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Exploring the perceived intrusion of mining into the landscape using the fuzzy cognitive mapping approach

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ABSTRACT

Fuzzy Cognitive Mapping (FCM) is a popular method used towards studying the structure and behaviour of complex systems in a wide range of applications. This paper presents the first application of FCM in exploring factors affecting the perceived nuisance caused by the impact of mining projects on the landscape. To this end, a team of experts in mining and landscape engineering was recruited to develop the conceptual model of the "mining-landscape-society" system. The individual Fuzzy Cognitive Maps (FCMs) were not significantly different among the experts, as regards the graph theory indices, and the most central concepts reported were related to the socioeconomic profile of the surrounding area, the characteristics of the mining project, and the characteristics of the landscape. The construction and analysis of the collective FCM offered further insights into the understanding of the system and allowed the analysis of its concepts by means of dynamic model inference. The FCM framework proved to be helpful in identifying and quantifying the factors interacting in the "mining-landscape-society" system and offered the ability to study the role and significance of central concepts in the overall system behaviour. In this sense, it is claimed that FCMs could significantly improve the domain of visual impact assessment related to mining activity. Nevertheless, much work remains to be done in order to improve the model and produce more reliable maps. Future efforts should be built on larger groups of experts from different disciplines as well as on non-experts who influence environmental decision-making.

1. Introduction

Landscape is a fuzzy concept taking different meanings depending on the context and scientific domain (González et al., 2014). For instance, in the Landscape Ecology tradition, landscape is considered "*a kilometers-wide mosaic, over which local ecosystems recur*" (Forman, 1995: 20). Its description, analysis and subsequent evaluation is actualized by metrics quantifying its plannimetric and vertical heterogeneity (O'neill et al., 1988; Turner et al., 2001; Morzaria-Luna et al., 2004; McGarigal et al., 2012). However, such metrics characterizing a landscape *per se* do not seem to grasp what landscape 'really' is. The current landscape approach in terms of management, planning, policy and design has adopted the European Landscape Convention (ELC) definition, according to which landscape is "*an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors*" (Council of Europe, 2000). As Ode et al. (2008) note, this definition stresses the importance of human experience and perception in capturing and evaluating the landscape's character. Under this perspective, landscape befalls in the category of socio-ecological systems. Such complex systems require sophisticated "methods or tools that support holistic understanding and management" and employ "soft systems methodology for analyzing and depicting human perceptions" (Wildenberg et al., 2010).

A special case of landscape analysis and evaluation pertains to the landscape and visual impact assessment (LVIA) (Swanwick, 2002; Churchward, 2013) of areas 'dominated' by open pits, in particular (Misthos and Menegaki, 2015). Such mining/post-mining landscapes, "with their specific and extreme character", exhibit certain characteristics differentiating them from the more common cases of agricultural, forest or urban landscapes (Sklenicka and Molnarova, 2010: 424). More specifically, surface mining activities and operations are connected with major landscape alteration (Dentoni et al., 2006; Dentoni and Massacci, 2015) being rated as "significant landscape offenders" due to "their geomorphological and aesthetic effects" (Menegaki and Kaliampakos, 2006: 185). In other words, the changes induced upon the landscape by mining activities are obvious and intense (Gagen, 1992), while the

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respective landscape and visual impact generates adverse reactions among “affected populations”, i.e. potential observers, “influencing the socioeconomic development of the surrounding impact territory” (Dentoni and Massacci, 2015: 527). Therefore, the landscape and visual impacts from surface mining activities are widely acknowledged. Yet, this ‘common knowledge’ is informative only in a qualitative and aggregate manner and level. In fact, the scientific research in this domain lacks: i) quantitatively specified criteria or thresholds whereby the visual impacts from mining landscapes can be definitely rated as acceptable/not acceptable and ii) adequate exploration of factors and variables contributing to this visual impact and investigation of their interrelations.

The literature review reveals some significant attempts to quantify landscape (topographic) alteration and viewing sensitivity (Menegaki and Kaliampakos, 2006, 2012), or the extent of the visible excavation and its chromatic contrast compared to the elements of the surrounding landscape (Dentoni and Massacci, 2007, 2013, 2015; Menegaki et al., 2015). Other research studies investigate the visual preferences in post-mining landscapes towards their evaluation by means of photograph ranking and questionnaires (e.g. Sklenicka and Molnarova, 2010; Svobodova et al., 2012, 2015). Since the assessment of such visual impacts is a multifarious issue involving, *inter alia*, “individual perceptions, aesthetic tastes and visual comprehension” of observers (Dentoni and Massacci, 2015: 527), it follows that aesthetic or visual nuisance is a vague notion with legal status and juridical history, however, chiefly construed as “an interference with the use and enjoyment of land” (Coletta, 1987: 142; Smith and Fernandez, 1991). In a practical context, when individuals claim aesthetic nuisance, that is “injury to their visual sensibilities”, the legislative impasse becomes prominent; “aesthetics is just too subjective a field on which to base an action in nuisance: [. . .] what is visually offensive to one individual may be visually exhilarating to another” (Coletta, 1987: 141). This apparent subjectivity of tastes and preferences is intermingled with other aspects/factors, such as economic ones, which, in their totality, regulate and shape the combined ‘perceptions’ or ‘attitudes’ of individuals. For instance, the economic exigencies of society significantly regulate land-use conflicts (Smith and Fernandez, 1991) while visual nuisance is sometimes subsumed under the class of negative externalities (Gouguet and Barget, 2006). The complex and subjective character of deciding whether, under what conditions (cognitive, socio-economic, and demographic) and to what degree the presence of an open pit causes visual nuisance could be investigated by resorting to soft computing methods and techniques capable of analyzing and visualising human perceptions and complex decision making problems, such as the Fuzzy Cognitive Mapping (FCM) method (Wildenberg et al., 2010; Kontogianni et al., 2013).

In this direction, this paper presents the first effort to explore the factors influencing human perceptions with respect to the nuisance provoked by mining-induced impacts to the landscape. More specifically, two objectives are formulated. Firstly, the factors/concepts involved in the exploration of the perceived visual nuisance in mining landscapes are to be delineated by a team of experts having knowledge and experience on the field. Secondly, experts’ valuable assistance is to be utilised in determining the interconnections of the occurring FCM (Kosko, 1992; Stylios and Groumpos, 1999) providing a compound schematic and semi-quantitative account of the manner in which the interconnected factors influence visual nuisance.The rest of the paper is structured as follows: Section 2 provides the theoretical and practical background of the FCM approach. Section 3 discusses the usefulness and limitations of the FCM approach with respect to the visual impact assessment of mining landscapes. Section 4 presents the application of the FCM approach with the involvement of experts towards better understanding the interlinkages and interdependencies of factors influencing a person’s perception of visual impact on the landscape due to mining works. Finally, Section 5 concludes with the main findings drawn from this study and the awaiting challenges for future work.

2. The FCM approach

2.1. Fuzzy cognitive maps

Cognitive maps were introduced by political scientist Robert Axelrod (1976) to represent social scientific knowledge and model decision making in social and political systems. However, since real-life parameters considered, rarely have crisp – but rather exhibit fuzzy – boundaries, Kosko (1986) proposed *Fuzzy Cognitive Maps* (*FCMs*) constituting an extension of cognitive maps by embedding to them the use of Fuzzy Logic. FCMs are interconnected, signed directed graphs consisting of nodes and edges/connections “*for representing causal relationships among concepts that stand for the states and variables of [a] system, emulating the cognitive knowledge of experts on a specific area*” (Kosko, 1986; Kandasamy and Smarandache, 2003; Angélico et al., 2013: 221). In FCMs, the connections are assigned fuzzy causal functions with real numbers in [−1, 1], instead of binary causal functions (Kosko, 1986). Furthermore, FCMs also encompass computational inference processing for analyzing and modelling both static and dynamic scenarios of a system (Kosko, 1986; Amer et al., 2011). In this sense, a FCM could be regarded as a combination of Fuzzy Logic, “efficient in representing heuristic, commonsense rules” and Neural Networks, “efficient in learning heuristics” (Kosko, 1992; Stylios and Groumpos, 1998: 339).

Graphically, FCMs – being signed directed graphs – consist of nodes representing the concepts or factors used to describe the behaviour of a system, while the connecting edges represent the causal relationships among concepts as weighted arcs, taking values in the interval [−1, 1]. More explicitly, FCMs consist of nodes, i.e. concepts, C_i, $i = 1\ldots N$, where N is the total number of concepts. Each interconnection between two concepts C_i and C_j has a weight, a directed edge W_{ij}, which is similar to the strength of the causal links between C_i and C_j. W_{ij} from concept C_i to concept C_j measures how much C_i causes C_j. The direction of causality indicates whether the concept C_i causes the concept C_j or vice versa. Each FCM can be expressed as a fuzzy comparison *adjacency matrix* [E], where each concept/variable is compared with one another according to causal relationships. According to Papageorgiou and Kontogianni (2012) there are three types of weights:

- $W_{ij} > 0$ indicates a positive causality between concepts C_i and C_j; the increase (decrease) in the value of C_i leads to the increase (decrease) on the value of C_j.
- $W_{ij} < 0$ indicates an inverse (negative) causality between concepts C_i and C_j; the increase (decrease) in the value of C_i leads to the decrease (increase) on the value of C_j.
- $W_{ij} = 0$ indicates no causality between C_i and C_j.

2.2. FCM structural analysis based on graph theory

FCMs’ structural properties can be analyzed by making use of Graph Theory and social networks analysis on the basis of their matrix representation (Özesmi and Özesmi, 2004; Papageorgiou and Kontogianni, 2012). Several indices such as density, indegree, outdegree, centrality, complexity and hierarchy can be derived in order to explore the complexity level and the relative importance of each individual concept within each FCM network.