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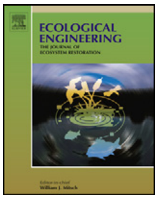

Evaluating mining landscape: A step forward

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ABSTRACT

Land rehabilitation constitutes an integral part of surface mining design aiming at returning the mined-out area to its former suitability to accept new land uses. The effectiveness of alternative rehabilitation plans depends on many parameters, the majority of which can be quantified in physical terms. One of the most difficult issues to deal with, however, is still the impact on the landscape during the operation and the improvement achieved after rehabilitation of the mine site. Towards this direction, the paper presents, through an illustrative example, a new method for the quantitative evaluation of the impacts on the landscape. This method, named LETOPID, focuses on the measurement of two main parameters: (i) the alteration of topographic relief and (ii) the sensitivity of observation conditions, both making use of GIS tools. The arithmetic values produced for each of the above parameters facilitates the discrimination of seemingly similar alternative design and rehabilitation plans.

1. Introduction

Land rehabilitation, implying the re-establishment of a stable and self-sustaining ecosystem and utilization of the site for its proposed land use after mining activities (Zellmer and Wilkey, 1979), is a compulsory task and at the same time a complex issue to solve. Toy and Daniels (2000) mention that the reclamation process of a degraded landscape consists of 10 sequential steps: (1) site characterization, (2) reclamation planning and engineering, (3) material management, (4) topographic reconstruction, (5) replacement of topsoil or soil substitute, (6) surface manipulation, (7) addition of soil amendments, (8) revegetation, (9) irrigation, if needed, and (10) site monitoring and maintenance. Within this process, the reprofiling of the landform holds a significant role, given that "the resulting landscapes are the foundations for all other reclamation practices and the surfaces for future land uses" (Toy and Chuse, 2005).

The complexity of the problem has led to an important effort worldwide for the development of techniques that could deal with the various aspects of mined land rehabilitation. As a result of this effort, there are recommended practices for soil management, erosion control, slope stabilization, species selection, seed collection, nursery establishment and maintenance, seeding and planting strategies, weed control, fauna attraction and other aspects of rehabilitation techniques (Neri and Sánchez, 2010), the effectiveness of which can be evaluated and even measured in quantitative terms. In the case of geomorphologic improvements, the primary tool so far has been the assessment of the visual quality of the landscape, which is measured by a variety of methods that evaluate the landscape character based upon landscape features (Bishop and Hull, 1991; Lothian, 1999).

Nevertheless, most of the existing visual impact assessment (VIA) methodologies are semi-quantitative and conclude in visual quality objectives or in visual sensitivity classes (e.g. USDA, 1973; BLM, 1980; PBC, 1997) without being capable of assessing the magnitude of impact caused by mining activity or the improvement achieved by different rehabilitation schemes. Hence, they provide little help in the context of modern mining environmental management. Moreover, expert landscape quality assessments have been criticized for having inadequate levels of precision (Daniel and Vining, 1983).

A key factor in achieving better results is the development of procedures capable of quantifying the various aspects of visual impact (Bishop, 1997). As Daniel (2001) notes, it is not sufficient simply to determine which landscape condition is aesthetically better, we must also know how much better. The evolution of Geographic Information Systems (GIS) gave rise to the development of new, more objective visual assessment procedures based on the use of maps as a source of information about the seen landscape. One of the drawbacks of the visibility analysis methodologies based on GIS, however, is that they introduce a level of uncertainty in the viewshed size, as not all of the targets of the terrain are used to compute visibility. In addition, the sensitivity as well as the number of viewers is not taken into consideration (Menegaki, 2003).

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Bearing in mind the abovementioned remarks, the paper describes a new method for the quantitative evaluation of the impacts of opencast mining on the landscape and the improvement achieved by alternative rehabilitation plans, called LETOPID (Landscape Evaluation Tool for Open Pit Mine Design). The methodology, which has been developed by the Laboratory of Mining and Environmental Technology (LMET) of the National Technical University of Athens (NTUA), is based on the main principles of VIA approaches and takes advantage of modern tools such as contemporary mining software and GIS (ibid.). The results are quite promising since it is proved that the methodology developed is capable of providing a coherent framework for the design and the evaluation of surface mining installations during all stages of mine's life (i.e. design, operation and closure).

To validate the methodology, a case study of an aggregate quarry site has been used. The quarry has been abandoned after massive exploitation, which took place during the last decades, causing serious environmental impacts. Two alternative rehabilitation plans have been proposed. In the paper the plans are evaluated with regard to the landscape improvement achieved in each case.

2. Methodological approach

The intrusion into the landscape by surface mining is attributed to the drastic change of topographic relief. The degree in which this change becomes perceptible depends on the number as well as the sensitivity of the viewers. Based on these commonly accepted assumptions, the LETOPID focuses on the measurement of two main parameters: (i) the alteration of topographic relief and (ii) the sensitivity of viewing conditions.

2.1. Measurement of the topographic relief alteration

For the measurement of the topographic relief alteration (TRA) five indices have been formed, namely the Landform Index (LI), the Altitude Index (AI), the Adjusted Landform Index (ALI), which is produced as a combination of the LI and AI, the Slope Index (SI) and the Aspect Index (AsI). Each one of these indices determines the average alteration of specific landform characteristics due to the surface mining activities. The necessary data for the calculation of each of the indices formed results from Digital Terrain Models (DTMs) created for the original contour and the surface under investigation (Menegaki and Kaliampakos, 2006).

The Landform Index (LI) is a quantified measure of the association between the original and the final surface. The LI examines whether the excavation or the reformed land follows the lines of the original contour. The development of the LI is based on spatial statistics and random variables theory. On this basis, the properties $z(x)$ (e.g. elevation, slope, etc.) of a certain point are random variables and the landform is considered to be the realization of a random function. Hence, landform is considered to be a regionalized phenomenon and each point property $z(x)$ is treated as a regionalized variable. On the ground of the above, both the original contour and the final shape of excavation or rehabilitated land constitute two regionalized phenomena, for which the degree of their association must be found. LI is estimated according to the following equation:

$$\mathrm{LI} = \frac{\mathrm{var}(Z_{\mathrm{orig}}) + \mathrm{var}(Z_{\mathrm{fin}}) - 2\mathrm{cov}(Z_{\mathrm{orig}}, Z_{\mathrm{fin}})}{\mathrm{var}(Z_{\mathrm{orig}}) + \mathrm{var}(Z_{\mathrm{fin}})} \quad (1)$$

where Z_{orig} = altitudes of the original topography, $\mathrm{var}(Z_{\mathrm{orig}})$ = variance of the variable Z_{orig}, Z_{fin} = altitudes of the final topography (excavated or rehabilitated), $\mathrm{var}(Z_{\mathrm{fin}})$ = variance of the variable Z_{fin}, $\mathrm{cov}(Z_{\mathrm{orig}}, Z_{\mathrm{fin}})$ = covariance of the variables Z_{orig} and Z_{fin}.

In the case where a uniform vertical shift of the original contour takes place, the two surfaces vary together, which means that $\mathrm{var}(Z_{\mathrm{orig}}) = \mathrm{var}(Z_{\mathrm{fin}}) = \mathrm{cov}(Z_{\mathrm{orig}}, Z_{\mathrm{fin}})$. In this case, LI equals 0, as follows:

$$\mathrm{LI} = \frac{2\mathrm{var}(Z_{\mathrm{orig}}) - 2\mathrm{var}(Z_{\mathrm{orig}})}{2\mathrm{var}(Z_{\mathrm{orig}})} = 0 \quad (2)$$

The latter indicates an ideal situation where the exploitation has changed the topographic relief only vertically without disturbing the continuity of the original contour. The LI is classified into 10 categories, where category 1 denotes the best condition and category 10 the worst.

The Altitude Index (AI) is set as a corrective index to the LI and measures the vertical change of the topographic relief on the assumption that no other change has occurred. For that reason, the mean altitude of the final surface is estimated and a new surface is created ($Z_{\mathrm{pseudofin}}$), which differs from the original surface only in elevation. The AI measures the deviation of the sampling points of the two surfaces (original and pseudo-final relief) from the mean altitude of the original surface and is described as follows:

$$\mathrm{AI} = \left(\frac{\sqrt{\sum_{i=1}^{\nu} (Z_{\mathrm{pseudofin}^i} - \mathrm{mean}\, Z_{\mathrm{orig}})^2}}{\sqrt{\sum_{i=1}^{\nu} (Z_{\mathrm{orig}^i} - \mathrm{mean}\, Z_{\mathrm{orig}})^2}} - 1 \right) \times 100 \quad (3)$$

where $Z_{\mathrm{orig}^i} = \text{point elevation of the original terrain at } X, Y$ coordinates, $Z_{\mathrm{pseudofin}^i} = \text{point elevation of the pseudo} - \text{final terrain at}$ X, Y coordinates, mean Z_{orig} = average altitude of the original terrain.

The AI is also divided in 10 value classes, where class 1 denotes the best condition and class 10 the worst.

The Adjusted Landform Index (ALI) is a linear function of the LI and AI, as follows:

$$\mathrm{ALI} = 0.8 \times \mathrm{LI} + 0.2 \times \mathrm{AI} \quad (4)$$

The ALI is classified into 10 categories, ranging from value 0.1 to value 1.0. The value 0.1 stands for the best condition, meaning very low landform alteration, whereas value 1.0 stands for the worst condition, meaning very high landform alteration.

Slope Index (SI) estimates the average slope difference between the original and the final surface and is calculated, as follows:

$$\mathrm{SI} = \frac{1}{\nu} \sum_{i=1}^{\nu} \frac{|S_{\mathrm{orig}^i} - S_{\mathrm{fin}^i}|}{90^{\circ}} \quad (5)$$

where S_{orig^i} = slope of the original surface at the sampling cell i, S_{fin^i} = slope of the final surface at the sampling cell i.

The denominator indicates the maximum inclination of a sampling cell towards the horizontal level and is used in order to normalize the results. SI is classified into 5 categories, based on the slope categories that usually occur in open pit designs, where category A denotes the best condition and category E the worst.

The Aspect Index (AsI) measures the average aspect change between the original and the final topography and is estimated, as follows:

$$\mathrm{AsI} = \frac{1}{\nu} \sum_{i=1}^{\nu} \frac{|\mathrm{As}_{\mathrm{orig}^i} - \mathrm{As}_{\mathrm{fin}^i}|}{180^{\circ}} \quad (6)$$

where $\mathrm{As}_{\mathrm{orig}^i}$ = aspect of the original surface at the sampling cell i, $\mathrm{As}_{\mathrm{fin}^i}$ = aspect of the final surface at the sampling cell i.

The denominator indicates the maximum aspect alteration (clockwise or counterclockwise) of a sampling cell and is used in order to normalize the results. AsI, after the study of numerous exploitation cases, is classified into 4 categories, where category A denotes the best condition and category D the worst.