

Comprehensive Evaluation of Elpidio Berovides Construction Materials Quarry in Artemisa Province

Evaluación integral de la cantera de materiales de la construcción Elpidio Berovides en la provincia de Artemisa

Luis Ángel González Díaz luisangel438@gmail.com⁽¹⁾

<https://orcid.org/0009-0008-3010-48351>

Mayda Ulloa Carcasés mulloa@ismm.edu.cu⁽²⁾

<https://orcid.org/0009-0003-2932-9785>

⁽¹⁾ Pinar del Río's Geominera Company, Pinar del Río, Cuba

⁽²⁾ University of Moa, Moa, Cuba

Abstract: A comprehensive evaluation of Elpidio Berovides quarry in Artemisa province, Cuba, was conducted by applying the Comprehensive Quarry Evaluation Matrix, adapted to the Cuban context. Expert-defined indicators and variables were used to characterize the deposit from technical, environmental, socio economic and safety perspectives. The quarry received a rating of 72.2% by collecting data *in situ* and calculating the Comprehensive Evaluation Matrix index. The importance of an integrated technological diagnosis is highlighted to ensure sustainable and efficient exploitation of mineral resources, proposing this methodology as a model for other quarries in the country.

Keywords: aggregate quarry, sustainability indicators, technological diagnosis

Resumen: Se realizó una evaluación integral de la cantera Elpidio Berovides en Artemisa, Cuba, mediante la aplicación de la Matriz de Evaluación Integral de Canteras, adaptada al contexto cubano. Se caracteriza el yacimiento desde una perspectiva técnica, medioambiental, económica, social y de seguridad, empleando variables e indicadores definidos por expertos. A través de la recogida de datos *in situ* y el cálculo del índice Matriz de Evaluación Integral, la cantera obtiene una calificación de 72.2 %. Se destaca la importancia del diagnóstico tecnológico integral para garantizar una explotación sostenible y eficiente de los recursos minerales, proponiendo esta metodología como modelo para otras canteras del país.

Palabras clave: cantera de áridos, indicadores de sostenibilidad, diagnóstico tecnológico

Introduction

Mining activity, as an activity responsible for numerous negative impacts on the environment, requires special control in its development (Brousett *et al.*, 2021; Bruguera *et al.*, 2022). The rational use of natural resources through efficient techniques increases resources applications and reduces the final waste volume (Aduvire, 2023). Quarry exploitation and evaluation plans are effective as they facilitate the calculation of economic resources, profits, and environmental impacts generated (Hernández, Ulloa y Rosario, 2011; Lyle-León, 2022; Aguilar Condori, 2024; Suárez-Jalca, Baquerizo & Vásquez, 2024).

It is necessary to evaluate construction companies so that they offer better products, contribute to efficient use of resources, and ensure processes improvement and productivity growth (González & Mariño, 2022; Rivero, 2022; Guilliany, Marcano & Suarez, 2022; Rocha & Ocospoma, 2024). Therefore, Cuban construction companies must count on quality management systems to achieve better resources control and meet the economic demands of the sector (Gutiérrez y López, 2022; Gutiérrez, López & Más, 2023).

It is important to evaluate the technical, environmental, safety, economic, and social factors influencing quarries development. The evaluation is achieved by conducting a comprehensive technological diagnosis to keep on meeting the demand for such materials in the aggregate sector, apart from making new investments that guarantee those services quality and efficiency. It is necessary for quarries to undergo comprehensive diagnoses that allow understanding their overall performance. They can be carried out using tools such as the Comprehensive Quarry Evaluation Matrix (CQEM), which was developed by Martínez (2009) and used for quarry evaluation by authors such as Hernández & Guilarte-Cutiño (2018), Sánchez-Arocha (2019), and González Martín (2022).

The CQEM, based on the MECA methodology, is a benchmarking tool that analyzes specific variables and indicators of each quarry to evaluate its performance in technical, environmental, economic, safety, and social aspects (Baptista *et al.*, 2024; Soca, De la Nuez & Pérez, 2024). This type of evaluation is essential to identify areas in need for

improvement and propose solutions that contribute to mining operations' sustainability and efficiency.

Elpidio Berovides quarry, located in Artemisa province, extracts mineral by means of excavation using drilling and blasting. Here, limestone is extracted and then transported to the mechanical processing plant. In its active plant, the material is crushed to a very small grain size, producing gravel (coarse and medium grains), sand (fines), and stone dust.

This quarry has not undergone a such evaluation, so it is necessary to carry it out by using the CQEM in order to assess the technical, environmental, occupational safety, economic, and social operating dimensions, and ensure the quality of the extracted materials and their impact on the environment, economy, and society. Elpidio Berovides quarry, as a significant source of limestone for numerous construction works in Artemisa province, requires a thorough analysis of its performance across different aspects.

Materials and Methods

Through expert consultation, compared scenarios, and on-site data collection, the variables and indicators to be evaluated were determined. The expert group was formed by specialists and technicians from the construction materials company of Artemisa, the provincial directorate of geological-mining services, and professors from the University of Moa. Once the results from the assessment and weighting of the technical, environmental, safety, economic, and social aspects were obtained, the CQEM index was calculated (Martínez-Segura, 2009).

Description of the method used to calculate the CQEM Index

This tool allows evaluating the performance of construction materials quarries according to the economic model used in Cuba. The CQEM evaluates 5 aspects. To analyze the partial result, each factor is evaluated separately.

Technical aspect: data on machinery, blasting, exploitation method, and processing plant were considered.

Environmental aspect: measures aimed at eliminating or reducing factors causing environmental damage and hazards in areas where workers are present were analyzed.

Safety aspect: information on measures to reduce existing hazards, prevent accidents on roads, at quarry faces, and in the processing plant was taken into account.

Economic aspect: The number of workers, workdays, services provided, investments and business magnitude, as well as factors or operations affecting the planned project economy were analyzed.

Social aspect: the quarry's positive and negative impacts on the surrounding population were examined.

CQEM Application Procedure

The CQEM consists of 2 main parts; the first includes, in questionnaire format, variables and indicators, which are evaluated once grouped in general sets, and the second represents the aspects related to each variable and indicator.

Weighting Matrix for the Aspects to be Evaluated

In order to maintain the same information scale, each aspect is assigned values between 10 and 30%; this is a scale assumed according to the interest of the researcher and the consulted specialists. In this study, the following values were assigned:

- Technical: 30%
- Environmental: 20%
- Safety: 30%
- Economic: 10%
- Social: 10%

The specific index is obtained by dividing the sum of all the evaluated aspect final scores by the sum of the maximum field value corresponding to the evaluated aspect. As shown in the equation, it refers to the values obtained in the CQEM once the vertical analysis has been carried out for each of the aspects. The sum of all global indices represents the quantitative value between 0 and 100 and constitutes the CQEM Index.

$$\text{Specific Index } x = \frac{\sum P_x}{\sum VMCex} * 100$$

Where:

X: Evaluated factor

ΣPx : Total sum of the evaluated factor score.

$\Sigma VM Cex$: Total sum of the maximum field value, corresponding to the evaluated factor.

The specific index is determined for each factor under analysis.

$$\text{Specific Technical Index } I_{Tech} = \frac{\Sigma P_{téc}}{\Sigma VM C_{e_{téc}}} 100$$

$$\text{Specific Environmental Index } I_{ENV} = \frac{\Sigma P_{MA}}{\Sigma VM C_{e_{MA}}} 100$$

$$\text{Specific Safety Index } I_{Safe} = \frac{\Sigma P_{Seg}}{\Sigma VM C_{e_{Seg}}} 100$$

$$\text{Specific Economic Index } I_{Eco} = \frac{\Sigma P_{Eco}}{\Sigma VM C_{e_{Eco}}} 100$$

$$\text{Specific Social Index } I_{Soc} = \frac{\Sigma P_{Soc}}{\Sigma VM C_{e_{Soc}}} 100$$

To complete the final allocation, the weight assignment value (weights) is used, which refers to the importance of each factor for the specific circumstances of the quarry under study. Each weight importance is multiplied by each aspect's specific index to obtain the global indices.

For the final rating, the values found are established in ranges determined by their quality, considering the particularities of the studied quarry, in order to classify its operation. These value ranges are:

75-100%: Excellent

51-75%: Good

26-50%: Fair

0-25%: Poor

Elpidio Berovides Quarry Comprehensive Evaluation

Technical Aspect: the mining technique includes technical elements and parameters that influence the development of the exploitation process: mobile machinery (including those at the plants), fixed machinery, blasting parameters, geometry and exploitation system, topographic work, and other elements that enabled information gathering.

Exploitation System: a deepening system with automotive transport is used. Sterile rock will be transported to an external waste tip. Progress will be made on the current work faces in the order established in the Schedule, until their orientation is achieved in the direction of the rock structure used as raw material. The working angle to be used for excavation will be 85°. Banks with non-standard heights will be subjected to gradual modification according to the mining equipment availability.

Rock Mining: it will be carried out with prior fragmentation of rocks using explosives (Amex as column charge and Senatel as bottom charge). The rock mass has a high compressive strength and physical-mechanical properties suitable for this method. The rock mass in the work area is dry and has a complex structure due to tectonism and karst. It is composed of strength-6 limestone rocks with a volumetric mass of 2.69 t/m³. Rock drilling will be performed with an Atlas Copco drill rig, with a productivity of 6 ml/h. The explosive material to be used as column charge will be Amex with a density of 0.82 t/m³. The bottom charge will be Senatel with a density of 1.15 t/m³.

Equipment for clearing, hauling, loading, and transport: the quarry has 1 Shan-Tuy TY 220 bulldozer, 1 Daewoo Mega 250 V front-end loader with a capacity of 2.4 m³, and 2 Kraz 256 B dump trucks with a capacity of 8 m³.

Pay Mineral Processing Plant: the quarry has two industrial processing plants, one of which is an operational CM-739/740 type.

Mine Roads Characteristics

As for access roads construction, the minimum visibility distance complies with Road Construction Regulations (Table 1). Access roads width, depending on the means of transport type, its load capacity, and the road category, meet the established standards (Table 2).

Table 1. Minimum visibility distance

Visibility (m)	Road category according to traffic intensity		
	More than 100 vehicles/h	100 to 15	Less than
		vehicles/h	15 vehicles/h
	I	II	III
From the road surface	50	35	25
From the oncoming vehicle	100	770	50

Table 2. Road width

Equipment width (m)	Load capacity (T)	One direction movement (m)	Two-direction movement (m)		
			Road categories		
			I	II	III
2.40	Up to 7	3.5	7.5	7.0	6.5
2.65	10	3.5	7.5	7.0	7.0
2.75	16	3.75	8.0	7.5	7.0
3.22	25	4.25	9.0	8.5	8.0
3.4-3.6	27-48	4.5	9.5	9.0	8.5-9.0
Up to 4	45-120	7.0	10.56	12.0	-

Roads built through box cuts must keep a distance of no less than 1.5 m from the edge on both sides. The longitudinal inclination angle of roads used by loaded vehicles must not exceed 10°; for those used by tractor, this angle can reach up to 15°. For empty vehicles, the aforementioned angle must not exceed 15° (Table 3).

Table 3. Minimum turning radius of roads

Dumpers and trailer trucks	Road category			Road capacity
	I	II	III	
With minimum truck turning radius of 9 m: under normal conditions	25	20	15	5 - 7
In trenches, accesses, and berms	20	15	15	5 - 7
With minimum truck turning radius of 12 m: under normal conditions	30	25	20	10 - 27
With minimum truck turning radius of 14 m: under normal conditions	35	30	29	40 - 60
In trenches, accesses, and berms	30	25	20	40 - 60

On sloping roads with considerable length, intermediate horizontal sections are built, with a length not less than 50 m (excluding the corresponding vertical curves), and with an inclination angle not exceeding 2°. The sections will be spaced more than 500 m apart. Curve radius on winding or spiral roads must not be less than 36 m (curvature degree = 32°). Roads on their curves have a transverse inclination angle (slope or super-

elevation) of 6°. This inclination is directed towards the origin of the curvature radius. Roads to be built on slopes with a gradient of 30° or more have a transverse inclination angle of 2°. Roads' inclination will be directed opposite from the edge of the slope.

Environmental Aspect

For the environmental factor, data were taken from company reports; besides, observations were made at the quarry. The existence of measures aimed at eliminating or reducing impacts and managing properly water, restoration level, hazards in areas where workers are present, signaling, and use of personal protective equipment were verified. The main impacts produced at the quarry are: visual impact and impact on the atmosphere.

The quarry comprises a mountain, thus presenting a significant visual impact due to its progressive disappearance. An aspect of interest is the existing level of restoration at the quarry. Although studies on quarry rehabilitation upon the termination of extractive activities have been made, the sector does not count on a partial closure plan.

Other environmental impacts include the site's morphological changes produced by earth movements, soil compaction caused by heavy machinery transfer, increased noise pollution as a result of blasting, atmospheric pollution due to increased gas and dust emissions, alterations to wildlife habitat and vegetation damage, and increase of relief morphological changes that modify the landscape as new faces are opened, expanding the exploitation area.

The main risks workers face at the facility are: falls on the same or different level, impacts from falling objects, trapping, noise, dust and harmful substances inhalation, vehicle rollover, and electrical contact.

Economic Aspect

To evaluate the economic aspect, investments, cost of work received from other companies, number of workdays, average number of employees, and annual production were considered. The relevant economic data show positive results.

Social Aspect

In the social aspect, the company positive and negative impacts on the quarry's surrounding community were taken into account.

- Positive impacts: job creation, relative increase in means of transportation benefiting local residents, and benefits in goods and services.

Variables and indicators determination

The variables and indicators were determined considering those parameters prone to evaluation that influence the entire deposit exploitation process. The process was carried out following specialists' criteria and direct field observation. Additionally, compliance with Cuban mining legislation (ANPP, 1994) and the variables and indicators from the Inspection Manual of the National Office of Mineral Resources (2013) were considered. Through analysis and exchange with specialists, a total of 21 variables and 151 indicators were determined for the evaluation of Elpidio Berovides quarry:

1. Quarry (11 indicators)
2. Technical provisions (5 indicators)
3. Mining concession boundaries (3 indicators)
4. Work face (4 indicators)
5. Work face stability (4 indicators)
6. Platforms conditions (3 indicators)
7. Access roads conditions (7 indicators)
8. Drilling and blasting passport (16 indicators)
9. Secondary fragmentation (SF) (4 indicators)
10. Bulldozer hauling (4 indicators)
11. Useful rock's loading and transport equipment (6 indicators)
12. Waste tip (3 indicators)
13. Processing plant and its safety system (48 indicators)
14. Control of received services (3 indicators)
15. Employment (4 indicators)
16. Accidents and incidents (5 indicators)
17. Worker training (3 indicators)
18. Investments (5 indicators)
19. Environment (4 indicators)

20. Mud dam (3 indicators)

21. Occupational health and safety (6 indicators)

Variables and indicators assessment

The assessment of each variable indicators is a process based on expert criteria and on-site data collection that consists of assigning scores or attributing qualitative or quantitative values, according to the importance or incidence of an indicator concerning the aspect evaluated at the quarry.

Total Evaluation Obtained for Each Aspect

Technical: 344.9

Environmental: 134.99

Safety: 210.95

Economic: 238.7

Social: 74.4

Specific indices calculation

The evaluated aspects were weighted considering their influence on the entire quarry's exploitation process.

Calculation of the Quarries Comprehensive Evaluation Matrix Index

Table 4 shows the CQEM index or global result.

Table 4. Determination of the CQEM Index

Aspect	Weights	Specific Indices	Global Indices	mEIC Index
Technical	30%	77.02%	23%	
Environmental	20%	68.58%	13.7%	
Safety	30%	67.35%	20.2%	72,2 %
Economic	10%	83.68%	8.4%	
Social	10%	75.53%	7.5%	

The global result (CQEM index) allows for an overall view about the current state of the quarry. According to the value obtained (72.2%), Elpidio Berovides construction materials quarry is rated as "Good". This rating demonstrates that the quarry needs to improve in aspects whose values are rated as Fair. Consequently, it is evidenced that the use of the CQEM methodology constitutes an effective tool for comprehensive technological diagnosis and decision-making aimed at the sustainability of aggregate operations in Cuba. This study can serve as a replicable model for other quarries in the country, fostering a continuous improvement and socio-environmental responsibility culture in the mining sector.

Conclusions

Upon the application of the Comprehensive Quarry Evaluation Matrix, an evaluation of 77.02 % was obtained for the technical aspect, 68.58 % and 67.35 % for the environmental and safety aspects respectively, and 83.68 % and 75.53 % for the economic and social aspects. The CQEM index for the Elpidio Berovides quarry is 72.2 %, which classifies its performance as "Good". This result evidences relevant strengths in its operational, economic, and social management, as well as areas requiring improvement, particularly those concerning environmental and industrial safety matters.

The general characterization of Elpidio Berovides quarry allowed for the determination of 21 variables and 151 indicators for the quarry. Following the experts' criteria, the scale to assess the selected variables and indicators was established.

Bibliographic References

- Aduvire, O. (2023). Gestión ambiental en minería: certificaciones para iniciar y finalizar la actividad minera. *Revista de Medio ambiente minero y minería*, 8(1), 32-41. http://scielo.org.bo/scielo.php?script=sci_arttext&pid=S2519-53522023000100004&Ing=es&tIng=es
- Aguilar Condori, P. (2024). Evaluación de los Impactos Ambientales en la Cantera Taparachi Generadas por la Explotación de Materiales Empleados en la Construcción. *Ciencia Latina*, 8(2), 1306-1326. https://doi.org/10.37811/cl_rcm.v8i2.10568

Asamblea del Poder Popular (ANPP). (1994). Ley 76 Ley de Mina. *Gaceta Oficial de la República de Cuba*. La Habana. [https://www.minen.gob.cuPDFley-76-94_ley_de_minas_1pdf-Ministerio de Energía y Minas](https://www.minen.gob.cuPDFley-76-94_ley_de_minas_1pdf-Ministerio_de_Energía_y_Minas)

Asamblea Nacional del Poder Popular (ANPP). (2023). *Ley No. 150 de los Recursos Naturales y el Medio Ambiente*. Gaceta Oficial de la República de Cuba.

Baptista, B., Tala, N., López, S., Henríquez, P., Dalaison, W., & Saldías, C. (2024). Transformando la construcción en América Latina y el Caribe. <https://publications.org/publications/spanish/document/Transformando-la-construccion-en-America-Latina-y-el-Caribe-digitalización-e-innovacion-como-claves-para-la-sostemibilidad.pdf>

Brousett, M.A., Rondan, G.G., Chirinosel, M., & Biamont, I. (2021). Impacto de la Minería en aguas superficiales de la Región Puno-Perú. *Fides et Ratio-Revista de Difusión cultural y científica de la Universidad La Salle en Bolivia*, 21(21), 187-208. <https://dialnet.unirioja.es/servlet/articulo?codigo=8751087>

Bruguera, N., Diaz Duque, J.A., Álvarez, J.R., Hernández, R., Ramírez, R. & Martínez, G. (2022). Impactos de los pasivos ambientales en la red hidrográfica de la región minera de Santa Lucía, Minas de Matahambre, Cuba. *Ingeniería Hidráulica y Ambiental*, 43(1), 63-78. <https://dialnet.unirioja.es/servlet/articulo?codigo=10076064>

González Martín, D. (2022). *Indicadores económicos para evaluar el desempeño sostenible de las canteras de materiales de construcción de Cuba*. (Master Thesis, University of Moa). <http://ninive.ismm.edu.cu/handle/123456789/3927>

González, Y., & Mariño, J.L. (2022). La contribución de la gobernanza a la gestión municipal del déficit habitacional en Cuba. *Cooperativismo y Desarrollo*, 10(2), 287-310. <https://dialnet.unirioja.es/servlet/articulo?codigo=8599487>

Guilliany, J.G., Marcano, A.P., & Suarez, H. (2022). Elementos de la Filosofía de la Gestión que sustentan la competitividad en empresas del sector construcción. *Revista de Ciencias Sociales*, 28(5), 184-197. <https://dialnet.unirioja.es/servlet/articulo?codigo=8471683>

- Gutiérrez, Y. & López, M.L., (2022). Costos de calidad en la Empresa de Materiales de Construcción asociado a la Ciencia y Tecnología. *Revista Universidad y Sociedad*, 14 (6), 360-369. <https://rus.ucf.edu.cu/index.php/rus/article/view/3384>
- Gutiérrez, Y., López, M.L. & Más, A. (2023). La gestión de la calidad y sus costos en el sector de la construcción. *Revista Cubana De Finanzas Y Precios*, 7(4), 70-79. https://www.mfp.gob.cu/revista/index.php/RCFP/article/view/07_V7N42023_YGGyOtros
- Hernández, N., Ulloa, M., & Rosario, Y. (2011). Impacto ambiental de la explotación del yacimiento de materiales de construcción El Cacao. *Minería y Geología*, 27(1), 38-53. <https://revista.ismm.edu.cu/index.php/revistamg/article/view/142>
- Hernández, N. & Guilarte-Cutiño, I. (2018). Diagnóstico del desempeño de la cantera de áridos La Inagua, Cuba, utilizando una matriz de evaluación. *Ciencia UAT*, 13(1), 06-18. <http://doi.org/10.29059/cienciauat.v13i1.923>
- Lyle-León, C.E. (2022). Optimización para extracción y explotación artesanal de material pétreo, El Tambo, Santa Elena, Ecuador. *Investigación y desarrollo*, 16(1). <http://doi.org/10.31243/id.v16.2022.1669>
- Martínez-Segura, M.A. (2009). *Diagnóstico tecnológico del sector de los áridos y su aplicación a la región de Murcia*. (Doctoral Thesis, Polytechnic University of Cartagena). <http://doi.org/10.31428/10317/1343>
- Oficina Nacional de Recursos Minerales. (2013). *Manual de Procedimiento Minero*. https://www.minem.gob.cu/sites/default/files/documentos/resolucion_1_2023-manual_de_procedimientos_mineros_pdf
- Rivero, D. (2022). Gestión de la calidad en la empresa constructora de obras para el turismo Cayo Coco. *Universidad & Ciencia*, 11(2), 174-187. <https://revistas.unica.cu/index.php/uciencia/article/view/2268>
- Rocha, C.A. & Ocrosopoma, F.N. (2024). Calidad y productividad en una empresa constructora. *Ciencia Latina, Revista Multidisciplinar*, 8(4), 11617-11633. <https://dialnet.unirioja.es/servlet/articulo?codigo=9742275&orden=0&info=link>

Sánchez Arocha, A. (2019). *Diagnóstico integral de la cantera de materiales para la construcción Maraví de la provincia Guantánamo*. (Degree Thesis, University of Moa).
<http://ninive.ismm.edu.cu/handle/123456789/3812>

Soca, J.N., De la Nuez, D., & Pérez, J. (2024). Procedimiento para la mejora del proceso de producción de empresas de materiales de la construcción. *Avances*, 26(1), 54-71.
<https://dialnet.unirioja.es/servlet/articulo?codigo=9269991>

Suárez-Jalca, M.A., Baquerizo, F.E., & Vásquez, A.E. (2024). Actividad económica Explotación de otras Minas y Canteras (CIIUB08): Análisis social y ambiental en Guayas, Ecuador. *Revista científica de Salud y Desarrollo Humano*, 5(4), 307-347.
<http://revista.vitalia.org/index.php/vitalia/article/view/367>