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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 are visible from the quarry cell i and k is the total number of town cells, based on the 100-m DTM.

For a given quarry cell i, if $vfe_i = 0$ then the specific cell is invisible from the town and if $vfe_i = 1$ then it is visible from all the town cells.

Considering the main principles of visibility impact assessment (VIA) methodologies and the guidelines set by the Greek legislative framework (OGG, 1980) concerning the visibility distance zones, the surrounding area is subdivided into tree zones (i.e. observation distances), namely 0–2 km; 2–5 km; and 5–8 km. A weighting factor is attributed to each and every quarry cell (od_i), according to the distance zone that it is located at with regard to the town, as follows (Eq. (2)):

$$od_i = d_i \tag{2}$$

where d_i is the weighting factor of the distance zone that the specific cell is located, as defined by Table 1.

The overall value of the Observation Intensity (OI) index for a quarry site is given, as follows (Eq. (3)):

$$OI(\%) = \frac{\sum_i^V V_i}{V_{\max}} \cdot 100 \tag{3}$$

where V_i is estimated by $vfe_i \cdot od_i$ and $V_{\max}$ is the maximum value obtained on the assumption that all the quarry cells are visible from all observation points ($vfe_i = 1$ for every cell within the quarry) and the quarry site is located at the foreground ($od_i = 1$ for every cell within the quarry).

The excavation exposure (EE) of each quarry site is defined according to Eq. (4):

$$EE(\%) = \frac{n_{vis}}{n_{all}} \cdot 100 \tag{4}$$

where n_{vis} is the number of cells of the quarry site that are visible from even one observation point and n_{all} is the total number of cells of the abandoned quarry.

When two or more quarry sites are situated within the distance zone of 8 km from the town, the Relative Visibility (RV) and the Relative Surface (RS) indices are developed in order to make the results comparable across quarries. These two indices are estimated, as follows (Eqs. (5) and (6)):

$$RV(\%) = \frac{n_{vis}}{n_{vall}} \cdot 100 \tag{5}$$

where n_{vis} is the number of cells of the quarry site that are visible from the town and n_{vall} is the total number of visible cells of all the quarries within the distance zone of 8 km.

$$RS(\%) = \frac{n_{all}}{n_{qall}} \cdot 100 \tag{6}$$

where n_{all} is the total number of cells of the quarry and n_{qall} is the total number of cells of all the quarries within the distance zone of 8 km.

Finally, for every quarry site located in the surroundings of a town (or every other place of interest), the Visibility Ranking Index (VRI) is calculated according to Eq. (7):

$$VRI(\%) = OI \cdot EE \cdot RV \cdot RS \tag{7}$$

In this way, a unique arithmetic value is attributed to each quarry site that incorporates the visibility of the quarry on a specific place of interest and provides its priority ranking in case of limited funds (i.e. the decision about which site should be restored first could be based on the quarry with the highest *VRI* value, assuming that no other significant environmental concerns are observed at the quarries under consideration).

Nevertheless, if multiple places of interest exist, the situation becomes more complex; every quarry site will probably have a different visual impact on each place of interest and, thus, a different *VRI* value. In this case, the above-mentioned procedure should be repeated for each place of interest, and, then, the *VRI* values of each quarry site must be normalized in order to produce the final priority ranking list.

The nuisance provoked by mining-induced impacts to the landscape depends on a number of factors (e.g. landscape characteristics, size of the mined area, socioeconomic factors, demographic characteristics, beliefs and perceptions) that influence human perceptions (Misthos et al., 2017). Assuming that targeted populations at the places of interest (e.g. inhabited areas) share common values about the landscape, the size of the population (i.e. the number of the observers) could be used as a weighting factor of the visual impact on each area. In this way, a population weighting factor (WP_i) is introduced for each site of interest, as follows (Eq. (8)):

$$WP_i = \frac{P_i}{P_{all}} \cdot 100 \tag{8}$$

where P_i is the number of population of the site i and P_{all} is the total number of population of all the sites of interest.

Based on the above assumption, the total *VRI* value for each quarry site derives as a summation function of the quarry's *VRI* value for each site of interest, adopting different weighting factors, according to Eq. (9):

$$VRI_{\text{total}} = \sum_i^V VRI_i \cdot WP_i \tag{9}$$

where VRI_i is the quarry's *VRI* for the site of interest *i* and WP_i is the weighting factor of the site of interest *i*.

2.1.2. Visibility analysis procedure

In order to implement the proposed approach detailed in Section 2.1.1, two Digital Elevation Models (DEMs) have to be prepared. The first 100-m cell size DEM is constructed within the boundaries of the places of interest, which means, in practice, that an observation point is placed every 10,000 m^2. The second DEM, with cell size set to 50-m, is created for the area surrounding the towns, which in this way is separated in cells of 2,500 m^2. This second DEM includes the abandoned quarries. Considering that from a distance greater than 8 km, an observer has a sense of the overall perspective without being able to discern details of the landscape (U.S. Dept. of the Interior, 1980; PBC, 1997), the analysis (and consequently the boundaries of the 50-m cell size DEM) is determined at a buffer zone of 8 km around the towns' boundaries.

The visibility analysis is conducted by means of GIS and is based on the intervisibility principle, meaning that if a point A can see the point B, then the point B can also see point A. The observation points are set inside the town, on the centers of the 100-m DEM, and the viewshed analysis is made for each point of the

Table 1
Distance zones weighting factors.

Distance zones	Distance in km	Weighting factor
Foreground (A)	0–2	1
Middle ground (B)	2–5	0.6
Background (C)	5–8	0.2

Table 2
Main populated areas of Milos island.

Clustered areas	Settlements	Inhabitants	Totals
Chora	Tripiti	540	2,776
	Plaka	749	
	Triovasalos	838	
	Pera Triovasalos	649	
Adamantas	Adamantas	1,347	1,347
Pollonia	Pollonia	272	284
	Voudia	12	

surrounding area (i.e. the centers of the 50 m DEM). More specifically, the viewshed analysis uses the elevation value of each cell of the DEM to determine the visibility from each observation point to the surrounding area. The coordinates and the visibility value for each point of the surrounding area are recorded to determine from where the town is visible. Hence, the Visibility (*V*) value for a cell located in the surrounding area equals to 0 when the town is non-visible from this point, 1 when only one observation point (which corresponds to a town area of 10,000 m^2) is visible, etc. The maximum value of V equals to the total number of cells of the 100-m DEM. Given that the analysis is being performed for the quarry sites located around the town up to a distance of 8 km, the cells inside the town and the cells of the surrounding area that fall outside the quarry sites are subtracted from the visibility analysis, in order to eliminate them from the weighting process.

2.2. Case study description

For illustrating the methodology developed, the island of Milos, Greece, has been selected as case study. Milos Island is located about 80 miles south of the Greek capital, Athens, and is part of the Cyclades Islands complex, which is being considered very popular destination among inbound tourists (Papatheodorou & Arvanitis, 2014; World Travel & Tourism Council, 2014).

Milos has a long mining history beginning at the Neolithic age, when Milos started exporting obsidian, a smooth and hard grey-to-black rock, which has been found to be used for making tools and weapons to Crete and to other Aegean islands, to mainland Greece and to Asia Minor (Arias et al., 2006). The long history of natural resources extraction reached a peak after the mid-war years with the intense exploitation of many industrial minerals and metals like manganese, barite, gypsum, kaolin, silicate, pozzolan, bentonite and perlite. This extensive activity resulted in many prosperous decades for the local community with very low unemployment, zero migration and an important fiscal aid at national level thanks to the vast amounts of exported minerals. In 2014, Greece was the world's leading producer of perlite and the second largest producer of bentonite, with almost 1.5 million tons of bentonite and perlite being exported from the island of Milos, from a sole producer (Kefalas, 2015).

It is obvious that mining is a strong pillar for local economy. Nevertheless, Milos has also a legacy of abandoned mines and quarries across the island which, due to fragmented initiatives and a lack of funds, have not being rehabilitated. These “open wounds” to the natural environment disturb the landscape and deteriorate the tourism product, which is the other strong pillar of Milos' economy. According to a Greek study of the Foundation for Economic & Industrial Research (Tserkezis & Tsakanikas, 2012), service sector (i.e. mainly tourism, education, health and supporting services) accounted for almost 59% of Milos' gross domestic product, while the industrial domestic product (i.e. construction and

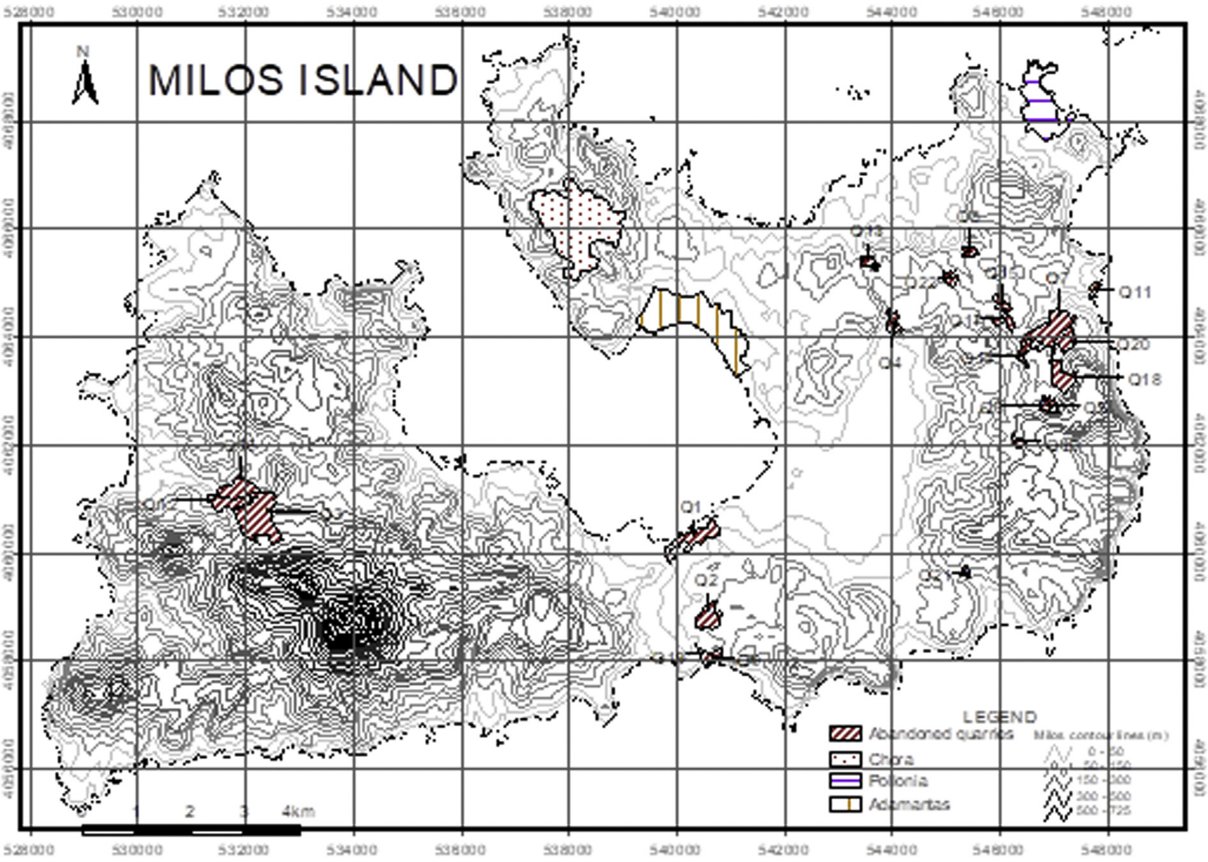

Fig. 1. Location of the abandoned quarries and the places of interest.

Table 3
Area of quarries under examination.

Quarry code	Quarry area (m^2)	Quarry code	Quarry area (m^2)
Q1	243,387	Q12	165,638
Q2	162,632	Q13	49,401
Q3	492,562	Q14	52,187
Q4	75,069	Q15	43,244
Q5	35,998	Q16	189,083
Q6	39,993	Q17	55,386
Q7	314,135	Q18	166,424
Q8	36,879	Q19	49,084
Q9	31,376	Q20	125,694
Q10	25,079	Q21	24,870
Q11	28,099	Q22	50,278

quarrying) amounted to 40%. The importance of both pillars indicates that a harmonic coexistence between these sectors should be kept, as different stakeholder groups are interpreting differently the ‘resources’ of the island and antagonisms emerge between the mining and the tourism activities (Lichrou & O'malley, 2006). As a result, the remediation of abandoned mines seems to be an important environmental, social and economic issue.

Milos has a surface of 158 km^2 and according to 2011 census, the island has 4,977 permanent inhabitants (Hellenic Statistic Authority, 2012). As shown in Table 2, there are three major populated clusters. Chora is a clustered area that consists of the villages of Tripiti, Plaka, Triovasalos and Pera Triovasalos and hosts all the public services of the island (e.g. hospital, town hall, post office, social welfare, police station). Adamantas, besides being Milos passenger port, is also an important tourist area. Finally, Pollonia is also a populated area of special interest, since it is a prime tourist destination during summer and is located very close to the village of Voudia, where the headquarters of a multinational extractive company and its major active bentonite mines are located.

In the area of interest, there are 22 abandoned quarries, the location and the characteristics of which have been provided by the Ministry of Interior, Prefecture of South Aegean, Department of Natural Resources of the Prefecture of South Aegean (2013). Fig. 1 illustrates the three (clustered) population areas and the quarries under examination, while the area of each quarry is given in Table 3.

3. Results

As a first step, a visibility analysis was performed for each of the three clustered areas (i.e. Adamantas, Chora and Pollonia) following the methodological approach described in Section 2.1.

As shown in Fig. 2, the total number of abandoned quarries registered in the island of Milos, i.e. 22, are within the range of 8 km from the Adamanda's boundaries. Among them, 7 quarries are visible from Adamantas. Fig. 3 presents the excavation exposure of these quarries to the town.

The numerical results of the analysis for Adamantas with regard to the visible quarries are presented in Table 4. According to the estimates, quarry Q1 has the highest *VRI* value, followed by quarry Q2, the *VRI* of which is much lower, however.

The viewshed analysis for the Chora is shown in Fig. 4. More specifically, within the 8 km range there are 15 quarries, 6 of which are visible from Chora. Further, Fig. 5 illustrates the excavation

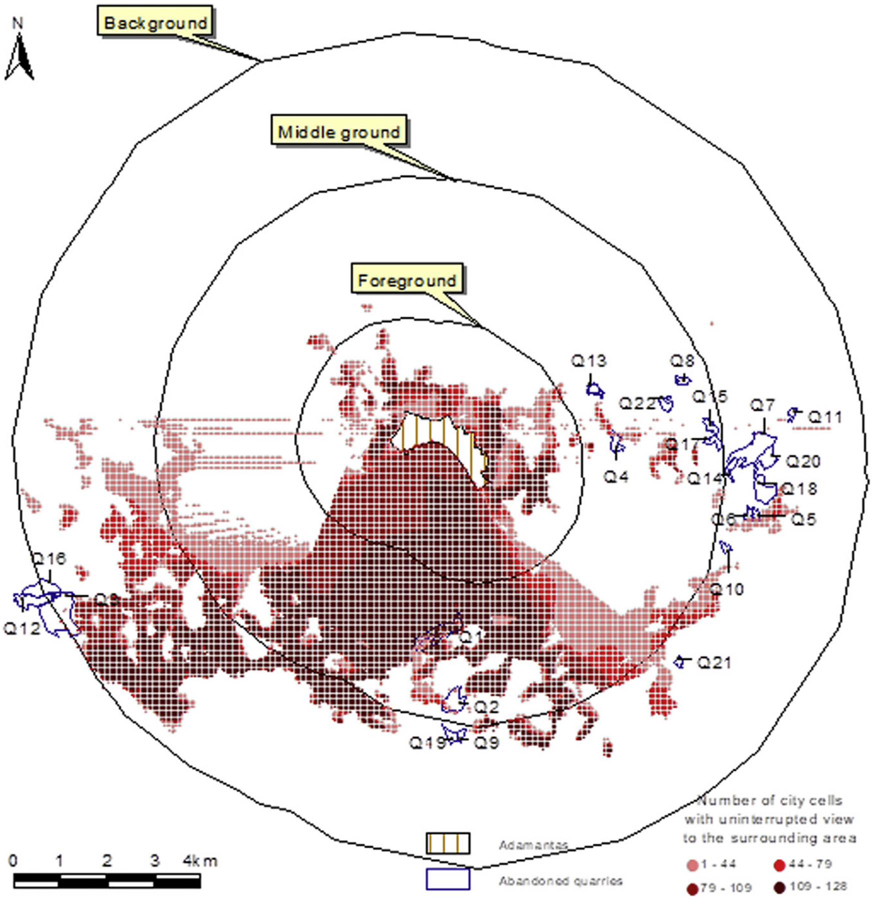

Fig. 2. Viewshed analysis from the town of Adamantas.

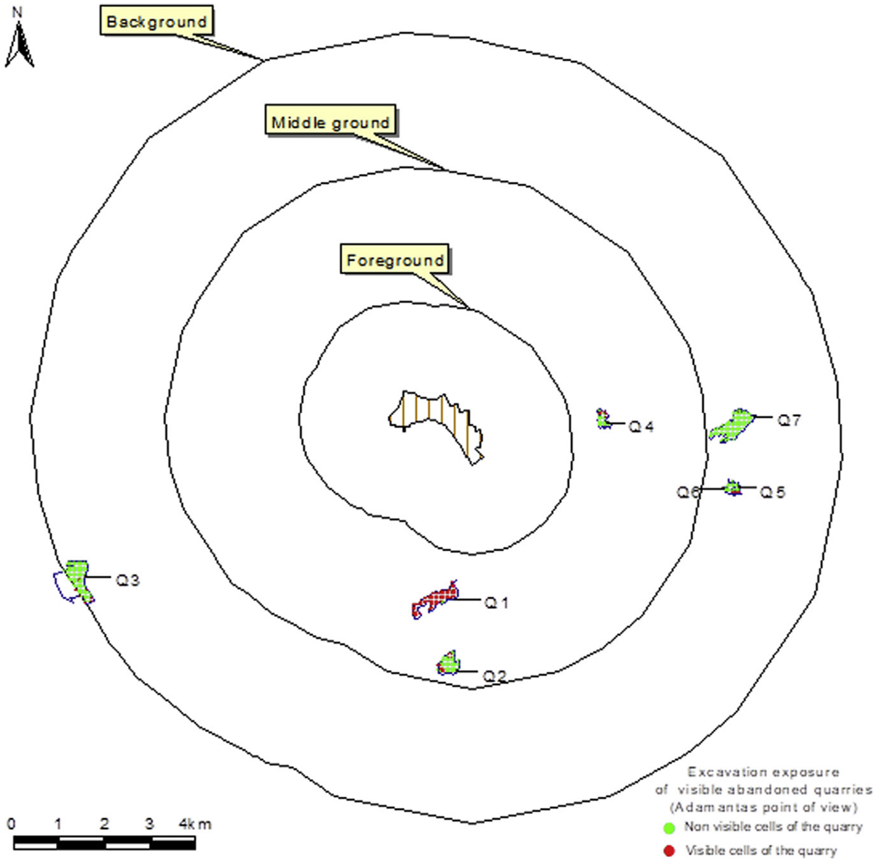

Fig. 3. Excavation exposure of visible quarries from Adamantas area.

Table 4
Viewshed analysis results for Adamantas.

Quarry	Observation Intensity (%)	Excavation Exposure (%)	Relative Visibility (%)	Relative Surface (%)	$VRI_{\text{adamantas}}$ (%)
Q1	49.49	96.94	74.80	12.11	4.35E-00
Q2	0.90	19.70	10.24	8.16	1.48E-03
Q3	0.52	6.78	6.30	14.59	3.23E-04
Q4	0.56	22.22	4.72	3.34	1.95E-04
Q5	0.19	21.43	2.36	1.73	1.66E-05
Q6	0.06	7.69	0.79	1.61	5.85E-07
Q7	1.56E-03	0.81	0.79	15.33	1.22E-08

exposure of the visible quarry sites and Table 5 presents the results of the analysis.

According to Table 5, the quarry with the highest VRI value is again the Q1, followed by Q3 this time. The change in priority ranking as regards the second place is mainly attributed to the sitting of the quarries Q2 and Q3. In the case of Adamantas, Q2 is closer to the town and Q3 is only partially within the zone of 8 km.

As regards Pollonia, the viewshed analysis showed that there is not any quarry visible within the range of 8 km (Fig. 6). Thus, although an important tourist destination, Pollonia is not included in the final ranking.

Provided that at least some of the abandoned quarries are visible from more than one areas of interest, the total Visibility Ranking Index (VRI_{total}) for each abandoned quarry was estimated following Eq. (9). The population weighting factors WP for each area were estimated from Eq. (8) using the figures of Table 2. More specifically, the WP_{Chora} is 63% and the $WP_{\text{Adamantas}}$ is 31%, respectively. The results are presented in Table 6.

According to the value of VRI_{total}, the quarry site that deserves to be restored first is Q1, while quarries Q3 and Q2 follow.

4. Discussion

According to Table 4, the quarry Q1 receives the highest ranking in VRI value ($VRI = 4.35\%$) for the area of Adamantas because it holds the highest values in OI, EE and RV. This is attributed to a combination of factors. To wit, the quarry Q1 is located in the "middle ground" zone, i.e. in a distance between 2 and 5 km from the Adamantas' boundaries. Further, a large percentage of the quarry area, i.e. 51.02%, is visible from all the observations points, i.e. 100%, of the area of interest (Table 7). All the other quarries have very low values of visibility, either because only a small percentage of the quarry area is visible from a high percentage of observation points or because a relatively high percentage of the quarry area is visible from a low percentage of observation points. For instance, in the case of quarry Q3, which occupies a larger area than quarry Q1, less than 1% of the excavation is visible from 78.91% of the potential observers, since it is located in the "background" zone (as defined in

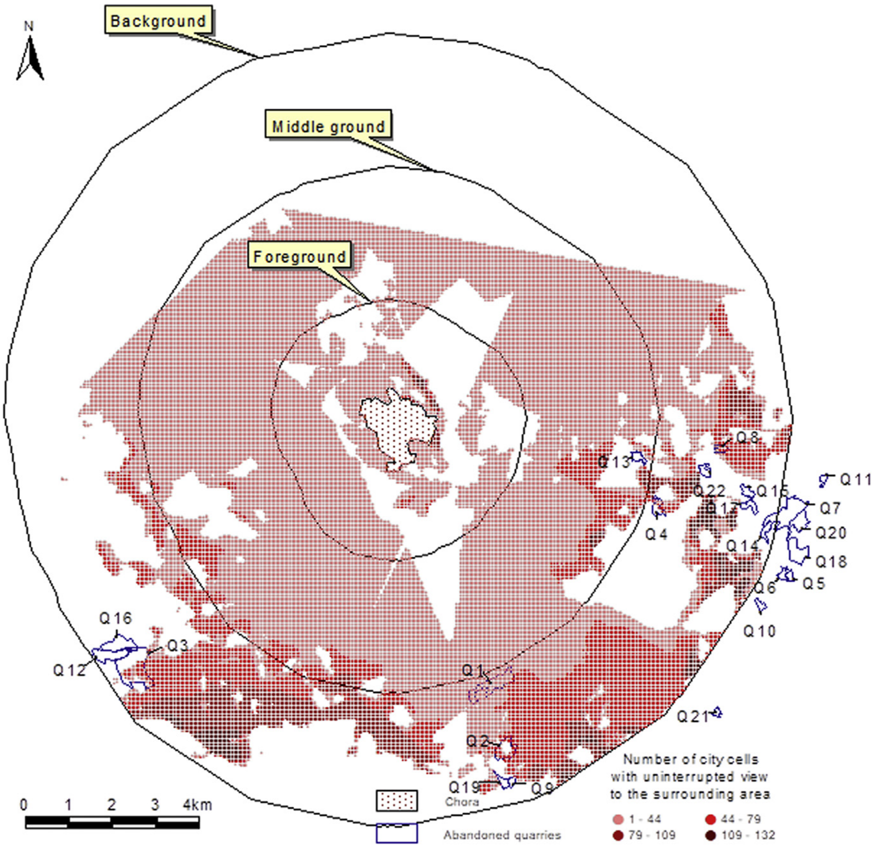

Fig. 4. Viewshed analysis from the town of Chora.

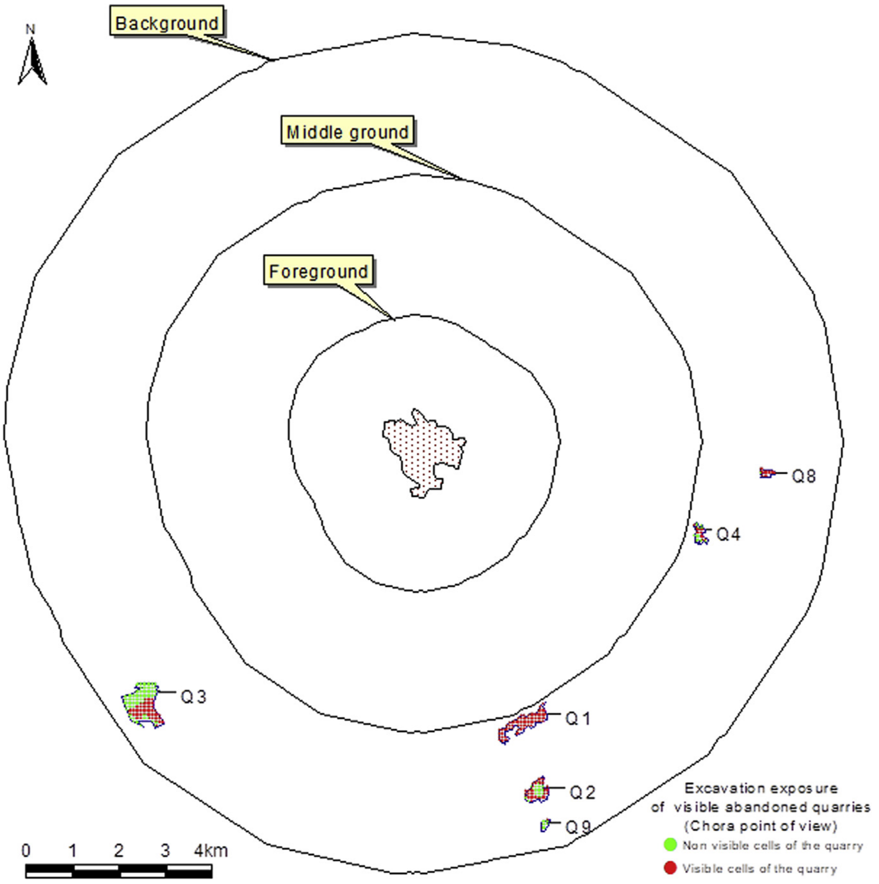

Fig. 5. Excavation exposure of visible quarries from Chora area.

Table 5
Viewshed analysis results for Chora.

Quarry	Observation Intensity (%)	Excavation Exposure (%)	Relative Visibility (%)	Relative Surface (%)	VRI_{Chora} (%)
Q1	3.61	100.0	37.80	13.79	1.88E-01
Q3	2.15	41.62	32.28	28.30	8.16E-02
Q2	3.50	65.67	17.32	9.63	3.83E-02
Q8	5.07	94.44	6.69	2.59	8.29E-03
Q4	1.88	45.16	5.51	4.45	2.09E-03
Q9	0.60	9.09	0.39	1.58	3.37E-06

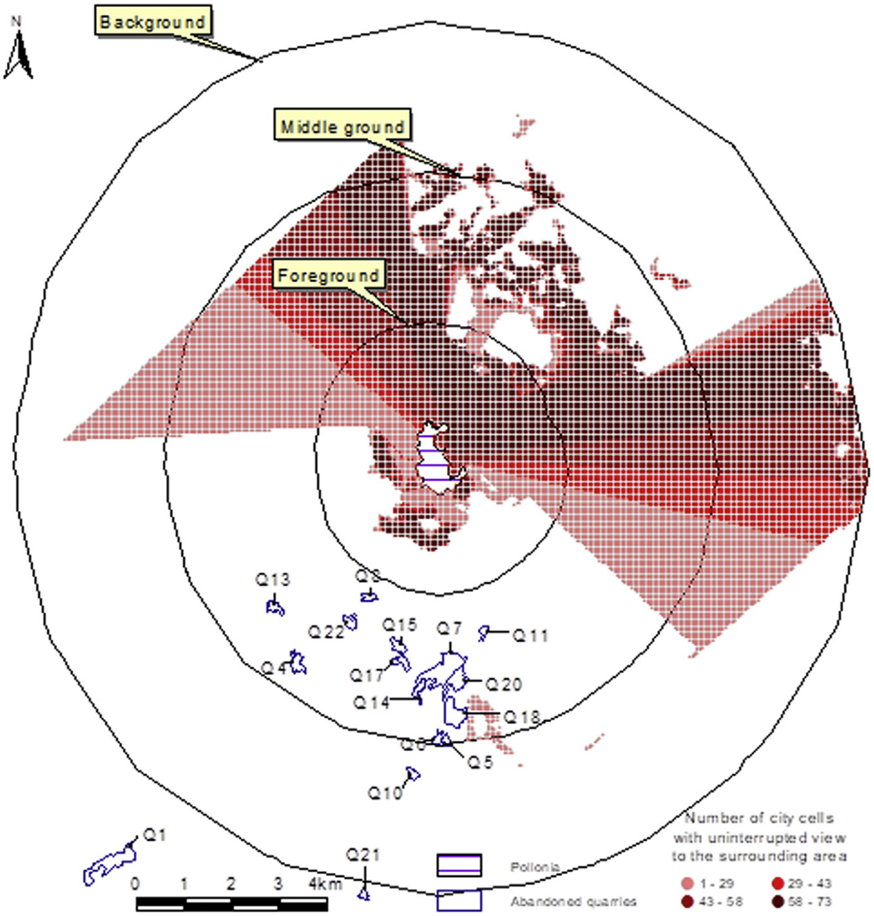

Fig. 6. Viewshed analysis of Pollonia.

Table 6
Total *VRI* values of Milos' abandoned quarries.

Rehabilitation Priority Ranking	Quarry	$VRI_{Adamantas}$ (%)	VRI_{Chora} (%)	VRI_{total} (%)
1	Q1	4.35E-00	1.88E-01	1.92E-00
2	Q3	3.23E-04	8.16E-02	0.26 E-00
3	Q2	1.48E-03	3.83E-02	0.12 E-00
4	Q8	–	8.29E-03	2.61E-04
5	Q4	1.95E-04	2.09E-03	6.64E-05
6	Q9	-	3.37E-06	1.06E-07
7	Q5	1.66E-05	-	5.08E-08
8	Q6	5.85E-07	–	1.79E-09
9	Q7	1.22E-08	–	3.74E-11

Table 7
Quarries' visibility from Adamantas.

Quarry	Maximum visibility of the quarry from the town	
	Percentage of the quarry (%)	Visible from (%) of the town
Q6	7.69	3.91
Q1	51.02	100.00
Q5	14.29	4.69
Q7	0.81	0.78
Q2	1.52	55.47
Q3	0.85	78.91
Q4	3.70	10.94

Table 1) and it is partially inside the range of 8 km. In the case of quarry Q5, 14.3% of its area is visible from less than 5% of the potential observers. Quarry Q7, although it is almost 10 times larger than quarry Q5, is ranked below Q5, since only a small percentage of the quarry (0.81%) is visible from less than 1% of the potential observers from Adamantas town.

As regards the area of Chora, the findings are also interesting (Table 5). Quarry Q1 is again ranked first ($VRI = 0.188\%$) but with a substantially lower value of *VRI* compared with that observed in

Adamantas area (i.e. 4.35%). The *EE* of Q1 in Chora (i.e. 100%) is higher than that in Adamantas (i.e. 96.94%), yet the *OI* is much lower (i.e. 3.61% and 49.49%, respectively). The latter derives from the fact that maximum only 1.04% of the quarry is visible from 27.9% of the potential observers (Table 8). Furthermore, the quarry Q1 is located now in the "background" zone, which means that the distance weighting factor reduces from 0.6 to 0.2. Finally, the *VRI* values of Q1 in Adamantas and Chora are influenced from the values of the *RV* index. In the area of Adamantas, the quarry Q1 dominates over the other quarries in terms of (relative) visibility, since it accounts for almost three-fourths of all visible excavation area. On the contrary, in the area of Chora the same quarry (i.e. Q1) accounts for less than 40% of all visible excavation area.

Quarry Q3 is ranked second in the area of Chora, since the quarry area is totally included in the "background" zone, and the *EE* value is much higher (41.62%) with regard to the *EE* value in the case of Adamantas (6.78%). The *OI*, *RV* and *RS* values are also higher. Thus, due to its size quarry, Q3 is ranked above quarry Q2.

It is also interesting to examine the difference in the *VRI* values of the quarries Q8 and Q2. The quarry Q8 holds the highest *EE* value (i.e. 94.44%). Further, around 11% of its area is visible from about 36% of the potential observers. Nevertheless, given that it is located in the "background" zone the *OI* is low (i.e. 5.07%). Still, this value is higher than the *OI* of the quarry Q2 (i.e. 3.5%), the area of which is visible at a percentage of 18% from 33% of the potential observers. Furthermore, the *EE* of quarry Q2 is much lower than that of quarry Q8 (i.e. 65.67% and 94.44%, respectively). In this case, the difference observed in the *VRI* values is mainly attributed to the *RV* and *RS* indices. Due to the size and the position of the two quarries, the *RV* and *RS* values of quarry Q2 are almost three to four times higher than those estimated for quarry Q8.

5. Conclusions

It is widely acknowledged that surface mining is associated with serious environmental, social and economic problems, e.g. removal of top soil, damage to fauna and flora, pollution of surface and groundwater and soil, etc. Whilst improvements in technology have managed to reduce the environmental impacts of mining, the changes induced upon the landscape by mining operations are still obvious and intense, especially in mining works adjacent to residential or touristic areas, generating adverse reactions among the affected populations. These problems are amplified in the case of abandoned mined land, especially in times of fiscal and financial belt tightening where there is often limited room for direct funding of restoration works and, consequently a prioritization of the restoration projects is necessitated.

Bearing in mind the above-mentioned remarks, the aim of this research is to provide a simple, quick and useful methodological tool for setting implementation priorities in the restoration of abandoned mines and quarries based on their visibility from critical areas of interest. To this direction, a new approach is being proposed which modifies the LETOPID methodology, in order to adapt it to the particular context. More explicitly, the methodology is supported by a viewshed analysis which aims to determine the view of the quarry site under investigation from one or more places of interest, e.g. settlements, archaeological sites, etc. In this way, the analysis determines from where the quarry site is visible and provides the means to estimate a set of indices that determine its priority ranking. The methodology can be utilized as an additional module in existing multicriteria prioritization models or it can be used standalone when examining surface mines having similar characteristics.

Table 8
Quarries' visibility from Chora.

Quarry	Maximum visibility of the quarry from the town	
	Percentage of the quarry (%)	Visible from (%) of the town
Q1	1.04	27.88
Q2	17.91	33.33
Q9	9.09	32.73
Q8	11.11	35.76
Q3	0.51	44.24
Q4	3.23	61.21

The methodology takes into consideration a number of parameters, such as the size and location of the mining area and the places of interest. To this end, the methodology is capable to rank mine restoration projects in a consistent and transparent way, regardless of the number of the places of interest in the surroundings. Moreover, it is suitable for both abandoned and active mining operations. For example, a mining company that owns multiple neighboring installations is able to assess the visibility of the sites from specific points of interest and, consequently, to maximize the allocation of the resources required to minimize the landscape and visual impacts from its activities. Yet, it should be noted once more that the framework presented sets the rehabilitation priorities focusing solely on the visibility of surface mining installations.

Ethical statement

Authors state that the research was conducted according to ethical standards.

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Conflict of interest

None.

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