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5TH REGIONAL SYMPOSIUM ON LANDSLIDES
IN ADRIATIC–BALKAN REGION

Landslide Modelling & Applications

Proceedings of the 5th ReSyLAB

Editors

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Martina Vivoda Prodan
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Proceedings of the
5th Regional Symposium on Landslides
in the Adriatic-Balkan Region

Croatian Landslide Group
University of Rijeka, Faculty of Civil Engineering
University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering

Under the sponsorship of International Consortium on Landslides (ICL)

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Foreword

The Regional Symposium on Landslides in the Adriatic-Balkan Region (ReSyLAB), organized under the auspices of the International Consortium on Landslides (ICL), has reached its fifth edition. This is an important milestone for ICL and for its Adriatic-Balkan Network (ABN).

Ten years ago, the ICL has encouraged the establishment of thematic and regional networks in the framework of its ten-year strategic Plan. The ABN was promptly launched in 2012, gathering together scientists, researchers, engineers, professionals and decision-makers, from the Adriatic and Balkan region and elsewhere, concerned with landslide hazard and risk, their reduction and impact on society.

Today we can say that this has proved to be a successful strategy and the ABN is perhaps the best example of successful regional network. Since its foundation in the year 2012, the ABN has regularly organized its regional symposium every two years, dedicated to specific issues, in various countries of the Adriatic-Balkan area: Croatia, Serbia, Slovenia, Bosnia and Herzegovina and Croatia again.

Participation has gradually expanded to other countries, throughout Europe and elsewhere. This year the Symposium sees the participation of scientists from ten countries, providing an effective platform to achieve fruitful cooperation among landslide researchers.

The ReSyLAB represents a successful contribution to the Kyoto Landslide Commitment (KLC2020) launched by ICL in the year 2020 for the global promotion of understanding and reducing landslide disaster risk. The main purpose of the KLC2020 is to build a common platform for sharing ideas, good practices and policies with key actors and stakeholders concerned with landslide risk at the global level. One of the main priority actions of KLC2020 is to facilitate and assess progresses through the organization of meetings at the regional and national level, to take place in respective countries, in order to show deliveries and performances made towards the achievement of objectives for landslide risk reduction on a global scale.

The general theme of the 5th ReSyLAB is “Landslide Modelling & Applications”, which clearly shows the close interplay between scientific research and its application in the engineering practice and for supporting risk reduction policies.

For these reasons, I am convinced that the example of the ABN and the ReSyLAB should be valued and exported in other geographical contexts.

Nicola Casagli
President of the International Consortium on Landslides
Florence, Italy

Foreword

The International Consortium on Landslides (ICL) was established in January 2002 in Kyoto, Japan, to promote landslide research for the benefit of society and the environment, and capacity building, including education, notably in developing countries.

In January 2005, the second UN World Conference for Disaster Reduction was organized in Kobe, Japan. ICL, UNESCO, WMO, UNU, IAHS etc. jointly organized a thematic session on Landslides (IPL) and Floods (IFI). The Letter of Intent on Earth System Risk Analysis and Sustainable Disaster Management was agreed in the session and signed by global partners (ICL, UNESCO, WMO, FAO, UNU, UN-ISDR, ICSU, WFEO within 2005. Participants included Professors Ognjen Bonacci from Croatia, Kyoji Sassa, Hideaki Marui, and Kaoru Takara from Japan.

In January 2006, ICL and its global partners (UNESCO, WMO, FAO, UNU, UN-ISDR, ICSU, WFEO etc.) organized the Round Table Discussion for the IPL and adopted the 2006 Tokyo Action Plan strengthening research and learning on landslides and related earth system disasters for global risk preparedness. In 2007, Science and Technology Research Partnership for Sustainable Development (SATREPS) program to promote international joint research for global issues based on the needs of developing countries was founded by the Government of Japan. This programme was very timely to promote the 2006 Tokyo Action Plan. The Croatia-Japan Joint SATREPS Project "Risk identification and land-use planning for disaster mitigation of landslide and floods in Croatia" was proposed in 2007 and accepted as one of the initial SATREPS projects in 2008.

In order to support this SATREPS project, the Ministry of Foreign Affairs of Japan organized a workshop in Tokyo aiming at regional cooperation in South-Eastern Europe on disaster management by inviting Professors Željko Arbanas, Matjaž Mikoš, Snježana Mihalić, Biljana Abolmasov, Sabid Zekan and others from Adriatic-Balkan Region on 14-17 December 2010. This workshop contributed to the establishment of the Adriatic-Balkan Network of International Consortium on Landslides (ICL ABN) in January 2012 and also its biannual regional symposium; the 1st ReSyLAB in March 2013 in Zagreb (Croatia), the 2nd in May 2015 in Belgrade (Serbia), the 3rd in October 2017 in Ljubljana (Slovenia) and the 4th in October 2019 in Sarajevo (Bosnia and Herzegovina), and 5th in March 2022 in Rijeka (Croatia). The ICL has launched the Open Access Book Series "Progress in Landslide Research and Technology" for Kyoto Landslide Commitment 2020 which is published twice a year. I wish to invite all participants of this symposium to contribute articles to this new open access book series. The target readers of the book series are practitioners and other stakeholders who apply in practice the most advanced knowledge of science and technology for landslide disaster risk reduction. Articles must be written in a simplified way easily understandable by practitioners and stakeholders.

The Adriatic-Balkan Network of International Consortium on Landslides (ICL ABN) is the most successful network of the ICL and its biennial symposium and its publication contributed to boost the regional potentials for reducing landslide disaster risk. I am very grateful for this tremendous effort to organize the fifth regional symposium of the International Consortium on Landslides. I wish the Adriatic-Balkan network a very successful meeting and a very good publication.

Kyoji Sassa
Secretary-General of the International Consortium on Landslides and the Kyoto Landslide Commitment 2020
Editor-in-Chief of the Open Access Book Series of the ICL
Kyoto, Japan

Preface

The 5^{th} Regional Symposium on Landslides in Adriatic-Balkan Region (ReSyLAB) will be held in the year of two important anniversaries: 20 years of establishing of International Consortium on Landslides (ICL) and 10 years of establishing regional and thematic networks of ICL. The regional Adriatic-Balkan Network (ABN) is one of the most active networks and this 5^{th} ResyLab2015 will contribute to regional cooperation and widening the Network by the new members in the region. Just for reminder, the 1^{st} ReSyLAB was held in Zagreb, Croatia, 2013; 2^{nd} ReSyLAB in Belgrade, Serbia; 3^{rd} ReSyLAB in Ljubljana, Slovenia and 4^{th} ReSyLAB in Sarajevo, Bosnia and Herzegovina. The 5^{th} ReSyLAB will be held three years after the last Symposium, disrupting the biannual schedule due to Covid-19 pandemic and will be held as hybrid event, but we believe that this will not diminish the significance of this Symposium.

This book contains peer-reviewed papers that will be presented at the 5^{th} Regional Symposium on Landslides in the Adriatic-Balkan Region entitled “Landslide Modelling & Applications”. The Symposium will be held in Rijeka, Croatia from March 23^{th} to 26^{th}, 2022. A wide range of landslide topics are presented in the Symposium sessions that include landslide monitoring, landslide investigation, landslide mapping, landslide susceptibility zonation, laboratory testing, physical and numerical modelling of landslides and landslide case studies. This collection of papers is beneficial to practitioners, researchers and other professionals dealing with landsides. The proceedings reflect the ongoing response of researchers and practitioners from 10 countries from the region and around the world. Unfortunately, the Covid-19 pandemic situation disables landslide scientists from Japan that were present at all previous ReSyLABs, to join us in Rijeka.

We would like to thank all authors and participants for sharing their ideas and research results in the area of landslide science and practice. We wish to acknowledge the help from all the reviewers in advising and refining the contributions to their final version published in this book.

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Shallow landslide susceptibility assessment for the Polog region (North Macedonia)

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Abstract This paper presents the results of a shallow landslide susceptibility assessment for the Polog region in Macedonia. The geomorphological setting of the Polog study area, the complex geology, and the specific hydro-meteorological conditions make this region one of the most landslide susceptible areas in the country. According to the available landslide inventory for the Polog region, 21% of landslides are classified as shallow landslides. The infinite slope stability method was used for shallow landslide susceptibility assessment over the study area. This is a simple but very useful model for planar sliding, which assumes that landslides are infinitely long but have a shallow sliding surface parallel to the ground surface. Due to the complexity of the analyzed phenomenon, the variability of influential factors, and uncertainty in parameters. Considering that this is a regional-scale analysis, selecting relevant parameters was very challenging. In order to get a sense of the susceptibility to shallow landslides, several possible scenarios were analyzed: with two groundwater levels (0.35 and 0.70 m of soil depth) and minimum and average values of geotechnical parameters of the lithological units. The obtained susceptibility maps indicate that the most prone zones for shallow landslide occurrences match with most landslides from the inventory. However, results are limited regarding the reliability of input data about soil thickness, the relevance of geotechnical parameters of soils, and the groundwater levels. In order to get more advanced analysis on a watershed scale, it is recommended to carry out more detailed geotechnical investigations and tests, monitoring of rainfalls, monitoring of surface water regimes, and groundwater levels.

Keywords shallow landslide, assessment, susceptibility map, Polog region

Introduction

Shallow landslides are typically translational sliding movements of soil material, either earth and/or debris, characterized by a pre-defined, planar sliding surface in a depth of up to 2.0 m (Cruden & Varnes 1996; Hungr et al. 2014). In addition, according to the Swiss recommendations (BWW, BRP, BUWAL 1997), landslides are classified as “shallow” if they are less than 2.0 m deep.

The shallow landslides are particularly destructive phenomena and lead to considerable loss of human life and property damage (Postance et al. 2017). For example, the catastrophic translational landslides, which occurred at Mt. Umyeon in July 2011, following nearly 49.5 mm/h of heavy rainfall, resulted in 18 deaths and more than 20 injuries in the central Seoul metropolitan area, along with tens of millions of dollars of residential and infrastructural damage (Lee and Park 2015). Another example is the event in October 2011, when the eastern Liguria (Vara Valley and Cinque Terre area) and northwestern Tuscany (Magra Valley) were affected by an extreme rainstorm with almost 600 mm/24 h that caused floods, thousands of shallow landslides, 13 casualties and damage to villages and infrastructure (Bartelletti et al. 2017). During 24–26 October 2010, an intense rainstorm during which the total precipitation in 3 days was around 250 mm affected a part of Tuscany and triggered 50 reported shallow landslides (Tofani et al. 2017). Presented examples lead to rainfall as the major trigger of shallow landslides.

The territory of Macedonia is severely and frequently affected by landslides, which are responsible for direct and indirect impacts on the structures, infrastructure, and population (Peshevski et al. 2017; Haque et al. 2016). A study on landslide distribution in the country has shown that the northwest part of the country, more precisely the Polog region, is the most prone to landslide processes, primarily triggered by heavy rainfalls and favoured by its geological, morphological, and tectonic setting (Peshevski et al. 2019). Therefore, appropriate risk management is urgently needed for this part of the country. Landslide susceptibility hazard and risk assessments are deemed necessary as well. For the Polog study area, preliminary landslide susceptibility studies were performed by Peshevski (2015). Some recent improvements were obtained by Peshevski et al. (2019), who presented a heuristic approach for preliminary regional landslide susceptibility assessment using a limited amount of data.

The main objective of this work was to develop a shallow landslide susceptibility map for the Polog region, considering that according to the landslide inventory, 21%

of the landslides in the region are confirmed in the class of shallow landslides (Nedelkovska et al. 2020).

Study area

The Polog region is located in the northwest part of Macedonia (Fig. 1). It is characterized by mountainous topography and dense hydrographic network comprising torrential streams and rivers and high population density along the Shar Planina Range and Vardar River. From almost all geological periods, geological formations can be found here: from the Cambrian to the Quaternary period, characterized by different types of igneous, sedimentary, and metamorphic rocks. The topographic relief of the Polog study area ranges from 265 to 2,700 m above the sea level with a complex morphology that is influenced by the tectonic and geologic conditions.

The Polog region has 3 types of climate:

- Hot continental at altitude of 600–900m a.s.l.
- Cold continental climate at altitude of 900-1100m a.s.l.
- Alpine mountainous climate at altitude over 2250m a.s.l.

Summers are warm and partly humid, winters are cold and snowy, whereas springs and autumns are characterized by rainfall. The study area has the highest annual average amount of rainfall in the country (Ilijovski 2013); it ranges from 600 mm/year to more than 1,250 mm/year.

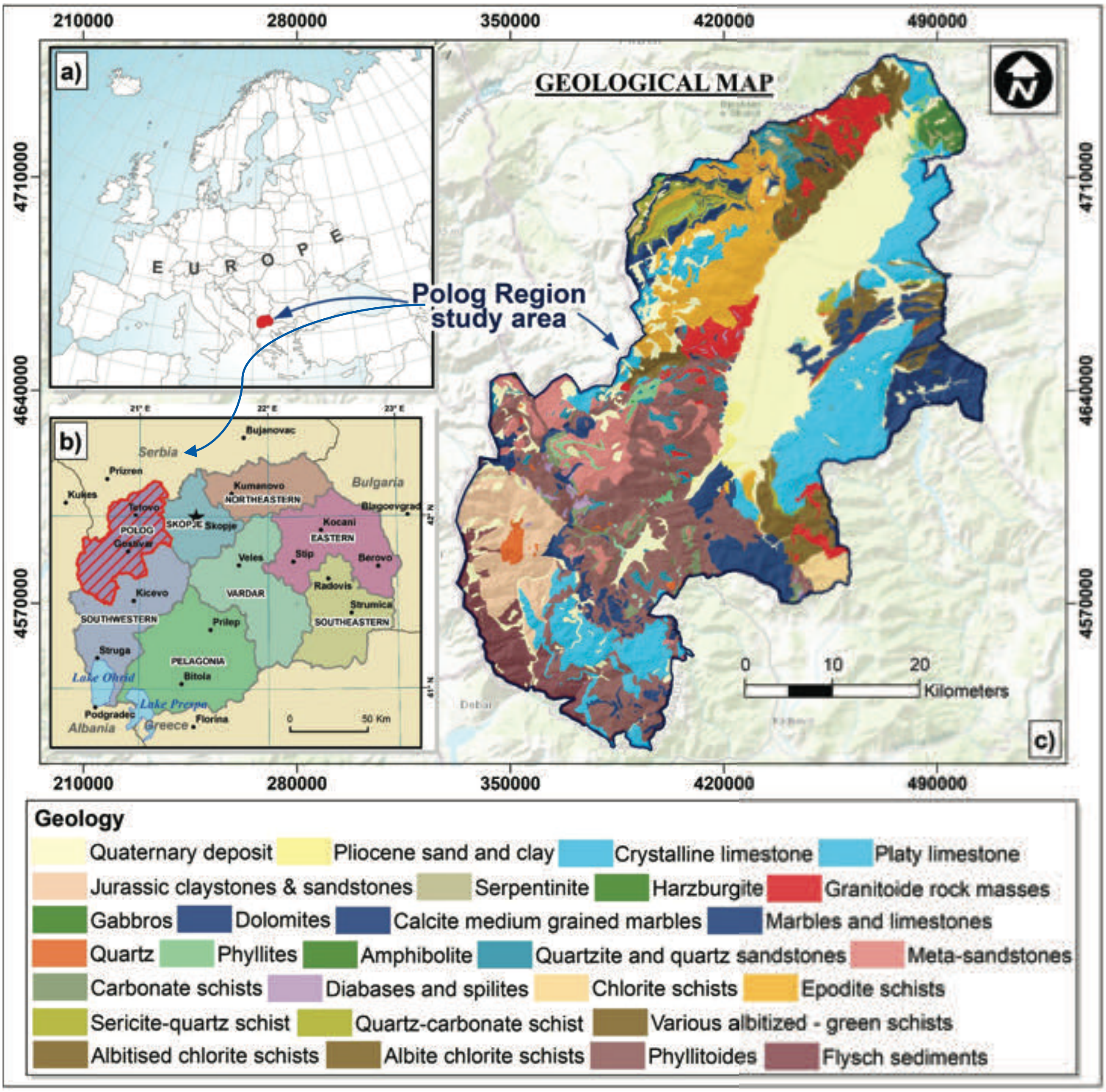

Figure 1 Polog region (North Macedonia) study area: a) location of North Macedonia in Europe; b) location of the Polog region in North Macedonia; c) geological map. (Jovanovski et al. 2021 – in print)

Historically, this region has been exposed to extreme weather conditions and frequent flooding. Numerous of devastating flash floods happened in 2015 and 2016 with huge human and economic losses (Peshevski et al. 2017). The losses were caused by torrential floods and mass flows and inappropriate land-use, such as construction in flood plains, rapid illegal building in hazard zones and constricted river courses, and increased erosion due to logging in forests. All these mentioned artificial changes alter the hydrological processes and regimes, increase the risk of floods and associated effects, such as landslides, rockfalls, mudflows, and generate other unfavorable engineering-geological processes. The effects of such activities are combined with climate changes as well, and related increases in the frequency of hydrological extremes.

Methodology

A variety of methods have been developed for slope stability analysis on a regional scale (e.g. Montgomery and Dietrich 1994; van Westen and Terlien 1996; Borga et al. 2002; Saha et al. 2002; Ray 2008). The infinite slope method by Skempton and DeLory (1957) is a simple but very useful model for shallow sliding on a slip surface parallel to the slope. The infinite slope model assumes that landslides are infinitely long but have the shallow sliding surface, and therefore, this model is appropriate for the analysis of shallow landslides. The following equation was used for calculation of the safety factor F in this study, which has also been used by several other researchers (van Westen and Terlien 1996; Acharya et al. 2006; Ray and Smedt 2008):

$$F = \frac{C_s + C_r}{\gamma_e D \sin\theta} + (1 - m\frac{\gamma_w}{\gamma_e})\frac{\tan\varphi}{\tan\theta} \qquad [1]$$

wherein: F is the slope stability factor (adimensional), Cs is the effective soil cohesion (kN/m²), Cr is the root cohesion (kN/m²), D is the depth of the soil above the sliding surface (m), φ is friction angle of the soil (°), θ is the slope angle (°), γ_w is the unit weight of water (kN/m³), γ_e is the effective unit weight of the soil (kN/m³), and m is wetness index. The effective unit weight is defined by Van Westen and Terlien (1996), as:

$$\gamma_e = \frac{q\cos\theta}{D} + (1-m)\gamma_d + m\gamma_s \qquad [2]$$

wherein: γ_d is the unit weight of the dry soil (kN/m³),γ_s is the unit weight (kN/m³) of the saturated soil, and q is any additional load on the soil surface (kN/m²).

The slope geometry and the different variables in the above equations are shown in Fig. 2, adapted from Skempton and DeLory (1957).

The cohesion, dry and saturated unit weight and the friction angle of the soil (Tab. 1) were adopted from the available 1:200 000 scale engineering-geological map of Macedonia (Geological survey Skopje, 1977).

The slope angle was derived from the digital elevation model of the terrain (DEM), with grid size of 10 x 10 m.

The approach proposed by Saulnier et al. (1997) was used, which expresses the depth of the soil above the sliding surface solely as a function of local elevation and has the form:

$$D = h_{max} - \frac{z_i - z_{min}}{z_{max} - z_{min}}(h_{max} - h_{min}) \qquad [3]$$

wherein: h_i is soil depth computed at pixel i, h_{max} and h_{min} are the maximum and minimum values of the soil depth in the area, z_i is the local value of elevation at pixel *i*, while z_{max} and z_{min} are the maximum and minimum values of elevation encountered in the test area.

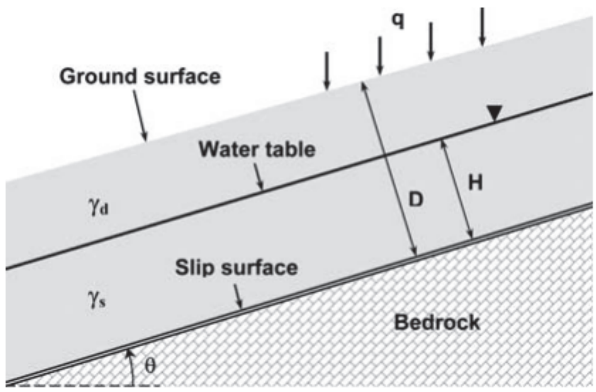

Figure 2Schematic representation of the infinite slope method depicting the different parameters and variables (adapted from Skempton & DeLory 1957).

Table 1 Geotechnical parameters for the lithological units (Engineering-geological map of Macedonia, Geological survey Skopje, 1977).

Lithological unit	Unit weight of dry soil γ_d [kN/m³]		Unit weight of saturated soil γ_s[kN/m³]		Cohesion Cs [kN/m²]		Angle of internal friction φ [°]	
	min	max	Min	max	min	max	min	max
Alluvial sediments	17.0	18.6	20.0	21.6	0.0	16.0	20.0	36.0
Proluvial sediments	15.5	16.5	18.5	19.5	1.0	22.0	24.0	32.0
Diluvial and eluvial -diluvial sediments	16.0	18.5	19.0	21.5	10.0	30.0	25.0	29.0
Glacial and fluvioglacial sediments	14.0	16.0	17.0	19.0	8.0	20.0	22.0	32.0
Lacustrine sandy-clayey sediments	15.5	18.0	18.5	21.0	13.0	28.0	21.0	34.0

Many researchers have estimated the value of root cohesion for different vegetation species growing in different environments that have been summarized in Chok et al. (2015). Considering the proposed values, as well as the forest cover information and land-use data for the Polog region from Corine Land Cover (CLC 2018) inventory, the representative values of root cohesion are presented in Tab. 2.

The parameter wetness index (m) theoretically expresses the relative position of the water table H/D, where H is the saturated thickness of the soil above the failure plain and D is the total depth of the soil above the failure plain (Ray and Smedt 2008). Since the available data for calculating the wetness index were very limited, two different scenarios were assumed of this value; namely, 0.35 and 0.70.

Since all input parameters were defined, the safety factor was calculated using the equations explained above. Considering that this is a regional scale geospatial analysis, the calculations are performed in GIS environment, using the software. Based on the obtained values for the safety factor, different stability classes (Tab. 3) were adopted according to Ray & Smedt 2008.

Table 2 Root cohesion for land-use types and species in the Polog region (adapted from Chok et al., 2015).

No.	Land-use type	Cr [kN/m^2]
1	Discontinuous urban fabric	0.0
2	Industrial or commercial units	0.0
3	Mineral extraction sites	0.0
4	Non-irrigated arable land	0.0
5	Fruit trees and berry plantations	2.0
6	Pastures	2.0
7	Complex cultivation patterns	1.5
8	Land principally occupied by agriculture, with significant areas of natural vegetation	2.0
9	Broad-leaved forest	7.0
10	Coniferous forest	10.0
11	Mixed forest	2.0
12	Natural grasslands	0.0
13	Moors and heathland	2.0
14	Sclerophyllous vegetation	2.0
15	Transitional woodland-shrub	2.0
16	Sparsely vegetated areas	0.0
17	Burnt areas	0.0

Table 3 Adopted slope stability classes (according to Ray and Smedt, 2008).

Safety factor	Slope stability class
F > 1.5	Stable
1.25 < F < 1.5	Moderately stable
1 < F < 1.25	Quasi stable
F < 1	Unstable

Results and discussion

Several scenarios were analyzed for the Polog region, to get landslide hazard/susceptibility assessment in two different groundwater levels (0.35 and 0.70 of soil depth) and by taking into consideration the minimum and average values of the geotechnical strength parameters of the lithological units. Fig. 3 shows the obtained shallow landslide susceptibility maps.

The obtained susceptibility maps show that the most shallow landslide-prone zones match with most landslides from the inventory. In addition, the results suggest that shallow landslides are more likely to occur in the northernmost watersheds than in southern ones. If we consider the hypsometric position of the susceptibility zones in all performed models, it is obvious that most landslides are expected to occur in the transition zone of the mountainous terrain towards the valley. Again, the northernmost part of the region is an exception because, therein, shallow landslides should be expected throughout the entire watersheds.

Conclusions

The obtained results are limited in regards to the precision of the data related to soil thickness and relatively low number of data (and unevenly distributed sampling points in the region) for the geotechnical parameters of soils, as well as the groundwater levels. All these limitations should be overcome in more advanced studies on sub/watershed scales.

Therefore, it is considered that the proposed approach helps in the preliminary zonation of shallow landslide susceptibility of the region. In order to perform a more detailed analysis on the coarser scale, and with a higher level of confidence in results, much more work should be performed on selected watersheds within the region. The exportation of the same procedure to other regions of Macedonia is envisaged in order to foster the improvement of awareness of authorities for the landslide hazards in the country context.

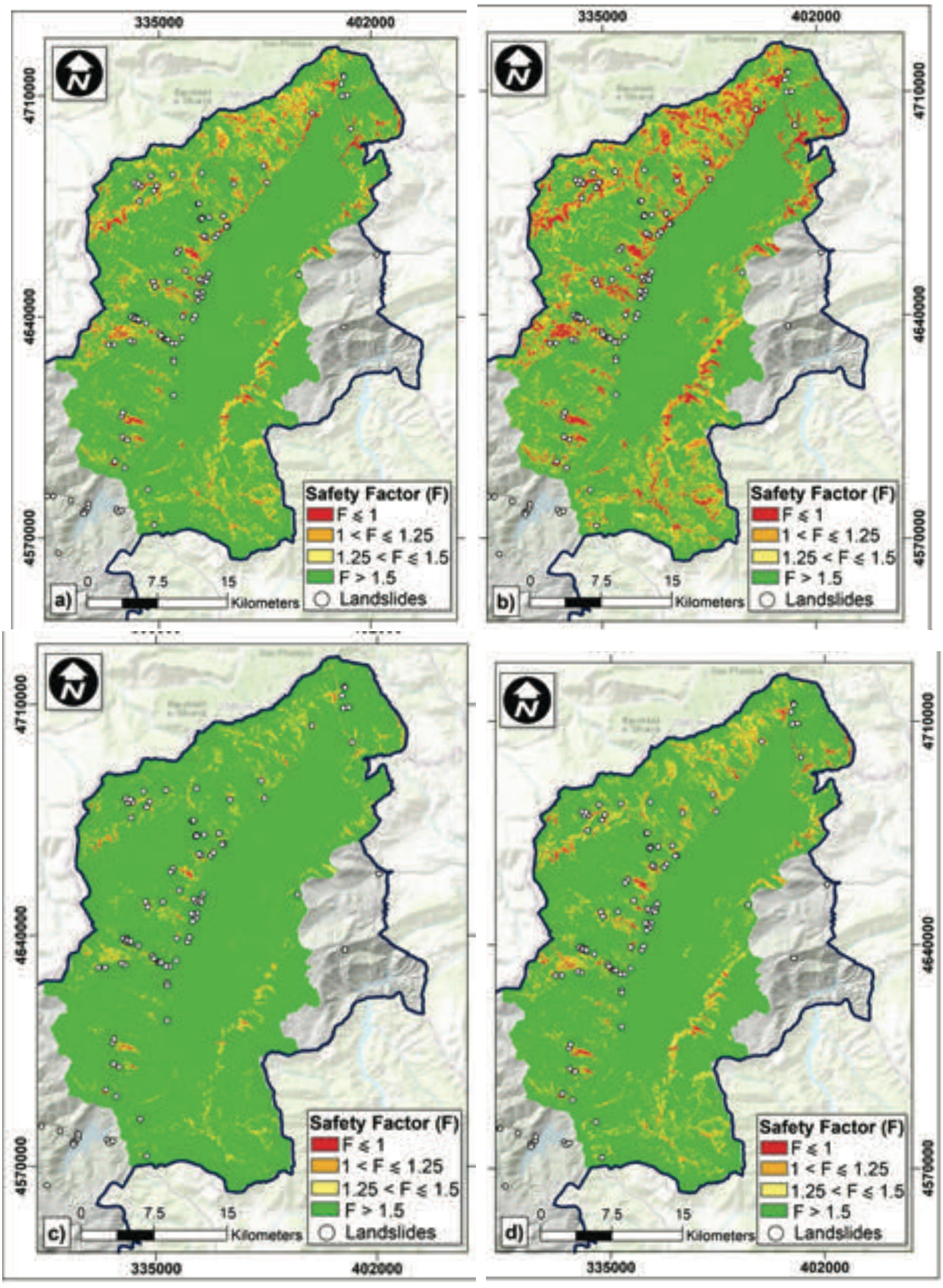

Figure 3 Shallow landslide susceptibility models for Polog Region: minimum values (Tab. 1) of the geotechnical parameters with a) m=0.35 and b) m=0.70; average values (Tab. 1) of the geotechnical parameters with c) m=0.35 and d) m=0.70.

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