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Slovenian national landslide database as a basis for statistical assessment of landslide phenomena in Slovenia

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ABSTRACT

Landslide databases on a national scale are an important tool for good spatial planning and for planning prevention measures or remediation activities. We have developed a modern national landslide database that enabled better landslide occurrence understanding, and will in the future help to assess landslide hazard, risk, potential damage, and enable more efficient landslide mitigation. In the paper landslide database construction steps and their properties are described. Following the collection of the landslide data from various sources and their input into the database the consistency of the database was assessed. Based on the data collected we have assessed basic statistical landslide properties, such as their overall spatial distribution, size and volume and the relation between them, landslide distribution in relation to engineering-geological units and different land-use, and past landslide mitigation activities. Analysis of landslide distribution also indicated areas in Slovenia where no landslide mapping was performed in the past, yet it should be, due to the high landslide susceptibility of these areas. Consequentially future national activities in relation to landslide problems should be governed primarily based on the findings of the database analyses to achieve the highest efficiency.

1. Introduction

Slovenian geology is quite complex. Though the territory consists mainly of sedimentary rocks (53.5%) and clastic rocks (39.3%), significant areas can be found where metamorphic (3.9%), pyroclastic (1.8%) and igneous rocks outcrop (1.5%) (Komac, 2005). From the regional aspect, Slovenian territory is composed of five major tectonic divisions — the Adriatic–Apulian Foreland, Eastern and Southern Alps and the Dinarides and Pannonian basins (Placer, 2008), which makes the area heavily dissected by faults and thrusts resulting in reducing the mechanical properties of rocks. All these geological conditions result in the fact that almost one quarter of Slovenian territory is highly susceptible to landslides (Komac, 2012).

Consequentially, many landslides (and other slope mass movements) occur annually in Slovenia, causing material damage and also taking lives. According to various news sources, there have been at least eight casualties in the past 20 years in Slovenia and the official direct damage, excluding remediation costs due to landslides between 1994 and 2008, was close to 100 million euros (SORS, 2014). We estimate that the damage during the period of 2008–2013 reached another 8–12 million euros, summing to approximately 110 million euros in the past 20 years. As landslides pose significant problems in Slovenia, several approaches to creating systematic inventory and subsequently landslide databases have been performed since the mid-1990s on a country-wide scale. At least three attempts were made in Slovenia in the past to build a landslide database on a national scale; the first in the early 1990s (Ribičič et al., 1994), the second in 2006 (Ribičič et al., 2006) and the last in 2013 (Komac et al., 2013), which was finally sustained, even after a project through which the database was erected. For now, the Geological Survey of Slovenia (GeoZS) is sustaining the database out of its own funds, as no state funds are available for this task. It is needless to stress that if any of the previous attempts had continue after the project ended, few repetitions of database construction would be made. At the same time, every next attempt is based on previous one, at least from the data aspect. In addition, the costs of simply maintaining the database with occasional upgrading would be much lower.

Good, understandable and accessible data represent a basis for assessment of landslide susceptibility, hazard and eventually risk, and consequently for landslide mitigation and sound spatial planning. For the same purpose, other national landslide databases around the globe have been constructed (Devoli et al., 2007; Kirschbaum et al., 2009; Foster et al., 2012; Van Den Eeckhaut and Hervás, 2012; Damm and Klose, 2014; Hess et al., 2014; Kirschbaum, 2014; Mrozek et al., 2014; NIED, 2014; Oppikofer et al., 2014).

Ribičič et al. (1994) estimated that there were between 7000 and 10,000 active landslides in Slovenia. Based on several larger events of numerous new landslide occurrences in the past decade, we estimate that this number is higher by about 20%. Based on the landslide occurrence in relation to the spatio-temporal factors that the landslide database from 2006 identified, Komac and Ribičič (2006) produced a

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landslide susceptibility model of Slovenia at a scale of 1:250,000, which was updated by Komac (2012) using a Monte-Carlo approach. The first model is still the official landslide susceptibility model for Slovenia.

The goals of the work presented in this paper were 1) to bring together scattered landslide data in Slovenia to a common denominator following the standardised procedure of database construction, 2) to assess the basic statistics of the landslide population in Slovenia, and based on that 3) to derive a basic overview of the landslide distribution in relation to engineering-geological and land-use types, and to assess the remediation measures that could be taken to minimise their impact.

2. Slovenian national landslide database

2.1. Landslide database background

In Slovenia, the landslide issue is legally divided between two areas of official procedures — prevention/intervention procedures that are in the domain of Administration of the Republic of Slovenia for Civil Protection and Disaster Relief (ACPDR) (OJ RS, 1994) and the area of remediation procedures that is in the domain of the Ministry for Agriculture and the Environment (MAE). While the first is focused on the hazardous occurrences and phenomena that endanger inhabitants, the second is focused on the spatial planning restrictions resulting in landslide risk mitigation (OJ RS, 2002a) and remediation measures in the post intervention phase of the phenomena (i.e., OJ RS, 1996; OJ RS, 2000a,b; OJ RS, 2002b, etc.). Each of these stakeholders collected landslide data for their own purposes in a form of simplified inventories focused on information for their own purposes. ACPDR uses its inventory for deriving landslide susceptibility maps (Komac and Ribičič, 2006; Komac et al., 2013), which help the Administration to better prepare for prevention/intervention measures. In addition, ACPDR has a damage reporting system — AJDA (ACPDR, 2012), which includes only landslides that have caused damage; hence, this system is not complete from the perspective of the landslide inventory for research purposes. The same can be stated for the landslide inventory that MAE builds for its purposes — for damage estimation to buildings, roads and agricultural land above a certain damage threshold value and for funding the remediation measures. It is obvious that both systems focus on damage issues so a clear question of inclusion of those landslide occurrences that do not cause damage, pose a threat or that caused damage below the minimum damage threshold value, remains. How can we efficiently and economically map landslides that are left out of these inventories?

The focus of the activities of the GeoZS is landslide research on a national, regional, local and individual phenomena scale. To effectively tackle this objective, the creation of a landslide inventory and database and their maintenance is a necessity. Hence, as complete a landslide database as possible, including landslides that do not pose a risk to anthropogenic environments, is of quintessential importance; due to limited funding, GeoZS adopted a pragmatic approach. As a basis for compiling and updating the national landslide database created in 2013 (Komac et al., 2013), inventories from five institutional and several municipal sources were used — ACPDR, MAE, GeoZS, Slovenian Roads Agency (SRA), Slovenian Environment Agency (SEA) and six municipalities (Table 1). In summation, the project goals were: (1) to establish an up-to-date central landslide database, which could also be used for other natural phenomena, and (2) to construct an information system that would allow different users to use the internet application for registering and reporting new slope mass movement occurrences, and making additional changes or correcting the data already stored. The database would: (1) represent the basis for spatial analysis of slope mass movement distribution, (2) serve as a foundation for the modelling of geohazard and georisk at different scales and (3) enable fast distribution of the slope mass movement data to different users in accordance with their data access rights. Until June 2014 altogether, 6234 landslide occurrences in point format were entered into the database. Except from the old existing GeoZS database from the 1990s in which 492 landslides are represented by polygons, landslide occurrences are represented by points and arranged in a much more simple way. With the purpose to sustain the database and its updates as frequently as possible, an update of inventory and database is included in the description of work of every project related to landslides that is performed at the GeoZS.

Table 1
Number of landslide records by source (status on June 2014).

Source	Number of landslide records
ACPDR	1672
Slovenian Roads Agency	432
Slovenian Environment Agency	500
MAE	1579
GeoZS	1822
	5788 (originally 6005 records, 217 duplicate records were removed)
Systematic data collection and inventory verification per municipality	
Municipality Puconci	35
Municipality Šentilj	70
Municipality Slovenj Gradec	41
Municipality Železniki	82
Municipality Velenje	211
Municipality Ptuj	7
Spring 2014 data update	**446 (total number of landslide records reported by municipalities in spring 2014)**
	6234 (total number of landslide records in the National landslide database)

Several other landslide inventories exist in Slovenia, but are currently not included in the national landslide database. In addition to the first landslide inventory from 1994 (Ribičič et al., 1994), landslide inventories were collected or updated in 17 municipalities by GeoZS (Bavec et al., 2010a,b, 2012), and in two additional municipalities by other institutions (ZRMK, 2010; Mrak et al., 2012). As the main purpose of collecting landslide data was to create landslide susceptibility maps for these 19 municipalities, the verification of the existing inventories was very limited, which hampered the simple transfer of these occurrences into the National database. Also, the majority of landslide data that is reported from municipalities is collected by non-experts, mainly by firefighters or municipal officials, who lack basic geological or geotechnical knowledge. These landslide data are hence reliable only to a certain extent, so they need to be verified prior to their inclusion into the landslide database. Verification is systematic, but slow; until now, only six municipalities were verified and 446 landslides were included in the database and were already a part of the 6234 landslides in the database. The coverage of existing landslide inventories and databases in Slovenia is graphically represented in Fig. 1.

2.2. Landslide database development

Based on the available and merged landslide inventories gathered from various sources, we constructed the Slovenian landslide database following the procedure of the data modelling consisting of five logical steps. The result was the entity–relationship data model (E–R model), which we present in the following text. For the development of the landslide database, we used SQL Server 2008, while the user interface was created in MS Access 2010.

The five steps of landslide database construction were: 1) the detailed study of the model of landslide related problems/issues; 2) the definition and the description of relations between objects and their functionality; 3) the definition of the logical data model; 4) the construction of the relational model between objects with hierarchically arranged objects; and 5) the establishment of the physical model of the database, including the input forms for end-users. The first step