Scientific Research Publishing

Open Journal of Civil Engineering, 2025, 15(3), 430-441
https://www.scirp.org/journal/ojce
ISSN Online: 2164-3172
ISSN Print: 2164-3164

Geospatial Distribution and Sustainable Management of Construction Materials in Congo-Brazzaville: Challenges and Perspectives

Séverin Jean Maixent Loubouth*, Sorel Gaël Dzaba-Dzoualou, Destin Gemetone Etou, Gildas Ngouono Ngakali, Narcisse Malanda

Laboratory of Mechanics, Energy, and Engineering, National Polytechnique High School, Marien Ngouabi University, Brazzaville, Republic of the Congo
Email: *beniloubouth@gmail.com, sorel_dzaba-dzoualou@umng.com, gemetoneetou@gmail.com, Ngak.dasgakali@gmail.com, nar6malanda@gmail.com

How to cite this paper: Loubouth, S.J.M., Dzaba-Dzoualou, S.G., Etou, D.G., Ngakali, G.N. and Malanda, N. (2025) Geospatial Distribution and Sustainable Management of Construction Materials in Congo-Brazzaville: Challenges and Perspectives. *Open Journal of Civil Engineering*, **15**, 430-441.
https://doi.org/10.4236/ojce.2025.153023

Received: June 26, 2025
Accepted: August 29, 2025
Published: September 1, 2025

Abstract

The Republic of the Congo holds significant geological potential in construction materials such as sand, gravel, clay, limestone, and hard rocks. However, their geospatial distribution, modes of extraction, and regulatory oversight remain insufficiently documented. This review consolidates existing literature and spatial datasets, with a focus on Brazzaville and its surrounding regions, to map the distribution of key resources and assess current extraction practices. Findings reveal concentrated deposits near major rivers and in the southern and eastern zones, where exploitation is predominantly artisanal and informal. Such unregulated practices result in considerable environmental degradation, including riverbank erosion, habitat fragmentation, and large-scale deforestation. In parallel, they generate complex socioeconomic challenges, notably land-use conflicts and the absence of formal labor protections within the informal mining sector. The study highlights critical gaps in geospatial data, institutional governance, and sustainable planning. It recommends the development of an interactive geological cadastre, formalization of artisanal mining, integration of GIS into territorial planning, and promotion of eco-friendly construction materials. These strategies are essential for aligning resource exploitation with environmental protection and inclusive urban development.

Keywords

Geospatial Distribution, Construction Materials, Artisanal Mining,

Congo-Brazzaville, Sustainable Development

1. Introduction

Rapid urbanization in sub-Saharan Africa, notably in the Republic of the Congo, has sharply increased demand for construction materials such as sand, gravel, clay, limestone, and timber [1]-[4]. Brazzaville and Pointe-Noire, key urban centers, rely heavily on local natural deposits shaped by regional geology and river systems. These resources are vital for infrastructure development but face challenges from overexploitation, weak regulation, poor transport infrastructure, and environmental degradation [1].

Advances in sustainable construction materials—such as geopolymer concrete, recycled aggregates, and natural fiber composites—offer viable alternatives to traditional Portland cement, with potential ecological and cost benefits over time [5]-[7]. However, their adoption is often limited by higher upfront expenses [8] [9].

Geographical disparities in resource availability in the Republic of the Congo create significant economic and logistical challenges, including high transportation costs and price volatility. Key raw materials for construction, such as limestone and clay for cement, are concentrated in Bouenza and Niari, while road-building laterite is found mainly in the central and northern regions, and timber resources are abundant in Sangha, Likouala, and northern Niari. These spatial imbalances are compounded by inadequate infrastructure, such as poor road and rail networks, which hinder the efficient extraction, transport, and distribution of these resources. Consequently, transportation expenses substantially increase production costs, as observed in similar contexts across Sub-Saharan Africa, where long-distance hauling and infrastructure deficits add considerable premiums to material prices [3] [8] [10] [11].

Most extraction remains informal and unregulated, contributing to unchecked environmental degradation such as riverbank erosion and habitat destruction [12]. These problems are exacerbated by weak institutional oversight and fragmented data. Artisanal mining in urban and peri-urban areas also incurs ecological and social costs.

Projects like PIC-ROC aim to promote local production and strengthen regional supply chains to reduce import dependence and stimulate decentralized development [13]. To address the economic, logistical, and environmental challenges, this review recommends integrated resource management, improved territorial planning, and stronger regulatory frameworks [14].

This article provides a comprehensive analysis of the geospatial distribution of construction materials in the Republic of the Congo, focusing on Brazzaville and its surroundings, and highlights strategies for sustainable resource governance. A major limitation of current geospatial databases is the absence of high-resolution deposit maps, hindering precise resource localization and quantification. Data on

extraction rates—especially from informal operations—and indicators of land degradation such as erosion, vegetation loss, or sediment loads are also lacking, limiting environmental impact assessments. This underscores the need for interdisciplinary research integrating geology, environmental science, and land-use planning to support informed decision-making.

Sustainable management of construction materials involves integrated governance of extraction, distribution, and utilization to ensure long-term environmental preservation, economic efficiency, and social equity. It aims to minimize ecological degradation, optimize local economic benefits through formalization and regulation, and ensure equitable access and protections for affected communities.

2. Methodology

This study employs a qualitative, narrative review methodology based on a narrative review of existing literature, technical documents, and spatial data concerning the distribution and management of construction materials in the Republic of the Congo. The objective was to compile, analyze, and interpret information on the spatial localization, exploitation practices, and governance of key construction materials, particularly in and around Brazzaville.

Data sources included official government publications (e.g., Ministry of Mines and Geology reports), scientific journal articles, development agency reports (e.g., World Bank, UNEP, FAO), and academic theses. Particular emphasis was placed on documents providing geotechnical, geological, and environmental insights relevant to resource extraction and land use.

Geospatial data were collected from available maps, satellite imagery, and datasets provided by institutions such as the U.S. Geological Survey and the Federal Institute for Geosciences and Natural Resources (BGR). Spatial patterns of resource deposits—such as sand, gravel, clay, laterite, limestone, and hard rocks—were identified through comparative visual analysis, focusing on proximity to urban centers, river systems, and known industrial zones. Due to the lack of standardized national geospatial databases, the analysis remains primarily descriptive and interpretative rather than quantitative.

Environmental and socioeconomic impacts were assessed through a synthesis of field observations reported in previous studies, with particular attention to the effects of artisanal and informal mining. The study does not include primary fieldwork or new data collection but provides a consolidated perspective that highlights critical knowledge gaps and proposes directions for future research using Geographic Information Systems (GIS) and integrated geospatial tools.

3. Results

3.1. Geospatial Distribution of Construction Materials

Construction materials such as sand, gravel, clay, laterite, limestone, and hard rocks show distinct spatial patterns across the Republic of the Congo. Sand and gravel are primarily found along riverbeds near the Congo and Djoué rivers [3]

[8] [14]. Clay is extracted near Brazzaville and Boko, while laterite dominates in Bouenza and the Batéké Plateaus. Limestone reserves are concentrated in Loutété and Mfouati, supporting major cement factories [15]. Hard rocks like basalt and granite are located in the Batéké Plateaus and Mayombe mountains.

3.2. Environmental Impacts

Artisanal mining along riverbanks significantly contributes to soil erosion, sedimentation, and water pollution due to the digging and sluicing activities, which often lead to the unmanaged release of mine tailings into waterways, causing siltation and river diversion or clogging [8]. The removal of vegetation for mining operations destabilizes soils and transforms them into unproductive wastelands, resulting in long-term degradation, increased erosion, and loss of biodiversity [16]. Furthermore, most artisanal miners (over 94%) do not conduct environmental impact assessments or implement rehabilitation plans, exacerbating environmental deterioration caused by wasteful practices and insufficient national legislation on sustainable land management [17]. This mining activity also leads to deforestation, water depletion, turbidity, and destruction of aquatic habitats. Weak enforcement of environmental regulations allows many mining companies to operate in non-compliance, dumping waste into the environment and polluting water, air, and soil, which worsens the physical degradation, biodiversity loss, and soil fertility decline [3] [18].

3.3. Socioeconomic Dynamics

Informal extraction dominates the sector, providing livelihoods but lacking legal protections, safety, or social services. Land-use conflicts often arise, especially where mining overlaps with agriculture. The absence of clear land tenure and coordinated planning results in fragmented governance. Formalizing artisanal mining could improve livelihoods and environmental compliance [17].

3.4. Role of Formal Private Sector

Cement companies such as SONOCC and Dangote significantly influence local governance and land-use dynamics in the Republic of Congo. Their operations affect regional development, infrastructure planning, and control over mineral-rich zones. Although these companies are regulated, their economic power often marginalizes small-scale miners and reinforces spatial inequalities in contexts where governance remains weak [19]-[21].

4. Construction Materials and Spatial Distribution

Figure 1 depicts the spatial distribution of the principal construction materials in the Republic of the Congo. The map highlights the geographic availability of sand, gravel, clay, laterite, limestone, and dens rocks across major towns and regions. This overview facilitates strategic planning for sustainable construction and effective resource management [14].

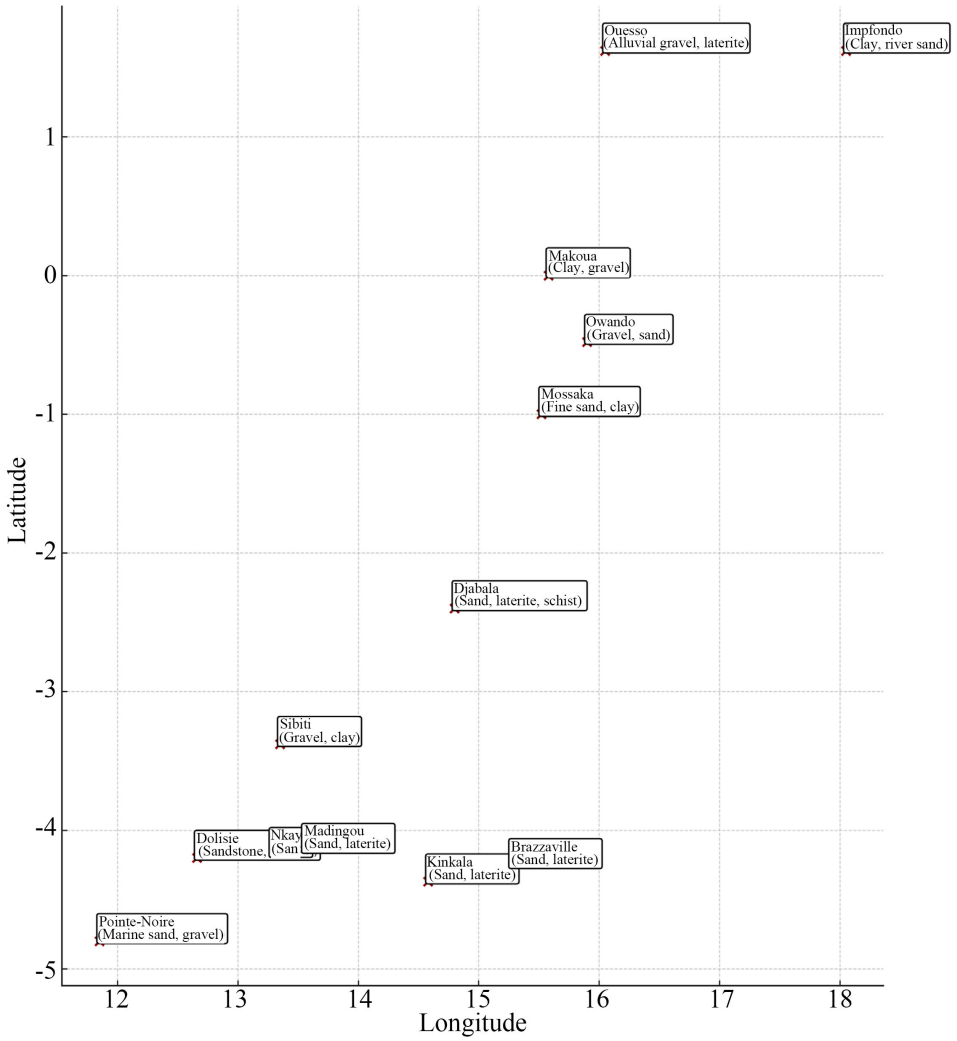

Figure 1. Spatial distribution of key construction materials in the Republic of the Congo.

4.1. Sand and Gravel

Sand and gravel deposits are unevenly distributed, with significant concentrations along the Congo and Djoué rivers. These materials are mainly extracted from riverbeds, generating significant environmental concerns such as habitat loss, deforestation, and land degradation due to unregulated activities in riparian and forested zones [3] [8] [18]. While the U.S. Geological Survey offers broader regional data on construction resources, specific datasets for Congo remain limited.

4.2. Clay and Laterite

Clay is mined primarily on the outskirts of Brazzaville (Makélékélé, Mfilou) and in the Boko area, where it supports small-scale brickmaking. These artisanal operations are largely informal and contribute to localized environmental degradation [3] [18]. Laterite, widespread in the Bouenza region and Batéké Plateaus, is extensively used for rural road construction due to its strength and accessibility [1].

4.3. Limestone

Limestone deposits are concentrated in the southwest, especially in Loutété and Mfouati (Bouenza Department). Loutété hosts two major cement plants operated by SONOCC and Dangoté, while Dolisie is home to the FORSPAK plant. Mfouati features karstic limestone hills with historical mining significance. These limestone reserves are central to the national cement industry [1] [3] [22].

4.4. Hard Rocks

Basalt is abundant on the Batéké Plateaus, while granite and quartzite are primarily found in the Mayombe mountains. These hard rocks are essential in infrastructure projects, including road bases, building foundations, and railway ballast [4] [17].

5. Environmental and Socioeconomic Issues

The extraction of construction materials in the Republic of the Congo is predominantly informal and poorly regulated, resulting in significant environmental and socioeconomic consequences. These impacts are particularly acute in areas of high demand, such as Brazzaville and its peri-urban zones [2] [20] [21].

5.1. Environmental Impacts

Artisanal mining along riverbanks, especially near the Congo and Djoué rivers, contributes to severe erosion, increased sedimentation, and water pollution. The removal of vegetation and destabilization of soils further accelerate ecological degradation. Such operations are frequently conducted without prior environmental impact assessments or subsequent rehabilitation plans, leaving long-term scars on the landscape [2] [19] [20].

Recent studies emphasize that quarrying and mining operations in the Republic of the Congo cause significant habitat destruction and landscape alteration, which exacerbate soil degradation and increase the risk of flooding in surrounding areas [2]. These operations also frequently encroach upon forests and ecologically sensitive zones, leading to deforestation and biodiversity loss. These pressures are further intensified by weak enforcement of environmental regulations and limited institutional capacity to monitor and manage the sector [2] [20]. Watha-Ndoudy *et al.* [2022] reported significant environmental degradation associated with geomaterials exploitation in the Republic of the Congo [2].

5.2. Socioeconomic Impacts

The dominance of informal extraction limits the sector's economic contribution to the state and undermines efforts to establish regulatory oversight. Artisanal miners often operate under precarious conditions, lacking safety equipment, social protection, and access to basic services such as healthcare and education [19] [23].

Furthermore, conflicts over land use are common, particularly where mining activities intersect with agricultural zones. These tensions are fueled by unclear land

tenure systems and the absence of coordinated land-use planning. The result is a fragmented resource landscape where competing interests go unresolved [17] [24].

Formalizing artisanal mining in the Republic of the Congo is essential to addressing the environmental degradation and social vulnerabilities associated with the sector [11]. By establishing clear legal frameworks, implementing social protection mechanisms, and enhancing regulatory oversight, formalization can improve the livelihoods of mining communities while supporting traceability and environmental compliance [11]. If not linked to broader development strategies, however, it may worsen poverty and environmental harm, reflecting the complex challenges observed in other contexts [17].

6. Governance and Institutional Challenges

Governance and institutional deficiencies in the Republic of the Congo hinder effective management of construction materials and extractive resources [10] [17]. Limited enforcement, fragmented data, and insufficient institutional capacity undermine effective regulation and sustainable use.

Additionally, infrastructural limitations, including inadequate transportation and energy networks, further constrain efficient resource management and distribution [25]. Although projects like the World Bank's PDRM initiative and participation in the Extractive Industries Transparency Initiative have enhanced transparency, significant gaps remain in legislation, revenue sharing, and stakeholder involvement [26]-[28]. These challenges hinder sustainable exploitation, equitable benefit distribution, and environmental protection, highlighting the need for stronger regulatory frameworks and better data management [27].

For example, while 163 quarry sites were identified across the country and environmental impacts related to extraction documented, the study lacked integration of volunteered geographic information (VGI) and crowdsourced spatial data to enhance the mapping. This absence of participatory geospatial analysis limits the ability to effectively link deposit locations with urban demand, transport logistics, and land-use planning, thereby reducing its practical utility for informing policy decisions and infrastructure development [29].

Similarly, valuable geotechnical insights into construction materials in the Brazzaville region are provided, though the study does not explore the spatial or ecological dimensions of resource availability. Such narrow scopes restrict the applicability of findings to broader planning and environmental assessment frameworks [1].

A major gap lies in the shortage of interdisciplinary research integrating geology, environmental science, and urban planning. There is also a need for open-access geospatial databases and the use of Geographic Information Systems (GIS) to support decision-making. Without this, material sourcing remains reactive, fragmented, and vulnerable to overexploitation [30] [31].

Addressing these gaps requires coordinated research initiatives that incorporate field surveys, remote sensing, socio-economic data, and environmental indicators to develop a holistic understanding of resource distribution and impact [30] [31].

7. Strategies for Sustainable Management

Addressing the growing demand for construction materials in the Republic of the Congo requires a comprehensive and integrated approach that balances economic development with environmental protection and social equity. The following strategies are essential for promoting sustainable management of these critical resources.

7.1. Development of an Interactive Geological Cadastre

A digital, up-to-date geological cadastre would provide a centralized platform for mapping mineral resources. This system would enhance transparency, facilitate resource allocation, and support regulatory bodies in overseeing extraction activities in real time, especially when integrated with broader sustainable infrastructure development models applicable in Sub-Saharan Africa [32]-[34].

7.2. Integration of Geographic Information Systems (GIS) in Urban and Regional Planning

Incorporating Geographic Information Systems (GIS) into resource management enables planners to identify optimal extraction sites by accounting for environmental sensitivities, infrastructure proximity, and transportation logistics, thereby enhancing spatial decision-making and promoting sustainable outcomes [35]. When combined with remote sensing technologies, GIS further strengthens the ability to detect extraction hotspots, monitor land-use changes, and support environmental protection initiatives. These tools provide a comprehensive framework for integrating environmental constraints, land-use planning, and logistical considerations into strategic planning processes.

7.3. Formalization and Regulation of Artisanal Mining

Artisanal mining plays a critical socio-economic role in the Republic of the Congo, particularly in providing livelihoods for vulnerable populations. However, its predominantly informal and unregulated nature poses serious environmental and social challenges [24] [33]. The formalization of this sector is therefore imperative. This process requires the establishment of clear legal frameworks, the strengthening of institutional capacity, and the enforcement of environmental safeguards to improve labor conditions, ensure regulatory compliance, and mitigate ecological degradation [36]. To be both effective and equitable, formalization efforts must also be guided by legal clarity and supported by socio-economic incentives that prevent the exclusion or marginalization of artisanal miners [24].

7.4. Promotion of Alternative Construction Materials and Technologies

Promoting the use of sustainable construction materials—such as geopolymers, recycled aggregates, and industrial by-products—can significantly reduce the reliance on natural deposits and mitigate environmental degradation [34] [37]. Ge-

opolymers, in particular, present a viable alternative to conventional cement due to their lower carbon emissions, enhanced durability, and capacity to incorporate industrial waste materials [35]. Advancing research and encouraging the adoption of innovative, eco-friendly building techniques are essential steps toward minimizing the environmental footprint of the construction sector and embedding sustainability principles into construction economics.

7.5. Strengthening Research, Education, and Institutional Capacity

Fostering collaboration between academic institutions, government agencies, and the private sector is key to advancing knowledge and technical expertise in sustainable construction. Applied research, training programs, and policy support will enable the development of context-appropriate solutions and long-term resource stewardship [36].

Sustainability strategies in construction materials management focus on minimizing environmental impacts while promoting social and economic benefits. Research highlights that adopting green construction practices reduces waste, energy use, and legal costs, improving economic outcomes alongside environmental and social performance [38]. Integrating Environmental, Social, and Governance (ESG) criteria in sustainable materials further supports the UN Sustainable Development Goals, fosters social equity, and creates healthier, energy-efficient buildings [39] [40]. Sustainable construction management plays a crucial role in optimizing resource use and enhancing overall project benefits [8] [41] [42].

Effective implementation of these strategies hinges on multisectoral coordination, robust governance frameworks, and active community involvement. Only through an integrated and sustained effort can the Republic of the Congo ensure the responsible use of its construction materials to support both present and future development needs.

8. Conclusions

The Republic of the Congo possesses significant deposits of construction materials—including sand, gravel, clay, limestone, laterite, and hard rocks—that are essential for the country's infrastructure development and economic growth. However, the current exploitation of these resources remains largely informal and poorly regulated, leading to substantial environmental degradation, logistical inefficiencies, and missed opportunities for economic optimization.

The uneven spatial distribution of these materials, combined with weak governance and the absence of comprehensive geospatial data, hinders effective resource management. This results in unsustainable extraction practices, such as riverbank erosion, habitat destruction, and increased transportation costs due to the lack of proximity between deposits and demand centers.

To overcome these challenges, the study advocates for a coordinated, multidisciplinary strategy that integrates geospatial technologies, improved regulatory frameworks, and community engagement. The development of an interactive ge-

ological cadastre, the formalization of artisanal mining, and the promotion of alternative, eco-friendly construction materials are critical steps toward ensuring sustainability.

By fostering stronger collaboration among government agencies, academic institutions, and private stakeholders, the Republic of the Congo can more effectively align construction material exploitation with environmental sustainability and inclusive socio-economic development. This integrated approach is vital to support the country's urbanization demands while preserving natural resources for future generations.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Bilembi, D., Elenga, H., Nsongo, T., Mabiala, B., Kimpena, A., Ngom, B.D., *et al.* (2017) Geotechnical Characterization of Local Materials Used in Road Construction in the Brazzaville Aera, Congo. *American Journal of Civil Engineering and Architecture*, **5**, 29-34.

[2] Oirere, S. (2017) West Africa Building Materials Demand Has Never Been Greater. *Aggregates Business*.

[3] Watha-Ndoudy, N., Melaine Dipakama, C., de Dieu Nzila, J., Kimpouni, V. and Louembé, D. (2022) Environmental Impacts of Geomaterials Exploitation in the Republic of Congo. *American Journal of Environmental Protection*, **11**, 47-61. https://doi.org/10.11648/j.ajep.20221103.11

[4] Writer, S. (2015) Rapid Rise for African Aggregate Demand. *Aggregates Business*.

[5] Ahmed, M., Colajanni, P. and Pagnotta, S. (2022) A Review of Current Research on the Use of Geopolymer Recycled Aggregate Concrete for Structural Members. *Materials*, **15**, Article 8911. https://doi.org/10.3390/ma15248911

[6] Ansari, M.A., Shariq, M. and Mahdi, F. (2023) Geopolymer Concrete for Clean and Sustainable Construction—A State-of-the-Art Review on the Mix Design Approaches. *Structures*, **55**, 1045-1070. https://doi.org/10.1016/j.istruc.2023.06.089

[7] Khasawneh, M.A. (2025) Geopolymer Concrete in Construction Projects: A Review. *Discover Civil Engineering*, **2**, Article No. 124. https://doi.org/10.1007/s44290-025-00281-1

[8] Chen, L., Yang, M., Chen, Z., Xie, Z., Huang, L., Osman, A.I., *et al.* (2024) Conversion of Waste into Sustainable Construction Materials: A Review of Recent Developments and Prospects. *Materials Today Sustainability*, **27**, Article 100930. https://doi.org/10.1016/j.mtsust.2024.100930

[9] Pacheco-Torgal, F. and Ding, Y. (2013) Handbook of Recycled Concrete and Demolition Waste. Elsevier.

[10] Byiers, B., Karaki, K. and Vanheukelom, J. (2017) Regional Markets, Politics and Value Chains: The Case of West African Cement. European Centre for Development Policy Management, 216.

[11] Limao, N. and Venables, A.J. (2001) Infrastructure, Geographical Disadvantage, Transport Costs, and Trade. *The World Bank Economic Review*, **15**, 451-479. https://doi.org/10.1093/wber/15.3.451

[12] Campos, P., Pimentel, C. and Lopes, J. (2022) Determinant Factors for the Strategic Management of the Supply Chain of the Angolan Cement Industry. *Journal of Industrial Engineering and Management*, **15**, 566-586. https://doi.org/10.3926/jiem.3410

[13] EITI (2024) EITI. Republic of the Congo.

[14] Addison, T. and Roe, A. (2018) Extractive Industries: The Management of Resources as a Driver of Sustainable Development. 1st Edition, Oxford University Press, 733 p.

[15] USGS (2022) The Mineral Industry of Congo (Brazzaville) in 2022—AWS. (Minerals Yearbook).

[16] Kadima, E., Delvaux, D., Sebagenzi, S.N., Tack, L. and Kabeya, S.M. (2011) Structure and Geological History of the Congo Basin: An Integrated Interpretation of Gravity, Magnetic and Reflection Seismic Data. *Basin Research*, **23**, 499-527. https://doi.org/10.1111/j.1365-2117.2011.00500.x

[17] U.S. Geological Survey (2019) Mineral Commodity Summaries 2019. US Geological Survey.

[18] Banza Lubaba Nkulu, C., Casas, L., Haufroid, V., De Putter, T., Saenen, N.D., Kayembe-Kitenge, T., *et al.* (2018) Sustainability of Artisanal Mining of Cobalt in DR Congo. *Nature Sustainability*, **1**, 495-504. https://doi.org/10.1038/s41893-018-0139-4

[19] Akinyoade, A. and Uche, C. (2017) Development Built on Crony Capitalism? The Case of Dangote Cement. *Business History*, **60**, 833-858. https://doi.org/10.1080/00076791.2017.1341492

[20] Blanche, M.F., Dairou, A.A., Juscar, N., Romarice, O.M.F., Arsene, M., Bernard, T.L., *et al.* (2024) Assessment of Land Cover Degradation Due to Mining Activities Using Remote Sensing and Digital Photogrammetry. *Environmental Systems Research*, **13**, Article No. 41. https://doi.org/10.1186/s40068-024-00372-5

[21] Hilson, G., Hilson, A., Maconachie, R., McQuilken, J. and Goumandakoye, H. (2017) Artisanal and Small-Scale Mining (ASM) in Sub-Saharan Africa: Re-Conceptualizing Formalization and 'Illegal' Activity. *Geoforum*, **83**, 80-90. https://doi.org/10.1016/j.geoforum.2017.05.004

[22] Ingram, V., Tieguhong, J.C., Schure, J., Nkamgnia, E. and Tadjuidje, M.H. (2011) Where Artisanal Mines and Forest Meet: Socio-Economic and Environmental Impacts in the Congo Basin. *Natural Resources Forum*, **35**, 304-320. https://doi.org/10.1111/j.1477-8947.2011.01408.x

[23] Wegenast, T. and Beck, J. (2020) Mining, Rural Livelihoods and Food Security: A Disaggregated Analysis of Sub-Saharan Africa. *World Development*, **130**, Article 104921. https://doi.org/10.1016/j.worlddev.2020.104921

[24] UNEP (2019) The Evolving Chemicals Economy: Status and Trends Relevant for Sustainability—Global Chemicals Outlook II Part I.

[25] Dzinamarira, T., Moyo, E., Cuadros, D.F., Herrera, H., Mano, O., Munyonho, F.T., *et al.* (2024) Occupational Health Risks and HIV Prevention Programming for Informal Extractive Miners in Sub-Saharan Africa: A Narrative Review of Interventions, Challenges, and Lessons Learned. *Merits*, **4**, 475-489. https://doi.org/10.3390/merits4040034

[26] Kumah, R. (2022) Artisanal and Small-Scale Mining Formalization Challenges in Ghana: Explaining Grassroots Perspectives. *Resources Policy*, **79**, Article 102978. https://doi.org/10.1016/j.resourpol.2022.102978

[27] Schwartz, F.W., Lee, S. and Darrah, T.H. (2021) A Review of the Scope of Artisanal and Small-Scale Mining Worldwide, Poverty, and the Associated Health Impacts. *GeoHealth*, **5**, e2020GH000325. https://doi.org/10.1029/2020gh000325

[28] World Bank (2025) Supporting Enhanced Transparency in Extractives: The World Bank's Support to EITI.

[29] Poncian, J. and Kigodi, H.M. (2018) Transparency Initiatives and Tanzania's Extractive Industry Governance. *Development Studies Research*, **5**, 106-121. https://doi.org/10.1080/21665095.2018.1486219

[30] Longley, P.A., Goodchild, M.F., Maguire, D.J. and Rhind, D.W. (2015) Geographic Information Science and Systems. John Wiley & Sons.

[31] Scholten, H.J. and Stillwell, J. (2013) Geographical Information Systems for Urban and Regional Planning. Vol. 17, Springer Science & Business Media.

[32] Benayed, W., Awijen, H., Bousnina, R. and Chroufa, M.A. (2024) Infrastructure for Sustainable Energy Access in Sub-Saharan Africa: Leveraging Social Factors and Natural Capital. *Journal of Cleaner Production*, **470**, Article 143304. https://doi.org/10.1016/j.jclepro.2024.143304

[33] Bhandari, S., Qin, K., Zhou, Q. and Evans, N.J. (2022) Geological, Mineralogical and Geochemical Study of the Aquamarine-Bearing Yamrang Pegmatite, Eastern Nepal with Implications for Exploration Targeting. *Minerals*, **12**, Article 564. https://doi.org/10.3390/min12050564

[34] Gibson, J. and Boe-Gibson, G. (2021) Nighttime Lights and County-Level Economic Activity in the United States: 2001 to 2019. *Remote Sensing*, **13**, Article 2741. https://doi.org/10.3390/rs13142741

[35] Zhuwarara, S.K. (2023) The Potential of Digitisation in Enhancing Regulation and Sustainability in the Artisanal and Small-Scale Mining (ASM) Sector in Zambia, Nigeria, and Ghana. In: Nalule, V.R., Ed., *Mining Law and Governance in Africa*, Routledge, 193-217. https://doi.org/10.4324/9781003284437-11

[36] Gabriele, M., Brumana, R., Previtali, M. and Cazzani, A. (2023) A Combined GIS and Remote Sensing Approach for Monitoring Climate Change-Related Land Degradation to Support Landscape Preservation and Planning Tools: The Basilicata Case Study. *Applied Geomatics*, **15**, 497-532. https://doi.org/10.1007/s12518-022-00437-z

[37] Agwu, K., Oraefo, O., Jude, B., Onuorah, I., Onyemaechi, C. and Chinenye, C. (2024) Exploring the Impacts of Sustainable Design Practices on Construction Cost. *International Journal of Progressive Research in Engineering Management and Science*, **4**, 1531-1537.

[38] Geenen, S. (2012) A Dangerous Bet: The Challenges of Formalizing Artisanal Mining in the Democratic Republic of Congo. *Resources Policy*, **37**, 322-330. https://doi.org/10.1016/j.resourpol.2012.02.004

[39] Sharma, N.K. (2020) Sustainable Building Material for Green Building Construction, Conservation and Refurbishing. *International Journal of Advanced Science and Technology*, **29**, 5343-5350.

[40] Kong Yap, C., Seng Leow, C. and Goh, B. (2024) Sustainable Construction Materials under ESG: A Literature Review and Synthesis. *MOJ Biology and Medicine*, **9**, 1-6. https://doi.org/10.15406/mojbm.2024.09.00208

[41] Davidovits, J. (2008) Geopolymer Chemistry and Applications. Geopolymer Institute.

[42] Mishara, S.K. (2024) The Role of Sustainable Construction Management in Enhancing Environmental, Economic, and Social Outcomes: A Comprehensive Analysis of Benefits in Modern Building Practices. *International Journal for Research in Applied Science and Engineering Technology*, **12**, 1260-1264. https://doi.org/10.22214/ijraset.2024.64344