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A methodological framework to assess the socio-economic impact of underground quarries: A case study from Belgian Limburg

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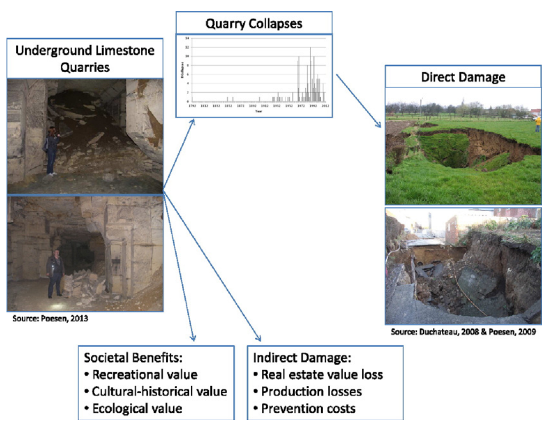
HIGHLIGHTS

- Presence and collapse of underground quarries has socio-economic consequences.
- Framework to assess different types of sinkhole-related damage and benefits
- Assessment of damages using repair cost and production and real estate value losses
- Assessment of recreational value using travel cost method
- Assessment of cultural–ecological value using contingent valuation

GRAPHICAL ABSTRACT



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ABSTRACT

This study developed a methodology to assess the socio-economic impact of the presence and collapse of underground limestone quarries. For this we rely on case study evidence from Riemst, a village located in Eastern Belgium and use both secondary and primary data sources. A sinkhole inventory as well as data about the prevention costs provided by the municipality was used. To estimate the recreational values of the quarries, visitor data was obtained from the tourist office of Riemst. Next, two surveys were conducted among inhabitants and four real estate agents and one notary. The direct and indirect damages were assessed using respectively the repair cost and production and real estate value losses. The total yearly direct and indirect damage equals €415 000 (±€85 000) and more than half of it can be attributed to the depreciation of real estate (€230 000). The quarries have recreational, cultural–historical and ecological values and thus generate societal benefits. The yearly recreational value was at least €613 000 in 2012 values. The ecological and cultural-historical values augment to €180 000 per year (in 2012 values). Further, our study indicates that the gains from filling up the quarries below the houses located above an underground limestone quarry outweigh the costs in the case study area. The net gain from filling up the underground quarry ranges €38 700 to €101 700 per house. This is only the lower bound of the net gain from filling up these underground quarries since preventive filling makes future collapses less likely so that future direct repair costs will be most likely smaller.

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1. Introduction

Worldwide, quarry activities lead to anthropogenic cavities. Due to anthropogenic and natural factors, sinkholes may form above these cavities (e.g. Parise, 2012; Van Den Eeckhaut et al., 2007). Sinkholes in general cause considerable damage to people, infrastructure and agricultural land and hereby induce costs, including direct costs to private and public property, indirect costs and intangible costs (e.g. Gutiérrez et al., 2014; Parise and Lollino, 2011; Sahu and Lokhande, 2015; Van Den Eeckhaut et al., 2007). For example in the case a house is affected by a sinkhole, direct losses refer to the costs of repairing or reconstructing the house and the injuries or fatalities caused by the collapse. Indirect damage includes the real estate value loss. In the case agricultural land is affected, direct damage refers to loss of agricultural output, while indirect damage may include decline of future productivity (output per hectare) due to the sinkhole formation. It is not only sinkhole formation that causes economic losses. The mere presence of underground quarries and the hazard of sinkhole formation, may already result in economic losses, particularly indirect damage due to real estate value losses.

Sinkhole risk can be reduced by limiting or prohibiting development in the most hazardous areas based on sinkhole susceptibility and hazard maps (e.g. Buttrick et al., 2001; Paukstys et al., 1999). However, this is not always a suitable strategy due to increases in human population which lead people to occupy more hazardous areas (e.g. Buttrick et al., 2011; Parise et al., 2009). Therefore, it may be more desirable and feasible to take corrective measures aimed at diminishing the formation of sinkholes or non-structural measures aimed at reducing or ameliorating the financial losses and harm to people (e.g. Gutiérrez et al., 2014; Jones and Blom 2014; Zhou and Beck 2011). To identify optimum mitigation strategies a cost–benefit analysis (CBA) needs to be made (Galve et al., 2012a). To assess potential losses, an assessment of the spatial and temporal probability of sinkhole formation is needed, as well as an assessment of the vulnerability of the elements at risk and an analysis of socio-economic sinkhole-related consequences. While sinkhole susceptibility and hazard studies are becoming more common (Argentieri et al., 2015; Galve et al., 2008; Guerrero et al., 2008; Ozdemir, 2015; Samyn et al., 2014; Taheri et al., 2015), few studies have concentrated on quantitatively analysing the socio-economic consequences of these features.

In a CBA, one compares the losses in a "without mitigation" scenario with the cost in the "with mitigation" scenario. The costs in the "with mitigation scenario" include the expenditures on mitigation plus the direct and indirect damage caused by sinkholes that cannot be prevented with the applied measures (residual risk). The benefits in the "with mitigation" scenario encompass the saved losses due to mitigation (Galve et al., 2012a,b) as well as the ecological and cultural benefits related to underground quarry stabilization measures. As such, a proper sinkhole-related damage assessment is needed to perform a CBA of mitigation measures. While a proper assessment of all sinkhole-related damage is needed, the losses – and particularly the indirect losses – are often difficult to identify and/or assess (Gutiérrez et al., 2014). As a consequence, many studies focus on qualitative or semi-quantitative damage assessments or focus only on one type of damage — typically direct damage (e.g. Sahu and Lokhande, 2015).

Therefore, the main goal of this study was to assess the socio-economic impact of the underground limestone quarries. In particular, we aim to develop a methodology to assess different types of sinkhole-related consequences. Previous studies indicated that mass movements such as landslides and sinkhole collapses have led to different types of damage (Markantonis et al., 2012; Papathoma-Köhle et al., 2015; Zêzere et al., 2008). Therefore, different types of data and methodologies were used to assess quantitatively their economic impact. Both direct as well as indirect damage is considered as well societal benefits linked to corrective measures aimed at diminishing the formation of sinkholes or non-structural measures aimed at reducing or ameliorating the financial losses and harm to people. All damage and benefits are expressed in monetary values as these allow comparison of all different types of costs and benefits. For this we rely on different valuation techniques, ranging from direct valuation approaches (cost-based and production function based approaches) to stated and revealed preferences approaches. The methodology is developed for a case study area in Belgium. However, this area stands as an example for many regions around the globe that are susceptible to sinkhole formation due to underground excavations. As such the methodology developed in this paper can be widely applied elsewhere.

The case study region is located in Eastern Belgium. Since Roman times, calcarenite limestone deposits have been exploited, first by opencast quarrying and later on by underground quarries in Eastern Belgium and South Eastern parts of The Netherlands (Medaerts, 2008). These limestone deposits are found at shallow depth and appeared to be an excellent building stone (Dusar et al. 2006). However, due to a combination of natural and anthropogenic factors, some quarries became unstable throughout time. This has led to the collapse of underground quarries with the formation of sinkholes as a consequence.

As the sinkhole-related costs have never been assessed in Belgium, this study aims to estimate the socio-economic consequences related to underground quarry collapses. For this we rely on case study evidence from the village "Riemst" located in Eastern Belgium. By 1958, around 200 ha was excavated in Riemst (Medaerts, 1998). The first documented sinkhole formation can be dated back to 1792 (Van Den Eeckhaut et al., 2007). One of the largest collapses took place on December 23, 1958 when the *Roosburg* quarry collapsed. At that time, several mushroom growers were working in the quarry and unfortunately this collapse caused the demise of 18 people. At least 3–4 ha of land was significantly deformed by subsidence or cracks caused by this collapse. After this event it was no longer allowed to grow mushrooms in the underground quarries and the extraction of calcarenite limestone shifted to an aboveground production (Medaerts, 1998). In the following years, new sinkholes formed which affected different types of elements (Fig. 1).

To quantify the socio-economic impact due to the presence of underground limestone quarries in Riemst, this study will assess (i) the direct, indirect and intangible damage, which includes a qualitative description of psychological damage due to the collapses, (ii) the forgone benefits in terms of recreational, cultural–historical and ecological values and (iii) the net benefits of possible preventive measures to limit future damage.

2. Study area

2.1. Location and characteristics

The municipality of Riemst (58 km^2) (Fig. 2A) consists of eleven boroughs/villages and lies in the South Eastern part of Belgian Limburg. Although other underground calcarenite limestone quarries can be found in the neighbouring municipality 'Heers' and in The Netherlands, this study focuses solely on Riemst because most (reported) sinkholes occurred in this municipality. Moreover, the quarries in Riemst are mainly located below residential areas which lead to high socio-economic damage when a quarry collapses (Van Den Eeckhaut et al., 2007). Fig. 2B, C and D shows for Kanne, Val-Meer and Zichen-Zussen-Bolder respectively (i.e. the three boroughs of Riemst where most calcarenite extraction has taken place) the extent of the quarries. The total excavated area is 200 ha, which corresponds to 3.45% of the surface area of Riemst, and the total length of the passages is ca. 400 km (Medaerts, 1998).

Riemst has a maritime temperate climate with an annual mean air temperature of 9.8 °C (Van Den Eeckhaut et al., 2007) and a mean annual rainfall of 764.7 mm as recorded in Maastricht, the most nearby measuring station (1983–2012; KNMI). Riemst has dry loamy soils because of the permeable chalk layers and the relatively large depth to the water