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Article

A comprehensive methodology for the Visual Impact Assessment of mines and quarries

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Abstract: Since the 60s, several multidisciplinary studies have been carried out worldwide to investigate the perception of landscape modification and define appropriate methodologies of Visual Impact Assessment (VIA). The criteria typically applied to evaluate the visual impact due to landscape alteration can be categorized into two classes: direct and indirect approaches (i.e. respectively perception test and numerical quantification of landscape modification). Both the approaches intend to overcome the limit of the judgment subjectivity in the evaluation process and its dependence on the observer's specific characteristics. As a matter of fact, the effect of landscape modification needs to be objectively estimated when the VIA procedures are mandated by regulatory policies and accurate evaluation techniques are required to support decision-making. The *Lvi* indicator (Level of visual impact) has been formerly proposed as a tool to enable the objective quantification of the visual impact magnitude produced by extensive surface excavation (i.e. mines and quarries). This article discusses the integration of the *Lvi* indicator into a comprehensive Landscape Assessment Model (LAM), which includes the three succeeding steps of the visual impact assessment procedure: 1. the identification of the Key Observation Points (KOPs) (i.e. intervisibility analysis), 2. the quantification of the visual impact magnitude from the selected KOPs (i.e. visual impact estimation), 3. the comparison with predefined levels of acceptable landscape modification (i.e. visual impact evaluation). The proposed assessment procedure has been applied to a quarry of inert materials located in Sardinia (Italy) to highlight and discuss the practical implications of the proposed procedure and its inherent limitations.

Keywords: Environmental Impact Assessment (EIA); Visual Impact Assessment (VIA); Land Assessment Model (LAM); landscape modification; surface excavation activities; mines and quarries.

1. Introduction

Mining and quarrying activities typically generate a number of environmental impacts among which landscape alteration is recognized as one of most significant. Landscape alteration typically generates an adverse reaction among the exposed population and sometimes influences the socio-economic development of the territory from where the alteration is visible. Previous studies proved the presence of active or non-reclaimed mines to represent a detrimental contribution to the perception of the entire surrounding territory, even though significant differences have been observed by comparing the perception of residents and non-residents [1,2]. As a matter of fact, the visual perception of landscape modification depends on many factors, such as the physical attributes of the visible alteration, the visual quality of the viewpoint from where the alteration is visible, the socio-cultural and psycho-physical characteristics of the observer [3]. However, the landscape visible modification needs to be objectively quantified in order to decide whether it is acceptable or not, on the basis of the visual quality of the landscape under consideration. The availability of an objective methodology becomes of primary importance when the Visual Impact Assessment (VIA) is required by regulatory policies and accurate evaluation techniques are required to support decision-making or withstand litigation that might result in a project being rejected or requiring further mitigation measures at higher cost [4,5,6]. A recent amendments of EIA Directive [7] recognizes that "*in order to better preserve historical and cultural heritage and the landscape, it is important to address the visual impact of projects, namely the change in the appearance or view of the built or natural landscape and urban areas, in environmental impact assessments*".

In order to objectively estimate the visual magnitude of the alteration produced by mines and quarries, the *Lvi* (Level of visual impact) impact indicator has been formerly proposed by the authors of the present article [8,9]. The *Lvi* indicator is calculated from the digital images of the landscape under investigation by means of a MATLAB code, which has recently been revised to improve the accuracy of the estimation technique [10]. The *Lvi* index accounts for the two physical variables that objectively define the magnitude of perceived change in a natural landscape: the solid angle (Ωv) subtended by the alteration from the viewpoint (i.e. alteration extent) and the chromatic contrast ($\Delta E\mu$) between the bare rock exposed by excavation and the surrounding unaltered landscape [11–14]. The indicator *Lvi* has been validated by comparing the impact levels calculated for a set of selected case studies with the results of a perception test performed with two groups of university students in Cagliari University: a linear regression model proved the *Lvi* to be well correlated to the judgement values expressed by the interviewees (R^2 = 0.83) [15].

This article discusses the integration of the *Lvi* index within a comprehensive Landscape Assessment Model (LAM) specifically designed for the assessment of the visual impact induced by surface excavation (i.e. mines and quarries, but also extensive excavation related to civil engineering works). The proposed methodology is described in paragraph 2, followed by the application to a selected case study located in Sardinia (Italy).

2. The Landscape Assessment Model (LAM)

A scientifically rigorous approach to the Visual Impact Assessment (VIA) must include the following fundamental steps [16,17]:

- the intervisibility analysis: selection of the Key Observation Points (KOPs) from where the alteration is visible;
- the estimation of the alteration visual magnitude: quantification of the landscape modification as perceived from the KOPs;
- the visual impact evaluation: comparison of the estimated visual magnitude with predefined levels of acceptable modification.

2.1. Intervisibility Analysis

In order to estimate the visual impact arising from a given landscape alteration, it’s necessary to identify the sensitive viewpoints from where the alteration is visible, i.e. Key Observation Points (KOPs) [16–17]. If the Digital Elevation Model (DEM) of the geographical area under investigation is available, the intervisibility analysis can be effectively performed by means of GIS-based applications (QGIS is hereby proposed) [18]. Among DEMs, it is important to distinguish between Digital Terrain Models (DTM) and Digital Surface Models (DSM), as DTMs simply represent the bare surface of the ground, whereas DSMs account for all the elements rising from the ground (e.g. trees, buildings, infrastructures, etc.) [6]. When performing the intervisibility analysis, DSMs must be preferred against DTMs in order to include the presence of those natural or anthropic elements that may compromise or favor the visibility of the alteration under investigation (e.g. natural/anthropic barriers interposed along the lines of sight; viewpoints located on top of building/infrastructures, etc.).

When dealing with the visual impact produced by mines and quarries, the intervisibility analysis must include the following successive steps:

A. Identification of the quarry surfaces (*S*) and definition of the alteration perimeter

B. Delimitation of the territory (*E*) from where the quarry is potentially visible

C. Identification of the Key Observation Points (KOPs)

Step A. Once the quarry under examination is identified, the altered surface (*S*) can be described by a set of N Target Points (TPi) located at constant distance *P*, along the quarry perimeter and along the internal contour lines of inter-distance *Q*. *P* and Q are set as to have a total number of TPi (N Target Points) greater than 100.

The *P/Q* ratio is in the range 0.8 - 1.2, as to obtain a uniform areal distribution of the TPs. Figure 1 represents an example of TPi distribution on a small portion of an altered surface, with *P* = 10 m and *Q* = 12 m.

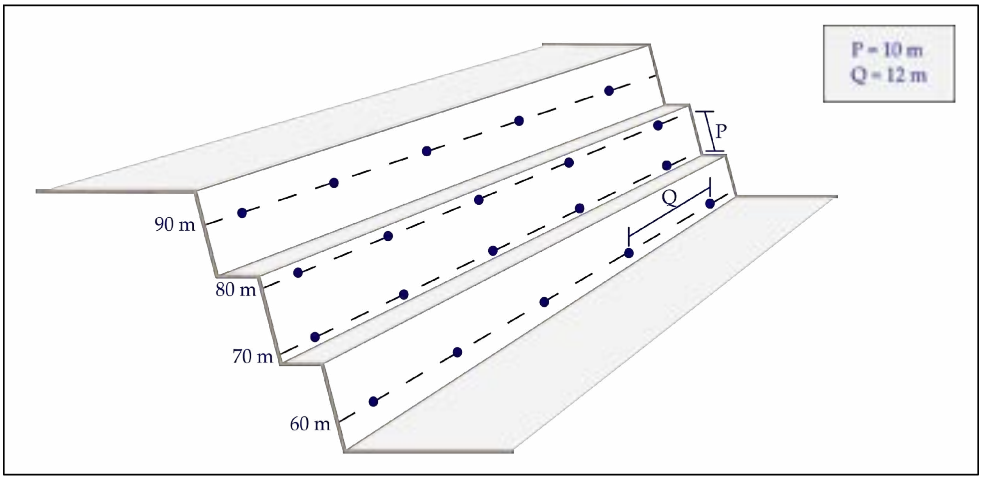


Figure 1. Distribution of the Target Points (TPi) (*P* = 10 m and *Q* = 12 m).

Step B. The extent of the territory from where the quarry is potentially visible (*E*) can be determined by applying the criterion according to which an object can be seen from an observation point (OP) at distance (*d*) if the solid angle that subtends the alteration from that point is greater than a predefined threshold limit value Ω_t. The delimitation of *E* can be simplified by considering only the prevailing linear dimension of the quarry (d_{max}), among the two measured along the vertical and horizontal direction. E is therefore defined as locus of points from which d_{max} can be seen under a limit plane angle (α_L) of 5°, which translates the general visibility criterion into a 2D space [17,19].

Step C. The visibility of each TP_i describing the alteration, from a given observation point (OP), can be analyzed by means of the Visibility Analysis tool provided by the QGIS application, which verifies the continuity of the Lines of Sight for each pair OP-TP_i: the value 1 is assigned if TP_i is visible from OP, the value 0 if it is not. A vector of N_{target} elements is obtained for that viewpoint under exam, which has $N_{1target}$ elements of value 1 and $N_{0target} = N_{target} – N_{1target}$ of value 0. The ratio $R_s = N_{1target}/N_{target}$ is the percentage of TP_i visible from OP: Figure 2 reports a 2D example of 6 Lines of Sight (TP_i – OP) laying in the same vertical plan: only TP_1 and TP_2 are visible from OP (R_s = 2/6 = 33%). The ratio R_s can be assumed as indicative of the proportion of altered surface *S* that is visible from the viewpoint OP.

The Visibility Analysis is automatically applied to all the points of the territory *E* (i.e. all the pixels representing *E*). A first screening of the viewpoints is performed by considering only the observation points with R_s from 5 to 100%. A second screening is then performed by considering only the points located on areas/places which can be actually reached by potential observers. This phase is implemented by matching the results of the Visibility Analysis with the information about the actual or potential use of the territory (dwellings, touristic places, naturalistic areas, roads, etc.). As a result, the Relevant Observation Points (ROPs) are identified.

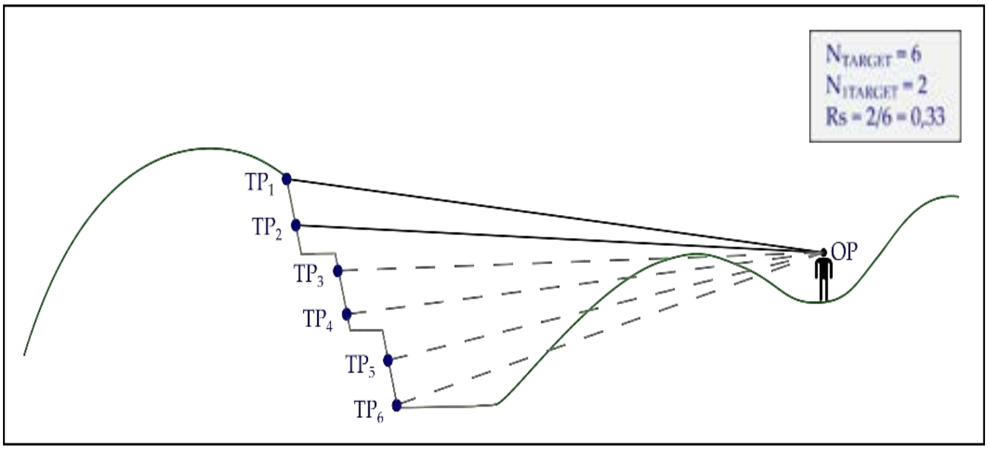


Figure 2. Calculation of R_s from OP for a given vertical section.

A last step of the procedure is then performed to identify the Key Observation Points (KOPs). For each ROP previously identified, the visible alteration surface *Sv* is calculated according to equation 1:

$$S_v = R_s \cdot S, \tag{1}$$

where R_s is the percentage of alteration visible from the ROP and *S* the entire alteration. The selection of the KOPs is then accomplished by applying the definition of solid angle subtended by a given surface from a viewpoint at distance *d*, expressed by equation 2:

$$\Omega = \frac{Sv}{d^2}, \tag{2}$$

Only the ROPs for which the solid angle Ω is greater than the limit value Ω_L (calculated with equation 3) are defined as KOPs:

$$\Omega_L = 2\,\alpha_L \cdot sin\left(\frac{\alpha_L}{2}\right) = 0{,}0076\,sr, \tag{3}$$

where α_L is the limit plane angle, as suggested by Integral for a plane horizonal angle [19]. KOPs can be defined as those observation points that are likely to be reached by the observer and from where the alteration is actually visible (i.e. solid angle greater than α_L).

2.2 Estimation of the Alteration Visual Magnitude

The alteration's visual magnitude can be estimated by means of direct or indirect approaches [20–22]. Direct approaches are based on the results of perception tests, which require a statistically significant number of potential observers to be interviewed [14, 23–28], whereas indirect approaches are based on the implementation of specific mathematical algorithms, which enable the numerical quantification of the alteration perceived by an average human observer [12, 18, 29–31]. Both statistical and numerical approaches intend to overcome the limit of the judgment subjectivity and its dependence on the observer's characteristics. With reference to landscape alteration due to surface excavation, a comparative analysis between direct and indirect approaches has been carried out in a recent article [32].

The alteration's visual magnitude is hereby estimated by calculating the visual impact indicator *Lvi* from the digital images of the alteration under investigation, taken from the selected KOPs (i.e. indirect approach). The estimation of *Lvi* enables to perform Step 2 of the assessment methodology hereby proposed [8]. The level of visual impact *Lvi* (expressed in dB) is described by Equation (4):

$$Lvi = 10\ lg\ \left(\frac{\Delta E_{\mu}}{\Delta E_{BW}} \cdot \frac{\Omega_v}{\Omega_0}\right), \quad (4)$$

where Ω_v is the solid angle subtended by the visible alteration from a given viewpoint, Ω_0 ($8{,}46 \cdot 10^{-8}$ sr) is the human visibility threshold in a black and white chromatic space (BW), ΔE_{μ} is the mean value of the chromatic contrast between the quarry and the surrounding natural landscape [12], ΔE_{BW} is the chromatic contrast between black and white. The solid angle Ω_v and the mean chromatic contrast ΔE_{μ} are obtained from the elaboration of digital images taken from the most representative viewpoints. The value of the solid angle Ω_v is given by equation (5):

$$\Omega_v = \Omega_p \cdot \frac{N_a}{N_p}, \quad (5)$$

where Ω_p is the solid angle subtended by the entire digital image, N_a and N_p are respectively the number of pixels representing the bare rock and the total number of pixels in the picture. Ω_p is a constant value that depends on the camera characteristics: focal length and CCD size (Charged Coupled Device).

The chromatic contrast between two pixels can be calculated as the Euclidean distance *ΔE*, according to Equation (6):

$$\Delta E = \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2}, \quad (6)$$

where *Δx*, *Δy* and *Δz* are the differences of the three chromatic coordinates representing the two points in a perceptually uniform color space (i.e. reference color systems that mirror the differences in color perceived by the human eye). Specifically, the mean chromatic contrast ΔE_{μ} in Equation (4) is calculated in the CIELab system and represents the mean value of the chromatic distances between each pixel of a selected unaltered surface around the excavation and the mean color of the rock exposed by excavation. The mean chromatic contrast ΔE_{μ} is divided by the Euclidean distance between black and white (ΔE_{BW}) to obtain the mean standard chromatic contrast ($\Delta E_{\mu}/\Delta E_{BW}$).

As mentioned above, the impact indicator *Lvi* has been recently revised to improve the accuracy of the estimation technique by eliminating some critical issues related to the manual pre-elaboration of the digital images (aimed at identifying the alteration perimeter and the unaltered surface to be use in the calculation of *Eμ*). To that end, the original *Lvi* code has been integrated with two image-processing algorithms (k-means clustering and ED matrix), which allow the automatic elaboration of the digital images, the identification of the excavation area and comparison surface, and the subsequent calculation of *Lvi* [11].

2.3 Visual Impact Evaluation

The last step of the proposed methodology (Step 3) requires the comparison of the *Lvi* values calculated for each KOP with predefined acceptable levels of visual impact (i.e. *Lvi* threshold values). In fact, the same *Lvi* can be acceptable or beyond a recognized limit depending on the visual quality of the landscape, as perceived from the viewpoints under consideration [10].

In order to define the acceptable limits of visual impact, two variables are hereby considered: the use of the area where the KOP belongs (actual use or land planning indications) and the frequency of visits (i.e. maximum daily number of observers). Table 1 reports a proposal of 7 classes of Visual Impact Sensitivity (VIS), which are identified on the basis of the two variables above mentioned. As regard the use/destination of the territory, five categories were considered, from A to E, which indirectly account for the quality of the viewpoint.

A preliminary distinction is made between *stationary* areas (A, B, C) and paths/routes/infrastructures (D, E). Class A includes notified Sites of Community Importance (SCI), special protected areas in EU, other protected areas specified by national or regional regulation. In class B are those areas of recognized historical, natural or touristic value which are not included in Class A (not recognized by law/regulation). In class C are sport, leisure and cultural areas, and accommodation facilities. In class D are pedestrian and cycling routes laying outside areas A, B, C. In Class E are main roads and infrastructures (railways, ports and airports).

The VIS scale is built by associating increasing numerical values (from 0 to 4) to the five categories of land (from A to E), when considering a high frequency of visits. In the same way, a scale from 1 to 3 is used to take into account a decreasing frequency of visits (from high to low): the category of land C, for example, which has VIS class 2 for high frequency of visits, will take class 3 and 4 respectively for medium and low frequency of visits.

As regard the limits of the three frequency classes (high, medium and low), specific reference values must be identified depending on the geographic area under consideration. The values proposed for the case study discussed below have been identified on the basis of the Sardinian (Italy) statistical data about attendance. Specifically, the following reference values have been adopted for areas included in categories A, B, C and D:

- High Frequency of visits: more than 1000 daily observers,
- Medium Frequency of visits: number of daily observers between 100 and 1000,
- Low Frequency of visits: less than 100 daily observers,

and the following for areas located in category E:

- High Frequency of visits: more than 5000 daily observers,
- Medium Frequency of visits: number of daily observers between 500 and 5000.
- Low Frequency of visits: less than 500 daily observers.

Once the VIS class of a given KOP is identified (on the basis of the two variables in Table 1), the visual impact threshold level can be derived from Table 2: the visual impact is considered acceptable if the alteration visual magnitude (*Lvi*) is lower than the assigned threshold value.

Table 1. Classification of Visual Impact Sensitivity (VIS classes).

Visual impact sensitivity (VIS) classes			Frequency of visits		
			High	Medium	Low
Use of the territory	A	Sites of Community Interest (SCI), special protected areas in EU, other protected areas specified by national or regional regulation	0	1	2
	B	Areas of recognized historical, natural or touristic value, which cannot be included in Class A (not identified by law/regulation).	1	2	3
	C	Sport, leisure and cultural areas. Accommodation facilities	2	3	4
	D	Pedestrian and cycling paths	3	4	5
	E	Roads, railways, ports and airports	4	5	6

Table 2. Acceptable visual impact level as a function of the VIS Class.

	Class 0	*Class 1*	*Class 2*	*Class 3*	*Class 4*	*Class 5*	*Class 6*
Acceptable levels of visual impact [dB]	32.0	35.0	38.0	41.0	44.0	47.0	50.0

It's worth mentioning that a first proposal of threshold values is indicated by the EU Decision 272/02 [33], which establishes the ecological criteria for the award of the Community eco-label for hard floor-coverings. The EU decision defines two impact indicators (the Rehabilitation Simultaneity Degree RSD and the Visual Impact Indicator *x*) and the respective impact classes, to be applied for the assessment of the landscape and visual impact due to the extraction of raw materials (marble, granite, other natural stones, aggregates, raw materials for the cement and ceramic industry). The four impact classes reported in Table 3 with reference to the *Lvi* index [8,10] are coherent with those proposed by the European Decision for the Visual Impact Indicator *x* [33].

Table 3. Visual impact evaluation from previous research studies [10].

	Negligible	*Moderate*	*Relevant*	*Unacceptable*
Lvi [dB]	*Lvi* < 40.0	40.0 < *Lvi* < 45.0	45.0 < *Lvi* < 50.0	*Lvi* > 50.0

The proposal of impact threshold levels in Table 2 intends to provide a more detailed categorization, in accordance to the 7 VIS classes in Table 1. As a matter of fact, the correlation of *Lvi* with the actual perception of potential observers has been demonstrated by the results of a perception test based on the observation of 10 case studies with *Lvi* values ranging from 25.6 dB to 53.5 dB [15]. The acceptable visual impact levels for the VIS classes in Table 1 have been assigned starting from the highest value in Table 2 (50.0 dB) and considering a decrease of 3 dB for each decrease in the VIS class (i.e. the acceptable visual impact halves, in a linear scale, from a one class to the preceding/more sensitive one).

The graphical scheme in Figure 3 summarizes the steps of the assessment methodology hereby discussed (Landscape Assessment Model).

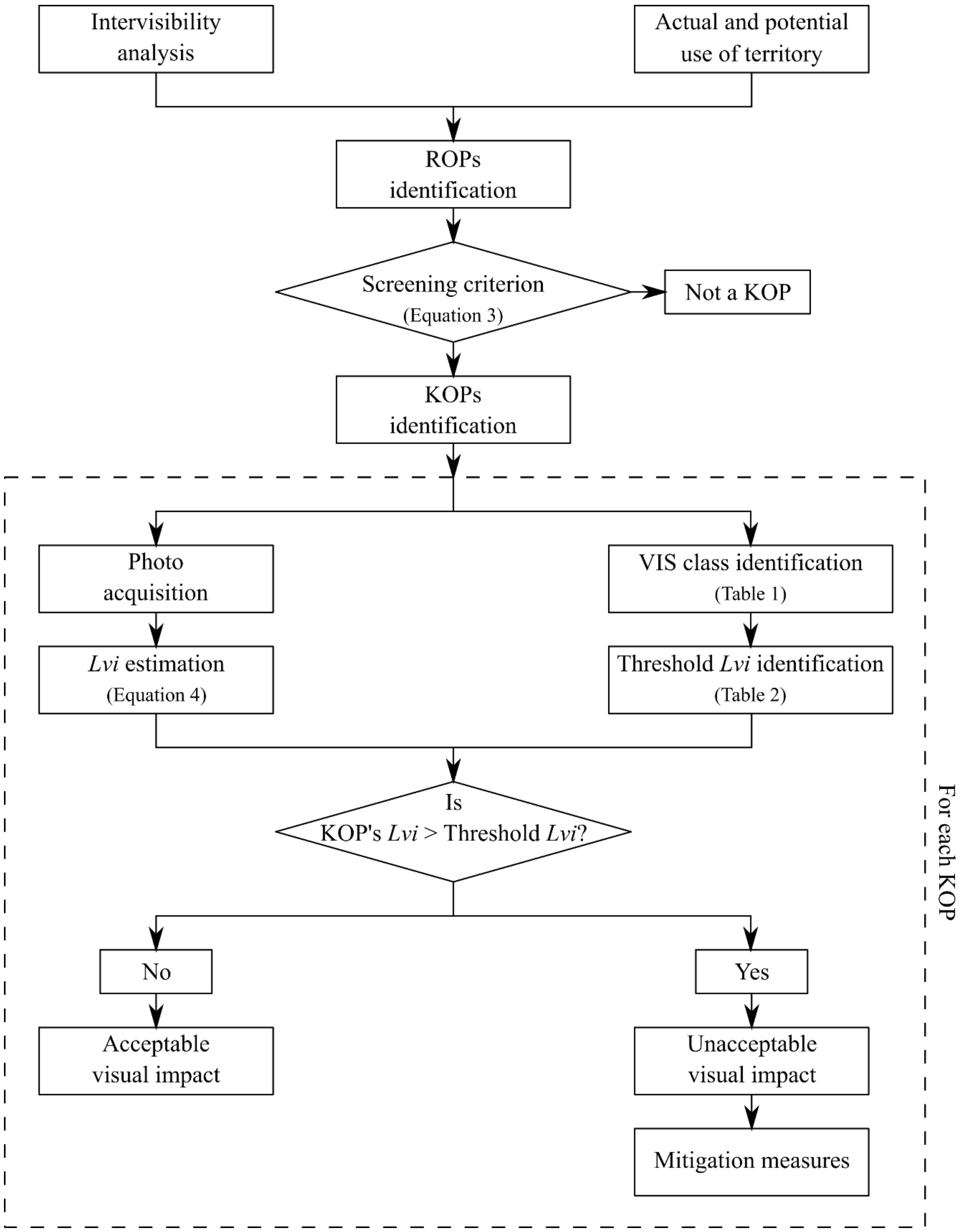


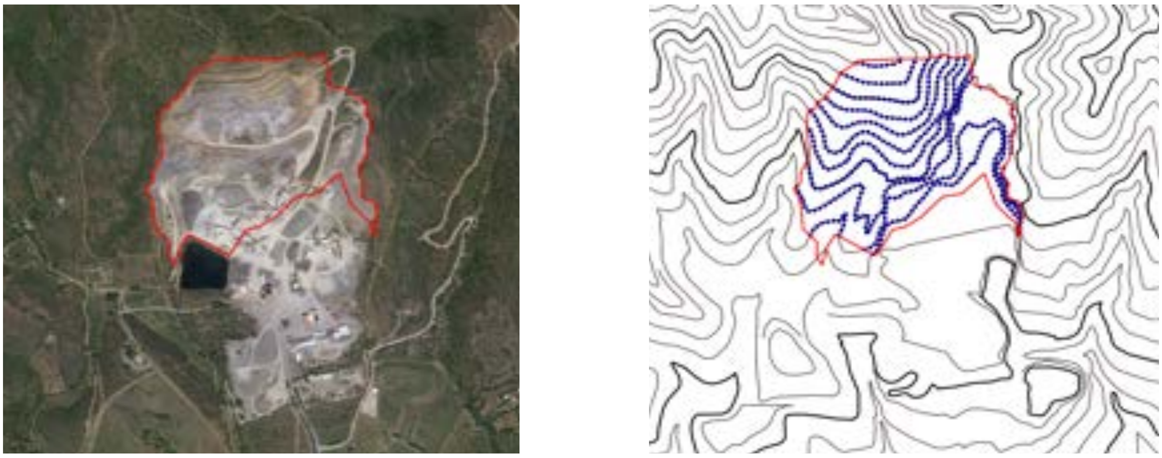
Figure 3. Graphical scheme of the Landscape Assessment Model.

3. Application of the LAM to a Case Study

3.1. Intervisibility Analysis

The LAM model was implemented to assess the visual impact generated by a quarry of inert materials located in the municipality of Sinnai (Sardinia, Italy). The territory surrounding the quarry is made up of hills of modest height and includes three inhabited centers (Sinnai, Maracalagonis and Settimo San Pietro) within a radius of 6 km.

The contour lines of equidistance Q = 12 m were identified over the sub-vertical surface of the quarry (S): a total of 469 target points (TP_i) were allocated at mutual distance P = 10 m, along the contour lines and the quarry perimeter (Figure 4). The quarry yard at the base of the excavated surface (S) has been excluded by the analysis as hardly visible from the hills around the quarry, due to their modest elevation. The territory from where the alteration is visible (*E*) was identified by outlining a circular perimeter of 5 km radius, centered on the quarry area, according to the criterion referred to as Step B in paragraph 2.1 [17,18]. 20 ROPs were found within the inhabited centers (Sinnai, Maracalagonis and Settimo San Pietro) and the extra-urban areas (Figure 5).



(**a**) (**b**)

Figure 4. (a) Perimeter of the surface alteration (S); **(b)** Distribution of the N Target Points (P = 10 m and Q = 12 m).

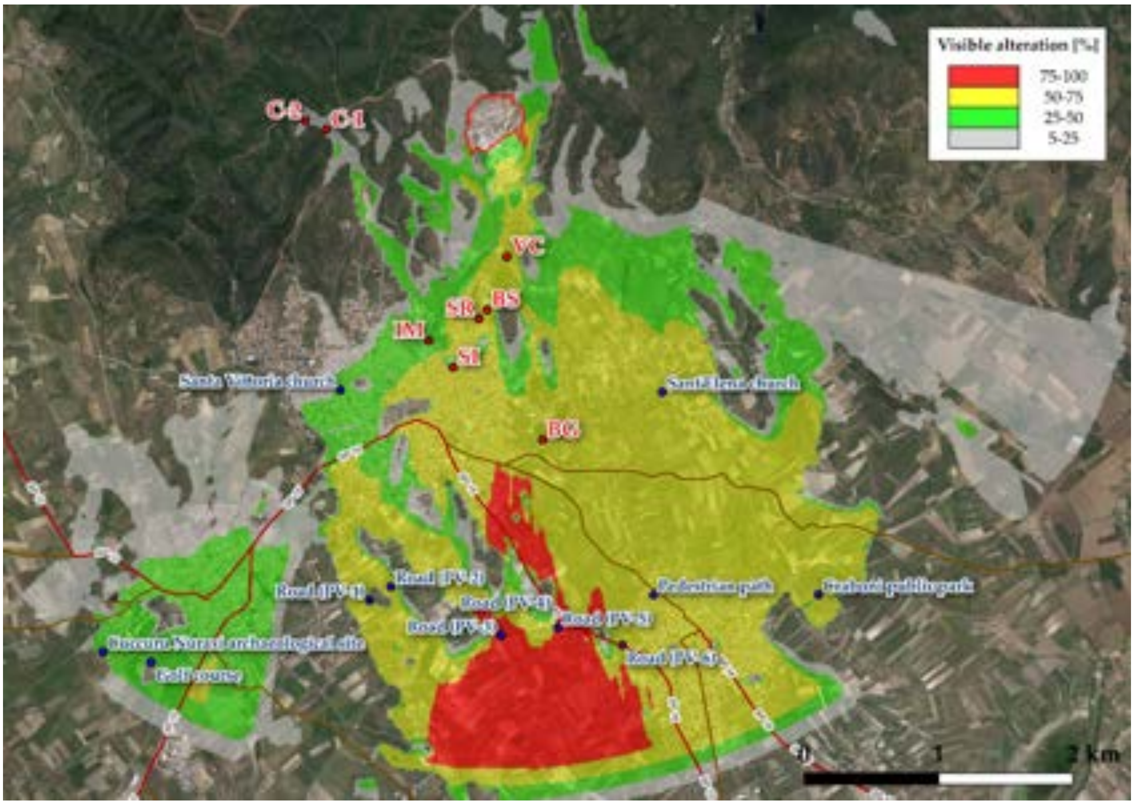


Figure 5. Intervisibility map and selected ROPs (the KOPs reported in Table 4 are marked in red).

From the set of 20 ROPs, 8 KOPs were selected by applying the screening criterion defined in paragraph 2.1 (i.e. the visual solid angle from the observation point must be greater than Ω_L): 5 KOPs in the town of Sinnai, 2 in the forest located on the outskirts of the same town (State Forest of Campidano) and 1 along an extra-urban road (Via Circonvallazione). Table 4 reports the ID of the KOPs and their main features: elevation above the sea level, distance from the quarry and percentage of *S* (visible surface).

Table 4. KOPs ID and main features.

ID	Location	a.s.l. (m)	Distance (m)	Visible surface (%)
VC	*Via Circonvallazione*	173	798	60
C-1	*Campidano Public Forest*	303	1036	23
BS	*Bellavista stadium*	154	1173	59
C-2	*Campidano Public Forest*	329	1198	24
SR	*Skating rink*	156	1239	60
IM	*Is Mitzas square*	141	1475	44
SI	*Sant'Isidoro square*	133	1621	43
BG	*B. Garofalo stadium*	118	2194	66

3.2. Estimation of the alteration visual magnitude

From each of the 8 KOPs, the photographs of the quarry were taken with a digital camera (23.5 x 15.6 mm sensor and 55 mm focal length), under specific conditions of clear sky and quarry surface entirely lightened by the sun (Figure 6).

Figure 6. Photographs of the quarry taken from the selected KOPs.

The alteration visual magnitude was estimated by means of the impact index *Lvi*, by implementing both the k-means clustering and the ED matrix algorithm to the 8 digital images [10]. For each KOP, Table 5 shows the values of the mean chromatic contrast between the bare rock of the quarry and the surrounding natural landscape (ΔE_{μ}), the value of the solid angle subtended to the excavated surface (Ω_{v}) from the viewpoint and of the level of visual impact (*Lvi*).

As highlighted in a recent article [10], the values of *Lvi* obtained by applying the two algorithms of image segmentation (k-means clustering and ED matrix) are comparable, therefore only the k-means clustering results will be henceforward indicated.

Table 5. Results of the visual impact estimation with reference to the selected viewpoints (KOPs).

	k-means clustering			ED matrix		
ID	***Ωv* [sr]**	***ΔEμ***	***Lvi* [dB]**	***Ωv* [sr]**	***ΔEμ***	***Lvi* [dB]**
VC	0.0143	26.2	46.5	0.0153	24.3	46.4
C-1	0.0039	24.5	40.5	0.0039	22.2	40.1
BS	0.0008	22.4	33.2	0.0010	22.5	34.1
C-2	0.0036	26.9	40.6	0.0041	24.3	40.6
SR	0.0060	23.9	42.3	0.0064	22.2	42.3
IM	0.0022	28.8	38.6	0.0018	29.2	37.8
SI	0.0006	24.2	32.4	0.0005	22.8	31.5
BG	0.0012	25.8	35.6	0.0015	23.1	36.0

3.3. Visual Impact Evaluation

In order to finalize the assessment procedure (LAM), the selected KOPs were preliminary classified according to the VIS classes reported in Table 1; the corresponding acceptable level of visual impact were consequently identified (Table 2). Table 6 reports for each KOP the following relevant information: use of land, frequency of visits, VIS class and *Lvi* threshold level.

Table 6. Use of land, frequency of visits, VIS class and *Lvi* threshold level for the selected KOPs.

ID	Use of land	Frequency of visits	VIS Class	Threshold Level (dB)
VC	Road (E)	Medium	5	47
C-1	Natural park (B)	Low	3	41
BS	Sports area (C)	Medium	3	41
C-2	Natural park (B)	Medium	2	38
SR	Sports area (C)	Low	4	44

IM	Leisure area (C)	Low	4	44
SI	Leisure area (C)	Low	4	44
BG	Sports area (C)	Medium	3	41

The visual impact evaluation has been performed by comparing the alteration visual magnitude expressed by *Lvi* with the corresponding threshold value: Table 7 indicates the two values for each KOP and shows that the limit level is exceeded only for KOP C-2 (*Lvi* = 40.6 dB), located within the Natural Park. For the other KOP within the Natural Park (C-1), the same alteration visual magnitude (*Lvi* = 40.5 dB) was found acceptable, due to the lower frequency of visits in its specific location.

Table 7. Visual impact evaluation for the selected KOPs.

ID	***Lvi* (dB)**	***Lvi* threshold (dB)**
VC	46.5	47
C-1	40.5	41
BS	33.2	41
C-2	40.6	38
SR	42.3	44
IM	38.6	44
SI	32.4	44
BG	35.6	41

4. Final Discussion: Practical Implications and Limitations

The described methodology intends to improve the objectivity of the Visual Impact Assessment (VIA) for mines and quarries through the definition of a dedicated Land Assessment Model (LAM) and the introduction of specific algorithms for the development of its succeeding steps, i.e. selection of Key Observation Points (KOPs), estimation of the alteration visual magnitude (*Lvi*) and evaluation of the visual impact.

For the KOPs selection (step 1 of the LAM), in particular, two criteria are introduced, which enables the delimitation of the territory from where the alteration is visible (*E*) and the determination of the viewpoints accessibility. The delimitation of E is based on the identification of a limit solid angle below which an object is unlikely to be noticed; its implementation implies a simplification from a 3D to a 2D criterion, according to which only the maximum linear dimension of the quarry is considered, and thus compared with a limit plane angle of 5° [18]. That simplification allows the reduction of the calculation time and guarantees a conservative outcome (i.e. the selected circular area around the quarry is larger than that attainable through the application of a rigorous 3D criterion).

The alteration visual magnitude is measured by means of the *Lvi* index (step 2 of the LAM), which is calculated through the elaboration of the alteration digital photographs taken from the most representative viewpoints (KOPs). The recent upgrade of the *Lvi* code, which was meant to overcome some inherent limitations deriving from the manual pre-elaboration of the digital images, is largely discussed in a previous article [10], as well as the correlation between the *Lvi* index and the actual perception of potential observers [15].

As regard the visual impact evaluation (step 3 of the LAM), an element of novelty is hereby introduced by the definition of the Visual Impact Sensitivity (VIS) classes. In analogy with the Acoustic Impact Assessment, a land classification is proposed which accounts for the actual/potential use of those areas from where the quarry is visible (i.e. indirect definition of the landscape quality); the land classification (from A to E) is integrated with a frequency parameter, to take into account the actual/potential number of observers per year (i.e. exposure parameter). As a function of those two parameters, 7 VIS classes are identified, each associated with a predefined level of acceptable impact (threshold *Lvi* values). The final impact evaluation is in fact performed by comparing the estimated magnitude of the visible alteration (*Lvi*) with predefined acceptable levels of visual impact. The difference between the estimated magnitude and the corresponding acceptable level can be used to define a priority among different KOPs when planning the implementation of mitigation measures.

According to the proposed model, the VIA assumes a quantitative and more objective value, once the methodology and its algorithms are shared. However, some inherent limitations must be taken into consideration:

- *Lvi* does not account for the excavation's shape, so that equal impact levels are associated to alterations with the same areal extension but different geometry (though it is widely recognized that predominantly horizontal alterations are less impacting than vertical ones);
- *Lvi* does not account for the skyline modification;
- The *Lvi* index is meant to be applied to alterations inserted into predominantly natural landscapes, devoid of conspicuous anthropic elements, such as built-up areas or industrial installations (this is not always the case of the application discussed here);
- The visual quality of a KOP not only depends on its location (as implied in the land classification hereby proposed), but also on the actual visual quality of the landscape as perceived from that specific point of view. Some observation points, even though belonging to areas of recognized quality, can be already compromised by the presence of other preexisting anthropic elements. That issue must be considered in order to decide whether the impact deriving from the alteration under exam (subjected to the assessment procedure) must be considered as an incremental impact (i.e. to be added to the preexisting situation) or, with an opposite view, that viewpoint must be considered of less value (i.e. with corresponding higher admissible limit).

These last two points, in particular, need to be looked into more depth in the ongoing development of this research.

5. Conclusions

An indirect approach has been formerly proposed by the authors of the present article to enable the objective estimation of the visual magnitude of change produced in a natural landscape by mines and quarries. The evaluation approach is based on the calculation of the *Lvi* index (Level of visual impact), which incorporates the two physical features that characterize the visible alteration: its areal extent and the chromatic contrast with the surrounding environment. *Lvi* is calculated through the elaboration of the digital images taken from the most representative viewpoints (KOPs).

This article discusses the integration of the *Lvi* index in a comprehensive Visual Impact Assessment procedure, which includes a preliminary phase of intervisibility analysis, for the identification of the KOPs and a final phase of impact evaluation (i.e. comparison with predefined admissible levels of visual impact). Two variables are used to define the acceptable limits of impact level to be compared to the alteration visual magnitude (*Lvi*): the quality of the territory where the KOP is located and the frequency of visits (maximum daily number of observers in a year). A case study located in Sardinia has been selected to discuss the applicability of the proposed methodology and its limitations.

With specific reference to mines and quarries, the proposed methodology may represents a valuable contribution to a scientifically rigorous approach to VIAs, in the frame of the requirements of the EIA Directive [7], as it aligns the visual impact assessment to the assessment procedures typically implemented to estimate the effect of other impact factors (noise, vibrations, emission of pollutants, use of natural resources, etc.) upon different environmental components (air, water, soil, public health, etc.), favoring the overcoming of controversies generated by qualitative and subjective approaches [9,15].

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