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Landslide prediction system for rainfall induced landslides in Slovenia (Masprem)

Sistem opozarjanja na nevarnost proženja zemeljskih plazov v Sloveniji (Masprem)

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Abstract

In this paper we introduce a landslide prediction system for modelling the probabilities of landslides through time in Slovenia (Masprem). The system to forecast rainfall induced landslides is based on the landslide susceptibility map, landslide triggering rainfall threshold values and the precipitation forecasting model. Through the integrated parameters a detailed framework of the system, from conceptual to operational phases, is shown. Using fuzzy logic the landslide prediction is calculated. Potential landslide areas are forecasted on a national scale (1: 250,000) and on a local scale (1: 25,000) for five selected municipalities where the exposure of inhabitants, buildings and different type of infrastructure is displayed, twice daily. Due to different rainfall patterns that govern landslide occurrences, the system for landslide prediction considers two different rainfall scenarios (M1 and M2). The landslides predicted by the two models are compared with a landslide inventory to validate the outputs. In this study we highlight the rainfall event that lasted from the 9th to the 14th of September 2014 when abundant precipitation triggered over 800 slope failures around Slovenia and caused large material damage. Results show that antecedent rainfall plays an important role, according to the comparisons of the model (M1) where antecedent rainfall is not considered. Although in general the landslides areas are over-predicted and largely do not correspond to the landslide inventory, the overall performance indicates that the system is able to capture the crucial factors in determining the landslide location. Additional calibration of input parameters and the landslide inventory as well as improved spatially distributed rainfall forecast data can further enhance the model's prediction.

Izvleček

V članku predstavljamo sistem za napovedovanje verjetnosti nastanka plazov v času v Sloveniji (Masprem). Sistem napovedovanja plazov, ki se bodo sprožili zaradi padavin, je osnovan na karti verjetnosti pojavljanja plazov, sprožilnih/mejnih količin padavin za posamezne geološke enote ter modelskih napovedi padavin. Preko vključenih parametrov je prikazan potek dela, od idejne do operativne stopnje. Pri izračunu napovedovanja plazov je bila uporabljena mehka logika. Območja nastanka možnih plazov se računajo dvakrat dnevno, in sicer na državni ravni (v merilu 1:250.000) ter na lokalni ravni (merilo 1:25.000), kjer se za pet izbranih občin računa izpostavljenost prebivalcev, objektov in infrastrukture. Zaradi različnega vpliva padavin na pojav plazov, sistem napovedovanja upošteva dva različna scenarija za padavine (M1 in M2). Plazovi, ki jih napovedujeta ta dva modela, so primerjani z plazovi v bazi plazov, z namenom preverjanja ujemanja in validacije. Posebej so obravnavane obsežne padavine med 9. in 14. septembrom 2014, ki so botrovale sprožiti preko 800 plazov po celotni Sloveniji ter povzročile veliko gmotno škodo. Rezultati modelov kažejo, da so predhodne padavine pomembne pri napovedovanju. Kar je razvidno iz rezultatov modela 1 (M1), kjer le te niso upoštevane. Čeprav so bili plazovi napovedani nekoliko pogosteje kot so se prožili, je na splošno učinkovitost pokazala, da sistem zajema ključne dejavnike za ugotavljanje lokacije plazu. Dodatne kalibracije vnesenih parametrov in same baze plazov ter izboljšanje natančnosti prostorske napovedi padavin bodo izboljšale napovedovanje plazov.

Introduction

The spatial-temporal prediction of landslide hazards is one of the important fields of geoscientific research. The aim of these methods is to identify landslide-prone areas in space and/or time based on the knowledge of past landslide events and terrain parameters, geological attributes and other information. In the last 25 years many countries, regions and cities have been affected by intense precipitation that led to catastrophic landslides. Therefore, public awareness of extreme events has adequately increased across the world in different sectors.

Landslides are serious geological hazards caused when masses of rock, earth, and debris flow down a steep slope during periods of intense rainfall or rapid snow melt (Varnes, 1978; Cruden, 1991; Hungr et al., 2014). In our particular case, almost one quarter of territory of Slovenia is subjected to landslides (Komac & Ribičič, 2006). According to technical reports and bulletins of the Administration for Civil Protection and Disaster Relief from 1991 to 2014, landslides claimed 15 people, disrupted communication and transportation on many roads and have caused considerable damage and economic loss (HAQUE et al., 2016).

Possible solutions for reducing damage are focused on landslide detection and the identification of causes which lead to slope failures. In Slovenia intense short and less intense, long duration rainfall is the primary cause of shallow landslides that to some estimations sum up to the number of 10,000 (Jemec Auflič & Komac, 2012; Jemec Auflič & Komac, 2013; Jemec Auflič et al., 2015). Landslide density per square kilometer can be seen in Figure 1. For this purpose, the available landslide records (6946) gathered from different sources of information (Jemec Auflič et al., 2015) were transformed into a point layer. The 1 km reference grid from the European Environment Agency (EEA) was used to calculate the landslide density for each 1km^2 of the territory. A color scale was used to depict landslide density per 1km^2. From Fig.1 the landslide density for the territory of Slovenia, produced from the available landslide records can be seen where green color indicates areas with no landslides per 1 km^2 and red the maximum number of landslides per 1 km^2.

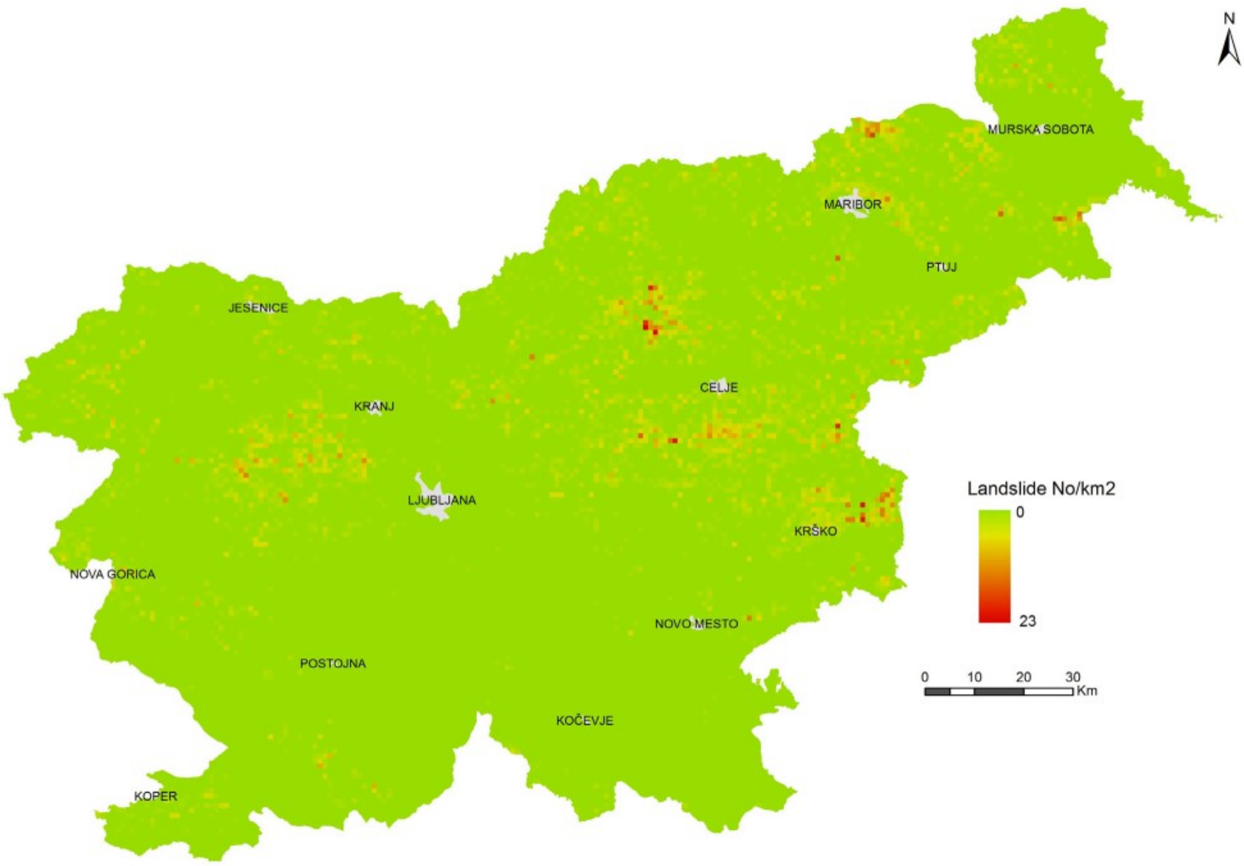

Fig. 1. Landslide density map from the available landslide records.

These events could be identified and to some extent also minimized if better knowledge on the relation between landslides and rainfall would be available. For example Rosi et al. (2016) calculated intensity-duration thresholds for Slovenia, where its territory was divided into four areas. One of the alternatives is the prediction of landslides in time, in relation to rainfall forecasts. Providing sufficient warning time before the impending landslide allows taking precautionary measures, minimizing the damage caused by the landslide. The primary objective of a modelling system to forecast landslide probability is to inform civil agencies or responsible authorities of an increased probability of landslide occurrence as a consequence of heavy precipitation that exceed the rainfall thresholds.

Various similar landslide prediction systems have been developed worldwide (Allasia et al., 2013; Baum et al., 2010; Osanai et al., 2010; Mercogliano et al., 2010; Tirante et al., 2014; Thiebes, 2012). In general, they vary by their observed parameters, technology used, and technological readiness level. For example, the landslide prediction system can be a prototype that is near, or at, planned operational system level or the system technology has been proven to work in its final form under expected conditions. Table 1 shows the range of technologies by country for some of the developed landslide prediction systems.

In Slovenia, the system for landslide prediction in time (acronym is Masprem) was developed in 2013 for the whole country and was financed by the Slovenian Disaster Relief Office and Ministry for Defense (Komac et al., 2013, Komac et al., 2014; Jemec Auflič et al., 2015, Šinigoj et al., 2015). At the moment, Masprem predicts landslide probability at a national scale (1: 250,000) and at a local level (1: 25,000) for five selected municipalities where the potential exposure of inhabitants, buildings and different type of infrastructures is displayed, twice daily for both. The system is now in validation phase. When rainfall induced landslide is reported the evaluation of the prediction models reliability is taken.

This paper aims to give an overview of the landslide prediction system in Slovenia, from the conceptual to operational phase. In this study predicted landslide areas are validated with landslides that occurred in September 2014.

Framework of the landslide prediction system

Landslides are triggered by the complex interaction of multiple factors (Reichenbach et al., 1998). In general, physical, mechanical and hydraulic soil properties, soil thickness, groundwater level, lithology and structural-geological features, vegetation cover and its contribution to soil strength, and local seepage conditions are particular to a geographical site and may induce variable instability conditions in response to rainfall (Crosta, 1998). In this study, we developed a landslide prediction system on national level that integrates three major components: (1) a landslide susceptibility map; (2) landslide triggering rainfall threshold values and (3) a precipitation forecasting model (i.e., ALADIN) (Fig. 2). Landslide prediction is also calculated on a local level, including exposure maps of inhabitants, buildings and different types of infrastructure to potential landslide occurrence at a scale of 1: 25,000 for five selected municipalities (Peternel et al., 2014). Probability of landslide occurrences on a local scale is calculated similarly to the calculations done for the probability of landslide occurrences on a national scale, the difference being in the scale of the landslide susceptibility map (1: 25,000).

The system is operational as of September 2013 and runs in a 12 hour cycling mode, for 24 hours ahead. The results of the probability of landslide models are classified into five classes, with values ranging from one to five; where class one represents areas with a negligible landslide probability and class five areas with a very high landslide probability. Landslide forecast models are automatically transferred to Administration for Civil Protection and Disaster Relief to inform them about the increased probability of landslide occurrences as a consequence of heavy precipitation, which exceeds the rainfall threshold. This landslide prediction system is now in validation phase using the landslide inventory. Therefore, the results need to be treated with care and within their reliability.

Landslide prediction system is a fully automated system based on open source software (PostgreSQL) and web applications for displaying results (Java, GDAL). When ALADIN/SI models are transferred to the GeoZS server the conversion process to raster data starts and stores data in a PostgreSQL database. The same procedure is repeated with the remaining two rasters data or static input data sets presented

Table 1. Developed landslide early warning systems by countries

Country	Type	Monitored area	Observed parameter	Name	Set up	Developer
USA	No longer in operation	San Francisco Bay	Rainfall thresholds		1986-1995	U.S. Geological Survey; National Weather Service
UK	Operational	Blackgang (local)	Ground movement		1994	Isle of Wight Council
Italy	Operational	Tessina landslide	Ground movement		1994	National Research Council
Brazil	Operational	Rio de Janeiro (regional)	Rainfall thresholds, intensity	Alerta Rio	1996	The Geotechnical Engineering Office of Rio de Janeiro
Malaysia	Operational	Kuala Lumpur Highway	Rainfall thresholds		1996	University of Malaya
China	Operational	Hong Kong	Rainfall thresholds, nowcasting		1997	Geotechnical Engineering Office
USA	Operational	Western Oregon	Rainfall thresholds		1997	Oregon
Italy	Operational	Valtellina (regional)	Ground movement, rainfall thresholds	EYDENET	1998	Istituto Sperimentale Modelli E Strutture
Switzerland	No longer in operation, destroyed in a rock slide	Preonzo (local)	Ground movement		1999-2012	Institute for Snow and Avalanche Research
China	Operational	Three Gorges Dam reservoir (specific locations)	Ground movement, pore pressure		1999	China Geological Survey
Italy	Operational	Nals (local)	Ground movement		2000	
New Zealand	Operational	Mt Ruapehu volcano	Lake water level, dam integrity	ERLAWS	2000	GNS Science
Italy	Operational	Lanzo Valleys (regional)	Antecedent rainfall, rainfall intensity	MoniFLaIR	2004	Environmental Protection Agency of Piedmont; University of Calabria
USA	Operational	Apalachians	Rainfall thresholds		2004	U.S. Geological Survey
China	Operational	Zhejiang Province (regional)	Rainfall thresholds		2004	China University of Geosciences
China	Operational prototype	Yaan (regional)	Rainfall thresholds		2005	China Institute of Geo-Environment Monitoring
USA	Operational prototype	Southern California burned areas	Rainfall thresholds		2005	National Oceanic and Atmospheric Administration; U.S. Geological Survey
Canada	Operational	Turtle Mountain (specific locations)	Ground movement		2005	Alberta Geological Survey; University of Lausanne; University of Alberta
USA	Operational prototype	Seattle	Rainfall, precipitation, soil moisture, pore pressure		2006	U.S. Geological Survey; National Weather Service; City of Seattle
China	Operational	Hubei Province (regional)	Precipitation		2006	China University of Geosciences
Switzerland	Operational	Illgraben catchment (local)	Ground movement, flow depth		2007	Swiss Federal Institute for Forest, Snow and Landscape Research
Indonesia	Operational prototype	Central Java, West Java, East Java, South Kalimantan, South Sulawesi (local)	Ground movement, rainfall intensity		2007	Gadjah Mada University; DPRI of Kyoto University; Asian Institute of Technology Thailand

Country	Type	Monitored area	Observed parameter	Name	Set up	Developer
Japan	Operational	Country-wide	Rainfall thresholds, soil moisture		2007	Ministry of Land, Infrastructure, Transport and Tourism; Japan Meteorological Agency
Colombia	Operational	Combeima-Tolima Region	Rainfall, ground movement		2008	Swiss Agency for Development and Cooperation
Indonesia	Operational	Ledokasari village (local)	Precipitation, rainfall thresholds, ground movement		2008	Geological Engineering Department
Phillipines	Operational	Albay (specific locations)	Rainfall thresholds	The Bell and Bottle EWS	2009	University of the Philippines Los Baños; Center for Initiative and Research on Climate Change Adaptation
India	Operational	Anthoniar Colony (local)	Soil moisture, ground movement, pore pressure		2009	Amrita Center for Wireless Networks and Applications; Amrita University
Italy	Operational	Country-wide	Rainfall thresholds	SANF	2009	Geo-Hydrological Hazard Assessment; Italian National Research Council
Italy	Operational prototype	Montagu earthflow	Surface displacement	ADVICE	2010	Geohazard Monitoring Group; CNR IRPI
Italy	Operational	Emilia Romagna (regional)	Rainfall thresholds	SIGMA	2010	Civil Protection Agency
Italy	Operational prototype	Umbria (regional)	Soil saturation	PRESSCA	2011	Umbria Region Civil Protection Centre
Italy	Operational	Torgiovannetto landslide	Ground movement		2011	National Civil Protection, Umbria Region, Perugia Province; University of Firenze
Italy	Operational prototype	Piemonte (regional)	Nowcasting	DEFENSE	2011	Regional Agency for Environmental Protection of Piemonte
Philippines	Operational	Tambis 2 and Lipanto, Cali and Limburan, Sitio Lunas	Ground movement	WSN FLEWS	2011, 2013, 2014	
Sri Lanka	Operational	Muzaffarabad (local)	Ground movement, rainfall thresholds, ground water levels	AsaniWasi	2013	Sri Lanka Institute of Information Technology
Norway	Operational	Country-wide	Rain, snowfall intensity		2013	Norwegian Water Resources and Energy Directorate
Slovenia	Operational	National	Rainfall forecast, landslide susceptibility, rainfall threshold	Masprem	2013	Geological Survey of Slovenia
Italy	Operational	Tuscany (regional)	Rainfall intensity		2014	University of Firenze
Bangladesh	Operational	Chittagong (local)	Rainfall thresholds		2015	Institute for Risk and Disaster Reduction; University College London

by landslide triggering threshold values and the landslide susceptibility map. Based on final results, Based on final results, the WMS service for distribution of data is created and displayed in a web application (Fig. 2). When the probability of landslide occurrences is increased, the system automatically sends an email to people responsible for disaster management at Civil protection Agency of Slovenia and to landslide experts at the Geological Survey of Slovenia.

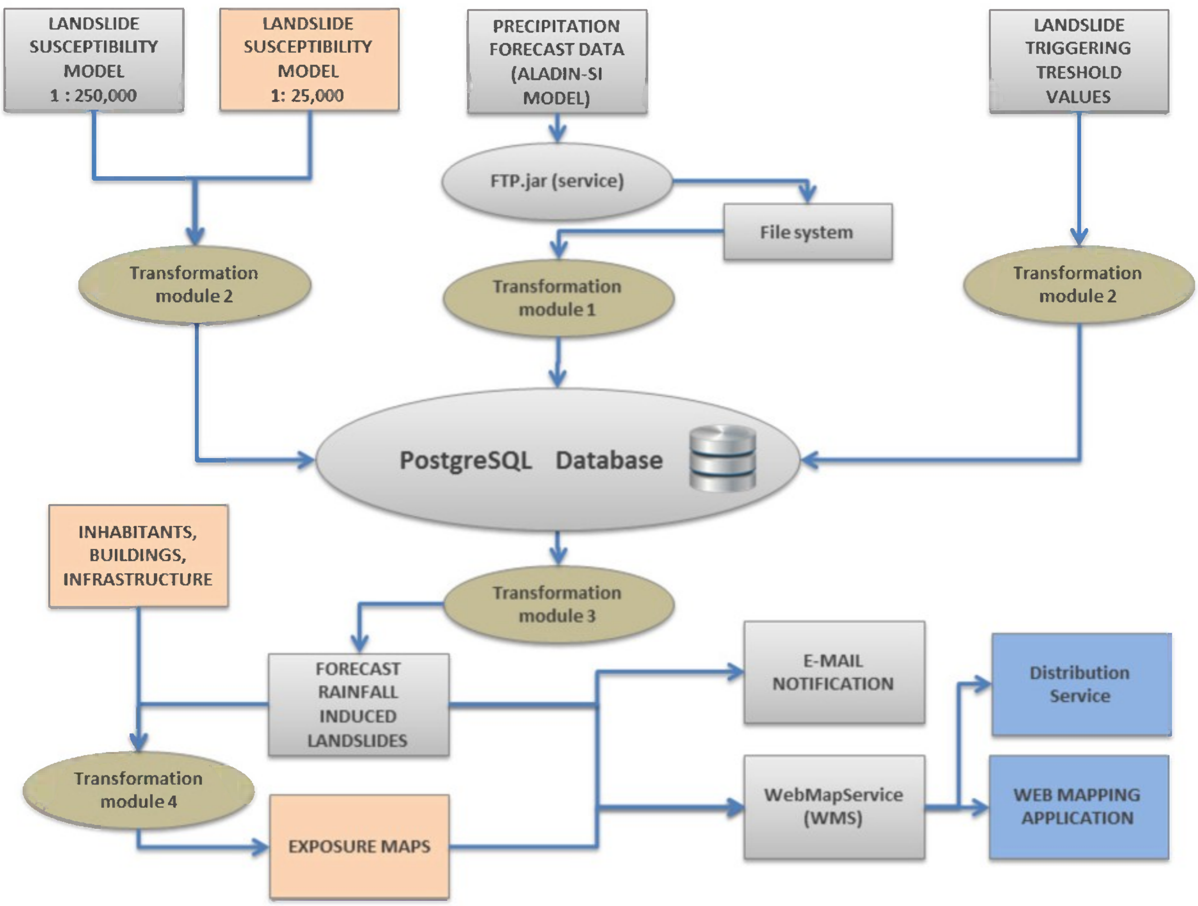

Fig. 2. Conceptual framework of the landslide prediction system on national and local level (after Šinigoj et al., 2015).

Input parameters

Landslide susceptibility map

Based on the extensive landslide database that was compiled and standardized at the national level, and based on analyses of landslide spatial occurrence, a landslide susceptibility map of Slovenia at a scale of 1:250,000 was produced (Komac & Ribičič 2006; Komac 2012) (Fig. 3A). Altogether more than 6,600 landslides were included in the national database. Of the 3,241 landslides with known location, random but representative 67 % were selected (landslide learning set) and used for the univariate statistical analyses (χ^2) to analyze the landslide occurrence in relation to the spatio-temporal precondition factors (lithology, slope inclination, slope curvature, slope aspect, distance to geological boundaries, distance to structural elements, distance to surface waters, flowlength, and landcover type). The landslide testing subset (33 % of all landslides in database) and representative areas with no landslides were used for the validation of all models developed.

The results showed that relevant precondition factors for landslide occurrence are (with their weight in a linear model): lithology (0.33), slope inclination (0.23), landcover type (0.27), slope curvature (0.08), distance to structural elements (0.05), and slope aspect (0.05).

For 14 Slovene municipalities, maps and web application were also elaborated based on archive data, detailed field inspection, and computer modeling (using own code) that enables state of the art landslide susceptibility prediction at a scale of 1:25.000 (Bavec et al., 2012).

Landslide triggering rainfall threshold values

Analyses of landslide occurrences in the area of Slovenia have shown that in areas where intense rainstorms occur (maximum daily rainfall for a 100 years period), and where the geological settings are favorable (landslide prone), an abundance of shallow landslides can be expected (Komac, 2005; Jemec Auflič & Komac, 2013). This clearly indicates the spatial and temporal dependence of landslide occurrence upon the intensive rainfall. For defining rainfall thresholds the frequency of spatial occurrence of landslide per spatial unit was correlated with a lithological unit, and 24-hour maximum rainfall data with the return period of 100 years. The result of frequency of landslide occurrence and rainfall data provides a good basis for determining the critical rainfall threshold over which landslides occur with high probability. Thus, the landslide rainfall threshold values were determined using non parametric statistical method chi-square (χ^2) for each lithological unit. In this order we separately cross-analyzed the occurrence of landslides within each unique class derived from the spatially cross analysis of lithological units and classes of 24-hour maximum rainfall. Maximum daily rainfall above 100 mm proved to be critical for landslide occurrence, especially in more loose soils and in less resistant rocks (e.g., Quaternary, Tertiary, Triassic, and Permo-Carbonian rocks). The critical 24-hour rainfall intensities (thresholds for engineer-geological units) can be found in Figure 3B.

Precipitation forecasting model

A regional ALADIN/SI model for Slovenia predicts the status of the atmosphere over the area of Slovenia up to 72 hours ahead (Pristov et al., 2012). A model simulates the precipitation (kg/m^2), snowfall, water in snow pack, and air temperature data. ALADIN/SI is a grid point model (439×2421×43), where the horizontal distance between the grid points is 4,4 km and it runs in a 6 hour cycling mode for the next 54 hours by the Environmental Agency of Republic of Slovenia (ARSO). In Figure 3C an example of numerical meteorological model ALADIN/SI is shown. Precipitation forecast as a real time rainfall data is used for modelling probability of landslides through time.

Methodology

The landslide prediction system aims to predict landslide occurrences for the next 24-hours over the study region. Modelling of landslide prediction is one of the key elements of the system. This model highlights fuzzy logic that allows a gradual transition between the variables (Krol & Bernard, 2012). The precise boundaries of the rainfall threshold over which a landslide always occur are very difficult to define. In this order, the model considers continuous rainfall threshold values for each engineering geological unit:

IF ([forecasted precipitation value (RT(x,y))]) > [rainfall triggering value (R_{FALL} (x,y))]) AND [landslide susceptibility value] = 1-5 THEN [forecasted rainfall induced landslide value] = 1-5.

The minimum threshold (R_{TMIN}) defines the lowest level, below which a landslide does not occur. The maximum threshold (R_{TMAX}) is defined as the level above which a landslide always occurs (White et al., 1996). Below certain value (R_{TMIN}) the probability of the triggering event is almost none (0), while above certain value (R_{TMAX}) the probability of the triggering event is almost certain (1). Between the two values the probability of triggering rises from 0 to 1, depending upon the membership function that defines the transition. The difference between the R_{TMIN} and R_{TMAX} is set to 30 mm to account for the classification

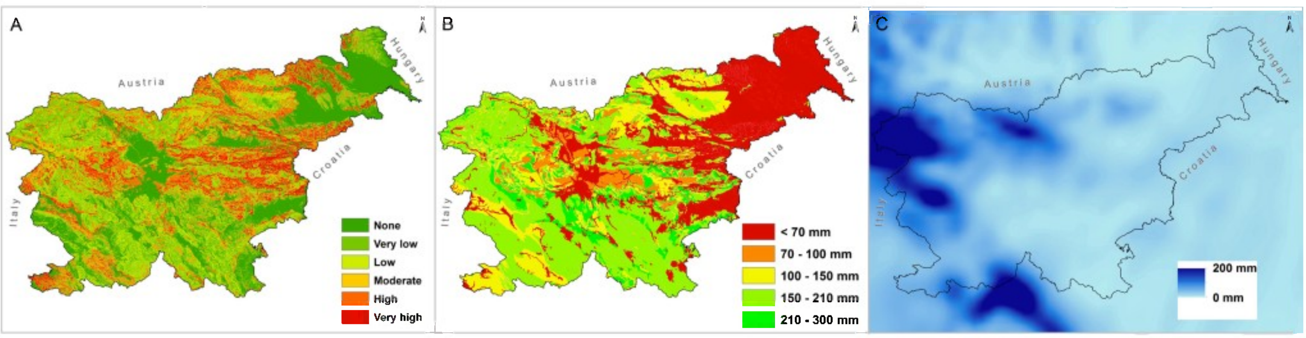

Fig. 3. Three major components (A - landslide susceptibility model; B - landslide triggering rainfall threshold values; C – an example of precipitation forecasting model) which are integrated into the prediction system through separate modules. Calculation of forecast models is performed through dynamic forecast modelling module.

error. R_{SUM} is a total amount of forecasted precipitation and rainfall threshold. It follows that landslide triggering rainfall threshold (R_{FALL}) for each location (cell) x,y in the time interval [0, t] is:

$$R_{FALL}(x,y) = \begin{cases} 0 & if\ \mathrm{Rsum}(x,y) < R_{TMAX}(x,y) \\ s, s \in (0,1) & if\ R_{TMIN}(x,y) \leq \mathrm{Rsum}(x,y) \leq R_{TMAX}(x,y) \\ 1 & if\ \mathrm{Rsum}(x,y) > R_{TMAX}(x,y) \end{cases}$$

Final landslide prediction (LandP) is expressed as:

$$\mathrm{LandP} = R_{FALL}(x,y) \times \mathrm{LSM}$$

where LSM is landslide susceptibility map. The final model values are classified into five probability classes –very low (1), low (2), moderate (3), high (4), and very high (5) (Fig. 4).

in Jemec and Komac (2013).

In this study we highlight the rainfall event that lasted from the 9th to the 14th of September 2014, with the peak on the 13th of September when abundant precipitation triggered over 800 slope failures around Slovenia and caused large material damage (Jemec Auflič et al., 2016). Precipitation was mainly concentrated in central, south-eastern and north-eastern part of Slovenia (Fig. 5). In these parts of the country, from 70 mm to 160 mm precipitation was measured (ARSO, 2015). The highest amounts of rainfall were measured in Murska Sobota (161 mm), Lisca (160 mm), Planina under Golica (149 mm), Novo mesto (143 mm), Cerklje airport (139 mm), Brežice (140 mm) and Malkovec (130 mm). Fig. 6 shows precipitation forecast posted on the evening of 12th September 2014 and the morning next day for the next 24 hours. Landslide prediction system calculated landslide probability;

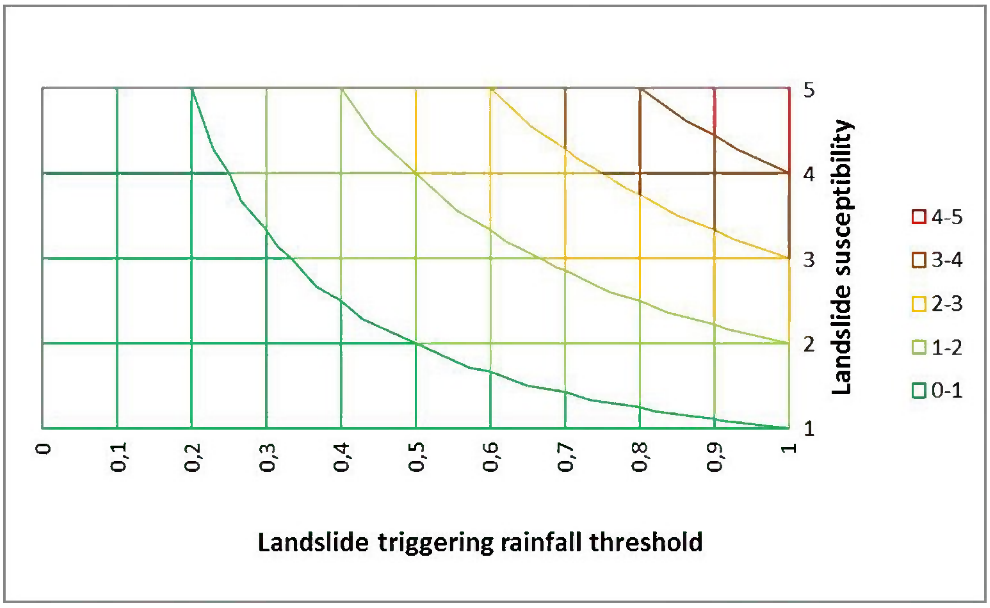

Fig. 4. Gradual transition between landslide triggering rainfall thresholds and landslide susceptibility.

Results and discussion

In the observed period, from September 2013 to August 2016, the system for calculating landslide prediction gave an alert about the probability of landslide occurrences in 84 cases.

System for landslide prediction considers two different rainfall scenarios (Jemec Auflič et al., 2015). The first one (*M1*) utilizes the landslide susceptibility map, landslide triggering rainfall threshold values and the ALADIN precipitation forecasting model for 24 hours ahead, while the second (*M2*) also integrates two days of antecedent rainfall. Significant impact of antecedent rainfall on landslide occurrences has been shown particularly both models M1 and M2 were forecasted for the zones with high probability for landslide occurrences presented in Figure 7. In general, both models predicted landslides for the eastern and north eastern part of country, with the difference that the M2 model calculated higher potential for landslides to occur. As can be seen from Figure 8 the landslide susceptibility classes of M2 predict larger area prone to landslides.

According to reports of Administration for Civil Protection and Disaster Relief numerous landslides occurred between the 12th and the 13th of September 2014. The location of landslides is shown on Fig. 7.

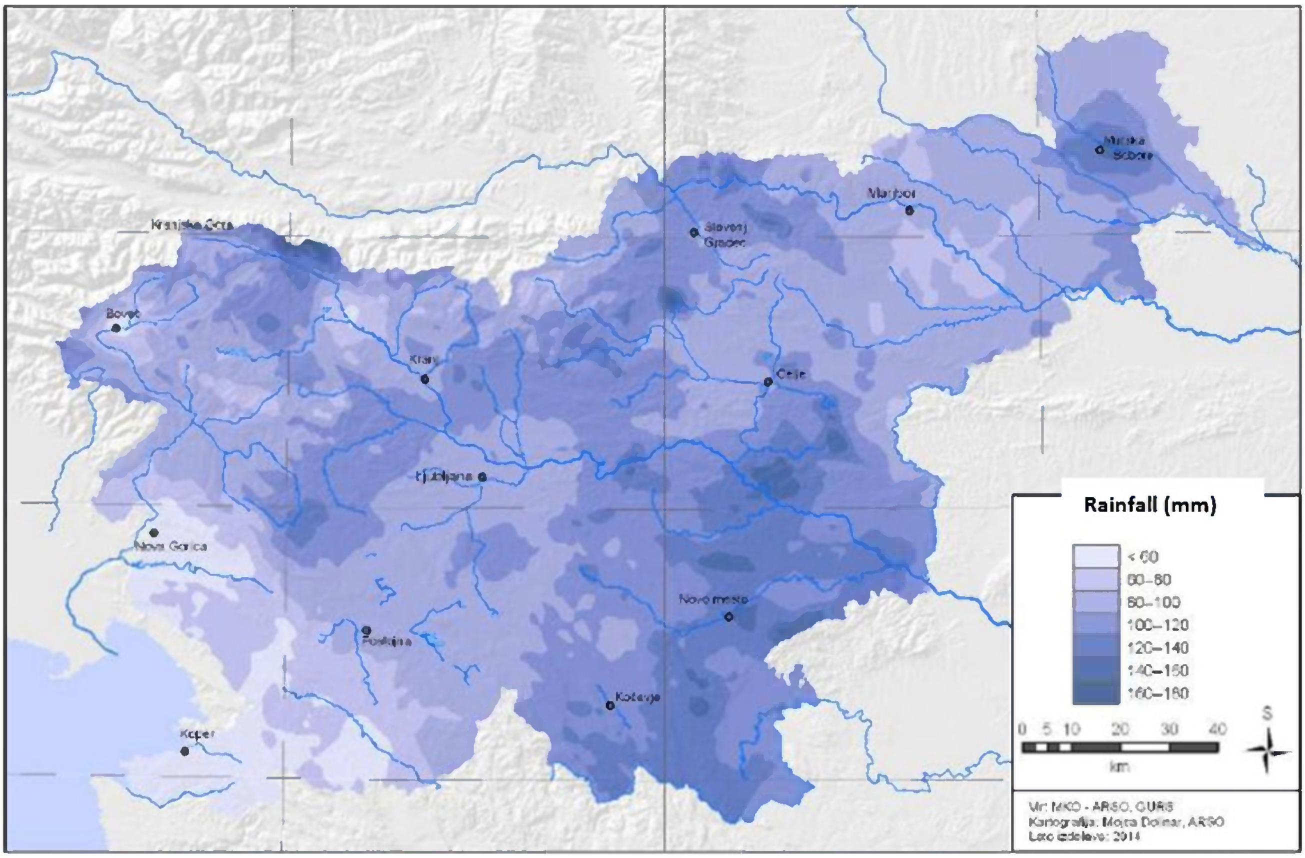

Fig. 5. Rainfall accumulation (mm) from the 9th of September in the morning until the 14th of September in the morning. Map is made on the basis of automatic meteorological data (ARSO).

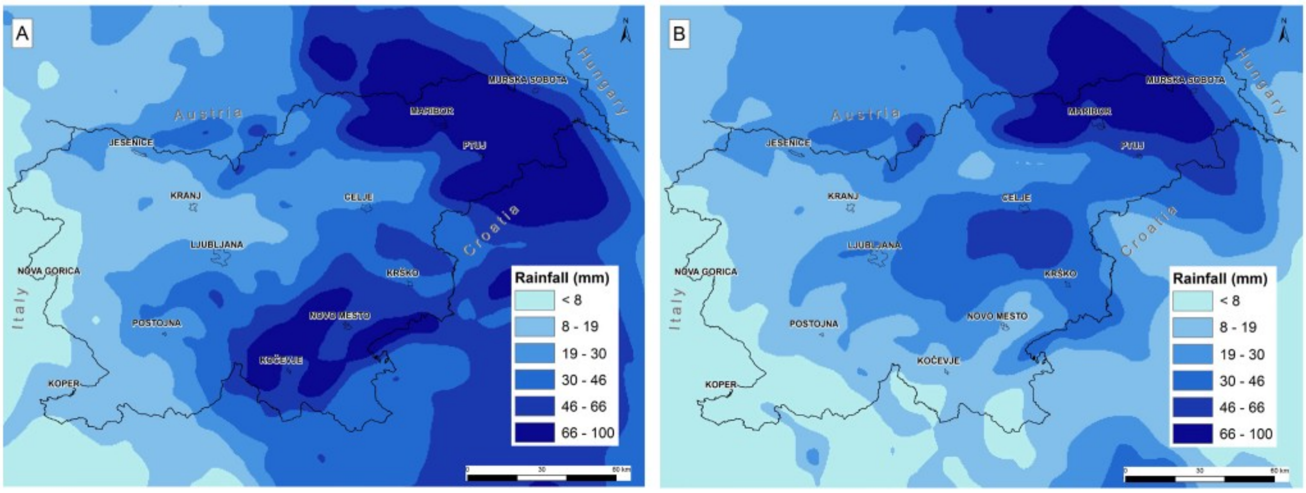

Fig. 6. ALADIN rainfall forecast posted on the evening of 12.9.2014 (A) and the morning of 13.9.2014 (B) (ARSO).

From the results, it is evident that M2 model (integrates two days of antecedent rainfall) forecast more areas where the probability of landslide occurrences is higher. Moreover, in M2 model more landslides correspond to classes with higher landslide susceptibility (Table 2). Altogether we investigated 102 landslides.

Table 2. Distribution of landslides according to the 5-level susceptibility scale considering two different rainfall scenarios (M1 and M2)

LSC	M1	M2
1	92	75
2	1	9
3	1	5
4	4	6
5	4	7

N=102

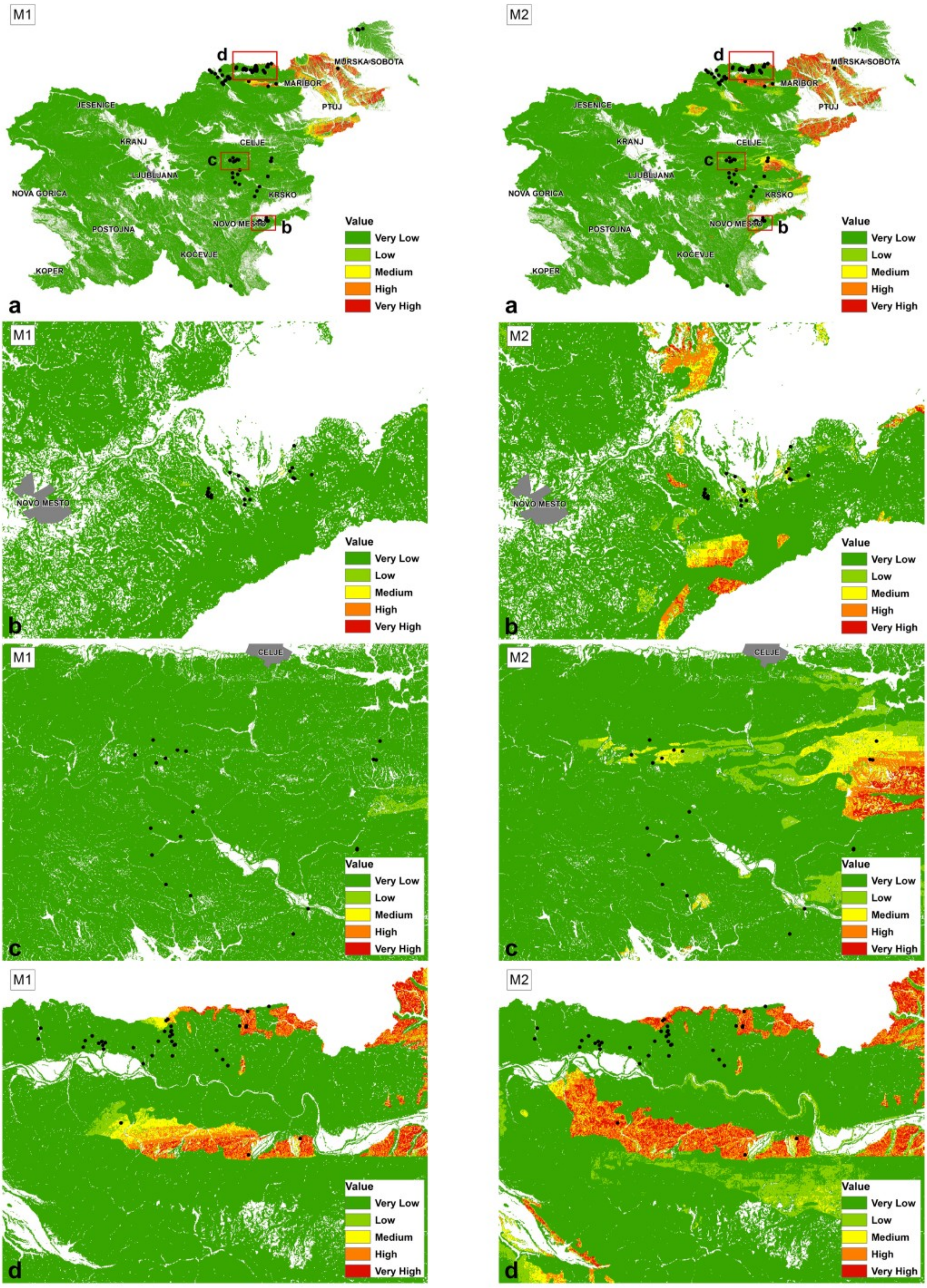

Fig. 7. Visualization of landslide prediction maps calculated on the evening of 12.9.2014, matched to occurred landslides. Note that the M1 indicates the model 1 and M2 model 2; black dots are landslides. a – landslide prediction maps on a national level; b – landslide prediction map on a local level close to town Novo mesto; c – landslide prediction map on a local level close to town Celje; d – landslide prediction maps on a local level close to Maribor.

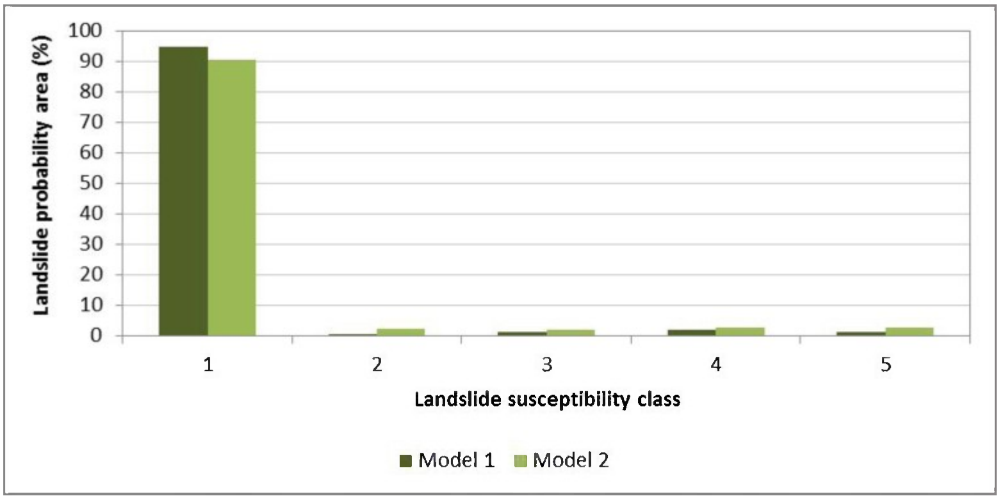

Fig. 8. Relative proportion of predicted landslide area (i.e., susceptibility class 5) according to models M1 and M2.

While the system has potential to become operational in use after the validation phase, there are also limitations related to the input data that should not be neglected: spatial resolution of the ALADIN model, the incomplete landslide inventory that is important for the validation, defining how many days of antecedent rainfall significantly influence the landslide occurrences, characteristic of lithological units according to water contents.

Conclusions

In Slovenia, precipitation and related phenomena represent one of the most important triggering factors for the occurrence of landslides. In the past decade, extreme rainfall events in which a very high level of precipitation occurs in a relatively short rainfall period have become increasingly important and more frequent, causing numerous undesirable consequences. Intense rainstorms cause flash floods and mostly trigger shallow landslides and soil slips. These events could be identified and to some extent also minimized if better knowledge on the relation between landslides and rainfall would be available. To tackle the problem from a prevention aspect, a landslide prediction system has been developed in 2013. The system aims to (1) predict rainfall induced landslides at national and local level by integrating a landslide susceptibility map, rainfall threshold values and a precipitation forecasting model and (2) inform inhabitants of an increased probability of landslide occurrences.

Despite the limitations currently affecting the landslide prediction system, results show that the system demonstrates capability in predicting rainfall induced landslides by considering the most important triggering factor, which is rainfall in this study. When the validation phase will be finished and the certainty of system will be high enough, the system will be able to inform infrastructure owners, civil agencies, and operators of potential landslide hazards.

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