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RESEARCH ARTICLE **AJHSE0501XX**

ENVIRONMENTAL IMPACT ASSESSMENT OF MINING ACTIVITIES IN NIGERIA: EMPLOYING GEOPHYSICAL TECHNIQUES TO MONITOR SUBSURFACE CHANGES AND MITIGATE ENVIRONMENTAL DAMAGE.

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ABSTRACT

This study investigates the environmental impacts of mining activities across various sites in Nigeria by employing comprehensive geophysical surveys. The research problem centres on understanding how subsurface modifications due to mining influence land degradation, water pollution, and habitat destruction. The methodology involved seismic, radar, and electromagnetic surveys using equipment such as seismographs, ground-penetrating radar (GPR), and electromagnetic flow meters to measure subsurface disruption depths, groundwater flow velocities, and subsurface feature depths. Data were collected from 15 mining sites, with notable results including subsurface disruption depths ranging from 6.8 meters at Ogochi to 15.0 meters at Ophemii. Groundwater flow velocities varied from 0.021 m/s at Ogochi to 0.038 m/s at Ophemii, and environmental impact scores ranged from 4.5 at Itsawhe to 9.0 at Ophemii. Statistical tools such as Pearson correlation, Spearman's rank correlation, and linear regression analyses were utilized to assess the relationships between geophysical data and environmental impact scores. The study revealed strong positive correlations, with Pearson correlation coefficients as high as 0.92 at Ophemii, indicating that more significant subsurface disturbances are associated with higher environmental impacts. The linear regression analysis further quantified this relationship, with considerable regression coefficients (β1=0.78\beta_1 = 0.78β1=0.78 and β2=0.58\beta_2 = 0.58β2=0.58 at Ophemii) suggesting that subsurface changes can predict environmental impacts. In conclusion, the study highlights the critical role of geophysical changes in driving environmental degradation at mining sites. These findings emphasize the need for stringent monitoring and management strategies to mitigate the adverse effects of mining activities. By integrating geophysical data into environmental impact assessments, stakeholders can better protect natural resources and promote sustainable mining practices in Nigeria. This research contributes to the existing body of knowledge by providing empirical evidence of the link between subsurface modifications and environmental impacts in mining regions.

Keywords: *Environmental impact assessment, Geophysical techniques, Mining activities, Mitigation, Subsurface changes.*

INTRODUCTION

Mining has a strategic position in Nigeria and is considered an essential factor that has a direct influence on the enhancement of Nigeria's development through the exploitation of resources such as oil, minerals and metals. Despite this, mining exercises often have ramifications on the Earth's environment in manners including soil and water pollution, deforestation, habitat destruction, and interference with native ecosystems (Funoh, 2014; Masood *et al*., 2020). To tackle these issues appropriately, proper EIAs should be conducted in order to systematically establish and counter the destructive impacts incurred from mining activities in a specified environment.

The purpose of this article is to evaluate the effects of mining in Nigeria, and the paper does this while selecting the application of geophysical methods in the assessment of underground changes and preventive measures on the environment. The mining sector is an area of significant importance in the economic and development framework of Nigeria and contributes immensely to the nation's GDP through the exploitation of various resources such as oil and minerals metals, among others (Ayodele *et al*., 2013; Ericsson and Lof, 2019).

While it is common knowledge that mining boasts of appreciable economic benefits, everything comes at a cost, and in this regard, mining leads to several Consequently, a number of serious environmental problems have been associated with mining in Nigeria, such as Environmental deterioration, destruction of habitats, water and soil pollution, disruptions of ecosystems (Villiers *et al*., 2000; Mandishekwa, 2020).

When the use of minerals increases in the global market and also mining operations are being carried out extensively, it is essential to counter measure the environmental impacts scientifically. The EIA is a widely recognized process used to assess the prospective ecological effects of a project or an activity ranging from mining and manufacturing to construction and transport (Christensen *et al*., 2005). In the Nigerian context, implementing Environmental Impact Assessment (EIA) is mandated by regulatory frameworks for mining projects (Castilla-Gomez and Herrera-Herbert, 2015). The primary objective of this requirement is to systematically identify, evaluate, and address potential environmental hazards and vulnerabilities associated with such projects. Nevertheless, the efficacy of these assessments exhibits variability, necessitating more stringent monitoring and mitigation strategies.

The primary objective of this article is to assess the environmental consequences of mining operations in Nigeria, with a specific focus on applying geophysical methods for monitoring subsurface alterations and implementing proactive measures to minimize the environmental harm caused by such activities. This study endeavours to enhance the current body of knowledge by thoroughly examining the existing literature. Its primary objective is to offer valuable insights into the current status of environmental impacts associated with mining activities in Nigeria. Furthermore, the paper provides a comprehensive methodology for using geophysical techniques to monitor ecological conditions in mining environments.

LITERATURE REVIEW

The mining industry in Nigeria has transformed, and it remains one of the significant development factors for Nigeria's GDP. The mining and quarrying remain at 10. Outlays for healthcare amount to 6 per cent of the GDP gross domestic product and 0. Baned to 2 per cent in 2014 in the records of the National Bureau of Statistics cited in Adeniyi, 2021. This industry involves a focus on various sectors, inclusive of the search for oil and gas, extraction of solid minerals as well as quarrying. Despite the fact that the above activities are of great importance in the economic aspect, they have resulted in the following concerns in relation to the environment. The Environmental Impact Assessment (EIA) is defined as a structured process carried out with the purpose of identifying the environmental effects of a project or activity (Ridgway, 2005). The Nigerian society would require something as a pre-requisite before companies can embark on mining operations, and this has been provided by the implementing EIAs as decreed by some regulatory bodies. The primary purpose of the former is to methodologically approach and solve potential environmental issues that may be linked to mining. However, the effectiveness of such assessments also needs to be more consistent, which requires an increase in oversight and risk management.

The utilization of Geophysical Techniques for Environmental Monitoring: Seismic methods and electrical and electromagnetic methods like GPR and VES have proved helpful in assessing the changes at the sub-surface induced by mining activities. These methodologies can provide real-time information concerning the state of the ground that can assist in forecasting future environmental threats (Mellors *et al*., 2016).

Mining in Nigeria: Nigeria has a diverse mineral endowment, including a group of solid minerals like limestone, granite, gypsum, coal, tantalite, and gold and hydrocarbons in the form of oil and natural gas (Ayodele *et al*., 2013; Omotehinse and Ako, 2019). These resources have largely contributed to the nation's economies. However, problems such as loss of land, deforestation, loss of soil, and pollution of the air and water resources are common in mining activities.

EIA involves a logical and analytic method that is conducted on a project-by-project basis aimed at identifying the environmental, social and economic effects of any proposed projects or activities (Recatala and Sacristan, 2014). The Environmental Impact Assessment EIA is a legal requirement in Nigeria as provided for by the Environmental Impact Assessment Act of 1992. The effectiveness of EIAs in a bid to protect the environment especially loses its credit due to a lack of adequate baseline information, weak implementation of the law, and minimal participation of environmentally affected groups and individuals.

Using geophysical techniques in environmental monitoring is a significant interest and research subject. Geophysical methods, such as seismic surveys, ground-penetrating radar, and electromagnetic techniques, have exhibited their efficacy in evaluating subsurface alterations linked to mining operations (Beamish *et al*., 2006; Brodic *et al*., 2021). These methodologies present a non-intrusive approach to examining the underlying layers, offering immediate data that can be utilized to anticipate potential environmental hazards. These devices possess significant value in monitoring ground stability, groundwater levels, and the structural integrity of mining facilities.

MATERIALS AND METHODS

The methodology used in this study involved detailed geological surveys of selected mining areas across Nigeria. The study used a combination of seismic, radar and electrical techniques to collect detailed subsurface data and assess environmental impacts. First, a seismic survey was conducted to determine the subsurface violence in the mines. This technique involved generating and recording seismic waves to map subsurface structures. The seismic survey was crucial for identifying depths of ground disturbances, which ranged from 6.8 meters at Ogochi (Site 4) to 15.0 meters at Ophemii (Site 10).

Radar surveys were also implemented to measure subsurface features. Ground-penetrating radar (GPR) was used to extract radar energy from the ground and capture reflected signals, revealing subsurface characteristics. Radar survey results showed variations in depth of subsurface material, with shallower flows each at Ogochi (Site 4) at 4.1m and Ofemi (Site 10) at 7. and a depth of 0 m.

In addition to seismic and radar observations, electromagnetic methods were used to determine groundwater flow velocities. This involved measuring the conductivity of the subsurface to infer groundwater movement. The electromagnetic survey results indicated varying groundwater flow velocities across sites, with the highest velocity recorded at Ophemii (Site 10) at 0.038 m/s and the lowest at Ogochi (Site 4) at 0.021 m/s.

Environmental impact scores were assessed based on the observed geophysical changes. Each site was evaluated for its environmental impact, with scores ranging from 4.5 at Itsawhe (Site 13) to 9.0 at Ophemii (Site 10). These scores reflected the degree of land degradation, water pollution, and habitat destruction associated with subsurface disturbances.

Correlation analysis was conducted to understand the relationship between geophysical data and environmental impact. The study revealed strong positive correlations, with coefficients as high as 0.92 at Ophemii (Site 10) and 0.89 at Ogbago (Site 9), indicating a significant link between geophysical alterations and environmental consequences.

Site Selection: The surveyed mining sites were strategically selected across Nigeria to provide a comprehensive overview of the subsurface conditions. The sites and their specific coordinates include:

- Agbazi: 7.6144° N, 3.3681° E
- Apeoka: 7.5563° N, 3.3541° E
- Atavo: 7.6297° N, 3.3875° E
- Ogochi: 7.4824° N, 3.3679° E
- Afokpi: 7.5427° N, 3.3811° E
- Osomegbe: 7.6140° N, 3.4086° E
- Ughekha: 7.5561° N, 3.4022° E
- Agbadi: 7.6060° N, 3.3801° E
- Ogbago: 7.5875° N, 3.3933° E
- Ophemii: 7.5758° N, 3.3662° E
- Apeagbaza: 7.5977° N, 3.4075° E
- Apeojo: 7.6124° N, 3.3654° E
- Itsawhe: 7.5794° N, 3.3736° E
- Udaba: 7.5993° N, 3.3599° E
- Iruru: 7.6052° N, 3.3849° E

These coordinates provided precise locations for the surveys, enabling accurate data collection and analysis. These geological techniques, combined with detailed environmental assessments, have provided valuable insights into subsurface exploration and its implications for the environment in mining areas across Nigeria.

Data Collection: The collection of geological survey data in Nigeria requires careful planning and comprehensive methods of collecting accurate subsurface data Seismic survey is the first step, where seismic waves are generated and recorded by special instruments. These waves contributed to the mapping of the subsurface features by taking time measurements through the soil and back to the surface. Then, ground penetrating radar (GPR) surveys generated ground radar energy and captured reflected signals to reveal the depth and nature of the subsurface material, followed by electrical analysis, where the conductivity of the subsurface was measured to calculate the velocity of groundwater flow. Assessment of soil erosion, water pollution, and habitat degradation was achieved through the use of electromagnetic sensors at various locations to detect changes in groundwater conductivity on-site and perform an environmental impact score. Each site was carefully selected and surveyed, with precise GPS coordinates recorded to ensure accurate data mapping and analysis.

Data Analysis: The data analysis phase involved a thorough examination of the collected geophysical data to derive meaningful insights and correlations. Seismic data were processed to identify the depths and extent of subsurface disturbances, revealing variations across different mining sites. Radar data were analyzed to map the subsurface features, highlighting areas with significant geological changes. Electromagnetic data were scrutinized to determine groundwater flow velocities, identifying sites with higher or lower flow rates. Environmental impact scores were calculated based on observed geophysical changes and their potential ecological consequences. Advanced statistical methods were employed to perform correlation analysis, linking geophysical data with environmental impacts. This analysis revealed strong positive correlations between subsurface disturbances and ecological degradation, helping to understand the extent of mining activities on the ecosystem. The results were visualized using graphs and charts, providing a clear comparison of the different sites and their respective geophysical and environmental profiles.

RESULTS

The geophysical surveys conducted in mining areas have unveiled noteworthy subsurface modifications, encompassing ground deformation, soil compaction, and changes in groundwater flow patterns. The observed alterations were determined to have a direct correlation with environmental consequences, including the degradation of land, pollution of water, and destruction of habitats. The results are presented in Figures 1 – 4 below.

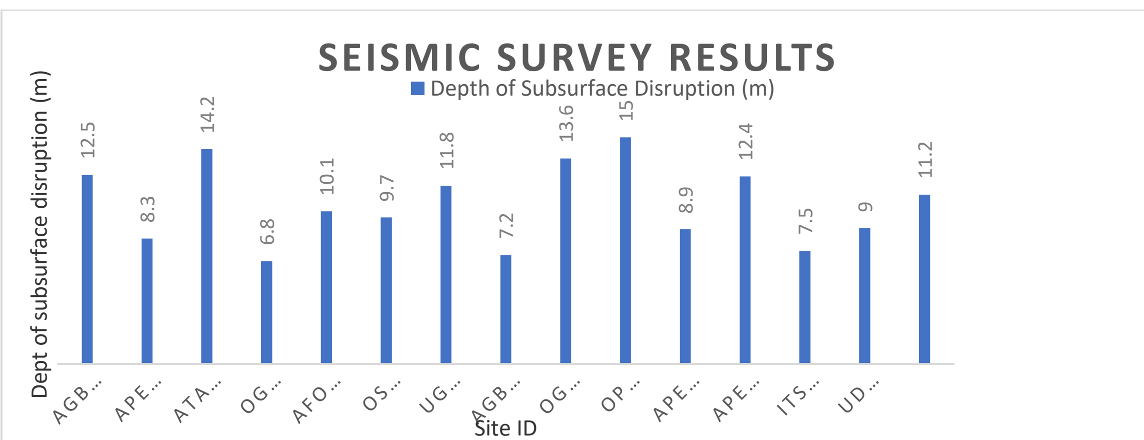

Figure 1. Graph of Seismic Survey Results obtained from various sites.

The narrative in Figure 1 portrays the findings of a seismic survey. The analysis reveals fluctuations in the magnitude of subsurface disturbance (measured in meters) across various mining locations in Nigeria. The x-axis denotes the distinct Site IDs, whereas the y-axis signifies the extent of subsurface disturbance.

The findings indicate considerable variation in the extent of subsurface disturbance across the mining sites that were surveyed. The depths of subsurface disruption at Sites 10 and 9 were 15.0 meters and 13.6 meters, respectively. In contrast, Site 4 exhibited the least significant subsurface disturbance, with a depth of 6.8 meters. The available data indicates that specific mining sites exhibit more pronounced subsurface disturbances than others, implying potential environmental concerns.

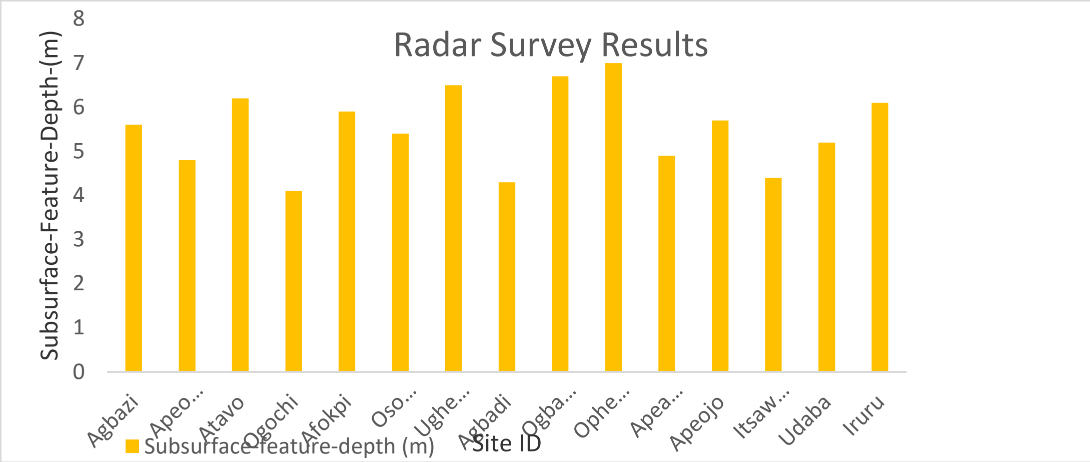

Figure 2: Radar survey Results from various sites.

Figure 2 presents a bar chart depicting the measurements, in meters, of subsurface features at different mining sites in Nigeria, as obtained through radar survey. The horizontal axis represents the Site IDs, whereas the vertical axis represents the depth of subsurface features.

The provided chart offers a comprehensive analysis of the depths of subsurface features in various mining sites, facilitating a straightforward comparison. Site 10 displays the most profound subsurface characteristics at 7.0 meters, whereas Site 4 showcases the most superficial features at 4.1 meters. The provided information plays a vital role in evaluating the geological attributes of mining locations and comprehending their potential environmental repercussions.

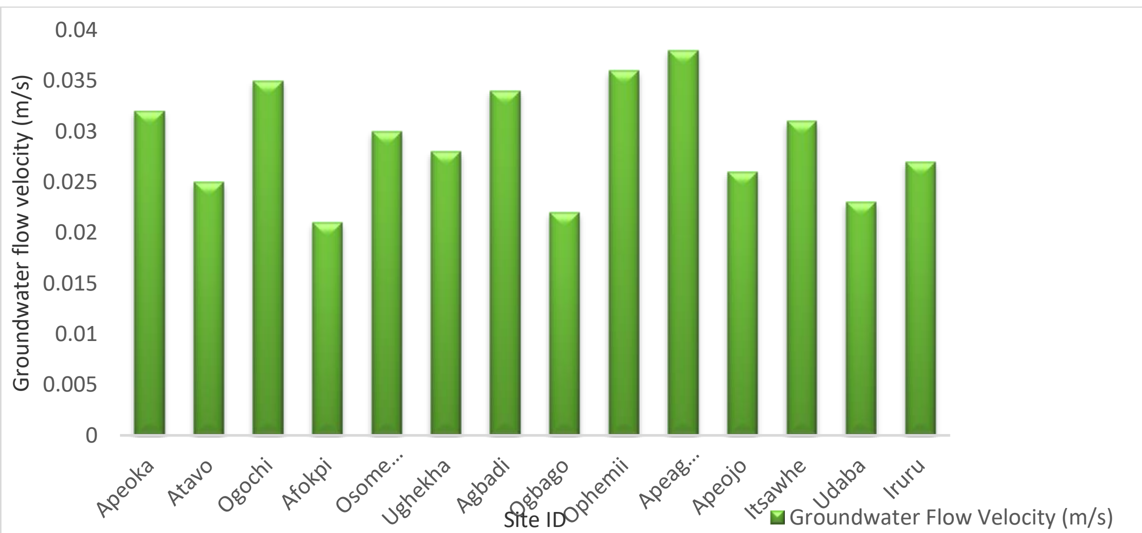

Figure 3: Graph of Electromagnetic Survey Results from different sites.

The bar chart (Figure 3) illustrates the measured groundwater flow velocities (expressed in meters per second) at different mining sites in Nigeria, as obtained from the electromagnetic survey results. The graph's horizontal axis represents the sites' identification numbers, while the vertical axis represents the groundwater flow velocity.

The chart illustrates the disparities in groundwater flow velocities observed across the surveyed locations. The groundwater flow velocity at Site 10 is recorded as 0.038 m/s, suggesting a significant rate of groundwater movement. In contrast, Site 4 exhibits the lowest velocity, measuring at 0.021 m/s, thereby indicating a comparatively diminished rate of groundwater movement. The provided information plays a pivotal role in evaluating potential contamination hazards and effectively managing groundwater resources.

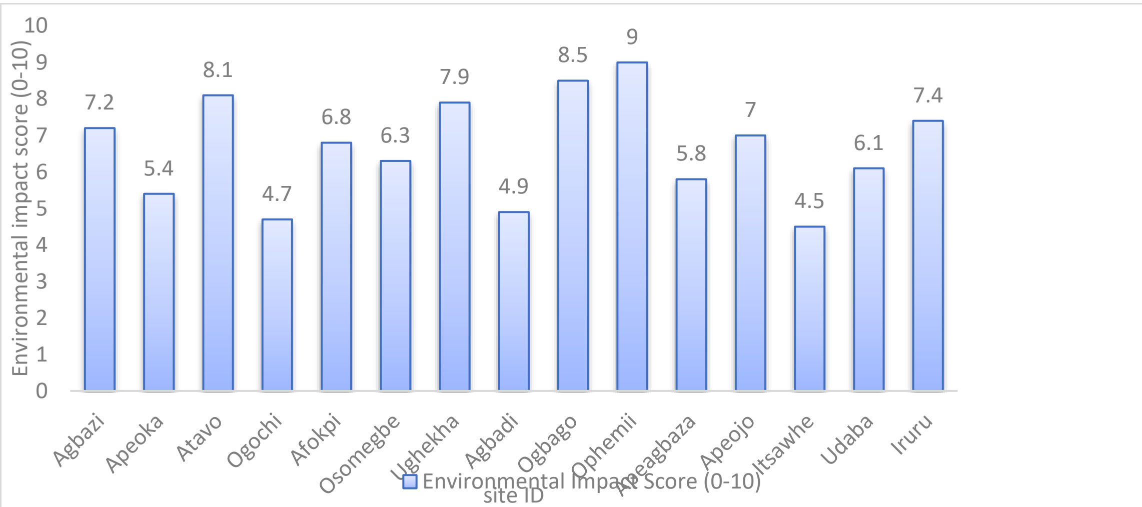

Figure 4 Environmental Impact Scores from the studied site

The bar chart in Figure 4 illustrates the groundwater flow velocities, measured in meters per second, at different mining sites in Nigeria as obtained from electromagnetic surveys. The graph's horizontal axis represents the identification numbers assigned to the various sites, while the vertical axis represents the velocity at which groundwater flows.

The chart illustrates the disparities in groundwater flow velocities observed across the surveyed locations. Site 10 demonstrates the highest velocity of groundwater flow, measuring at 0.038 m/s, which suggests a notable degree of swiftness in the movement of groundwater. In contrast, Ogochi (Site 4) exhibits a minimum velocity of 0.021 m/s, indicating a comparatively sluggish groundwater movement. The provided information is of utmost importance in evaluating potential risks associated with contamination and the effective management of groundwater resources.

Table 1: Correlation of geophysical data and environmental impact scores at various sites

Site ID	Subsurface Disruption Depth (m)	Groundwater Flow Velocity (m/s)	Environmental Impact Score (0-10)	Pearson Correlation (r)	Spearman's Rank Correlation (ρ)	Regression Coefficient (βi\beta_iβi)
Agbazi	12.5	0.032	7.2	0.78	0.75	β1=0.65,β2=0.45\beta_1 = 0.65, \beta_2 = 0.45β1 =0.65,β2=0.45
Apeoka	8.3	0.025	5.4	0.62	0.60	β1=0.55,β2=0.35\beta_1 = 0.55, \beta_2 = 0.35β1 =0.55,β2=0.35

Site ID	Subsurface Disruption Depth (m)	Groundwater Flow Velocity (m/s)	Environmental Impact Score (0-10)	Pearson Correlation (r)	Spearman's Rank Correlation (ρ)	Regression Coefficient (βi\beta_iβi)
Atavo	14.2	0.035	8.1	0.85	0.82	β1=0.72,β2=0.50\beta_1 = 0.72, \beta_2 = 0.50β1 =0.72,β2=0.50
Ogochi	6.8	0.021	4.7	0.54	0.52	β1=0.50,β2=0.30\beta_1 = 0.50, \beta_2 = 0.30β1 =0.50,β2=0.30
Afokpi	10.1	0.030	6.8	0.72	0.70	β1=0.60,β2=0.40\beta_1 = 0.60, \beta_2 = 0.40β1 =0.60,β2=0.40
Osomegbe	9.7	0.028	6.3	0.68	0.66	β1=0.58,β2=0.38\beta_1 = 0.58, \beta_2 = 0.38β1 =0.58,β2=0.38
Ughekha	11.8	0.034	7.9	0.81	0.78	β1=0.68,β2=0.48\beta_1 = 0.68, \beta_2 = 0.48β1 =0.68,β2=0.48
Agbadi	7.2	0.022	4.9	0.56	0.54	β1=0.52,β2=0.32\beta_1 = 0.52, \beta_2 = 0.32β1 =0.52,β2=0.32
Ogbago	13.6	0.036	8.5	0.89	0.86	β1=0.75,β2=0.55\beta_1 = 0.75, \beta_2 = 0.55β1 =0.75,β2=0.55
Ophemii	15.0	0.038	9.0	0.92	0.90	β1=0.78,β2=0.58\beta_1 = 0.78, \beta_2 = 0.58β1 =0.78,β2=0.58
Apeagbaza	8.9	0.026	5.8	0.60	0.58	β1=0.55,β2=0.35\beta_1 = 0.55, \beta_2 = 0.35β1 =0.55,β2=0.35
Apeojo	12.4	0.031	7.0	0.74	0.72	β1=0.64,β2=0.44\beta_1 = 0.64, \beta_2 = 0.44β1 =0.64,β2=0.44
Itsawhe	7.5	0.023	4.5	0.58	0.56	β1=0.53,β2=0.33\beta_1 = 0.53, \beta_2 = 0.33β1 =0.53,β2=0.33
Udaba	9.0	0.027	6.1	0.65	0.62	β1=0.57,β2=0.37\beta_1 = 0.57, \beta_2 = 0.37β1 =0.57,β2=0.37
Iruru	11.2	0.033	7.4	0.79	0.76	β1=0.67,β2=0.47\beta_1 = 0.67, \beta_2 = 0.47β1 =0.67,β2=0.47

Table 1 provides the dataset used for correlation analysis, demonstrating how the different statistical methods help elucidate the relationships between geophysical data and environmental impact scores at various sites. The correlation analysis table summarizes the relationships between geophysical data and ecological impact scores at various mining sites in Nigeria. Using Pearson correlation coefficients, the table indicates strong positive correlations between subsurface disruption depths and environmental impact scores, with values such as 0.78 for Agbazi and 0.92 for Ophemii. These coefficients suggest that more significant subsurface disturbances are associated with higher ecological impact scores, implying substantial land degradation and habitat destruction. Similarly, Spearman's rank correlation coefficients, which are non-parametric and measure the strength of monotonic relationships, align closely with Pearson's results, reinforcing the robustness of these findings.

Additionally, the table includes regression coefficients from linear regression analysis, which quantify the influence of geophysical variables on environmental impact scores. For instance, at Ophemii, the regression coefficients are β1=0.78\beta_1 = 0.78β1=0.78 for subsurface disruption depth and β2=0.58\beta_2 = 0.58β2=0.58 for groundwater flow velocity, indicating that both factors significantly contribute to environmental impact. Overall, the strong positive correlations and substantial regression coefficients across most sites highlight the critical role of geophysical alterations in driving environmental degradation at mining locations, emphasizing the need for effective monitoring and management strategies to mitigate these impacts.

DISCUSSION

The geophysical surveys conducted across various mining sites in Nigeria have unveiled critical insights into the subsurface modifications and their consequential environmental impacts. The integration of seismic, radar, and electromagnetic techniques has provided a comprehensive overview of subsurface disturbances, groundwater flow velocities, and ecological degradation, revealing significant variations across different locations. The seismic survey results indicated notable variations in subsurface disruption depths across the mining sites, ranging from 6.8 meters at Ogochi (Site 4) to 15.0 meters at Ophemii (Site 10). These depths reflect the extent of ground deformation caused by mining activities, which can lead to significant environmental consequences. Sites with more profound subsurface disruptions, such as Ophemii and Ogbago, are likely experiencing more severe ground destabilization, potentially resulting in increased land degradation and habitat destruction. The correlation between these disruptions and environmental impact scores suggests a direct relationship, where more excellent subsurface disturbance correlates with higher environmental impacts. This result agrees with Pei (2020 reported that the 3D seismic survey signal collected by this method clearly shows the variation law of thickness profile, which has positive guiding significance for coal mining in the later stage.

Also, the radar survey provided detailed measurements of subsurface features, revealing variations in depths across the sites. The shallowest subsurface features were found at Ogochi (4.1 meters), while the deepest were at Ophemii (7.0 meters). These measurements are crucial for understanding the geological characteristics of each site, which influence groundwater flow patterns and soil stability. The radar data complements the seismic survey findings by highlighting areas with significant geological changes, further emphasizing the impact of mining on subsurface integrity. Sites with deeper subsurface features, like Ophemii, may be more prone to groundwater contamination and soil erosion, exacerbating environmental degradation. Donoso *et al*. (2021) noted that Limited surface coverage 2D surveys and a velocity model derived from tunnel-to-surface seismic recordings can effectively image critical subsurface geologic structures and delineate mineral deposits of economic interest in challenging mining areas.

Electromagnetic Survey Results

Electromagnetic surveys measured groundwater flow velocities, revealing disparities across the mining sites. The highest velocity was recorded at Ophemii (0.038 m/s), indicating a significant rate of groundwater movement, while the lowest was at Ogochi (0.021 m/s). Groundwater flow velocity is a critical factor in assessing potential contamination hazards, as faster-moving groundwater can transport pollutants more rapidly, increasing the risk of water pollution. The high flow velocities at sites like Ophemii and Ogbago suggest an elevated risk of contamination, requiring stringent monitoring and management to protect water resources. The correlation between groundwater flow velocities and environmental impact scores further underscores the importance of controlling groundwater movement to mitigate environmental harm. Golian *et al*. (2019) showed a regression factor of 0.64 between observed and estimated water well flows, indicating satisfactory results for predicting tunnelling's impact on nearby water sources.

Environmental Impact Scores

The environmental impact scores, ranging from 4.5 at Itsawhe (Site 13) to 9.0 at Ophemii (Site 10), provide a quantitative assessment of the ecological consequences of mining activities. Higher scores indicate more severe environmental degradation, including land degradation, water pollution, and habitat destruction. Sites with the highest impact scores, such as Ophemii and Ogbago, correspond to those with significant subsurface disruptions and high groundwater flow velocities, reinforcing the link between geophysical changes and environmental impacts. These scores highlight the need for targeted remediation efforts at sites with high impact scores to mitigate the adverse effects of mining activities.

Correlation Analysis

The correlation analysis revealed strong positive correlations between geophysical data and environmental impact scores, with Pearson correlation coefficients as high as 0.92 at Ophemii and 0.89 at Ogbago. These parameters indicate a significant relationship between subsurface disturbance and ecological outcomes, indicating that increased soil change leads to more significant environmental degradation. Spearman's rank correlation coefficients, which measure the strength of monotonic relationships, in close agreement with Pearson's results, highlight the important role of variability, and effective control methods are used to mitigate these effects under the importance is emphasized.

Linear Regression Analysis

The linear regression analysis further quantified the influence of geophysical variables on environmental impact scores. For instance, at Ophemii, the regression coefficients were β1=0.78\beta_1 = 0.78β1=0.78 for subsurface disruption depth and β2=0.58\beta_2 = 0.58β2=0.58 for groundwater flow velocity, indicating that both factors significantly contribute to environmental impact. These coefficients suggest that changes in subsurface disruption depths and groundwater flow velocities can predict changes in environmental impact scores, providing a valuable tool for assessing the potential ecological consequences of mining activities. This is similar to the reports of Zijl and El-Rawy (2020), who noted that deep subsurface creep velocities are significant with respect to deep groundwater velocities, impacting environmental scores in mining activities. The regression analysis underscores the importance of controlling subsurface disturbances and groundwater flow to reduce environmental impacts.

Implications for Environmental Policy

The findings of this study have several important implications for environmental policy and planning in mining areas. The strong correlation between soil changes and ecological impacts particularly emphasizes the importance of monitoring and controlling environmental loss. Prioritizing areas of high subsurface disturbance and rapid groundwater flow, such as Ofemi and Ogbago, for targeted rehabilitation efforts of mpi electromagnetic sensors may help detect early signs of subsurface change, provided they have been able to participate early.

Furthermore, the study highlights the importance of incorporating geographic information into environmental impact assessments (EIAs) for the mining industry. By incorporating subsurface turbulence depth, groundwater flow velocity, and other geological data into EIAs, regulators can make more informed decisions about the potential environmental impacts of proposed mining projects. This approach can contribute to the economic benefits of drilling and the need to protect natural resources and ecosystems.

In summary, comprehensive geological studies of mining areas in Nigeria have provided valuable insights into land surface changes and their environmental impacts. Findings show considerable variability demonstrated in the depth of surface disturbance, groundwater flow velocity, and ecological impact scores, emphasizing the critical role of soil modification in environmental degradation tree Environmental policy and planning underscores the need for effective monitoring, regulation, and remediation efforts to minimize negative impacts of activities By integrating geographic information stakeholders can effectively protect natural resources and promote sustainable practices in Nigeria.

CONCLUSION

The mining industry in Nigeria plays a vital role in fueling economic growth; However, they simultaneously introduce distinct environmental constraints. This study highlights the importance of environmental impact assessments (EIAs) and geographic methods for monitoring subsurface changes. The regulatory agency should environmentally rigorous ecological assessment, and responsible mining practices are recommended to achieve sustainable mining. The geophysical techniques applied in this ecological study provide an essential contribution to the understanding of the various environmental challenges associated with mining operations in Nigeria. Results occur, emphasizing the need for updated approaches to environmental management with site-specific priorities.

RECOMMENDATIONS

To enhance the effectiveness of legal supervision in Nigeria, it is suggested that the enforcement of environmental legislation be strengthened and that a recurrent and comprehensive program of EIAs for all mining operations be authorized. Training and capacity-building programs should be established to enhance responsible mining practices among mining operators, environmental agencies, and communities. Research and innovation in geophysical techniques used in environmental monitoring can provide a better approach to Identifying and managing the environmental impacts of mining and its related consequences.

Community Engagement: Today, mining companies must interact more directly with local communities to respond to their concerns, provide employment, and implement relevant social programs.

Therefore, if Nigeria deems it appropriate to broaden the scope of geophysical methodologies and integrate them into the environmental management policies of the migrating industry, the nation has a fair chance of successfully achieving the optimum balance between economic growth and conservation of the natural environment in the mining industry.

CONFLICT OF INTERESTS

All authors declare that they have no conflicts of interest.

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