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The Impact of Human Activities on Dolines (Sinkholes) – Typical Geomorphologic Features on Karst (Slovenia) and Possibilities of their Preservation

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Abstract

This paper focuses on dolines, one of the main geomorphologic features on Karst (Slovenia). Dolines are a dominant surface feature and also a main source of fertile soil on Karst. Consequently they represent a significant element of the Karst landscape and an important part of traditional agricultural land use.

Negative impacts due to rapid economic development in the last decade are affecting Karst seriously, mostly by degradation of typical landscape features. The main purpose of our work was to document the current extent of damage caused on dolines and consequently on Karst landscape. The paper discusses the gravity of the problem and points out the insufficiency of current legislation concerning landscape protection. Based on the research results the paper comments on possible consequences if the degradation process continues.

Key words: Karst, doline, sinkhole, landscape, degradation, preservation, heritage

Introduction

The term karst refers to a kind of surface (topography) and subsurface formed in limestone, rarely in dolomite, gypsum, or other soluble rocks. It is characterized by different geomorphologic features, like dolines (sinkholes), karst valleys (polje), blind valleys and caves, formed by chemical and mechanical water activity and underground drainage. (Pavšič, 2006; Glossary of landform and geologic terms, 2008).

The international term karst is derived from the name of the karst plateau (SW Slovenia) in the background of Trieste bay (Adriatic Sea), on the Slovene-Italian border, called Kras in Slovene, Carso in Italian and Karst in German language (Kranjc, 2001) (figure 1). Due to various characteristic karst features, and being located at the crossroads of the civilized world from Central Europe (specially from Vienna) to Trieste, the Kras region became the locus of the first scientific research of karst morphology and hydrology in the 19th century. Most descriptions were published in the German language, using the German version of the name. Thus, Kras was the area that gave the scientific name to all similar land formations around the world, which is why the scientific community refers to this region as Classical Karst. (Kranjc, 2001).

This paper focuses on dolines. In American scientific publications, the term sinkhole is preferred (Gams, 2003). Dolines are a dominant surface feature on Karst and consequently a significant element of the Karst landscape. Being also the main source of fertile soil on Karst, they have always been an important part of traditional agricultural land use (Gams, 2003).

Present research is the current result of our work at the Institute of the Republic of Slovenia for Nature conservation (IRSNC) which includes regular

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Figure 1. Location of the Karst
Source: Kranjc, et al., 1999; original source: Institute of Geography Anton Melik ZRC SAZU

monitoring of protected areas. Karst is one of the larger nature protected areas in Slovenia because of its geomorphologic characteristics, biodiversity and scientific significance mentioned above. Consequences of recent rapid economic and social development are shown also through several negative impacts on nature protected areas. On Karst, according to Breg (2007) these result in tangible changes in the landscape, specifically the disappearance of geomorphologic features such as dolines. This paper presents some actual cases of misuse and degradation of dolines recorded during our field work. We discuss the need to adopt a more efficient protection system to ensure proper protection and preservation of landscapes of special importance. It concludes with some recommendations for further work.

Materials and Methods

For the purpose of this research recognizable methods and approaches for collecting, analysing and comparing of data were used. For collecting data different sources were used. Historic maps and pictures were analysed and compared to present orthophotos. Current laws and regulations concerning the discussed topic were examined. Contributions of the Syposium on Karst and Man were reviewed with special attention to researches made about human impact on dolines and Karst landscape in '70ies and '80ies. Findings were compared to recent publications of Slovenian authors discussing the problem, especially Breg (2007). To determine the extent of damage caused on protected area we used an accepted method of evaluation. Evaluation method is based on assessing the endangerment rate and loss of determinant characteristics that suit established criteria for recognizing a protected area. Determinant characteristics and criteria were defined in the Inventory of the most important Natural Heritage of Slovenia 2nd part: central Slovenia (1991). Our field work consisted in general field survey and examination of ongoing activities concerning the dolines. Known construction areas and locations of damaged dolines were examined in different periods of time. At the same time a search for new and not known damaged areas was going on. All the significant findings were recorded on camera; corresponding locations marked on the map and representatives of local population interviewed about use and misuse of dolines. The conclusions presented in this paper were drawn by the means of comparative and analytical approaches as well as personal observations.

Dolines formation and characteristics

Dolines are natural closed depressions on karst. Determined by subsurface drainage, they form either by dissolution of the surface of underlying bedrock, called solution dolines (solution sinkholes) (figure 2), or by the collapse of underlying caves within bedrock, called collapse dolines (collapse sinkholes) (figure 3) (Glossary of landform and geologic terms, 2008). Dolines come in many different sizes and shapes; they are commonly subcircular in plan and funnel-shaped, but they can also be elliptical or linear (Kochanow, 1999, Kranjc, 2006). Their overall form can range from pan-shaped to conical or even cylindrical. They range from a few metres to about a kilometre in middle surface diameter, with sides ranging from gently sloping to vertical (Gams, 2003, Kranjc, 2006). Consequently, their depth generally varies from a few metres to few tens of metres, but in the case of collapse dolines, they can be more than hundred metres deep.

Formation of dolines, their shape and size, their arrangement on the surface, and surface density is the result of different processes taking place and depends on various factors. Besides the rock

Figure 2. Typical solution doline, sinkhole on Karst
Source: Karst, 2008; author: Smrekar, A.

Figure 3. Collapse doline, sinkhole known as Risnik on Karst
Source: Kranjc, et al., 1999; author: Mihevc, A.

type, the rate and velocity of physical and chemical weathering of the bedrock also depends on the chemical composition of the limestone, rock formation processes (diagenesis), tectonic processes and underground drainage system or the mode and velocity of water percolation through the vadose cone (Kochanow, 1999). Comparing figures 4 and 5 we notice a high doline density on the on the figure 4 and almost no dolines present on the figure 5. On figures dolines could be seen as minus signs in ovals. The laws of gravity account occurrence: on the flat Karst plateau, water percolates vertically generating specific underground drainage, while surface water runoff prevails over vertical percolation on the angled slopes surrounding the plateau.

Due to their formation processes and characteristics, dolines represent one of the most important connections between karst surface and karst underground.

They are not only a surface geomorphologic feature but also a geological locality and a hydrologi-

Figure 4. High doline density on the plateau near village Krajna vas
Source: National topographic map (NTM) 1:25000; Digital orto-photo

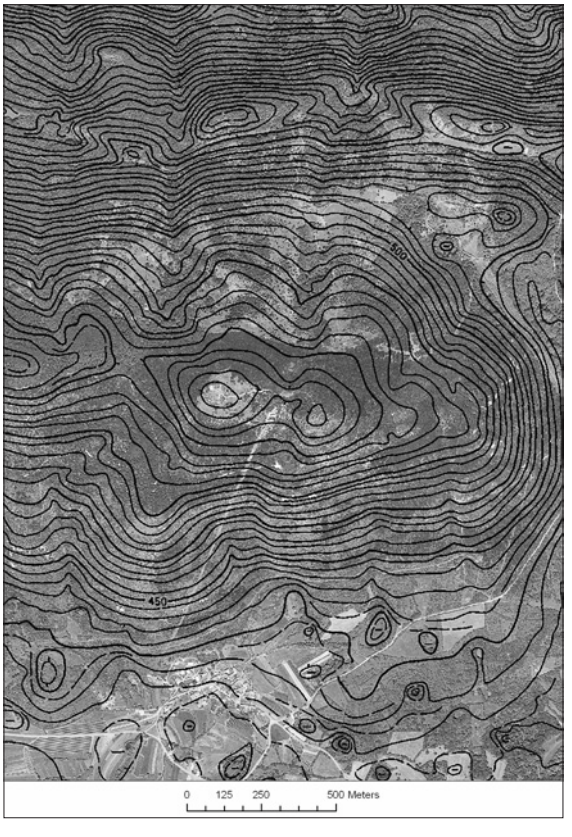

Figure 5. Slopes on the northern part of Karst plateau – dolines are rare
Source: National topographic map (NTM) 1:25000; Digital orto-photo

cal locality. Changes in depth affect microclimatic conditions which may vary significantly between the doline bottom and upper edge; therefore, dolines are also climate locality. In the bottom of the doline, a specific type of soil is formed (discussed in the next section) that affects the type of vegetation and also defines dolines as a pedologic and ecologic locality. (Breg, 2007).

Traditional use of dolines on Karst

One of the remarkable natural characteristics of Karst that we notice first is reddish coloured soil, called 'terra rossa' (synonym: 'jerina', 'jerovica'). It is actually loam, a non-soluble residue of dissolution of limestone bedrock and represents the most frequent type of soil on Karst. (Pavšič, 2006; Kladnik, et al., 2005). Red soil covers underlying limestone bedrock mainly in small, thin amounts suitable merely for pastures and meadows. Layers thick enough to be cultivated are only found in dolines and a few other concave features typical for Karst. (Kranjc, et al., 1999). Aware of limited resources, inhabitants have always considered dolines a significant part of traditional agricultural land-use and have transformed them in accordance with their needs.

Rocks were removed out of dolines manually and used to build stone walls at the doline margin or along existing routes and parcel borders. Usually a small field or a vineyard was placed in the doline's bottom as shown on figure 6. Sometimes small amounts of fertile soil were removed from the doline and used to improve the amount and quality of soil underlying vineyards around the villages and gardens. (Radinja, 1987a, Gams, 1987, 1999). Reddish coloured soil, pastures and meadows, stony walls, patches of forest, vineyards and small villages with tightly clustered houses all together formed a mosaic of the typically fragmented Karst landscape (figure 7). Dolines, whether cultivated or naturally preserved, are a significant element of this landscape.

Huge socio-economic changes after the Second World War, expressed mostly in industrialization, urbanization and deagrarianization, induced radical changes in the way of life (Radinja, 1987b). The Karst was no exception. Traditional agricultural methods were considered to be inefficient in adapting to new circumstances. The introduction of mechanical work and intensive cultivation demanded meliorations. Dolines were too small and widespread for efficient cultivation. Consequently they were abandoned and overgrown by vegetation. Intensive cultivation efforts were concentrated on meliorated areas closer to settlements (Radinja, 1987b). On figure 8 we see a view of transformed Karst landscape near village Komen; meliorated areas close to settlements, fragmented fields and pastures and abandoned dolines are shown.

Despite attempts to improve agrarian land use and increase production, the rocky and unleveled Karst terrain with densely placed dolines proved not to be an ideal background for such practices.

Figure 6. Traditional use of doline
Source: Cernatič, A., March 2010

Figure 7. Fragmented Karst landscape
Source: Kranjc, et al., 1999; author: Hanc, J.

By the mid 90s, land improvement projects were withdrawn and considerable fragmentation of Karst landscape was preserved.

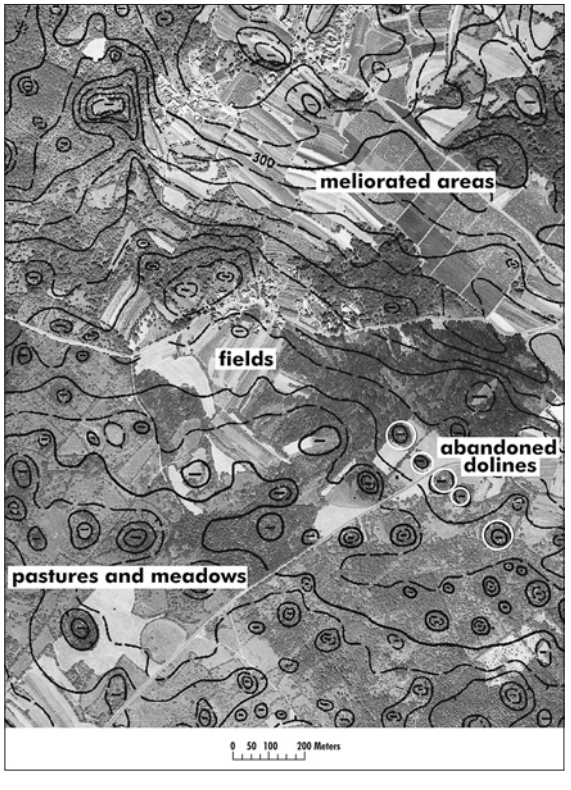

Figure 8. Karst landscape near village Komen
Source: National topographic map (NTM) 1:25000; Digital orto-photo

Degradation of dolines

Like many Central European Countries Slovenia has undergone several important challenges in the process of becoming independent and part of European Union in 2004. This has provided many advantages but also expectations, demands and, of course, issues. Aspirations for spreading and increasing capital have given rise to short-term and excessive economics. Junction of the European countries has brought forward advantages, like the development of international traffic connections, energy connections and logistic centres, international trade and free borders. However, achieved assets cause several conflicts. Negative impacts on the Karst have primarily been seen in the degradation of landscape features. Among them, the most vulnerable are the dolines (Breg, 2007).

Exavations

Vast mechanical soil excavations are literally empting the dolines, causing irreparable damage. To get to the doline bottom, tractor roads are being built on doline slopes. All accessible amounts of soil are carried out and taken away, for different proposes; preparing terrain for new vineyards, covering dump sites, selling soil to Italy, etc. Excavated slopes are steep, and erosion processes take over, making it impossible for vegetation to regrow. Emptied dolines are left damaged and often become convenient dumping sites. Figures 9 and

Figure 9. Doline during mechanical excavation
Source: Zega, M., March 2009

Figure 10. Doline after mechanical excavation
Source: Zega, M., March 2010

10 show the damaging of dolines during and after excavations.

Extinction and pollution

New infrastructure investments; like expansion of traffic and energy connections and construction of new logistic centres and industrial zones, demand extensive areas of flat terrain. Huge amounts of excavated material and other waste material are produced on construction sites every day. To obtain flat terrain and 'get rid of' waste materials numerous dolines have been filled completely, ''flattened'', and covered with constructions. The case of the Risnik industrial zone near town Divača (east part of Karst) is shown on figure 11. Waste material filling the dolines is usually not autochthonic sometimes even brought from Italian construction sites and quarries. In many cases hazardous waste (e.g. asbestos tiles) was recorded (figure 12), which according to current legislation should be disposed properly (Regulation on conditions under which, ... ,materials containing asbestos have to be removed). The problem becomes even more serious if we take in account the vulnerability of karst underground drainage system. Because water moves readily from the surface down through solution cavities and fractures it undergoes very little filtration and groundwater in limestone is easily polluted (Kochanow, 1999). Similarly, the rain water becomes leachate by percolating through disposed waste in dolines and ends up in underground water.

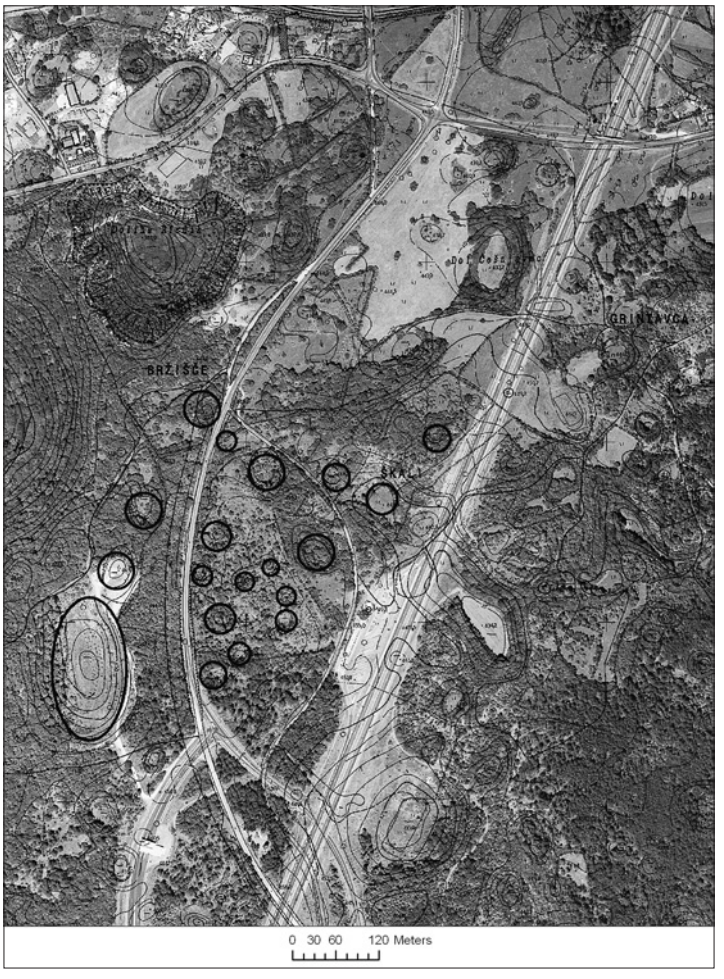

Figure 11. The view of the area before building the industrial zone Risnik with already extinct dolines and those slated for development marked
Source: Basic topographic map (BTM) 1:5000; Digital ortophoto

Figure 12. Dumping waste material in the doline near village Križ
Source: Zega, M., 2009

Figure 13. Filled doline Grižni dol near Divača town
Source: Zega, M., 2010

Results and Discussion

Based on field-work findings and recordings we determined that dolines are being filled and covered daily. Relief changing due to degradation is rapid and irreversible. In fact, no case of doline remediation has been documented so far. These activities take place not only in areas of big constructions but all over Karst, including non-populated and naturally preserved areas. There is absolutely no control, no documentation and no written evidence about the amount of material and waste being deposited or about the number of dolines that have undergone extinction as a result. Figure 13 shows a recently partially filled doline; it is about 210 m long, 135 m wide and 30 m deep.

The result of our evaluation showed that the loss of significant element of Karst landscape, in present case the dolines, leads to degradation and possible extinction of determinant characteristics that define Karst landscape. These determinant characteristics are: fragmented Karst landscape, unlevelled Karst relief, density and arrangement of Karst surface and subsurface geomorphologic features and related biodiversity.

As mentioned above documented activities lack of proper control and guidance completely. The main reason for this fault is in current legislation designed to protect only exceptional areas (Law on the conservation of nature). Thus, concerning the research area only some single dolines and restricted parts of Karst landscape are protected by law. This concept of protection is similar to what Breg (2007) recommended. She suggested dividing Karst in smaller "priority" protected areas in order to be able to provide better control over planned activities and more efficient protection of dolines (Breg, 2007). However, the result of our evaluation rises up doubts in the efficiency of protection based on divided protected areas. This concept of protection eliminates the majority of dolines and ignores the complexity of the Karst as whole. In case of dolines we believe that it is not possible to define a reasonable number of dolines that can be obliterated without causing an irreparable damage for Karst as whole. Besides, we seriously doubt in the reasonableness of such assessments and concepts when considering the importance of Karst as world phenomena.

Conclusion

Although Karst is recognized as a unique landscape that forms under specific conditions and is identified as a worldwide phenomena, a proper system of protection and conservation is not established. Degradation and loss of significant geomorphologic features of Karst landscape occur on daily basis. Among these the most vulnerable are the dolines. By the present day there are no known data about the number of dolines that have undergone extinction in the recent years. By our research and evaluation of the extent of dam-

age caused on Karst landscape by degradation of its significant features, we came to the conclusion that the loss of significant features leads to degradation and possible extinction of major characteristics that define Karst landscape. The main reason that disables proper protection is in current legislation designed to protect only exceptional and restricted parts of Karst. This kind of approach divides Karst in small protected areas and ignores the complexity of Karst as whole.

In future our intention is to use the present research for education purposes and to raise public awareness. Our plan is to involve the related scientific public and present the research to local authorities. Conservation advisors working at the Institute (IRSNC) are successfully collaborating with the recently formed Karst Civil Initiative that aspires to conservation of Karst landscape and sustainable development on Karst.

We believe that that Karst landscape recognized worldwide to be of special importance and its landforms should be considered as a non-renewable natural resource and a unique natural and cultural heritage and therefore properly protected at the international level.

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