



Visual impact of quarrying in the Polish Carpathians

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Dentoni V., Massacci G. and Radwanek-Bak B. D. (2006) — Visual impact of quarrying in the Polish Carpathians. *Geol. Quart.*, 50 (3): 383–390. Warszawa.

Landscape alteration is generally one of the most significant impacts resulting from surface mining and quarrying, particularly when the excavation activities are located within environmentally sensitive areas. We describe the results of two different methods of visual impact assessment applied to selected case studies in the Polish Carpathians. The study concerns areas of significant landscape value and holiday destinations for many people living in the Silesian and Kraków urban-industrial agglomerations. One of the two methods refers to the EC decision 272/02, which establishes ecological criteria for the award of the Community eco-label for hard floor-coverings. The second method was proposed in previous research and is based on the application of a visual impact indicator (*Lvi*) in which two objective aspects of landscape alteration are included: the extent of the visible excavation and its chromatic contrast with its surroundings. The results of the two methods are compared and discussed for each of the case studies considered.

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Key words: quarrying, environment, visual impact, digital pictures, solid angle, chromatic contrast.

INTRODUCTION

Surface mining and quarrying usually generate a number of environmental impacts among which landscape alteration can certainly be considered one of the most significant. Although landscape and visual impact does not directly affect public health it easily generates a negative reaction within the population and sometimes strongly influences the socio-economic development process of the territory involved.

The start of mining and/or quarrying in an area is often associated with changes in the actual or potential use of the territory, with loss of agricultural potential, with deforestation and with alteration of the landscape and its aesthetic values. These negative effects of exploitation are more marked in mountainous areas than elsewhere.

Of the environmental impacts arising from excavation activities, landscape and visual impact most obviously involves socio-economic and cultural issues which strongly influence the assessment method. Landscape and visual impact assessment (LVIA), in fact, relies more on judgement and less on

measurements, involving individual perceptions, aesthetic tastes and visual comprehension (Nicholson, 1995). Landscape alteration arising from mining activities might be perceived very negatively by those individuals who do not live in the area (tourists or occasional visitors) and who therefore are not prepared to accept incongruities in the landscape; this is a major issue in areas of high scenic value or where the tourist industry has potential for growth. On the other hand, local residents tend to justify the permanent landscape alteration associated with mines and quarries as they associate these changes with a traditional source of wealth and employment opportunity.

However, some aspects of landscape modification can be objectively measured in order to quantify the magnitude of change, in particular, the extent of the visibly altered area and the degree of chromatic contrast between the bare rock and the predominant colour of the surrounding environment.

The aim of this paper is to give a preliminary representation of visual impact arising from the quarries located in the Polish Carpathian area (Małopolska) on the base of objective indicators. Three medium-size quarries were chosen for this study. All of them are visible from the main roads and located within protected areas of high scenic value.

LANDSCAPE AND VISUAL IMPACT ASSESSMENT METHODS

With regard to legislation and standards, the EC decision 272/02 (Commission Decision, 2002) establishes ecological criteria for the award of the Community eco-label for hard floor-coverings. This decision defines two indicators applicable to the assessment of the visual and landscape impact arising from the extraction activities of raw material (marble, granite, other natural stones, aggregates, and raw materials for the cement and ceramic industry): the Rehabilitation Simultaneity Degree (*RSD*) and the visual impact indicator x .

The *RSD* is defined as the ratio of the compromised area (including quarry faces and active dumps) to the surface of the authorized area. The visual impact indicator x of the quarry is calculated by selecting a number of viewpoints (nearby towns and villages, major roads, places of remarkable environmental and cultural value, regularly frequented places and so on) from where the most significant vertical cross-sections are traced.

For each section the visual impact indicator x is calculated considering the visible vertical extent of the compromised area and the distance from the view point considered. For a specific visual point P , x is defined as:

$$x = \frac{h^2}{(L \tan 30^\circ)^2} \times 100 \quad [1]$$

where: h — vertical height of altered area visible from P [m]; L — horizontal distance between P and the altered area [m]; $\tan 30^\circ$ — tangent of the average angle of the vision cone of the human eye; x — visual impact indicator [%].

The term h^2 approximates the base surface of the visibility cone within which the compromised area can be seen, while the term $(L \tan 30^\circ)^2$ approximates the base area of the average visual cone of the human eye.

For each of the two indicators defined by the EC decision a score is assigned according to the values shown in Table 1.

Table 1

Evaluation classes according to the EU decision

Score	5 excellent	3 good	1 sufficient	Exclusion hurdle
<i>RSD</i> [%]	<15	15–30	31–50	>50
x [%]	$0 \leq x \leq 10$	$10 < x \leq 20$	$20 < x \leq 30$	$30 < x$

The score obtained for each indicator is corrected by applying one or more weighting factors in order to allow for the environmental sensitivity of the land where the quarrying or mining activity is located.

For the visual impact indicator x , only the weighting factors $W1$ and $W3$ are considered.

$W1$ is specifically related to the natural value of the area (notified sites of Community importance, specially protected areas in the EU, areas outside the EU which fall under specific provisions of UN conventions). $W3$ refers to the population density of those settlements situated within 5 km of the quarry

or mine site, the latter factor being closely related to the number of regular observers (mainly residents).

An alternative method for landscape and visual impact assessment is based on the elaboration of a number of digital images taken from the most significant viewpoints. For each picture a single visual impact indicator Lvi is calculated which includes both the extent of the visible alteration and the chromatic contrast between the uniform colour of the bare rock exposed by excavation and the variable chromatic characteristics of the surrounding area (Dentoni *et al.*, 2004).

The visible alteration extent can be expressed in dB as a visibility level Lv , defined as:

$$Lv = 10 \log(\Omega_v / \Omega_0) \quad [2]$$

where: Ω_v — vision solid angle subtended by the altered area; $\Omega_0 = 8.46 \times 10^{-8}$ [sr] — visibility threshold under maximum contrast conditions in a black and white space.

More specifically Ω_v is the solid angle within which the altered area can be seen from the viewpoint, considering the distance between the quarry and the observer as well as the masking effect due to morphology and vegetation.

Ω_0 is obtained by multiplying two plane visual angles of one minute each along two perpendicular directions; in fact the standard definition of normal visual acuity (1.0 or 20/20 vision) is the ability to distinguish alternating black and white lines separated by a visual angle of one minute arc; a smaller angle would make the pattern appear as a mass of solid gray. Since in practical cases the solid angle takes values ranging from Ω_0 to a few tens of thousandths of [sr], the use of the logarithmic function expressed in [2] is convenient.

When using digital images, the vision solid angle is $\Omega_v = \Omega_p \times N_a / N_p$, where Ω_p is the solid angle subtended by the entire picture, while N_a and N_p denote respectively the number of pixels representing the altered area and the total number of pixels of the picture.

The visual impact of any landscape alteration is enhanced by the degree of chromatic contrast with the surroundings. Any colour can be defined through three chromatic coordinates, referring to a specific colour space. The chromatic contrast between two given colours can be evaluated as the Euclidean distance ΔE between two points, defined as:

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad [3]$$

where: ΔL , Δa and Δb — the differences between the values of the three chromatic coordinates of the two colours in the CIE Lab colour space.

The CIE Lab system is a perceptually uniform colour space, in the sense that the distance ΔE is approximately proportional to the effective contrast perceived by the observers. The procedure described here considers the CIE Lab colour system, as its use is prevalent compared to possible alternative perceptually uniform colour spaces (as the CIE Luv). Moreover the CIE Lab colour space has been applied to estimate the perception of chromatic differences in visual impact-related issues (Bishop, 1997; Dentoni *et al.*, 2005).

The visual impact indicator Lvi is expressed by the following equation:

$$Lvi = 10 \log \left(\frac{\Delta E_{\mu}}{\Delta E_{BW}} \times \frac{\Omega_v}{\Omega_0} \right) \quad [4]$$

where: ΔE_{μ} — the mean of the values ΔE calculated for each pixel of a portion of the picture, selected as a comparison area. The mean of ΔE values (ΔE_{μ}) is divided by the Euclidean distance between black and white (ΔE_{BW}) to obtain the mean standard chromatic contrast ($\Delta E_{\mu}/\Delta E_{BW}$). The value of ΔE_{BW} is 100 in CIE Lab colour space, as the chromatic coordinates of black and white are respectively ($L = 0; a = 0; b = 0$) and ($L = 100; a = 0; b = 0$). Other explanations as on equation [2].

VISUAL IMPACT OF SELECTED QUARRIES IN MAŁOPOLSKA

STUDY CASES

The two methods described above were applied to three quarries located in Małopolska. Two of them are the sandstone quarries near Nowy Sącz and might be recognized as representative of the whole Polish Carpathian region considering the type of rock extracted, the landscape characteristics, the socio-economic situation and the planning aspects. The third case study is the porphyry quarry in Zalas, near Kraków. All these cases are within Landscape Protected Areas, located near villages, cities and roads.

Referring to the three quarries, both the visual impact indicator x and the level of visual impact Lvi have been calculated. The data used for the evaluation of the two indicators was ob-

tained through the elaboration of digital photographs representative of the study cases and taken from significant viewpoints.

The pictures were taken in late summer (August/September) during sunny days. The pictures of the sandstone quarries were taken in the forenoon and around noon, when the quarry faces were illuminated by the sun. The transparency of air was typical for a dry but slightly misty day.

The picture of Zalas was taken from a viaduct over the highway at a distance of about 5 km. The quarry faces were illuminated by the sun. The transparency of the air was good and typical for a sunny late summer afternoon. Because this picture was taken over the weekend, the air transparency was a little better compared to that of a working day when the traffic is heavier.

The sandstone quarries in Klęczany and Dąbrowa are situated in the central part of the Polish Outer Carpathians, about 50 km south-west of Kraków near Nowy Sącz, which is a local administrative centre (Fig. 1). The region is characterized by high nature and landscape values and it is a part of an extensive Landscape Protected Area. It is also a popular tourist region, and a place where many citizens from Kraków usually spend their summer and winter holidays.

From the geological point of view the area belongs to the Dukla sedimentary basin where thick sequences of flysch-type sediments were deposited. Their age range from upper Cretaceous to Oligocene.

CASE 1

The multilevel quarry in Klęczany (9 levels) is the biggest quarry in the Polish Carpathians, with an area of about 300 000 m². It occupies the south slope of an extensive hill (615.8 m above sea level), formerly covered by a forest and now partly deforested. Its walls are about 150 m high (Figs. 2

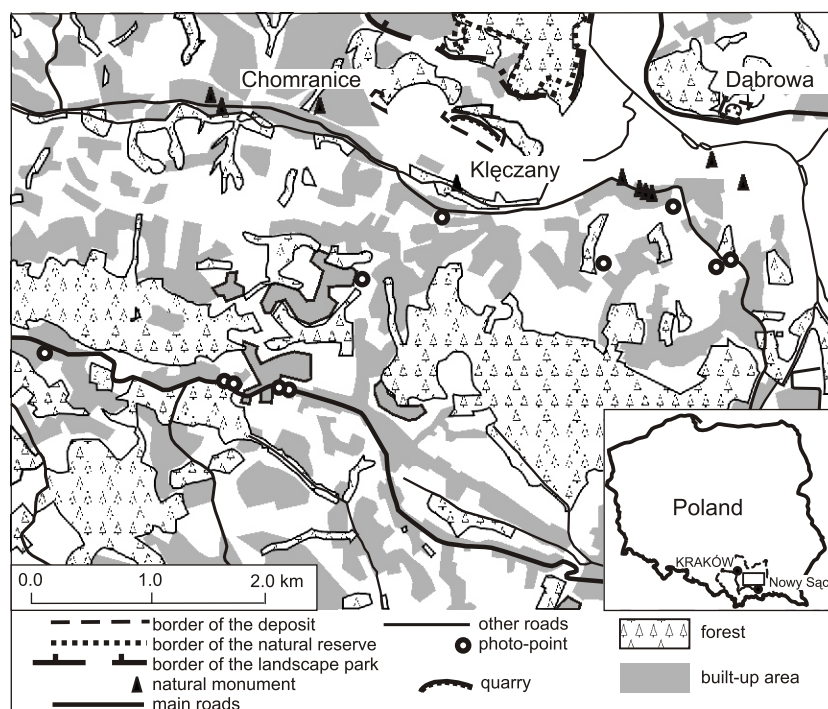


Fig. 1. Location of Klęczany and Dąbrowa quarries



Fig. 2. Multilevel Kłęczany sandstone quarry (picture K2)



Fig. 3. Multilevel Kłęczany sandstone quarry (picture K4)

and 3). The Oligocene Cergowa Sandstones extracted in the thick-bedded Kłęczany deposit are grey in colour and fine- to coarse-grained. The deposit includes several sandy lenses within shale sequences. The thickness of the sequence exposed in the quarry varies from 5.9 m to 226 m. The average content of shale in the profile of the deposit is 23%, but it differs in individual successions from about 5% to more than 90%. The sandstone itself has good technical properties, in particular a high compression strength. It is used as high quality material for railway and road construction.

The quarry has been active since 1912. It has been exploited at a large scale by blasting methods since the 1960's. The output level in the 1970's and the 1980's was about 1 Mt/y. Now it has reduced to 0.5–0.6 Mt/y. A considerable part of this hill has been removed and taken away as a result of mining activity. During the exploitation and processing of raw material a great deal of waste (mainly shales) is formed. Waste is stored in large inner and outer dumps.

The quarry is easily visible from a distance, in particular from a main road, from a number of local roads, from the villages of Kłęczany and Marcinkowice and from several tourist trails.

CASE 2

The quarry in Dąbrowa is located a few kilometres from Kłęczany, in the valley of the Dunajec river, on a hill slope, and occupies an area of about 40 000 m² (Fig. 4). The stone extracted is used as a high quality building material. The extraction started in 1955; the present output is about 20–30

thousand t/y, but in the 1970's and 1980's it reached 70–80 thousand t/y. The Dąbrowa quarry is situated near Nowy Sącz, by the main road which connects the village with Kraków.

The deposit in Dąbrowa represents the typical thick-bedded Eocene-Oligocene Cergowa Sandstones. The extraction is carried out on a 22 m thick succession of sandstone layers. The average content of shale intercalations is about 8.6%. The quarried stone is used as material for road and building construction.

CASE 3

The porphyry quarry in Zalas is located a few kilometres west from Kraków in a highly built-up area, near the Kraków–Katowice highway and several local roads, by the borders of the Jura-valleys Landscape Park (Figs. 5 and 6).

The pinkish-red porphyry is a part of Permo-Carboniferous laccolith, covered by Upper Jurassic (Oxfordian) platy limestone. The quarry has been active from 1900 and mined by blasting methods. It has been exploited on a large scale since the 1960's.

Nowadays the quarry is about 1 km in length, 350 m in breadth and 100 m high. Most of the waste is stored in dumps in the north-east part of the quarry area.

RESULTS

In Table 2 the impact indicator values are shown for the selected study cases.

For each of the quarries considered the x value was found to be less than 10%: according to the European Decision those quarries should be regarded as excellent when visual impact is being considered.

However, the variability of the L_v level is not always consistent with the variability of the x indicator. This result was to



Fig. 4. A face of the Dąbrowa sandstone quarry (picture D3)

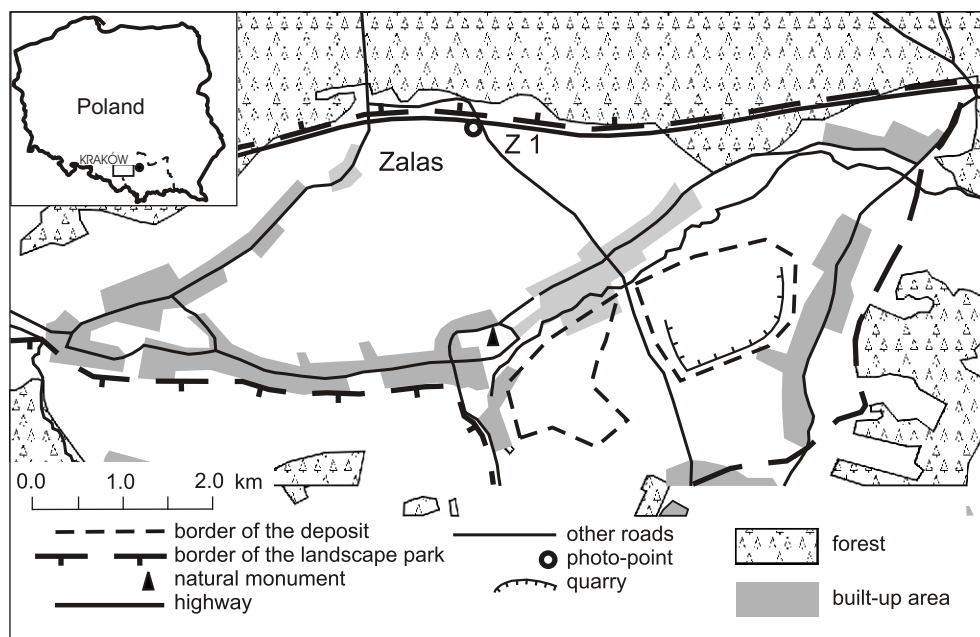


Fig. 5. Location of Zalas quarry

be expected considering that the visual impact indicator x does not take into account the lateral extent of the quarry and therefore tends to underestimate the visual impact of those quarries which are considerably wider than high.



Fig. 6. Porphyry opencast quarry at Zalas near Kraków (picture Z1)

Table 2

Visual impact parameters for the selected study cases

Quarry	Picture	Distance [km]	x [%]	Ω_v [sr]	L_v [dB]	$\Delta E_u/100$	L_{vi} [dB]
Klęczany	K1	4.0	2.5	0.00642	48.8	0.212	42.1
Klęczany	K2	3.5	3.5	0.00792	49.7	0.230	43.3
Klęczany	K3	3.0	3.3	0.00320	45.8	0.328	40.9
Klęczany	K4	1.1	9.4	0.02037	53.8	0.330	49.0
Dąbrowa	D1	1.7	4.7	0.00490	47.6	0.398	43.6
Dąbrowa	D2	1.7	4.8	0.00528	48.0	0.397	43.9
Dąbrowa	D3	1.3	5.4	0.00668	49.0	0.405	45.1
Zalas	Z1	5.0	1.0	0.00179	43.2	0.196	36.2

Table 3

Limit values of the impact classes according to the European Decision (x) and corresponding L_v limit values for square-shaped quarries

x [%]	$\varphi = \theta$ [rad]	Ω_v [sr]	L_v [dB]
10	0.033	0.0011	41.0
20	0.064	0.0041	46.8
30	0.094	0.0088	50.2

A different result is given when the visual impact is calculated through the visual solid angle Ω_v ; in this case the ratio between the visible altered area and its distance from the viewpoint is considered while the actual shape of the quarry faces is not taken into account.

The comparison between case K1 and D3 shows the same values for the L_v levels (48.8 dB and 49.0 dB respectively) while the visual impact indicator x remains significantly different (2.5% and 5.4%). L_{vi} values in Table 2 indicate the visual impact levels when the chromatic contrast is taken into account. The reduction coefficients ($\Delta E_u/100$) accounting for the chromatic contrast show variability within a minimum value of 0.196 and a maximum value of 0.405.

Table 3 shows the L_v values which correspond to the limits of the evaluation classes indicated by the European Decision when square-shaped quarries are taken into account (i.e. when the aspect ratio w/h is equal to 1, where w is the visible quarry width and h is the visible quarry height).

Referring to the four impact classes (*excellent*, *good*, *sufficient* and *exclusion*) as defined through the limit values in Table 3, for the study cases hereby considered the following circumstances can be noted.

According to the L_v values in Table 2, none of the 8 cases considered was found to be in the *excellent* class (when using the x indicator): two cases were *good*, five were *sufficient* and one was not acceptable, as the *exclusion* threshold was exceeded.

When considering the additional contribution of the chromatic contrast through the application of the L_{vi} indicator, 5 out of 8 cases were found to be *good*, two were *excellent* and one *sufficient*. The *exclusion* threshold was never exceeded.

According to the results given by the application of the indicator L_{vi} , although based on a limited number of viewpoints, the visual impact arising from the quarry in Dąbrowa should be

considered as acceptable (*good*) while the visual impact of the quarry in Zalas should be negligible (*excellent*).

It is worth mentioning that in this last case the viewpoint considered was just one along the highway between Kraków and Katowice and very far away from the quarry (about 5 km). This is the main reason for such low values of x and Ω_v . Moreover in the Zalas case some of the quarry levels are deep, and only part of the quarry is visible from the road.

The low value of the chromatic contrast for Zalas is mainly the consequence of the decay associated with atmospheric scattering when significant distances are involved. In this case, however, the grey-pink porphyry rock, partly weathered in the upper levels (which have not been active lately), keeps the contrast low. The situation in Zalas is expected to improve as a consequence of re-vegetation. The rock characteristics and the presence of many fissures are some of the favourable factors for vegetation development.

According to these results, the visual impact of the quarry in Klęczany is acceptable for most of the viewpoints considered, whereas in one case the Lvi value was found to be close to the exclusion threshold. The picture representing this last case was taken along the local road in the centre of the village of Klęczany.

CONCLUSIONS AND DEVELOPMENT DIRECTIONS

The application of the Lvi indicator to the case studies considered here allows a preliminary assessment of visual impact in the Polish Carpathians, highlighting at least two cases (Dąbrowa and Klęczany) for which the impact factor cannot be considered irrelevant.

However, the final assessment should take into account both the environmental value of the area and its development prospects, while a preliminary analysis of the viewpoints from where the pictures were taken might help to define the number and characteristics of potential observers.

Referring to the assessment method, the application of which is still to be considered as experimental, the results clearly show that the Lvi indicator is affected by a quarry's lateral extent (whereas the x indicator is not). Lvi does not include a shape factor and therefore tends to consider equivalent those quarries with the same visible area (in terms of solid angle) but with different aspect ratio w/h . All this being taken into account, the Lvi indicator can not be completely consistent with the common perceptive experience which tends to be in better harmony with the natural environment where alterations with prevalent lateral extent (wider than high) exist. On the other hand, the underestimation of the impact given by the application of the indicator $x\%$ seems to be even farther from a subjective perception.

The considerations described above suggest that the correlation between the Lvi values and the actual perception of the observers should be investigated. The methods most frequently used to verify such a correlation are based on the results of tests and questionnaires through which visual preferences are expressed referring to a number of pictures representing different cases of interest. Investigations of this type have been carried out for industrial sites (Hands and Brown, 2002) and rural districts (Arriaza *et al.*, 2004). As regards quarries and mining activities, a satisfactory correlation was found by comparing the Lvi values calculated for a number of selected cases and the value judgements expressed by a sample of potential observers (Dentoni *et al.*, 2005).

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