Integrated Spatial Analysis of Liberia's Mining Sector: Impacts on Population, Infrastructure, and Environmental Sustainability and Administrative Regions

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Integrated Spatial Analysis of Liberia's Mining Sector: Impacts on Population, Infrastructure, and Environmental Sustainability and Administrative Regions

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Abstract

This study conducts an integrated spatial analysis of Liberia's mining sector, examining its effects on population, infrastructure, and environmental sustainability. The country's abundant reserves of gold, iron ore, and diamonds are crucial to its economy, creating jobs, generating revenue, and improving infrastructure. Nevertheless, the rapid growth of mining operations has resulted in significant environmental and socio-economic problems such as deforestation, soil degradation, and pollution, impacting both ecosystems and local communities. Through the utilization of various geospatial data sets, including land cover change maps from 2017 to 2023, details on mining licenses, locations of mineral deposits, and data on populated areas, this research offers a thorough evaluation of how mining influences changes in land cover, socio-economic circumstances, and infrastructure development in Liberia. The methodology involves a thorough analysis of land cover changes, including overlay and proximity assessments, as well as statistical evaluations to measure the correlation between mining activities and their effects. Significant land cover shifts are identified, particularly the transformation from vegetation to rangeland and urban areas, indicating trends of deforestation and urbanization. The spatial distribution of mineral deposits coincides with protected regions, leading to concerns regarding environmental consequences. Analysis of population density reveals diverse socio-economic effects, while infrastructure assessment highlights the importance of promoting sustainable development. This research underscores the importance of stringent environmental regulations, sustainable land management practices, and effective socio-economic protections to harmonize economic progress with environmental preservation and community well-being within Liberia's mining industry.

Keywords: Policy, risk management, profitability, revenue, jobs, productivity, technology, value chain climate change, companies, development, environmental sustainability, regions, sector zoning, economic growth, and network.

1 Introduction

Liberia, a nation endowed with abundant natural resources, boasts a lengthy history of mining endeavors that substantially contribute to its economic stability(Dietler et al., 2021a). The mining industry, which includes valuable minerals like gold, iron ore, and diamonds, plays a pivotal role in creating jobs, revenue, and infrastructure enhancement(Enaruvbe et al., 2019). Nevertheless, the repercussions of mining activities on the environment and socio-economic aspects have become a subject of concern for policymakers, scholars, and local communities(Boakye et al., 2012). The swift growth of mining operations has resulted in deforestation, land deterioration, and contamination, impacting both the natural surroundings and the welfare of Indigenous populations(The Mining Sector of Liberia: Current Practices and Environmental Challenges,2017 (Samuel T. K. Wilson,2017). This research aims to carry out a comprehensive spatial analysis of Liberia's mining sector, with a focus on its impacts on population, infrastructure, and environmental sustainability. By utilizing a range of geospatial datasets, such as land cover change rasters spanning from 2017 to 2023, mining license information, mineral deposit locations, and inhabited areas, the objective is to offer a thorough insight into how mining activities affect land cover changes, socio-economic circumstances, and infrastructure advancements in Liberia(Wilson et al., 2017; Wong et al., 2012).

2 Literature Review

2.1 Environmental Impacts of Mining

The mining industry contributes significantly to the Liberian economy, accounting for many exports and GDP. However, negative impacts on local populations often offset socioeconomic benefits. The World Bank (2018) highlights the importance of transport connectivity and infrastructure development to promote economic growth and improve access to markets and services. Despite these efforts, the expansion of the mining industry has led to displacement, health issues, and limited access to clean water for local populations ((Brennan-Horley et al., 2010; Mathews et al., 2005; Petkova-Timmer et al., 2009,Wilson et al., 2017).

2.2 Socio-Economic Impacts

The mining industry contributes significantly to the Liberian economy, accounting for many exports and GDP. However, negative impacts on local populations often offset socioeconomic benefits. The World Bank (World Bank,2018,Robertson, 2024)) highlights the importance of transport connectivity and infrastructure development to promote economic growth and improve access to markets and services. Despite these efforts, the expansion of the mining industry has led to displacement, health issues, and limited access to clean water for local populations ((Yellishetty et al., 2009,Wilson et al., 2017).

2.3 Land Cover Change and Deforestation

Land cover change, particularly deforestation, is a critical issue in Liberia. The Liberia Land Cover and Forest Mapping Report (2016) analysed land cover types and changes over time and highlighted the impacts of human activities, including mining, on forest cover. The report stressed the need for accurate and timely land cover data to support sustainable land use planning and environmental management (Forest Carbon Partnership, 2016,Siegel & Veiga, 2009)).

2.4 Spatial Analysis in Environmental and Resource Management

Spatial analysis techniques such as GIS and remote sensing are widely used to assess the environmental and socioeconomic impacts of mining activities. Studies have demonstrated the effectiveness of spatial analysis in identifying areas of environmental degradation, assessing infrastructure needs, and supporting land use planning (Durning, 2012; Oliveira-Andreoli et al., 2021; Turečková et al., 2022) Combining spatial data with socioeconomic indicators provides policymakers and stakeholders with valuable insights into managing natural resources and mitigating negative impacts(Cocheci et al., 2019).

3 Methodology

The approach adopted for the integrated spatial analysis of Liberia's mining industry involves a comprehensive methodology that combines diverse geospatial datasets and analytical methods. Key sources of primary data comprise a change in land cover raster (2017-2023), shapefiles of mining licenses, locations of mineral deposits, data on exploration facilities, and information on populated areas(Dessureault, 2007; Lambarri & Cochrane, 1994). The initial stage of data processing entails a detailed examination of the land cover change raster to quantify and map significant changes in land use patterns, with a specific focus on deforestation, expansion of bare ground, and urban development. Subsequently, an overlay analysis is conducted, whereby mining license data is overlaid on the land cover change map to determine spatial correlations between mining operations and changes in the environment(Curry, 2008; Zhang et al., 2009). The delineation of mineral deposits and the positioning of exploration facilities are conducted to assess their proximity to regions undergoing notable alterations in land cover. A proximity analysis is executed to evaluate the socio-economic implications, utilizing a dataset of inhabited areas to measure the distances among mining sites, exploration facilities, and human settlements(Foley, 2009). The evaluation of infrastructure development entails an examination of the spatial correlation between mining operations and the existing transportation networks. Various statistical methodologies, such as correlation analyses, are utilized to quantify the connections between mining activities, changes in land cover, and socio-economic parameters. Furthermore, a hotspot analysis is carried out to pinpoint clusters exhibiting significant environmental and socio-economic effects. The ultimate phase encompasses the development of comprehensive Geographic Information System (GIS) maps and visual representations delineating the spatial distribution of changes in land cover, mining operations, and their diverse impacts on the populace, infrastructure, and environmental sustainability of Liberia(Christmann, 2021; Okimiji et al., 2021). This methodological

approach enables a holistic examination of the mining sector's influence on Liberia's landscape and society, providing crucial insights for informed decision-making and sustainable resource management(Sopper, 1992; Subasinghe et al., 2022).

4 Results

4.1 Integrated Spatial Analysis of Land Cover Change and Mining Activities in Liberia

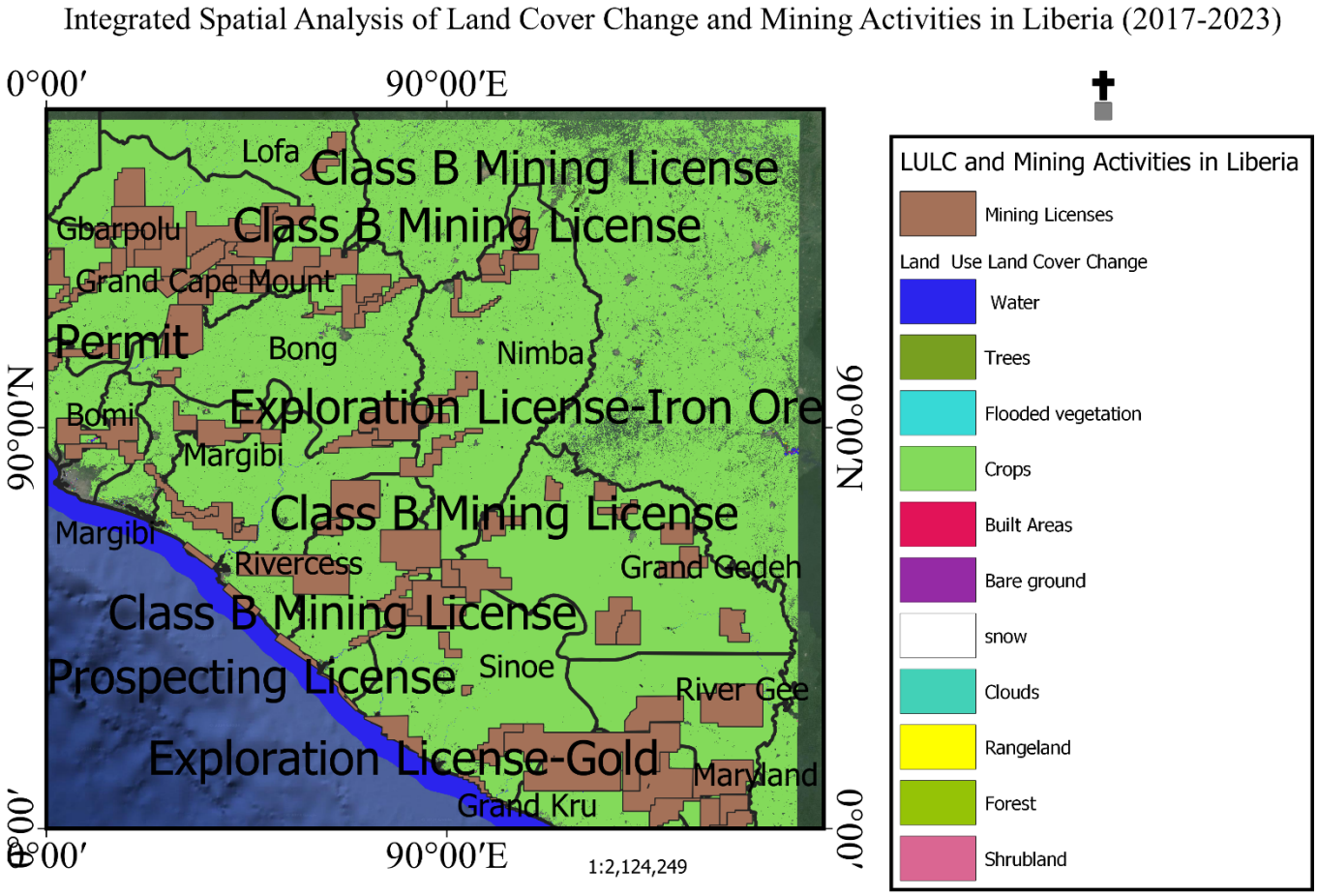

Figure 1. Shows the map of the Land Cover Change and Mining Activities in Liberia.

4.2 Table of Land Use Land Cover Change in Liberia (2017-2023)

Land Use Change,	Area in Hectares
Forest to Waterbody	6713.02
Flooded Vegetation to Waterbody	2425.45
Crops to Waterbody	80.45
Built -Area to Waterbody	61.81
Bare ground to a water body	452.38
Clouds to a water body	457.13
Rangeland to a water body	#249.32
water to Vegetation	2593.29
Flooded Vegetation to Trees	4484.06
Crops to vegetation	2335.57
Built -Area to Vegetation	1468.59
Bare ground to Vegetation	1261.9
Clouds to Vegetation	5327.91
Water to Flooded Vegetation	516.73
Trees to Flooded Vegetation	1874.46
Flooded Vegetation -No Change	14730.27
Crops to Flooded Vegetation	85.76
Built -Area to Flooded Vegetation	10.21
Bare ground to Flooded Vegetation	102.95
Clouds to Flooded Vegetation	215.69
Rangeland to Flooded Vegetation	673.11
Water to Crops	14.93
Trees to crops	3085.45
Flooded vegetation to crops	167.48
Crops -No Change	1451.27
Built Area to Crops	66.79
Bare ground to crops	16.12
Clouds to crops	108.22
Rangeland to Crops	2014.65
Waterbody to Built Area	182.91
Forest to Built Area	41401.23
Flooded Vegetation to Built Area	435.46
Crops to Built Area	1147.15
Bare Ground to Built Area	413.0

Clouds to Built Area	6119.6
Rangeland to Built Area	8670.44
Waterbody to Bare ground	214.07
Vegetation to Bare ground	67.31
Flooded Vegetation to Bare ground	4.44
Crops to Bare ground	6.37
Built Area to Bare ground	37.95
Bare ground-No Change	268.47
Clouds to Bare ground	ä10.81
Rangeland to Bare ground	32.44
Waterbody to clouds	11.87
Vegetation to Clouds	817.02
Flooded Vegetation to Clouds	22.53
Crops to Clouds	22.58
Built Area to Clouds	87.08
Ba reground to Clouds	21.85
Waterbody to Rangeland	292.11
Vegetation to Rangeland	202214.23
Flooded Vegetation to Rangeland	698.61
Crops to Rangeland	912.63
Built Area to Rangeland	735.38
Ba reground to Rangeland	590.59
Cloud to Rangeland	1409.01

Figure 2. Shows the table of Land Use Land Cover Change in Liberia (2017-2023)

4.3 Major land use transitions in Liberia between 2017 and 2023

Flooded Vegetation to Waterbody: 2425.45 hectares
Crops to Waterbody: 80.45 hectares
Built-Area to Waterbody: 61.81 hectares
Bare ground to a water body: 452.38 hectares
Clouds to a water body: 457.13 hectares
Rangeland to a water body: 249.32 hectares
Water to Vegetation: 2593.29 hectares
Flooded Vegetation to Trees: 4484.06 hectares
Crops to Vegetation: 2335.57 hectares
Built-Area to Vegetation: 1468.59 hectares
Bare ground to Vegetation: 1261.9 hectares

Figure 3. Shows the table of the Major land use transitions in Liberia between 2017 and 2023.

4.4 Proportion of Top 5 Land Use Land Cover Changes in Liberia (2017-2023)

The most significant land use change is "Vegetation to Rangeland," accounting for about 63.21% of the total area changed.
The second largest change is "Vegetation to Built Area", representing approximately 12.94% of the total change.
"Flooded Vegetation - No Change" is the third largest category, which might indicate areas that remained as flooded vegetation during this period.
"Rangeland to Built Area" and "Vegetation to Water body" round out the top 5 changes, each accounting for less than 3% of the total change.
Total area changed: 319892.11 hectares

Figure 4. Shows the table of the Proportion of the Top 5 Land Use Land Cover Changes in Liberia.

4.5 Bar Chart of the Top 5 Land Use Land Cover Changes in Liberia (2017-2023)

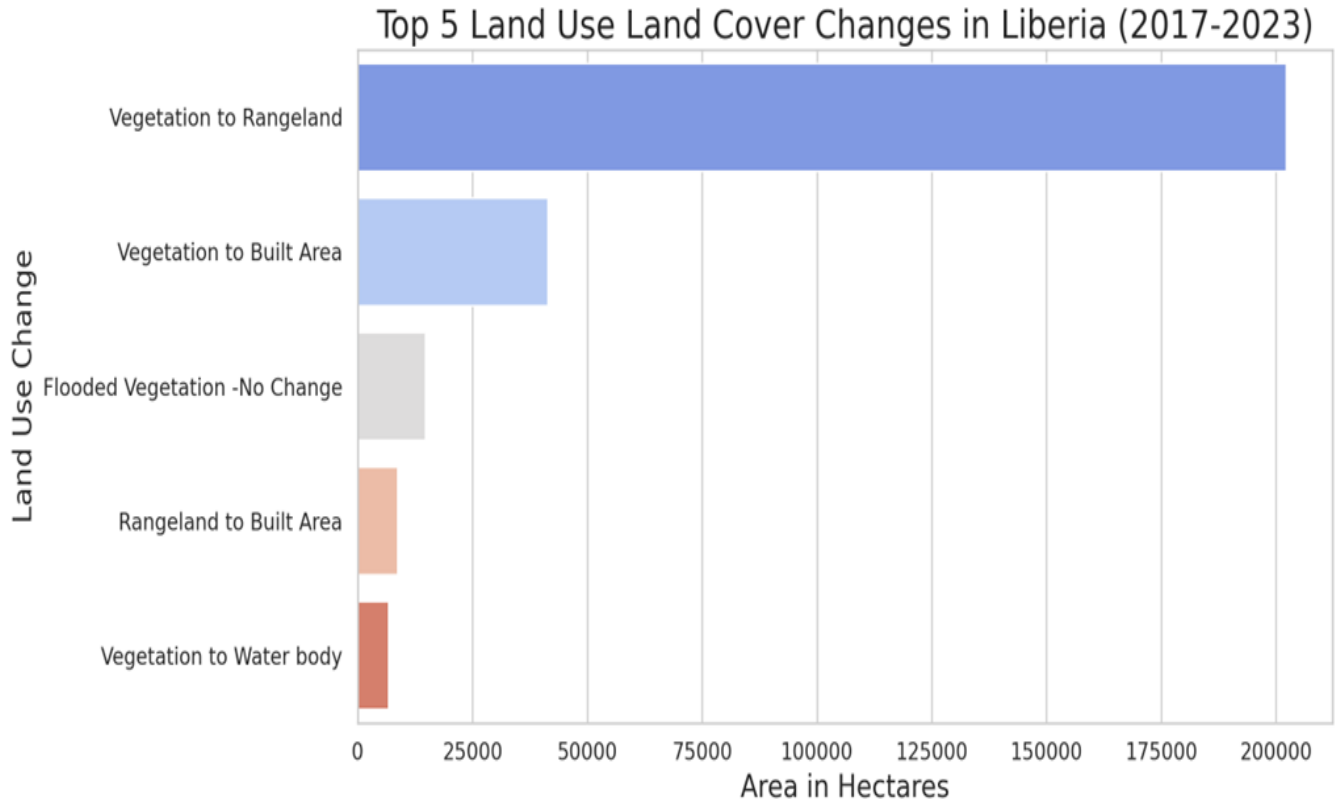

Figure 5. Shows a bar Chart of the Top 5 Land Use Land Cover Changes in Liberia.

4.6 Distribution of Major Land Use Transitions in Liberia (2017-2023)

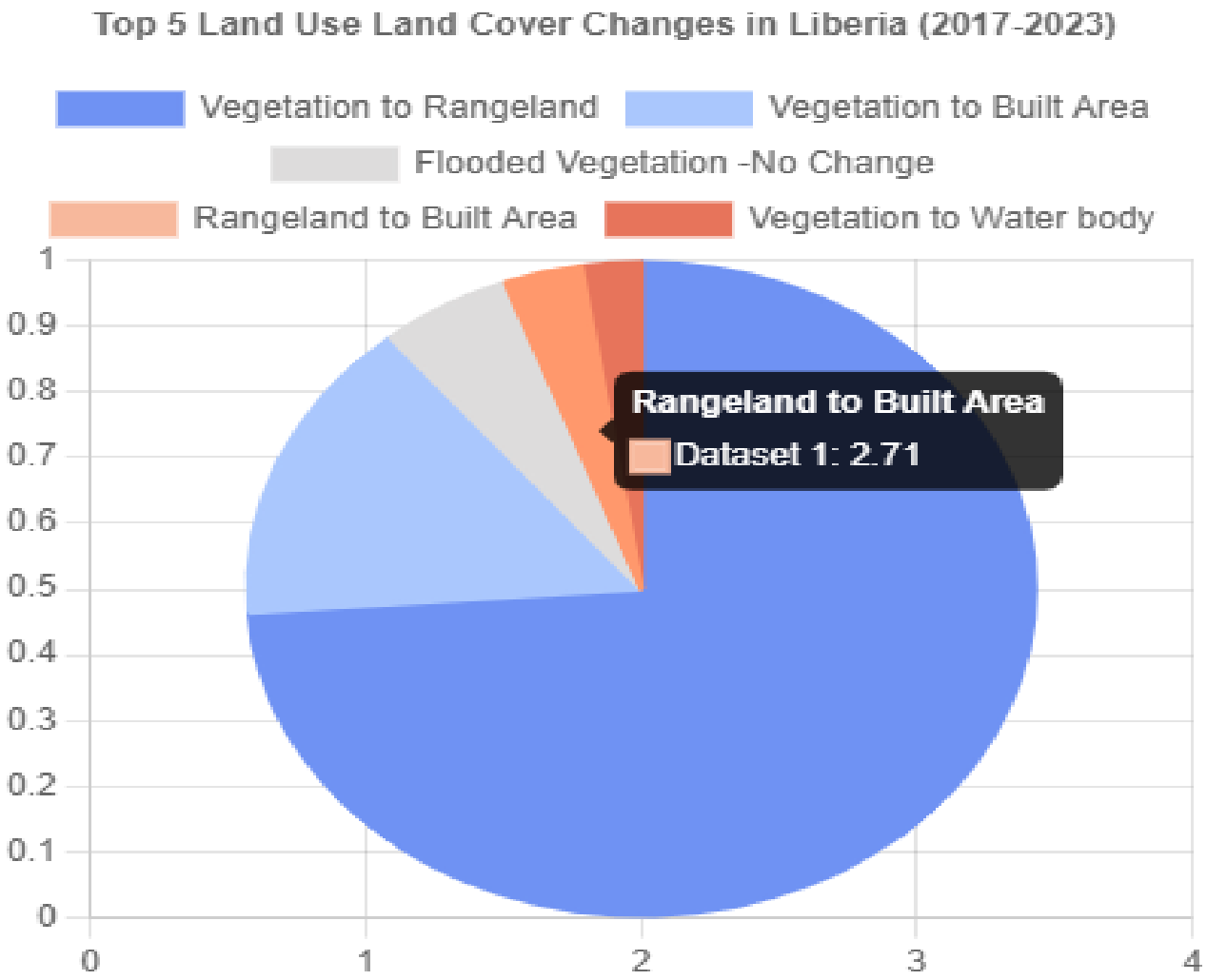

Figure 6. Shows Donut chart of major land use transitions in Liberia

4.7 Mineral Deposits and Administrative Regions of Liberia

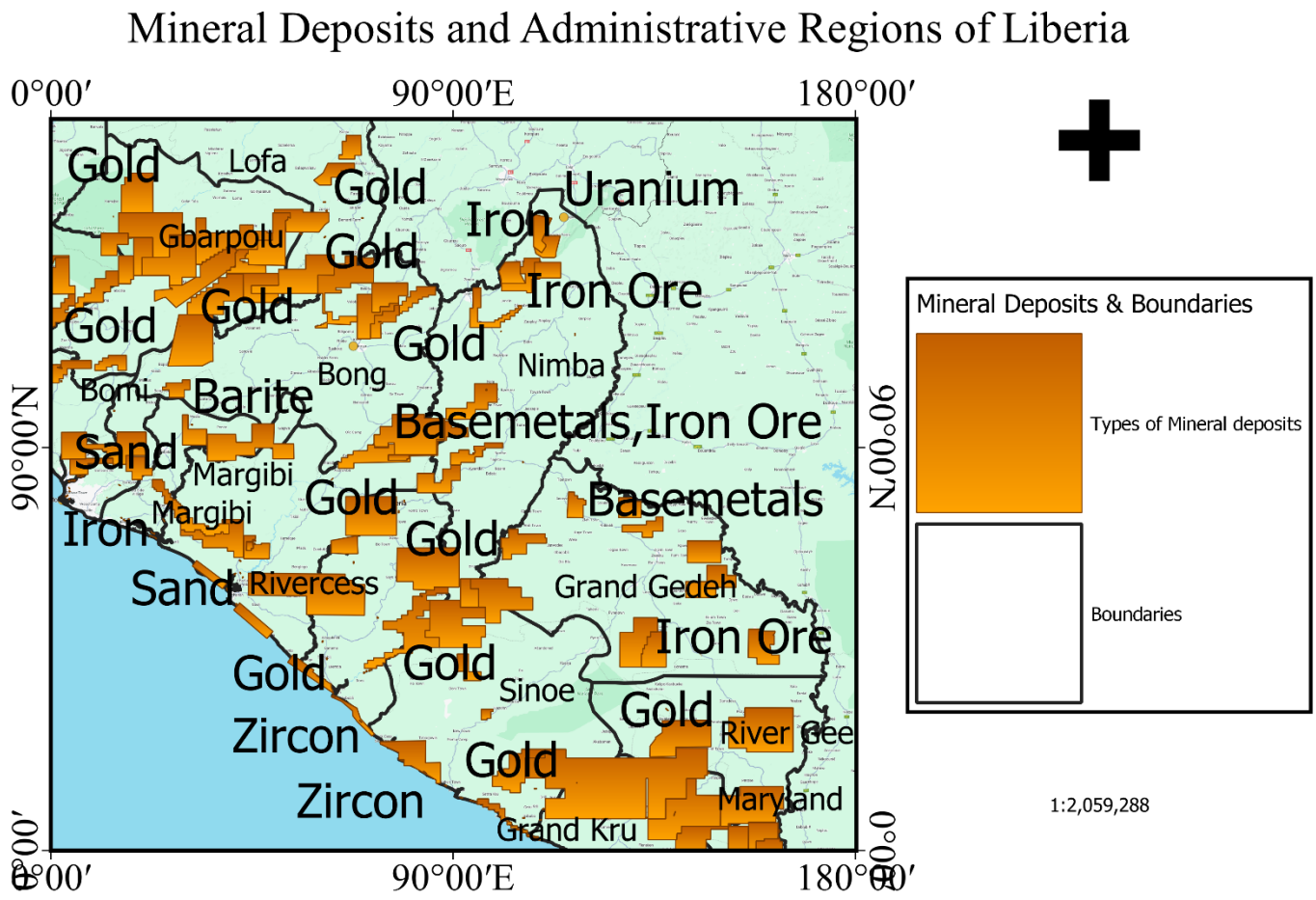

Figure 7. Shows the map of Mineral Deposits and Administrative Regions of Liberia.

4. 8 Active and Potential Mineral Deposits in Liberian Counties

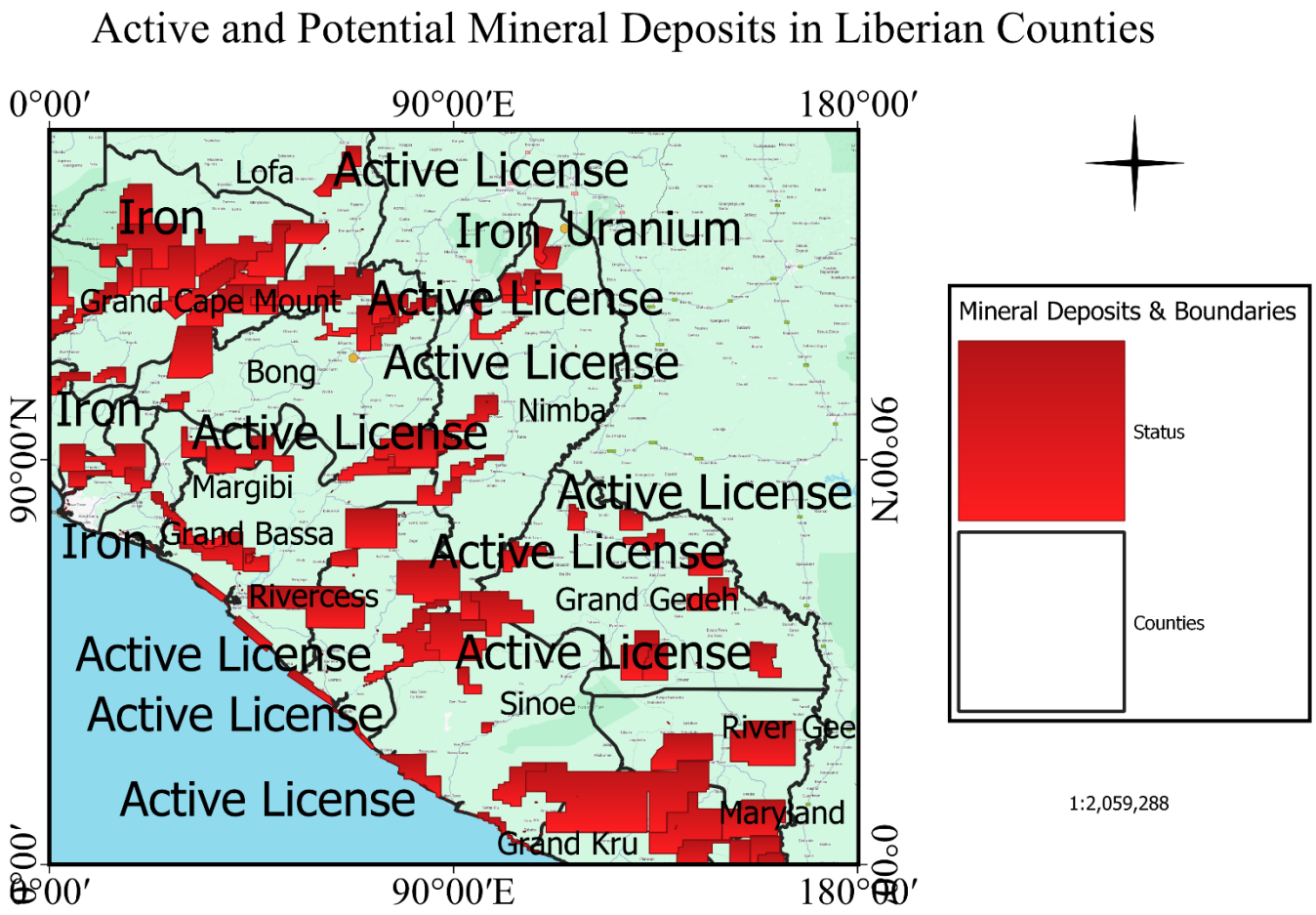

Figure 8. Shows the map of the Active and Potential Mineral Deposits in Liberian Counties.

4.9 Protected Areas and Mining Licenses in Liberia

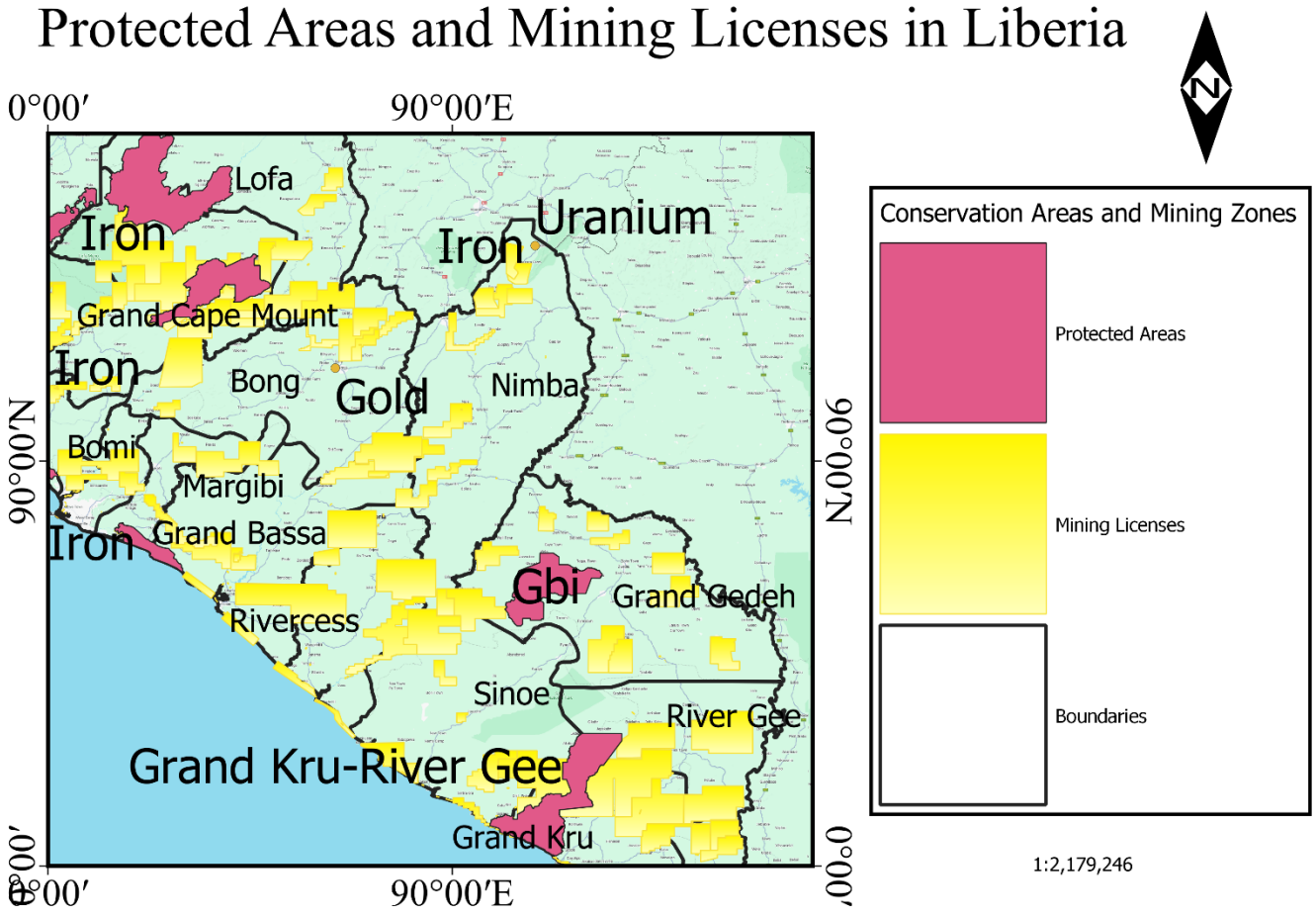

Figure 9. Shows the map of the protected areas and Mining Licenses in Liberia.

4.10 Mining Exploration Types and Population Density in Liberia

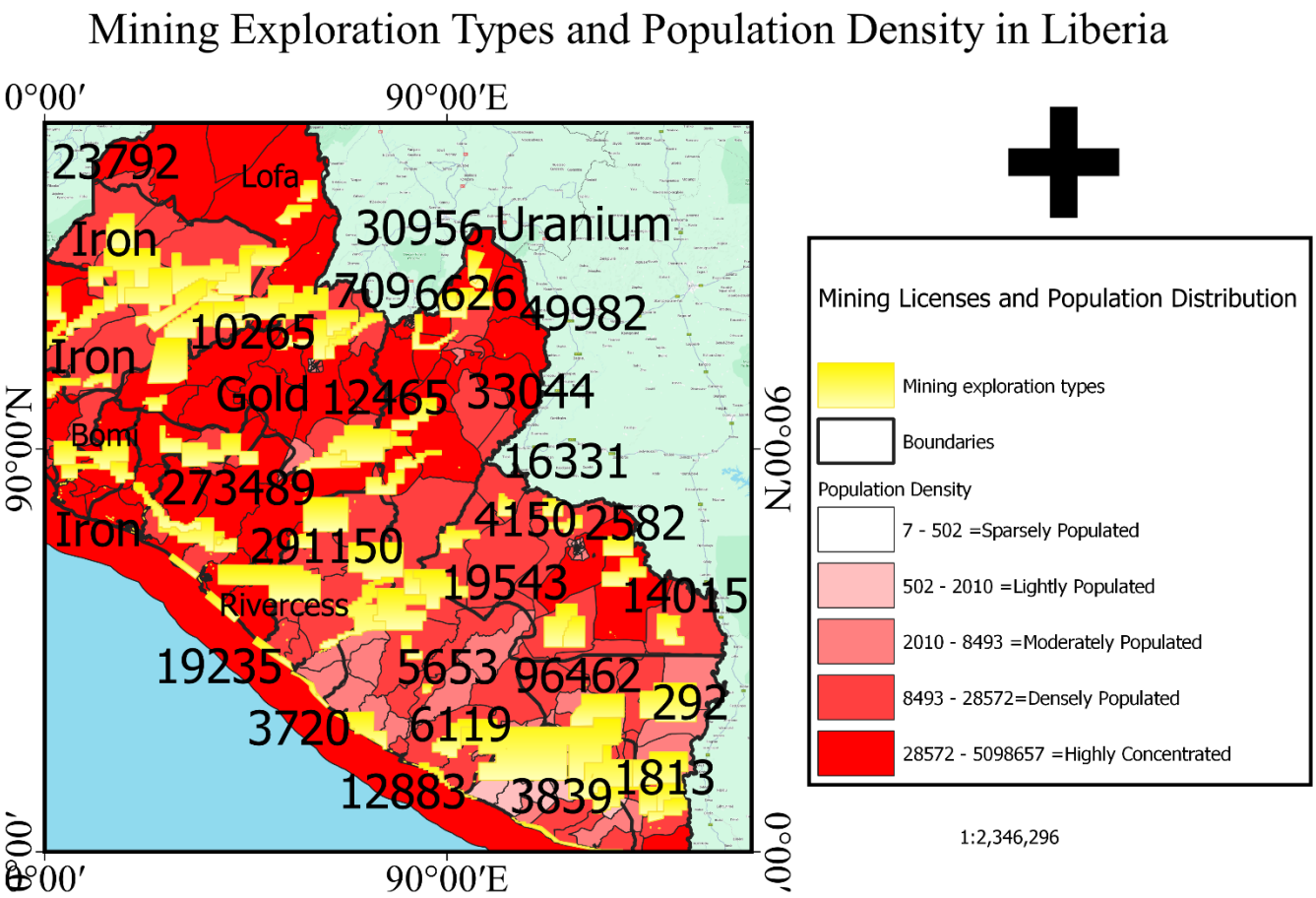

Figure 10. Shows the map of the Mining Exploration Types and Population Density in Liberia.

4.11 Mining Licenses and Road Network Infrastructure in Liberia

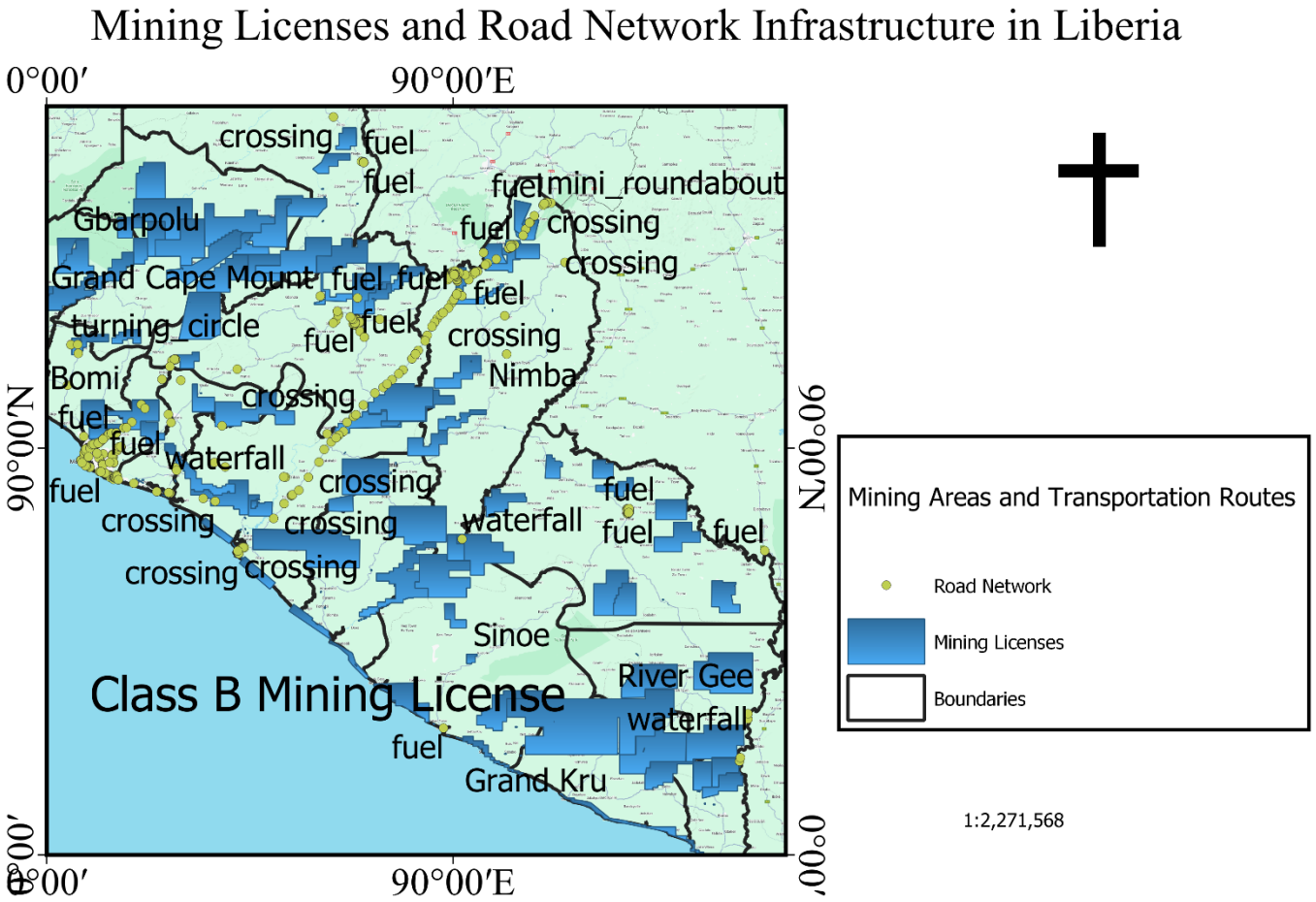

Figure 11. Shows the map of the Mining Licenses and Road Network Infrastructure in Liberia.

4.12 Mining Licenses and Natural Features in Liberia

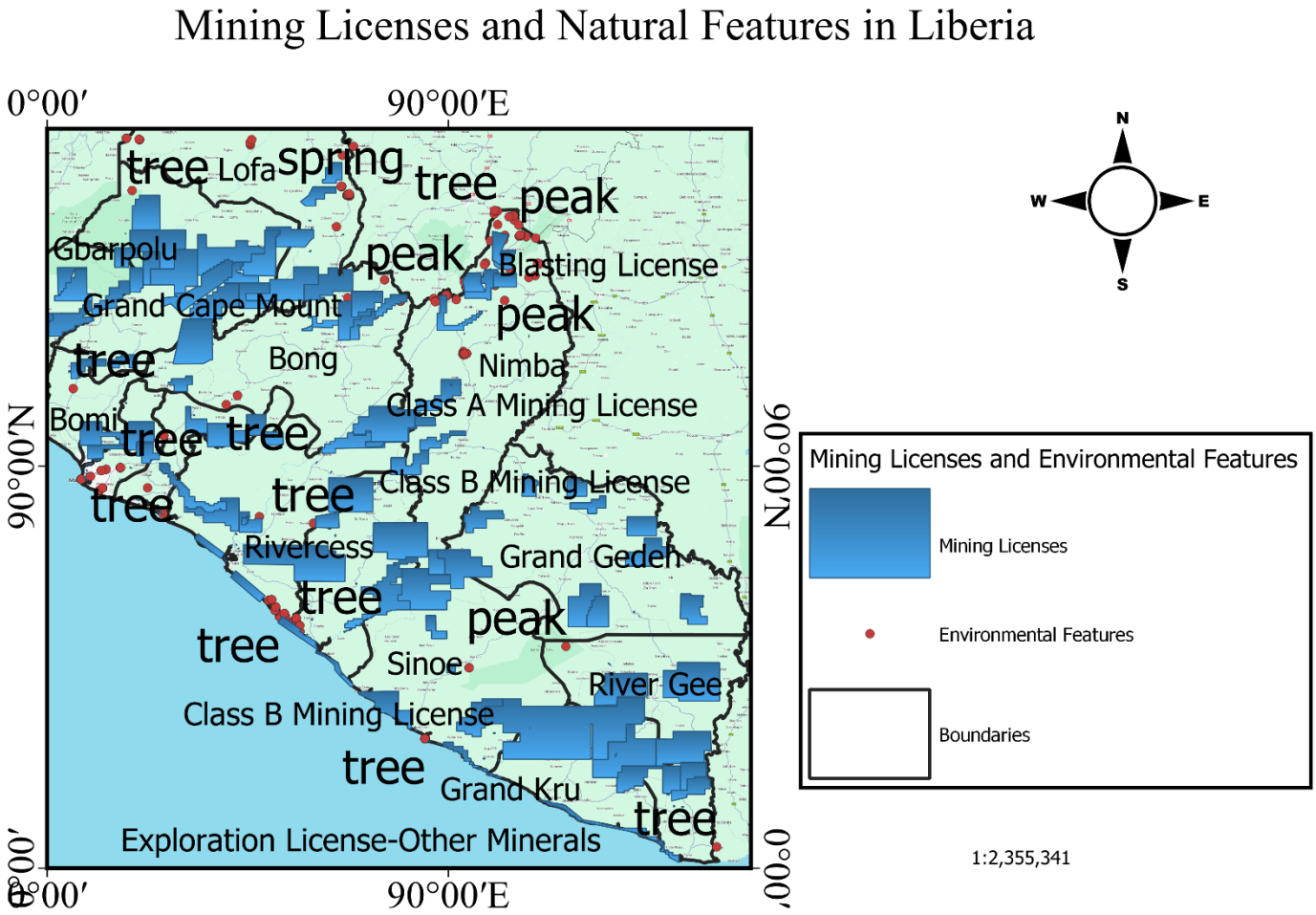

Figure 12. Shows the map of the Mining Licenses and Natural Features in Liberia.

4.13 Temporal Distribution of Mining Licenses and Natural Features in Liberia

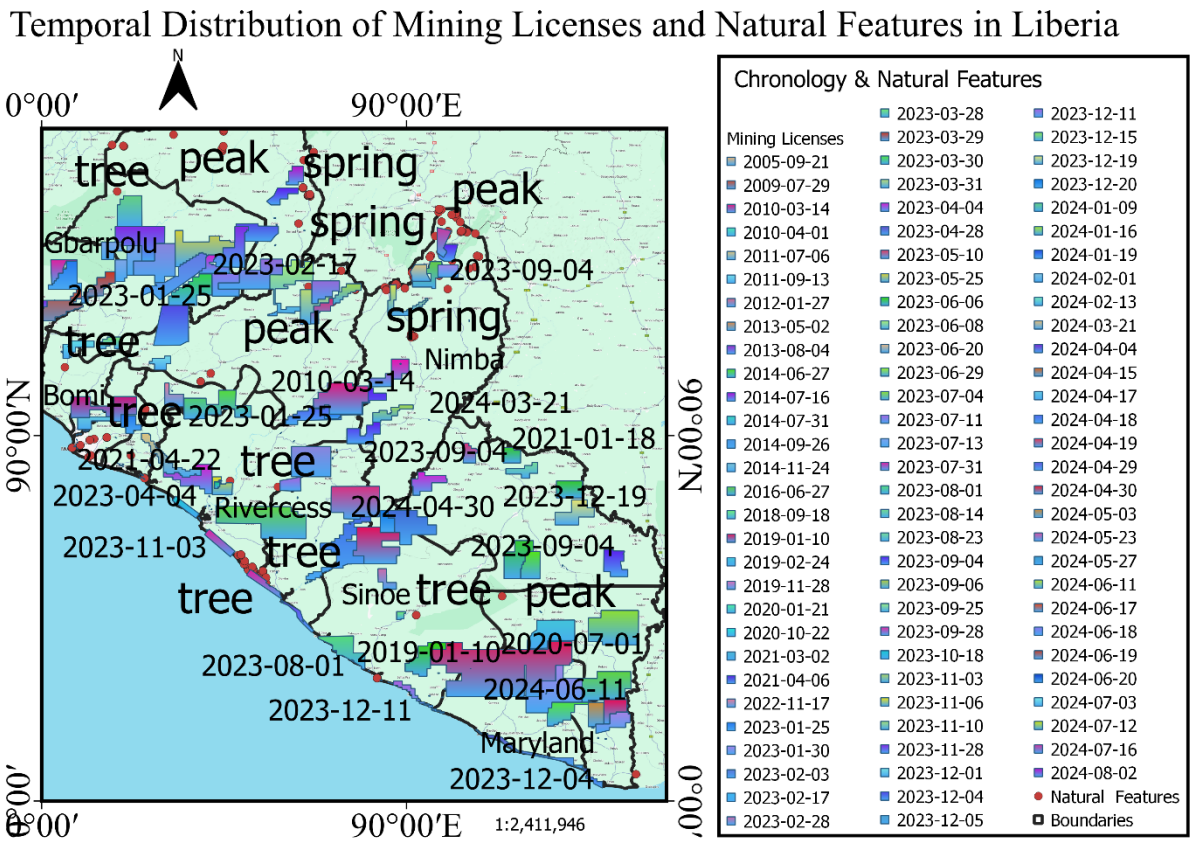

Figure 13. Shows the temporal distribution of Mining Licenses and Natural Features in Liberia.

4.14 License Expiration Dates and Environmental Elements in Liberia

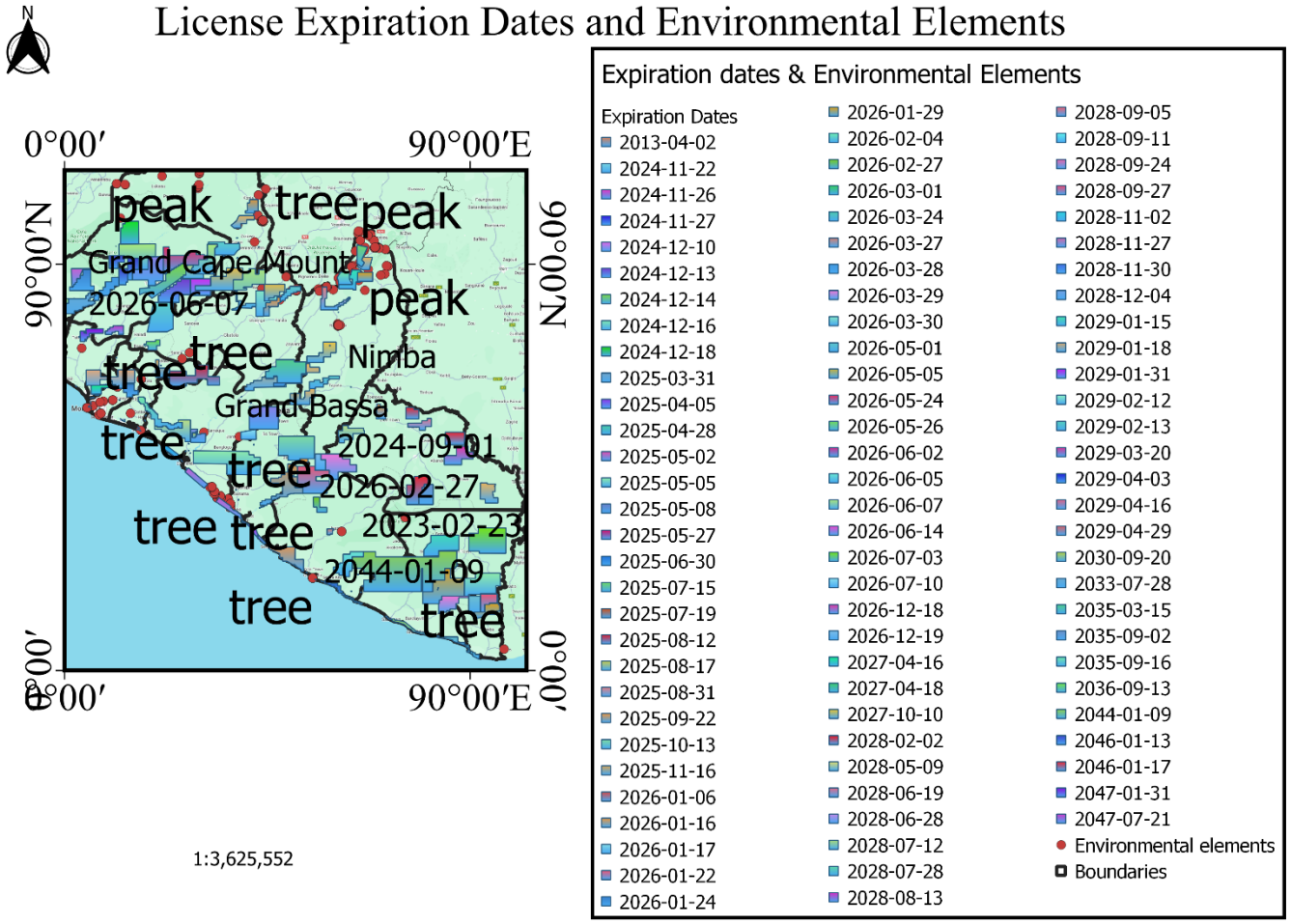

Figure 14. Shows the license Expiration Dates and Environmental Elements in Liberia.

4.15 Ownership of Mining Licenses and Natural Features Distribution in Liberia

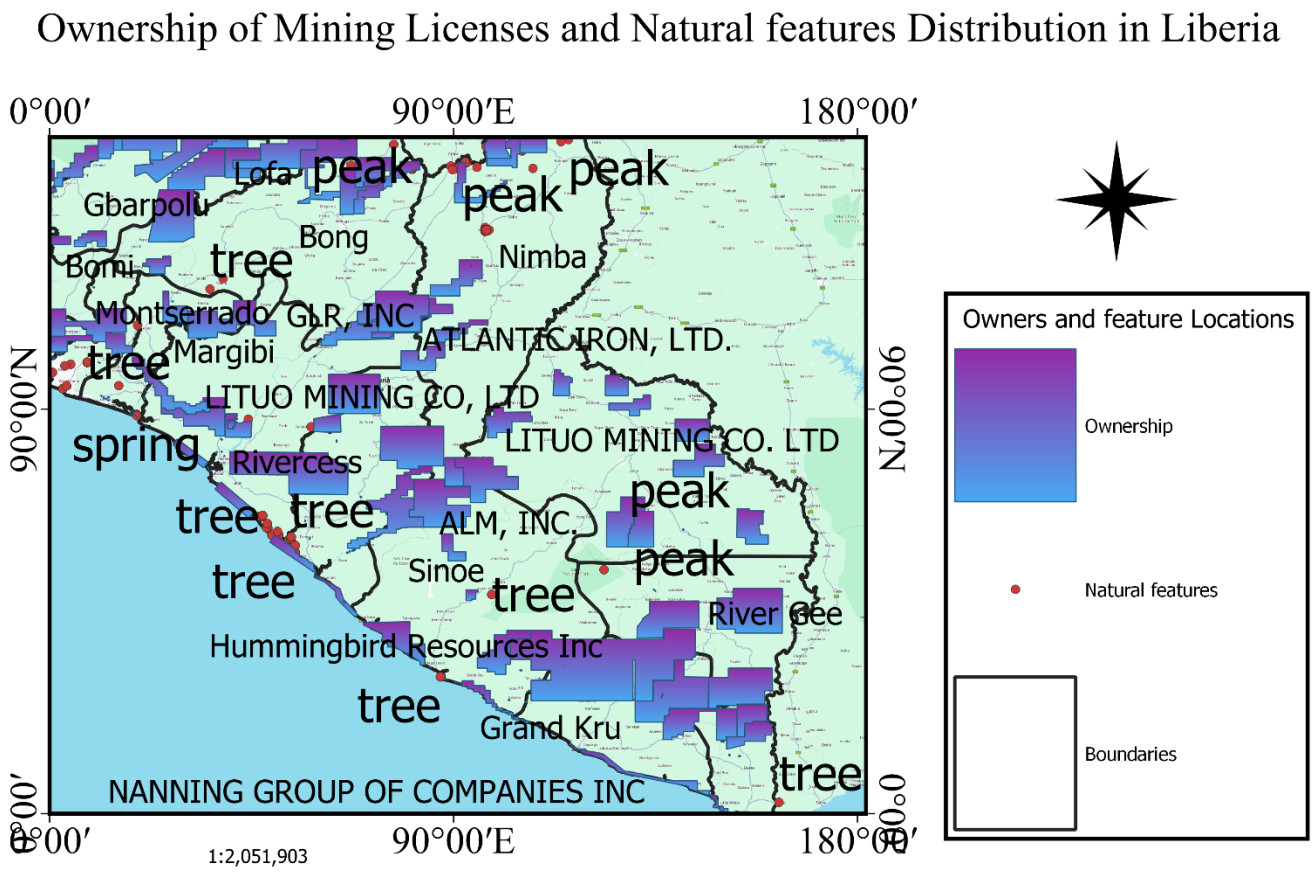

Figure 15. Shows the map of the Ownership of Mining Licenses and Natural Features distribution.

5 Discussion

5.1 Land Cover Change and Mining Activities

An analysis of land cover change and mining activities in Liberia shows that the landscape has undergone significant changes between 2017 and 2023. Maps and tables illustrate the dynamic interaction between natural land cover and human activities, particularly mining activities. The land cover change categories identified include water, trees, flooded vegetation, crops, cultivated land, bare land, snow, clouds, pasture, forest, and shrubland. These changes are driven by various exploration licenses in several regions of Liberia, including iron ore, gold, and Class B mining licenses (Figure 1)(Anderson et al., 2021; Parkes et al., 2019). The transformation of land cover types, as shown in Figures 2 and 3, highlights the extensive impact of mining and other anthropogenic activities. Notably, vegetation-to-rangeland conversion accounts for the largest proportion of land use change, with significant areas of forest and vegetation being converted to rangeland and built areas. This indicates a trend towards deforestation and urbanization, which has profound implications for biodiversity, climate regulation, and ecosystem services(Hegde et al., 2022).

5.2 Major Land Use Transitions

The major land use changes between 2017 and 2023, as illustrated in Figures 3 and 4, show substantial transitions in specific land cover types. For instance, the shift from flooded vegetation to trees and from bare ground to vegetation indicates some areas may be undergoing reforestation or natural regeneration. However, the considerable change from vegetation to

rangeland and built-up areas highlights the pressure on natural habitats from expanding agriculture and urban development(Leuenberger, Winkler, et al., 2021a).

5.3 Mineral Deposits and Administrative Regions

The bar chart (Figure 5) and pie chart (Figure 6) exhibit these changes, with the transition from vegetation to rangeland accounting for most of the land use change (63.21%). This is followed by vegetation in built-up areas (12.94%), pointing to a trend of increased human settlement and infrastructure growth at the expense of natural landscapes. The geographic distribution of mineral deposits across Liberia, as depicted in Figures 7 and 8, highlights the concentration of valuable resources such as gold, iron ore, barite, uranium, base metals, zircon, sand, and diamonds in specific counties. The maps reveal that counties like Sinoe, Grand Gedeh, Nimba, Bong, Gbarpolu, Rivercess, Bomi, and Lofa are abundant in mineral deposits, which has implications for regional development and economic planning(Maja & Ayano, 2021; Orimoogunje et al., 2011; Using a GIS to Select Priority Areas for Conservation (2000) | S.P. Woodhouse | 59 Citations, n.d.).

5.4 Protected Areas and Mining Licenses

The overlap between protected areas and mining licenses, as shown in Figure 9, raises concerns about the potential environmental impacts of mining activities on ecologically sensitive regions. Protected areas such as Gbi, Grand Kru-River Gee National Park, Lofa National Park, Lake Piso Multiple Sustainable Use Reserve, Gola Rainforest National Park, Margibi Mangrove, Kpo Mountains, and Foya National Park are vital for biodiversity conservation. The presence of mining licenses for uranium, gold, and iron ore within these areas necessitates

stringent environmental regulations and monitoring to mitigate adverse effects(Hughey et al., 2003).

5.5 Population Density and Mining Licenses

The analysis of population density around mining licenses (Figure 10) reveals that mining activities are distributed across areas with varying population densities. This spatial relationship is critical for understanding the socio-economic impacts of mining on local communities. Areas with higher population densities may experience more significant disruptions and require more robust social and environmental safeguards(Finucane, 2008).

5.6 Road Network Infrastructure and Mining Licenses

The integration of road network infrastructure with mining licenses (Figure 11) underscores the importance of transportation routes for mining operations. The dominance of crossings as the primary transportation route highlights the need for improved infrastructure to support mining activities and ensure efficient logistics. This also has implications for environmental sustainability, as road construction and maintenance can lead to habitat fragmentation and increased human-wildlife conflicts(Luthfi Marfungah et al., 2024; Morrison et al., 2012).

5.7 Natural Features and Mining Licenses

The spatial distribution of natural features such as trees, peaks, and springs about mining licenses (Figures 12 and 13) provides insights into the potential environmental impacts of mining. Trees, being the most dominant natural feature, play a crucial role in maintaining ecological balance. The temporal distribution of mining licenses from 2005 to 2024 indicates

ongoing and future mining activities, necessitating continuous environmental monitoring and management(Agboola et al., 2020).

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5.8 License Expiration Dates and Environmental Elements

The analysis of license expiration dates and environmental elements (Figure 14) highlights the temporal aspect of mining activities and their potential long-term impacts. The expiration dates ranging from 2013 to 2047 indicate varying durations of mining operations, which can influence the extent of environmental degradation and recovery(Leuenberger, Winkler, et al., 2021b; Lyatuu et al., 2021).

5.9 Ownership of Mining Licenses and Natural Features

The ownership of mining licenses, as shown in Figure 15, reveals a diverse range of companies involved in mining activities in Liberia. Companies such as Hummingbird Resources INC, Lituo Mining Co. LTD, Atlantic Ron LTD, GLR INC, Nanning Group of Companies INC, and others have significant stakes in the mining sector. Understanding the ownership structure is crucial for assessing corporate responsibility and ensuring compliance with environmental regulations(Dietler et al., 2021b).

6 Conclusion

The spatial analysis of Liberia's mining industry reveals the intricate interactions between mining, land use change, population trends, infrastructure growth, and environmental sustainability(Wood, 1993). The major land transitions, especially the conversion of vegetation into rangelands and developed areas, highlight the necessity for sustainable land management to balance economic progress and environmental protection(Kalokoh & Kochtcheeva, 2022). The locations of mineral deposits and their overlap with protected zones necessitate strict environmental laws to safeguard ecologically fragile areas(Wilson et al., 2017). The connection between mining licenses and population density stresses the importance of social safeguards to mitigate mining's socioeconomic impacts on communities. Improved road infrastructure is vital to support mining operations but must be developed sustainably to minimize habitat fragmentation. Ongoing environmental monitoring and management are essential to address mining's potential effects on natural features like trees, peaks, and springs(Mathews et al., 2005). The timeline of mining licenses and the range of ownership models underscore the need for robust regulations to ensure corporate accountability and environmental compliance. Overall, this study offers valuable insights into the spatial dynamics of Liberia's mining industry and establishes a foundation for informed decision-making that promotes sustainable development and environmental sustainability.(Antoci et al., 2019; Leuenberger, Dietler, et al., 2021; Yao et al., 2021).

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