Digital Innovations for Sustainable Forest Management: A Review of Strategies and Applications in the Nigerian Context

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ABSTRACT

The sustainable management of forest resources is imperative for environmental preservation and societal well-being, particularly, for countries like Nigeria facing significant challenges in resource governance. Traditional approaches have proven inadequate in addressing issues such as deforestation, illegal logging, and insufficient monitoring and enforcement. In response, the integration of digital tools present promising solutions to enhance forest resource management in Nigeria. Digital technologies, including satellite monitoring, remote sensing, GIS, and big data analytics offer opportunities for real-time data driven decision-making and improved governance. By adopting digital strategies, Nigeria can address forest-related challenges, combat illegal activities, and promote large-scale forest restoration and reforestation initiatives. Thus, integrated land use planning, supported by digital tools, fosters sustainable development by balancing conservation objectives with economic growth.

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INTRODUCTION

The importance of forest resources cannot be overstated, as numerous nations rely on them to meet various daily needs (Sambe *et al.*, 2020; Kibon *et al.*, 2020; Fekadu *et al.*, 2021). Consequently, the sustainable management of forests is a global priority due to their crucial role in environmental preservation and the promotion of a healthy society. In developing nations like Nigeria, inadequate forest resource management poses a critical threat, endangering land and other natural assets. Nigeria, as a country endowed with abundant natural resources, faces the critical challenge of effectively managing these resources to ensure sustainability, economic development, and environmental conservation (Okeri *et al.*, 2016; Akinsorotan, 2021; Abdulkadir, 2021).

The nation's diverse resource base includes vast forest reserves, rich biodiversity, extensive mineral deposits, and significant agricultural potential. However, the management of these resources has been marred by various issues such as deforestation, illegal mining activities, biodiversity loss, and unsustainable exploitation (Okeri *et al.*, 2016). Additionally, the impact of climate change further complicates the task of resource management in Nigeria, posing significant threats to the country's ecosystems and livelihoods (Olaniyi *et al.*, 2013; Ebele and Emodi, 2016; Wakdok and Bleischwitz, 2021). Thus, there is an urgent need for comprehensive and sustainable resource management strategies that integrate modern technologies,

community engagement, and effective governance to address these multifaceted challenges and unlock the full potential of Nigeria's natural resources for the benefit of the present and future generations.

The conventional approach has often relied on manual data collection methods, limited spatial analysis capabilities, and a lack of digital technologies for monitoring and assessing forest dynamics (Oke and Akindele, 2022). This has hindered the ability to gather comprehensive real-time information and make informed, data-driven decisions for sustainable forest management. Furthermore, the static nature of traditional approaches to forest management has limited their capacity to adapt to evolving environmental, social, and economic dynamics. These approaches have struggled to address emerging challenges such as the impacts of climate change, shifting land use patterns, and the increasing demand for forest products, gradually eroding the resilience of forest ecosystems.

Digitalization entails employing digital technologies to augment the daily lives of individuals (Bespalova *et al.,* 2021). The advent of digitalization disrupts conventional practices in the forest-based industry; traditional regulations, tailored for non-digital economies are challenged by digital transformation (Watanabe and Naveed, 2019). In recent years, the application of digital solutions has emerged as a transformative force in the realm of forest resources management, offering innovative solutions to age-old challenges (Rohmy and Nihayaty, 2023; Nitoslawski *et al.,* 2021). Presently, a number of tools and technologies exist, enhancing the efficiency of information collection and exchange (Nitoslawski *et al.,* 2021). Adopting a spectrum of technologies including geographic information systems (GIS), remote sensing, big data analytics, and mobile applications, digital solutions have revolutionized the way forest resources are monitored, preserved, and sustainably utilized (Nitoslawski *et al.,* 2021). These technologies provide unprecedented capabilities to collect real-time data, map forest cover changes, monitor wildlife activities, and engage with local communities, thereby enabling more informed decision-making and proactive conservation efforts. The integration of digital strategies not only enhances the efficiency and accuracy of forest management practices but also facilitates the empowerment of local stakeholders and the preservation of invaluable ecosystems. As such, the role of digital solutions in forest resources management extends beyond mere technological advancement, serving as a catalyst for achieving long-term ecological balance, economic prosperity, and social equity within forest-dependent regions (Gavilanes Montoya *et al.,* 2023). In the proceeding sections, we examine digital strategies for forest management and how innovative technologies reshape traditional practices, offering new avenues for sustainable conservation.

Challenges in Forest Resources Management in Nigeria

Nigeria grapples with a multitude of challenges in managing its forest resources, spanning from deforestation and illicit activities to governance deficiencies and insufficient community engagement (Mfon *et al.,* 2014; Ahmed and Olaitan, 2023). The traditional forest management approaches have proven inadequate in addressing these challenges due to their limited technological integration, insufficient community involvement, and lack of adaptive capacity. This section highlights the challenges facing forest resource management in Nigeria while advocating for the adoption of innovative digital strategies and the incorporation of a more inclusive, adaptive approach to forest management. Such measures can help surmount these limitations and foster more effective, sustainable stewardship of Nigeria's invaluable forest resources.

Deforestation and Degradation

Nigeria contends with substantial rates of deforestation and forest degradation, propelled by agricultural expansion, logging, infrastructural development, and urbanization (Ahmed and Olaitan, 2023). These activities result in the depletion of valuable forest cover, disruption of ecosystems, and a reduction in biodiversity, presenting significant environmental and socio-economic challenges.

Illegal Logging and Land Encroachment

The widespread occurrence of illegal logging, unregulated land encroachment, and unsustainable resource extraction practices has compromised the integrity of Nigeria's forest ecosystems (Sambe *et al.,* 2020; Chigonu *et al.,* 2022). These activities contribute to habitat destruction, soil erosion, and the depletion of crucial forest resources, heightening the vulnerability of forest-dependent communities and indigenous populations.

Inadequate Monitoring and Enforcement

The effectiveness of forest resource governance in Nigeria is hindered by a constrained capacity for monitoring and law enforcement (Chigonu *et al.,* 2022). The absence of robust monitoring systems, including surveillance technologies and real-time data collection methods, complicates the detection and prevention of illegal activities, allowing for the unchecked exploitation of forests and their resources.

Digital Technologies in Forest Resource Management

The effective management of forest resources is crucial for maintaining ecological balance, preserving biodiversity, and sustaining livelihoods (Ikemeh, 2013; Ojomah and Fasoro, 2023). In the contemporary era, the integration of digital tools and technologies has revolutionized the way forest resources are monitored, conserved, and utilized. Here, the exploration delved into the diverse array of digital solutions and technologies that have proven instrumental in enhancing forest resources management, offering innovative solutions to complex challenges, and empowering stakeholders to make informed decisions.

Geographic Information System (GIS)

Geospatial tools encompass a range of technologies and software utilized for collecting, analysing, and visualizing spatial data related to forests, including Geographic Information Systems (GIS) and Global Positioning Systems (GPS). These tools empower forest managers to map forest resources, monitor changes in land use, and assess biodiversity. They have also been employed as a tool for wildlife management (Burger and Burger, 2006).

GIS serves as a critical tool by addressing inquiries regarding location, condition, trends, patterns, and modelling techniques essential for effective forest management activities (Creutzburg *et al.,* 2017; Kibon *et al.,* 2020). With GIS, foresters can generate comprehensive maps, pinpoint deforestation hotspots, and evaluate the impact of land use changes on forest ecosystems. Numerous studies in Nigeria (Kibon *et al.,* 2020; Ahuchaogu *et al.,* 2020; Akinola and Akindele, 2020) have highlighted the effectiveness of GIS technology in monitoring and managing forests. However, there remains untapped potential for exploiting its benefits in the management of public forests (Oke and Akindele, 2022). Additionally, GIS enables the integration of diverse datasets, such as satellite imagery and field observations, to support informed decision-making and effective conservation strategies.

Remote Sensing

The emergence of remote sensing technologies, including satellite imagery and aerial drones, has revolutionized the monitoring and assessment of forest resources on a large scale. This discipline involves acquiring information about a phenomenon, object, or surface feature from distant platforms, typically satellites or airborne sensors, without direct physical contact (Sonti, 2015; Lwin, 2018). Satellite remote sensing ensures continuous observation of forest cover dynamics, identification of illegal logging activities, and detection of disturbances caused by natural disasters or human interventions. Similarly, unmanned aerial vehicles, commonly known as drones, equipped with high-resolution cameras and LiDAR sensors (Sofia *et al.,* 2022), facilitate detailed, real-time monitoring of forested areas, providing invaluable insights for forest inventory, biodiversity assessment, and habitat mapping.

This technology aids in monitoring forest conditions, detecting disturbances like wildfires, and assessing the effectiveness of conservation efforts. Both geospatial tools and remote sensing are integral in modern forest management, offering valuable data and insights for decision-making, monitoring, and planning. Together, they contribute significantly to the sustainable use and conservation of forest resources by facilitating efficient and informed management practices. GIS softwares have been used by researchers at the Forestry Research Institute of Nigeria to analyse forest cover loss and gain from Google Earth platform data in addition to the various applications of remote sensing techniques in Nigerian forestry (Akindele *et al.*, 2022).

Big Data Analytics

The advent of big data analytics has revolutionized the processing and analysis of large volumes of forest-related information. By exploiting powerful algorithms and machine learning techniques, big data analytics can derive meaningful patterns and trends from complex datasets, facilitating predictive modelling of forest dynamics, species distributions, and ecosystem services (Adewoye *et al.,* 2022). Moreover, big data analytics

enables the integration of socio-economic data with ecological indicators providing a holistic understanding of the interdependencies between forest resources and human well-being.

Mobile Applications

Mobile applications and tracking software play a crucial role in monitoring the flow of forest products from the forest to the end consumer (He and Turner, 2021). The widespread availability of mobile applications designed for forest resources management has democratized processes such as data collection, stakeholder engagement, and decision support. Numerous open-source digital tools are accessible for data collection on various mobile operating systems, including Android and iOS (Adewoye *et al.*, 2022). These applications empower local communities, forest rangers, and conservation practitioners to report forest-related incidents, document wildlife sightings, and participate in citizen science initiatives. Moreover, mobile applications facilitate the dissemination of conservation guidelines, educational materials, and market information, fostering a culture of environmental stewardship and promoting sustainable forest use among diverse user groups.

Benefits of Integrating Digital Strategies in Nigerian Forest Resources Management

While digital initiatives hold promise for enhancing forest management, there is a need to ensure the integration of traditional ecological knowledge and meaningful community participation in these efforts. Embracing a participatory approach that acknowledges local expertise and engages forest-dependent communities is crucial for the success and sustainability of digital projects. The potential benefits of integrating digital strategies in Nigerian forest resources management are significant, offering opportunities to address specific challenges in the Nigerian context. Some of the benefits and opportunities include and not limited to:

Enhanced Monitoring and Surveillance: Digital strategies such as satellite monitoring, remote sensing and GIS can enable real-time monitoring of forest cover changes, illegal activities, and ecosystem health. These technologies offer opportunities to strengthen surveillance efforts, detect deforestation and degradation, and facilitate prompt intervention to mitigate forest threats.

Data-Driven Decision Making: Digital tools provide the opportunity to collect, analyse and visualize extensive datasets related to forest resources. By leveraging on these technologies, decision makers can access comprehensive, evidence-based information to inform policy formulation, land use planning, and conservation strategies. This data-driven approach enhances the precision and effectiveness of forest management interventions.

Community Engagement and Empowerment: Digital strategies offer opportunities to engage local communities and indigenous groups in forest resources management. Platforms for participatory mapping, citizen science initiatives, and mobile-based reporting systems can empower communities to contribute their knowledge, monitor forest activities, and collaborate with authorities in safeguarding forest resources.

Improved Governance and Transparency: Digital platforms can enhance transparency and accountability in forest management by facilitating the open sharing of data, promoting stakeholder participation, and increasing public access to information. This can lead to more transparent governance practices, reduced corruption, and enhanced public oversight of forest management activities.

Efficient Resource Allocation: Through the integration of digital technologies, forest agencies can optimize resource allocation, prioritize conservation areas, and streamline operational planning. Advanced modelling and simulation tools can help forecast the impacts of different management scenarios, enabling more efficient and strategic allocation of resources.

Climate Change Mitigation and Adaptation: Digital strategies can support Nigeria's efforts to mitigate and adapt to climate change impacts on forest resources. By using predictive modelling, remote sensing for carbon monitoring, and climate data integration, technology can assist in developing resilient forest management strategies th*at al*ign with climate change goals.

Adopting digital strategies in Nigeria presents multifaceted opportunities to address forest-related challenges through enhanced law enforcement and surveillance technologies like satellite imagery and geospatial analysis. These tools will strengthen efforts to combat forest-related crimes while supporting large-scale forest restoration and reforestation initiatives. Integrated land use planning, facilitated by digital tools, fosters

sustainable development by balancing conservation goals with economic growth, optimizing land use decisions, and minimizing deforestation for agricultural expansion.

CONCLUSION

In summary, the review underscores the potential of adopting digital strategies in forest resource management in Nigeria, emphasizing the necessity for a comprehensive policy framework and governance structure. The integration of digital tools offers opportunities to address specific challenges such as illegal logging, community empowerment, forest restoration, and sustainable land use planning. A robust policy framework is crucial to establish clear guidelines, promote stakeholder engagement, address data governance, build capacity, regulate technology adoption, and foster cross-sectoral collaboration. By creating an enabling environment for the effective implementation of digital strategies, Nigeria can enhance sustainable management of its invaluable forest resources, contributing to environmental conservation, economic development, and social well-being. As we harness the potential of these digital solutions, prioritizing equitable access, capacity building, and ethical considerations is vital to optimize their positive impact on forest ecosystems and the communities dependent on them.

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