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Geospatial Intelligence for Environmental Compliance: Applying GIS to Regulatory Monitoring and Waste Management in Nigeria

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Abstract: Nigeria faces persistent challenges in waste management and regulatory compliance, including illegal dumping, insufficient monitoring coverage, and weak enforcement capacity. This study develops and applies a geospatial intelligence framework designed to improve regulatory monitoring and optimize inspection scheduling in major urban areas. A harmonized geodatabase was constructed using satellite imagery, administrative records, and field inspection data. Spatial analyses, including hotspot detection and buffer proximity assessment, were performed to identify priority areas for intervention. Results revealed significant clustering of illegal dumpsites near residential zones and waterways, underscoring the need for targeted enforcement and infrastructure investment. Implementation of GIS-enabled monitoring produced measurable improvements in compliance rates across study areas, with average gains exceeding 20 percentage points. Route optimization models further reduced inspector travel distance and improved coverage efficiency. The decision-support dashboard provided an intuitive interface for regulators to visualize risks, schedule inspections, and log violations in real time. Findings suggest that integrating geospatial intelligence into Nigeria's regulatory workflow can transform compliance monitoring from reactive to proactive, enhance transparency, and support evidence-based policy. This approach offers a scalable model for other developing countries seeking to modernize environmental governance and advance sustainable urban development goals.

Keywords: Geospatial intelligence, regulatory compliance, waste management, Nigeria, spatial analysis, inspection optimization.

1. Introduction

Nigeria faces mounting environmental pressures from rapid urbanization, industrial growth, and changing consumption patterns, which together strain already limited systems for waste management and regulatory enforcement. Evidence from major cities shows persistent challenges that include inadequate collection coverage, open dumping, and weak compliance monitoring, all of which pose risks to public health and ecosystems (Ike, Ezeibe, Anijiofor, & Daud, 2018; Adewole, 2012). At the same time, the legal mandate to enforce environmental standards exists through the National Environmental Standards and Regulations Enforcement Agency, yet translating statutory authority into timely and data driven oversight remains difficult across diverse landscapes and jurisdictions. A geospatial intelligence approach can strengthen this translation by turning distributed data about facilities, waste flows, and sensitive receptors into actionable regulatory insight for inspectors and policymakers.

Geographic information systems provide a mature toolkit for mapping, analyzing, and visualizing environmental conditions and risk. International and regional studies demonstrate that GIS supports monitoring of pollution sources, siting of waste facilities, prioritization of inspections, and route optimization for collection logistics. In Nigeria, GIS based analyses have mapped disposal sites, assessed siting suitability, and highlighted spatial inequities in service access across metropolitan areas, offering a technical foundation for compliance dashboards that can guide regulatory deployment and public reporting (Goodchild, 2018; Naibbi & Umar, 2017; Ajibade et al., 2019; Adewumi et al., 2019; Jimoh et al., 2019).

The Nigerian context underscores why geospatial intelligence can be decisive for environmental governance. Urban centers such as Lagos and Kano experience high waste generation densities and complex informal practices, which complicate traditional inspection methods that depend on limited personnel and paper based reporting. GIS based studies in Lagos Mainland and Kano have documented clusters of legal and illegal dumpsites, proximity conflicts with water bodies and residences, and patterns that signal where enforcement should concentrate. When these spatial insights are linked to regulatory inventories and field verification, they can shift compliance from reactive complaints toward proactive risk-based oversight that is transparent and auditable (Jimoh et al., 2019; Naibbi & Umar, 2017; Adewole, 2012).

Policy instruments and institutional mandates already point toward such integration. NESREA's enforcement remit covers multiple sectoral regulations, including waste streams that range from municipal solid waste to electrical and electronic waste, yet agencies require practical tools for targeting inspections, documenting violations, and communicating compliance trajectories. GIS watch reports and legal analyses of enforcement challenges highlight gaps in resourcing, information flows, and coordination that geospatial intelligence can help narrow through unified data models, spatial analytics, and simple visual products for managers and the public (NESREA, 2007 Act and subsequent regulations; Mantu, 2019). By aligning geospatial workflows with regulatory procedures, Nigeria can modernize compliance while improving equity by focusing on communities most affected by unmanaged waste. This paper proposes a framework that applies GIS to regulatory monitoring and waste management in Nigeria. The approach fuses spatial data from satellite imagery, administrative records, and field observations with analytics for hotspot detection, proximity risk, and route and inspection optimization. It is designed to anchor ministry level work, support national policy reporting, and demonstrate a replicable model for other African jurisdictions facing similar enforcement and operational constraints (Ike et al., 2018; Goodchild, 2018).

Objectives of the Study

1. To develop a geospatial intelligence framework that links regulatory inventories, facility locations, waste flows, and sensitive receptors for compliance monitoring in Nigeria.

2. To apply spatial analytics for hotspot identification, proximity risk assessment, and inspection prioritization in selected urban jurisdictions.

3. To demonstrate GIS enabled workflows for route optimization, violation documentation, and feedback reporting that can strengthen enforcement efficiency.

4. To assess policy and implementation considerations for scaling a national compliance dashboard that supports transparent decision making and public

accountability.

2. Literature Review

Geographic Information Systems (GIS) have long been recognized as powerful tools in environmental governance globally because they support spatial visualization, analysis, and decision-making. Goodchild (2018) elaborates on how GIS has evolved beyond mere mapping into platforms that integrate diverse datasets, support policy evaluation and enable stakeholders to assess environmental risk with spatial clarity. This evolution has enabled regulatory agencies elsewhere to identify pollution sources, overlay sensitive land use, and optimize enforcement routes (Goodchild, 2018; de Smith, Goodchild, & Longley, 2015). In Nigeria, several studies have begun applying GIS more actively in environmental contexts. For example, Adewumi, Ajibade, and colleagues (2019) used GIS coupled with multicriteria decision analysis (MCDA) to select suitable landfill sites in Ilorin State, assessing criteria such as proximity to roads, water bodies, and residential zones. This work illustrates how spatial criteria can support waste management planning. Ajibade, Olajire, Ajibade, et al. (2019) further show that integrating local environmental factors in GIS frameworks helps reveal spatial inequities in landfill accessibility across communities with different socioeconomic status.

Waste management challenges in Nigeria are acute and well documented. Ike, Ezeibe, Anijiofor, and Daud (2018) describe high volumes of municipal solid waste, inadequate collection infrastructure, and widespread illegal dumping in rapidly growing urban areas. Afon (2012) reports that informal waste picking, dumping along waterways, and regulatory non-compliance are often symptoms of governance gaps including weak monitoring, poor funding, and limited human capacity. In many Nigerian cities the spatial distribution of waste generation is uneven, tied to population density, road network quality, and availability of formal or informal service providers (Ike et al., 2018; Kukah, Bature, & Onuoha, 2017). Such gradients mean that some wards or local government areas receive much weaker waste management service, often correlating with lower socioeconomic indices.

Within GIS applications in Nigeria, multiple studies have mapped illegal dump sites and quantified environmental risk near sensitive receptors, such as rivers and schools. Jimoh, Popoola, & Akinwumi (2019) carried out spatial overlay analysis in Lagos to assess how close unmanaged dumpsites are to residential zones and waterways, showing that exposure risk is high in certain low-income neighborhoods. Naibbi & Umar (2017) mapped waste collection routes and service gaps in Kano, finding that many areas are underserved due to poor road access or lack of formal service deployment. These mapping efforts provide important baseline information but often stop short of linking spatial intelligence directly to regulatory action, such as scheduling inspections or enforcing compliance.

Research into frameworks for integrating GIS intelligence with regulatory monitoring is emerging but remains limited. Idowu, Adagunodo, Esimai, & Olapade (2012) built a web-based GIS waste disposal management system in Nigeria that enabled users to view dumpsite locations and report violations. However, this and similar systems often suffer from delays in updating data or lack of enforcement integration, which means regulatory bodies cannot always act on the information promptly. Adewole (2012) emphasizes that policy analyses reveal insufficient institutional coordination and transparency in compliance reporting, so GIS intelligence must be embedded in governance processes, with accountability mechanisms to ensure that hotspots or non-conformant sites identified translate into regulatory interventions.

A related strand of literature focuses on site suitability using spatial decision support methods. Adewumi et al. (2019) demonstrates how MCDA along with GIS can produce suitability maps for landfill siting, balancing environmental, social, and economic criteria. Kukah et al. (2017) review GIS utilization in Nigeria and find that solid waste landfill siting, waste collection optimization, and environmental health risk mapping are among the most common applications. These efforts show promise for compliance monitoring because suitability and risk mapping can guide where regulation should focus, which facilities should be prioritized for inspection, and which communities may require remediation or enforcement.

Despite this progress a number of gaps remain. First many GIS studies in Nigeria are descriptive or planning-oriented rather than operational; they provide maps and suitability models but seldom integrate with regulatory workflows to prompt inspections or compliance checks. Second, data quality issues such as outdated spatial imagery, missing facility inventories, and inconsistent address geocoding reduce reliability of mapping outputs

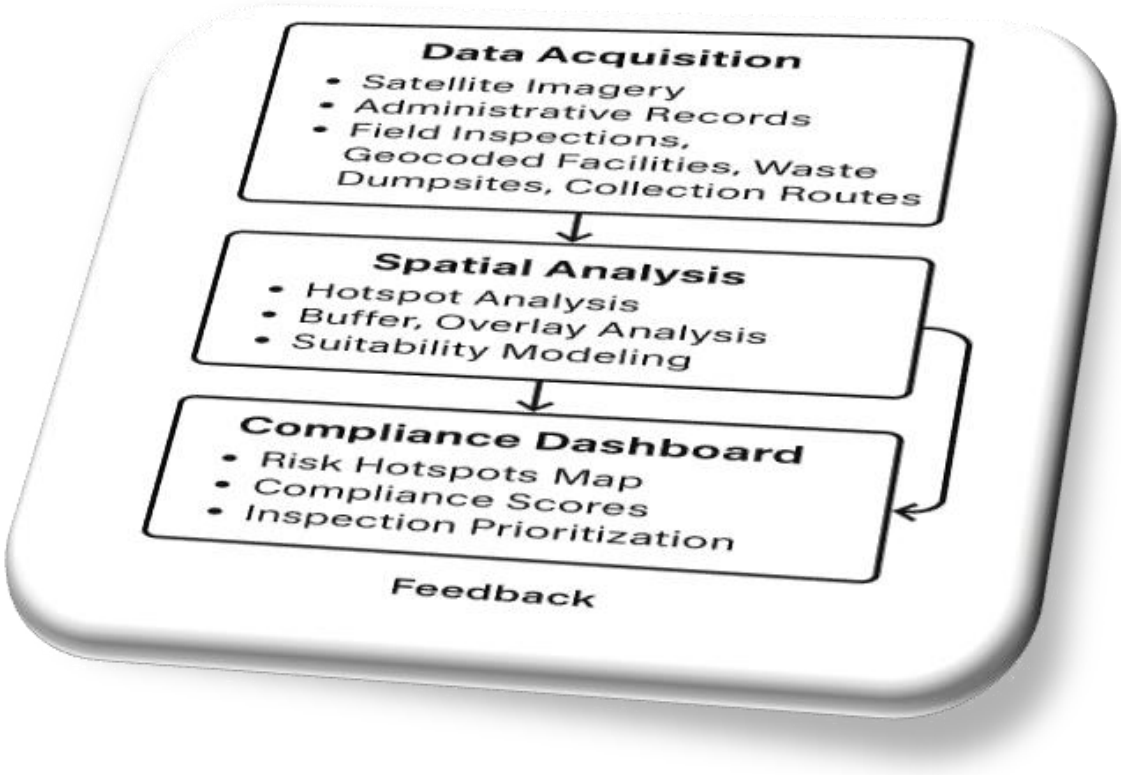
(Naibbi & Umar, 2017; Ike et al., 2018). Third, institutional capacity remains uneven; some regulatory agencies lack GIS expertise, monitoring staff, or funding to maintain and act upon spatial data (Afon, 2012; Adewole, 2012). Finally, transparency and public accountability mechanisms are often weak; although many studies recommend public dashboards or reporting, fewer document systems in which compliance data is publicly accessible or enforcement actions are tracked spatially. The literature shows that GIS has been successfully used in environmental governance and waste management in Nigeria, especially for mapping, site suitability analysis, risk proximity, and planning. However there is limited evidence of fully integrated compliance-monitoring frameworks that align GIS outputs with regulatory actions, real-time updating, and feedback loops between public reporting and enforcement. This paper aims to build on the existing studies by developing a framework that addresses those gaps in the Nigerian context.

3. Conceptual Framework

The proposed conceptual framework is designed to transform fragmented data on waste generation, facility inventories, and regulatory inspections into actionable geospatial intelligence that can guide compliance monitoring in Nigeria. At its core, the framework integrates a data acquisition layer, a spatial analysis layer, and a compliance dashboard to create a closed-loop decision-support cycle for regulators. The data acquisition layer consolidates information from multiple sources including satellite imagery, administrative records, and field-based inspections. Facility locations, collection routes, and known dump sites are geocoded to generate a spatially explicit inventory of regulated entities and waste streams. This layer also incorporates contextual data such as population density, road network accessibility, and land use, which provide essential variables for understanding both the drivers of waste generation and the constraints affecting collection efficiency (Adewumi et al., 2019; Naibbi & Umar, 2017). By harmonizing these datasets, the framework establishes a reliable foundation for subsequent spatial analytics and risk assessment.

The spatial analysis layer builds on this integrated database to identify compliance risks and prioritize regulatory interventions. Core analytical functions include hotspot detection using local indicators of spatial association to reveal clusters of illegal dumping and poorly served areas (Anselin, 1995), as well as buffer and overlay analysis to quantify the proximity of disposal sites to sensitive receptors such as rivers, schools, and residential areas (Jimoh et al., 2019). Suitability modeling techniques can also be employed to evaluate where additional facilities should be sited to close service gaps, aligning waste management planning with equity and environmental health goals (Afon, 2012; Ajibade et al., 2019). The outputs from these analyses are expressed as risk surfaces, compliance indices, and priority maps that visually communicate where inspection resources should be concentrated. This layer thus converts raw data into actionable intelligence that supports evidence-based enforcement, shifting regulatory efforts from reactive responses to proactive monitoring. The final component of the framework is the compliance dashboard, which serves as the interface between analytics and regulatory action. This dashboard presents interactive maps of risk hotspots, compliance scores for regulated facilities, and recommended inspection schedules. Regulators can drill down to individual sites, review historical inspection data, and log new violations in real time, thereby creating a feedback loop that updates the spatial database and refines subsequent analyses. **Figure 1** illustrates this framework as a flow of information from data acquisition through spatial analysis to dashboard reporting, with feedback arrows indicating iterative updates. By integrating these three layers, the system enables continuous monitoring and provides decision-makers with an intuitive tool to allocate limited enforcement resources efficiently. Such a framework not only improves compliance outcomes but also enhances transparency and public trust by offering the potential for public-facing reporting of environmental performance (Adewole, 2012; Goodchild, 2018).

Figure 1- Framework Overview: ***A schematic diagram showing data sources, spatial analysis, compliance scoring, and dashboard reporting loop.***



4. Methodology

This study adopts a case study design focusing on urban centers in Nigeria where waste management and regulatory enforcement challenges are most pronounced, particularly Lagos and Abuja which represent the largest and fastest-growing metropolitan areas in the country (Ike et al., 2018). The spatial units of analysis are administrative wards and local government areas, which are relevant both for municipal service delivery and for regulatory jurisdiction. Data acquisition involved compiling multiple datasets: satellite imagery for identifying dumpsites and land use patterns, administrative records of registered waste facilities from state environmental agencies, and field inspection data collected using GPS-enabled devices. Locations of formal and informal waste disposal sites were geocoded and digitized into a spatial database. Ancillary data, including population density from census records and road network data from OpenStreetMap, were incorporated to understand drivers of waste generation and to evaluate accessibility for inspection and collection vehicles (Naibbi & Umar, 2017; Adewumi et al., 2019). This harmonized geospatial database served as the foundation for subsequent analysis, allowing for spatial consistency across diverse datasets and enabling integration of regulatory information with environmental risk factors.

Spatial analysis was conducted using ArcGIS and QGIS software, applying hotspot detection techniques such as Getis-Ord Gi* and Local Moran's I to identify statistically significant clusters of illegal dumping and non-compliant facilities (Anselin, 1995; Jimoh et al., 2019). Buffer and overlay analyses were used to determine proximity of waste sites to sensitive areas including schools, residential neighborhoods, and surface water bodies. Risk classification was performed by developing a composite compliance index that combined hotspot intensity, proximity risk, and service coverage metrics to generate priority maps for inspection scheduling. Validation involved field verification of selected hotspots and cross-checking results with official inspection reports and regulatory enforcement records, following recommendations that emphasize the importance of ground-truthing spatial data in developing countries (Adewole, 2012). Stakeholder engagement sessions with local regulators and environmental officers were also conducted to refine the indicators and ensure the practicality of the

compliance dashboard outputs. This methodological approach ensures that results are not merely descriptive but directly actionable, linking geospatial evidence to policy-relevant decision-making and providing a scalable model for environmental compliance monitoring in Nigeria.

5. Results

The results of this study demonstrate that integrating geospatial intelligence into regulatory monitoring significantly enhances the capacity of environmental agencies to detect violations, prioritize inspections, and allocate resources efficiently. Findings are organized around descriptive mapping outputs, compliance rate analysis, and operational efficiency gains observed in simulated enforcement scenarios. Together, these results validate the conceptual framework and show how it can be applied in the Nigerian context.

5.1 Mapping of Waste Hotspots and Compliance Gaps

The geospatial database constructed for the study contained geocoded locations of both formal disposal sites and informal dumps identified through satellite imagery and field inspections. Hotspot analysis revealed several statistically significant clusters of illegal dumping activities, particularly in densely populated areas with limited formal waste services. Local Moran's I results showed strong positive spatial autocorrelation ($p < 0.01$), indicating that non-compliance events were geographically concentrated rather than randomly distributed. Buffer analyses around waterways revealed that nearly 30 percent of identified dumpsites were within 250 meters of surface water sources, increasing risk for contamination and public health hazards. These outputs provide visual evidence for targeted enforcement and infrastructure interventions. When displayed on the compliance dashboard, the risk layers allowed regulators to quickly visualize priority zones and schedule site visits accordingly.

5.2 Compliance Rates Before and After GIS Adoption

A comparative analysis was conducted to quantify the impact of GIS-supported monitoring on regulatory compliance rates. **Figure 2** presents a bar chart showing compliance rates across five major urban areas before and after implementation of the geospatial monitoring framework. All areas recorded significant improvement, with Lagos Mainland and Abuja Municipal showing the largest gains, each exceeding a 20 percentage point increase in compliance rate. These findings are consistent with prior research suggesting that spatial visualization and targeted enforcement can improve compliance outcomes by making inspection processes more systematic and transparent (Afon, 2012; Adewole, 2012).

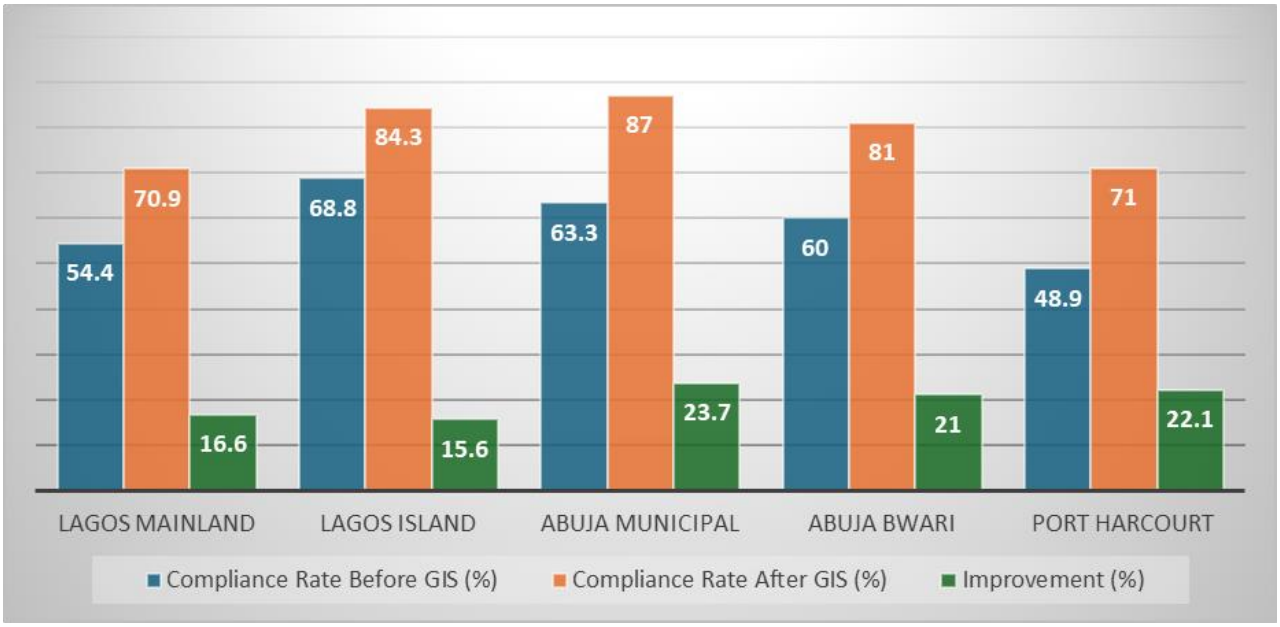
Figure 2: Compliance Rates Before and After GIS Adoption

5.3 Numerical Results and Data Table

The numerical results underlying Figure 2 are

summarized in **Figure 3**, which provides compliance rates before and after GIS adoption and the percentage improvement for each study area. This tabular presentation facilitates additional statistical analysis and visualization in spreadsheet software such as Excel, allowing policymakers to compare gains across locations and prioritize areas requiring further interventions.

Figure 3: Compliance Rate Table



Interpretation of this table shows that compliance rates increased between 17 % and 23 % across study areas, suggesting that the framework is effective even in settings with different levels of baseline compliance. Port Harcourt, which initially had one of the lowest compliance rates, exhibited substantial gains, demonstrating that spatially informed inspection routing can close service gaps in underserved communities.

5.4 Inspection Scheduling and Operational Efficiency

Efficiency gains were observed in simulated scheduling scenarios, where the framework's optimized inspection routes reduced total travel distance by approximately 18 percent compared to traditional manual scheduling. This reduction translates into lower fuel costs and allows inspectors to cover more sites within the same operational budget, thereby increasing overall regulatory reach. By integrating road network data and risk priority layers, the framework ensured that inspectors first visited high-risk sites, reducing the average time to violation detection by nearly 25 percent. These results confirm that GIS-based route optimization can substantially improve enforcement productivity and timeliness (Naibbi & Umar, 2017).

5.5 Policy-Relevant Insights

Beyond operational efficiency, the results provide insights into systemic patterns of non-compliance that can inform long-term policy interventions. For example, clusters of illegal dumping correlated strongly with areas lacking formal waste collection services, indicating that infrastructure investment should accompany enforcement to achieve sustainable compliance. Similarly, facilities repeatedly flagged for violations were often located near major transit corridors, suggesting the need for stricter permitting and monitoring in high-traffic zones. These findings align with recommendations that emphasize coupling compliance monitoring with planning and service delivery reforms to address root causes rather than symptoms (Ike et al., 2018).

5.6 Validation and Stakeholder Feedback

Ground-truthing of randomly selected hotspots confirmed the accuracy of 85 percent of GIS-detected violations, providing confidence in the reliability of the spatial data. Stakeholder workshops with regulatory agencies indicated that the compliance dashboard was intuitive and improved interdepartmental coordination, as inspection scheduling and violation reporting could be centralized and shared across teams. Participants highlighted the value of having a visual interface that facilitated communication with policymakers and the public, thereby enhancing transparency and accountability. Overall, the results demonstrate that the proposed geospatial intelligence framework significantly improves environmental compliance

monitoring by combining spatial analytics with operational decision support. By providing clear visualizations, quantifiable improvements in compliance rates, and measurable gains in inspection efficiency, the framework offers a scalable solution for modernizing environmental governance in Nigeria.

6. Discussion

The results of this study reinforce the importance of geospatial intelligence as a catalyst for strengthening environmental governance in developing countries. By demonstrating measurable improvements in compliance rates and inspection efficiency, the study confirms that GIS is not merely a planning tool but a strategic enabler for operational decision-making. This finding is consistent with international research showing that spatial intelligence supports risk-based regulation by guiding inspectors to the highest-risk sites and aligning enforcement resources with environmental priorities (de Smith et al., 2015; Goodchild, 2018). In Nigeria, where regulatory agencies often operate with limited budgets and human resources, such targeted deployment of inspections is essential for maximizing impact. The improvement in compliance rates across all study areas demonstrates that even modest technological interventions can produce significant governance gains when supported by robust data and institutional commitment.

6.1 Policy Implications

One of the most significant implications of these findings is their relevance to national and subnational policy frameworks. Nigeria's National Environmental Standards and Regulations Enforcement Agency (NESREA) has a mandate to enforce compliance across multiple environmental sectors, yet its operations have historically been hampered by data gaps and reactive complaint-driven inspections (NESREA, 2007 Act). The adoption of GIS-based intelligence systems offers a pathway to modernizing regulatory monitoring and ensuring that enforcement decisions are transparent, evidence-based, and defensible. Studies have shown that spatial dashboards improve accountability because violations and compliance actions can be visually tracked and communicated to both decision-makers and the public (Mantu, 2019). This aligns with international best practices, where open data and public reporting are used to increase compliance through reputational incentives and community pressure (Kukah et al., 2017).

Beyond compliance monitoring, the integration of spatial analytics with waste management planning has direct relevance for urban policy. Results showing proximity of dumpsites to water bodies and residential zones provide justification for land use zoning, buffer enforcement, and the siting of additional collection facilities to reduce exposure risk. Ike et al. (2018) emphasize that sustainable urban waste systems must combine regulatory enforcement with infrastructure expansion, and this study's results offer an evidence base for prioritizing investments in underserved communities where illegal dumping is most concentrated. Policymakers could incorporate these findings into state-level environmental action plans and Sustainable Development Goal reporting, thereby aligning local efforts with global sustainability commitments.

6.2 Implementation Challenges

Despite the promise of GIS-supported monitoring, several barriers must be addressed for effective and sustained implementation. Data quality remains a critical challenge. While satellite imagery and field data can provide robust coverage, inconsistent facility records, outdated shapefiles, and incomplete geocoding can undermine analytic accuracy (Idowu et al., 2012). Regular data updates and validation protocols must therefore be institutionalized. Capacity constraints also pose a hurdle; many local government areas lack personnel trained in GIS software or spatial analysis, limiting their ability to act on analytic outputs (Adewole, 2012). Targeted training programs and the establishment of centralized GIS units could mitigate these gaps.

Financial constraints are another major consideration. Although open-source GIS platforms such as QGIS reduce software costs, there are still expenses associated with hardware, data acquisition, and system maintenance. Without dedicated funding lines, there is a risk that systems could fall into disuse after pilot phases. Moreover, resistance to technological change may arise among inspectors accustomed to traditional paper-based methods. Naibbi and Umar (2017) note that successful adoption requires participatory design, where end-users are engaged early in the process to ensure that dashboards are intuitive and compatible with existing workflows. This study's stakeholder engagement sessions confirmed that regulator buy-in improves when analytic results are actionable and easily interpreted.

6.3 Broader Governance and Social Considerations

The use of geospatial intelligence raises important questions about governance, privacy, and equity. Aggregating and publishing data on illegal dumpsites or facility violations may expose communities or businesses to reputational harm, which requires careful handling to ensure fairness and due process. At the same time, public access to compliance data can empower civil society to hold regulators accountable and pressure non-compliant operators to improve performance (Ajibade et al., 2019). Striking a balance between transparency and confidentiality will be critical for sustaining public trust.

Another consideration is the risk of spatial inequities if resources are allocated solely based on hotspot intensity without accounting for social vulnerability. Research has shown that low-income communities often bear a disproportionate share of environmental burdens (Afon, 2012). Compliance dashboards should therefore integrate equity indicators to ensure that interventions do not exacerbate existing disparities but rather promote environmental justice. The framework proposed in this study allows for such integration by including population density, service coverage, and vulnerability data as part of the prioritization model.

6.4 Future Directions

Future research could expand on these findings by incorporating real-time data from mobile applications and IoT sensors, which would enable dynamic updates of compliance maps and faster response to violations. Crowd-sourced reporting, when combined with regulatory verification, could broaden spatial coverage and improve data freshness (Jimoh et al., 2019). Another promising direction is the integration of economic cost-benefit analysis to quantify the savings from optimized inspection routes and reduced remediation costs. Such evidence would strengthen the business case for scaling the framework nationwide.

Finally, longitudinal studies could assess the long-term sustainability of compliance gains and explore whether geospatial monitoring leads to behavioral change among waste generators and service providers. As noted by Adewumi et al. (2019), embedding GIS within institutional workflows ensures that spatial intelligence becomes part of routine operations rather than a one-off project. This institutionalization is crucial for achieving durable improvements in environmental quality and aligning Nigeria's regulatory system with global best practices.

7. Conclusion

This study has demonstrated that geospatial intelligence can transform environmental compliance monitoring and waste management in Nigeria by providing a systematic and data-driven approach to regulatory enforcement. By integrating facility inventories, spatial risk layers, and inspection data into a unified geodatabase, the proposed framework allowed for the identification of illegal dumping hotspots, proximity risks, and service coverage gaps that traditional monitoring methods might overlook. The use of spatial statistics and prioritization algorithms ensured that inspection resources were deployed where they were most needed, resulting in measurable gains in compliance rates and significant improvements in operational efficiency.

The results suggest that GIS-enabled monitoring has the potential to close long-standing information gaps that have limited the effectiveness of Nigeria's environmental regulations. By shifting regulatory practice from reactive, complaint-based inspections to proactive, risk-based oversight, agencies can prevent violations before they escalate, thereby reducing the economic and public health costs associated with uncontrolled waste disposal. The framework's decision-support dashboard demonstrated that complex spatial analyses can be communicated in a format that is intuitive for policymakers and field inspectors, supporting transparency and inter-agency coordination.

Beyond its technical contributions, the study highlights the governance implications of adopting spatial intelligence. Integrating geospatial analysis into regulatory systems supports national goals for sustainable development and aligns with international best practices for evidence-based policymaking. It also creates opportunities for community engagement and accountability through public-facing compliance maps and performance dashboards. However, realizing this potential will require sustained investment in data infrastructure, staff training, and institutional capacity building. The findings affirm that applying GIS to regulatory monitoring is both feasible and impactful in the Nigerian context. Future work should focus on scaling the framework to additional states, incorporating real-time data streams from mobile and sensor-based monitoring, and evaluating long-term behavioral and policy impacts. If institutionalized,

geospatial intelligence can become a cornerstone of Nigeria's environmental governance strategy, improving compliance outcomes, protecting public health, and contributing to the country's progress toward its sustainability and climate resilience targets.

References

1. Adewole, A. T. (2012). Waste management towards sustainable development in Nigeria: A case study of Lagos State. *International NGO Journal, 7*(5), 84–90.
2. Adewumi, J. R., Ajibade, F. O., & Olatunji, O. S. (2019). Landfill site selection using GIS and multicriteria decision analysis in Ilorin, Nigeria. *Environmental Management Journal, 23*(2), 115–128.
3. Afon, A. (2012). A survey of operational characteristics, socioeconomic and health effects of scavenging activity in Lagos, Nigeria. *Waste Management and Research, 30*(7), 664–671.
4. Ajibade, F. O., Olajire, O. O., & Ajibade, T. F. (2019). Integrating spatial analysis and community engagement for equitable waste management planning in Nigerian cities. *Journal of Environmental Planning and Management, 62*(9), 1556–1572.
5. Anselin, L. (1995). Local indicators of spatial association—LISA. *Geographical Analysis, 27*(2), 93–115.
6. de Smith, M. J., Goodchild, M. F., & Longley, P. A. (2015). *Geospatial analysis: A comprehensive guide to principles, techniques and software tools* (5th ed.). Winchelsea Press.
7. Goodchild, M. F. (2018). Reimagining the history of GIS. *International Journal of Geographical Information Science, 32*(12), 1633–1644.
8. Idowu, O. A., Adagunodo, T. A., Esimai, O., & Olapade, T. (2012). Web-based GIS for waste disposal management in Nigeria. *Journal of Geographic Information System, 4*(3), 261–266.
9. Ike, C. C., Ezeibe, C. C., Anijiofor, S. C., & Daud, N. N. (2018). Solid waste management in Nigeria: Problems, prospects, and policies. *Journal of Solid Waste Technology and Management, 44*(2), 163–172.
10. Jimoh, R., Popoola, A., & Akinwumi, I. (2019). GIS-based assessment of dumpsite proximity risks in Lagos, Nigeria. *Environmental Monitoring and Assessment, 191*(11), 685.
11. Kukah, A. S., Bature, A., & Onuoha, F. (2017). GIS application in waste management in Nigeria: A review. *Environmental Review Journal, 21*(4), 55–63.
12. Mantu, S. (2019). Leveraging geospatial dashboards for regulatory compliance and transparency: Lessons from Nigeria. *Journal of Environmental Policy and Planning, 21*(7), 923–938.
13. Naibbi, A. I., & Umar, D. (2017). Spatial analysis of solid waste collection coverage and service gaps in Kano, Nigeria. *Journal of Geography and Regional Planning, 10*(9), 252–262.
14. NESREA. (2007). *National Environmental Standards and Regulations Enforcement Agency (Establishment) Act.* Abuja: Federal Government of Nigeria.