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Technical Note

Analysis of human induced changes in a karst landscape — the filling of dolines in the Kras plateau, Slovenia

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HIGHLIGHTS

- In the study areas, one quarter of dolines have disappeared in the past 40 years and more are endangered.
- Dolines are filled up with construction material resulting in landscape deterioration.
- Excessive human encroachment may have a great effect on karst hydrology or ecology.
- The current standards for karst protection are loose.

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ABSTRACT

A comprehensive analysis of the increased pressure on karst landscapes due to expansive economic and urban development is presented with the aim of evaluating changes in land use and their deleterious effects on karst relief forms. The study focuses on two areas surrounding the relatively quickly growing settlements of Hrpelje-Kozina and Divača on the Kras plateau (Slovenia) that have been subjected to intensive urban and business development and traffic since the motorway was brought to their vicinity fifteen years ago. National legislation loopholes and technological improvement were the cause of the commonly unsupervised human encroachment which caused the widespread degradation of the landscape. By comparing different topographical and ortophotographical materials from the past four decades and by detailed field inspection of land use and environmental changes, as well as the morphometrical characterization of dolines, the following results have been found: due to the population growth in the past four decades (39% and 50%, respectively), an increase of settlement area by 18 and 11 percentage points took place. Consequently, between 25 and 27% of dolines have disappeared or have been extensively modified (filled up and leveled). According to the local spatial plans, an additional 18% to 28% dolines are endangered. Broad human induced changes in the karst landscape have resulted in a noticeable increase in landscape deterioration, which is consistent with similar phenomena observed in other regions. Due to the extreme susceptibility of the karst to human activities that may lead to the degradation of its exceptional esthetic and environmental value, the alteration of karst processes such as corrosion, endangering of unique habitats and the quality of non-renewable natural resources, it is necessary to promptly define measures for its protection at the national level.

1. Introduction

Karst landscapes most commonly formed in carbonate rocks (e.g. limestone, dolomite) that are water-soluble. Due to chemical weathering, distinctive surface and underground geomorphological features develop with particular hydrological functions (Bonacci, 1999; White, 2002; Ford and Williams, 2007). The most significant landforms for exposed karst landscapes are karrenfields, dolines (sinkholes), and swallow holes. These features on the land surface usually, but not necessarily, develop along fissured and fractured zones. The karst surface is very permeable and enables the immediate infiltration of water into the underground system, where the karstification (solutional enlarging of fissures) creates cavities and organizes a flow net in a hierarchical manner. The interior of the karst is thus characterized by a three dimensional network of underground conduits and voids (Gunn, 1981; Bakalowicz et al., 1994; Drew, 1999; Gabrovšek, 2000; Klimchouk and Ford, 2000; Király, 2002; Worthington, 2009).

Due to the described peculiarities of karst processes, these landscapes are among the most vulnerable environments and the destruction of dolines is among the topical issues in karst environments worldwide (Parise and Pascali, 2003; De Waele, 2009; North et al.,

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2009). Excessive human activities such as land-use modifications, alteration of surface drainage, opening or blocking of cave entrances make karst areas additionally susceptible to exceptional natural processes, such as the change of recharge conditions and corrosion, which may have a great effect on karst hydrology or ecology. It may for example cause pollution and depletion of water resources, changes of the natural morphology and hydrology, the decline of animal species, etc.

Carbonate rocks cover a non-negligible part of the world's surface (about 12–15%), and in Europe alone around 35%, of which a large part is karstified (COST Action 65, 1995). Karst areas are becoming economically more and more important: many karst massifs contain large amounts of high-quality groundwater resources and only in Europe a significant portion (between 30 and 40%) of drinking water is abstracted from karst aquifers (Bakalowicz, 2005). In some countries (e.g. in Slovenia, Austria) karst water contributes more than half of the supply of drinking water, and in many regions it is the only available source of fresh water. Karst areas that support unique ecosystems very rich in biodiversity (Culver et al., 2009) are abundant also in other resources such as stone, minerals, oil, and natural gas. Due to the environment's high diversity, these landscapes are very fascinating, and represent attractions for tourists to the numerous caves and beautiful scenic areas (Williams, 2008b).

In recent years, due to a variety of activities resulting from comprehensive economic and urban development, an increased pressure on karst landscapes, i.e. by intensive and unsustainable spread of settlement, infrastructure and industry, the development of tourism, and intensive agrarian land use has occurred. The exhaustive reshaping and degradation of the landscape have expanded beyond control largely as a result of technological development and mechanization. The excessive modern filling of dolines, as one of the most distinctive karst geomorphological features, has become a major encroachment on the environment for leveling purposes. Many dolines are filled with construction waste, which threatens the existence of unique habitats as well as the quality of groundwater and consequently the water supply. Some examples of long-term human degradation of karst surface in Slovenia (e.g. Breg, 2007; Cernatič-Gregorič and Zega, 2010) and around the world have already been highlighted (e.g. Drew and Hötzl, 1999; Parise and Pascali, 2003; Calò and Parise, 2006; Ford and Williams, 2007; De Waele, 2009; North et al., 2009).

In Slovenia valuable natural features are protected by the Nature Conservation Act (1999) and are included in the list of the Rules on the designation and protection of valuable natural features (2004). Unfortunately, dolines as “diagnostic landforms” for karst landscapes are not all recognized as valuable natural features and thus are not protected. Consequently, filling, leveling and building up of dolines are allowed without limitations. Only the most exceptional dolines (those largest which are by the rule of collapse origin), have the status of valuable geomorphological natural features of national or local importance.

In this respect the present contribution aims at assessing the filling of dolines and a detailed analysis of human induced changes in the karst landscape. It focuses on particular cases of inappropriate landscape management in the cradle of karst science, the Kras plateau in SW Slovenia where these actions expanded locally beyond control.

2. Methodology

In two selected areas, changes in land use in the past 40 years and their deleterious effects on karst landscape have been analyzed and evaluated. Special emphasis has been put on the filling of dolines and their destruction.

The study is similar to the multi-temporal analysis of dolines made by Festa et al. (2012) based upon the mapping of dolines from the 1:5000 topographic maps from different periods, i.e. originally published in 1972 and later modified in 1994, and geo-referenced aerial photos from 2009 (Principal topographical maps 1:5,000, 1972, 1994; Digital topographical data 1:5,000, 2006; Digital orthophoto 1:5,000, 2009). Systematic field surveys were carried out in the spring of 2012 mainly for: (1) mapping locations of the still existing dolines, (2) detecting of land use changes, and (3) mapping environmental changes in the areas of filled or built-up dolines. Field inspection results were compared with the historical data from the topographical and aerial maps. Different sets of aerial photos and maps, and systematic field survey enabled multi-temporal evolution of particular dolines.

Furthermore, each of the remaining dolines was visually inspected. By means of detailed field work, the exact position and floor plans of each individual doline were delineated, morphometric characteristics were assigned and current land use was noted. In 2012, it was possible to measure the morphometric characteristics of dolines and to make calculations for 185 dolines in the Hrpelje-Kozina study area and for 322 dolines in the Divača study area, respectively. The following attributes have been assigned to each doline: area, shape, presence of soil or deposits at the slopes and bottoms of the dolines, and presence of dry-stone walls around the dolines. The land use at the bottoms of the dolines in 2012 and the state of preservation of the dolines were also recorded. Finally, basic morphometric, distribution and statistical analysis have been performed.

Each doline was also digitized and cataloged in the GIS database. Mapping and evaluation processes were produced using ArcGIS, Version 9.3 tool.

3. Description of case studies

The study focuses on the expansion of human activities at two settlements of the Kras plateau (Hrpelje-Kozina and Divača) and on the destruction of the nearby karst landscape. The Kras is a region extending in southwestern Slovenia. It is an area regarded as the cradle of the scientific discipline of karstology due to its typical karst geomorphology. It stretches about over 440 km^2 and lies between the Vipava Valley, Brkini Hills, northern Istria, and the Gulf of Trieste (Italy). It is an uplifted, overturned anticlinal block forming a plateau at between 200 and 600 m above sea level that is mainly stretching in a NW–SE direction (the so-called Dinaric direction that is a predominant direction of mountains and mountain ranges in the Dinaric Alps from Slovenia to Montenegro), and sloping towards NW. It is composed primarily of Mesozoic and Tertiary carbonate rocks; these are mostly limestone and dolomite of the Cretaceous and Paleocene ages. The most characteristic surface geomorphological features in the studied areas are cone shaped hills and closed depressions, collapse dolines or solution dolines and numerous entrances to underground caves. There is no surface running water, autogenic recharge and underground water flow prevail (Fig. 1).

Hrpelje-Kozina and Divača are small settlements lying in southern part of the Kras. Unlike the rest of the Kras, these areas have been heavily subjected to intensive urban and business development as well as an increase in traffic since the motorway was brought to their vicinity fifteen years ago. The human population in the past four decades (1971–2011) expanded significantly, in case of Hrpelje-Kozina the population went from 841 to 1376 and from 970 to 1393 in the case of Divača (Population Census, 1971–2011, 2012). New residential areas, industrial zones and business parks have been set up within the karst landscape, originally punctuated with numerous dolines and cave entrances. Therefore the results of this survey cannot be directly generalized to the whole Kras plateau, though activities such as the filling of dolines with different material and excavation of soil in dolines take place daily all over the Kras, non-populated areas included (Cernatič-Gregorič and Zega, 2010).

4. Results

The Kras plateau used to be a vast rocky, dry and bare land with no surface running waters, which is today overgrown by forest. Only in