub-links) collect the pixels encountered along their extent and sum their relative hazard values. These sums are subsequently normalized into 0-1 range by using the network maxima and minima of the landslide hazard sums. In this way, two distant parts of the network can have equal criteria when compared to which one is more affected.

Outputs

The 2050 time split of landslide hazard, anticipated by means of moderate RCP4.5 scenario (suggesting that greenhouse gas emissions will remain the same or slightly decrease by then) is translated from previously outlined very high to very low hazard zones to road vectors.

The link exposure (Fig. 5) suggests that the most affected are the ones in the hilly areas and along large river valleys or coastlines, e.g., in mountainous regions in western Serbia, central Albania, central Montenegro and central Bosnia and Herzegovina. Exposure to landslides might be even reduced in the future (due to a general decrease in precipitation and an increase in temperature) when the links are observed in general. However, local climate change effects (more extreme rainfalls with higher intensity and concentrated frequency) are better depicted in the case of sub-link exposure to landslides (Fig. 6). Sub-links are more prone to localized effects, but the patterns are clear (mountainous and remote areas are most prone). It is also apparent that much greater extents of the network is categorized as potentially highly impacted in the case of links (e.g., all red links), whereas sub-link analysis provides a more realistic output. The very high exposure class is identified to a total of 1005 km (or ~20% of the network) along the links while 763 km (or 15% of the network) along the sub-links.

It is further possible to extract a desired number of all links or sub-links, per entire network or per country etc. Making comparisons is thereby enabled as well as prioritization of the hotspots (identified spatially and by ID) which require more attention than the others (Tab. 2).

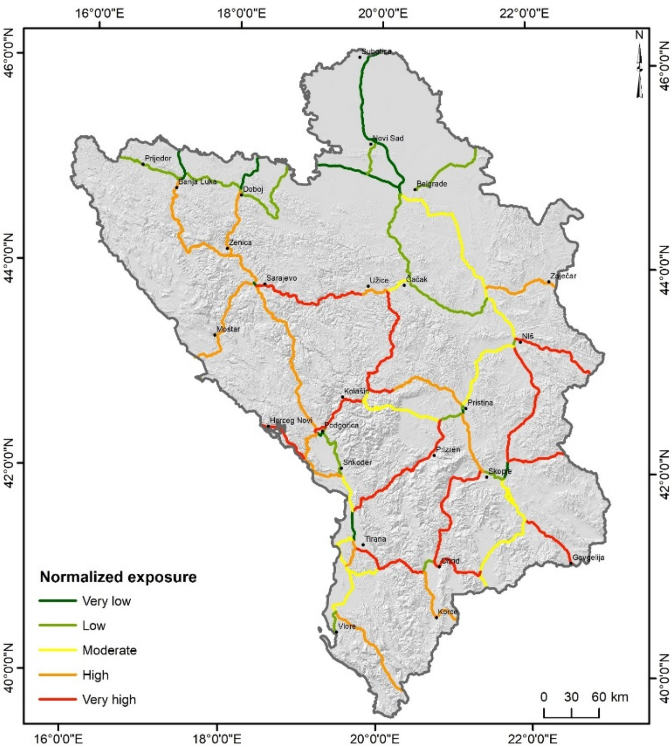

Figure 5. The spatial extent of the road link exposure to landslide hazard for 2050 time split.

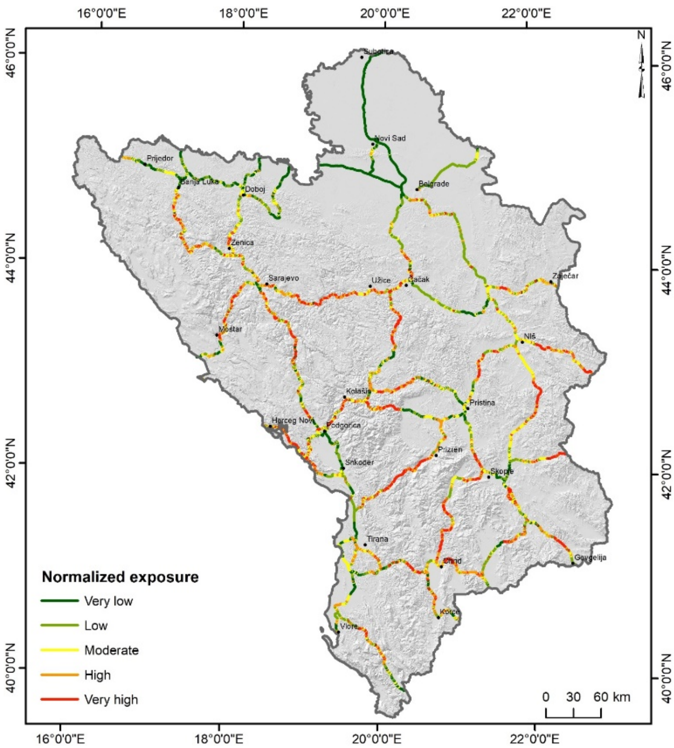

Figure 6. The spatial extent of the road sub-link exposure to landslide hazard for 2050 time split

Based on their length, the identified type of hazard (landslides) and other features it is possible to direct design measures for their efficient remediation or prevention. Landslide impact is herein directly reflected through the relative hazard value, whereas one can argue that road features are also important when calculating the total risk and its impact. These aspects are elaborated in detail in the project and continued through the Criticality Assessment, but herein, omitted due to simplicity.

Table 2 Top ten links and their hazard exposure score.

Link ID	Length (km)	Route	Hazard score	Rank
243	25.86	E65	1.00	1
177	27.58	E80	0.90	2
4791	41.54		0.86	3
276	21.69		0.75	4
174	18.68	E80	0.75	5
109	38.26	E763	0.70	6
114	31.24	E763	0.69	7
5589	10.61		0.66	8
1948	11.43		0.64	9
4777	22.72	E65	0.62	10

Conclusions

The proposed methodology benefits over the official EU Guidance in several aspects (Corporate Authors, 2021). Although it is successful in labelling high and low vulnerable (exposed) parts of the road network, it fails to establish a comparative ranking among them and therefore disables prioritisation as an important step in road management. The sub-link analysis level allows for a more detailed analysis and seem more realistic. Naturally, this level can have a significant mismatch with the concrete cases from the field and should be used for general planning purposes. This approach is also convenient for comparison among different time splits which might confirm or disproof specific link's priority over time.

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