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Cost Optimisation for Minimizing the Visual Impact of Ornamental Stone Quarrying. A Case Study in Murcia Region

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Abstract

Quarrying of ornamental stone has adverse effects that are both visual and environmental. This paper aims to develop a methodology for minimising the costs associated with reducing the visual impact of ornamental stone quarrying. This study uses digital topographical maps of the study zone and a GPS and GIS application to calculate the extent of the area affected by quarrying activities for each altitude designated in the work plan and to calculate the extent of the potential visual impact. The results obtained applying the proposed methodology for the selected area suggested that the potential visual impact is minimal for an altitude of 520 metres, this being the optimal point for the observer. When altitude increases, the potential visual impact increases and the optimal point for the observer diminishes until the highest impact altitude (740 m) is readied. The optimal point that the exploitation should reach is that at which the values of the diagram generated by the (%) area of potential visual impact and area of exploitation (%) intersect. The methodology allows the optimal altitude to be determined for mining exploitations and helps assess the viability of a given exploitation from an environmental point of view.

Keywords

Restoration Costs, Ornamental Stone, Visual Impact, Limestone, Quarrying

1. Introduction

Natural stone quarrying is a long established industry which, like many others, is undergoing a transformation as a result of the international economic climate.

The natural stone sector was severely affected by the construction sector crisis. Production, both ex works and processed, has been also harshly affected dropping from 8 Mt/y in 2007 to 3.49 Mt/y in 2015, particularly in the marble and granite sectors, since slate has always been a mainly exporting sub-sector. In the latest times, thanks mainly to exports, production apparently has slowly started to recover.

Spain, with an overall natural stone production of 3.49 Mt (2015), is currently the 7^{th} stone world producer, after China, India and Iran—who have recently emerged as main global producers—Turkey, Italy and Brazil. By sectors, marble and limestone marble represented 61% of the production, granite 19%, roofing slate 19% and other stones 1%. Roofing slate has suffered less the crisis thanks to the fact that it is mainly an exporting sector. The number of quarries has slightly reduced in the last few years, but the main stone processing centres (around 750) have survived the turmoil of the crisis by reducing production and engaging in an important international trade campaign. Spain exported, in 2013, 1.6 Mt (1.35 Mt in 2014) of marble (more than 76% of the production) and 70% of the production of granite. Slate, a traditionally exporting sector, maintained exports in around 80% of the total production [1] [2].

The increased competition from these mega-producing countries, the appearance of new, competitively priced products and the construction crisis have led countries like Spain to change their outlook and to become world leaders in the research and development of new technologies applicable to ornamental stone sector. However, besides facing competition from these new producers, the European stone quarrying industry also has to apply rigorous environmental impact laws, which, among other demands, oblige companies to restore abandoned mining land. The growing competition from abroad, EU environmental demands and the inevitable economic implications mean that it is of enormous importance to know, from the initial stages of exploitation, the optimal design for minimising subsequent restoration costs, in an attempt to remain competitive on the world stage.

Land rehabilitation is an essential part of mining and quarrying, and could be defined as human involvement for removing the damage caused by quarries, in order to enable new land uses [3] [4]. Mining is a temporary form of land use, and the end of the exploitation has to be subjected to a careful planning, considering future land use options [5] [6]. Ornamental stone quarrying usually takes place on hill slopes using open-pit methods, where bedrock is cut. The quarry face progressively expands into the hill, growing in width and height, while terraces are formed during the quarrying process [7]. These activities produce significant alterations in land morphology, water, soil, vegetation and fauna [8] [9]. For this reason, visual impact evaluation is an important component of environmental analysis for landscape projects, since the resulting visual impact is one of the most important consequences of quarrying [10] [11].

Mining activities could be associated with sustainable development if site rehabilitation and remediation is considered before the exploitation starts. In Spain, the first legislation appeared in 1982, and, since then, mining projects must be accompanied by a mandatory Restoration Plan [12].

European Directive 2006/21/EC [13] demands the rehabilitation of areas in which mining has been practised, as did the already existing Spanish Mining Law (22/1973) [14] and as does more recent legislation (Royal Decree 975/2009) [15] on the management of wastes from the extractive industry and the protection and rehabilitation of the space affected by mining activities. This decree proposes that the post-mining conditions of land stability and usage have to be comparable to those that existed before the exploitation. Reclamation concerns include stabilization and the vegetation of disturbed lands, controlling drainage from portals and rubble, the neutralization or removal of process solutions and restoration of the visual landscape. Article 42 of this decree mentions that "calculation of the financial guarantee will take into account the environmental impact of the mining activities", in agreement with the European directive.

All the above should be considered in the light of section 24 of the Johannesburg Plan of Implementation on Sustainable Development [16], which focuses on the protection of natural resources. According to the plan, it is necessary to protect the natural resources that are the basis of economic and social development and to reverse the current trend towards the degradation of such natural resources, and to manage the same in a sustainable and integrated way.

Environmental planning in relation to open-cast mining was developed as a consequence of the evident need to make the profitable exploitation of geological resources compatible with environmental protection by studying land use in areas suited to the activity [17]. Nowadays, the location of the resource (cost) and profitability of the same (benefit) are not the only factors that must be considered, but also the compatibility of any activity with the environment. This determines the limits for the activity (threshold) based on the potential of regional landscapes and the territorial and environmental legislation as regards prevention and correction of negative impacts.

The environmental vacuum in the mining sector underlines the need for an initial design that minimises the impact of each development stage of an ornamental stone exploitation and that balances the activity and environment protection.

Four stages can be established in the design of a mining exploitation (**Figure 1**):

Stage 1: Study of the technical and environmental conditions of the potential area.

Stage 2: Mining exploitation.

Stage 3: Restoration work during exploitation phase and after abandoning the activity.

Stage 4: Re-use of the area for traditional activities.

Mining activities often produce a visual impact, such as the opening of quarry pits, modification the zone's morphology, geometric forms of wastes generated, that contrast with the natural landscape and infrastructure construction (roads, electrical power lines, reservoirs, temporary buildings, etc.). The visual impact of open-cast mining activities in the ornamental stone sector is one of the most significant alterations and probably the main cause of its rejection by local populations (Figure 2).

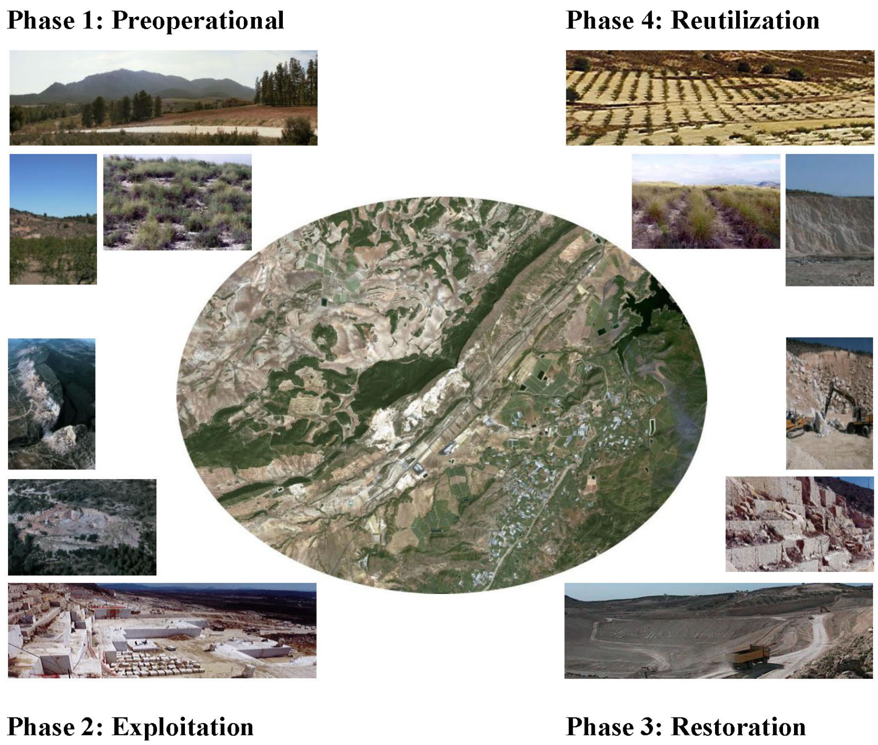

Figure 1. Planning an ornamental stone exploitation.

Figure 2. View of an ornamental stone exploitation in the studied area.

The aim of this work was to develop a methodology to predict and evaluate the visual impact of open cast mining activities before the exploitation phase in an attempt to minimise the environmental impact and optimize the cost of restoration.

2. Material and Methods

2.1. Study Area

The case study presented in the paper takes place in Murcia Region (SE, Spain), in the locality of Cehegín. This area was chosen to study potential visual impacts produced as a consequence of mining activities, because contains the largest number of open cast mining exploitations in the province of Murcia (**Figure 3**). The area comprises a mountain range which combines abrupt slopes and ravines with areas a flat slope, all of them of a carbonated nature.

2.2. Applied Methodology

This study uses digital topographical maps of the study zone and a GPS and GIS application to calculate the extent of the area affected by quarrying activities for each altitude designated in the work plan and to calculate the extent of the potential visual impact. For this, ArcGis version 9.1 software was used. To achieve the detail necessary for this sort of study, a balance must be struck between work

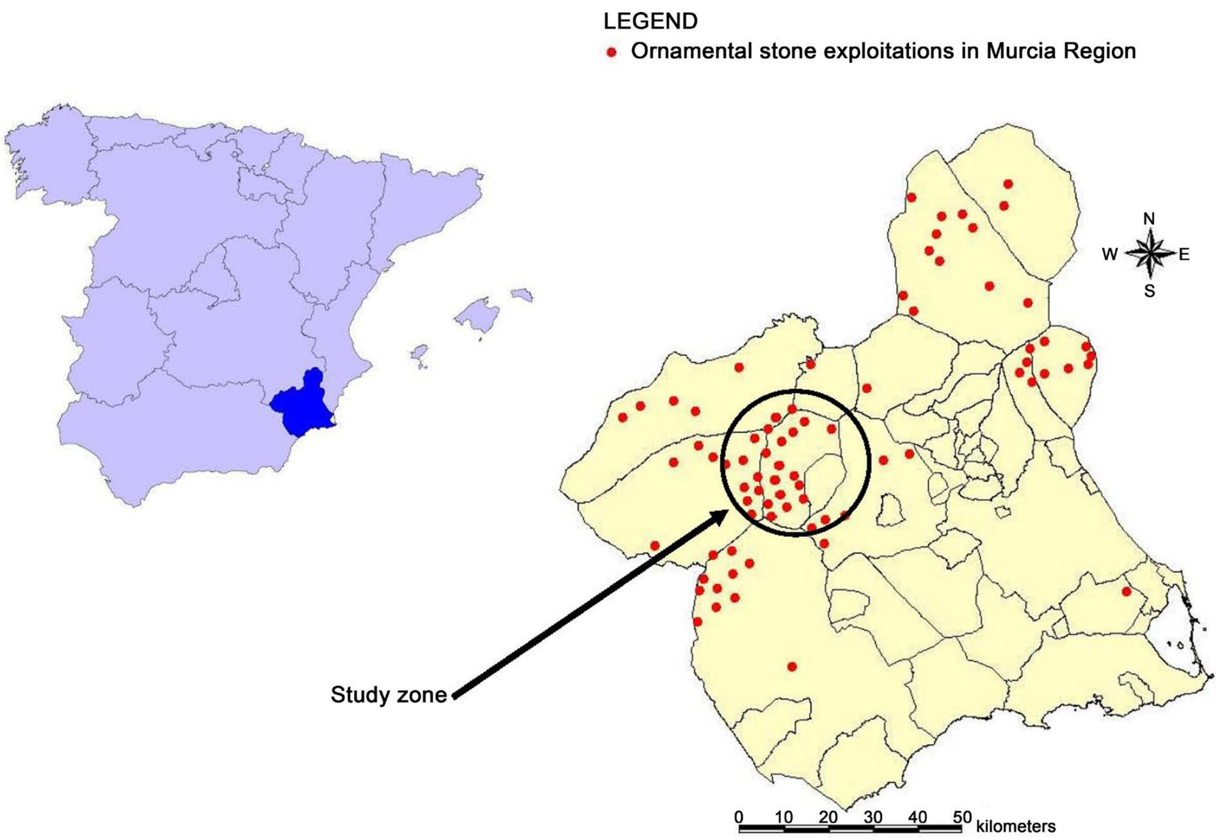

Figure 3. Spatial distribution of the ornamental stone quarries in the province of Murcia.

scale, time and available resources.

The method was applied in three steps: i) Determination of the visual field; ii) Determination of potential visual impact as a function of the distance to the quarry; iii) Estimation of restoration costs.

The visual field is the area from which a given point is visible. The concept is related with the intervisibility term, which analyses a territory as a function of the degree of mutual visibility between different points within the territory. To determine the visual field, a digital model of elevations (DME) was constructed using a GIS. The visual fragility of the territory and visual acuity of the observer were also incorporated. According to Gerald Westheimer [18], the human eye has a visible minimum, given that the minimum visibility is the detection of the presence of a visual stimulus. Visual fragility could be defined as the susceptibility of a landscape to change when a given activity is carried out in it, in this case the quarrying of ornamental stone. From the visual basin values, information for evaluating the potential visual impact and restoration costs can be obtained.

The applied methodology to determine the potential visual impact and its influence on the cost of restoration is detailed as follows:

1) Construction of the Digital Elevation Model (DEM) of the study area.

2) Calculation of the radius of the visual basin as a function of observes visual acuity and the size of the observable object.

3) Establishment of reference points for constructing the visual basins, a number that varies as a function of the morphology of the study zone and taking into account the minimum and maximum altitudes of the exploitation [19].

4) Determination of areas of the visual basins and their sum, which corresponds to the maximum frequency of observation, the maximum visual fragility and the maximum visual impact [20].

5) Finally, determination of the areas affected and, as a function of the restoration costs, the exploitation design can be proposed.

3. Results and Discussion

3.1. Determination of the Visual Basin

The visual basin will depends on its radius and will be a function of the visual acuity of the observer and the size of the observable object. The human eye has a minimum visible, that is, minimum visibility is the detection of the presence of a visual stimulus (Adler, 1992). In a normal observer, with an optimum approach and a distance of 6 m, the minimum angle of resolution is 1 arcminute, that is, 6/6 or 20/20, equivalent to 100% of visual acuity (**Figure 4**). At a distance of 6 m from an observation point, the minimum letter size is 8.73 mm (equivalent to 5 minutes of arc) and has an opening of 1.75 mm (equivalent to 1 arcminute). Then, the observation distance in the landscape ranges from 6 m to infinity. The arc length equivalent to 1 minute (L) gives the observable object's size as a function of the distance (d) in the following equation:

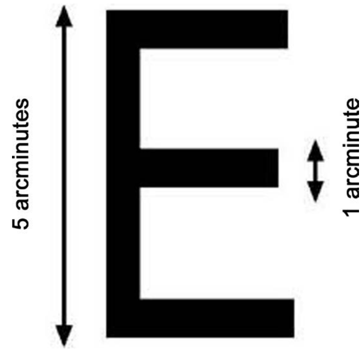

Figure 4. Snellen chart.

$$L = \frac{\Pi}{180} \times \frac{1}{60} \times d \quad (1)$$

Applying (1) and at a distance of 6 metres, the human eye does not differentiate objects smaller than 1.75 mm.

In ornamental stone quarrying, the mean elevation of the pit face and auxiliary buildings is 2.90 m. Substituting $L = 2.90$ m in (1), the distance at which the human eye can distinguish objects of this size is 10 km. Therefore, 10 km is the radius for determining the visual basin of quarrying exploitations.

3.2. Potential Visual Impact Determination as a Function of Distance from the Exploitation

The potential visual impact is directly related with the visual fragility of the affected zone, which is related with the greatest observation frequency. That is, the more frequent the observation, the greater the impact on the landscape. When the reference points for calculating the visual basin area were chosen, potential observers (from roads, urban nuclei), the morphology of the study zone and minimum (520 m) and maximum (740 m) altitudes of the exploited pit faces were taken into account. The altitudinal gradient selected was 20 m (**Table 1**). Based on the established DEM in the study zone and taking into account the selected points, raster maps of the visual basins were constructed with a radius of 10 km. The observer point of view is situated in the future exploitation, from where the visual basins are constructed. The resulting maps are summarised in **Figure 5** and give an idea of the visual basin from each of the reference points. Analysis of these maps provides information on the areas potentially affected by visual impact and suggest that the greatest potential visual impact area corresponds to the highest point considered.

3.3. Estimation of Restoration Costs

A quarry has to be commercially viable and environmentally acceptable and for this reason, the visual impact is of great importance in the development of ornamental stone exploitations. In order to optimise the restoration costs it is essential to minimise the visual impact, and certain criteria need to be taken into

Table 1. Relationship between the surface of the visual field and the potential visual impact.

Point and altitude (masl*)	Visual field surface (ha)	Visual impact increment (%)
1 (520)	162	0.00
2 (540)	1359	16.90
3 (560)	2523	20.56
4 (580)	3692	18.18
5 (600)	3692	0.00
6 (620)	3692	0.00
7 (640)	4779	16.93
8 (660)	4779	0.00
9 (680)	5435	10.19
10 (700)	5913	7.40
11 (720)	5913	0.00
12 (740)	6436	8.14

(*) metres above the sea level.

account: the maximum height of the pit face; the area covered by the exploitation and the area affected by visual impact (10 km). In our study and to estimate the restoration costs two cases were contemplated: the existence, or not, of obstacles between the observer and the affected zone.

3.3.1. Case 1: Restoration Costs without Obstacles between the Observer and the Affected Area

Figure 6 represents an observer facing a quarry a metres wide and h metres high. Let us consider that a section of height Δh and width a has to be restored at a cost per m^2 of P euros. $\Delta h = h_1 - h$, where h_1 is the maximum height of the exploitation (difference between the maximum and minimum altitude) and h is the height above which restoration must be carried out (difference between optimum altitude and minimum altitude of the exploitation). The cost of restoration (X_1) is represented in Equation (2):

$$X_1 = (a \times \Delta h)P \tag{2}$$

The restoration costs fall as Δh decreases, fulfilling Equations ((3) and (4)):

$$\Delta h \le \frac{X_1}{P \times a} \tag{3}$$

$$(h_1 - h) = \frac{X_1}{P \times a} \tag{4}$$

Equation (5) corresponds to a straight line with slope $\frac{-1}{P \times a}$ and ordinate origin (h_1). The lower the amount of money available (X_1) the larger the area that will not be restored.

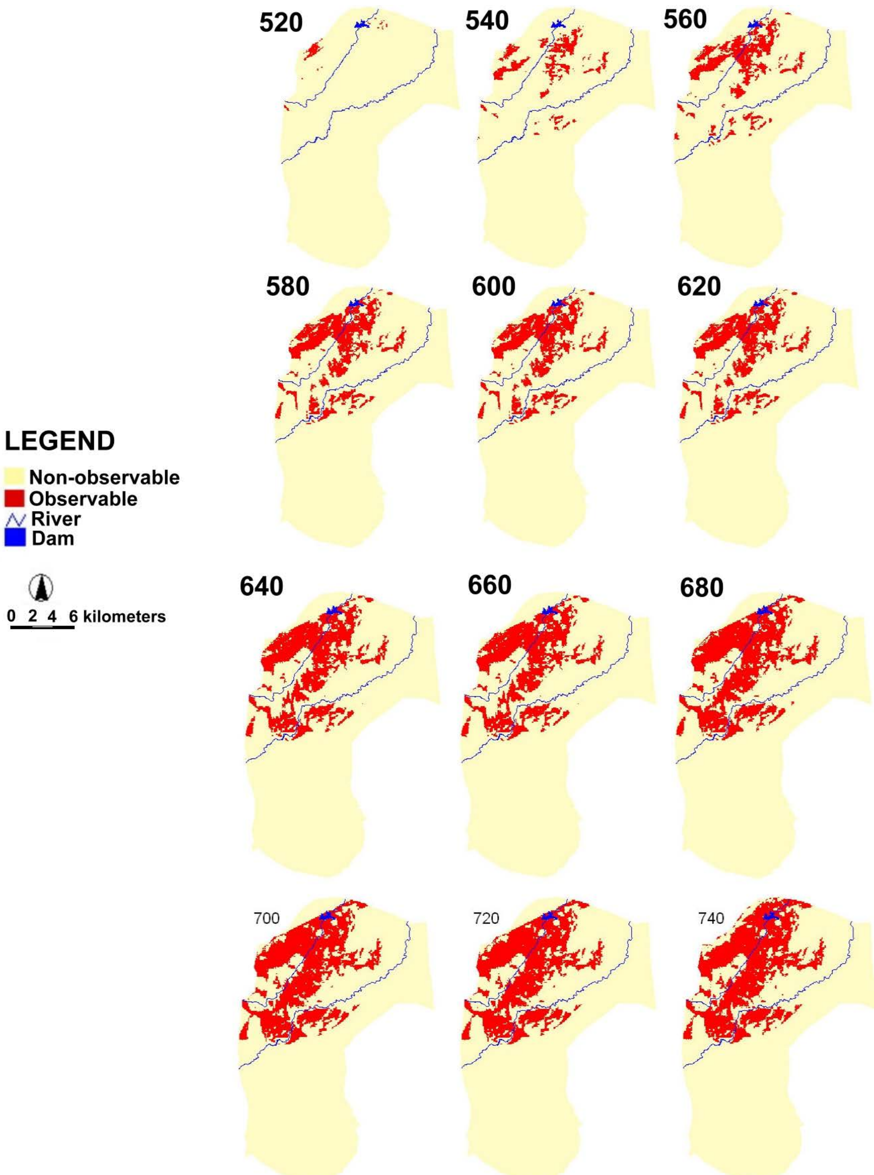

Figure 5. Observable and non-observable areas from 520 to 740 m.

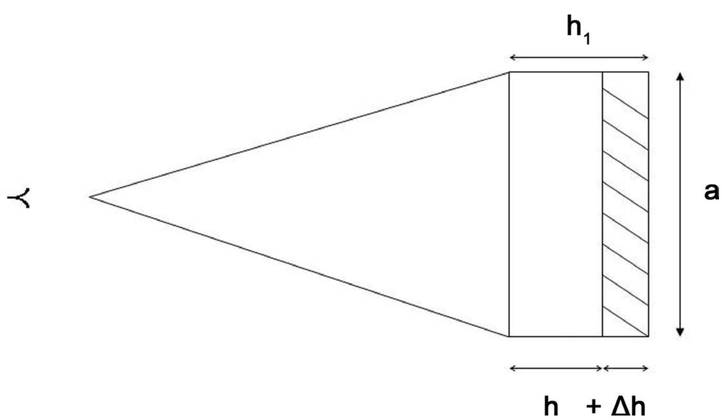

Figure 6. Restoration diagram for a visual field without obstacles.

$$h = h_1 - \left(\frac{1}{P \times a}\right) \times X_1 \tag{5}$$

3.3.2. Case 2: Restoration Costs with Obstacles or Hills between the Observer and the Affected Area

The visibility between two points depends on the presence of obstacles such as hills, rocks, trees, houses or dunes. In the pre-operational phase, costs can be determined as a function of the visual impact (Equation (6)):

$$S \times P = X\left(\text{potential}\right) \tag{6}$$

Figure 7 showed an observer facing the exploitation with an obstacle intervening. Consider that C is the obstacle height; d_1 is the distance between the observer and the obstacle; H is the height of the affected mountain range which cannot be observed because of the obstacle; D is the distance between the observer and the affected area and Δh is the height of the affected mountain range which can be observed. $\Delta h = h_1 - h$, where h_1 is the maximum height of the exploitation (difference between maximum and minimum altitudes of the exploitation) and h is the elevation up to which restoration must be carried out (difference between optimal altitude and minimum altitude of the exploitation).

If all the affected area is restored, $\Delta h = 0$, $\alpha = \beta$ and $\text{tg}\alpha = \text{tg}\beta$ (Equation (7)):

$$\text{tg}\alpha = \frac{C}{d_1} = \frac{H}{D};\ \text{tg}\beta = \frac{h_1}{D}$$

$$\frac{C}{d_1} = \frac{h_1 - \Delta h}{D} \tag{7}$$

As the restoration costs are $X = \left(a \times \Delta h\right) \times P$, the optimal restoration cost will be (8). The ideal restoration costs are constant as a function of the distance to and height of the obstacles.

$$X_2 = \left(h_1 - C \times \frac{D}{d_1}\right) \times P \times a \tag{8}$$

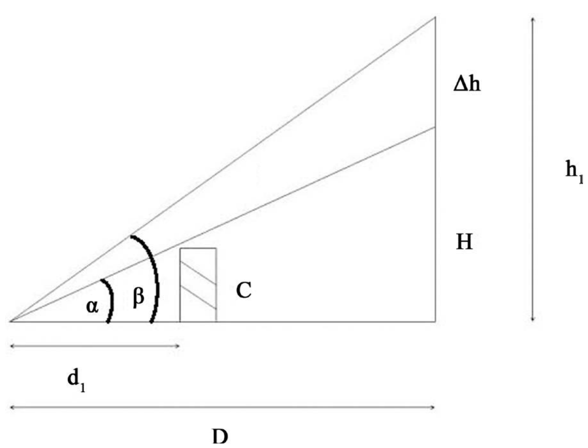

Figure 7. Restoration diagram for a visual field with obstacles.

3.4. Application to a Quarry in Cehegín

Visual impact is a consequence of introducing new elements in the landscape. In our case, the greatest impact will be the quarry face and dumps in the hillside. This visual impact is directly related with the visual fragility of the affected zone, which, in turn, is related with the frequency of observation; that is, the greater the frequency, the greater the impact on the landscape. Observation frequency is related with topography, the presence of visual screens, population density, the dispersion of inhabited nuclei, the density of the communications network and the frequency of use. The distance at which any observation is made is also important. At less than 5 km distance, the perception of alterations in the landscape is usually very strong. The impression is usually negative because of the extreme nature of the contrast with the surroundings as result of moving earth, opening excavations, the presence of auxiliary buildings, etc. Movement through interior visual basins is usually slow since journeys are generally made along mountain roads and unsurfaced tracks, which increases the observation time. The impact will be directly proportional to the intensity of public use of the zone, the road network and its quality, as well as to the protective frameworks present in the affected spaces. At a medium distance (5 - 10 km) the perception of landscape alteration is also strong. Observations are usually made from roads outside the immediate centre of alteration and the observation time is usually shorter because the roads are better and faster, and the topography may interrupt the view more frequently. The affected area can also be observed from isolated houses of population centres if the topography does not intervene, and the impression is usually negative since the exploitation is regarded as an aggression against the normal state of the landscape.

At distances from 10 to 50 km only a slight modification of the background tonality is perceived, from roads, individual dwellings or urban centres. This perception is not necessarily negative and diminishes as the distance increases.

Based on the above considerations, we have constructed visual basins for a radius of 10 km, considering that the main visual impacts are: i) alterations of the landscape background as a result of excavations and topographic alterations; ii) new elements in the landscape such as roads, dumps, auxiliary buildings, etc., some of them producing sharp contrasts with the landscape.

The visually impacted area (**Table 2**) gradually increases as elevation rises, especially in the first 100 m. An observer situated at the lowest reference point will see a small area of the total visual basin since their line of vision will be interrupted by the land morphology. From higher observation points, the visible area increases gradually until the average altitude is reached. Above this elevation, the natural obstacles diminish in size and the percentage of visible surface is increased. At higher elevations, the increase in the percentage of visible area slows down until the greatest possible area is observed, representing the strongest visual impact.

Previous theoretical demonstration allows the optimal altitude for the work

Table 2. Relationship between visual field surface and exploitation surface.

Point and altitude (masl*)	Exploitation surface %	Exploitation surface (ha)	Potential impact surface (%)
1 (520)	100	90.86	2.51
2 (540)	76.65	69.95	21.11
3 (560)	63.43	57.64	39.16
4 (580)	52.54	47.74	57.34
5 (600)	41.55	37.76	57.34
6 (620)	33.20	30.17	57.34
7 (640)	23.85	21.67	74.27
8 (660)	16.82	15.29	74.27
9 (680)	10.16	9.23	84.46
10 (700)	5.19	4.72	91.86
11 (720)	2.06	1.87	91.86
12 (740)	0.22	0.20	100

(*) metres above the sea level.

plan to be calculated. This is a useful tool for knowing, in the pre-operational phase, the magnitude of the impact by comparing restoration costs. This aspect must be taken into account during the planning stage to determine whether the exploitation is viable from an economic and environmental point of view. An important issue, during the optimization of restoration costs, is to know precisely the extent of the affected area for each altitude. Knowing this, it is possible to check the possible relationship between the size of the restored area and the diminution of the potential visual impact. For this aim, the work plan, topographical maps (1:5000) and GPS measurements could be used. Then, it is possible to calculate the area affected by mining activities for each altitude and the results can be expressed as % in order to better illustrate how the affected surface increases with altitude.

The results obtained for the selected area suggested that the potential visual impact is minimal for an altitude of 520 m, this being the optimal point for the observer. When altitude increases, the potential visual impact increases and the optimal point for the observer diminish until the highest impact altitude (740 m) is readied. The optimal point that the exploitation should reach is that at which the values of the diagram generated by the (%) area of potential visual impact and area of exploitation (%) intersect, that is, up to the altitude at which the relation between the exploitation area and the visual impact generated is considered acceptable.

The relation between the diminution of the visual impact and the investment necessary is shown in **Figure 8**, allowing the optimal altitude that an exploitation can reach without producing an excessive visual impact to be defined. The optimal point of exploitation is the intersection of the two variables. Below this

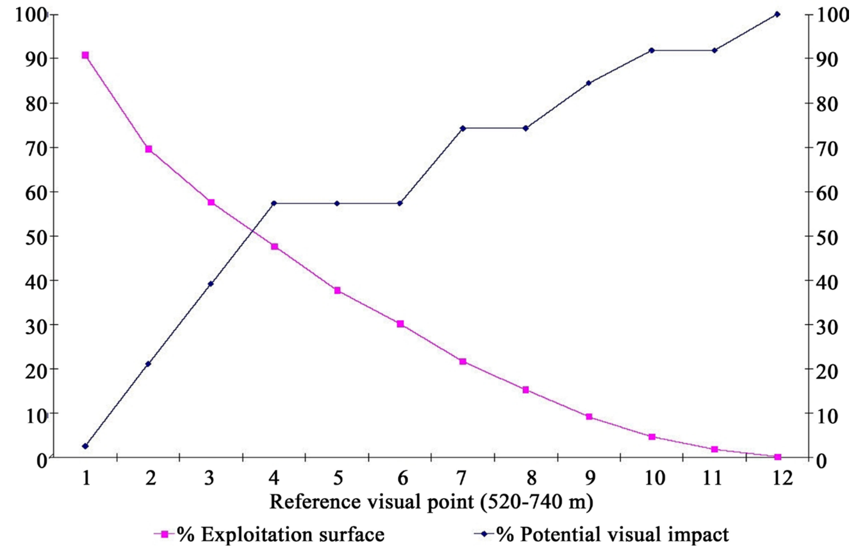

Figure 8. Relationship between the surface of visual impact and exploitation surface curves.

point the exploited area is greater (greater production), this area corresponding to a smaller visual basin and acceptable potential visual impact. Above this optimal point, the exploited area diminishes as the altitude increases, accompanied by growing visual impact, meaning that the financial guarantees needed for restoration increase.

4. Conclusions

The proposed methodology could be summarised as follows: 1) Determination of the potential visual field as a function of the visual acuity of observers; 2) Determination of the surface of the potential visual impact as a function of the altitude: considering the exploitation surface, the optimal point is the intersection point between the affected surface and the potential impact; 3) The optimal exploitation corresponds to the intersection between the exploitation surface and the potential visual impact.

The restoration costs are a function of the affected area and so, during the design (in the pre-operational stage) the input in the landscape can be minimized.

The proposed methodology could be a useful tool to assess in the planning stage of the exploitation, the varying of restoration costs and the magnitude of the potential visual impact, depending on the altitudinal position reached by the exploitation. In addition, the proposed methodology could help on the design phase to ensure the economic and environmental viability of mining activities according to European and national legislation, facilitating the task of decision makers.

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