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INTEGRATING GEOSPATIAL TECHNOLOGIES AND MACHINE LEARNING FOR MONITORING AND ASSESSING ENVIRONMENTAL IMPACTS OF MINING ACTIVITIES IN THE SOUTH EAST OF NIGERIA: A STRUCTURED REVIEW

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ABSTRACT

The environmental impacts of mining activities in Southeast Nigeria pose significant challenges and threats to the local ecosystems and communities. Research reveals that the impact of these activities had hitherto been poorly monitored or assessed due to the inefficient manual approach used. Now, there are currently gaps in the literature on the potential of advanced technologies for sustainable environmental management vis-à-vis the mining practices in the Southeast and Nigeria. This research therefore seeks to bridge this gap and has adopted a review of the literature method to synthesize existing knowledge and determine the prospects and potential of the integration of geospatial technologies and machine learning for monitoring and managing these environmental impacts and support improved decision-making. This review adhered to the PRISMA guidelines, which involved an initial evaluation of 550 articles and which eventually resulted in 64 relevant materials used for this study. The findings indicate that mining activities led to severe land degradation, deforestation, and water contamination, adversely affecting biodiversity and local livelihoods. The study also revealed that advanced geospatial and machine learning technologies hold great potential for environmental monitoring, assessment, and management in the Southeast of Nigeria and Nigeria as a whole and call for urgent policy considerations from relevant stakeholders and governments.

Keywords: Environmental degradation, Environmental monitoring, Geospatial technologies, Machine learning, Mining impacts

INTRODUCTION

Mining has historically been a vital component of Nigeria's economy, providing essential raw materials that support various industries and contribute to local and national economic growth (Abalaka & Aga, 2016; Olalekan et al., 2016). The South East region is rich in mineral resources, including coal, gas, limestone, galena, sphalerite, micas, marble, gypsum, intrusive rocks etc, which have attracted both large-scale mining operations and artisanal miners (Onwe-Moses et al., 2020). According to the Nigerian Extractive Industries Transparency Initiative (NEITI), the mining sector has the potential to significantly enhance the country's GDP and create numerous job opportunities for the local population (Natsa, 2024). The economic benefits derived from mining activities extend beyond direct employment, as they also stimulate ancillary industries, such as transportation, equipment supply, and service provision (Miningworld.com, 2024B; Brimco, 2023). The rapid expansion of mining operations has undeniably contributed to significant economic growth, particularly in regions rich in natural resources. However, this growth comes at a considerable environmental cost, raising urgent concerns about the sustainability of such practices. Mining activities often lead to land degradation, deforestation, and the disruption of local ecosystems, which can have long-lasting effects on biodiversity. The extraction processes can result in soil erosion, which not only diminishes the land's agricultural potential but also contributes to sedimentation in nearby water bodies, adversely affecting aquatic life. Furthermore, the contamination of water resources due to the leaching of heavy metals and toxic chemicals poses serious health risks to local communities that rely on these water sources for drinking, fishing, and irrigation. The cumulative impact of these environmental challenges necessitates a careful examination of the balance between economic growth and environmental sustainability (Jovanović et al., 2023; Miningworld.com, 2024).

Now the aim of this research is to determine the prospects and potential of integration of geospatial technologies and machine learning for assessing and monitoring the environmental impacts of mining activities in the Southeastern Nigeria. By leveraging remote sensing, GIS, and advanced analytical models, the study seeks to provide a comprehensive perspective that supports the detection of land degradation, deforestation, and pollution associated with mining activities. This approach aims to enhance environmental management strategies, support policy formulation, and promote sustainable mining practices in the region.

Geology of the South East of Nigeria and Solid Minerals Distribution

The geology of the region falls within the three geologic basins of the southern Benue Trough, the Anambra Basin, and the Niger Delta Basin, which extend from the Abakaliki Formation to the Benin Formation (as shown in Table 1). The formations host quite a number of minerals, oil, and gas with intrusive rocks at various places within the southern Benue Trough. Figure 1 summarizes the major minerals in the region and Nigeria; their states of origin, and their locations. It is obvious that despite the years of degradation suffered across the regions where mining operations had occurred, there is no sign that an end is in sight.

Figure 1: A map of solid mineral resources deposit across the South-East Nigeria
Source: Adapted from (Sampson Iwuoha & Lawal, 2021)

Furthermore Table 1 shows the stratigraphic packaging/succession of South East basins and their mineral deposits.

Table 1: Stratigraphic packaging of South East basins and their Lithologies)

Era/Period	Epoch/Stage		Basins	Lithostratigraphic Units	Sea Movement	Delta Growth Phases	Lithology
Cenozoic	Quatenary		Niger Delta	Benin Formation	Regression	Cenozoic Niger Delta	Sand & Clay
	Pliocene						Sand & Clay
	Miocene			Ogwashi-Asaba Fm			
	Oligocene						Lignite, Shale, Lime stone.Sst.
	Eocene			Ameki Group			
	Paleocene	Thanatian	Anambra Basin	Imo Formation	Transgression	Transition	Shale,Clay,LimestoSandstone
		Danian		Nsukka Formation		Anambra Delta	
Mesozoic (Cretaceous)	Maastrichtian			Ajali Formation	Regression		Sst.clay
				Marmu Formation			Shale,Coal,Sst
	Campanian			Nkporo Group	Transgression	Prodelta	Shale, mudstone,Silt St

Santonian	Southern Benue Tough	Awgu Fm/Agbani Sst./Ogugu Fm	Regression	Shale, mudstone,Silt St
Coniacian				Shale,Sst,
Turonian		Eze Aku Group(Eze Aku Shale, Amasiri Sst.,Diorite	Transgression Regression	Siltstone, Lstone,Sst
Cenomanian		Mfamosing Fm.	Transgression	Limestone, Shale
Albian		Asu ‖River Group / Abakaliki Fm./Mamfe Fm.		Shale
Aptian Neocomian				Shale

Source: (Nwajide, 2022; Kearey, 2001; and NGSA,2008

Figure 1 shows the map of solid mineral resources deposits of Southeast Nigeria. These are also potential resources for mining activities.

Environmental Impacts of Mining Activities in the South East and Nigeria

The environmental repercussions of mining activities in South East Nigeria are extensive and multifaceted. One of the most significant impacts is land degradation, which occurs when mining operations strip away vegetation and topsoil, leading to the loss of arable land and habitat for local wildlife (Ali et al., 2018; Odoh et al., 2017). This degradation not only affects the immediate area surrounding mining sites but also has broader implications for regional ecosystems. Deforestation is another critical issue, as large tracts of forest are cleared to facilitate mining activities, disrupting ecosystems and contributing to biodiversity loss (Odoh et al., 2017). The removal of trees and vegetation exacerbates soil erosion, which destabilizes the soil and increases the risk of landslides and sedimentation in nearby water bodies (Karamage et al., 2016). Meanwhile cases of abandoned mine sites had become major challenges across the region. There had been reported cases of missing children who were later found to have drowned the pit lakes of the abandoned mine sites. Figure 2 is a case of abandoned surface sites in Ebonyi State of South East region of Nigeria.

Figure 2: Case 1 of abandoned surface mine sites in Ebonyi State of South East region of Nigeria
Source: Source: (Admineconai, 2023)

Case 2 of Figure 3 is another similar case of abandoned mine sites across the South East of Nigeria

Figure 3: Case 2 of an abandoned mine in the South East Region of Nigeria
Source: (Admineconai, 2023)

Meanwhile Figure 4 shows a summary of the mining hazards maps of Nigeria, showing the different states of the federation of Nigeria and the associated hazards due to mining activities.

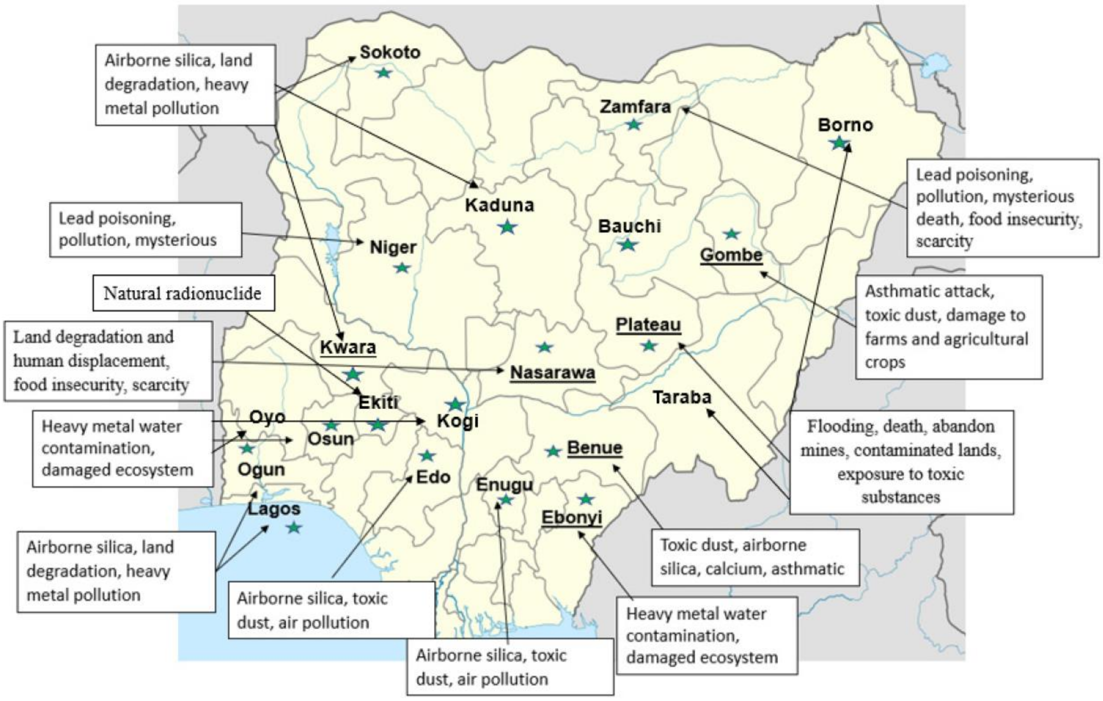

Figure 4: Mining hazards map of Nigeria
Source: (Afolayan et al., 2021)

Water Contamination and Consequences Due to Mining Activities

Water contamination is a particularly pressing concern associated with mining activities in South East Nigeria. The extraction and processing of minerals often involve the use of hazardous chemicals, which can leach into nearby water sources, rendering them unsafe for consumption and harming aquatic life (Onugha & Chimeebere, 2020; Temitope Oyedotun, 2022). Furthermore, the impacts of the mines have resulted to AMDs and other geochemical changes of surface and groundwater (Onyeabor & Nwatalari, 2017; Edeani, 2015). Contaminated water can have dire consequences for local communities, as it affects their access to clean drinking water and poses significant health risks. The pollution of rivers and streams can disrupt fishing activities, further impacting the livelihoods of those who rely on these resources (Edeani, 2015). The soils which host plants are also affected resulting to bioavailability of heavy metals (Onyeabor et al.2019). The cumulative effects of these environmental challenges underscore the urgent need for effective monitoring and management strategies to mitigate the impacts of mining on the environment and local communities. Figure 5 shows another case of abandoned mining pits on farmland near a stream in the Sabon Barki area of Plateau State of Nigeria.

Figure 5: Abandoned mining pits on farmland near a stream in the Sabon Barki area of Plateau State (Source: Admineconai, 2023)

The Need for Innovative Monitoring Approaches

Given that there is an urgent need for innovative measures to monitor and track the environmental consequences of mining activities. Traditional methods of environmental assessment often fall short in capturing the full extent of degradation caused by mining operations, particularly as these activities expand into new areas. Advanced technologies, such as geospatial technologies and machine learning, offer promising solutions for enhancing environmental monitoring. These technologies offer powerful tools for mapping and monitoring land use changes, enabling researchers and policymakers to visualize the extent of environmental degradation caused by mining activities (Maria Silvia Binetti et al., 2024). They also facilitate the collection and analysis of large datasets, enabling stakeholders to identify patterns and trends in environmental degradation more effectively.

By integrating these technologies into environmental assessments, it becomes possible to develop more accurate models that predict the potential impacts of mining activities on local ecosystems. Moreover, fostering interdisciplinary collaboration among researchers, environmental scientists, and mining professionals is crucial for developing innovative solutions that address both economic and environmental concerns. Engaging local communities in the monitoring process is also essential, as their knowledge and experiences can provide valuable insights into the environmental impacts of mining activities. This participatory approach can help ensure that monitoring efforts are relevant and socially responsible, ultimately leading to more effective strategies for mitigating the adverse effects of mining on the environment and local communities. By prioritizing these innovative measures, stakeholders can work towards a more sustainable future that balances economic development with environmental stewardship, ensuring that the benefits derived from mining activities do not compromise ecological integrity.

Geospatial Technologies

Geospatial technologies represent a diverse array of tools and methodologies that are essential for the collection, analysis, and visualization of spatial data, which is critical for understanding various environmental dynamics (Imperatore & Pepe, 2016). These technologies include a wide range of applications, among which Geographic Information Systems (GIS) and remote sensing stand out as pivotal components that have gained significant traction in the field of environmental monitoring (Parra, 2022). GIS is particularly powerful because it allows for the seamless integration of multiple data sources, enabling users to conduct in-depth analyses of spatial relationships and patterns. This capability is invaluable for researchers and policymakers alike, as it facilitates the creation of detailed maps that illustrate the distribution of natural resources, the extent of land use changes, and the impacts of anthropogenic activities, such as mining, on the environment (Atlas 2025). By employing GIS, stakeholders can identify critical areas that require immediate attention and develop strategies that promote sustainable management of resources, ultimately contributing to more effective environmental stewardship (Kumar et al., 2015).

In contrast, remote sensing serves is a complementary technology that provides high-resolution data through the acquisition of images from satellites or aerial platforms (He & Weng, 2018; NASA, 2021). This method allows for the monitoring of extensive geographical areas and the detection of subtle environmental changes that may not be easily observable through traditional ground-based approaches. Remote sensing is particularly adept at capturing dynamic changes in land cover, such as deforestation, urban expansion, and alterations in water bodies, thereby offering crucial insights into the ecological ramifications of mining activities (Mehra & Janaki Ballav Swain, 2024). By analyzing temporal data collected through remote sensing, researchers can evaluate the effectiveness of various environmental management strategies and identify emerging trends that may signal potential future impacts (Xie et al., 2020). The integration of remote sensing data with GIS enhances the overall understanding of environmental processes, enabling stakeholders to make more informed decisions regarding resource allocation and conservation initiatives.

In the mining sector, the utilization of geospatial technologies significantly improves the capacity to detect and monitor environmental changes associated with extraction activities (Lo, 2014; Rushton, 2023). By harnessing the combined strengths of GIS and remote sensing, stakeholders can develop comprehensive models that take into account a multitude of environmental factors and their interrelations, leading to more accurate assessments of the ecological impacts of mining operations. This integrated approach not only aids in pinpointing areas that are at risk of degradation but also supports the formulation of targeted interventions designed to mitigate adverse effects on the environment (Werner et al., 2019). Moreover, the ability to visualize and analyze spatial data empowers policymakers to make well-informed decisions that strike a balance between economic development and environmental conservation (Hoalst-Pullen & Patterson, 2010). Ultimately, the effective application of geospatial technologies within the mining context enhances the potential for sustainable resource management, ensuring that the benefits derived from mining activities do not compromise ecological integrity and contribute to long-term environmental sustainability (Goparaju et al., 2017).

Machine Learning in Environmental Monitoring

Machine learning, a prominent subset of artificial intelligence, is revolutionizing various fields, including environmental monitoring (Sarker, 2021). It involves the creation of algorithms that can learn from data, adapt to new information, and make predictions based on historical patterns (Sarker, 2021). This capability is particularly significant in environmental contexts, where the complexity and variability of ecosystems can make traditional analytical methods insufficient. For instance, machine learning can process vast amounts of data from diverse sources, such as satellite imagery, environmental sensors, and historical records, to uncover insights that would otherwise remain hidden. By employing techniques such as regression analysis, decision trees, and neural networks, machine learning can identify intricate relationships between environmental variables, leading to a deeper understanding of ecological dynamics (Devgupta et al., 2024). This is especially crucial in sectors like mining, where the interplay of various environmental factors can complicate the assessment of impacts, necessitating advanced analytical approaches.

The integration of machine learning into environmental monitoring enhances the accuracy and efficiency of data analysis, allowing for more precise assessments of environmental impacts (Alotaibi & Nassif, 2024). Traditional methods often struggle to account for the multifaceted interactions within ecosystems, leading to uncertainties in impact evaluations. However, machine learning algorithms excel in identifying patterns and trends within large datasets, enabling researchers to detect subtle changes in environmental conditions over time (Ümit Demirbaga et al., 2024). For example, in the mining sector, machine learning can analyze data related to land use changes, water quality, and biodiversity, providing stakeholders with actionable insights. This predictive capability is invaluable for anticipating potential environmental degradation and informing proactive measures to mitigate adverse effects. By leveraging big data, machine learning not only improves the quality of environmental assessments but also fosters a more comprehensive understanding of the ecological consequences of mining activities (Sahoo & Tripathy, 2025).

Furthermore, the combination of machine learning with geospatial technologies represents a significant advancement in environmental monitoring. Geographic Information Systems (GIS) and remote sensing tools can capture spatial data related to land cover and environmental changes, while machine learning algorithms can analyze this data to predict future scenarios (Srivastava & Sharma, 2024). This integrated approach allows for the development of robust models that account for various environmental factors and their interactions, ultimately leading to more effective mitigation strategies. For instance, stakeholders can utilize these models to simulate different mining practices and their potential impacts on local ecosystems, enabling informed decision-making regarding resource management and conservation efforts. By harnessing the power of machine learning and geospatial technologies, policymakers can prioritize interventions in areas most affected by mining activities, ensuring that environmental protection measures are both targeted and effective (Sahoo & Tripathy, 2025). This synergy not only enhances the capacity for environmental monitoring but also contributes to sustainable resource management practices that are essential for preserving ecological integrity in the face of industrial activities.

Further Analysis on Integration of Geospatial Technologies and Machine Learning

The integration of geospatial technologies and machine learning marks a transformative leap in environmental monitoring and assessment, particularly in complex sectors such as mining. Geographic Information Systems (GIS) and remote sensing provide robust spatial analysis capabilities that allow for the visualization and interpretation of environmental data across various landscapes (Parra, 2022). When these technologies are combined with the predictive power of machine learning, stakeholders can create comprehensive models that not only account for individual environmental factors but also consider the intricate interactions between them (Alotaibi & Nassif, 2024). For instance, and as earlier indicated, machine learning algorithms can analyze historical data to identify patterns in land use changes, water quality fluctuations, and biodiversity impacts, enabling a more nuanced understanding of how mining activities affect local ecosystems (Mirhossein Mousavinezhad et al., 2023). This integrated approach significantly enhances the ability to detect, monitor, and predict environmental changes, equipping policymakers, environmental scientists, and mining companies with the necessary tools to make informed decisions that prioritize ecological sustainability. By leveraging these advanced technologies, stakeholders can develop targeted interventions that mitigate the adverse effects of mining, ensuring that resource extraction is conducted in a manner that is both economically viable and environmentally responsible.

Despite the promising capabilities of integrating geospatial technologies and machine learning, significant challenges persist, particularly in the context of the Nigerian mining sector (Igbokwe & Ono, n.d.). The limited application of these advanced technologies in Nigeria highlights the need for comprehensive studies that explore their potential benefits and challenges. One of the primary obstacles is the lack of high-resolution environmental data, which is crucial for effective analysis and modelling (Igbokwe & Ono, n.d.). Many regions in Nigeria suffer from insufficient data on land use changes, water quality, and biodiversity indicators, which hampers the ability of researchers and policymakers to accurately assess the environmental impacts of mining activities (Agbaje et al., 2017; Oboh, 2025). Furthermore, there is a pressing need for interdisciplinary collaboration among researchers, local communities, and industry stakeholders to address these gaps and promote the integration of geospatial technologies and machine learning into mining practices. By fostering such collaboration, stakeholders can develop innovative solutions that not only enhance environmental monitoring but also contribute to sustainable mining practices. Addressing these research gaps is essential for realizing the full potential of these technologies, ultimately paving the way for more effective environmental management strategies that protect ecosystems while supporting economic development in the region.

Meanwhile Figure 6 shows the steps to integrate geospatial technology and machine learning for environmental monitoring of solid mineral mining activities in South East region Nigeria.

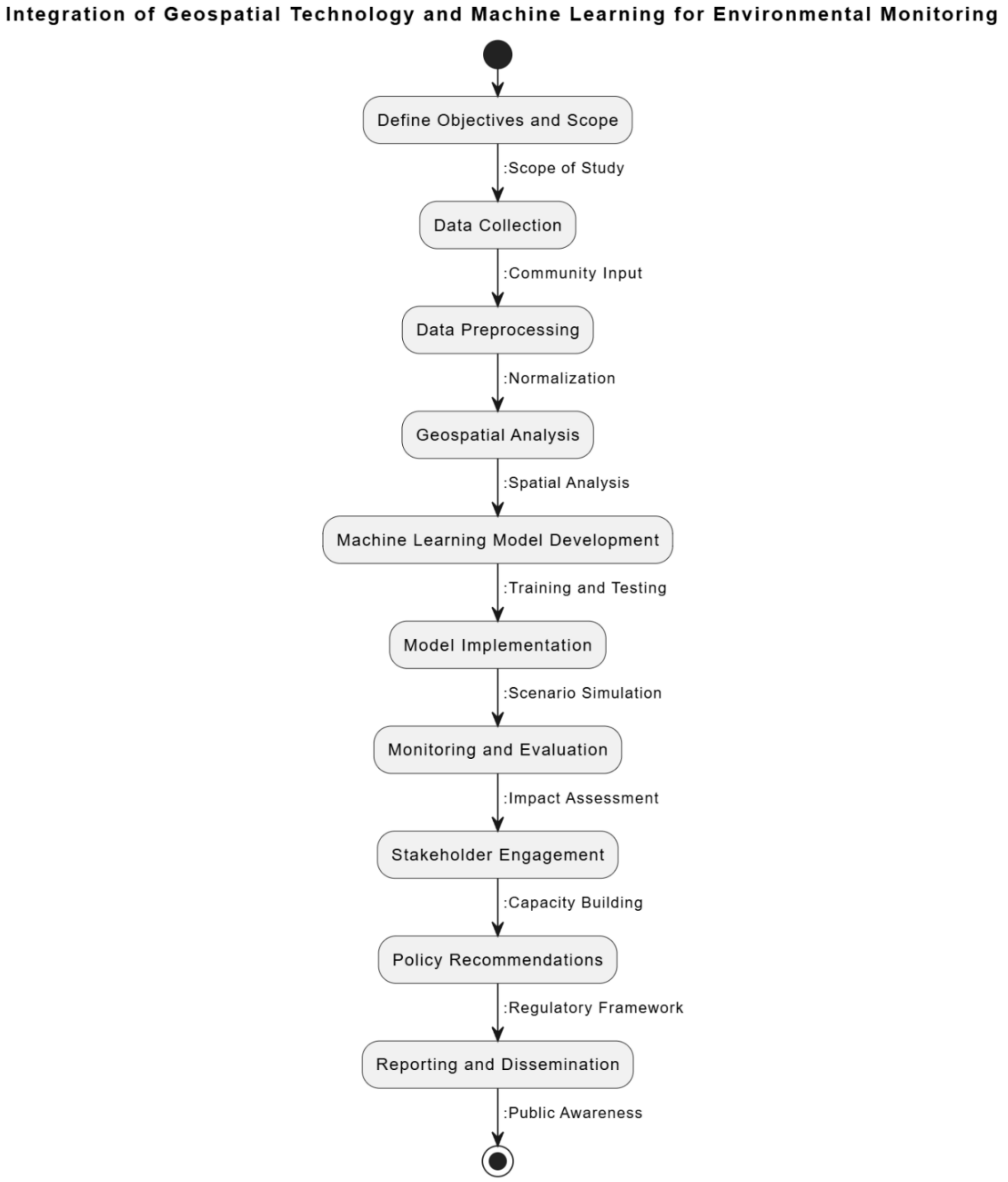

Figure 6: Steps to Integrate Geospatial Technology and Machine Learning for Environmental Monitoring of Solid Mineral Mining Activities in South East Nigeria

Data Collection

Data collection is the foundation of effective environmental monitoring. This step involves gathering geospatial data, such as satellite imagery and GIS datasets, alongside environmental data on soil, water, and biodiversity. Engaging local communities can also provide valuable qualitative insights into the environmental changes they have observed due to mining, enriching the dataset.

Data Preprocessing
Data preprocessing is essential for ensuring the quality and reliability of the collected data. This includes cleaning the data to remove inaccuracies, integrating various data sources into a cohesive database, and normalizing data formats for consistency. Proper preprocessing enhances the effectiveness of subsequent analyses and model development.

Geospatial Analysis
Geospatial analysis utilizes GIS and remote sensing techniques to visualize and assess the impacts of mining activities on the environment. By creating detailed maps and conducting spatial analyses, researchers can identify patterns of land use change, vegetation health, and water quality. This analysis provides critical insights into the relationships between mining and environmental degradation.

Machine Learning Model Development
Developing machine learning models involves selecting relevant features from the datasets that influence environmental impacts and choosing appropriate algorithms for analysis. The dataset is then split into training and testing sets to build and validate the models. This step is crucial for creating predictive tools that can assess the potential environmental consequences of mining activities.

Model Implementation
Once developed, the machine learning models are implemented to conduct predictive analyses and simulate various mining scenarios. This allows researchers to assess potential environmental impacts, such as soil erosion and water contamination, under different conditions. The insights gained from this implementation can inform decision-making and mitigation strategies.

Monitoring and Evaluation
Continuous monitoring is vital for tracking environmental parameters over time and assessing the effectiveness of mining practices. Regular updates to the datasets ensure that the models remain accurate and relevant. Evaluating the impact of mining activities based on model predictions and real-world observations helps identify areas for improvement and intervention.

Stakeholder Engagement
Engaging stakeholders, including researchers, local communities, and government agencies, fosters collaboration and ensures comprehensive monitoring efforts. Building capacity through training enables local practitioners to effectively use geospatial technologies and machine learning tools. This engagement is essential for promoting sustainable practices and addressing environmental concerns.

Policy Recommendations
The findings from the integrated approach can inform policymakers about the environmental impacts of mining and the need for sustainable practices. Data-driven policies can guide the development of regulations that promote responsible mining and environmental protection. Advocating for such policies is crucial for ensuring long-term sustainability in the mining sector.

Reporting and Dissemination
Effective communication of findings is essential for raising awareness and promoting action. Preparing detailed reports and sharing results with stakeholders, including local communities and the public, helps highlight the importance of sustainable mining practices. Disseminating information fosters a collective understanding of environmental issues and encourages community involvement in resource management.

Interdisciplinary Collaboration and involvement of Local Communities for Sustainable Solutions
Fostering interdisciplinary collaboration among researchers, environmental scientists, and mining professionals is crucial for developing innovative solutions that address both economic and environmental concerns (Roy et al., n.d.). By working together, as demonstrated by ECOWAS in 2020, stakeholders can develop comprehensive action plans that prioritize environmental protection while also supporting economic development (ECOWAS, 2020). Engaging local communities in the monitoring process is also essential, as their knowledge and experiences can provide valuable insights into the environmental impacts of mining activities (Yu et al., 2024). This participatory approach can help ensure that monitoring efforts are relevant and effective, ultimately contributing to more sustainable resource management.
Local communities play a vital role in the monitoring and management of environmental impacts associated with mining activities. Their traditional knowledge and understanding of local ecosystems can provide valuable context for assessing the effects of mining on the environment. Involving local communities in the monitoring process can also foster a sense of ownership and responsibility for environmental stewardship, encouraging sustainable practices and resource conservation. By integrating community perspectives into environmental assessments, stakeholders can develop more effective strategies for mitigating the impacts of mining and promoting sustainable resource management (Miningworld.com, 2024; International Institute for Environment and Development, 2009; Www.iisd.org, 2023).

Potential Challenges to Implementing Advanced Geospatial Technologies and Machine Learning in Environmental Monitoring in the South East and Nigerian Context
Despite the potential benefits of integrating geospatial technologies and machine learning in environmental monitoring, several challenges must be addressed to facilitate their effective implementation.

Data Accessibility and Quality
One significant challenge is the lack of high-resolution environmental data, which is essential for accurate analysis and modelling. In many regions, particularly in developing countries like Nigeria, the absence of comprehensive datasets can impede the effective application of these technologies. Many geospatial datasets in Nigeria are either outdated or not readily accessible (Igbokwe & Ono, n.d.; Oboh, 2025; TWAS, 2016).

Limited Capacity of Local Researchers
Another significant challenge is the limited capacity of local researchers and practitioners to utilize advanced technologies effectively. Many researchers in Nigeria may lack access to training, resources, and technical support necessary to harness the full potential of geospatial technologies and machine learning. This skills gap can hinder the effective application of these tools in environmental monitoring and assessment, leading to suboptimal outcomes. To overcome this challenge, it is essential to invest in capacity-building initiatives that

equip local researchers with the necessary skills and knowledge to implement advanced technologies in their work. Now, the leading nations with advanced technology and significant investment in AI and environmental research, such as China and the United States, dominate the research landscape. In contrast, many developing countries, especially in Africa and parts of Asia, have limited contributions in this area. This gap highlights the need for global efforts to strengthen capabilities and support the use of AI and machine learning for environmental monitoring across different settings, including the developing contexts and Nigeria in particular. Collaborative work between major nations and underrepresented regions could enhance the global relevance of AI/ML solutions and ensure these technologies are inclusive and beneficial for all, particularly those confronting the most urgent environmental challenges (Alotaibi & Nassif, 2024).

Standardization Issues

There are inconsistencies, duplication, and standardization problems with geospatial data. Different government agencies and private sectors collect and store data independently, leading to irrelevant overlaps and lack of conformity in standards and formats (Njepuome, 2009).

Inadequate Infrastructure and Technology Access

The implementation of geospatial technologies and machine learning also faces challenges related to inadequate infrastructure and access to technology. Many regions in Nigeria suffer from poor internet connectivity, limited access to computing resources, and insufficient technical infrastructure, which can impede the effective use of these advanced tools. Without reliable access to technology and infrastructure, researchers may struggle to collect, analyze, and share data effectively, limiting the overall impact of their work. Addressing these infrastructural challenges will require significant investment in technology and connectivity to support the integration of advanced technologies in environmental monitoring (Igbokwe & Ono, n.d.; BusinessDay, 2024; Tayo et al., 2015).

Regulatory and Policy Frameworks

The absence of robust regulatory and policy frameworks can also pose challenges to the effective implementation of geospatial technologies and machine learning in Nigeria. Existing policies may not adequately address the integration of advanced technologies in environmental monitoring or provide clear guidelines for their application in the mining sector. This lack of regulatory support can create uncertainty for researchers and practitioners, hindering their ability to implement effective monitoring and management strategies. Developing comprehensive policies that promote the use of advanced technologies in environmental monitoring is essential for fostering a conducive environment for sustainable mining practices.

Financial Constraints

Finally, financial constraints represent a significant challenge in implementing advanced technologies for environmental monitoring in Nigeria. Limited funding for research and development can restrict the ability of institutions to invest in necessary technologies, training, and infrastructure. Additionally, the high costs associated with acquiring and maintaining advanced geospatial tools and machine learning systems can be prohibitive for many local researchers and organizations. To address this challenge, it is essential to explore funding opportunities, partnerships, and collaborations that can support the integration of advanced technologies in environmental monitoring efforts (Olufemi Kazeem Oluoje, 2025).

Future Directions for Research and Practice

The future of environmental monitoring in South East Nigeria depends on the ability to leverage advanced technologies and approaches to create a more sustainable and resilient environment for current and future generations. Future research should focus on promoting interdisciplinary collaboration, establishing robust data collection frameworks, and implementing capacity-building initiatives to empower local researchers, particularly in the developing context and Nigeria in particular. By taking these steps, the mining sector can move towards a more sustainable future that balances economic development with environmental stewardship. This review aims to contribute to the ongoing discourse on sustainable mining in South East Nigeria by highlighting the potential of advanced technologies in addressing environmental impacts and fostering a more sustainable future for the region.

The integration of geospatial technologies and machine learning offers a promising pathway for addressing these challenges, enabling stakeholders to better understand the environmental consequences of mining and develop strategies to mitigate degradation. By prioritizing environmental protection and engaging local communities, it is possible to promote sustainable mining practices that balance economic development with environmental stewardship. This review aims to provide a comprehensive assessment of the effectiveness of geospatial technologies and machine learning in addressing the environmental impacts of mining activities in South East Nigeria, ultimately contributing to the development of more effective strategies for sustainable resource management.

MATERIALS AND METHODS

Literature Search Strategy

The literature search strategy for this structured review was meticulously designed to ensure a comprehensive and systematic approach in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines. The search was conducted across multiple academic databases to capture a wide array of relevant studies. The databases consulted included Web of Science, Scopus, Google Scholar, ScienceDirect, and Open Google search. These databases were selected for their extensive coverage of scientific literature, particularly in the fields of environmental science, geospatial technologies, and machine learning. The search process began with the formulation of a robust search strategy that utilized a combination of keywords and phrases relevant to the topic. The keywords included "Geospatial technologies," "Machine learning," "Environmental impacts," "Mining activities," "South East Nigeria," "Remote sensing," "Geographic Information Systems (GIS)," "Environmental monitoring," and "Sustainable resource management." To refine the search results, Boolean operators such as AND and OR were employed, allowing for a more targeted approach. For instance, the search string constructed was: ("Geospatial technologies" OR "Remote sensing" OR "GIS") AND ("Machine learning") AND ("Environmental impacts" OR "Environmental monitoring") AND ("Mining activities") AND ("South East Nigeria"). This comprehensive search strategy aimed to ensure that all relevant literature was captured, providing a solid foundation for the review. The initial search yielded a total of 550 articles, which were then subjected to a rigorous screening process to identify studies that specifically addressed the integration of geospatial technologies and machine learning in assessing the environmental impacts of mining activities in South East Nigeria.

Inclusion and Exclusion Criteria

To systematically evaluate the identified literature, specific inclusion and exclusion criteria were established to ensure that only the most relevant studies were considered for the review. The inclusion criteria were designed to capture studies that were published in peer-reviewed journals, as this ensures a level of quality and rigor in the research. Additionally, the studies had to focus on the application of geospatial technologies and machine learning in assessing environmental impacts specifically related to mining activities. Furthermore, only research conducted in South East Nigeria or studies that had direct relevance to the study or to the South East region were included, as the review aims to address the unique environmental challenges faced in this geographical context. Policy documents and verified credible newspaper reports on prevailing government positions were also included. Conversely, the exclusion criteria were equally important in narrowing down the literature. Studies that did not relate to mining activities or environmental impacts were excluded. Research focusing on other geographical regions without relevance to South East Nigeria, unless they were used as case studies, was also excluded. Finally, articles that were not available in full text were excluded to ensure that all included studies could be thoroughly analyzed. This systematic approach to inclusion and exclusion ensured that the final selection of studies was both relevant and of high quality, providing a solid basis for the review's findings.

Study Selection Process

The study selection process was conducted in a systematic and transparent manner, following the PRISMA guidelines to ensure clarity and reproducibility. As earlier indicated, the initial search yielded a total of 550 articles across the selected databases. The first step in the selection process involved the removal of duplicate entries, which resulted in 348 unique articles. Following this, a screening of titles and abstracts was conducted against the established inclusion and exclusion criteria. This initial screening led to the exclusion of 246 articles that did not meet the criteria, leaving 102 articles for further consideration. The next step involved a full-text review of the remaining articles to assess their relevance and applicability to the review's objectives. During this stage, an additional 70 articles were excluded due to various reasons, including a lack of focus on the integration of geospatial technologies and machine learning in the context of mining activities or insufficient empirical data. Ultimately, a total of 32 articles met the inclusion criteria and were included in the final review. This rigorous selection process ensured that the studies included in the review were not only relevant but also provided valuable insights into the integration of advanced technologies for assessing environmental impacts in South East Nigeria. The systematic approach to study selection, including the clear documentation of the number of records identified, screened, and included, will be visually represented in a flowchart in accordance with PRISMA guidelines, enhancing the transparency and clarity of the review process.

Data Extraction

Data extraction was a critical component of the review process, aimed at synthesizing relevant information from the selected studies to inform the overall findings and conclusions. The data extracted included essential elements such as the study's objectives, methodologies employed, key findings, and implications for environmental monitoring and management in the context of mining activities in South East Nigeria. Particular attention was given to the specific geospatial technologies and machine learning techniques utilized in each study, as well as the environmental impacts assessed. Additionally, information regarding the geographical scope of the studies, including the specific locations within South East Nigeria, was documented to provide context for the findings. The data extraction process was conducted by the authors/researchers with all intent to minimize bias and ensure accuracy. This thorough data extraction process not only facilitated a comprehensive understanding of the current state of research on the integration of geospatial technologies and machine learning in environmental assessments but also highlighted areas where further research is needed. The synthesized data will serve as the foundation for the review's analysis and recommendations, ultimately contributing to the development of more effective strategies for sustainable resource management and environmental stewardship in the region. This process is further shown in Figure 2.

Table 2 based on the text provided, summarizing the indicated figures and the processes described:

Table 2: Summary of article selection process for the literature review

Stage	Number of Articles	Action
Initial Search	550	Total articles identified across all databases.
After Removing Duplicates	348	Duplicates removed, leaving unique articles.
Screening (Titles and Abstracts)	102	246 articles excluded based on inclusion/exclusion criteria.
Full-Text Review	32	70 articles excluded for lack of relevance or data.
Final Articles Included	32	Articles meeting all inclusion criteria for the review.

Also, Figure 7 is the PRISMA flow chart/diagram for the literature search strategy.

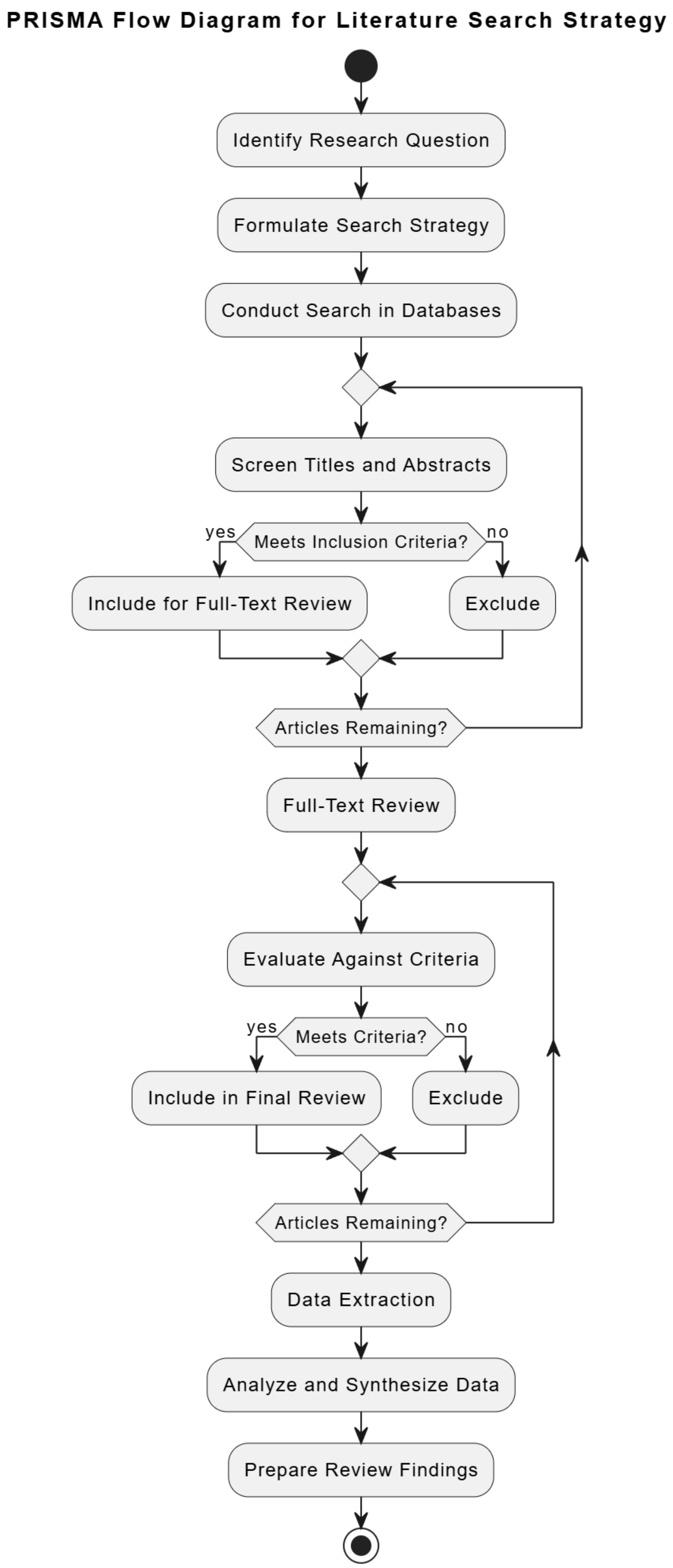

Figure 7: PRISMA flow chart/diagram for the literature search strategy

RESULTS AND DISCUSSION

Results

Enhanced environmental monitoring through geospatial technologies

The findings of this review underscore the significant potential of geospatial technologies, particularly Geographic Information Systems (GIS) and remote sensing, in enhancing environmental monitoring and assessment in South East Nigeria. GIS serves as a robust platform for integrating various spatial data sources, allowing for detailed mapping and analysis of land use changes over time. By utilizing GIS, researchers can visualize the spatial distribution of mining activities and their associated environmental impacts, such as land degradation, deforestation, and soil erosion. This capability is crucial for understanding the extent of environmental degradation and for identifying areas that require immediate attention and intervention. Remote sensing complements GIS by providing high-resolution satellite imagery and aerial data that can capture changes in land cover and land use at a larger scale. The ability to monitor these changes over time enables stakeholders to assess the effectiveness of environmental management strategies and to make informed decisions regarding resource allocation and conservation efforts. For instance, studies have demonstrated that remote sensing can effectively detect changes in vegetation cover and land use patterns associated with mining activities, providing valuable insights into the ecological consequences of these operations. The integration of GIS and remote sensing thus represents a powerful approach for enhancing environmental monitoring, enabling stakeholders to develop targeted interventions that mitigate the adverse effects of mining on local ecosystems (Parra, 2022; Atlas 2025; Kumar et al., 2015; He & Weng, 2018; NASA, 2021; Mehra & Janaki Ballav Swain, 2024; Xie et al., 2020; Lo, 2014; Rushton, 2023; Werner et al., 2019; Hoalst-Pullen & Patterson, 2010; Goparaju et al., 2017).

Advanced Data Analysis with Machine Learning

In addition to the capabilities offered by geospatial technologies, the findings also highlight the transformative role of machine learning in environmental monitoring and assessment. Findings show how machine learning models enable advanced data analysis that can identify complex patterns and trends within large datasets, which may not be readily apparent through traditional analytical methods. By leveraging historical data, machine learning algorithms can be trained to recognize relationships between various environmental factors and predict future impacts based on these patterns. For example, machine learning techniques such as regression analysis, decision trees, and neural networks can be employed to model the relationships between mining activities and their effects on soil quality, water contamination, and biodiversity loss. This predictive capability is particularly valuable in the context of mining, where understanding the potential future impacts of current practices can inform proactive measures to minimize environmental degradation. Furthermore, machine learning can enhance the accuracy of environmental assessments by reducing uncertainties associated with data interpretation. By integrating machine learning with geospatial technologies, stakeholders can develop comprehensive models that account for the interactions between different environmental variables, leading to more robust predictions of future environmental conditions. This integrated approach not only improves the quality of environmental assessments but also fosters a deeper understanding of the complex dynamics of ecosystems affected by mining activities, ultimately contributing to more effective resource management and conservation strategies (Sarker, 2021; Devgupta et al., 2024; Alotaibi & Nassif, 2024; Ümit Demirbaga et al., 2024; Sahoo & Tripathy, 2025; Srivastava & Sharma, 2024; Sahoo & Tripathy, 2025).

Identifying Patterns and Predicting Environmental Impacts

The ability of machine learning to identify patterns and predict environmental impacts based on historical data is a significant advancement in the field of environmental monitoring. The findings indicate that machine learning algorithms can analyze vast amounts of data generated from various sources, including remote sensing imagery, environmental sensors, and field surveys. This capability allows researchers to detect subtle changes in environmental conditions that may be indicative of broader trends associated with mining activities. For instance, machine learning can be utilized to analyze satellite imagery to monitor changes in land cover, such as the conversion of forested areas to mining sites, and to assess the subsequent impacts on local ecosystems. Additionally, machine learning models can be trained to predict the likelihood of water contamination based on historical data related to mining practices and chemical usage. By identifying correlations between mining activities and environmental degradation, stakeholders can develop targeted interventions to mitigate these impacts. The predictive power of machine learning also extends to assessing the potential long-term consequences of mining on biodiversity and ecosystem health. By understanding these relationships, policymakers and resource managers can implement proactive measures to protect vulnerable ecosystems and ensure sustainable resource management. Overall, the integration of machine learning into environmental monitoring represents a paradigm shift in the ability to assess and address the complex challenges posed by mining activities in South East Nigeria.

Implications for Policy and Resource Management in the South East of Nigeria

The findings of this review have significant implications for policy and resource management in the context of mining activities in South East Nigeria. The integration of geospatial technologies and machine learning into environmental monitoring provides stakeholders with the tools needed to make informed decisions regarding resource allocation and environmental protection. By utilizing GIS and remote sensing for detailed mapping and monitoring, policymakers can identify areas most affected by mining activities and prioritize interventions to mitigate environmental degradation. Furthermore, the predictive capabilities of machine learning can inform the development of evidence-based policies that address the potential future impacts of mining on local ecosystems and communities in the South East of Nigeria. For instance, machine learning models can be used to simulate various scenarios related to mining practices, allowing stakeholders to evaluate the potential outcomes of different management strategies. This proactive approach to resource management can lead to more sustainable practices that balance economic development with environmental stewardship. Additionally, the findings emphasize the importance of collaboration among researchers, policymakers, and local communities in implementing effective monitoring and management strategies. Engaging local communities in the South East of Nigeria in the monitoring process can enhance the relevance and effectiveness of interventions, as their knowledge and experiences can provide valuable insights into the environmental impacts of mining activities. Ultimately, the integration of geospatial technologies and machine learning into environmental monitoring represents a significant advancement in the ability to address the complex challenges posed by mining in South East Nigeria, paving the way for more sustainable resource management practices.

Discussion

Addressing Research Gaps in Technology Integration

Despite the promising capabilities of geospatial technologies and machine learning in enhancing environmental monitoring and assessment, significant research gaps remain, particularly regarding their limited integration within the Nigerian mining sector. One of the primary challenges is the lack of comprehensive and high-resolution environmental data, which is essential for effective analysis and modelling. In many regions of Nigeria, including South East Nigeria, data on land use changes, water quality, soil conditions, and biodiversity indicators is often sparse or non-existent. This lack of data hampers the ability of researchers and policymakers to accurately assess the environmental impacts of mining activities and to develop effective mitigation strategies. Furthermore, the existing datasets may not be sufficiently detailed or relevant to the specific contexts of different mining operations, leading to generalized conclusions that may not accurately reflect local conditions (Igbokwe & Ono, n.d; Oboh, 2025; Unstats.un.org, 2005).

To address these research gaps, it is crucial to establish robust data collection frameworks that prioritize the systematic gathering of high-quality environmental data. This could involve the use of remote sensing technologies, field surveys, and community-driven initiatives to compile comprehensive databases that reflect the unique environmental and socio-economic conditions of South East Nigeria. For instance, remote sensing can provide valuable insights into land cover changes over time, while field surveys can offer ground-truthing data to validate remote sensing findings. By creating a centralized repository of environmental data, stakeholders can facilitate informed decision-making and resource management, ultimately leading to more sustainable mining practices. Moreover, the establishment of partnerships between governmental agencies, academic institutions, and local communities can enhance data collection efforts, ensuring that diverse perspectives and expertise are incorporated into the monitoring process (Igbokwe & Ono, n.d.; Ali et al., 2018; Eni et al., 2024).

Capacity-Building Initiatives for Local Researchers

Another critical aspect highlighted in the review is the need for capacity-building initiatives aimed at empowering local researchers and practitioners in the effective use of geospatial technologies and machine learning. Many local researchers in Nigeria may lack access to advanced training and resources necessary to harness the full potential of these technologies. This skills gap can hinder the effective application of geospatial tools and machine learning algorithms in environmental monitoring and assessment. To bridge this gap, it is essential to implement targeted training programs that focus on equipping local researchers with the necessary skills and knowledge to utilize these technologies effectively (Dell'oro, 2014; Kufoniyi, 2006; Kufoniyi, 2013).

Such initiatives could include workshops, seminars, and hands-on training sessions that cover various aspects of geospatial analysis, remote sensing, and machine learning applications in environmental science. For example, training programs could focus on teaching local researchers how to use GIS software for spatial analysis, as well as how to apply machine learning algorithms to analyze environmental data. Additionally, fostering partnerships between local researchers and international institutions can facilitate knowledge exchange and provide access to advanced tools and methodologies. Collaborative research projects can also serve as platforms for skill development, allowing local researchers to gain practical experience while contributing to meaningful environmental assessments. By investing in capacity-building initiatives, stakeholders can enhance the local research community's ability to conduct rigorous environmental assessments and contribute to the development of evidence-based policies that promote sustainable mining practices (Dell'oro, 2014; Kufoniyi, 2006; Kufoniyi, 2013).

Development of Region-Specific Models

The development of region-specific models that consider the unique environmental and socio-economic conditions of South East Nigeria is another crucial recommendation arising from the review. The environmental challenges faced by mining activities in this region are influenced by a complex interplay of factors, including local geology, climate, land use practices, and socio-economic dynamics. Therefore, generic models that do not account for these specific conditions may yield inaccurate predictions and ineffective management strategies.

To create more relevant and applicable models, it is essential to engage local stakeholders, including community members, environmental scientists, and mining professionals, in the model development process. This collaborative approach can ensure that the models reflect the realities of the local context and incorporate local knowledge and expertise. For instance, participatory modelling techniques can be employed to involve local communities in the development of environmental models, allowing them to share their insights and experiences regarding the impacts of mining activities on their livelihoods and ecosystems (Antunes, 2003). Additionally, region-specific models should be designed to address the specific environmental impacts associated with different types of mining activities, such as artisanal versus large-scale operations. By tailoring models to the unique conditions of South East Nigeria, stakeholders can enhance the accuracy and effectiveness of environmental assessments, ultimately leading to more informed decision-making and improved resource management practices (Antunes, 2003).

Importance of Interdisciplinary Collaboration

The integration of geospatial technologies and machine learning into environmental monitoring and assessment also underscores the importance of interdisciplinary collaboration across environmental and computer sciences, among researchers, policymakers, and local communities (Alotaibi & Nassif, 2024). In fact the field of geospatial artificial intelligence (geoAI) involving the integration of geospatial science, technology and artificial intelligence/machine learning is highly interdisciplinary involving many scientific fields including engineering, computer science, spatial science and statistics (VoPham et al., 2018). Environmental challenges associated with mining are complex and multifaceted, requiring input from various fields, including environmental science, data analytics, geography, and social sciences. Collaborative research efforts can lead to innovative solutions that leverage the strengths of different disciplines, ultimately enhancing the effectiveness of environmental assessments and management strategies.

For instance, interdisciplinary teams can work together to design and implement monitoring programs that utilize remote sensing data and machine learning algorithms to assess the impacts of mining on ecosystems. Environmental scientists can provide insights into ecological processes, while data analysts can develop algorithms to process and interpret large datasets. Furthermore, engaging local communities in the research process can provide valuable insights into the socio-economic dimensions of mining activities, ensuring that environmental assessments are not only scientifically rigorous but also socially relevant. By fostering interdisciplinary collaboration, stakeholders can develop comprehensive action plans that address both economic and environmental concerns, ultimately promoting sustainable mining practices that benefit local communities and ecosystems (Chavez, 2010; Forward Pathway, 2025).

CONCLUSION

By leveraging advanced technologies, stakeholders can significantly enhance their ability to mitigate the environmental impacts of mining and promote sustainable resource management practices. The integration of geospatial technologies and machine learning into environmental monitoring provides a powerful toolkit for understanding and addressing the complex challenges posed by mining activities. These technologies enable the collection and analysis of high-resolution data, allowing for detailed assessments of land use changes, water quality, and ecosystem health. As a result, stakeholders can make informed decisions that balance economic development with environmental protection. However, the successful implementation of these technologies requires a concerted effort to engage local communities in the research process. Future research should prioritize participatory approaches that involve community members in the design and implementation of environmental monitoring programs. By actively involving local stakeholders, researchers can ensure that the findings are not only relevant but also applicable to the specific contexts in which mining activities occur. Local communities possess invaluable knowledge about their environments, and their insights can help shape monitoring programs that address the unique challenges they face. This collaborative approach fosters a sense of ownership and responsibility among community members, empowering them to advocate for their rights and contribute to sustainable resource management practices. Furthermore, continuous evaluation and refinement of existing models and methodologies are essential to effectively address the dynamic nature of environmental challenges. The environmental landscape is constantly changing due to various factors, including climate change, land use changes, and socio-economic developments. Therefore, it is crucial for researchers and practitioners to regularly assess the effectiveness of their monitoring strategies and make necessary adjustments to improve accuracy and reliability. This iterative process of evaluation and refinement not only enhances the robustness of environmental assessments but also ensures that the methodologies remain relevant in the face of evolving challenges. By fostering a culture of continuous learning and adaptation, stakeholders can enhance their capacity to respond to emerging environmental issues and promote sustainable resource management practices. Ultimately, the path forward requires a commitment to integrating advanced technologies with participatory approaches, ensuring that environmental monitoring efforts are both scientifically rigorous and socially relevant. This holistic approach will pave the way for more sustainable mining practices that protect ecosystems, support local communities, and contribute to the long-term health of the environment.

REFERENCES

Abalaka, I., & Aga, T. (2016). A Review of Geology and Coal Mining In South Eastern Nigeria: Implication for Sustainable National Development. *IOSR Journal of Applied Geology and Geophysics*, *4*(2), 15–22. https://doi.org/10.9790/0990-0402011522

Admineconai. (2023, March 31). *Abandoned Mines: A danger to communities across Nigeria*. Econaiplus.com; PROJECTS. https://projects.econaiplus.com/2023/03/31/abandoned-mines-a-danger-to-communities-across-nigeria/

Agbaje, G. I., Bello, I. E., & Ojo, A. G. (2017). Empirical assessment of the role of geospatial technology in delivering governance and strengthening democracy in Nigeria. *GeoJournal*, *83*(4), 743–756. https://doi.org/10.1007/s10708-017-9797-4

Ali, A., Abdullahi, A., & Zangina, A. (2018). Environmental Issues and the Prospects of Mining in Nigeria. *Dutse Journal of Pure and Applied Sciences (DUJOPAS)*, *4*(2), 531–539. https://fud.edu.ng/journals/dujopas/2018_JUNE_Vol_4_issue_2/062%20edited-1.pdf

Atlas.co. (2025). Data Fusion in GIS. https://atlas.co/glossary/data-fusion-in-gis/

Alotaibi, E., & Nassif, N. (2024). Artificial intelligence in environmental monitoring: in-depth analysis. *Discover Artificial Intelligence*, *4*(1). https://doi.org/10.1007/s44163-024-00198-1

BusinessDay. (2024, December 27). *Nigeria's poor, weak internet connectivity frustrates digital transformation goals - Businessday NG*. Businessday NG. https://businessday.ng/news/article/nigerias-poor-weak-internet-connectivity-frustrates-digital-transformation-goals/

Chavez, A. (2010). Crossing boundaries for environmental science and management: combining interdisciplinary, interorganizational and international collaboration. *Environmental Conservation*. https://doi.org/108492327/thumbnails/1

Citationsy. (2025, January 23). *Machine Learning Referencing Guide*. Citationsy. https://citationsy.com/styles/machine-learning

Dell'oro, L. (2014). *GIS and Capacity Development*. https://geospatialworld.net/gwf/2014/presentation/GeoCapacity/UNOSAT_GIS_Capacity%20Building_GWF_2014_pdf.pdf

Devgupta, R., Dandekar, R. A., Dandekar, R., & Panat, S. (2024). Scientific machine learning in ecological systems: A study on the predator-prey dynamics. *ArXiv (Cornell University)*. https://doi.org/10.48550/arxiv.2411.06858

ECOWAS. (2020, March 3). *ECOWAS Environmental Action Plan 2020 - 2026* [Review of *ECOWAS Environmental Action Plan 2020 - 2026*]. ECOWAS; USAID. https://ecowap.ecowas.int/media/ecowap/file_document/2020_ECOWAS_ECOWAS_ENVIRONMENTAL_ACTION_PLAN_Final_Version_-_ENG.pdf

Edeani, C. (2015). Geochemistry of Surface Waters of Ishiagu Ebonyi State Nigeria [Review of *Geochemistry of Surface*

Waters of Ishiagu Ebonyi State Nigeria]. *International Journal of Innovative Science Engineering and Technology*, *2*(7), Pg 90-95. https://www.ijiset.com/vol2/v2s8/IJISET_V2_I8_14.pdf

Forward Pathway. (2025, January 27). *Innovations in Environmental Monitoring and Sustainable Development - Forward Pathway*. Forward Pathway. https://www.forwardpathway.us/innovations-in-environmental-monitoring-and-sustainable-development

Goparaju, L., Rama Chandra Prasad, P., & Ahmad, F. (2017). Geospatial technology perspectives for mining vis-a-vis sustainable forest ecosystems. *Present Environment and Sustainable Development*, *11*(1), 219–238. https://doi.org/10.1515/pesd-2017-0020

He, Y., & Weng, Q. (Eds.). (2018). High Spatial Resolution Remote Sensing: Data, Analysis, and Applications (1st ed.). CRC Press. https://doi.org/10.1201/9780429470196

Hoalst-Pullen, N., & Patterson, M. W. (2010). Geospatial Technologies in Environmental Management. In *Springer eBooks*. Springer Nature. https://doi.org/10.1007/978-90-481-9525-1

Igbokwe, J., & Ono, M. (n.d.). *Nigeria's National Geo-spatial Data Infrastructure: Problems and Prospects*. Retrieved January 28, 2025, from https://www.fig.net/resources/proceedings/fig_proceedings/cairo/papers/ts_31/ts31_07_ikbokwe_ono.pdf

Imperatore, P., & Pepe, A. (2016). Geospatial Technology - Environmental and Social Applications. In *InTech eBooks*. https://doi.org/10.5772/61680

International Institute for Environment and Development. (2009). *Mining, Minerals and Sustainable Development (MMSD)*. CHAPTER 9: *LOCAL COMMUNITIES AND MINES*). https://www.iied.org/sites/default/files/pdfs/migrate/G00901.pdf

Jovanović, V., Stanković, S., & Krstić, V. (2023). Environmental, Social and Economic Sustainability in Mining Companies as a Result of the Interaction between Knowledge Management and Green Innovation—The SEM Approach. *Sustainability*, *15*(16), 12122. https://doi.org/10.3390/su151612122

Karamage, F., Shao, H., Chen, X., Ndayisaba, F., Nahayo, L., Kayiranga, A., Omifolaji, J. K., Liu, T., & Zhang, C. (2016). Deforestation Effects on Soil Erosion in the Lake Kivu Basin, D.R. Congo-Rwanda. *Forests*, *7*(11), 281. https://doi.org/10.3390/f7110281

Kearey, P. (2001). The Penguin Dictionary of Geology. Penguin Group. Second Edition.

Kufoniyi, O. (2006). *Improving Capacity Building in Earth Observation and Geo-information Science in Africa through Educational Networking*. Retrieved January 29, 2025, from https://www.isprs.org/proceedings/XXXVI/part6/289_XXXVI-part6.pdf

Kufoniyi, O. (2013). Building on Geospatial Information Capacity for Sustainable Development in Africa. *FIG Working Week 2013 Environment for Sustainability Building on Geospatial Information Capacity for Sustainable Development in Africa.* https://www.fig.net/resources/proceedings/fig_proceedings/fig2013/papers/ps_3/Kufoniyi.pdf

Kumar, N. Yamac, S.S. Velmurugan, A.V. 2015. Applications of Remote Sensing and GIS in Natural Resource Management. (n.d.). ResearchGate. Retrieved April 8, 2021, from https://www.researchgate.net/publication/325011344_Applications_of_Remote_Sensing_and_GIS_in_Natural_Resource_Management

Lo, C. (2014, February 3). *Lay of the land: the role of geospatial data in mining*. Mining Technology. https://www.mining-technology.com/features/featurelay-of-the-land-the-role-of-geospatial-data-in-mining-4170674/?cf-view

Maria Silvia Binetti, Massarelli, C., & Vito Felice Uricchio. (2024). Machine Learning in Geosciences: A Review of Complex Environmental Monitoring Applications. *Machine Learning and Knowledge Extraction*, *6*(2), 1263–1280. https://doi.org/10.3390/make6020059

Mehra, N., & Janaki Ballav Swain. (2024). Assessment of land use land cover change and its effects using artificial neural network-based cellular automation. *Journal of Engineering and Applied Science*, *71*(1). https://doi.org/10.1186/s44147-024-00402-0

Miningworld.com. (2024, August 22). *How to Balance Mining and Environmental Conservation*. MiningWorld. https://miningworld.com/how-to-balance-mining-and-environmental-conservation/

Miningworld.com. (2024B, August 24). *The Role of Mining in Economic Development*. MiningWorld. https://miningworld.com/the-role-of-mining-in-economic-development/

Mirhossein Mousavinezhad, Atabak Feizi, & Mehdi Aalipour. (2023). Performance Evaluation of Machine Learning Algorithms in Change Detection and Change Prediction of a Watershed's Land Use and Land Cover. *International Journal of Environmental Research*, *17*(2). https://doi.org/10.1007/s41742-023-00518-w

Mobasheri, A., Pirotti, F., & Agugiaro, G. (2020). Open-source geospatial tools and technologies for urban and environmental studies. *Open Geospatial Data, Software and Standards*, *5*(1). https://doi.org/10.1186/s40965-020-00078-2

NASA. (2021, May 18). *Remote Sensing | NASA Earthdata*. NASA Earthdata. https://www.earthdata.nasa.gov/learn/earth-observation-data-basics/remote-sensing

Natsa, R. T. (2024, October 31). *Solid minerals contributed N1trn to Nigeria's GDP in 17 years - NEITI - Businessday NG*. Businessday NG. https://businessday.ng/news/article/solid-minerals-contributed-n1trn-to-nigerias-gdp-in-17-years-neiti/

Geology and Mineral Resources of South East Zone (2008). Nigerian Geological Survey Agency. Ministry of Mines and Steel Development. First Edition.

Njepuome, A.P.C. (2009). *Challenges Of The National Geospatial Agency Regarding Accelerated Development In Nigeria*. Retrieved January 29, 2025, from https://www.fig.net/resources/proceedings/fig_proceedings/fig2009/papers/ts01g/ts01g_njepuome.pdf

Nwajide, C. S. (2022). Geology of Nigeria's Sedimentary Basins. Mtu.edu.ng. ISBN 978-978-996-022-4 http://opac.mtu.edu.ng/cgi-bin/koha/opac-detail.pl?biblionumber=6790&shelfbrowse_itemnumber=10571

Obinna, C. (2025, January 22). *Inadequate data hampering Nigeria's environmental sustainability goals - Luther Nwobodo*. Vanguard News. https://www.vanguardngr.com/2025/01/inadequate-data-hampering-nigerias-environmental-sustainability-goals-luther-nwobodo/

Oboh. (2025, January 22). *Inadequate data hampering Nigeria's environmental sustainability goals - Luther Nwobodo*. Vanguard News. https://www.vanguardngr.com/2025/01/inadequate-data-hampering-nigerias-environmental-sustainability-goals-luther-nwobodo/

Odoh, C.K, Akpi, U.K & Anya, F. (2017). *Environmental Impacts of Mineral Exploration in Nigeria and their Phytoremediation Strategies for Sustainable Ecosystem Environmental Impacts of Mineral Exploration in Nigeria and their Phytoremediation Strategies for Sustainable Ecosystem*. *17*. https://globaljournals.org/GJSFR_Volume17/3-Environmental-Impacts-of-Mineral.pdf

Olalekan, D., Oladipo, Afees, N., Oluwashina, & Ayodele, A., Sunday. (2016). An Empirical Analysis of the Contribution of Mining Sector to Economic Development in Nigeria. *Khazar Journal of Humanities and Social Sciences*, *19*(1), 88–106. https://doi.org/10.5782/2223-2621.2016.19.1.88

Olufemi Kazeem Oluoje. (2025, January 28). *Beyond the Hype: The Real Challenges of AI Adoption for Nigerian SMEs - Businessday NG*. Businessday NG. https://businessday.ng/opinion/article/beyond-the-hype-the-real-challenges-of-ai-adoption-for-nigerian-smes /

Onwe-Moses, F. D., Ozumba, M. B., & Chijiuka, O. (2020). Geology and mineral resources of Ebonyi State, South East Nigeria. African Journal of Engineering and Environment Research, 1(2), 122-155

Onugha, A., & Chimeebere. (2020). Galena Mining And Water Quality Of Amata, South East Nigeria. *International Journal of Scientific & Engineering Research*, *11*(6). https://www.ijser.org/researchpaper/GALENA-MINING-AND-WATER-QUALITY-OF-AMATA-SOUTH EAST-NIGERIA.pdf

Onyeabor, C.F., Ezeh, H.N. and Anike, L.O. (2019). Assessment And Bioaccumulation Of Cu And Pb In The Biota (Tuber Plant) In A Mining District Of Ameka-Enyigba, Abakaliki Mining District, South East Nigeria: A Comparative Study. *International Journal Of Research In Engineering & Science*, 3(6). doi:https://doi.org/10.26808/rs.re.v3i6.01

Onyeabor, F.C., & Nwatalari, R.A. (2017). Irrigation Suitability of Surface Waters of Enyigba Ebonyi State, South East Nigeria. *IJISET -International Journal of Innovative Science, Engineering & Technology*, *4*, 2348–7968. https://ijiset.com/vol4/v4s9/IJISET_V4_I09_08.pdf

Parra, L. (2022). Remote Sensing and GIS in Environmental Monitoring. *Applied Sciences*, *12*(16), 8045. https://doi.org/10.3390/app12168045

Roy, P., Abdullah, M., & Siddique, I. (n.d.). Machine learning empowered geographic information systems: Advancing Spatial analysis and decision making. *World Journal of Advanced Research and Reviews*, *2024*(01), 1387–1397. https://doi.org/10.30574/wjarr.2024.22.1.1200

Rushton, D. (2023, July 6). *The role of geospatial data in optimizing mining operations*. Picterra. https://picterra.ch/blog/the-role-of-geospatial-data-in-optimizing-mining-operations/

Sahoo, A. K., & Tripathy, D. P. (2025). Applications of AI and machine learning in mining: digitization and future directions. *Safety in Extreme Environments*, *7*(1). https://doi.org/10.1007/s42797-025-00118-1

Sarker, I. H. (2021). Machine Learning: Algorithms, Real-World Applications and Research Directions. *SN Computer Science*, *2*(3), 1–21. Springer. https://doi.org/10.1007/s42979-021-00592-x

Sampson Iwuoha, & Lawal, O. (2021, March). *Exploration of urban growth trends in States of South East Nigeria: 1986 to 2016*. ResearchGate; unknown. https://www.researchgate.net/publication/350890547_Exploration_of_urban_growth_trends_in_States_of_South_East_Nigeria_1986_to_2016

Srivastava, A., & Sharma, H. (2024). AI-Driven Environmental Monitoring Using Google Earth Engine. *Smart Sensors, Measurement and Instrumentation*, 375–385. https://doi.org/10.1007/978-3-031-68602-3_19

Temitope Oyedotun. (2022, March 29). *Open cast mining: threat to water quality in rural community of Enyigba in south-eastern Nigeria*. Applied Water Science; Springer Nature America, Inc. https://www.academia.edu/74899647/Open_cast_mining_threat_to_water_quality_in_rural_community_of_Enyigba_in_south_eastern_Nigeria

TWAS. (2016, September 2). *The big data challenge for developing countries* [Review of *The big data challenge for developing countries*]. TWAS: The World Academy of Science; UNESCO. https://twas.org/article/big-data-challenge-developing-countries

Ümit Demirbaga, Gagangeet Singh Aujla, Jindal, A., & Oğuzhan Kalyon. (2024). Machine Learning for Big Data Analytics. *Big Data Analytics*, 193–231. https://doi.org/10.1007/978-3-031-55639-5_9

Unstats.un.org. (2005, March 3). *ENVIRONMENTAL STATISTICS: SITUATION IN FEDERAL REPUBLIC OF*

NIGERIA [Review of *ENVIRONMENTAL STATISTICS: SITUATION IN FEDERAL REPUBLIC OF NIGERIA*].; United Nations Department of Economic and Social Affairs Statistics. https://unstats.un.org/unsd/ENVIRONMENT/nigeria.pdf

Vision 2020 National Technical Working Group on Minerals and Metal Development. 2009. *Report of the Vision 2020 National Technical Working Group on Minerals and Metal Development*. https://www.delvedatabase.org/resources/report-of-the-vision-2020-national-technical-working-group-on-minerals-metals-development

VoPham, T., Hart, J. E., Laden, F., & Chiang, Y.-Y. (2018). Emerging trends in geospatial artificial intelligence (geoAI): potential applications for environmental epidemiology. *Environmental Health*, *17*(1). https://doi.org/10.1186/s12940-018-0386-x

Werner, T. T., Bebbington, A., & Gregory, G. (2019). Assessing impacts of mining: Recent contributions from GIS and remote sensing. *The Extractive Industries and Society*, *6*(3), 993–1012. https://doi.org/10.1016/j.exis.2019.06.011

Www.iisd.org. (2023, September 9). *IGF Case Study: Environmental and Social Impact Assessments in Mining Legal Frameworks* [Review of *IGF Case Study: Environmental and Social Impact Assessments in Mining Legal Frameworks*].

Www.iisd.org; Intergovernmental Forum on Mining Minerals Metals and Sustainable Development. https://www.iisd.org/system/files/2023-09/environmental-social-impact-assessments-mining-legal-frameworks.pdf

Xie, W., Yang, J., Li, Y., Lei, J., Zhong, J., & Li, J. (2020). *Discriminative Feature Learning Constrained Unsupervised Network for Cloud Detection in Remote Sensing Imagery*. *12*(3), 456–456. https://doi.org/10.3390/rs12030456

Yu, H., Izni Zahidi, Chow Ming Fai, Liang, D., & Dag Øivind Madsen. (2024). Elevating community well-being in mining areas: the proposal of the mining area sustainability index (MASI). *Environmental Sciences Europe*, *36*(1). https://doi.org/10.1186/s12302-024-00895-9