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Landslide mapping and zonation at national, regional and local scale - Recent experiences from Republic of Macedonia

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Abstract The paper presents anoverview of recent landslide mapping and zonation projects in Macedonia at different scales. On national level, the most recent study is a national scale susceptibility mapping performed within a geohazards study - part of the spatial plan of Macedonia. Due to limitations with regards to landslide characterization and a relatively poor landslide database, the rather simple arbitrary polynomial approach was applied. Lithology, terrain slope, rainfalls, earthquake acceleration and land use were considered causal factors for landslide development. Two susceptibility models, with different return periods for maximum expected earthquake acceleration according to Eurocode 8, were produced. The results are compared with previously performed studies and certain conclusions and recommendations for further activities were drawn. The second part of the paper is dedicated to regional and local scale mapping case studies, mostof which are done for the Polog region. Several techniques for landslide susceptibility mapping had been applied, such as LiDAR semi-automated susceptibility mapping, frequency ratio method, arbitrary polynomial method, DInSAR "hotspot" detection. Depending on data availability, different datasets were used for the specific methods. Based on results of the landslide susceptibility mapping, the landslide hazard and risk for a number of most critical locations was assessed at a local scale. These locations were considered for design of remedial measures. Namely, the preliminary remediation designs were made, consisting of at least two possible solutions per location. The solutions were then subjected to a cost-benefit analysis, upon which the final design was done for the most feasible one. Solutions are now beingimplemented. Some other regional and local scale assessments are presented only briefly in the paper.

Keywordslandslide, zonation, national, regional, local, Macedonia

Introduction

Landslides in Republic of Macedonia have been investigated for a long period. First "extensive" landslide mapping, has been perform during the time of Yugoslavia. Namely, between 1960 and 1980, in frame of the basic geological mapping for the entire territory of the country at 1 : 100,000scale, over 150 landslides were detected. Unfortunately, only the landslide polygons are now available, while the associated data on the landslides characteristics have been lost. After this period, the landslides had been treated sporadically, mostly during the construction of large infrastructure projects. The Geological survey and the large construction companies had great capacity in investigating and remediating the landslides. With the downfall of these entities, the landslides problems had become harder to tackle. Moreover, the procedures and laws related to the landslide management have delayed the interventions, usually leading to obstacles in the use of public infrastructure for unreasonable long periods. Due to limited budgets, municipalities have even more difficulties in landslide remediation. In some cases with obvious life threatening risk being overlooked. First attempt to present the landslide threats on national level was done by Jovanovski in 2010. Peshevski (2015) performed a regional landslide susceptibility mapping for the Polog region. Milevski et al.(2019) produced an AHP susceptibility map for Macedonia. UNDP sponsored a project related to landslide risk reduction for Polog region, where some local scale analyses were performed (Jovanovski et al. 2021). Case studies for earthquake-induced landslide hazard in local and regional contexts were presented by Bojadzieva et al. (2018 and 2022). Nedelkovska (2023) performed a multi-method susceptibility assessment of the Polog region. In 2023 Peshevski et al. performed a national scale susceptibility mapping framed within the national spatial plan.

National scale studies

Jovanovski(2010) presented an overview map of landslide locations in Macedonia (Fig.1). The main idea of the paper was to stress the most critical regions threatened by landslides and to propose more specific geographic regions for which detailed studies should be performed. Some data for larger landslide risk assessment also for the surroundings was presented. This paper stressed the need for a more systematic approach in the landslide hazard and risk mapping in Macedonia.

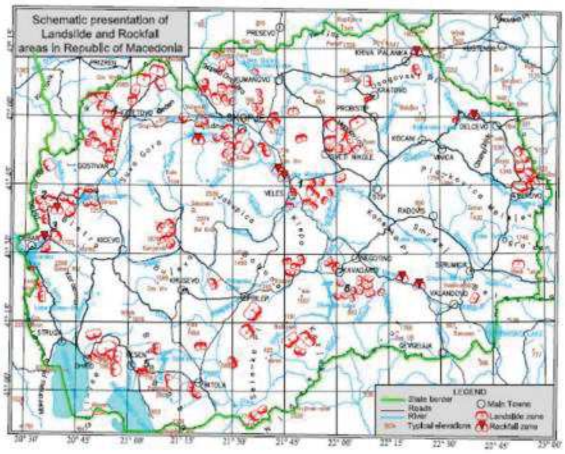


Figure 1 Schematic presentation of landslide and rockfall areas in the country (Jovanovski 2010).

Peshevski(2015) prepared a landslide inventory map of Macedonia consisting of over 300 occurrences (Fig. 2). The level of data available for each landslide ranges from very detailed to very poor - even unknown location (i.e. only from spoken information). The final map consisted of 255 landslide occurrences.

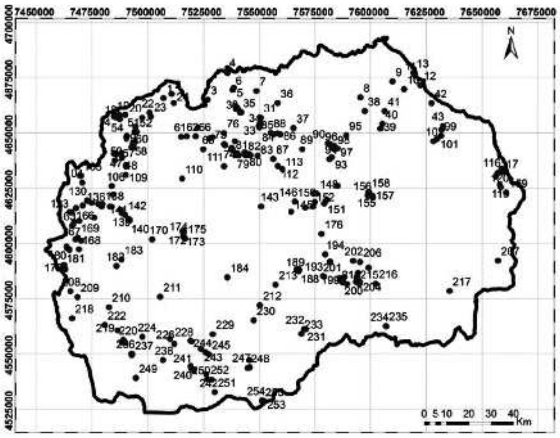


Figure 2 Landslide inventory map of the Republic of Macedonia (Peshevski 2015).

Milevski et al. (2019) performed statistical and expert based susceptibility modelling on a national scale (Fig. 3). Authors applied combination of Frequency Ratio and Analytic Hierarchy Process modelling. Lithology, slope, plan curvature, precipitation, land cover, distance from streams and distance from roads, had been selected as landslide preconditioning factors. The authors considered this approach to be very useful and practical in case of poor landslide inventory.

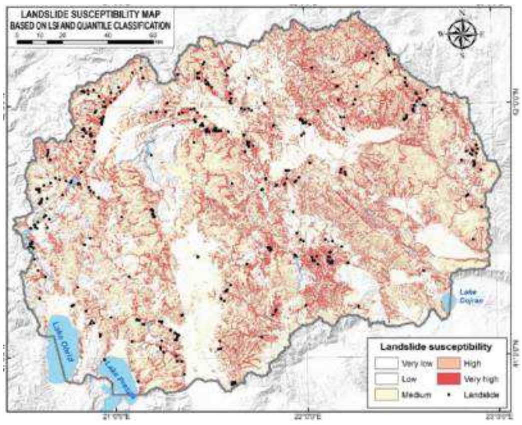


Figure 3 Landslide susceptibility map based on LSI and Quantile classification, Milevski et al. (2019).

Then, in the frames of the Geohazards study for the Spatial plan of Republic of Macedonia for planning period 2021-2040, Peshevski et al. (2023) applied the heuristic arbitrary polynomial approach. This method was previously applied at a regional level for the Polog region and gave satisfactory results (see in Peshevski 2015). Particularly, the geology, slope, precipitation, expected seismic acceleration according to Eurocode 8 for return periods of 95 and 475 years, and land use were assumed as landslide preconditioning factors. Adopted ratings for each conditioning factor are presented in the following tables and graphs.

Table 1 Maximum possible rating according importance of the conditioning parameter.

Classification parameter	Rating
Lithological type	3
Slope	3
Precipitation	2
Seismic zoning per Eurocode 8	1
Land use	1
Maximum possible rating	10

The data for lithology was taken from the Basic geological map of Macedonia at 1:200,000 scale. Lithological units were zoned according the potential for development of landslides. Five groups were delimited, by empirically assigning values ranging from 0 up to 3. In total, 161 lithological units were classified. The number of units clearly implies to the uncertainty of any used susceptibility model, no matter what type of methodology is used. This means that when dealing with regional and local scale landslide zoning, future studies should pay a lot of attention in defining the soil and rock geotechnical properties. For this goal, extensive geotechnical studies should be performed, while the gathered data should be statistically analyzed. Groundwater monitoring should be also performed.

The rating of slope is defined using a polynomial interpolation method, where the following graph was used (Fig. 4).

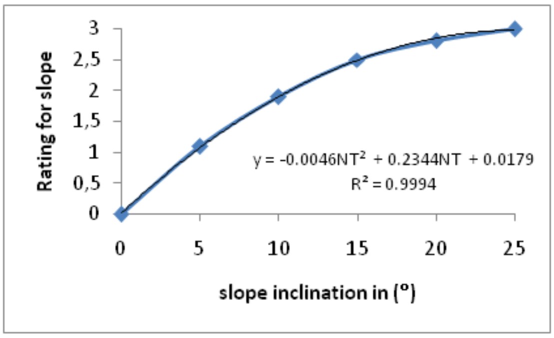


Figure 4 Slope rating adoptation according polynomial interpolation.

Values of rating for precipitation, seismic acceleration and land use are respectively presented in Table 2 trough Table 5.

Table 2 Ratings according to average precipitation (arbitrarily adopted).

Precipitation (mm/year)	Rating
400-500	0,1
500-600	0,2
600-700	0,3
700-800	0,4
800-900	0,8
900-1000	1,0
1000-1250	1,5
>1250	2,0

Table 3 Rating according to agR in units of the gravitational acceleration 1q= 9.81m/s^2 for type A of soil - return period 95 years. According МКС-ЕН1998-1/2004-Eurocode 8.

Maximum ground acceleration (agR)	Rating
Z1 (0.05 g)	0,1
Z2 (0.1 g)	0,2
Z3 (0.15 g)	0,35

Table 4 Rating according to agR in units of the gravitational acceleration 1q= 9.81m/s^2 for type A of soil - return period of 475 years. According МКС-ЕН1998-1/2004-Eurocode 8.

Maximum ground acceleration (agR)	Rating
Z1 (0.1 g)	0,2
Z2 (0.15 g)	0,35
Z3 (0.20 g)	0,65
Z4 (0.25 g)	0,85
Z5 (0.30 g)	1,0

Table 5 Ratings according to land use.

Land use type (Corine-CLC 2018)	Rating
1.Forest areas	0,1
2.Pastures	0,3
3.Agricultural areas	0,6
4.Artificial areas	0,9
5.Bare rock	1,0

Every specific combination of these evaluation factors is related to different degree of susceptibility to landsliding. The sum of individual ratings gives the total rating of landslide susceptibility (Eq.1):

$$TLSR = LTR + NTR + GVR + IR + ZPR \quad [1]$$

where:

TLSR – total landslide susceptibility rating
LTR – value of rating for lithological type
NTR – value of rating for slope inclination
GVR – value of rating for precipitation
IR – value of rating for seismic acceleration
ZPR – value of rating for land cover

The maximum value of TLSR is 10, and the minimum is 0.3. After performing the algorithm and obtaining the TLSR value, the terrain susceptibility to landsliding is reclassified in 5 classes (applying the appropriate mathematical classification model Jenks natural breaks).

Final susceptibility maps are presented in Fig.5 and Fig.6, while details can be found in Peshevski et al. (2023).

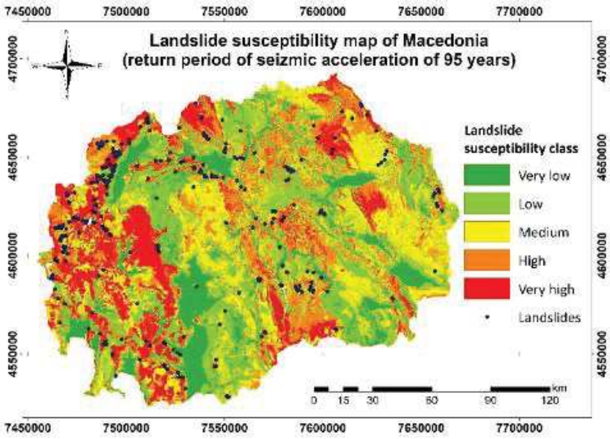


Figure 5 Landslide susceptibility map of Macedonia, for return period of seismic acceleration of 95 years (Peshevski et al. 2023).

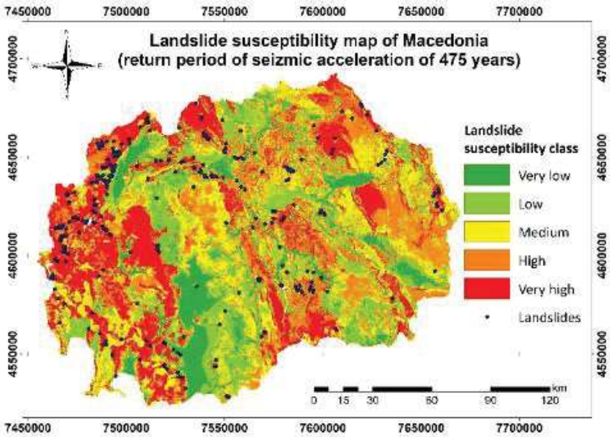


Figure 6 Landslide susceptibility map of Macedonia, for return period of seismic acceleration of 475 years (Peshevski et al. 2023).

All of the national susceptibility models considered above have their limitations and advantages, but main conclusion is that they are correlating between each other. Therefore, future studies should focus more on the regional and local scale landslide zonation.

Regional scale mapping for Polog region

As seen from national scale mapping examples, the Polog region seems that should be considered as the most prone to landslides. In fact, almost 2/3 of registered landslides in the country are located in this region. First attempt to perform susceptibility zoning of Polog was by done by Peshevski et al. in 2015 and 2019. The above mentioned arbitrary polynomial method was applied, where the landslide inventory was formed predominantly by use of historical data and Google Earth imagery.

More recently, Nedelkovska (2023) performed again an assessment of the landslide susceptibility for the region by using the Frequency Ratio (FR) model. It is worth to mention that on this occasion, the existing landslide inventory for the region was upgraded by two methods that were applied for the first time in Macedonia. Namely, Differential Interferometry Synthetic Aperture Radar (DInSAR) remote sensing method was applied to indicate “unstable” zones (Fig.7). The second method is the Light Detection And Ranging (LiDAR) which was used to generate DEM of the terrain in different resolutions and detect some landslide scarsby visual approach (Fig.8). In addition to this, the LiDAR was also applied in a semi-automatic approach for Scarp Identification and Contour Connection Method (SICCM) (Fig.9) as proposed by Bunn et al. 2019. Then, twelve landslide conditioning factors were generated for landslide susceptibility modelling: slope, elevation, aspect, plane curvature, profile curvature, roughness, distance to roads, lithology, distance to faults, rainfalls, distance to rivers and land use/land cover. Frequency Ratio (FR) values were used to produce the Landslide Susceptibility Index (LSI), based on which the study area was divided in five zones of relative landslide susceptibility. Validation was done by calculation of the so-called R-index. The results showed that the FR is reliable method for landslide susceptibility assessment. Final map prepared in scale 1:100,000 is shown in Figure 10. More details in Nedelkovska, 2024 (in print).

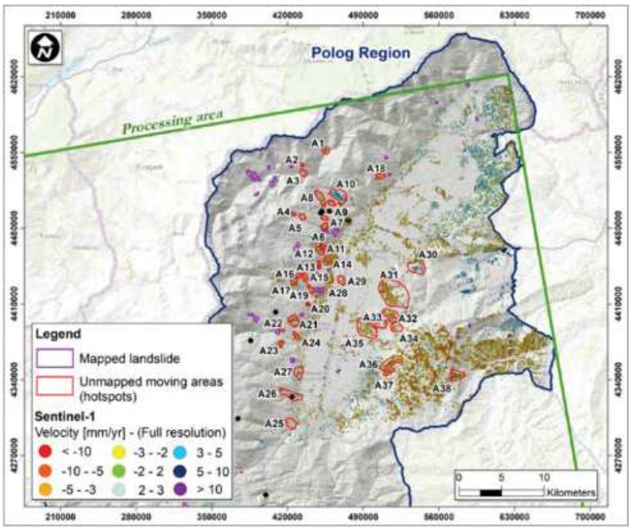


Figure 7 Map of indicated “unsable” zones using Sentinel DInSAR data at low resolution.

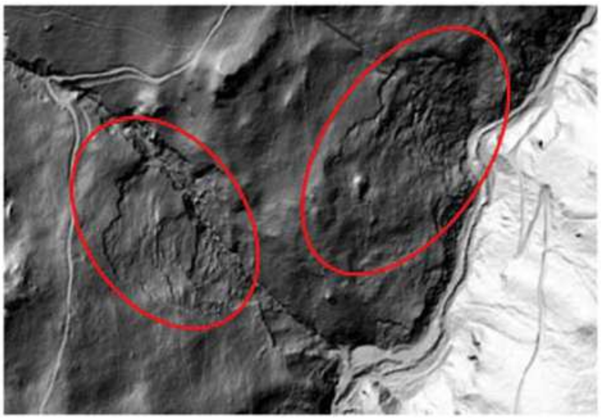


Figure 8 Detection of landslide scars from LIDAR survey, Nedelkovska 2023.

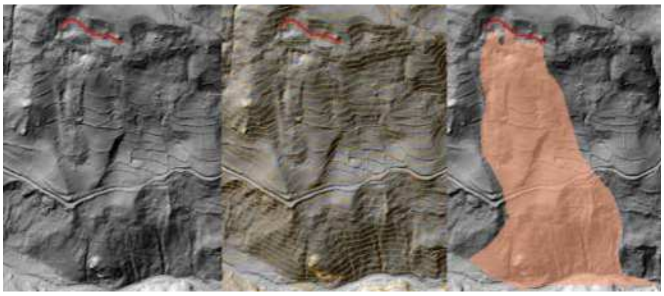


Figure 9 Example of the process for landslide zones modeling by SICCM.

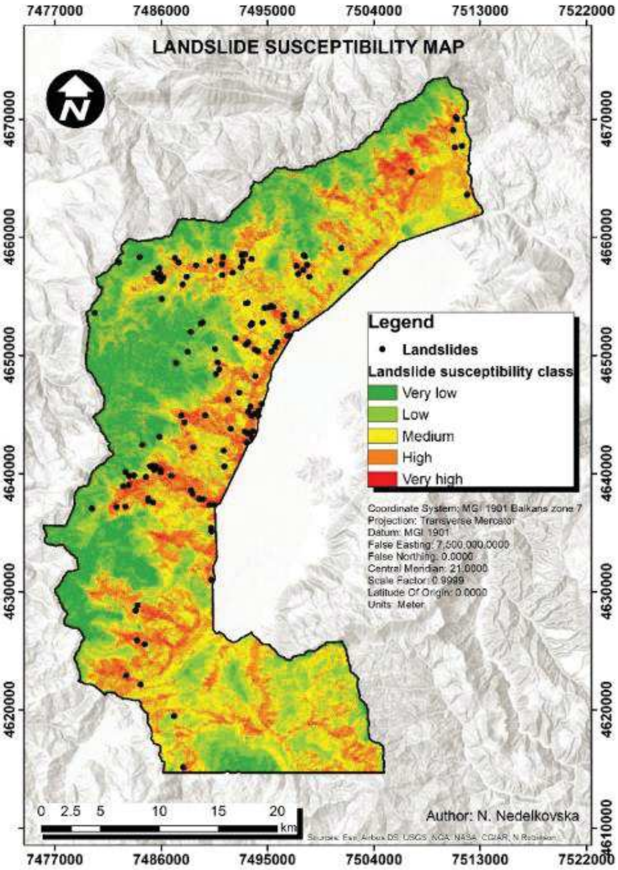


Figure 10 Final landslide susceptibility map obtained by FR model, Nedelkovska 2023.

Landslide hazard and risk assessment

Upon finalization of the regional susceptibility maps and the field collection of data, the next logical step for Polog region was to attempt and define the landslide hazard (and risk) for the most critical locations. To this aim, in first instance a combination of the approaches by Larsen et al. 2010, Ikeya 1981, SedNetNZ 2015 as well as own expert analysis was applied. The goal of these methods is to assess the sediment yield from landslides, which is one form of expression of the landslide hazard.

As a first step, the landslides of interest were analyzed in respect to how close they were to a particular main stream or tributary and which part of the landslide is possible to be reactivated during an extreme rainfall event was assessed. After the "landslide selection", in the following stage a total landslide volume through the landslide area was defined, in a semi-empirical manner. The findings of Larsen et al. (2010) were used as a starting point, with certain calibrations performed for landslides with known quantity of detached material in historical events, specific active area, depth, etc. Each landslide was considered thoroughly and appropriate coefficients were adopted. In order to assess the landslide volume, the following empirical equations were applied:

For shallow landslides:

$$V_L=0.2\text{-}0.5*La^{1.1\text{-}1.3} \qquad [2]$$

For deep landslides:

$$V_L=0.2\text{-}0.5*L_a^{1.3\text{-}1.6} \qquad [3]$$

where:

V_L- landslide volume (m^3)
L_a– landslide area (m^2)
0.2-0.5 and 1.1-1.6 empirical coefficients suggested by Larsen et al. (2010) (in most cases we have used the most optimistic coefficients: 0.2 for both shallow and deep landslides, usual exponent of 1.1 for shallow and 1.3 for deep landslides).

In the next stage the expected landslide run out distance was defined, by using the formula of Ikeya (1981):

$$L=8.6*(V_L*\tan\theta)^{0.42} \qquad [4]$$

where:

θ - landslide slope in degrees
L- run out distance (m).

We note that this equation is generally intended for the assessment of run out distance of debris flows and shallow landslides. However, due to scarcity of data from past events, it was also considered as acceptable for deep landslides. We consider this approach as conservative in predicting mass quantities.

In following step, the sediment delivery ratio (SDR) was assessed. This parameter is defined as the sediment yield from an area divided by the gross erosion of that same area. In general terms, SDR is expressed as a percentage and represents the efficiency of the watershed in moving soil particles from areas of erosion to the point where sediment yield is measured. In this case, SDR is considered as the percentage of landslide sediment yield from the total landslide volume, according to the approach of Chiuet al. (2019).

$$SDR=(L-D)/L \qquad [5]$$

where:

D (m) - distance between the centre of the landslide area and the nearest downslope stream channel
L (m)- Landslide migration distance is the maximum possible moving distance of the sediment produced in a newly added landslide area.

From the literature it was found that SDR varies in different regions, in the range between 80-100% for short landslides directly connected to the stream channel below, and from 20-80% for landslides with gentle slope. According to the SedNetNZ study (2015), for shallow landslides, the average value of SDR is about 0.5.

The SDR was first calculated for all selected upstream landslides in each watershed, according to the above equation. In addition, the quantity of material, which has been removed (cleaned) from the respective watershed main stream at its outlet to the plain, was known for several cases, a data which served as benchmark to see if the calculated SDR was appropriate.

Finally, calculation of the possible landslide sediment yield for each particular landslide and every subwatershed of the region was performed. It is worth to mention that there was no possibility to make further calibration, in the sense of whether the material stops upstream in the sub-watershed where the landslide belongs. Therefore, the quantities obtained are presented only as preliminary, and more precise assessment should be done upon detailed in situ investigations and geotechnical and hydrological monitoring. Some examples of the calculated expected sediment load are presented in Table 6.

Table 6. Event based landslide sediment yield assessment (some examples).

Land slide tab ID	Depth of landslide	Assumed area that can be activated (m^2)	Calculated volume (m^3)	Sediment delivery ratio (SDR)	Landslide sediment yield (m^3)
1002	Shallow	7.564	3695	0.57	2.122
1	Shallow	44.615	23029	0.171	4.452
17	Shallow	86.946	54.225,62	0.089	4.845
015*	Deep	30.000	132.217	0.5	66.108
1001	Deep	117.640	489.699	0.083	40.647
009	Shallow	110.721	70.742	0.24	17.111

Fig. 11 presents an excerpt of the final map of landslide hazard for the so called Poroj watershed.

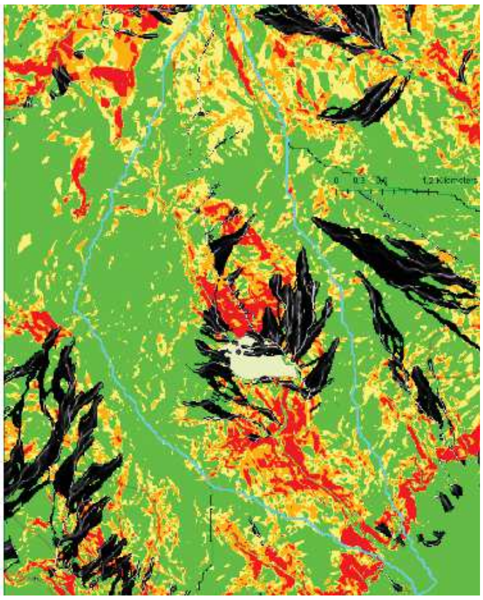


Figure 11 Integral landslide hazard in the Poroj watershed. Legend: Pale blue-watershed border; pale green polygon-Gjermo landslide; black zones-expected debris flow runout zones (obtained by Flow-R software); yellow to red colored zones-landslide susceptibility classes.

Besides the ability to obtain a sense of the quantity of landslide generated sediment yield in extreme events, the temporal component remains undefined. This means that even if the quantity of material to reach the stream can be assessed with certain level of confidence, the dynamics of the occurrence during an extreme rainfall event can't be defined fully. In some cases, we can have extreme rapid movement of an entire landslide and transformation in debris flow, while in other there can be slow gradual erosion of the landslide continuing for days and even weeks. In the latter case, the same total amount of sediments might reach the local stream, however with smaller quantities being transported within a longer period. Since there is no data for registered fast debris flows or blockage of rivers due to landslides in the region for a period from 1970-2020 and even before, these estimations should be taken with great precaution and revised once monitoring data becomes available.

Preliminary risk assesment

Besides the fact that there was a lack of data to perform regular risk analyses at a local level in the period of 2020, the typical risk formula was applied:

$$R=H^*(E^*V) \qquad [6]$$

where:

R– risk (total damages due to landsliding)
H – landslide hazard
E – elements exposed to landslide hazard (population & goods)
V – vulnerability of exposed elements.

In this sense, we can consider the following analyses as a preliminary or relative risk assessment.

Namely, due to the relatively poor knowledge on the frequency of landsliding, which is a prerequisite for risk assessment, the rules that were applied to perform relative risk were set up empirically. By analyzing all landslides from the database and taking into account the build-up area, the prioritisation Tab. 7 was created. Using these criteria, the final list of landslides considered for conceptual design development is presented in Tab. 8.

Table 7 Landslide prioritisation criteria and points for relative risk ranking (values in table are prioritization ranking points).

Prioritisation criteria	Very low	Low	Medi-um	High	Very high
1. Ability of landslide to threaten settlements or critical infrastructure	1	5	10	15	20
2. Landslide has the potential to dam a river with potential for outburst flow	1	5	10	15	20
3. Landslide might directly transform into flow with long travel distance and affect lowland areas	1	5	10	15	20
4. Relative size of landslide in comparison to other landslides in the inventory	1	5	10	15	20
5. Information for landslide hazard from municipalities	1	5	10	15	20

Table 8 Prioritization list of Landslides considered for conceptual design development.

Location	Priorit. points	Landslide type	Subject of hazard
1. Gjermo and Poroj	100	Deep landslide	Part of village of Gjermo & possible outflow of debris toward Tetovo. River damming is not excluded.
2.Bozovce	80	Complex slide	Entire village of Bozovce under risk of debris-flow
3.School in Pirok	71	Translatory sliding	Elementary school and several houses under risk.
4.Jelovjane landslide	66	Complex slide	Part of village Jalovjane, past event recorded large damages and resettlement.
5.Landslide near el. hydro power plant	60	Rock slide	Risk for busy local road.
6.Landslide on road Senokos – Lomnica	47	Rockfall and translatory sliding	On several locations along the road with possibility for blockage of the road.
7.Damped material in Senokos	41	Complex slide	Possibility to affect several houses below dump zone.
8.Jegunovce – Staro selo	36	Rockfall	Risk to village below rock outcrop, road to Ljuboten peak.
9.Jegunovce– Road to Ljuboten peak	31	Rock slide	Risk to block the road to Ljuboten peak.
10.Dolna Leshnica	27	Landslide	Possibility to block local road to Gorna Leshnica and houses.

Two possible remediation solutions were then developed for almost all of the analysed cases. Depending on each separate case, solutions were from various nature: setting up of a geotechnical monitoring system, planting vegetation and terracing of the terrain, gabion walls, support walls, rockfall bariers, dewatering. Appropriate stability analyses were performed to confirm the reliability of the proposed solutions. Finaly, a bill of quantity was prepared for all of the considered cases. Due to the character of the paper, these analyses are not presented here, while further below in the text details on the developed solution for the case of Gjermo landslide are provided.

For all of these landslides risk analyses by use of software RAMMS were preformed (Fig. 12), with scenarios of not undertaking and undertaking the possible designed remediation measures. This enabled performing the cost-benefit analyses that followed, as a subsequent logical step.

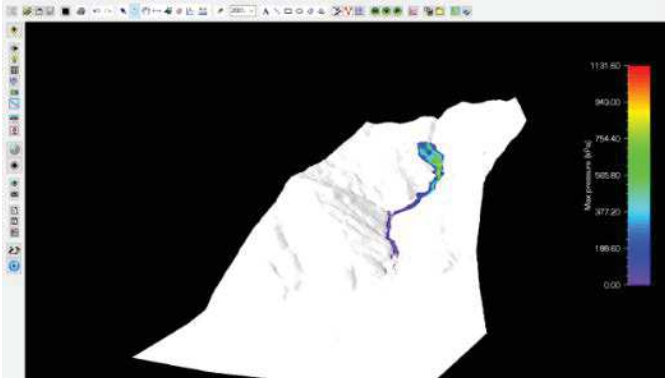


Figure 12 Example of RAMMS simulation for Gjermo landslide.

The risk analysis consisted of considering the following elements:

Landslide area and volume,
Expected run out distance,
Elements at risk (No of affected houses),
Total houses area,
No of houses in low landslide risk,
No of houses in medium landslide risk,
No of houses in high landslide risk,
Affected critical infrastructure,
Length of affected road infrastructure,
Directly affected population,
Total affected population.

After the simulations, Benefit-Cost Analysis (BCA) were performed. Main purpose of the benefit-cost analysis was to use the project cash flow forecasts to calculate suitable net return indicators. A particular emphasis was placed on three financial indicators:

Net Present Value (NPV),
Internal Rate of Return (IRR),
Benefit-Cost Ratio (B/C).

In the preparation of the BCA the following main input parameters and assumptions were used:

- reference time horizon of 25 years, including one “0-year” as project implementation period, while all other capital expenditures and benefits take place from year 1 onward;
- it is assumed that if no mitigation measures are applied at the sites (Do nothing scenario), at least one landslide event with assessed/modeled severity would occur over the 25-year period;
- all analyzed alternative technical solutions pertaining to the same landslide site, result in accomplishment of equal level of benefits (avoided damages and losses);
- discount rate of 3.5%;
- all costs are VAT free;
- all benefits and costs are valued at constant prices (2020);
- all calculations are in MKD denars.

A residual value at the end of the analyzed 25-year period was applied, as a proxy of the value of all subsequent project costs and benefits.

The categories of landslide mitigation benefits assessed in this analysis are:

- Avoided direct property damage (e.g. houses, buildings, roads, bridges, etc.);
- Avoided direct business interruption loss (e.g. damaged industrial and commercial facilities);
- Avoided infrastructure repair costs (as a consequence of the landslide event);
- Avoided environmental damage (increased flooding caused by the landslide);
- Avoided/reduced societal losses (monetary losses as a results of working population not being able to go to work for several days due to blocked roads, etc.).

The investment costs for implementation of the landslide mitigation efforts at the analyzed sites for all alternative solutions were estimated based on input from the engineering analysis as described above. Maintenance costs required for the continuous functioning of the applied technical landslide remediation solutions (infrastructure), including labor, equipment maintenance and repair, replacements, etc., were also considered.

The results showed that the analyzed landslide sites in CBA terms varied to a large extent (Tab. 9). However, except for two sites – Senokos-Lomnica and Jegunovce-Staro selo, which had negative NPV values and B/C values (below 1) –the interventions were in general economically viable, which confirmed the benefits that would accrue from the investments outweigh the costs incurred.

From the CBA it was concluded that the projects will generate sustained beneficial socio-economic impact, perceived above all in reduced risk of landslide damages and losses for the local population. Therefore, in following stage further developments of the landslide remediation activities were carried out. These consisted of more detailed field investigations, engineering geological mapping, drilling, geotechnical testing etc. Then advanced basic designs were developed for some of the landslides, while some are still in discussion and design phase. Further comments are presented below.

Table 9 Summary of BCA results.

Location	Landslide type	Investments (MKD) Alternatives		B/C ratio		NPV alternative	IRR alternative
		A1	A2	A1	A2		
Gjermo, Poroj river	Deep landslide	37.333.906		7.6		282.055.585	46%
Bozovce	Complex slide	5.862.142		32.3		246.039.306	230%
School in Pirok	Translatory sliding	10.003.635	4.632.188	1.5	2.8	13.234.122	20%
Jelovjane	Complex slide	997.100		27.7		50.656.946	277%
HPP in Pena watershed	Rock slide	5.078.880	4.636.880	1.5	1.5	3.035.098	8%
Senokos-Lomnica	Rockfall and translatory sliding	7.050.290	6.088.966	0.5	0.6	-2.268.303	0.1%
Jegunovce	Rock slide	5.002.250	10.126.990	2.4	1.0	8.782.042	15%
Jegunovce-Staro selo	Rockfall	5.036.200	4.688.450	0.6	0.6	-2.272.381	-1%
Dolna Leshnica	Landslide	2.326.250	3.819.115	1.8	1.2	2.241.677	10%
Settlement near Senokos	Complex slide	5.251.000	2.065.532	3.8	8.3	18.835.757	54%

Risk assesment methodology for Basic design

The first of the case studies presented in Tab. 9, the Germo landslide and Poroj river watershed, are presented here as an example of a Basic design study. To support the decisions for the design, the risk assessment methodology had to be upgraded on higher level.

The catchment area of Poroj River river is with highest altitude of 2376 m (Fig. 13). There are two villages in the catchment area: the village of Poroj down at the transition from mountain to plain area, as well as the village of Gjermo at an elevation of about 1070 m. In terms of rainfalls, the study area is characterized by the highest annual average rainfall in the country, in the range 600 - 1250 mm/year.

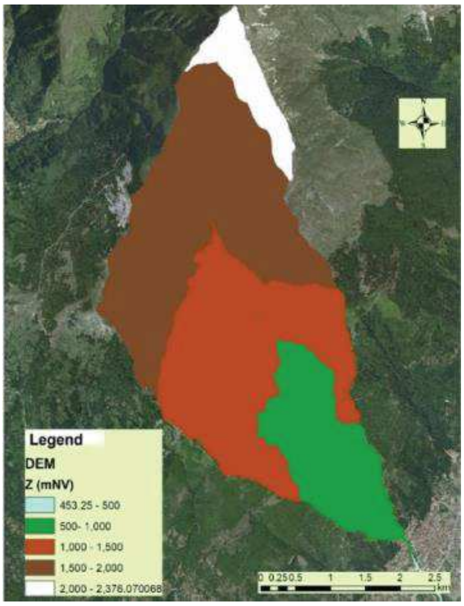


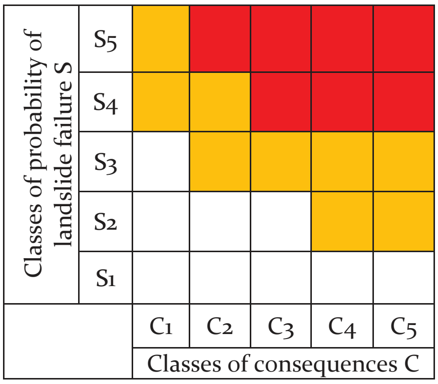
Figure 13 Elevation distribution of the Poroj river watershed.

One of the most important elements of the catchment area is the existence of deep landslide at the area of village Gjermo.

The applied methods related to holistic approach for risk assessment, so the following steps were performed:

- review of all previous data and knowledge for the study area;
- use of methods for detecting and characterizing the unstable phenomena;
- preparation of shallow landslide susceptibility (relative hazard) models;
- calculation of slope stability of Gjermo landslide and definition of probability of failure;
- assumptions of exposed elements at risk and possible consequences;
- preparation of risk map;
- suggestion of measures for further development of design documents for protection from flooding and landslides.

In this paper we only briefly present the component of risk map preparation. The risk assessment process consisted in the determination of the expected damages and losses from possible fast reactivation of landslide Gjermo. The simple methodology is used in forming of risk matrix, as a combination of 5*5 consequences (C) and probability of failure class (S), as presented in Fig.14.



Classes of probability of landslide failure S						
	S5	🟧	🟥	🟥	🟥	🟥
	S4	🟧	🟧	🟥	🟥	🟥
	S3	⬜	🟧	🟧	🟧	🟧
	S2	⬜	⬜	⬜	🟧	🟧
	S1	⬜	⬜	⬜	⬜	⬜
		C1	C2	C3	C4	C5
		Classes of consequences C				

Figure 14 Risk matrix used for preparation of risk map combining the classes of consequences (C) expressed as socio-economic costs and classes of probability of landslide failure (S); red colour is for areas with high landslide risk; orange for areas with medium landslide risk; white for areas with low landslide risk.

The consequence analysis considered the total affected population, possible damages on houses, possible number of people killed, possible damage on road infrastructure, several small Hydro Power Plants (HPP), environmental consequences, requirement of remediation, remedial costs etc. Landslide probability is assessed using variation of input parameters in some range, in order to see the effects on variation on the Safety Factor and Probability of Failure.

As a final product from all analyses, a simple risk map was prepared. In its preparation, adequate calculations of socio-economic costs and a comparative analysis of relevant probability and consequences classeswere carried out (Fig. 15).

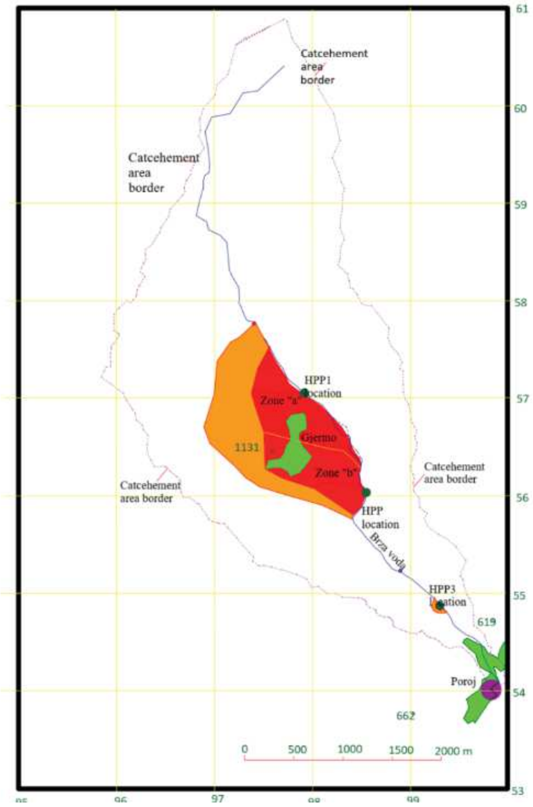


Figure 15 Risk map for Poroj River watershed. Legend: landslide risk 1.orange-medium, 2.red-high, 3.white-low, green colour-settlement area

Conclusions

Recent experiences dealing with the assessment of landslide susceptibility, hazard and risk in Macedonia are positive. Application of new tools and methods made it possible to raise the level of confidence in the produced susceptibility models on national level. By this time, it can be said that the main regions in which landslide problems are present and can be expected in the future are relatively well defined, and they should be a subject of more detailed analyses at a regional and watershed level. For some areas, sub-watershed analyses will be of tremendous importance. In this sense, we consider that the presented Polog projects can serve as a good starting guide for other regions and watersheds in the country. In order to create positive conditions for such analyses in systematic way, i.e for improved overall treatment of the landslide risk in general terms, certain actions should be taken on different levels. These should include capacity building of institutions, law changes, establishing of geohazards database, installing geotechnical monitoring systems for defined landslides, educating and attracting larger number of students in the field of landslides, awareness rising of the population and decision makers in general.

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