ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2521-0890 (Print)
ISSN: 2521-0491 (Online)
CODEN: GBEEB6

Geological Behavior (GBR)

DOI: http://doi.org/10.26480/gbr.01.2024.32.37

CrossMark

REVIEW ARTICLE

REMOTE SENSING FOR ENVIRONMENTAL MONITORING AND REMEDIATION OF AREAS DEGRADED BY MINING ACTIVITIES IN THE DEMOCRATIC REPUBLIC OF CONGO: CALL FOR ACTION

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ARTICLE DETAILS

Article History:

Received 20 March 2024
Revised 28 April 2024
Accepted 23 May 2024
Available online 28 May 2024

ABSTRACT

The Democratic Republic of Congo (DR Congo) is a country with strong potential in mineral raw materials; therefore, it is qualified as a “Geological Scandal." It is the world's leading producer of cobalt, and in 2022 it will be among the five major copper producers in the world. Although the mining sector plays a major role in economic growth, the country does not fully benefit from these resources due to the uncontrolled exploitation of raw materials, fraud, mining smuggling, and the lack of means for local processing of minerals. natural resources. DR Congo was classified by the World Bank as one of the five poorest countries in the world in 2022, despite the potential it presents. Given the great importance of critical minerals in the energy transition, the demand for raw materials is increasingly high. The DR Congo receives more requests for mining titles for the exploitation of resources. Unfortunately, these resources are non-renewable, and their exploitation destroys the environment. New technologies based on spatial analysis and remote sensing applied in the mining sector are capable of monitoring operating activities to combat the anarchic exploitation of resources and also control the waste evacuated by mining companies during the mining phases of exploration and especially during the hydrometallurgical treatment of ores. Areas damaged by these activities can be remediated using new remediation engineering techniques and tools. Remote sensing would also be involved in the acquisition of data that is difficult to access based on gaps in environmental reports. For the application of these techniques, the Ministry of Mines of DR Congo will have to act through its technical services and other services of the Ministry of Scientific Research and Technological Development, such as the national remote sensing center, the national geological service, and the geographical institute of Congo.

KEYWORDS

Environmental degradation, Mining, Biodiversity, Pollution, Remediation engineering

1. INTRODUCTION

The country known as the Democratic Republic of Congo (DR Congo) has been called a "Geological Scandal" and is thought to have untapped natural resources worth over $24 billion (Directorate General of the Treasury, 2019). More than 90% of the nation's exports are made up of copper, zinc, and cobalt (Extractive Industries Transparency Initiative, 2022). With an increase from 35,500 to 144,936 tons between 2009 and 2022, the Democratic Republic of the Congo is by far the world's top producer of cobalt and retained its place in 2024 with a production of 140 thousand tons (Mines.cd, 2024). It was ranked in 2023 third globally in terms of copper output, with 2,200,000 tons produced in 2022 (Statista, 2023). The DR Congo is now the second-largest producer of copper in the world, behind Peru. Peru's Ministry of Mines and Energy reported 2.76 million tons of copper output in 2023, while the Democratic Republic of the Congo produced about 2.84 million tons, according to a Reuters article (Mines.cd, 2024).

The geological environment of the DR Congo is in higher demand than ever after a strong demand for raw materials owing to their significance in the energy transition. Investors utilize a variety of remote sensing-based techniques to pinpoint regions with mineral potential, including those for the aforementioned minerals as well as gold, diamonds, and other mineral deposits with substantial economic value. The extractive industries transparency initiative study states that the mining industry accounted for the majority of the DR Congo's economic growth in 2021, with the country's Gross Domestic Product (GDP) declining by 1.7% when the mining industry was excluded. This indicates that the economy is less diversified. Due to the increased demand for mining raw materials, there is an alarming incidence of unchecked resource exploitation, unlawful exploitation, and fraud in the mining industry (Annan, 2000; Mazalto, 2008).

This study aims to evaluate recent techniques based on spatial analysis and remote sensing in recent research work to propose sustainable solutions in order to mitigate and avoid the risks that these activities present to the environment, fight against uncontrolled exploitation of resources for sustainable exploitation of resources, and ensure the sustainable development of the DR Congo.

2. METHODS

The significance of the mining context in the DR Congo, as well as the abundance of published papers on the topic, drove the research question

Quick Response Code	Access this article online	
	Website: www.geologicalbehavior.com	**DOI:** 10.26480/gbr.01.2024.32.37

Cite The Article: Innocent Mufungizi (2024). Remote Sensing for Environmental Monitoring and Remediation of Areas Degraded by Mining Activities in The Democratic Republic of Congo: Call for Action. *Geological Behaviour 8(1): 32-37.*

for this study. The inquiry of how remote sensing and spatial analysis may be valuable instruments for tracking mining operations and restoring places that have been harmed by them served as the impetus for this study. We used the scientific search engine Google Scholar using a few key terms (Environmental degradation, Mining, Biodiversity, Pollution, Remediation engineering) to find relevant literature in order to meet the study's goals. The found works were chosen based on their significance and connection to the research topic. Additionally, we gathered data on the DR Congo's geology on the United State Geological Survey (USGS) on the Science-base website. The scale of this global data is 1:5000,000, and they offer multiple extensions compared to the Environmental Systems Research Institute (ESRI) format, which was taken into consideration for this research (Persits and al., 1997). The DR Congo's geological map was created by processing the latter using Geographic Information System (GIS) tools. Lastly, we made use of information from the mining cadastre (CAMI), which offers the portfolios of mining titles for the same time period as well as the yearly reports from 2016 to 2022 presented in Table 1 (CAMI, 2016–2022).

Table 1: Presentation of the data used

Type	Description	Source	Reference	Link
Geological data	Data containing geology, oil and gas fields and geological provinces of Africa	USGS	(Persits et al., 1997)	https://www.sciencebase.gov/catalog/item/60d0ff26d34e86b938aab404
Reports	Annual report from 2009 to 2022	CAMI	(CAMI, 2009-2022)	https://cami.cd/rapports/
Statistics	Mining and Quarry Rights Portfolio from 2018 to 2022	CAMI	(CAMI, 2018-2022)	https://cami.cd/statistiques/
Statistics	Register of Mining and Quarry Rights from 2018 to 2023	CAMI	(CAMI, 2018-2023)	https://cami.cd/statistiques/
Reports	Relaxed report ITIE-DRC 2018-2019 1st semester 2020 adopts	ITIE-RDC	(ITIE, 2020)	https://www.itierdc.net/publications/rapports-itie-rdc-2000/rapport-itie-rdc-2018-1er-sem-2020/
Reports	Report ITIE – RDC 2020-2021	ITIE-RDC	(ITIE, 2022)	https://www.itierdc.net/raports_itie/
Statistics	Main copper producing countries in the world from 2013 to 2022	USGS, Statista	(Statista, 2023; USGS, 2023)	https://pubs.usgs.gov/publication/mcs23 https://fr.statista.com/statistiques/565205/production-de-cuivre-dans-les-principaux-pays/
Statistics	Main cobalt producing countries in the world from 2013 to 2022	Statista	(Statista, 2023)	https://fr.statista.com/statistiques/565284/cobalt-production-miniere-par-pays-principaux/#:~:text=Cette%20statistique%20présente%20la%20production,de%20144.000%20tonnes%20en%202022.

2. Main Text

Copper, tin, alkaline and basic magmas, precious minerals, iron, manganese, and mineral fuels are among the various groupings that comprise the mineralization of the Democratic Republic of the Congo (Figure 1). Copper, cobalt, uranium, zinc, lead, cadmium, and germanium are the elements that define deposits in the copper-cobaltiferous belt. The country's eastern tin reserves include beryl, monazite, wolframite, columbo-tantalite, and tin. Gold, platinum, and silver precambrian belt deposits can be found in the Archean craton as well as the Kibalian and Burundian orogenic cycles. Manganese is present in a variety of mineral associations (Lutandula et al., 2019; Somarin, 2019; Oyediran et al., 2020; Bampole et al., 2020; Bird, 2016; Mbo et al., 2023; Beukes et al., 2016).

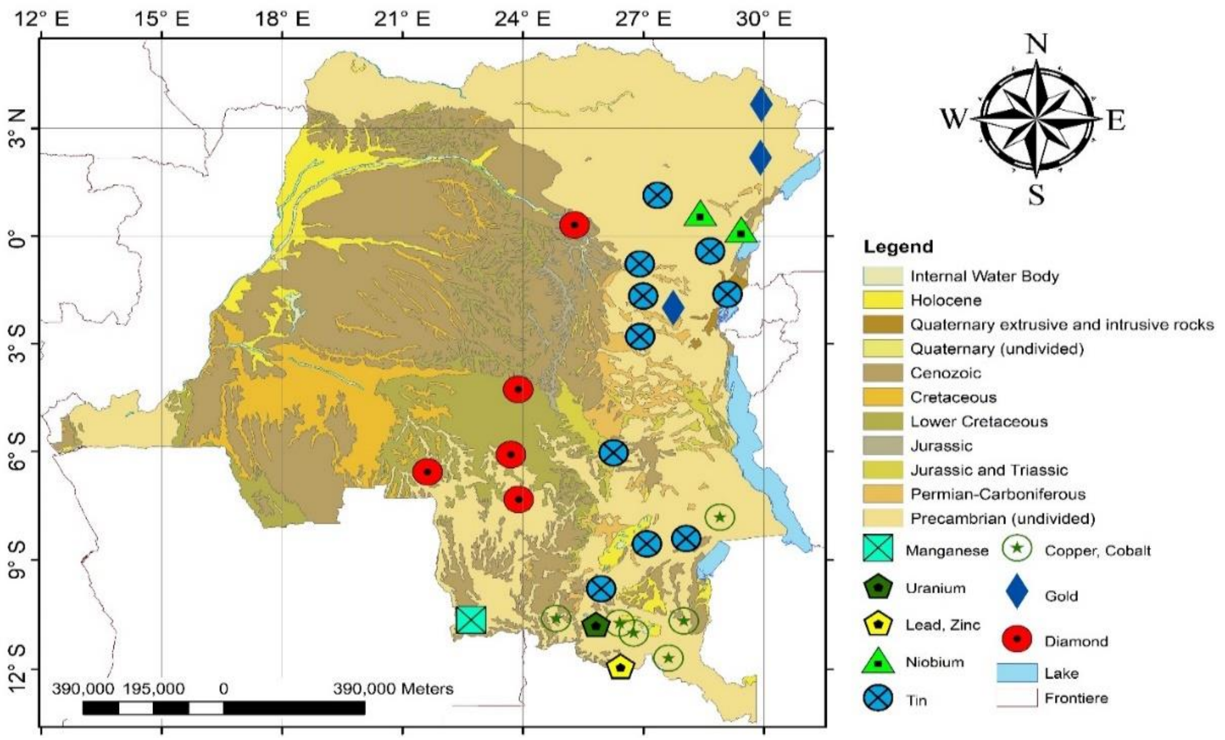

Figure 1: Geological map of the DR Congo with locations of areas of exploitation of mineral raw materials.

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These mineral raw materials are critical minerals and play a very large role in the energy transition (Sarah et al., 2018; Shuronjit et al., 2022). Copper is commonly used in renewable energy technology due to its conductivity. More than 31 million tons of copper were used in 2021, making over 70% of all the minerals needed for the energy transition that were consumed (IEA, 2023). Due to its growing application in low-carbon technologies, especially in lithium-ion and nickel metal hydride batteries for electric or hybrid vehicles, as well as wind turbine magnets, cobalt is becoming more and more visible (Slack et al., 2016). On land, there are reserves of 25 million tons of cobalt. The majority of these minerals are found in the "Copper Belt," a mining region that includes a sizable portion of the Democratic Republic of the Congo's Katanga province. As of 2022, production in the region amounted to 120,000 tons out of a total of 170,000 tons worldwide (Figure 2B), with 3,500,000 tons on a world total reserve of 7,600,000 tons (Figure 2A) (USGS, 2022).

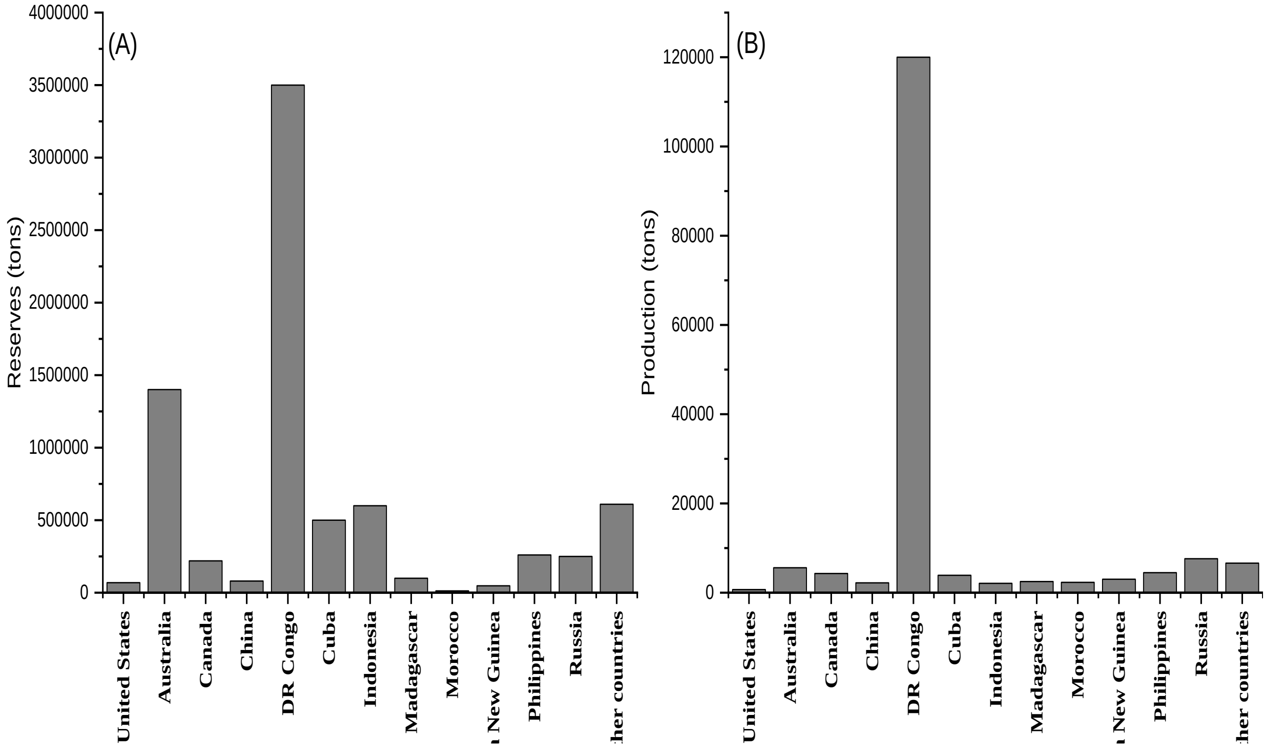

Figure 2: Global cobalt reserves in tons (A) and global cobalt production in 2021 in tons (B) (USGS, 2022).

This reserve is the basis of the strong demand for mining titles recorded by the Mining Cadastre (CAMI), a technical service of the Ministry of Mines of DR Congo. Mining titles are classified as follows: Research Permit (PR); Discharge Exploitation Permit (PER); Small Mine Exploitation Permit (PEPM); Exploitation Permit (PE); Careers in Public Utilities (CUP); Research Authorizations for Quarry Products (ARPC); and Permanent Quarry Exploitation Authorizations (AECP). Research permits are the most requested in 2021, followed by operating permits (Figure 3) (CAMI, 2022).

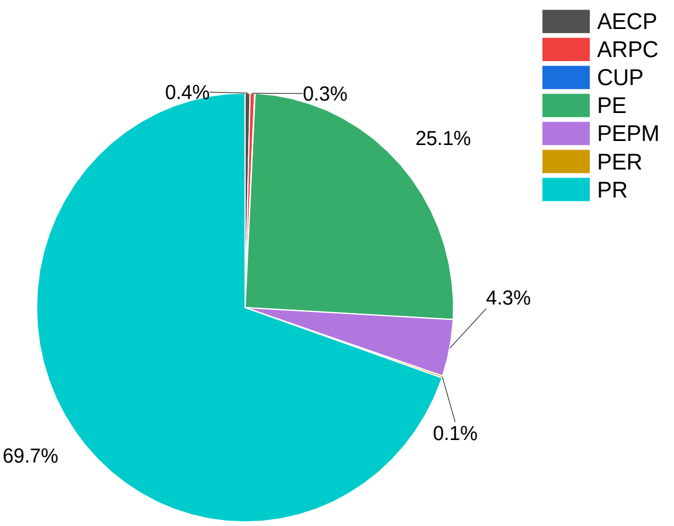

Figure 3: 2D Pie Chart presenting the proportion of mining titles according to classifications (CAMI, 2022).

Due of the high demand of critical minerals, there is a high demand for mining squares and operation permissions. The DR Congo's national territory was covered by mining titles on average 10.39% of the time between 2016 and 2022 (CAMI, 2016–2022). The Congolese government began by launching the mining project (PROMINES) in 2010 with the aim of creating a strong institutional framework to enhance the sector's management for the benefit of social and economic development in light of these findings, which support the idea that mineral resources are non-renewable (Desrousseaux, 1980; Venayen, 2017; Geenen and Custers, 2010). Following this, the FOMIN, or Mining Fund for Future Generations, was created (Prime Minister-DRC, 2019). Despite all of these efforts, the economic situation of the Democratic Republic of the Congo remains unchanged. It is uncertain if the most recent remote sensing and spatial analytic technologies should be utilized to assure sustainable and controlled exploitation of natural resources, as none of these initiatives have yielded the expected results.

The technology industry's high demand for mineral raw materials leads to environmental problems such as deforestation and biodiversity loss during exploration and mining phases, soil and landscape degradation during massive deforestation that causes landslides, erosion, and soil subsidence, pollution of surface and groundwater during hydrometallurgical processing of ores with the release of heavy minerals, acid residues, and various chemicals into tributaries, and dust pollution from rock fragmentation, movement, and machinery circulation (Promines, 2014). The United Nations Environment Program claimed that industrial and artisanal mineral mining was causing environmental deterioration that same year, with a focus on heavy metals and other harmful compounds that were contaminating streams and landscapes (UNEP, 2014; Ruppen et al., 2023). Due to accessibility issues in some places, the majority of environmental reports which contain information on solid discharges, air pollutants from mining industries, and the volume and quality of liquid effluents are incomplete. However, by utilizing new geospatial technologies based on remote sensing to manage emergencies and disasters, remediate and repair damaged land, and monitor and enforce environmental regulations using monitoring techniques, these extremely concerning issues can be lessened and occasionally avoided (Chugg et al., 2021; Abdalla and Li, 2010).

When fluids containing residual chemical elements contaminate tributaries, the analysis of multiple spectral characteristics can be used for quantitative pH mapping in the mining environment (Kopačková, 2014; Kopačková and Hladíková, 2014). Through these publications, the scientists provided the first demonstration of a method for quantitatively modeling pH in a mining environment using image spectroscopy. The study's findings show that hyperspectral remote sensing is a useful technique for monitoring the environment that can be used by the mining industry in the DR Congo. After that, they presented a method for mapping the relative abundances of water released from mining plants using hyperspectral image data and linear spectral unmixing (LSU), which was restricted to a 5 m spatial resolution for HyMap data. According to these studies, these methods could be used to classify mine water into basic groups. This is useful in the case of the DR Congo, where mine drainage problems are evident in both artisanal and industrial mines, causing acid mine drainage (AMD) (Otamonga and Poté, 2020; Kebede, 2017; Muedi et al., 2022; Maheshe and Beak, 2018; Wei and Viadero, 2007; Larsson et al., 2018).

Alternatively, studies on the horizontal and vertical variability of soil properties in an area contaminated by trace elements can be conducted (Burgos et al., 2008; Kanso et al., 2018; Huang et al., 2022). It is feasible to anticipate soil contamination and quantitatively assess the impacts of mining activities on vegetation by identifying the factors of control using data gathered remotely, given that certain operators do not make certain data public (Gao et al., 2022; Sun et al., 2022).

Several studies have highlighted the priority that should be given to the use of native vegetation on mining sites. Indeed, its high biomass, rapid growth, and ability to adapt to adverse environmental conditions make it a better indicator of restoration success (Zamora-Ledezma et al., 2021; Mourinha et al., 2022; Diarra et al., 2022; Radu et al., 2023). The author, Bandyopadhyay, showed the need to use an innovative genomic approach to heavy metal remediation practices to develop new remediation concepts in mining areas with enhanced application of marker detection (Bandyopadhyay, 2022). This work highlighted important climatic factors including soil clay content and plant age in arid regions, rainfall and plant age in semi-arid regions, normalized difference vegetation index (NDVI) and plant age in subhumid regions. The majority of the DR Congo maintains a tropical climate due to its proximity to the equator. According to the Köppen Geiger climate classification, the center portion of the Congo Basin has a tropical rainforest climate (type Af) (Peel et al., 2007). Along the margins of the Congo Basin, the climate shifts to a tropical monsoon climate.

As a result, the DR Congo has tropical weather in its north and south and equatorial weather in its center (Whatstheweatherlike, 2023; Belgium.be, 2023). This means that when managing water resources and restoring ecosystems in areas damaged by mining operations, the use of the methods and technology discussed in this study can be done in mining areas located in humid tropical climates. Through significant advancements in remediation engineering strategies based on bi-based photocatalysts, remediation methods and techniques based on sulfate radicals, and mapping of natural habitats and their conservation, remote sensing can contribute to the conservation of nature and the persistence of biological diversity in the DR Congo (Hassan et al., 2022; Xie et al., 2023; Corbane et al., 2015).

3. Conclusion

This work reviews the latest research with the aim of identifying new spatial analysis and remote sensing technologies to monitor mining activities by evaluating the contamination of soils, tributaries, water and air, but also highlighting the latest engineering technologies for remediation of areas degraded by mining activities. The demand for mining titles is strong in the DR Congo, a large proportion of which are research permits and operating permits. Given that these resources are non-renewable, the Ministry of Mines should encourage the application for mining titles in the exploitation permit class for the reasonable and sustainable exploitation of natural mineral resources to achieve sustainable development. The research encountered obstacles to the extent that gathering environmental data on pollution in the mining industry for integrated processing became challenging. Furthermore, it would be preferable to provide absolute values rather than rates and to make disclosures more meaningful by providing details about negative consequences in line with the open data principles, giving specifics on the mining site, and providing clarity regarding the parameters applied. In terms of the nation's economic context, future research can start with monitoring certain contaminants, the spatiotemporal variation of land cover, and external dynamics phenomena using databases like Google Engine, which are accessible to indigenous researchers. After that, the research can concentrate on remediation-based techniques. Impact analyses based on the Geographic Information System for the geographical distribution of air and water pollutants in the mining region can be performed in the specific scenario of air contamination. The National Remote Sensing Center is the structural pilot of remote sensing research in the DR Congo but it should involve not only the Ministry of the Environment, Agriculture, and Public Health but also the technical services of the Ministry of Scientific Research and the Ministry of Mines, such as the Geographical Institute of Congo (IGC), the national geological service, the mining cadastre (CAMI), the technical cell for coordination and mining planning (CTCPM), and other appropriate services for multidisciplinary studies to take into account these and other methods in recent research to monitor, regulate, and remedy these problems.

Authors' Contributions

Innocent MUFUNGIZI: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing-original draft, Visualization, Supervision, Project administration, Funding acquisition

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