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Research paper

Setting rehabilitation priorities for abandoned mines of similar characteristics according to their visual impact: The case of Milos Island, Greece

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ABSTRACT

Mine rehabilitation is nowadays an essential part of the mine life-cycle. Nevertheless, due to the inadequate legislative framework and the lack of appropriate financial instruments in the past, abandoned mined land is present in almost all regions with a mining history. Especially in times of fiscal and financial belt tightening, where direct funding is almost impossible, the restoration of abandoned mines becomes a difficult task and, consequently, prioritization of the restoration projects is necessitated. So far, several models have been developed for that purpose. The existing models, however, usually underestimate that, especially for non-reclaimed mines located close to populated areas, landscape degradation generated by surface mining is a critical factor. To this end, this paper presents, through an illustrative example, a new approach providing the means for prioritizing mine restoration projects based on the visibility of surface mines with regard to the neighboring areas of interest. The proposed approach can be utilized as an additional module in existing prioritization models, or it can be used standalone when considering a group of surface mines where what distinguishes them from each other is primarily the disturbance of the landscape.

1. Introduction

The extractive resource industry plays an important role in the development of our modern societies, and, in many instances, acts as an important driver for regional and national economies. According to the International Council of Minerals and Metals, the mining and metals industry both at formal and informal scale employs more than 20 million people worldwide (ICMM, 2012). Moreover mining by its nature contributes to the socio-economic development of the host communities (Mhlongo & Amponsah-Dacosta, 2016). Nevertheless this comes at considerable cost due to the adverse environmental impacts of mining activities, such as deforestation, land surface deformation, biodiversity degradation and air, water and groundwater pollution. Aiming at restoring the disturbed land to its initial state and preventing or mitigating the negative effects of extractive activities, mine rehabilitation is carried out as the last and final among the various phases of mining activity life-cycle (Doley & Audet, 2013; Heikkinen, Noras, & Salminen, 2008). However, due to the inadequate legislative framework and the lack of appropriate financial instruments (e.g. reclamation bonds) in the past, land degradation attribute to extractive operations is present in almost all regions with a mining history (Damigos, 2011). The abandoned mines are formally sites where works have halted and "… *mining leases or titles no longer exist and responsibility for rehabilitation cannot be allocated to any individual, company or organization responsible for the original mining activities* …" (MCMPR & MCA, 2010). Until today, there is no official global inventory of abandoned mines, although, several countries, with Canada, USA and Australia amongst the most prominent of them, are leading the way towards adequate abandoned mine sites inventory creation (Unger, Lechner, Kenway, Glenn, & Walton, 2015). For instance, estimates for the number of abandoned mines in the USA vary from 200,000 (USEPA, 2000) to as high as 557,650 (Struhsacker & Todd, 1998). In Europe, Slovakia has registered more than 17,000 old mining sites and Hungary has reported some 6,000. In Bosnia and Herzegovina the total area affected by mining activities is 330,000 ha. In the Czech Republic, the area of land devastated mainly by mining operations reaches about 9,500 ha, and in Georgia, 15,000 ha (UNCCD, 2000).

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The environmental concerns related to mining activity are more apparent and, usually, more intense in the case of abandoned mines and reflect the difficulties involved in their rehabilitation. According to UNEP and COCHILCO (2001), the rehabilitation of abandoned mines struggles with the lack of clearly assigned responsibilities, the absence of criteria and standards of rehabilitation, and the potential high cost of rehabilitation. Most importantly, abandoned mine rehabilitation projects suffer from lack of funds, as the economic phase of the mine will have ceased (Mhlongo & Amponsah-Dacosta, 2016). The only valid possibility is that of public funding from national governments, state agencies or regional authorities. Even then, however, the funds could not be adequate for all the abandoned sites and the vital question is how the sites will be prioritized during the decision making process.

Numerous studies point the necessity of methodological tools for the prioritization of reclamation programs (a more detailed discussion can be found in Kubit, Pluhar, & De Graff, 2015). For instance, Gorokhovich, Reid, Mignone, and Voros (2003) presented a GIS-based methodology for prioritizing the reclamation of abandoned coal mines in the United States. Mayes, Johnston, Potter, and Jarvis (2009) introduced a national strategy for the prioritization of abandoned quarries in England based on the environmental and socio-economic factors. Similarly, Hagiou and Konstantopoulou (2010) developed a methodology for environmental planning of abandoned quarry rehabilitation based on multicriteria analysis and GIS. Mhlongo, Amponsah-Dacosta, and Mphephu (2013) developed a rehabilitation prioritization methodology through hazard maps compilation. Finally, Kubit, Pluhar, and De Graff (2015) developed a model for assisting decision-making process in a transparent way incorporating factors such as reclamation methods and the applicability and validity of them. The model addresses different methods to reclaim land disturbance and mine waste piles through topographic reconstruction.

The existing models are usually based on scoring systems that represent the most common and significant environmental, human health, and public safety hazards found at abandoned mines. Some of the models display deficiencies in terms of lack of transparency, absence of important parameters and reclamation methods, and/or lack of model calibration (Kubit, Pluhar, & De Graff 2015), Others, however, tend to work well and consist valuable assessment tools towards identifying higher priority sites (ibid.). What is usually underestimated in existing models, however, is that the landscape degradation remains one of the most significant environmental impacts generated by surface mines and quarries. For this reason, it should gain considerable attention, especially for operations located close to populated areas, as it strengthens public's reactions against surface mining (Dentoni & Massacci, 2013; Menegaki & Kaliampakos, 2006, 2012). So far, significant attempts have been made to quantify the visual impacts from mining activities on the original landform in terms of shape or chromatic contrast (e.g. Dentoni & Massacci, 2007, 2013; Dentoni, Grosso, & Massacci, 2015; Menegaki & Kaliampakos, 2006, 2012). Other studies have investigated the visual preferences in mining landscapes by using photograph ranking and questionnaires (e.g. Sklenicka & Molnarova, 2010; Svobodova, Sklenicka, & Vojar, 2015; Svobodova, Sklenicka, Molnarova, & Salek, 2012) or by resorting to soft computing methods, such as the Fuzzy Cognitive Mapping (FCM) method (Misthos, Messaris, Damigos, & Menegaki, 2017). Yet, these approaches can be data-demanding and time-consuming.

Keeping in mind the abovementioned considerations, the paper seeks to expand the existing dialogue in the field of models and tools used for the prioritization of reclamation programs for abandoned mines. More specifically, it describes an approach to setting ranking priorities for abandoned mines based on the visibility of the non-reclaimed operations to neighboring areas of interest. The priority list deriving from the proposed approach can be utilized as an additional parameter in existing multicriteria prioritization models. Further, it can be used standalone when considering a group of surface mines with similar characteristics (e.g. a group of coal mines or a group of marble quarries) where what distinguishes them from each other is primarily the disturbance of the landscape. In order to keep the process as simple as possible, the proposed model does not attempt to quantify aspects of visual impacts caused by mining and quarrying works, such as alteration of topographic relief, chromatic contrast, etc., or to identify the visual preferences of the public for mining landscapes. It takes for granted that the presence of non-reclaimed mines is perceived very negatively by observers and is a fundamental contributor to the negative perception of the whole landscape (e.g. Svobodova et al., 2012), and, thus, it emphasizes on the visibility of mined land from points of interest, e.g. inhabited areas, archeological sites, etc.

To achieve its purpose, the proposed model is based on an existing methodology, namely LETOPID, which has been modified accordingly by the authors. The LETOPID (Landscape Evaluation Tool for Open Pit Mine Design) has been developed by the Laboratory of Mining and Environmental Technology (LMET) of the National Technical University of Athens (NTUA). It quantifies the sensitivity of viewing conditions based on the main principles of Visual Impact Assessment approaches and utilizes modern GIS tools (Menegaki & Kaliampakos, 2005; 2012).

The rest of the paper is structured as follows: Section 2 describes the materials used and the methodology developed for prioritizing the restoration projects (or project requests). Section 3 provides the results of an illustrative example of the methodology in the case of Milos Island, Greece, where a lot of active and abandoned mines coexist with tourism activities. Section 4 discusses the results of the illustrative application. Finally, Section 5 summarizes the main conclusions drawn from this research.

2. Materials and methods

2.1. Methodological description

The methodology developed introduces the Visibility Ranking Index (VRI), which estimates the visibility of surface mining operations with regard to the places of interest (henceforward "town" given that the main interest in this research lies in the visibility of abandoned quarries from inhabited areas) in the surrounding area. The estimation of the VRI is accomplished through the quantification of four selected sub-indices, namely: the Observation Intensity (OI), the Excavation Exposure (EE), the Relative Visibility (RV) and the Relative Surface (RS), as detailed hereinafter.

2.1.1. Definition and estimation of the proposed sub-indices

The Observation Intensity (OI) value is estimated using the results of the viewshed analysis (see Section 2.1.2). Each point located in the quarry sites is weighted by means of two different categories of weighting factors: (i) the visibility field extend to the town, and (ii) the influence of the distance between the quarry cell and the town.

The visibility field extend (VFE) of each quarry cell (vfe_i) from each and every possible observation point within the town (v_i) is estimated, as follows (Eq. (1)):

$$vfe_i = \frac{v_i}{k} \tag{1}$$

where v_i is the number of town cells (i.e. observation points) that