Visual impact evaluation of mines and quarries: the updated *Lvi* method

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Abstract

The article deals with the evaluation of the visual impact arising from quarrying, mining and civil engineering works that involve extensive surface excavation. An indirect method has been formerly proposed to quantify the Level of visual impact (*Lvi*) based on the two physical variables that define the magnitude of change in a natural landscape: the solid angle subtended by the visible alteration from a given viewpoint (Ωv) and the chromatic contrast between the alteration and the surrounding landscape ($\Delta E\mu$). These two objective variables are determined by elaborating the digital images of the landscape under investigation, taken from the most representative viewpoints. The *Lvi* indicator has proven to be highly correlated with the judgement values expressed by potential observers and thus may represent a valuable operative tool in the Environmental Impact Assessment (EIA) procedures, both for the proponent of new projects and for the governmental authorities in charge of decision-making. This article describes a further development of the *Lvi* method, which aims at improving the repeatability of the impact evaluation by eliminating some critical issues related to the definition of both the excavation limits and the natural comparison surfaces representing the natural landscape. To that end, the original calculation code has been implemented with two image segmentation algorithms, which objectively designate the areas within the picture to be used for the automatic calculation of the impact level *Lvi.* The updated code has been validated against the original *Lvi* method, thus confirming the suitability of the revised methodology to represent the perception of potential observers.

Keywords*: environmental impact assessment; landscape assessment model; landscape change; surface excavation; chromatic contrast; visual perception.*

1. Introduction

The visual impact defines the modification of a given visual resource and the consequent effect on the perception of potential observers. The visual impact is defined as adverse when the modification represents a discordant intrusion in the original landscape and thus contributes to the reduction of its visual quality. Quarrying and surface mining projects typically generate an adverse effect on the original landscape quality, together with a variety of negative impacts on different environmental components: loss of soil and vegetation, soil and water pollution, dust dispersion, noise, geological and geomorphological disruptions, eco-systems modification, etc. (Byizigiro et al. 2015; Manna and Maiti 2014). While many of those negative effects have been progressively reduced with the development of new technologies, landscape changes due to extensive surface excavation result apparent worldwide and represent a significant component of the overall environmental impact, especially when those changes are visible from major residential areas or tourist sites and therefore affect a relevant number of observers (Mavrommatis and Menegaki 2017; Alphan 2017). In fact, landscape alteration does not directly affect public health but often generates an adverse reaction within the exposed population and in some cases strongly influences the socio-economic development of the territory from which the alteration is visible. Previous studies proved the presence of active or non-reclaimed mines to be a fundamental contributor to the negative perception of the landscape as a whole (Svobodova et al. 2012), even though significant differences were observed by comparing the visual perception of residents and non-residents (Sklenicka and Molnarova 2010).

Indeed, the assessment of the landscape quality and the evaluation of the perceived modification involve many subjective factors, such as individual perception, aesthetic taste and visual comprehension (Nicholson 1995). However, some aspects of landscape modification need to be estimated in order to define the magnitude of change; in particular when the Visual Impact Assessment (VIA) is mandated by regulatory policies (Directive 2014/52/EU and national legal implementations) and accurate evaluation techniques are required to support decision-making or withstand litigation that might result in a project being rejected or requiring additional mitigation measures at higher cost (Canter 1996; Gobster et al. 2019).

The criteria typically applied to evaluate landscape changes can be categorized into direct or indirect methods (Shafer 1969). Direct methods are based on the judgement values expressed by potential observers (interviewees), who are asked to evaluate the landscape modification directly on site, from the relevant viewpoints. It has long since been proven the possibility of implementing direct methods by observing the photographs of the landscape under investigation (Shafer 1969; Daniel and Boster 1976; Shafer and Brush 1977; Shafer et al. 1969; Shuttleworth 1980) or by using the support of advanced visualization tools (Bishop 1997, 2003; Bishop and Rohrmann 2003; Bishop et al. 2002; Groß 1991; Lange 2001).

Indirect methods are based on the quantification of a number of measurable variables that characterize the landscape modification (Pinzari and Re 1990; Pinto et al. 2002; Misthos and Menegaki 2016). With specific reference to the visual impact produced by surface excavation, Menegaki et al. (2014) performed a comparative analysis between direct and indirect methods. The current trend is the use of psychophysical criteria, where the two approaches are integrated.

In order to estimate the visual magnitude of landscape modification due to quarrying and mine activities, the use of the impact indicator *Lvi* (Level of Visual Impact) has been formerly proposed by Dentoni et al. 2004. The impact indicator *Lvi* is calculated from the digital images of the scenery under investigation, as a function of two objective variables: the extent of the visible alteration and its chromatic contrast with the surrounding landscape. The *Lvi* method was successfully 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 interviewees (Dentoni and Massacci 2007): the statistical elaboration of the perception test gave evidence of a good correlation between *Lvi* and the median of the judgement values expressed by potential observers ($R^2 = 0{,}83$).

The *Lvi* method has been applied to several cases of surface excavation in Sardinia and in the Polish Carpathian (Dentoni et al. 2006; Dentoni and Massacci 2013; Dentoni et al. 2015). Recent studies have suggested the implementation of the *Lvi* indicator as an integrative tool for assessing alternative hypotheses of residential development around mining and extraction sites (Alfaro Degan et al. 2014).

This article describes a further development of the *Lvi* method, which aims at improving the accuracy of the impact evaluation by eliminating some critical issues related to the subjective definition of the input parameters (i.e.: excavation limits and comparison surface representing the unaltered landscape within the picture). To that end, the original *Lvi* code has been integrated with two image-processing algorithms, which allow the objective selection of those parts of the picture to be used for the automatic calculation of the impact level.

The updated code has been applied to eight cases of surface excavation and the results were found in accordance with those obtained with the original *Lvi* method, thus confirming the suitability of the revised methodology to represent the perception of potential observers (Dentoni and Massacci 2007).

2. The original *Lvi* method

The level of visual impact *Lvi* is defined by Equation (1), where Ωv is the solid angle subtended by the visible altered area from a given viewpoint, Ω_0 (8,46·10-8 sr) is the human visibility threshold in a black and white (BW) colour space (maximum chromatic contrast), $\Delta E\mu$ is the mean value of the chromatic contrast between the quarry and the surrounding landscape, ΔE_{BW} is the chromatic contrast between black and white.

$$Lvi = 10 \lg \left(\frac{\Delta E_\mu}{\Delta E_{BW}} \cdot \frac{\Omega_v}{\Omega_0} \right) \qquad (1)$$

The vision solid angle Ωv is calculated from the digital image according to Equation (2),

$$\Omega_v = \Omega_p \cdot \frac{N_a}{N_p} \qquad (2)$$

where Ωp is the solid angle subtended by the entire picture, *Na* and *Np* are respectively the number of pixels representing the bare rock exposed by the excavation and the number of pixels composing the entire picture. Ωp is determined on the basis of the camera focal length and the size of the Charged Coupled Device (CCD).

The chromatic contrast between two points in a given chromatic space can be calculated as the Euclidean distance ΔE, according to Equation (3).

$$\Delta E = \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2} \quad (3)$$

where Δx, Δy and Δz are the differences of the three chromatic coordinates representing the two points.

Digital images from commercial cameras are commonly in the RGB format, the colorimetric space commonly used for file coding, CCD sensors of cameras and scanners, etc. (Wesolkowski and Jernigan 1999). The RGB colour space is not perceptually uniform, which means that differences among colours perceived as the same by the human eye are not mirrored by similar distances in the RGB space (Lucchese and Mitra 2001). This problem can be considerably reduced by using a perceptually uniform reference system, such as the CIELUV or the CIELAB space. The CIELAB colour space, in particular, has been widely used in a number of industrial applications (automobile industry, textile industry, etc.) and already applied to estimate the perception of chromatic differences in visual impact related issues (Bishop 1997).

The mean chromatic contrast $\Delta E\mu$ in Equation (1) is calculated in the CIELAB colour space and represents the mean value of the chromatic distances between each pixel of a selected comparison surface representing the natural unaltered landscape and the mean colour of the bare rock exposed by the excavation. The mean chromatic contrast $\Delta E\mu$ 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 an example, the histograms in Figure 1 show the frequency distribution of the ΔE values for three different quarries (A, B and C) and the resulting mean chromatic contrast $\Delta E\mu$. The histograms A1 and A2, in particular, show the variability of the result when considering two different comparison surfaces within the same picture (Dentoni et al. 2004).

In order to calculate the two physical variables representing the magnitude of change (Ωv and $\Delta E\mu$), the original MATLAB code needs three input files: the picture of the entire landscape and the binary masks of both the quarry and the

comparison surface. The two binary masks must be preliminarily elaborated in order to define the portions of the original picture to be used for the calculation of Ωv and $\Delta E\mu$, according to the previously described procedure. Those pre-elaboration steps raise at least two critical issues: the approximation in the manual detection of the excavation contour and the subjective choice of the comparison surface representing the natural landscape.

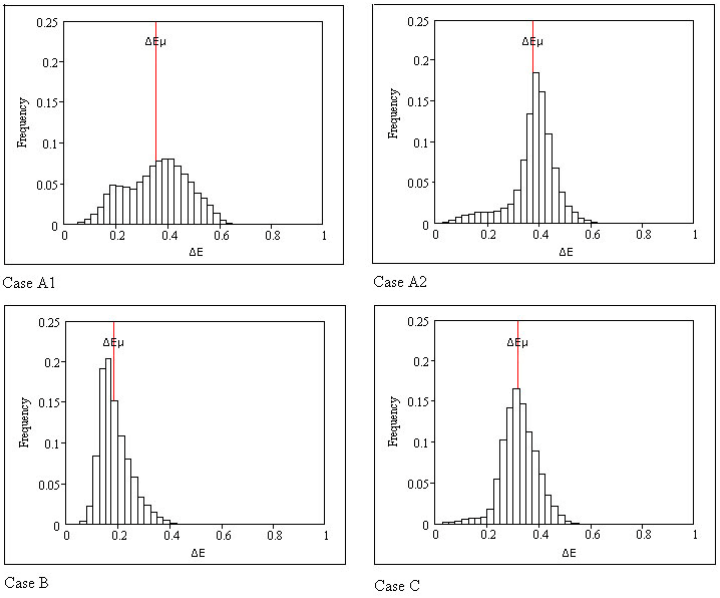

Fig. 1 Frequency distribution of the chromatic contrast ΔE for case studies A, B and C (Dentoni et al. 2004)

3. The revised *Lvi* code

In order to eliminate the pre-elaboration steps in the original *Lvi* method and improve the accuracy of the impact evaluation, the calculation routine has been integrated with two techniques of image segmentation: the Euclidean distance matrix (ED matrix) and the *k*-means clustering algorithm. The two techniques enable the objective selection of those areas within the picture to be used for the automatic calculation of the impact indicator *Lvi*.

The main body of the updated code has been developed in MATLAB environment (Image Toolbox), where the landscape's digital image is treated as a matrix of *m* by *n* elements, each representing a pixel. In colour images, the chromatic attribute is encoded by a triplet of values (chromatic coordinates). For monochromatic images,

the numerical value associated to each pixel is a non-negative integer proportional to the average light intensity. In the case of binary images, the numerical value associated with each pixel can be either 0 or 1.

When the file representing the landscape image is uploaded in the MATLAB code, the user is asked to cut a focus of the area around the quarry, in order to reduce the elaboration time and exclude the presence of disturbing elements (houses, buildings, installations, etc.), which might interfere with the succeeding elaboration steps. The focus of the picture is then converted from the original RGB format into the CIELAB system and the user can choose between one of the two techniques of image segmentation described below to automatically elaborate the required binary masks.

3.1 The ED matrix

The ED matrix is commonly applied to digital images characterized by discernible objects of homogeneous colour. In those cases, it is possible to segment the picture by extracting from the original matrix the pixels of the desired area and then switching to a binary image, where each pixel assumes value 1 or 0, depending on whether it belongs or not to a predefined colour range. As regards hillside quarries, the characteristic colour of the bare rock exposed by excavation can be used as discriminator to segment the visible alteration from the rest of the picture. If the colour of the quarry faces is sufficiently homogeneous, the average colour of a small portion can be considered representative of the quarry as a whole. The chromatic contrast between the mean colour of that selected portion (L', a', b') and the colour of each other pixel (L, a, b) is calculated in terms of Euclidean Distance (Equation 3). A m by n matrix is then obtained (the ED matrix), where a chromatic contrast value is associated to each pixel within the image. The next step is the definition of an admissible range of chromatic distances [d'-2σ < D < d'+2σ], which allows the automatic detection of the quarry limits. That range is defined by the mean value (d') and the standard deviation (σ) of the chromatic distances. The pixels falling within that range D assume value 1 (white), the others 0 (black). A binary image of non-connected regions is generated, as information regarding the position of the pixels in the matrix is not taken into consideration initially. A further elaboration is therefore necessary to include spatial information and define homogeneous regions

of adjacent pixels belonging to the same class. The small areas outside the quarry that result in the admissible range of chromatic distance are filtered to be excluded from succeeding calculations. Morphological operations within the quarry area are then performed with the 8-connected structural elements function to change the first assignation within the binary image and obtain a sharper definition of the quarry limits.

Figure 2 reports the colorimetric map of the ED matrix (left) and the original picture with the excavation contour (right). The minimum values of chromatic contrast in the ED matrix clearly represent the quarry (dark blue); increasing distances from the quarry mean colour are in a scale from blue to yellow. The automatic definition of the quarry contour allows the elaboration of the quarry binary mask and the calculation of the quarry's relative extent in the picture (*Na*/*Np* in Equation 2).

If the colour of the natural landscape around the quarry is sufficiently homogeneous, the same elaboration steps described above are reiterated to segment the comparison surface. Starting from a small portion of the image representing the unaltered vegetation around the quarry, the segmentation is performed to isolate the entire comparison surface contour (Figure 3) and then elaborate its binary mask.

Once the two binary masks are defined, the MATLAB code proceeds with the calculation of the chromatic distances (ΔE) between the mean colour of the entire quarry and the colour of each pixel within the comparison surface. The mean chromatic contrast $\Delta E\mu$ is calculated as the arithmetic mean value of the chromatic distances (ΔE_i) in the CIELAB reference system, according to the original *Lvi* method. The programme requires the solid angle of the digital camera (Ωp) and calculates the Level of visual impact (*Lvi*), according to Equation (1).

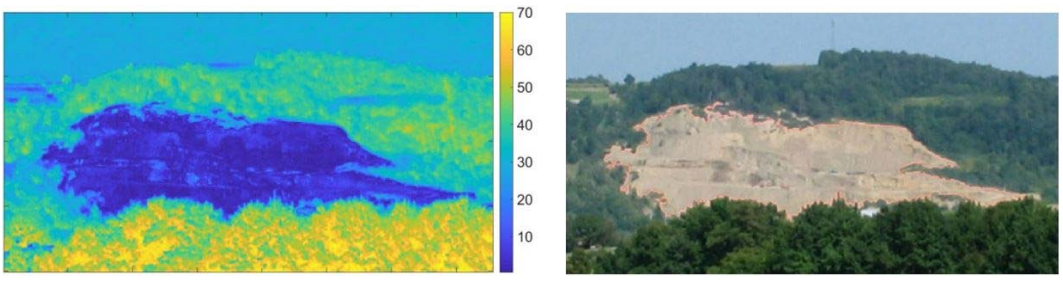

Fig. 2 The colorimetric map of the ED matrix and the excavation limits (red line) in the original picture

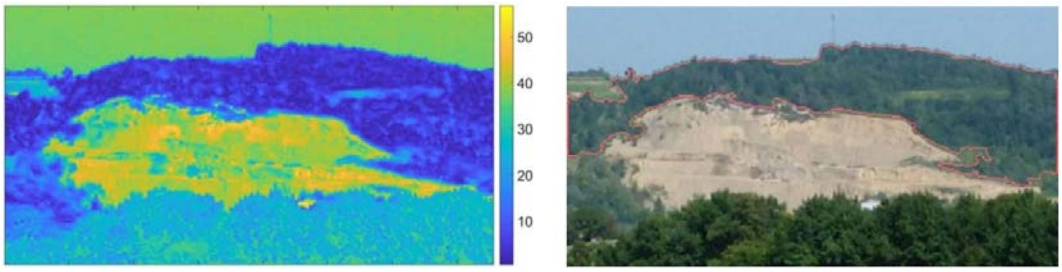

Fig. 3 The colorimetric map of the ED matrix and the comparison surface limits (red line) in the original picture

3.2 The *k*-means clustering algorithm

The most common algorithm used to perform image segmentation is the *k*-means clustering method (McQueen 1967). Given a number *k* of clusters, a set of *n* data, a distance metric and a stop criterion, the *k*-means algorithm divides the *n* data into *k* clusters, so that intra-cluster similarity is high. Each cluster is defined by an initial centroid (cluster centre). The colour metrics typically used in clustering methods (Duda and Hart 1973) are the Euclidean distance (Equation 3) and the cosine distance (or vector angle). The cosine distance between two vectors x_s and x_t is defined by Equation 4:

$$d_{st} = 1 - \frac{x_s x'_t}{\sqrt{(x_s x'_s)(x_t x'_t)}} \quad (4)$$

where x_s represents the chromatic attributes of a given pixel and x_t those of a given cluster centroid. The *k*-means function in MATLAB uses the *k*-means clustering algorithm (Lloyd's algorithm), an iterative data-partition algorithm that assigns *n* observations to a predefined number *k* of clusters: the objects attributes are represented as vectors and each cluster is identified by an initial centroid or midpoint (Lloyd 1982). The clustering algorithm proceeds as follows:

1. Selection of *k* clusters with initial centroids.

2. Computation of point to cluster centroid distances for all the observations.

3. Assignment of each observation to the cluster with the closest centroid (or manual reassignment of observations to different centroids, if that implies the reduction of the Squared Sum (SS) of point-to-centroid distances).

4. Computation of the average value of the observations for each cluster (mean colour of pixels within a cluster) and definition of new centroids for the *k* clusters.

5. Reiteration of steps 2 to 4 until cluster assignments do not change or the maximum number of iterations is reached.

The result of the *k*-means implementation to the same landscape image represented in Figures 2 and 3 is reported in Figure 4: four clusters are discernible, which represent the vegetation in the foreground (cluster 1, top left), the sky (cluster 2, top right), the excavation area (cluster 3, bottom left) and the vegetation around the quarry (cluster 4, bottom right). From clusters 3 and 4, it is possible to create the required binary masks.

As in the ED matrix method, the segmentation obtained with the *k*-means clustering algorithm does not account for the spatial relationship between pixels (Jain et al. 1995) and non-connected regions are found around the excavation and the comparison surface (see cluster 3 & 4 in Figure 4). Again, the filtration of those non-connected areas outside the limits and the implementation of the 8-connected structural elements allow a sharp definition of the two binary masks. Once the two binary masks are elaborated, the MATLAB code proceeds with the automatic calculation of *Lvi*.

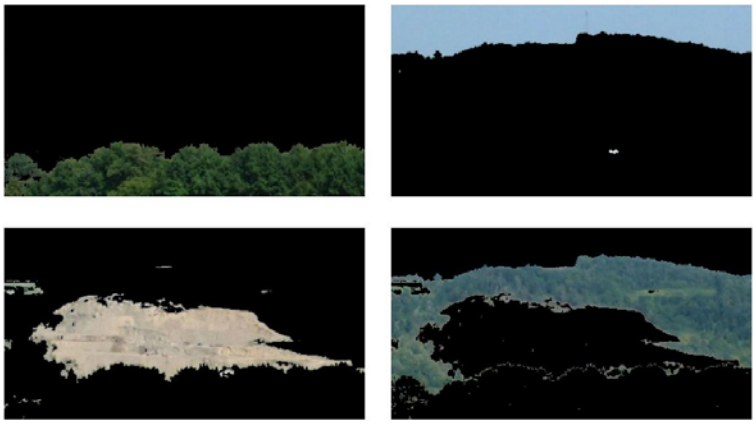

Fig. 4 The four clusters obtained with the *k*-means algorithm: cluster 1 & 2 on top (foreground vegetation and sky), cluster 3 & 4 underneath (excavation area and the vegetation around the excavation)

3.3 ED matrix vs *k*-means clustering

The ED matrix method is simple to apply and implies low computational costs. The result can be influenced by the definition of the two initial portions of the picture that represent the bare rock and the comparison surface in terms of chromatic attributes. In the event that too small portions of the picture are selected, the code may not recognize the two areas in their entireness and therefore generate some discrepancies in the calculation of the impact indicator *Lvi*. However, this problem becomes negligible once the morphological corrections are applied. The ED matrix method has proven to be accurate in estimating chromatic contrast when low saturation values occur. Considering that the representative viewpoints from which the photographs are usually taken are located up to 8 km from the alteration, so as to include a significant share of the natural landscape under investigation, the required condition of low saturation is generally verified. In fact, both the alteration and the surrounding natural setting are in most cases part of the picture's background, where the colours become poorly saturated and quite homogeneous due to the atmospheric attenuation phenomena (Bishop 2003; Magill and Litton 2016).

Compared to the ED matrix, the *k*-means clustering method requires longer computational costs, but it is less affected by the user's subjective choices; it results very flexible and more accurate in a greater range of case studies. The cosine distance is a metric that better captures the differences in hue, whereas the Euclidean distance better accounts for the light intensity (Dony and Wesolkowski 1999). At low saturation values, light intensity is more relevant than hue, while colour is of greater importance when high saturation occurs (Carron and Lambert 1994). Depending on the saturation degree within the excavation area, the k-clustering method implements the most suitable chromatic metric, thus obtaining the most accurate result depending on the image characteristics.

4. Validation of the revised *Lvi* method

4.1 Case studies

Eight case studies of surface excavation discussed in previous studies were selected to validate the revised *Lvi* method (Dentoni et al. 2006; Dentoni and Massacci 2007;

Dentoni and Massacci 2013; Dentoni et al. 2015). The images representing the landscape changes under consideration are shown in Figure 5, where the picture identification codes refer to the municipality to which the case belongs and to the specific point of view (CPT: Capoterra; DBR: Dąbrowa; FLR: Florinas; KLC: Klęczany-1; RNI: Orani; SRC: Sarroch; THN: Siniscola; ZNY: Klęczany-2).

The authors took all the pictures in Figure 5, from selected Key Observation Points (KOPs) in Italy (Sardinia) and in Poland (Polish Carpathian), during clear and sunny days, when optimal lighting conditions occurred, mainly at noon or in the early afternoon. The distances between the observation point and the altered area were between 0,5 km and 7,5 km; as for greater distances (>8 km) the observer gets a sense of the overall perspective, but he is not able to discern the landscape details (Misthos and Menegaki 2016). In most cases, the altered area is in the background, which implies a significant reduction in sharpness and colour saturation.

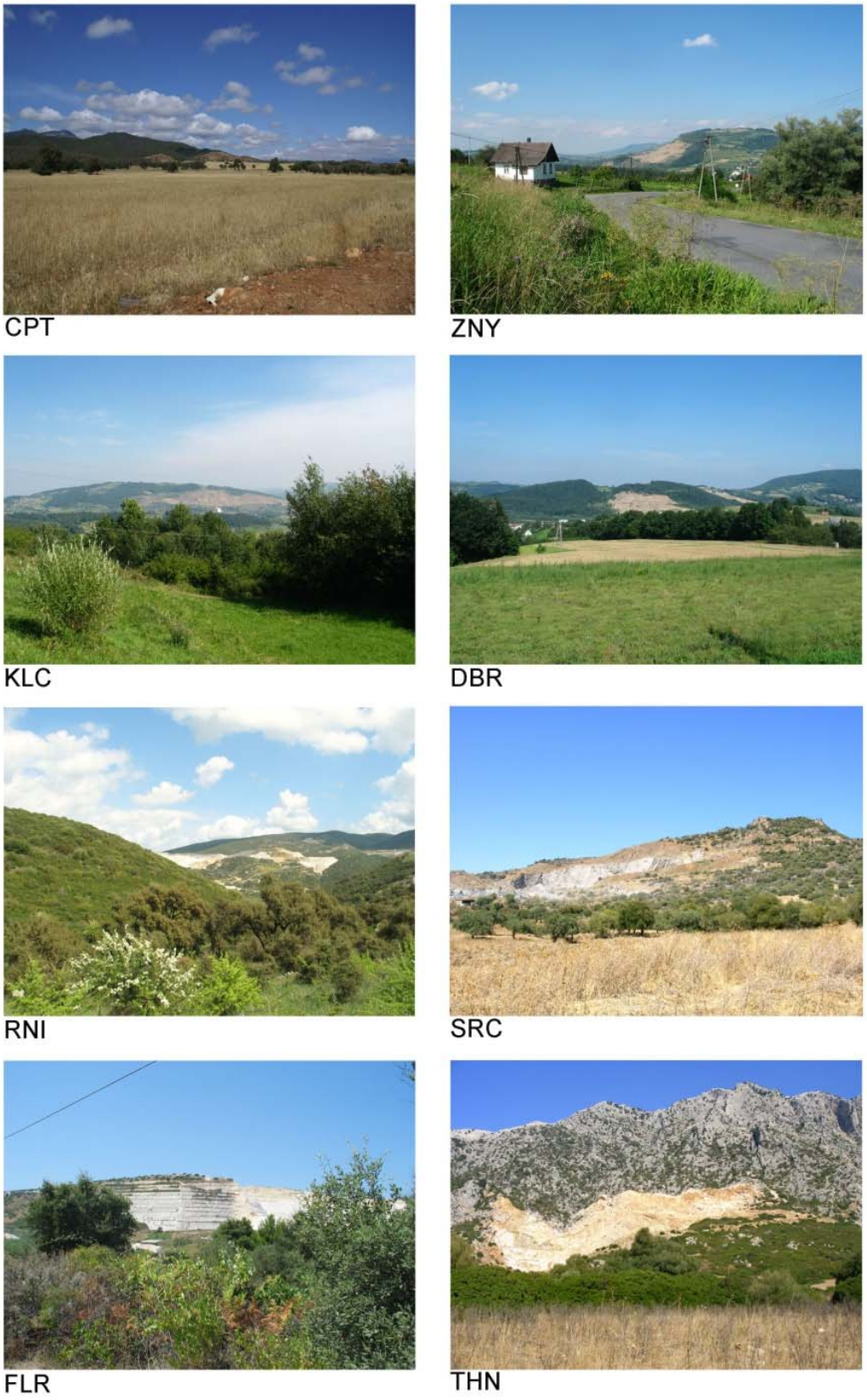

Fig. 5: The photos used to validate the updated *Lvi* algorithm

4.2 Results and implications

Table 1 reports the impact levels obtained with the original *Lvi* method and those obtained with the revised code, considering both the image-processing algorithms (ED matrix and k-means clustering). The impact data has been ordered from the lowest to the highest impact level, which also corresponds to the arrangement of the photos in Fig. 5 (increasing impact from left to right and top to bottom). The comparison of the results proves that the impact levels obtained with the revised code are in good agreement with those obtained with the original *Lvi* method, with differences between 0,1 dB (DRB) and 0,8 dB (FLR and THN). Wider deviations were found when considering the two physical variables separately (Ωv and $\Delta E\mu$); in this case the highest relative difference was about + 36% for the alteration extent Ωv (SRC and KLC) and about – 25% for mean chromatic contrast $\Delta E\mu$, both obtained with the ED matrix (SRC).

	Original *Lvi*			ED matrix			*k*-means clustering		
	Ω_v [sr]	$\Delta E\mu$	*Lvi* [dB]	Ω_v [sr]	$\Delta E\mu$	*Lvi* [dB]	Ω_v [sr]	$\Delta E\mu$	*Lvi* [dB]
CPT	0,0033	17,6	38,3	0,0036	18,2	38,9	0,0032	20,4	38,8
ZNY	0,0032	32,8	40,9	0,0023	38,9	40,3	0,0031	36,8	41,4
KLC	0,0079	23	43,3	0,0108	17,9	43,6	0,0099	17,6	43,1
DBR	0,0049	39,8	43,6	0,0051	38,9	43,7	0,0057	35,9	43,8
RNI	0,0076	38,2	45,4	0,0068	37,0	44,7	0,0067	38,5	44,8
SRC	0,0163	29,5	47,5	0,0221	22,1	47,6	0,0186	23,9	47,2
FLR	0,0368	33,8	51,7	0,0293	37,3	51,1	0,0348	29,7	50,9
THN	0,0453	38,4	53,5	0,0641	35,5	54,3	0,0641	35,8	54,3

Table 1 Results and comparison between the original and the revised code

It is worth noticing that higher values of the solid angle Ωv (positive deviations) obtained with a given segmentation algorithm are compensated by corresponding lower values of the mean chromatic contrast $\Delta E\mu$ (negative deviations). In fact, both segmentation algorithms identify the altered area according to its chromatic attributes and sometimes include in the alteration limits a strip of deforested territory around the excavation, where a chromatic transition from the bare rock to the surrounding natural landscape occurs (see pictures SRC and KLC). The identification of a wider excavation surface implies the calculation of a wider solid angle, with a mean colour partially affected by the sporadic vegetation and thus less

in contrast with the untouched vegetation cover (i.e.: lower value of the mean chromatic contrast). As a result, the overall impact levels *Lvi* calculated with the updated code remain comparable with those obtained with the original method, which proves the revised methodology to be still suitable to represent the perception of potential observers (Dentoni and Massacci 2007).

Apart from the comparative analysis discussed above, it is worth observing as the case studies in Figure 5 represent different settings (different quarries or same quarry from different viewpoints), which according to the authors' subjective perception go from a case of negligible visual impact (CPT) to at least two cases of very relevant impact (THN and FLR).

Under the assumption of lands of equal *visual quality*, a proposal of impact classes is reported in Table 2, where four judgment values (*negligible*, *moderate*, *relevant* and *very relevant*) are associated to the case studies under exam, depending on the magnitude of change expressed by *Lvi.*

It is worth highlighting that acceptable levels of visual impact (*limit values*) must be defined beforehand in order to finalise the VIA procedure, according to the established *visual quality* of the land under investigation. In fact, the same *Lvi* can be acceptable or beyond a recognized limit, depending on the value of the landscape visual resources, as perceived from the selected Key Observation Points (KOPs).

Visual impact classes			
Negligible	***Moderate***	***Relevant***	***Very relevant***
Lvi < 40.0	40.0 < *Lvi* < 45.0	45.0 < *Lvi* < 50.0	*Lvi* > 50.0
CPT	ZNY, KLC, DBR, RNI	SRC	FLR, THN

Table 2. Proposal of visual impact classes and reference levels

According to Palmer (2019a), a scientifically rigorous approach to Visual Impact Evaluation (VIA) must include the following fundamental steps of a Landscape Assessment Model (LAM):

1. Determination of the territory with potential visibility of the proposed project (intrusion/alteration) and selection of Key Observation Points (*visibility analysis*).

2. Estimate of the project's visual magnitude from the KOPs (*visual magnitude*).

3. Definition of land sensitivity to changes (*visual quality*) and corresponding levels of acceptable modification.

With specific reference to landscape changes due to mines and quarries, the *Lvi* indicator, with the revision of the calculation routine hereby discussed, can be incorporated in the LAM above described to enable the objective estimation of the excavation's *visual magnitude* (step 2).

4.3 Limitations of the proposed methodology

4.3.1 Preliminary considerations

The visual perception of landscape modification (i.e.: visual impact) depends on the physical characters of the visible alteration, the visual quality of the observation point and the socio-cultural and psychophysical characteristics of the observer.

The identification of KOPs by means of *visibility analysis* (step 1 of LAM) is objectively carried out with the aid of GIS-based applications and does not introduce specific limitations and/or uncertainties in the assessment process (Dentoni et al. 2018; Palmer 2019a).

The evaluation of the alteration's visual magnitude (step 2 of LAM), on the other hand, is developed through complex processes based either on direct observation performed by a statistically significant number of observers (direct method) or on mathematical algorithms, such as the proposed *Lvi* index, whose objective is the numerical quantification of the alteration perceived by an average human observer (indirect method). Both approaches, statistical or numerical, allow to overcome the limit of the judgment subjectivity and its dependence on the observer's characteristics.

4.3.2 Limitations of *Lvi*

The *Lvi* index is calculated as a function of Ωv and $\Delta E\mu$ (Equation 1), which are obtained by the digital images of the landscape taken with commercial photo cameras (the other parameters included in the formula structure are constant).

The parameter Ωv is the vision solid angle subtended from a given viewpoint by a circular surface with areal extent equal to the alteration. The structure of Equation

2 allows the objective estimation of Ωv, which does not depend on the specific camera characteristics and set up. The limitations in the assumption of Ωv as a descriptive parameter of the visible alteration derive from not taking into account the alteration shape and its relative location within the observed scenery (for instance, Ωv does not consider the additional negative effect deriving from the skyline modification).

The parameter $\Delta E\mu$ is the mean chromatic distance between the alteration and the selected comparison surface. The use of a perceptually uniform reference system (such as CIELAB) allows the calculation of chromatic distances that are representative of the chromatic contrast perceived by the human eye. However, the introduction of the average value $\Delta E\mu$ in Equation 1 establishes a limitation with respect to the effect produced by the distribution of the chromatic distances within the comparison surface (Figure 1). Differently from Ωv, $\Delta E\mu$ depends on the camera characteristics and set up, as well as the specific shooting conditions: brightness, air transparency, exposure to sun, etc. The perception of the chromatic contrast, as a matter of fact, is always affected by ambient factors, either when the evaluation is performed by field observation or through digital images. Therefore, the evaluation of $\Delta E\mu$ should always take place under standardized shooting conditions.

As for the uncertainties arising from the choice of both the altered and the comparison surface, from which Ωv and $\Delta E\mu$ are calculated, they are overcome by the introduction in the calculation routine of the image segmentation algorithms discussed hereby (ED matrix and K-mean clustering), which allow the automatic calculation of Lvi, thus strengthening the objectivity of the proposed evaluation methodology.

Even under the assumptions and limitations above discussed, the *Lvi* index remains capable of effectively representing the human perception of the visual impact magnitude. This has been demonstrated for alterations inserted into predominantly natural landscapes devoid of conspicuous anthropic elements (such as built-up areas or industrial installations) by comparing the direct evaluation of a numerically significant group of observers and the corresponding *Lvi* values (Dentoni and Massacci 2007).

5. Conclusions

In order to assess the visual impact produced by quarries and mines, an indirect method has been formerly proposed by the authors of the present article, which allows the calculation of a Level of visual impact (*Lvi*) on the basis of the two physical variables that define the magnitude of change: the solid angle subtended by the visible alteration from a given viewpoint (Ωv) and the chromatic contrast between the colour of the rock exposed by excavation and the surrounding natural landscape ($\Delta E\mu$). The two variables, Ωv and $\Delta E\mu$, are calculated from the digital images of the landscape under investigation, taken from the most representative viewpoints (KOPs).

The article discusses a further development of the original *Lvi* method, which aims at improving the repeatability of the visual impact evaluation by eliminating some critical issues related to the subjective definition of both the alteration contour and the comparison surfaces within the picture. To that end, the original *Lvi* code has been implemented with two alternative algorithms of image segmentation that allow the automatic designation of the pixels to be used for the calculation of Ωv and $\Delta E\mu$.

The updated *Lvi* indicator was applied to eight selected cases of surface excavation and the results compared to the impact levels obtained with the original code. The comparison demonstrates the consistency of the results and thus the capability of the revised methodology to represent the perception of potential observers (Dentoni and Massacci 2007).

The proposed methodology, with the revised calculation routine hereby discussed, may represent a valuable contribution to a scientifically rigorous approach to VIAs (Palmer 2019b), in the light of the recent amendments of EIA Directive (2014), which recognized 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 fact, the updated *Lvi* indicator allows the objective description of the landscape modification generated by mines and quarries and aligns the evaluation methodology to those typically implemented to estimate the impact on other

environmental components, favoring the overcoming of controversies generated by qualitative and subjective approaches (Gobster 2019).

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