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Proceedings of the 2nd Regional Symposium on LANDSLIDES in the Adriatic - Balkan Region

14-16th May 2015 Belgrade - Serbia

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Proceedings of the 2nd Regional Symposium on LANDSLIDES in the Adriatic-Balkan Region, ReSyLAB, Belgrade 14-16 May 2015

University of Belgrade, Faculty of Mining and Geology
May 2017

PUBLISHER:
University of Belgrade, Faculty of Mining and Geology

FOR PUBLISHER:
Prof. Dušan Polomčić, Dean

COVER DESIGN:
Srđan Krstić

PRINTED BY:
Sapient Graphics

ISSUED:
250 Copies

FRONT COVER PHOTO:
Landslide Leva Reka, Kraljevo, Serbia (by Biljana Abolmasov)

BACK COVER PHOTO:
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CIP - Каталогизација у публикацији
Народна библиотека Србије, Београд

551.4.037(082)
624.131.53(082)
624.138(082)

REGIONAL Symposium on Landslides in the Adriatic-Balkan Region (2 ; 2015 ; Beograd)
Proceedings of the 2nd Regional Symposium on Landslides in the Adriatic-Balkan Region, RESYLAB, Belgrade 14-16 May 2015 [Elektronski izvor] ; editors Biljana Abolmasov, Miloš Marjanović, Uroš Đurić / editors Biljana Abolmasov, Miloš Marjanović, Uroš Đurić. - Belgrade : University of Belgrade, Faculty of Mining and Geology, 2017 (Belgrade : Sapient Graphics). - 1 elektronski optički disk (CD-ROM) ; 12 cm

Sistemski zahtevi: Nisu navedeni. - Tiraž 250. - Invited lecturer: str. 256-261. - Nasl. sa naslovnog ekrana. - Bibliografija uz svaki rad. - Registar.

ISBN 978-86-7352-296-8

a) Клизишта - Зборници b) Косине - Зборници
COBISS.SR-ID 234417420

Landslide events in Serbia in May 2014: An Overview

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Abstract In this paper we overview the landsliding aftermath caused by a 100-year rainfall maximum in Western and Central Serbia in mid May 2014, by applying various spatial analyses. The extreme character of the event is well depicted throughout the damage and cost estimations and explored for their spatial patterns and relations to other characteristics, such as landslide typology, metrics (surface area, volume, depth), rock types, etc. Analyses are also performed on administrative level, per municipality and bigger settlements, as well as road communications, to enhance the overview of economic and social effects of the event. We herein exploit only reported landslides and their effects, while the realistic estimates are only discussed. Shallow slip-slides were the most dominant, although considerable number of flows, which are uncommon for climatic and environmental conditions in Serbia, was also reported. As a result, extreme landsliding, directly affected 34 municipalities, wherein municipalities of Čukarica, Zvezdara, Mionica, Krupanj and Loznica had the highest abundance of landslides per municipality area. Analysis of landslide buffers zones suggest that significant amount of road communications was heavily affected. Most importantly, the buffer shows high percentage of affecting the population for several landslides. These results are valuable supplements to the general estimates performed during the RNA (Recovery Needs assessment) reporting stage.

Keywords rainfall, landslides, Cyclone Tamara, spatial analysis

Introduction

In climate changing conditions, the Balkan region is witnessing increased landsilidng activity in the past decade. Precipitation patterns are clustered (Bajat et al. 2013), whereas wet areas receive even more precipitation and drying areas even less (Klein Tank and Können 2003). Therefore, rainfall-triggered landslides are meeting necessary conditions for becoming more abundant. Unfortunately, there are no systematic overviews of landslide events in Serbia. Existing inventories are missing temporal dimension, as they all only compile reported historic events, therefore failing to serve as good support for event-driven analyses. This is especially important in the cases of extreme events, when massive landsliding exceeds the boundaries of expected, and leads to uncommon mechanisms at unprecedented rates. One such episode stroke Serbia during the extreme rainfall event, that affected the entire Balkan region, in mid May 2014.

Heavy precipitation peaked on May 14-16, as Cyclone Tamara swept the region in West-East direction, passing through Croatia, Bosnia and Herzegovina and Serbia. The rainfall locally exceeded monthly rates up to 4 times in these 3 days. In Western and Central Serbia, daily precipitation on May 15 exceeded the normal average of the entire month (RHMSS 2014). Several rain gauges in Belgrade, Valjevo and Loznica, registered over 100 mm/day, which is the highest daily precipitation total ever recorded in Serbia, since the begining of recording in 1888. The rainfall event was concentrated on the Sava River catchment and partly the Velika Morava River system. The first torrential floods appeared in Bosnia-Herzegovina, and Western and Central Serbia, while the the flood wave started within the following days along the Sava River. The first landslides (debris/earthflows) occurred on May 15, and early estimates of their number were in the order of hundreds (WorkGroup2 2014, UNDAC 2014).

Landsliding event and aftermath overview

Such a massive event required a quick response and immediate mapping and assessment campaigns. Geological surveys of Serbia and domestic/foreign experts, as well as international working groups (the European Union, the United Nations and the World Bank) have initialized inventorying on a municipality level. Initially standardized, the landslide reports were to contain all the necessary pieces of information: location, metrics, type, mechanism, activation date, previous activity stage, estimated damage/cost and prognostic cross-sections. After further harmonization of location and classification standards, these reports were used in the spatial analyses.

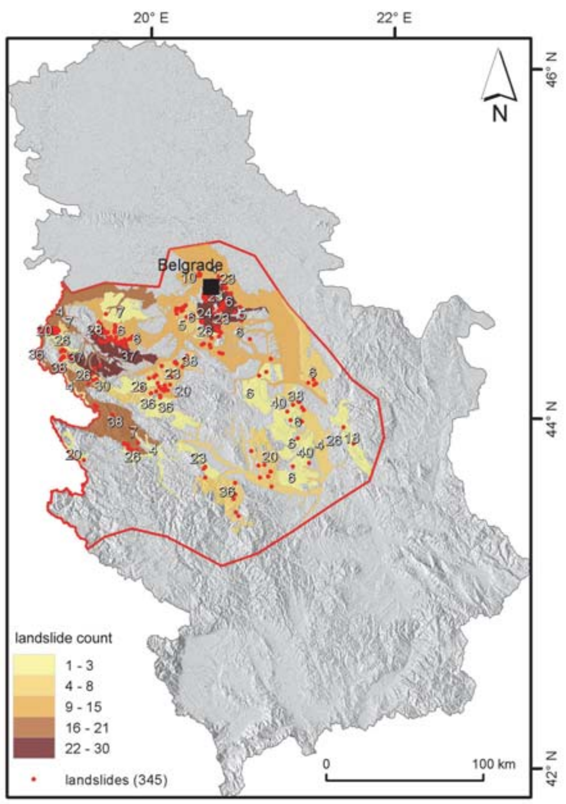

Figure 1 Landslides following the May 2014 rainfall and relevant Engineering Geological units (rock types exampled in Table 1 are here given by their ID labels in white). The tone of each unit depends on the landslide count (intense tones have more landslides). Encircled area is the area of interest chosen for the analysis.

The total of (345) landslides were reported (Fig. 1), including: 34 debris flows, 33 debris slides, 34 earthflows, 223 earthslides, and 8 rockfalls, while 37 instances remained unclassified (Fig. 2a,b). Earth slides were the largest in volume (also the biggest in area and the deepest) of all landslide types, as 59 of 70 landslides that were larger than 10000 m^3 belong to this type (Fig. 2a). Majority of the landslides (80% or 277/345) were relatively shallow (<5 m). All reported landslides are identified as entirely new, caused by the May 2014 rainfall, but this finding is arguable due to the absence of reliable activation date estimates in many reports. The most damaging were the earthslides and debrisflows (Fig. 2b).

Relative damage was not equally distributed: 108 high, 84 low, 115 medium, but it is well correlated with landslide volumes (Fig. 2c). In comparison to the estimated remediation cost, relative damage was locally overestimated in some cases, mostly in the Belgrade City area where landslides depicted in red have high relative damage estimates, while actual costs were estimated to reasonably lower values (Fig. 2d). The opposite, underestimated costs are apparent usually in relation to earthslides, which is understandable given that these can be considered uncommon in normal mass movement events. Total remediation cost estimates range up to RSD 300 million per individual landslides, which is equivalent to EUR 2.5 million.

Table 1 Engineering Geological units enlisting rock types that hosted the most of the landslides (count>20).

ID	rock type	count
6	sand, clay, gravel (alluvial-proluvial complex)	30
20	Cretaceous flysch	26
37	Paleozoic flysch complex	24
24	Cretaceous flysch-like complex	23
38	Paleozoic low-crystaline schist	21

For the purpose of rock type relations to landslides, we overlaid the landslide data to archived Engineering Geological Map 1:500000 (Čubrilović 1969). Regarding these Engineering Geological controls, it is evident that landslides dominated in certain rock types, primarily proluvial complexes, which is directly related to debrisflows initiation. Weathered flysch-like complexes (labeled 20, 37, and 24; mostly composed of alternating conglomerate-sandstone, marl, and shale) and weathered low-crystalline Paleozoic schists (labeled 38) expectedly hosted many reported landslides (Fig. 1). Saturating their thick detritus was critical for appearance of shallow landslides, which were the most abundant.

Socio-economic elements overview

We further analyzed municipalities that were affected by landsliding, i.e. those that had at least one landslide occurrence over their territory.

The following municipalities suffered the greatest damage to landsliding (Fig. 3a): Kraljevo, Mionica Koceljeva, and Osečina, followed by Svilajnac, Ljubovija, Užice, Jagodina, Paraćin, etc. However, significant number of reported instances did not include the total remediation cost estimates (30% or 106/345). This is likely the reason why these estimates are not that well correlated with the actual landslide abundance or relative landslide area - the total area of all landslides in a municipality divided by the size of that municipality (Fig. 3b). The latter is probably the most realistic estimate (than for instance the landslide count) as it normalizes the surface area of landslide by the area of the municipality. It is therefore, more justified to say that the landsliding hotspots and the hotspots of the economic impact due to landsliding where concentrated on municipalities in Western Serbia: Loznica, Krupanj, and Mionica. Relations between the relative damage and landslide volume also support this view (Fig. 2c).

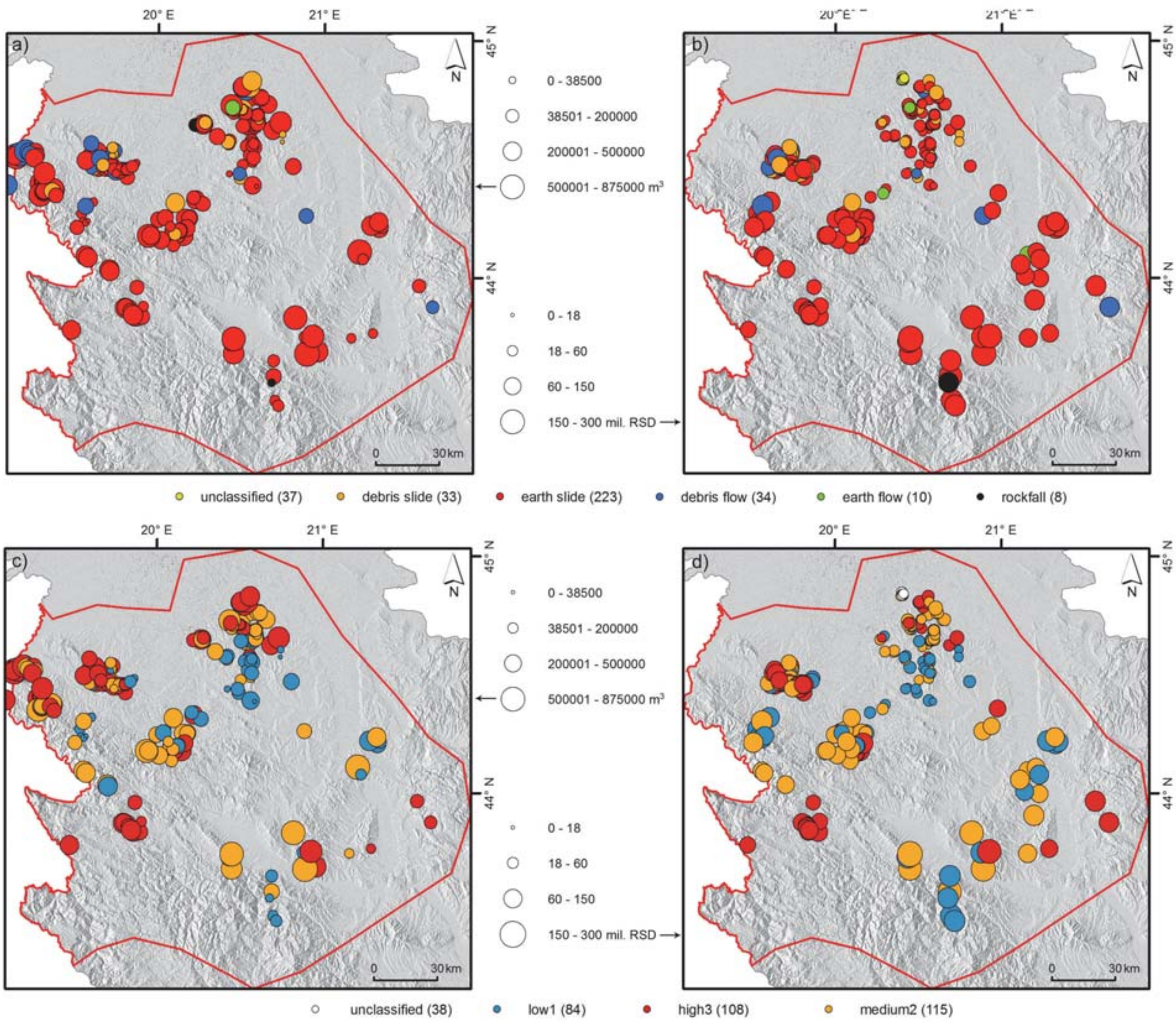

Figure 2 Scaled landslide instances plots: a) landslide types vs. volume, b) landslide types vs. estimated remediation costs, c) estimated relative damage vs. landslide volume, d) estimated relative damage vs. estimated remediation costs.

We further analyzed the socio-economic influence of the landslide buffer zone on the road communication infrastructure and settlements. Assuming the buffer zone around each individual landslide, we acknowledged the critical radius of 10km (the greatest reported landslide length). Overlaying the road network to the landslide buffer gives a preliminary insight into the affected infrastructure (Fig. 3c). Summing the effect of landslide vicinity over these linear features leaves defines the roads closest to landslides as the most affected. Only the road network in the affected municipalities was observed. According to these calculations, around 975 km of the highest rank roads (national and regional) falls within the most critical class (<1km away from the landslide). We followed the same analogy for depicting the most affected larger settlements, i.e. cities. Overlaying (Fig. 3c) suggests that Loznica, Belgrade, Užice, Krupanj remain the hotspots in terms of endangered settlements (given in gradual tones from darker to lighter, depending on the value of the total landslide vicinity).

Finally, we estimated the affected population based on the realistic population distribution from 2006. The dasymetric map at 100 m resolution is now available for all municipalities in Serbia for free at: http://osgl.grf.bg.ac.rs/. Consistently with the preceding analyses we used only affected municipalities for overlaying the landslide data with dasymetric data (relative population density at 0-100% range). By extracting dasymetric values per each landslide, we were able to scale landslide instances plot (Fig. 3d). The results show that around 20% of population was directly or indirectly influenced by landslides (superponing to other economic and ifrastructure issues elaborated before). Fortunately, small percentage (around 4%) falls on population that is dense (more than 50% of the total population of each municipality). The critical buffer of 10 km however, split the population to 70-30% split, wherein 70% of considered population remains in the wider critical zone. These results confirmed that wider areas of Loznica, Belgrade, Užice, Krupanj are true hotspots of socio-economic effects of the May 2014 landslide events.

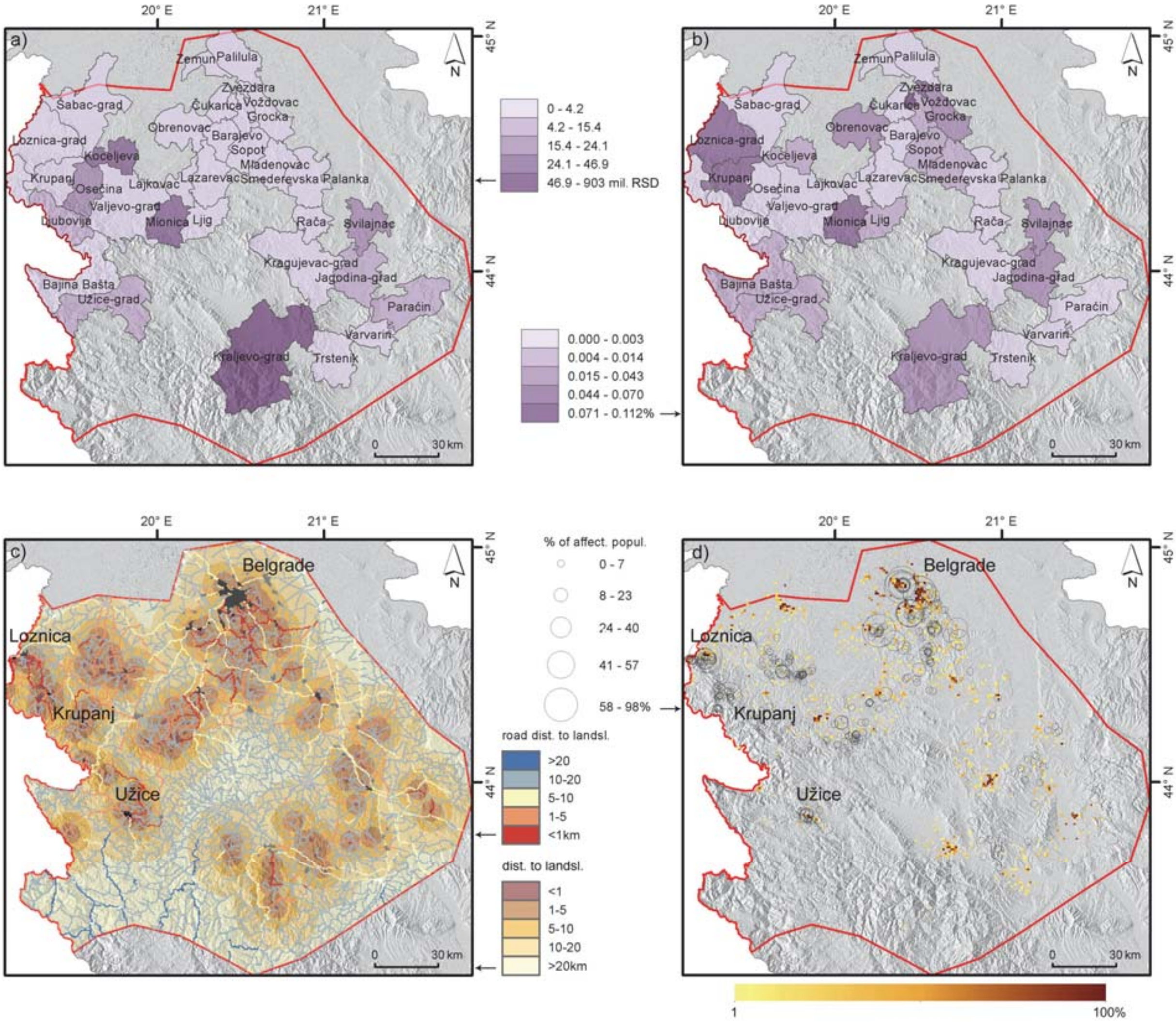

Figure 3 Choropleths and scaled plots: a) Municipality total remediation costs (darker tones depict higher costs), b) relative landslide area (landslide area in comparison to the municipality area), c) affected road communications and cities in vicinity of landslides, d) impact on realistic population distribution (relative density in % per pixel is given as the scale for individual landslides effects on population).

Conclusions

This overview of the landslide events takes into account spatial patterns and relationships of landslide characteristics and its socio-economic aftermath. To the best of our knowledge, it is a unique summary of the event. The scale, typology and metrics of the landslide events are summarized and some particular relations discovered, such as typology vs. metrics and costs, and relative damage vs. metrics and costs. The second part of the research was concentrated on socio-economic effects upon administrative entities, i.e. municipalities, cities, population and road infrastructures. Some interesting relations reveal the landsliding hotspots not only event-wise, but also cost-wise and in respect to other socio-economic influences. It is finally important to emphasize that all the analyses were based on reported data, but we have found enough evidence to believe that the actual landslidng (unreported occurrences) was much more abundant and widespread. Reported occurrences probably involved only the most threatening examples, wherein some property or infrastructure was damaged. It is necessary to further analyze the event in greater detail, i.e. to endeavor detailed and more general landslide inventorying of the entire affected area to properly characterize the May 2014 event and relate it to past and future events. Our current hypothesis, based only on reported landslides, already suggests that it was an extreme event in terms of scale, and typology of occurrences, as well as its socio-economic impacts.

Acknowledgements

This work was supported by the project of TUM University Foundation Fellowship and the project of Ministry of Science of the Republic of Serbia (TR 36009). Hereby we thank Geological Survey of for leaving their data at disposal. A special thanks goes to Vukašin Vučević from Ministry of Mining and Energy of Serbia, and Jelka Krušić and Dragana Petrović from University of Belgrade, Faculty of Mining and Geology for helping us retrieve the analogue data.

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