Proceedings of the 9th World Congress on Civil, Structural, and Environmental Engineering (CSEE 2024)
London, United Kingdom – April 14-16, 2024
Paper No. ICEPTP 169
DOI: 10.11159/iceptp24.169

Criteria-Based Environmental Quality Assessment for Small-Scale Open-Pit Mines (Quarries)

Willian Leandro Henrique Pinto[1], Bernardo Tavares Freitas [1, 2], Pablo Brito-Parada [3]
[1]School of Technology, Universidade Estadual de Campinas (UNICAMP)
Paschoal Marmo St., 1888, Jd. Nova Itália, Zip Code:13484-332, Limeira, São Paulo, Brazil
[2]Currently at the Geosciences Institute, Universidade Estadual de Campinas (UNICAMP)
w181798@dac.unicamp.br; freitasb@unicamp.br
[3]Department of Earth Science and Engineering, Royal School of Mines, Imperial College London
London SW7 2AZ, United Kingdom
p.brito-parada@imperial.ac.uk

Abstract - Mining has great potential for environmental impacts if control and mitigation actions are neglected. Its licensing process is based on environmental and mineral legislation and on the knowledge on possible effects of the pressure from this type of activity on natural resources. The complexity of legal technical requirements, together with particular environmental aspects related to mining activities commonly result in delays in the licensing processes and difficulties in monitoring and mitigation of potential environmental impacts. Here we present and discuss criteria to establish environmental quality indicators for small-scale open-pit mines (SSOPM) that extract sand, clay, limestone, basalt and diabase. The criteria framework, consisting of 65 criteria, was developed using documentary analysis, literature review and expert consultation through the Delphi decision-making method. The main expected result of this study is the development of an environmental quality assessment index, which can be used for monitoring the environmental quality of mining activities, contributing to environmental licensing and to the execution of preventive and remedial actions, and for the guidance of supervisory and licensing bodies as well as by the entrepreneurs themselves.

Keywords**:** Environmental quality of open-pit mining, Environmental impacts of open-pit mining, Quarrying, Small-scale open-pit mines, Environmental indicators, Environmental licensing, Mining legislation, Quarrying legislation.

1. Introduction

Mineral exploration, although essential for development, presents potential environmental impacts and, therefore, requires techniques capable of predicting, evaluating and mitigating these impacts. The growth of anthropogenic pressure, especially on natural resources, has triggered global discussions in recent decades. The mining sector is one with a high potential for negative impact on the environment and generation of significant pollution [1]. Therefore, mineral extraction and associated activities should receive special attention.

Mining activities may negatively affect the natural resources through dust dispersion, soil erosion and pollution, changes in the quantity and quality of surface and underground water resources, air contamination, changes in the quality of the soil in adjacent areas, geological and geomorphological disruptions, loss of soil, vegetation and biodiversity, landscape change, eco-systems modification, among other impacts [2-5]. Therefore, it is necessary to implement an environmental management plan and a pollution mitigation strategy to control the impacts caused by mining activities. Such actions can be measured and monitored using environmental indicators [6].

The application of sustainability principles to mining activities is challenging, because this type of enterprise represents the act of withdrawing and consuming limited resources, which is incompatible with the vision of sustainability [7]. To overcome this degree of irreversibility, mining enterprises need to invest in social and human well-being and mitigate the environmental impacts generated. During the operation of this type of enterprise, several environmental aspects are directly or indirectly affected and, as a result, environmental quality must be constantly monitored so that economic development follows a path compatible with the conservation of natural resources in a harmonious way. Thus, the study of methodologies and tools for monitoring and environmental inspection is extremely important as it helps in the efficiency and agility of the environmental licensing process. Research topics related to sustainability in mining, environmental indicators and criteria for environmental quality assessment have increased recently [6, 8-16].

The assessment of environmental sustainability is a major challenge and, therefore, is widely discussed. The use of environmental indicators is one of the available alternatives for this assessment as they provide simplified and clear information about the current condition, trends and changes in the environment [17, 18]. The use of indicators is a strategy used for the presentation of information in a concise, simplified and scientifically reliable way [19]. They are able to provide clear information about complex systems to policy makers and assist in decision- making [20].

The object of this study are small-scale open-pit mines (SSOPM) that extract sand, clay, limestone, basalt and diabase. The term "open-pit mine" is used by some authors [21-23] while "quarry" is used by others [21, 24-27]. In literature, the term "opencast mine" [5, 28-30] and “open-pit quarry” [31] are also used. Regardless of the terminology, these are mines that are open on the earth's surface and not underground.

For this study, SSOPM is defined as an enterprise with a valid operation license or permit for the extraction of clay, diabase, basalt, sand and limestone, with an extraction pit of up to 500.000 m^3 and total volume of extraction in situ up to 20.000.000 m^3. In this way, using documentary analysis, literature review and expert consultation through the Delphi decision-making method, a criteria framework that influence an environmental quality indicator of SSOPM mines is discussed.

2. Materials and methods

The criteria framework was developed using documentary analysis, literature review and expert consultation through the Delphi decision-making method.

2.1. Documentary analysis and literature review

Documentary research and analysis was carried out, from March to July 2022, to collect valid Operating Environmental Permits of SSOPM operations located in the Municipalities of Rio Claro, Cordeirópolis, Ipeúna and Santa Gertrudes, state of São Paulo, Brazil (BR). This region was used in this study, since these municipalities are included in a sectoral plan to reduce atmospheric emissions from SSOPM and mineral processing activities. The data were obtained from the public registry of the Environmental Agency of the State of São Paulo (CETESB) and the Brazilian Mineral Agency (ANM). Additionally, a complementary study was carried out in April 2023 in London, United Kingdom (UK), to collect Environmental Permits and Planning Permissions of active quarries.

Environmental quality criteria were correlated to the conditions of Environmental Permits and Planning Permissions. Literature review was used to incorporate criteria that had not been considered. Thus, an environmental quality criteria framework was developed.

2.2. The Delphi method

This tool is characterized by multiple iteration or rounds of questionnaires answered anonymously by the participants of a group of experts on the subject under study. The responses are processed, by a coordinator that investigate central and extreme tendencies, and fed back to the respondents. The rounds continue until a consensus has formed [32-36]. The minimum number of experts participating in studies using the Delphi method is 10 [37-39]. In this study, a group of 10 experts in SSOPM environmental licensing was formed. All experts have more than 6 years of experience in this subject.

Microsoft Forms was used to collect the analysis. In round 1, a questionnaire was developed based on documentary analysis and literature review. The questionnaires in round 2, 3, 4 and 5 were developed based on the discussions in the previous rounds. In each round, a questionnaire was sent to evaluate the importance or not of each criterion for the environmental quality of small mines. During the rounds, experts could argue about their choices and the choices of other experts.

3. Results and discussion

44 environmental quality criteria were proposed from the analysis of 85 valid Operating Environmental Permits of small-small-scale open-pit mines (BR). 19 Environmental quality criteria were proposed after analysing the Planning Permissions Permissions of 3 active Quarries (UK). The literature review contributed to inclusion of 4 other criteria. Thus, the partial 67 67 criteria framework was proposed.

The partial criteria framework was submitted to the 10 experts for analysis through questionnaires in Microsoft Forms and using the Delphi method. The analysis resulted in the exclusion of 7 criteria, the inclusion of 6 new criteria and the unification of 2 criteria. After 5 rounds, consensus was reached that 65 criteria are needed to the environmental quality of SSOPM. The final criteria framework is presented in Table 1 and Table 2.

Table 1: Environmental quality assessment criteria framework for SSOPM (subjects no. 1 to no. 8).

Subject	Criteria
1.Solid waste and tailings	1.1.Classification and storage of solid waste
	1.2.Destination and/or disposal of solid waste
	1.3.Tailings
2.Noise and vibration	2.1.Sound pressure level (SPL) of blasting operations
	2.2.Resultant particle velocity (Vr) of blasting operations using explosives
	2.3.Level of noise emitted by the activities of the enterprise
	2.4.Transparency/disclosure of blasting activity schedules with explosives
3.Fossil fuel combustion (burning) - greenhouse gases emission	3.1.Operation and adjustment of equipment that burns fuel, aiming at proper combustion
	3.2.Operation and adjustment of mobile sources of emission
	3.3.Fuel storage and fill up operations
	3.4.Oil change operations and maintenance of machinery, equipment and vehicles
4.Dust emission	4.1.Mineral storage
	4.2.Mineral processing
	4.3.Internal and external mineral transportation
	4.4.Compliance with sectoral emission reduction plans
	4.5.Mineral drying
	4.6.Particulate matter emission control from internal and external mineral transportation
	4.7.Vegetation at the site boundary as dust barriers
	4.8.Dust control from external transport of machines and vehicles*
5.Water resources	5.1.Drainage
	5.2.Settling basins
	5.3.Water quality of natural surface water resources
	5.4.Springs
	5.5.Water table
	5.6.Water impoundment
	5.7.Water Reuse
6.Sanitary sewage	6.1.Separation, treatment and disposal of sanitary sewage
7.Erosion	7.1.Slope drainage system
	7.2.Drainage arrangements for rainwater containment and runoff control
	7.3. Surface slope of the mining pit
8.Demarcation	8.1.Demarcation of areas authorized for extraction and areas of environmental preservation

*Criteria suggested by the experts

Table 2: Environmental quality assessment criteria framework for SSOPM (subjects no. 9 to no.20).

Subject	Criteria
9. Restoration	9.1.Measures of control, recovery and environmental monitoring
	9.2.Topsoil, subsoil, or overburden from stripping
	9.3.Activities after restoration
	9.4.Technician with the knowledge of and expertise in degraded area restoration
10.Slopes	10.1.Slope stability
	10.2.Project for the implementation and operation of the mining benches
11.Safety in operation	11.1.Safe distance between the extraction area and other structures, facilities and preservation areas
	11.2.Safe distance between the extraction area, power transmission lines, highway, road and gas pipeline
	11.3.Rock blasting operations with the use of explosives
12.Protected areas	12.1.Conservation reserve and conservation area that protects water resources (registration and regularization programs)
	12.2.Restoration commitments
	12.3.Native and exotic vegetation
	12.4.Archaeological assets
	12.5.Nature reserves and buffer zones*
	12.6.Speleological heritage*
	12.7.Paleontological heritage*
13.Documentation requirements	13.1.Conditions of the environmental permit or planning permission
	13.2.The enterprise identification
	13.3.Unique Taxpayer Reference (UTR)
	13.4.Federal Technical Registry of Potentially Polluting Activities and Users of Environmental Resources
14.Vehicle movements and cleaning	14.1.Vehicle movements
	14.2.Vehicle cleaning
15.Authorized operations	15.1.Extraction aiming a phased basis
	15.2.Mineral export limit
	15.3.Operation hours
	15.4.Commencement of works and operation
	15.5.Authorized operations
16.Junctions and alterations to the Public Highway	16.1. Junctions and alterations to the public highway
17.Schemes and plans to be submitted and approved	17.1.Best operating practices and procedures
	17.2.Contaminated land reports, when potential contamination is verified
18.Energy	18.1.Energy consumption
19.Violation of environmental regulations and penalties	19.1.Violation of environmental regulations and penalties
20.Local communities	20.1.Traditional communities*
	20.2.Proximity to residential clusters*

*Criteria suggested by the experts

4. Conclusion

The results of this study present valuable contributions to the licensing process and environmental monitoring of SSOPM. The 65 criteria, which were proposed based on Operating Environmental Permits, Planning Permissions, literature literature review and validated by experts, may be used as indicators of the environmental quality of SSOPM. As a future study, it is intended to analyse the level of importance of each criterion for the environmental quality of SSOPM.

Acknowledgements

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001.

References

[1] O. G. Burdzieva, V. B. Zaalishvili, O. G. Beriev, A. S. Kanukov and M. V. Maysuradze, "Mining impact on environment on the north ossetian territory," Int. J. of GEOMATE, vol. 10, n. 1 (Sl. n. 19), pp. 1693-1697. https://doi.org/10.21660/2016.19.5327
[2] A. Azapagic, "Developing a framework for sustainable development indicators for the mining and minerals industry," vol.12 (6), pp. 639-662, 2000. https://doi.org/10.1016/S0959-6526(03)00075-1
[3] A. Mechi and D. L. Sanches, D. L, "Impactos ambientais da mineração no Estado de São Paulo," Estudos avançados, vol. 24, n. 68, pp. 209-220, 2010. https://doi.org/10.1590/S0103-40142010000100016
[4] A. Manna A, R. Maiti, "Opencast coal mining induced defaced topography of Raniganj coalfield in India-remote sensing and GIS based analysis," J Indian Soc Remote Sens, vol. 42, pp. 755–764, 2014. https://doi.org/10.1007/s12524-014-0363-y
[5] R.V. Byizigiro, T. Raab andT. Maurer, "Small-scale opencast mining: an important research field for anthropogenic geomorphology," DIE ERDE J Geogr Soc Berl, vol. 146, pp. 213–231, 2015. https://doi.org/10.12854/erde-146-21
[6] S. Sinha, S. Chakraborty and D. Shome, "Mining footprint: a spatial indicator of environmental quality—a case study of a manganese mine in Bhandara district, Maharashtra," Arab J Geosci, vol. 12, n. 96, 2019. https://doi.org/10.1007/s12517-019-4260-0
[7] M. R. Gorman and D. A. Dzombak, "A review of sustainable mining and resource management: Transitioning from the life cycle of the mine to the life cycle of the mineral," Resources, Conservation and Recycling, vol. 137, p.p. 281-291, 2018. https://doi.org/10.1016/j.resconrec.2018.06.001
[8] A. Azapagic and S. Perdan, "Indicators of sustainable development for industry: a general framework," Process Safety and Environmental Protection., vol.78, pp. 243-261, 2000. https://doi.org/10.1205/095758200530763
[9] S. H. N. Aguiar, C. N. Gobbi, M. G. Rodrigues and R. R. R. S, B. Cunha, "Indicadores de Sustentabilidade em Empreendimentos de Mineração," Revista Internacional de Ciências. vol. 1, n. 1, 2011. https://doi.org/10.12957/ric.2011.3627
[10] E. Marnika, E. Christodoulou, E. and A. Xenidis, "Sustainable development indicators for mining sites in protected areas: tool development, ranking and scoring of potential environmental impacts and assessment of management scenarios," Journal of Cleaner Production, vol. 101, n. 68, pp. 57-70, 2015. https://doi.org/10.1016/j.jclepro.2015.03.098
[11] E. D. Yaylaci, and H. S. Düzgün, "Indicator-based sustainability assessment for the mining sector plans: Case of Afşin-Elbistan Coal Basin," International Journal of Coal Geology, vol. 165, pp. 190-200, 2016. https://doi.org/10.1016/j.coal.2016.08.018
[12] N. T. Bui, A. Kawamura, K. W. Kim, L. Prathumratana, T-H. Kim, S-H. Yoon, M. Jang, H. Amaguchi, D. D. Bui and N. T. Truong, "Proposal of an indicator-based sustainability assessment framework for the mining sector of APEC economies," Resources Policy, vol. 52, pp. 405-417, 2017. https://doi.org/10.1016/j.resourpol.2017.05.005
[13] I. A. Dialga, "A Sustainability Index of Mining Countries," Journal of Cleaner Production, vol. 179, pp. 278-291, 2018. https://doi.org/10.1016/j.jclepro.2017.12.185

[14] G. M. Morais, H. C. Martins, and V. F. Santos, "Relatórios de sustentabilidade de empresas mineradoras no Brasil: Uma análise do seu alinhamento com a agenda de sustentabilidade global e especificidades locais" Braz. J. of Develop., vol. 6, n. 6, pp. 39032-39059, 2020. https://doi.org/10.34117/bjdv6n6-445

[15] P. W. Souza-Filho, R. B. L. Cavalcante, W. R. Nascimento Jr, S. Nunes, M. Gastauer, D. C. Santos, R. O. Silva Jr, P. K. Sahoo, G. Salomão, M. S. Silva, S. J. Ramos, C. F. Caldeira, R. Dall'agnol, and J. O. Siqueira, "The sustainability index of the physical mining Environment in protected areas, Eastern Amazon," Environmental and Sustainability Indicators, vol. 8, 2020. https://doi.org/10.1016/j.indic.2020.100074

[16] M. Fuentes, M. Negrete, S. Herrera-León and A. Kraslawski, "Classification of indicators measuring environmental sustainability of mining and processing of copper," Minerals Engineering, vol. 170, pp. 107033, 2021. https://doi.org/10.1016/j.mineng.2021.107033

[17] G. Mitchell, A. May and A. Mcdonald, A, "Picabue: a methodological framework for the development of indicators of sustainable development," Int. J. Sustain. Dev. World Ecol., vol. 2, pp. 104–123, 1995. https://doi.org/10.1080/13504509509469893

[18] C. Bockstaller and P. Girardin, "How to validate environmental indicators," Agric. Syst., vol. 76, pp. 639–653, 2003. https://doi.org/10.1016/S0308-521X(02)00053-7

[19] H. Haberl, M. Wackernagel, and T. Wrbka, "Land use and sustainability indicators: an introduction," Land Use Policy, vol. 21, n. 3, pp. 193–198, 2004. http://dx.doi.org/10.1016/j.landusepol.2003.10.004

[20] D. Niemeijer and R. De Groot, R, "A conceptual framework for selecting environmental indicator sets," Ecol. Indic., vol. 8, n. 1, pp. 14–25, 2008. http://dx.doi.org/10.1016/j.ecolind.2006.11.012

[21] A. Blishchenko, "Modern mine survey techniques in the process of mining operations in open pit mines (quarries)," in Scientific and Practical Studies of Raw Material Issues, V. Litvinenko, Ed. CRC Press: London, 2019, pp. 58-62. https://doi.org/10.1201/9781003017226

[22] A. H. Altiti, R. O. Alrawashdeh and H. M. Alnawafleh, "Open Pit Miining," in Open Pit Mining, Mining Techniques—Past, Present and Future, ed. 1, A. Soni, Ed. IntechOpen: London, UK, 2021. http://dx.doi.org/10.5772/intechopen.9220

[23] J.-C. Padró, J. Cardozo, P. Montero, R. Ruiz-Carulla, J. M. Alcañiz, D. Serra and V. Carabassa, "Drone-Based Identification of Erosive Processes in Open-Pit Mining Restored Areas," Land, vol. 11, pp. 212. 2022. https://doi.org/10.3390/land11020212

[24] B. Jawecki, T. Kowalczyk and Y. Feng, "The Evaluation of the Possibility to Use the Water from Quarry Lakes for Irrigation," Journal of Ecological Engineering, vol. 20, pp. 188-201, 2019. https://doi.org/10.12911/22998993/112490

[25] British Geological Survey – BGS (2020). Directory of Mines and Quarries, 2020. Retrieved April 5, 2023, available: https://www2.bgs.ac.uk/mineralsuk/download/dmq/Directory_of_Mines_and_Quarries_2020.pdf

[26] V. Dentoni,, B. Grosso, G. Massacci, G. and G. P. Soddu, "Visual impact evaluation of mines and quarries: the updated Lvi method", Environ Earth Sci, vol. 79, 100, 2020. https://doi.org/10.1007/s12665-020-8833-8

[27] P. Pradhananga and M. Elzomor, "Environmental implications of quarry rock dust: A sustainable alternative material to sand in concrete." In: Proceedings of the Construction Research Congress 2020. Reston, VA: American Society of Civil Engineers, 2020. pp. 916-924. http://dx.doi.org/10.1061/9780784482889.097

[28] D. Jahed Armaghani, M. Hajihassani, M. Monjezi, E. T. Mohamad, A. Marto and M. R. Moghaddam, "Application of two intelligent systems in predicting environmental impacts of quarry blasting", Arab J Geosci vol. 8, p.p. 9647–9665, 2015. https://doi.org/10.1007/s12517-015-1908-2

[29] M. C. Manetti, G. Mazza, L. Papini, F. Pelleri. "Effects of mixture and management on growth dynamics and responses to climate of Quercus robur L. in a restored opencast lignite mine," iForest, vol. 15, pp. 391-400, 2022. https://doi.org/10.3832/ifor4108-015

[30] G. Certini, M. C. Manetti, B. Mariotti, A. Maltoni, G. Moretti and F. Pelleri. "Does association with N-fixing nurse trees improve carbon sequestration in walnut plantations? Case-study on a reclaimed opencast mine in Italy," Forest Ecology and Management, vol. 545, 2023. https://doi.org/10.1016/j.foreco.2023.121245

[31] C. Zou, "Analysis on Dust Control Technology in Open-pit Quarry", Journal of Energy and Natural Resources. vol. 10, n. 1, pp. 28-32, 2021. https://doi.org/10.11648/j.jenr.20211001.13

[32] G. Rowe, G. W. Wright and F. Bolger, "Delphi: A reevaluation of research and theory," Technological Forecasting and Social Change, vol. 39, n. 3, pp. 235-251, 1991. https://doi.org/10.1016/0040-1625(91)90039-I
[33] J. W. Murry Jr. and J. O. Hammons, "Delphi: A Versatile Methodology for Conducting Qualitative Research." The Review of Higher Education, vol. 18, n. 4, pp. 423-436, 1995. https://doi.org/10.1353/rhe.1995.0008
[34] G. Rowe and G. Wright, "The Delphi technique as a forecasting tool: issues and analysis," International Journal of Forecasting, vol. 15, pp. 353-375, 1999. https://doi.org/10.1016/S0169-2070(99)00018-7
[35] J. Osborne, S. Collins, M. Ratcliffe, M., R. Millar, R. Duschl, "What "Ideas-about-Science" should be taught in school science? A Delphi study of the expert community," Journal of Research in science teaching, 40 (7), 692-720. 2003. https://doi.org/10.1002/tea.10105
[36] T. Grisham, "The Delphi technique: a method for testing complex and multifaceted topics," International Journal of Managing Projects in Business, vol. 2, n. 1, pp.112-130, 2009. https://doi.org/10.1108/17538370910930545
[37] H. Jones and B.L. Twiss, Forecasting technology for planning decisions. New York: Macmillan, 1978.
[38] S. W. Cochran, "The Delphi method: Formulating and refining group judgements," Journal of the Human Sciences, vol. 2, p.p. 111-117, 1983.
[39] M. Adler and E. Ziglio, Gazing into the oracle: the Delphi method and its application to social policy and public health. London: Jessica Kingsley Publishers, 1996.