Engineering Geology 232 (2018) 147–159

Contents lists available at ScienceDirect

Engineering Geology

journal homepage: www.elsevier.com/locate/enggeo

The rainfall-induced landsliding in Western Serbia: A temporal prediction approach using Decision Tree technique

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ARTICLE INFO

Keywords:
Landslides
Rainfall threshold
Decision Tree algorithm
Serbia
Bosnia and Herzegovina

ABSTRACT

This paper focuses on modeling rainfall-induced massive landsliding in the Western Serbia in the 2001–2014 period. The motivation for conducting the study was the rainfall-induced flooding and landsliding that took place across most of the Serbia and Bosnia and Herzegovina in May 2014, and had devastating effects, including human casualties, and destruction of natural and urban environment. In the first part of the study, the general analysis was conducted. It includes a wide area (70,000 km^2), wherein spatial rainfall patterns were identified using the monthly rainfall data from the 2001–2014. Areas that have higher monthly precipitation than the baseline monthly rainfall (1961–90) were outlined. One location within these zones was chosen as critical – Loznica in Western Serbia. The area of Loznica was further examined: comparison between local daily rainfall and local landslide events recorded in 2001–2014; correlation between specific rainfall conditions, i.e. cumulative rainfall for different time windows, and the landsliding events in the specified period; identification of additional non-reported rainfall events that were potentially responsible for landsliding; analyses of the rainfall thresholds and temporal rainfall distribution. The Decision Tree algorithm was used to identify rainfall conditions that triggered landslides in the specified period. It was hypothesized that short-term rainfall has less influence on massive landsliding than the mid/long-term rainfall. Unlike other black-box techniques, Decision Tree-based modeling gives a good insight into the thresholding process. Namely, it was possible to follow the Decision Tree structure and reconstruct the critical cumulative rainfall distribution and thresholds that have led to landsliding. The main findings suggest that a high-yield mid-term rainfall (2 and 3-day rainfall) are the most important for massive landsliding, while long-term cumulative rainfall (30-day) has some additional influence in the case of Loznica. The upper threshold values extracted from the original, and appended synthetic rainfall events were about 30 mm for 2- and 3-day rainfall, and 140 mm for 30-day rainfall, which is in agreement with the evidence of the May 2014 event. It is thereby shown how proposed approach can be used preliminarily in the case of rainfall/landslide data scarcity for rough threshold estimation and extrapolation. However, limitations regarding utilization of such data must be accounted for.

1. Introduction

Serbia has a predominantly continental climate with sharply distinguished seasonal temperature and precipitation trends over a year, which vary between − 20–40 °C, and 600–1000 mm, respectively. Exceptions are the highlands with the Alpine climate, and southernmost areas that have the sub-Mediterranean climate, with higher annual precipitation than the country's average. There is a high spatial variability of weather patterns within these zones, including severe anomalies such as cyclones with heavy rainfall and temperature extremes. One such extreme took place in mid-May 2014, when 3-day precipitation between 200 and 300 mm caused severe damages and dozens of human casualties across Bosnia and Herzegovina, Serbia and Croatia (UNDAC, 2014). Floods, which were widespread over the entire affected area (along the Sava, the Drina, the Kolubara and the Velika Morava river systems) had the most adverse aftermath (Fig. 1), whereas

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https://doi.org/10.1016/j.enggeo.2017.11.021
Received 4 February 2017; Received in revised form 17 October 2017; Accepted 25 November 2017

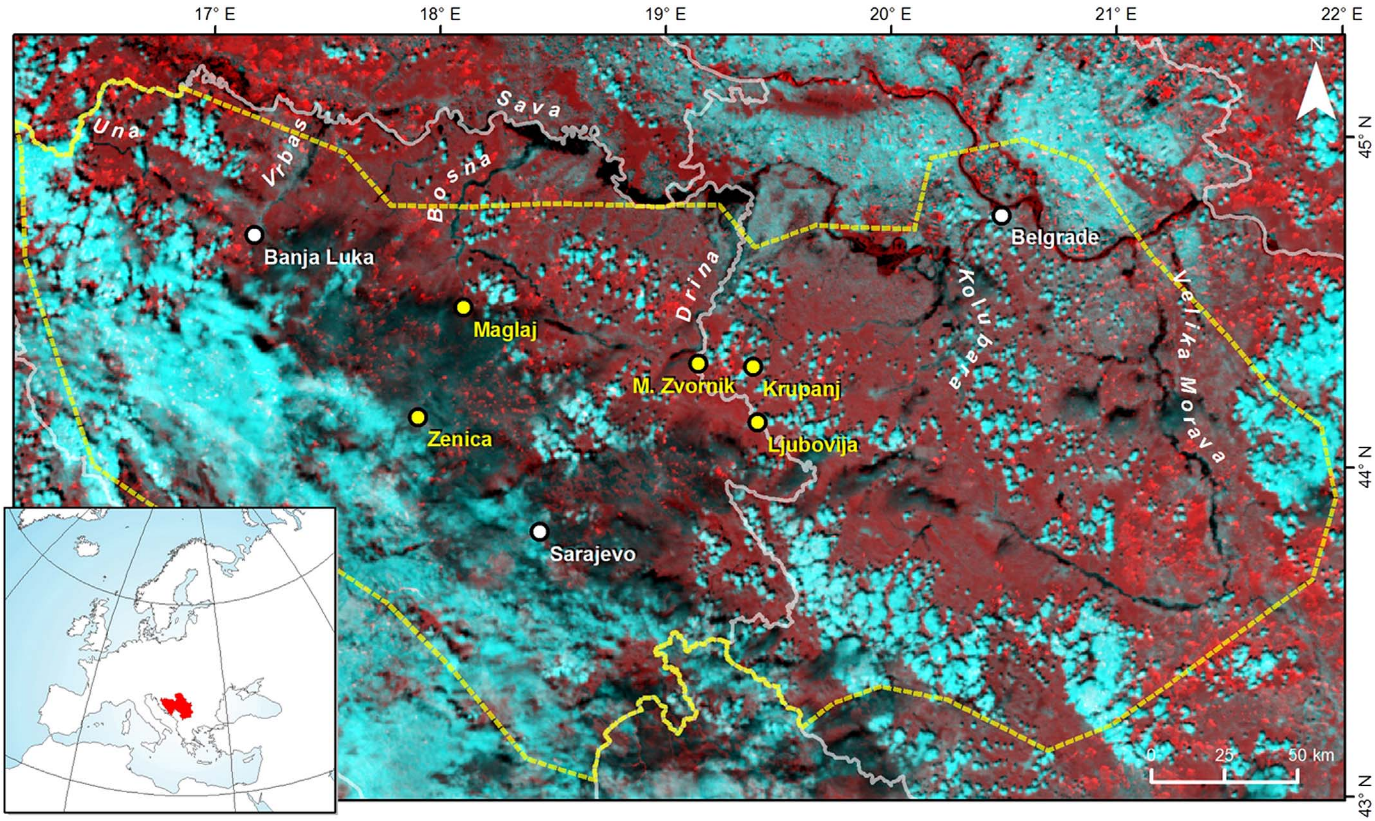

Fig. 1. Pre/post May 2014 event – RGB composite image of MODIS derivatives (8-day image; Level 3 processing; resolution 250 m, pre-event image 9–16.5.13, post-event image 17–24.5.14, R = Temporal Principal Component of pre- and post-event band 7-SWIR, G = B = post event band 7-SWIR). The figure depicts flooded areas around rivers marked in black. The affected area is shown as a dashed yellow contour and represents the wider area of interest. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

landslides that followed were mostly occurring around local hotspots (towns of Zenica and Maglaj in Bosnia and Herzegovina, and Krupanj, Ljubovija and Mali Zvornik in Serbia). Therein, we found additional motivation to analyze recent rainfall-landslide patterns in Serbia, without speculating about the underlying climate change effects, but not excluding them. It is generally argued that the higher frequency of weather anomalies implies climate change effects and links them with more frequent landslide occurrences. However, in some areas opposite has been reported (Gariano and Guzzetti, 2016).

There is an increasing body of evidence for major shifts in the spatio-temporal signatures of weather extremes, regarding their abundance, clustering and frequency in Serbia. Bajat et al. (2013) modeled the average annual precipitation in Serbia from 1961 to 90 and discovered significant spatial clustering of measured precipitation in certain regions, indicated by a high Moran's autocorrelation index (0.24 in these regions). Kržič et al. (2011) and Luković et al. (2009) addressed disproportional temperature trends for 1987–2006, wherein warm days have disproportionately higher increment rates than the cold days, showing an increase of 0.7 °C for warm days in the N, NW and NE Serbia. These findings fit into the large-scale analysis for 1946–99 (Klein Tank and Können, 2003), which indicated that heavy and extreme precipitation is more likely to increase across mid and high latitudes in Europe. The authors predicted a trend of even heavier precipitation in wet areas, while dry areas will tend to receive less and less rainfall. The most recent statistical rainfall analysis in Serbia (Prohaska et al., 2014) is in agreement with the former statements. The authors concluded that the cumulative rainfall during the May 2014 event itself was not as unusual (e.g. for Loznica T = 400y, for Belgrade T = 700y) as a cumulative rainfall for the entire month, which locally matched the 1000-year return period (e.g. for Loznica T = 667y, for Belgrade T = 2500y). Thereby, the hypothesis of mid/long-term rainfall effects on landsliding can be argued. We herein define the following terminology that will be used throughout the article:

- short-term rainfall – rainfall within the first 24 h
- mid-term rainfall – cumulative rainfall within 15 consecutive days
- long-term rainfall – cumulative rainfall within 30 consecutive days

The principal idea was inspired by findings of some other research groups (Martha et al., 2015; Vasu et al., 2016), and suggests that massive landsliding is likely to be induced by continuous exposure to a mid/long-term, high-yield antecedent rainfall in combination with an additional short-term rainfall extreme (Aleotti, 2004). In compliance with the hypothesis, the principal objectives of this study are:

- to establish rainfall-landsliding relation within the desired period (2001–2014)
- to extrapolate additional rainfall events that could have been responsible for landslides, but were not documented
- to establish the rainfall thresholds that potentially lead to massive landsliding.

The absence of an official landslide initiation dataset was a general obstacle in this work. It was compensated by defining approximate location and date of a landslide. Another problem was the absence of accurate hourly or sub-hourly precipitation records for the target area within 2001–2014. This shortcoming hindered the calculation of the rainfall event duration and intensity, thereby disabling the typical regression-based analysis of rainfall-landslides relation (Aleotti, 2004; Guzzetti et al., 2007; Brunetti et al., 2010). Instead, relations between the rainfall and initiated landslides were analyzed by aggregating the daily rainfall and antecedent rainfall (cumulative rainfall for different