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Sinkhole formation above underground limestone quarries: A case study in South Limburg (Belgium)

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Abstract

Historical records were used for the compilation of a database of sinkholes resulted from collapses of abandoned shallow underground limestone quarries (mines) in two villages in Belgian South Limburg. During the last 350 years the formation of such sinkholes caused at least 38 casualties, but more often it caused a change in topography and damage to public and private property. The objective of this study is to better understand the spatial and temporal patterns of quarry collapse-related sinkholes in the study area. Apart from sinkhole locations and ages, the compiled database provides information on the dimensions of the area affected and the damage caused by sinkhole formation, as well as the causal factors of sinkholes.

One hundred seventy-three sinkholes have been reported since 1665, but most (80%) reported sinkholes postdate 1965. Sinkhole dimensions provided information on the type of collapse. Seven large sinkholes, displacing a total sediment volume of 480,000 m^3, resulted from large-scale roof breakdown after pillar failure. The smaller sinkholes were the result of fall of the overburden into galleries after local roof collapse or suffosion of a solution pipe. In total, these small sinkholes displaced 12,300 m^3 of sediment. At present almost all large underground quarries in the study area have been affected by sinkholes. These features were caused by natural and anthropogenic factors, and occur in zones with thin roofs, where pillars were affected by pillar robbing, or on locations with inappropriate sewerage systems above quarries. The formation of sinkholes was often reported in spring during years with high moisture contents in the overburden, caused by high groundwater recharge or above average precipitation. With increasing time since quarry abandonment, quarries become more susceptible to pillar creep and bending of the roof. Hence, if no appropriate mitigation measures are taken to reduce such deterioration processes, the number of sinkholes is expected to increase.

Keywords: Underground limestone quarry; Sinkholes; Spatial distribution; Temporal patterns; Rainfall; Groundwater

1. Introduction

Sinkholes, formed by subsidence and cavern collapse in lithologies susceptible to karst such as limestone, gypsum and salt, occur worldwide, with notable examples in the USA (Hyatt and Jacobs, 1996; Langer, 2002; Johnson, 2005; Gao et al., 2005) and Europe (Forth et al., 1999; Delle Rose et al., 2004; Doğann,

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2005; Gutierrez et al., 2004; Jones and Cooper, 2005). They are generally fairly localized in extent and are usually recognized by an abrupt depression evident at the soil surface. Worldwide sinkhole formation has been responsible for extensive damage to many structures throughout the years (Department of Environmental Protection Pennsylvania; USA). Not only collapses of naturally dissolved caverns, but even more so collapses of underground quarries (mines) or other subsurface excavations such as cellars, sewers and tunnels frequently result in sinkholes (Gongyu and Wanfang, 1999; Cooper, 2002; Delle Rose et al., 2004; Merad et al., 2004; Bell et al., 2005). Previous investigations were often geotechnical studies that focused on the strength characteristics of underground quarries.

In Belgium, semi-natural active karst phenomena such as sinkholes are mainly recorded in a region around Tournai, west-central Belgium (Loy, 1983; Van Rentergem et al., 1994; Kaufmann and Quinif, 2002). In these cases paleokarst is reactivated by human-induced lowering of the groundwater table through pumping, which reduces buoyant support and increases groundwater flow towards the pumping well with removal of the paleokarst infillings. Isolated collapses of subsurface excavations have been reported in different places throughout central Belgium (Gullentops, 1952; Dusar and Hammenecker, 1993; Dusar and Lagrou, 2000; Delfosse, 2001).

This study focuses on sinkholes observed after quarry collapse in South Limburg, east-central Belgium (Fig. 1), a region where Maastrichtian limestone was extracted over the last millennium for building stones, lime production or soil amendment. In the region under study, most quarrying activities stopped early in the 19th century, but even at present sinkhole formation occasionally causes death, injury and damage (Fig. 2), and remind local residents and authorities that after the extraction activities the underground quarries remain in a marginally stable state. The worst catastrophe occurred on December 23, 1958 when 4 ha of the 20 ha Roosburg quarry (Riemst) collapsed, killing 18 persons who were growing mushrooms in the cool and humid galleries (Medaerts, 1998). More collapses during the following days affected at least additional 2 ha (Bekendam, 1998).

Although many of these historical sinkholes were reported in technical or popularising reports (e.g. Breuls, 1983) and local newspapers, so far no database of sinkholes in the region is available. By providing information on the location and age of the sinkholes as well as their dimensions, causal factors and damage, such a database would allow us to explain the processes of sinkhole formation, to create hazard maps and to define prevention and remediation measures. Therefore, this study aims at a better understanding of the spatial distribution and temporal patterns of sinkholes above underground limestone quarries in South Limburg. In order to meet this objective, this study includes (1) analysis of the location of sinkholes and timing of their formation, (2) determination of sinkhole dimensions, (3)

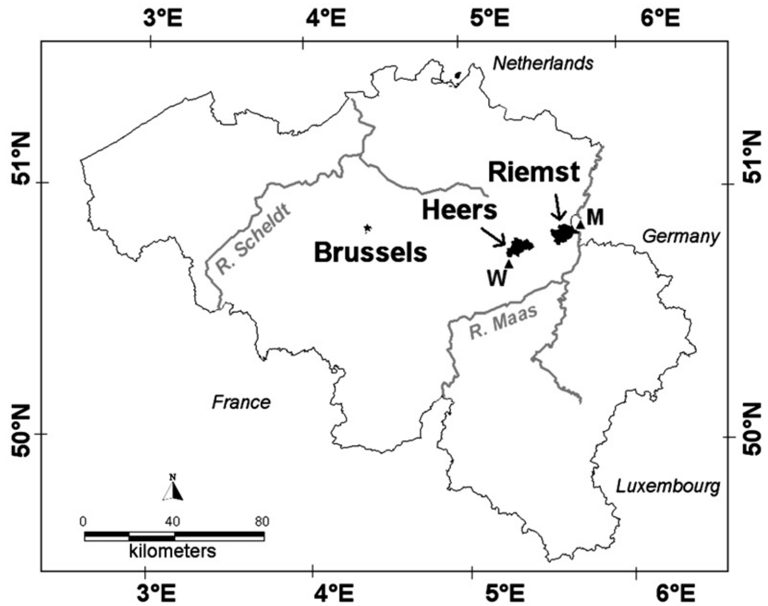

Fig. 1. Location of the two study areas, Heers and Riemst, in Belgium. Black triangles indicate the location of the rainfall stations at Waremme (W) and Maastricht (M; The Netherlands).