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Integrative GIS-Based Mapping of Active Mining Sites, Exclusion Zones, and Potential Mining Areas in Southwestern Nigeria

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Abstract

Nigeria's mining sector was once a major driver of national economic growth during the 1960s and 1970s, but its prominence declined sharply following the rise of the crude oil industry, leaving it with a marginal GDP share of just 0.17% between 2018 and 2022. Reports from the Development Agenda for Western Nigeria Commission highlight that the country's Southwestern states possess rich mineral reserves such as gold, tin, zircon, rutile, feldspar, and quartz giving the region strong potential to emerge as a global mining hub. Realizing this potential, however, has been constrained by illegal mining operations, overlapping land-use claims, and a lack of reliable spatial data, all of which have undermined effective resource planning and revenue collection. In response, this study carried out a spatial mapping exercise to delineate zones suitable for mineral exploration and extraction, drawing on land use and land cover data to distinguish built-up settlements, licensed mining concessions, and legally restricted zones as defined under the Nigerian Minerals and Mining Act 2007. Findings show that of the region's total 80,061.3 km² landmass, 13,755.7 km² is already under licence, while 49,765.2 km², representing 62.2% of the area, remains available for future mineral leasing. The analysis further identified 1,434 active mining sites, over half of which (759, or 52.9%) overlap with land designated for residential expansion, pointing to considerable spatial conflict. The study concludes that GIS-driven spatial analysis offers a robust tool for guiding licence allocation, land-use planning, and environmentally responsible mining development across Nigeria.

Keywords: Geographic Information System; illegal mining activities; mining suitability; mineral exploration; Southwestern Nigeria.

1. Introduction

Mining plays a pivotal role in economic development by providing the raw materials needed for industrialization, infrastructure development, energy generation, construction, manufacturing and technological advancement. It promotes employment opportunities, foreign direct investment, regional development and government revenue generation through royalties/taxes and export proceeds. As a result, governments across mineral-endowed countries are intensifying efforts to leverage mining for economic diversification and sustainable development initiatives (McMahon and Moreira, 2014; Hilson & Maconachie, 2020; Azubuike et al., 2023). For instance, Nigeria is endowed with over forty (40) solid minerals found in various rock formations in the country. These include gold, iron ore, limestone, granite, bitumen, marble, feldspar, kaolin, quartz, tantalite, tin, among several others. With proper exploration and utilization policies, these solid minerals could help drive industrialization, create employment opportunities, generate foreign exchange, and promote economic growth and diversification in the country. Furthermore, successive governments have established various mineral policies with the intent of fast-tracking industrial mineral production as well as commercial mining of solid minerals to reduce Nigeria's reliance on crude oil. Therefore, mineral resources found within Nigerian territory are vested in the Government by the Constitution of the Federal Republic of Nigeria and licensed pursuant to the Nigerian Minerals and Mining Act. These laws provide regulations guiding mineral exploration, licensing, exploitation activities and environmental management practices within the mining sector (Federal Republic of Nigeria, 1999; Federal Republic of Nigeria, 2007; Azubuike et al., 2023). However, illegal mining operations outside licensed areas are still commonplace in Nigeria. Illegal mining involves activities outside sanctioned licenses and approvals which lead to environmental destruction, deforestation, loss of biodiversity, soil erosion, abandonment of degraded mining sites, water pollution, conflicts between mining communities and host communities among several others. Illegal mining has contributed to financial leakages due to lack of supervision and destruction of livelihoods and protection of lives in general. Thus, there is an increasing demand for tools that can aid sustainable mineral monitoring needed for evidence-based mineral governance in Nigeria (Hilson & Maconachie, 2020; Olujobi & Irumekhai, 2024; Ngom et al., 2023). The Nigerian Minerals and Mining Act (2007) also recognizes several Exclusion Zone areas where prospecting, mining or carrying out any mining operation is restricted. Locations within these exclusion zones are prohibited from any form of mining activities. Establishing these zones are hinged on preserving lives, environmental conservation, safeguarding public properties and protection of sensitive areas. Identified exclusion zones include inhabited settlements, roads, railways, airports, dams, reservoirs, military installations, oil/gas pipelines, fenced-off forests and woodlands, archaeological sites, sacred centres, recreational parks and reserves, among other public locations. Therefore, these statutory provisions on exclusion zones are critical in sustainable mining practices because it prevents indiscriminate allocation of mining licenses within environmentally protected and sensitive areas that can lead to land use conflicts and environmental destruction (Federal Republic of Nigeria, 2007; Olujobi & Irumekhai, 2024).

Similarly, at the continental level, African countries are guided by the Africa Mining Vision (AMV) policy framework to help ensure transparency in mineral governance and accountability in mining industry investments. The framework also promotes good stewardship of natural resources, environmental sustainability, local value addition as well as incorporation of modern geospatial technologies for enhanced decision-making in the mining sector. Member states are, therefore, expected to establish extractive industries

transparently and responsibly to ensure that mining contributes to economic growth and development in Africa. This ultimately aligns with increasing demands for reliable spatial information that can support sustainable mineral exploration and environmentally conscious land-use practices within mining regions of Africa (African Union Commission, 2009; Economic Commission for Africa, 2017). Geographic Information Systems (GIS), remote sensing, and earth observation technologies have increasingly been adopted for mineral exploration activities. These technologies allow users to conveniently acquire, integrate, visualize, store, analyse, and manipulate spatial datasets over extensive areas. For example, Sentinel-2 satellite imagery coupled with GIS-based spatial analytics offers a rapid and cost-effective alternative to conduct supervised classification of land use and land cover, mapping of active mining sites, monitoring rapid expansion of mining activities, delineation of environmentally sensitive areas and determining suitable mining locations based on prevailing land uses. Due to its ability to integrate and analyse geological, environmental, and infrastructural data simultaneously, GIS technologies have found widespread applications in mineral prospectivity mapping, environmental assessments, and mining-related decision support systems (Werner et al., 2019; Tagwai et al., 2023; Lakhlifa et al., 2022; Maus et al., 2022; Shirmard et al., 2022; Yousefi et al., 2021).

Southwestern Nigeria is one of the country's mining provinces, consisting of Lagos, Ogun, Oyo, Osun, Ondo and Ekiti States. Large deposits of gold, granite, limestone, quartz, feldspar and tantalite can be found within these States. While industrial-mining activities take place across several mining license areas, artisanal mining is common in rural parts of the region. Due to rapid urbanization, increasing populations, developing transportation corridors and emerging agricultural activities, competition for land resources continues to surge. Mining activities are no exception and may lead to increased disputes if proper channels are not taken to monitor and manage active mining operations. Therefore, there is a need to systematically identify active mining regions that fall within recognized mining license areas in Southwestern Nigeria (Maus et al., 2022; Tagwai et al., 2023). To date, several remote sensing and GIS studies have been undertaken to understand mineral distribution/exploration, generate geological maps, assess environmental degradation caused by mining activities and examine land-use change dynamics within Southwestern Nigeria. However, no existing studies have combined land use and land cover classification, active mining regions, statutory mining exclusion areas, transportation networks, Oil & Gas installations and valid Mining Licenses issued by the government into a single GIS-based spatial decision-support system for the region. It is important to understand that exploration and mining are prohibited on land designated for military purposes, as well as within a 50 km radius of any oil pipeline license area, railway, public road, reservoir, dam, or government/public buildings. Additionally, restrictions apply to land occupied by towns, villages, markets, or cemeteries, as well as ancestral, sacred, or archaeological sites, national parks, and areas governed by the National Commission for Museums and Monuments Act, Chapter N19, LFN 2004. Moreover, any area designated as closed to mining operations is also restricted.

This limits opportunities for evidence-based mineral licensing, environmental monitoring, and land-use planning within mining communities in Southwestern Nigeria. In this context, this study aimed to employ an integrated GIS and Remote Sensing approach to map existing mining sites, delineate statutory mining exclusion zones and identify potential areas suitable for mining activities across Southwestern Nigeria. To achieve these objectives, land use and land cover mapping was conducted using Sentinel-2 satellite imagery, active mining sites were extracted and their distribution analysed, mining activities within statutory mining

exclusion zones were assessed and potential areas suitable for future mining exploration were delineated after excluding existing statutory mining exclusion zones and environmentally sensitive areas. The generated products can serve as a robust geospatial decision-support system that can aid governments, stakeholders and regulatory bodies in promoting sustainable development of solid minerals improve mineral governance and planning within Nigeria's mining sector.

Study Area

This study focuses on Southwestern Nigeria, a region that spans approximately 76,825 km² and includes six states: Lagos, Ogun, Oyo, Osun, Ondo, and Ekiti. The study area extends from Batabi Town in Oyo State (9.187988°N, 3.861361°E) in the north to its southern boundary at the Atlantic Ocean near Gbege-Eke Village in Ondo State (5.887397°N, 4.976413°E). To the east, the boundary reaches Ikakumoh Village in Ondo State (7.526461°N, 6.005120°E), while to the west, it stretches to Alagbado, a border town in Ogun State (7.881514°N, 2.676914°E).

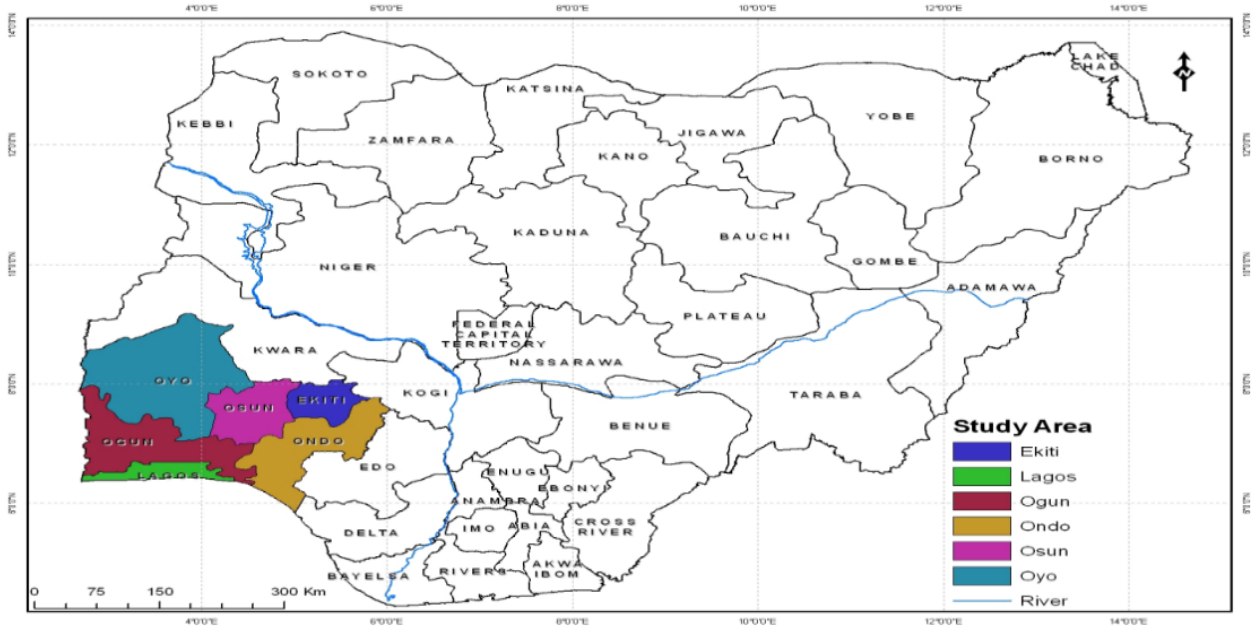


Fig 1: Southwestern Nigeria, comprising Lagos, Ogun, Oyo, Osun, Ondo, and Ekiti States.

2. Method

The research relied on GIS and remote sensing methods to delineate known mining locations, statutory mining exclusion zones, and potential mining areas in all six states in Southwestern Nigeria. The application of GIS and remote sensing technologies has been commonly accepted for mineral prospectivity mapping, land suitability analysis, and spatial decision-making due to the capability of these systems to acquire, integrate, analyse, and visualise numerous geospatial datasets within a spatially referenced framework (Longley et al., 2015; O'Sullivan & Unwin, 2010). Primary datasets for this study include Sentinel-2 multispectral satellite imagery and field observations (ground-truth), while secondary spatial datasets such as mining licences, road networks, oil and gas pipelines, public buildings, forest reserves, dams, and other statutory mining exclusion features were acquired from relevant authorities/agencies. All datasets were geo-referenced and imported into a common geospatial database for spatial analysis. Twenty-two Sentinel-2 multispectral image tiles

needed to cover the entire study area were downloaded to the GIS workspace. The imagery was composited, mosaicked, and clipped, and supervised classification was performed into land use/land cover (LULC) categories. Image pre-processing techniques were applied to improve image radiometric quality and eliminate sensor anomalies for compatibility with other spatial datasets needed for subsequent spatial analyses (European Space Agency, 2015; Richards, 2022). Ground-truth surveys were carried out to verify the locations of mining sites, mining exclusion features, and to validate the accuracy of the classified LULC map.



Fig 2: CAT S30



Fig 3: PDC Mobile application

Field observations collected as points, lines, and polygons were geolocated using the built-in GPS capabilities of the Android-based devices. see (Fig. 2). Field data was captured using the Polaris Data Collector (PDC) mobile application installed on the Android tablet computers (Fig. 3). Attribute and photo documentation of geolocated points, lines and areas of interest were acquired using the PDC application. Classified imagery was assessed for accuracy using the field observations following standard procedures for remote sensing accuracy assessment (Congalton & Green, 2019).

Secondary spatial datasets were sourced from the Mining Cadastre Office, Federal Ministry of Solid Minerals Development, Federal Ministry of Environment, Ministry of Defence, Federal Ministry of Transport, Federal Ministry of Water Resources, Department of Petroleum Resources, and the relevant State Ministries in charge of physical planning, forestry, sports and culture. Secondary datasets acquired include maps of known mining sites (active mining licences), road networks, railways, oil and gas pipelines, reservoirs, public buildings, forest reserves, markets, parks, museums, cemeteries, and other statutory mining exclusion datasets and features (Table 1.). All datasets were projected using a common coordinate reference system and imported into the ArcGIS Pro Desktop work environment for spatial analysis. A combination of GIS overlay operations, buffering, spatial querying, and thematic mapping was used to determine the spatial relationships between mining sites and statutory exclusion zones/features. Buffer zones were created around each restricted feature following the Nigeria Minerals and Mining Act (2007). Potential mining areas were then delineated by subtracting built-up areas, active mining licence polygons, statutory mining exclusion zones/features, transportation corridors, and other areas restricted for mining activities from the total surface area of Southwestern Nigeria. Thematic maps were created, and area summary statistics computed from the resultant spatial datasets for use in mineral suitability evaluation and evidence-based land-use decision-making processes (Tomlin, 1990; ESRI, 2024).

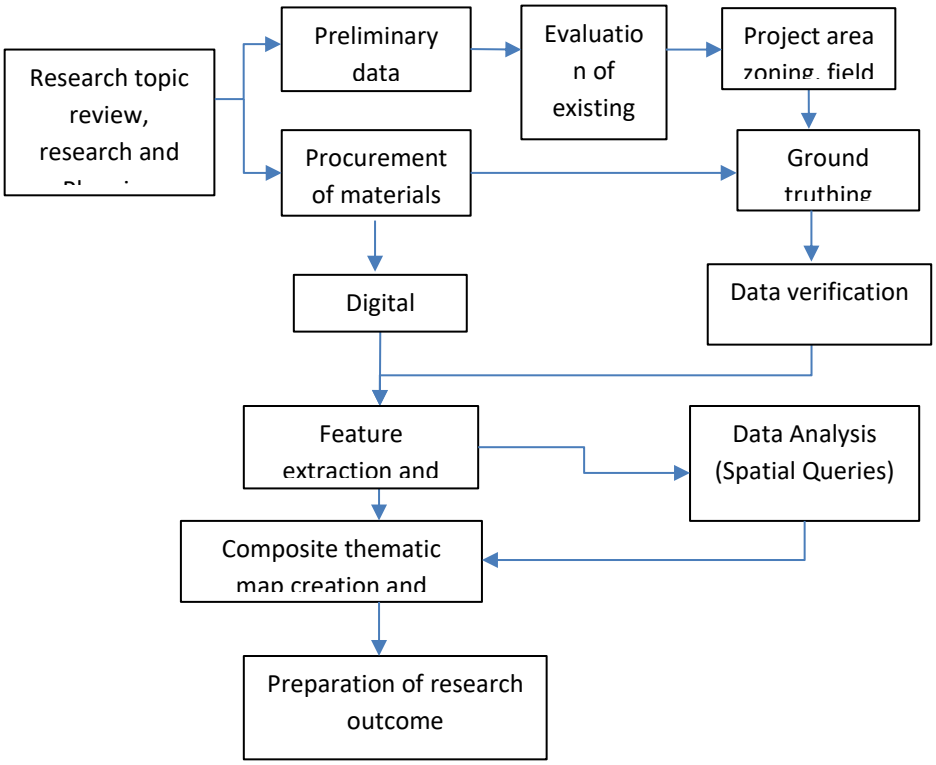


Fig 4: Workflow showing the stages involved in the study

Table 1. Spatial datasets used for delineating statutory mining exclusion zones in Southwestern Nigeria

Spatial Dataset	Responsible Agency	Data Source
Military Zones	Ministry of Defence	Government Gazette
Special Government Restricted Areas	Federal Ministry of Environment	Government Gazette
Active Mining Licences	Mining Cadastre Office	Mining Cadastre Database
Markets	State Ministries of Physical Planning	State GIS Database
Sports Facilities	Federal and State Ministries of Sports	State GIS Database
Cemeteries	State Ministries of Physical Planning	State GIS Database
Oil Pipelines	Department of Petroleum Resources	National Pipeline Database
Gas Pipelines	Department of Petroleum Resources	National Pipeline Database
Railway Network	Federal Ministry of Transport	National GIS Database
Road Network	Federal and State Ministries of Transport	National GIS Database
Public Buildings	State Ministries of Physical Planning	State GIS Database
Reservoirs	Federal Ministry of Water Resources	National GIS Database
Forest Reserves	State Forestry Departments	Forestry GIS Database
National Museums	Ministry of Culture and Tourism	National GIS Database
Public Parks	Ministry of Culture and Tourism	National GIS Database
Tourist Sites	Ministry of Culture and Tourism	National GIS Database

3. Results and Discussion

3.1. Ownership and Regulation of Mineral Resources

The Nigerian legal framework in control of mineral resources establishes that ownership and regulatory authority over all mineral resources encompassing those found in, beneath, or above land, reside with the Federal Government, acting in the interest of the Nigerian populace. This encompasses resources located within the nation's territorial seas, the contiguous continental shelf, and all associated rivers, streams, and watercourses. Under this framework, any land where commercially viable minerals are discovered will be expropriated by the Federal Government in accordance with the provisions set forth in the Land Use Act

(Cap. L5). Upon lawful extraction of these resources, ownership is transferred from the Government to the entity engaged in the mining activities, contingent upon compliance with this Act.

Prohibitions on mineral exploration and exploitation, under this regulatory framework, certain lands are earmarked as restricted for mineral exploration or exploitation activities. Mineral titles issued pursuant to this Act do not permit reconnaissance, exploration, or extraction activities in the following zones: (a) Areas designated for military use, unless prior consent is obtained from the President; (b) Regions situated within one hundred meters of any licensed oil pipeline area under the Oil Pipeline Act; (c) Lands developed or utilized for towns, villages, markets, burial grounds, cemeteries, ancestral or sacred sites, archaeological sites, areas assigned for railway construction, or those located within fifty meters of such infrastructure, as well as proximity to government or public facilities, reservoirs, dams, or public highways; (d) Areas governed by the National Commission for Museums and Monuments Act (Cap. N19, Laws of the Federation of Nigeria, 2004) and the National Parks Service Act (Cap. N65, Laws of the Federation of Nigeria, 2004); (e) Zones where existing mineral titles have been previously awarded by the Mining Cadastre Office, provided such titles remain valid.

No exploration activities shall be undertaken, nor shall mineral titles be granted in regions classified as closed to mining operations according to Nigerian minerals and mining act, Sections 1 and 3 (Nigerian Minerals and Mining Act, 2007)

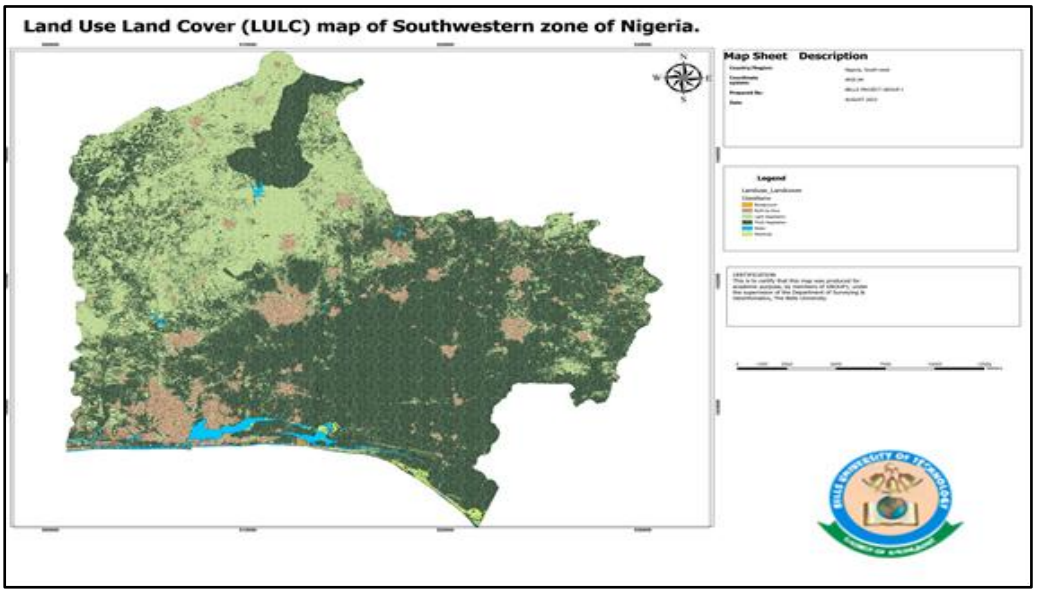
3.2 Land Use/Land Cover Distribution

The classified Land Use/Land Cover (LULC) image derived from Sentinel-2 data reveals that the entire area under study in Southwestern Nigeria covers 80,061.3 km2. From Figure 5, the area covered by built-up lands was found to be 8582 km2, representing 10.72% of the total study area. Statutory Mining Exclusion zones covered an area of 6751.3 km2 (8.43%), while licensed mining area covered an area of 13755.7 km2 (17.18%). Other restriction areas covered a land area of 135.7 km2 (0.17%), 169.3 km2 (0.21%) and 902.1 km2 (1.13%) for pipeline buffer zone, oil and gas buffer zone, and national road buffer zone, respectively. When built-up areas, licensed mining areas and all statutory restriction areas were deducted from the total land area of Southwestern Nigeria, an area of 49,765.2 km2 becomes available for future mining purposes, representing 62.2% of the total area. This result shows that even though statutory restrictions and other land uses cover a significant area of Southwestern Nigeria, there is still land available for mining activity if conducted within the ambit of the law (The Nigerian Minerals and Mining Act, 2007). Also, the available mining area identified will allow future mineral exploration and mining activities to take place with less conflict with mining infrastructure and environmentally sensitive areas.

Table 2. Land Use/Land Cover Distribution in Southwestern Nigeria

Land Use Category	Area (km²)	Percentage (%)
Built-up Area	8,582.0	10.72
Classified Restricted Area	6,751.3	8.43
Licensed Mining Area	13,755.7	17.18

Pipeline Buffer	135.7	0.17
Oil and Gas Buffer	169.3	0.21
National Roads Buffer	902.1	1.13
Potential Mining Area	49,765.2	62.16
Total Study Area	**80,061.3**	**100.00**



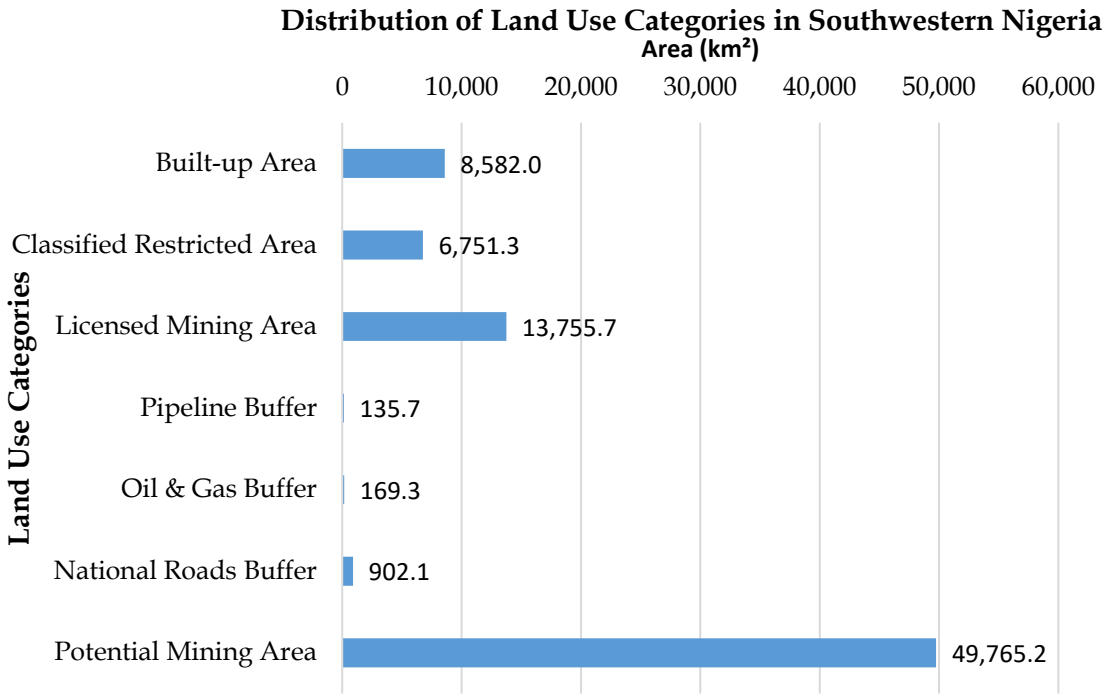


Fig 6: Distribution of Land Use Categories in Southwestern Nigeria

From Figure 6, the Potential Mining Area has the largest share of the study area (49,765.2 km²; 62.2%). This implies that the majority of the area analysed is still available for mineral development when statutory exclusion zones and other land uses have been considered. The licensed mining area was discovered to have the second-highest coverage among all categories of land uses in Southwestern Nigeria (13,755.7 km²; 17.18%). Built-up Areas (8,582 km²; 10.72%) and Classified Restricted Areas (6,751.3 km²; 8.43%) have comparatively lower percentages of area covered when placed side by side with other categories. Pipeline Buffers, Oil and Gas Buffers and National Roads Buffers also have low distribution across the study area. However, mining operations carried out within these areas or their immediate vicinity, may jeopardize national assets and the safety of citizens due to the nature of this infrastructure. They should therefore still be considered statutory units to be avoided when allocating mining licenses. Overall, the distribution pattern of area covered by each land-use class derived using GIS-based land suitability analysis clearly demonstrates its capability to separate potentially available land for mineral development from areas that require statutory protection from mining activities when used along with spatial information on known land uses.

3.3 Spatial Distribution of Active Mining Sites

The total number of identified active mining sites was 1,434 sites spread across Southwestern Nigeria (Figure 7), suggesting that mining activities are prevalent across the study area. The pattern of spatial distribution of mining sites in Figure 7 revealed clustered tendencies rather than being randomly distributed throughout the study area. This is because mineral exploration usually occurs where geological formations are found together with the spatial occurrence of economic grade/mineral deposits. Thus, lithological controls and mineral resource endowment influence the distribution of mining sites across the landscape and are unlikely to occur randomly in space (Maus et al., 2020; Lakhlifa et al., 2022). Most mining locations were recorded within zones with known occurrences of significant mineral deposits and few mining sites within densely urbanised centres and statutory mining-off limits areas. This implies that lithological controls and existing land-use characteristics controlled the clustering tendency of mining sites. GIS-based mining literature reported a similar pattern in the distribution of mining sites, which were found to be controlled by the available geological/mineral resource potentials, environmental conditions and prevailing land-use patterns (Tagwai et al., 2023; Werner et al., 2019). The spatial database developed in this study will provide baseline information needed for mineral resource planning, environmental monitoring and mining licence administration. Government agencies responsible for mining regulations will find the integration of active mining locations into a GIS-based decision-support-system helpful in updating existing mining sites and their distribution for monitoring mining operations, detecting illegal mining locations and ensuring prompt enforcement of statutory mining regulations. Moreover, mapped active mining locations provide baseline information for overlay analyses with statutory mining-off limits areas for potential land-use conflicts and evidence-based mineral governance.

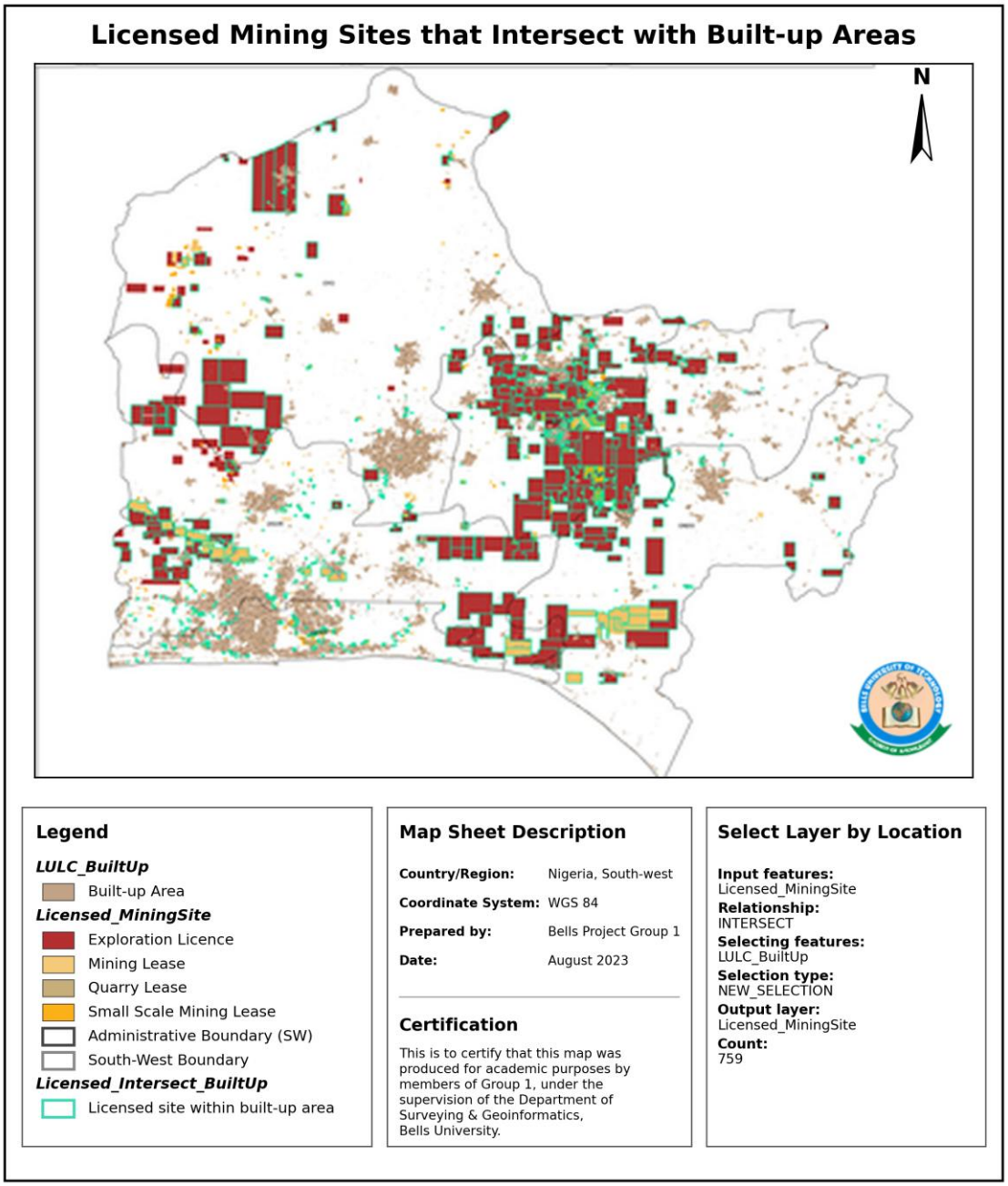


Fig 7: Spatial Distribution of Active Mining Sites in Southwestern Nigeria

Figure 7 shows the spatial distribution of mining occurrences within Southwestern Nigeria. From the thematic map, mining occurrences are clustered rather than randomly distributed throughout the study area due to the presence of favourable geological formations and confirmed mineral deposits. Mining occurrence sites are clustered together mostly in mineral-bearing regions while few occurrences were observed in highly urbanised regions. Thus, it can be concluded that favourable geology and existing land-use dictate mining occurrence sites. The map overall depicts how GIS-based spatial analysis can aid in revealing distribution

patterns in mining activities and provide information necessary for mineral resource planning, monitoring and evidence-based mining governance in Southwestern Nigeria.

3.4 Mining Site Intersections with Statutory Exclusion Zones

By overlaying licensed mining sites against statutory mining exclusion zone layers, a total of 1434 licensed mining sites were identified within the study area, of which 759 (52.9%) fall within built-up areas (Table 3). These findings reveal that a large proportion of mining activities occur within built-up areas, implying severe spatial competition for land resources and potential for land-use conflicts. Mining activities around settlement areas, if not well checked, might subject inhabitants within such localities to pollution, infrastructure destruction, and danger to the lives and property of residents around mining sites (Edwards et al., 2014; Sonter et al., 2018). A total of 52 mining leases were observed within the study area, representing a 3.6% proportion of licensed mining sites. Of these identified mining leases, 33 mining leases (63.5%) fall within built-up areas, showing that quite a significant number of mining leases fall across built-up areas. These results suggest the need to continually monitor mining activities using statutory mining maps for compliance with the Minerals and Mining Act of Nigeria, which restricts mining activities within statutory mineral exclusion zones in Nigeria (Federal Republic of Nigeria, 2007; Olujobi & Irumekhai, 2024). Two mining leases were observed intersecting oil pipeline corridors, while five mining leases fall across gas pipeline corridors. Mining leases near pipelines, if not properly managed, can lead to damage to oil infrastructure, environmental pollution, disruption of operations, and a threat to public safety. These examples show GIS-based overlay analysis can serve as a decision support tool for finding spatial land-use conflicts for evidence-based mining licence administration towards sustainable mineral resource governance. (Werner et al., 2019; Tagwai et al., 2023).

Table 3. Spatial Relationships Between Licensed Mining Sites and Statutory Exclusion Zones

Spatial Indicator	Number	Percentage (%)
Licensed mining sites	1,434	100.0
Mining sites within built-up areas	759	52.9
Mining leases	52	3.6
Mining leases within built-up areas	33	63.5*
Mining leases intersecting oil pipelines	2	3.8*
Mining leases intersecting gas pipelines	5	9.6*

*Percentages are calculated using the 52 identified mining leases as the denominator.

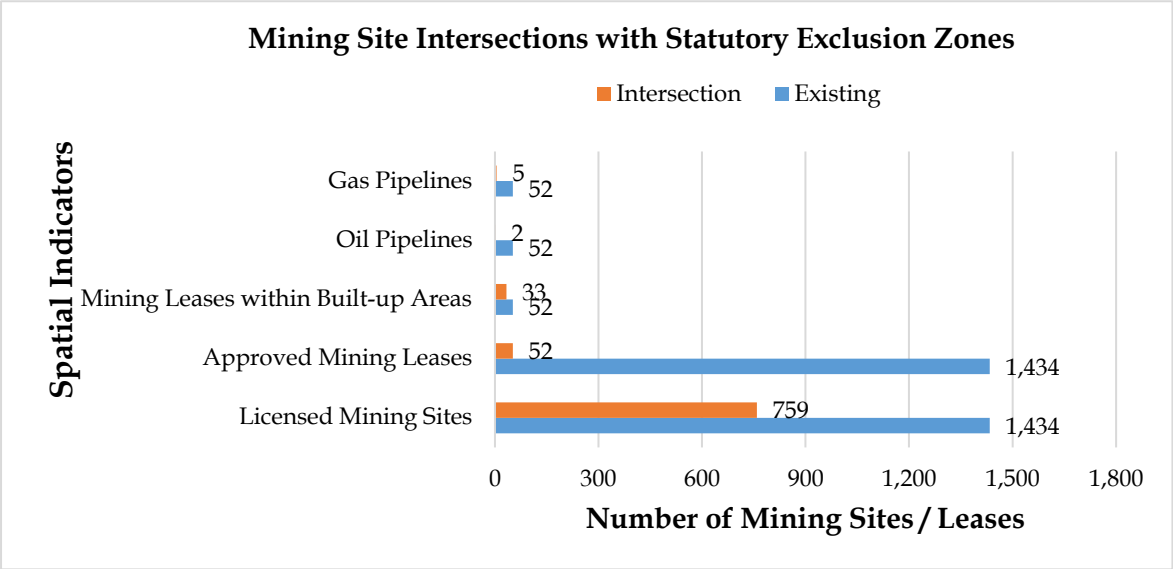


Fig 8. Comparative Analysis of Mining Site Intersections with Statutory Exclusion Zones.

Figure 8 revealed a comparison between the licensed mining sites that fall within statutory exclusion zones in Southwestern Nigeria. Among licensed mining sites with a total count of 1434 obtained from the study area, 759 occur within built-up areas which constitute about 52.9% of the entire study area (Fig. 8). Built-up area is the predominant feature where mining activities take place showing the highest spatial conflicts and this observation reveals that more than half of licensed mining sites fall within settlements/agricultural settlements indicating increase competition between minerals and other land uses developed within the area. It also shows that mining settlements exist within gazetted settlements/zones and strict enforcement and adherence to mining regulations are needed within the study area. The Licensed Mining Sites intersected with approved mining leases obtained a very small portion that accounts for 52 approved mining leases were obtained from the study area representing 3.6%. Out of these 52 approved mining leases obtained, 33 take place within built-up areas showing that 63.5% of mining leases fall within built-up areas which is very close to the built-up environment and thus requires constant monitoring. Mining activities around these gazetted built-up areas need to be monitored and evaluated to avoid negative environmental and socioeconomic impact created from mining activities. Also, among mining leases obtained from the study area, it was observed that only two mining leases intersect oil pipeline corridors while five intersect gas pipeline corridors showing very less points of intersection were observed among these features, mining activities within pipelines corridors pose serious threats to critical infrastructure, environment and safety but overall built-up areas are predominant which causes the major spatial conflict. This comparative analysis among mining activities supports the statement that GIS based-overlay analysis serves as decision support tool for the identification of high-risk areas, improvement on mining license administration thus aid mineral resources governance.

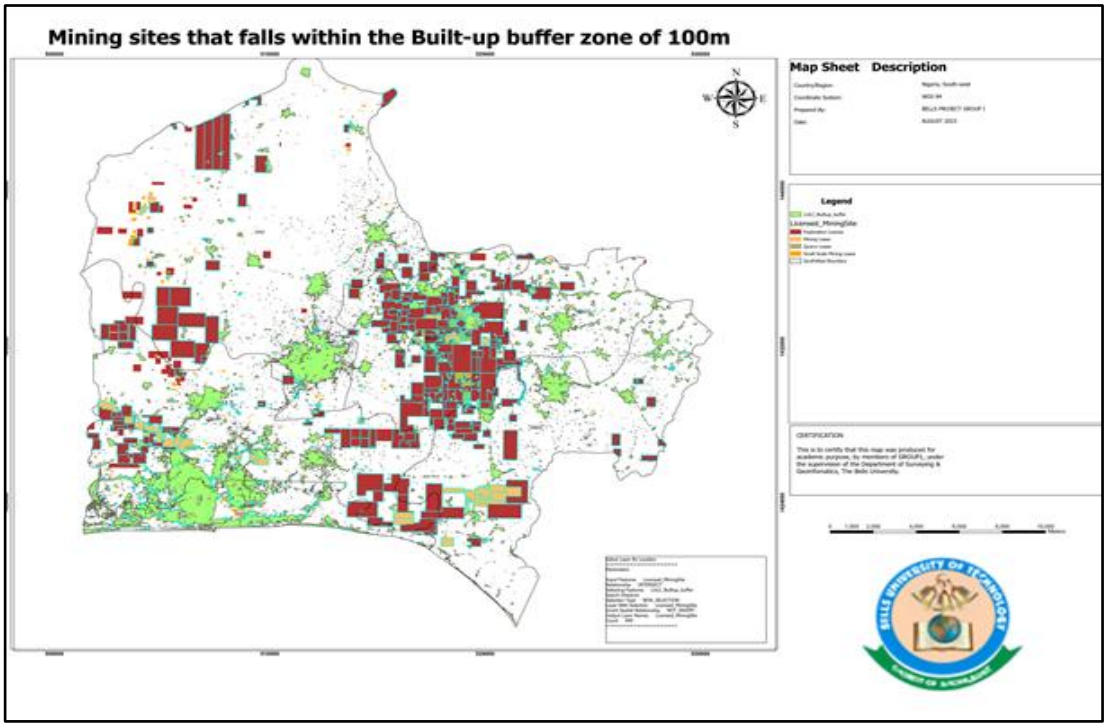


Fig 9. Active Mining Sites Intersecting Statutory Exclusion Zones in Southwestern Nigeria

Figure 9 shows the location of mining sites that overlap built-up areas/zones reserved by law in Southwestern Nigeria. This result supports the analysis shown in Table 3 and Figure 8, providing locational information on mining sites overlapping built-up zones. Mining areas where conflicts occur are mostly concentrated within built-up areas in need of strict monitoring to avoid adverse effects on built structures and residents and help better regulate mining activities within such localities. Quantitative analysis and location using GIS-enabled spatial analysis of mining sites overlapping built-up areas is essential for evidence-based grant mining licenses.

3.5 Potential Mining Areas

GIS analysis identified 49,765.2 km2 or 62.2% of the total surface area of Southwestern Nigeria as potential areas for future mineral exploration and mining activities after discounting built-up lands, mining lease allocations, transportation route corridors, oil and gas pipeline buffers and other statutory setbacks (Table 4). This implies that most of the region is still open for future mineral exploration and exploitation considering the negative impacts of human activities such as urbanization and statutory land-use reserves.

Similar studies have shown that combining geological, environmental and land-use information using a GIS approach is effective for mineral prospectivity mapping and sustainable land-use allocation (Bonham-Carter, 1994; Carranza, 2009). Maps depicting areas suitable for future mineral exploration and exploitation will serve as a spatial decision-aid tool for government agencies involved in mineral resources planning and issuance of mining licences in Southwestern Nigeria. Overlaying statutory restrictions during the suitability analysis will enable exploration companies to focus their efforts on regions with little or no conflict with the environment and enhance efficiency and transparency in mineral resource management activities. Mineral prospectivity mapping using GIS has been found as effective means of providing information needed for an evidence-based mineral exploration decision-making process (Porwal et al., 2003; Carranza & Laborte, 2015). However, areas mapped as

potentially suitable should not be considered as reserved mining sites. There is still the need for intensive geological fieldwork, environmental impact assessment and socio-economic impact assessment before any exploration or mining activity can commence. This approach will ensure mineral exploration and mining activities are carried out responsibly, avoiding conflicts with existing land uses and other critical infrastructure as well as promoting sustainability in mining activities. (Moran et al., 2014; Sánchez & Hartlieb, 2020).

Table 4: Potential Mining Area in Southwestern Nigeria

Variable	Area (km²)	Percentage (%)
Total Study Area	80,061.3	100.0
Potential Mining Area	49,765.2	62.2
Restricted and Occupied Area	30,296.1	37.8

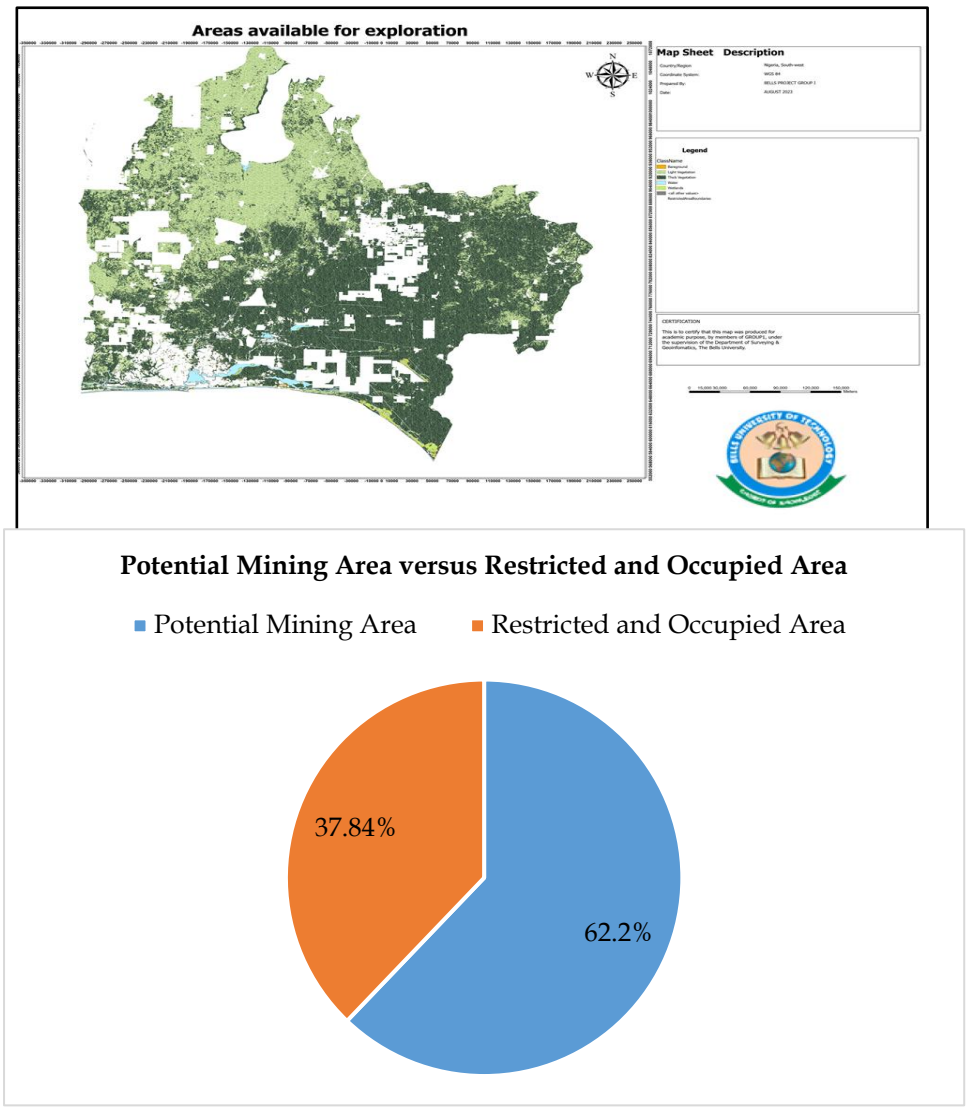


Fig 11: Distribution of Potential Mining and Restricted/Occupied Areas in Southwestern Nigeria.

As depicted in Figure 11, 62.2% of the total study area was left as potentially suitable areas for future exploration. Areas already occupied by existing land uses and statutory exclusion areas account for 37.8% of the study area. The fact that most of the study area was left as potentially suitable areas for future mineral exploration confirms that there are still opportunities for mineral exploration in the future without conflicting with protected areas and existing land uses. This again confirms the applicability of GIS-based suitability analysis in sustainable land-use planning and fact-based mining licence allocation.

4. Conclusion

The study harnessed GIS and remote sensing approaches to map out active mining sites, statutory mining exclusion zones, and potential mining areas in Southwestern Nigeria. A combination of Sentinel-2 satellites imagery and spatial datasets obtained from relevant government agencies enabled the generation of a geospatial database necessary for mapping of mining suitability and land-use conflicts.

Results from our study indicate that when excluding built-up areas, existing mining licenses, transportation corridors, pipeline buffer zones, and other areas subject to statutory restrictions, a total of 49,765.2 km² (62.2%) of the study area is available and suitable for future mineral exploration. The study identified 1,434 active mining sites within the region, of which 759 (52.9%) are located in built-up areas, highlighting the spatial conflicts between active mining operations and urban development. The analysis shows that approximately 62.2% of the land mass in southwest Nigeria is suitable for the issuance of exploration licenses, mining leases, quarry leases, and small-scale mining leases. The land use and land cover classification revealed that built-up areas encompass 8,582 km², while areas classified as restricted under the Nigerian Minerals and Mining Act account for 6,751.3 km². Licensed areas for exploration, mining, quarrying, and small-scale mining cover 13,755.7 km². Additionally, the oil pipeline buffer zone spans 135.7 km², the oil line buffer occupies 169.3 km², and the national roads buffer constitutes 902.1 km². Overall, the southwest region of Nigeria covers a total of 80,061.3 km², of which 30,296.1 km² is considered unavailable for mining activities.

Furthermore, the presence of mining leases within oil and gas pipeline corridors calls for stringent enforcement of statutory mining exclusion principles with a view to protecting the country's vital infrastructure and ensuring public safety. From the study, we can conclude that GIS-based spatial analysis is a decision- support tool that can be applied for mineral resource planning, mining licence administration and environmental management purposes. This database and maps will assist in improved mining governance practices, reducing land use conflict, eliminating illegal mining practices as well as effective management and sustainable mineral resource development in Nigeria. The inclusion of geological datasets, environmental datasets, socio-economic datasets, and mineral potential datasets will improve the suitability assessment approach for future studies focusing on mineral exploration and land use planning in evidence-based decision-making.

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Conflict of Interest

The authors declare that they have no competing interests.

Data Availability Statement

The data supporting the findings of this study can be obtained from the corresponding author upon a reasonable request.

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