AMERICAN JOURNAL OF GEOSPATIAL TECHNOLOGY (AJGT)

ISSN: 2833-8006 (ONLINE)

VOLUME 3 ISSUE 1 (2024)

PUBLISHED BY
E-PALLI PUBLISHERS, DELAWARE, USA

American Journal of
Geospatial Technology (AJGT)

Volume 3 Issue 1, Year 2024
ISSN: 2833-8006 (Online)
DOI: https://doi.org/10.54536/ajgt.v3i1.2621
https://journals.e-palli.com/home/index.php/ajgt

GIS and Artificial Intelligence Application in Smart Forest Ecosystem Sustainability Evaluation of Olokemeji Forest Reserve, Ogun State, Nigeria

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Article Information

Received: March 01, 2024

Accepted: March 28, 2024

Published: April 02, 2024

Keywords

Geographic Information Systems (GIS), Artificial Intelligence (AI), Convolution Neural Network (CNN), Normalized Difference Vegetation Index (NDVI), Satellite Imagery

ABSTRACT

The increase in human population over the years has accelerated growth in anthropogenic activities, which have led to the conversion of forest reserves to other land uses. In the sequel, it has become imperative for researchers to focus on the mapping of forest reserves through the use of GIS and Artificial Intelligence (AI) with time-efficient, automated, and low-cost methods to preserve the existing forest reserve and its sustainability evaluation implementation. This research aimed at utilizing GIS and artificial intelligence applications in smart forest ecosystem sustainability evaluation of Olokemeji forest reserve, Ogun State, with the following objectives: (i.) assessment of the current state of the forest ecosystem. (ii.) identify potential threats and risks to the study area and (iii.) develop sustainable management strategies for its conservation and preservation. In pursuance of this, GIS and AI were deployed in this study to assess the spatial characteristics of the forest ecosystem in Olokemeji forest reserve. Landsat imagery, ground coordinates, and a research questionnaire were the major data used. Object-based classification, Normalized Difference Vegetation Index (NDVI), and Land Use Land Cover in ArcGIS 10.2 software was deployed in data generation and analysis. The results showed that in 2013, about 1657.115 ha of the study area was occupied by dense forest cover while in 2023, it decreased to 1188.060 ha, with a difference of about 469.055 ha. By implementing smart forest monitoring and evaluation systems that use artificial intelligence, the government and commercial groups should set regulations focused on reducing the escalating risks to forest reserves.

INTRODUCTION

Globally, enhancing human well-being and the reduction of greenhouse gases (GHGs), forests offer a variety of services and activities (Kyere-Boateng & Marek, 2021). The benefits of forests help communities and individuals who rely on them for their livelihoods to thrive. However, Deforestation and Forest Degradation (D&FD) are a twin environmental crisis that threatens the world's forests, leading to widespread loss of forest biodiversity and ecosystem services and eventual forest cover loss. Ghana in West Africa is susceptible to D&FD brought on by humans, just like any other tropical forest in developing nations (Kyere-Boateng & Marek, 2021; Amoah & Korle, 2020; Oyediji & Adenika, 2022; Morgan, 2022). Forests also play a crucial role in maintaining ecological balance, regulating climate, conserving biodiversity, and providing various ecosystem services. However, due to deforestation, illegal logging, and climate change, forest ecosystems face significant challenges. To ensure forest long-term sustainability, it is imperative to develop effective monitoring and evaluation mechanisms (Zhang *et al*., 2020). Smart forest ecosystems are essential to maintaining the sustainability and wellbeing of earth planet. The combination of Geographic Information Systems (GIS) with Artificial Intelligence (AI) can offer useful tools and insights for assessing and monitoring the sustainability of these ecosystems (González-Vélez *et al*., 2021). With the help of this combination, complicated spatial and non-spatial data may be gathered, analyzed, and interpreted, enabling well-informed decision-making and pro-active management techniques. (Corbett and Mellouli, 2017). Geographically referenced data are collected, managed, analyzed, and presented using GIS technology. Through the use of GIS, numerous sorts of information, including human activity, soil quality, biodiversity, forest cover, and vegetation patterns, can be combined and represented in a spatial context (Salem, 2023). Spatial awareness is essential for evaluating the state and functionality of forest ecosystems and identifying regions that need conservation efforts or intervention. On the other hand, artificial intelligence improves the evaluation process by utilizing sophisticated algorithms and machine-learning strategies Nivanya (2024). Using historical and real-time data, AI may be used to evaluate massive datasets, spot patterns and trends, and make predictions (Jahani, *et al*., 2016). With the help of this capability, forest managers may better understand the ecological dynamics, spot irregularities or disturbances, and predict changes to the ecosystem in the future. (Holzinger *et al*., 2023).

Some identified challenges in the implementation of smart forest ecosystem sustainability evaluation using GIS and Artificial Intelligence (AI) include:

(i) High cost of and resource-intensive nature of conventional forest monitoring methods, which are often prohibitive.

(ii) Reliability of data and findings vary significantly, affecting the overall effectiveness of the ecosystem assessment.

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(iii) The lack of a comprehensive implementation strategy for these technologies means that their potential is not fully realized, and their integration into existing systems is slow.

(iv) Moreover, there is often resistance to adopting new technologies due to lack of understanding or trust in their capabilities, coupled with regulatory and policy challenges that hinder widescale adoption. Addressing these challenges is crucial to making informed decisions for sustainable forest management and unlocking the potential of GIS and AI capabilities.

Therefore, the goal of this research is to carryout GIS and artificial intelligence applications in smart forest ecosystem sustainability evaluation within Olokemeji forest reserve, Ogun state, Nigeria, with a view to enable data-driven decision-making, promote sustainable forest management practices, and contribute to the conservation and preservation of forest ecosystems for future generations. The following research questions enable the research aim to be achieved:

(i) what is the current state of the forest ecosystem?

(ii) what are the potential threats and risks to the forest ecosystem?

(iii) What are the sustainable management strategies required for the development of conservation and preservation of smart forest ecosystem sustainability evaluation implementation using GIS and Artificial Intelligence?

Realizing the full potential of GIS and AI in smart forest ecosystem sustainability evaluation in combination with remote sensing techniques (Pei, 2021) requires addressing these issues and limits. Overcoming these obstacles will make it possible to create trustworthy and efficient decision-making tools, which will result in more informed and sustainable forest management practices.

LITERATURE REVIEW

The array of studies reviewed for the current research highlights significant advancements and challenges in the field of Smart Forest Ecosystem Sustainability Evaluation, particularly utilizing GIS and AI. Zhang *et al*., (2020) focused on optimal grain size for landscape analysis, finding 30-60m as the ideal range, while Nitoslawski *et al*., (2019) emphasized the importance of integrating urban forests into smart city planning, highlighting the role of digital infrastructure in urban green spaces management. In exploring applications of machine learning and AI in forestry ecology, Liu *et al*. (2018) and Gonzalez-Velez *et al*. (2021) provide significant contributions.

The former examined various machine-learning techniques in forest ecology, discussing their potential and limitations, while the latter developed a synthetic intelligence framework for predicting wildlife-vehicle collision hotspots, endorsing the Random Forest algorithms as the most effective. Afroz *et al*., (2022) study assessed changes in land use and land cover (LULC) patterns and forest cover in the Dinajpur district of Bangladesh over the periods 1989–1999, 1999–2010, 2010–2020, and 1989-2020, They revealed that the majority of forest land was converted to homestead and crop/fallow land, resulting in a substantial reduction of forest area. The research of Jahani *et al*., (2016) introduced an optimized model for predicting forest degradation, while Yin *et al*., (2021) proposed an AI-assisted planning framework for the terrestrial ecosystem restoration, however, both focused on modeling and planning for ecosystem sustainability and restoration as well as highlighting the promising role of advanced computational models in forest management. Aroge *et al*.,(2023) identified optimal locations for new primary health care facilities in the Ado Local Government Area using a novel method integrating GIS, MCDA, and AHP. The findings revealed that only 10% of the land mass was most suitable, while 53% was suitable, and 37% was unsuitable for primary health care facilities.

Collectively, these studies provide a rich tapestry of methodologies, findings, and insights, yet none have specifically focused on Smart Forest Ecosystem Sustainability Evaluation using GIS, Remote Sensing techniques, and AI concurrently in the research area, which is the gap that is filled in this study.

MATERIALS AND METHODS

Study Area

The study site is between the boundary of the lowland rainforest and the derived savanna ecological zone (Figure 1). The site is also referred to as the wooded grassland within the 7,100 ha of Olokemeji forest reserve (Hopkins, 1956). It is within Abeokuta North Local Government Area (LGA) of Ogun State Southwestern Nigeria and located between Latitude 7º 25´N & 7º 39´N and Longitude 3º 32´E & 3º44´E. According to (Ogunleye *et al*., 2004) it occupies about 59km^2 and has a population of 6, 379,500 based on the 2023 population projection (Brinkhoff, 2022). The terrain configuration of the forest reserves area is characterized by hills and valleys with elevation values varying from 90m to the lowest, while the highest point is about 140m (msl). However, a quartzite ridge occupying the western side of study area conspicuously towered above 240m (Agbo-Adediran *et al*., 2016). The annual rainfall varies from 1200mm to 1300mm and used to occur from March to November, while the month-by-month temperature ranges from 28^{0}C to 36^{0}C (Hopkins,1965). The drainage pattern of the research area is dendritic and form part of the median channel of River Ogun draining nearly all the Precambrian basement complex rocks of Southwestern Nigeria (Ogundele & Odewunmi, 2012; Wilson, 1922).

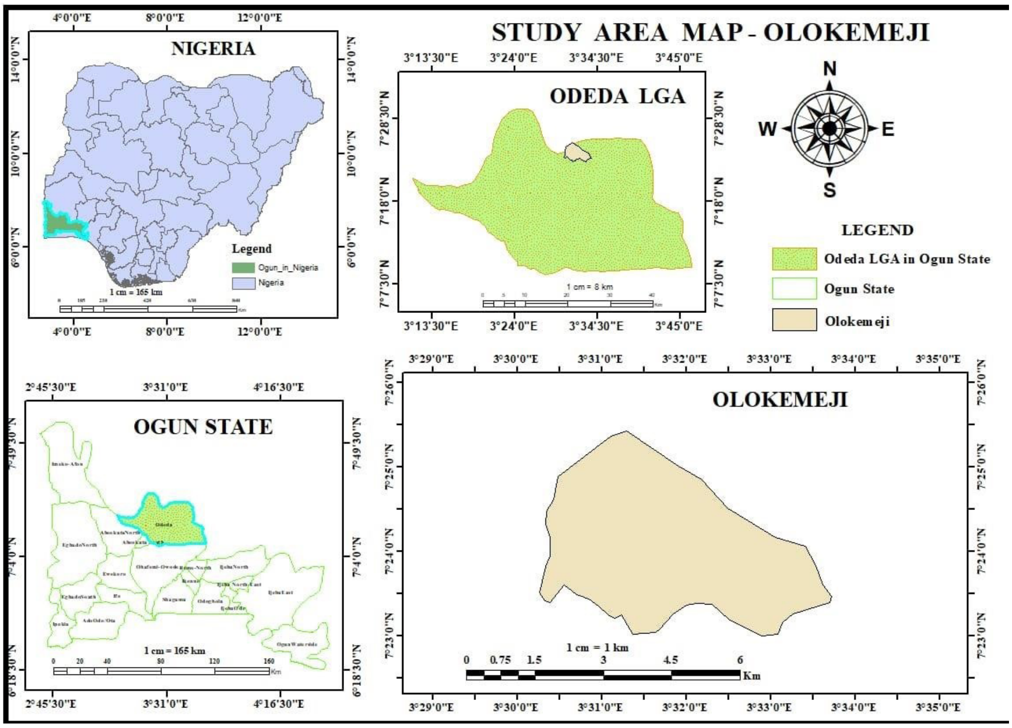

Figure 1: Study Area

Data Collection and Processing

The flowchart of the research methodology is as shown in Figure 2

The data used in this study are in two parts which include the primary and the secondary data. The primary data involves the data that was acquired directly from the field which include the coordinates of some selected points within the study area, and the 210 detailed socioeconomic survey responses collected from the local population. Specifically, random sampling techniques were the method used in distributing the questionnaire, and it was tested before the actual field survey exercise. The data collection was supported by hardware and software tools. Similarly, the Secondary data consisted of, Landsat 7 Enhanced Thematic Mapper Plus (ETM+) imageries for 2013 and Landsat 8 imageries (OLI-2/TIRS-2) for 2023, sourced from the United States Geological Survey at 30m resolution, supplemented by Google Earth Imagery.

A comprehensive approach was taken to process both primary and secondary data, and the adoption of a mixed-methods approach facilitated the thorough evaluation of the forest ecosystem's sustainability using Geographic Information Systems (GIS) and Artificial Intelligence (Pei, 2021). The data underwent a coordinate transformation

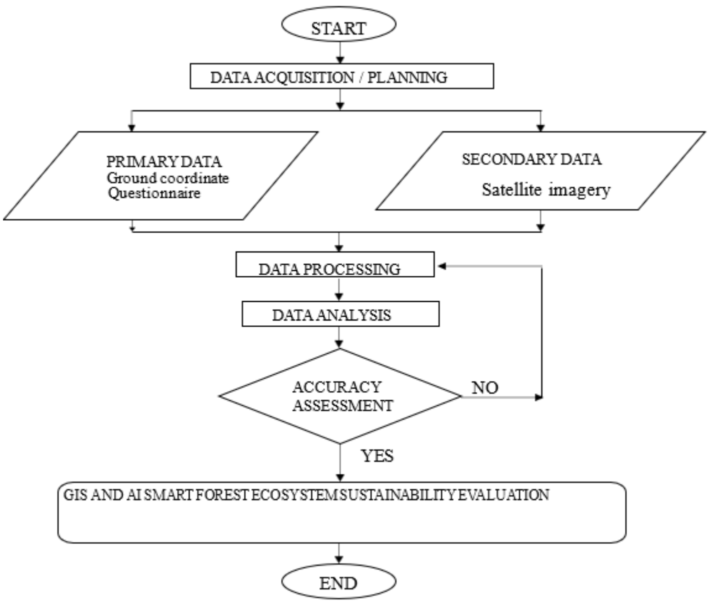

Figure 2: Flowchart of research methodology

to align different sources within the Universal Tranverse Mercator (UTM) system, zone 31N, which was essential for integrating the datasets in a common spatial language. Georeferencing attached real-world coordinates to satellite images using Ground Control Points, a step critical for accurate spatial analysis within the ArcMap software environment. Raster data from satellite imageries were converted into vector format, which allowed for the digitization of features enhancing the spatial analysis capability. This vectorization process was pivotal in creating a detailed and interactive study area map.

Central to the AI component of the study was the use of Convolutional Neural Networks (CNNs) for land cover classification. The CNNs preprocessing involved several steps to prepare the satellite imagery for analysis. Resampling ensured uniform spatial resolution across images, while band selection targeted the spectral bands most relevant to identifying different land cover types. Data augmentation techniques like rotation and scaling generated additional training data, enhancing the robustness of the CNN model against variability in input data. The model training phase involved feeding the preprocessed data into CNN, designed with an input layer to match the image dimensions and spectral bands and an output layer corresponding to the various land cover classes. A suitable loss function and optimization algorithm were selected to iteratively adjust the model's weights, with the aim to minimize classification errors. Validation of the model was a crucial step in ensuring its accuracy and generalizability. The model's performance was assessed using a separate validation dataset, which was not part of the training set. Metrics such as accuracy, precision, recall, and the F1-score provided quantitative measures of the model's efficacy. This phase also helped in fine-tuning the model by adjusting hyperparameters to prevent overfitting and to improve its predictive capabilities. Change detection analysis complemented the AI classification, utilizing NDVI calculations to provide insights into vegetation health and density changes over-time. This analysis, along with the AI-derived classifications, were synthesized into detailed maps using ArcGIS 10.2.

Maintaining data quality was a crucial aspect of the research. Ground truthing was carried out to check the conformance of the secondary data to the primary data. Also, it was ensured that the secondary data used were up-to-date, accurate, and properly validated to ensure good data quality.

The implementation of these advanced data processing techniques ensured the generation of reliable and actionable insights for the conversation and management of the forest reserve.

RESULT AND DISCUSSION

The result's analysis is categorized into three sections: land cover changes, Normalized Difference Vegetation Index (NDVI), and Questionnaire analysis.

Land Cover Changes

The table 1 shows the land cover analysis of the wooded grassland of Olokemeji forest reserve area while Figure 2 shows the corresponding land cover map of the study area. The classification was mainly Forest area and Grass

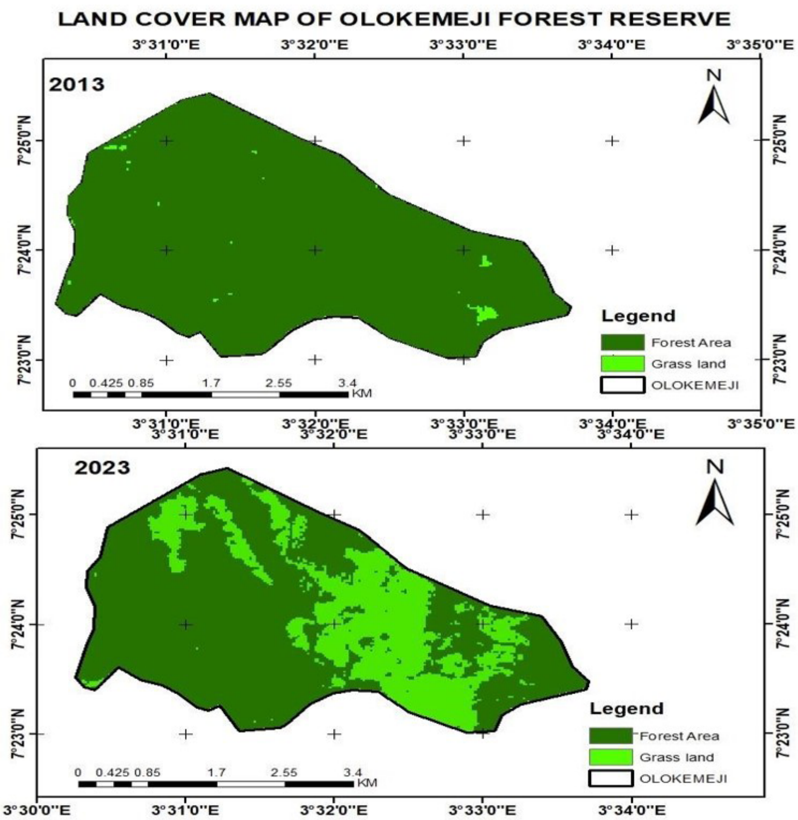

Figure 2: Land cover map of the study area for 2013 and 2023

Table 1: Land cover analysis of Olokemeji forest reserve area

Class	Area (ha)(2013)	%	Area (2023)	%
Forest area	1657.115	99.44	1188.060	71.29
Grass land	9.349	0.56	478.404	28.71
Total	**1666.464**	**100**	**1666.464**	**100**

land. It indicates that in 2013, forest area covers 1657.115 Hectares (99.44%), and Grass land covers 9.349 Hectares (0.56%), While in 2023, forest area covers 1188.060 Hectares (71.29%), and Grass land covers 478.126 Hectares (28.71%). This corroborates with the work done by (Aigbokhan, *et al.*, 2022) which indicated a declining trend for forest cover due to habitat loss from uncontrolled incursion into the forest reserve area for daily survival. Specifically, their study revealed that forests covered about 20,338 ha (26%), 13440 ha (17%) and 10427 ha (13%) in the years 2001, 2011 and 2021 respectively.

Normalized Difference Vegetation Index (NDVI)

Essentially, according to Figure 3, the study area has transformed from being densely and moderately vegetated with NDVI values (0.122684978 minimum to 0.449542463 maximum) in the year 2013 to being sparsely and moderately vegetated with NDVI values (0.111201495 minimum to 0.296176106 maximum) in year 2023. The implication of this is that the vegetation health and density in the study area have declined significantly from 2013 to 2023.

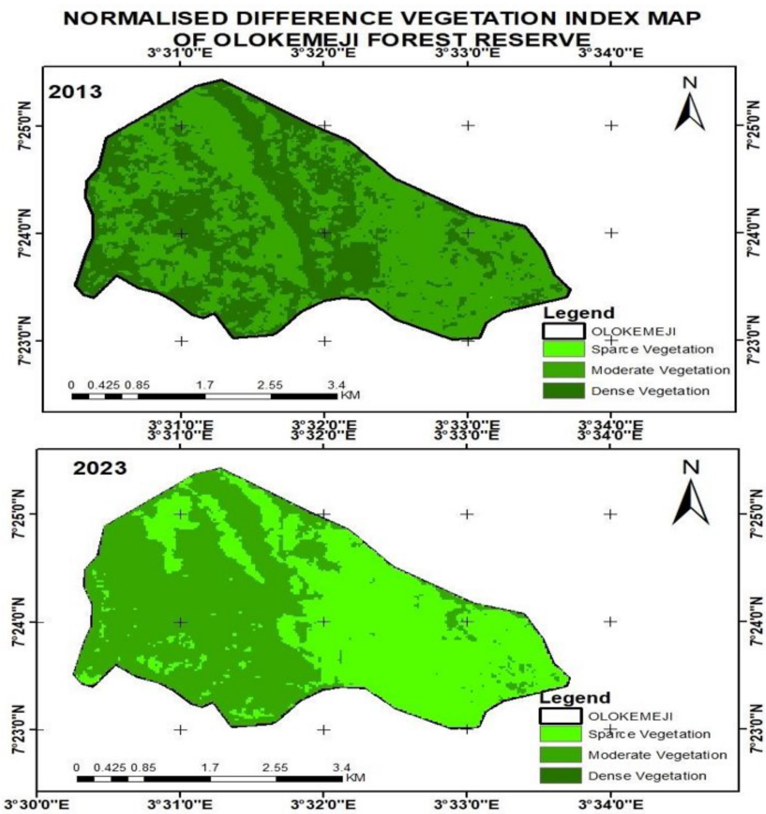

Figure 3: Normalized Difference Vegetation Index for the year 2013 and 2023

Figure 4: Normalized Difference Vegetation Index for the year 2013 and 2023

Questionnaire Analysis

The demographic data of the respondents are presented in figure 5. Considering the 210 respondents, 76.2% were males. All the respondents were 18years and above. Most of the participants were first Degree holders while 57.1% and 38.1% are Master's Degree holders. The respondent was purposely selected because of the nature of the research which focus on GIS and artificial intelligence application in smart forest ecosystem sustainability evaluation and the unwavering conviction that its mainly a male occupation.

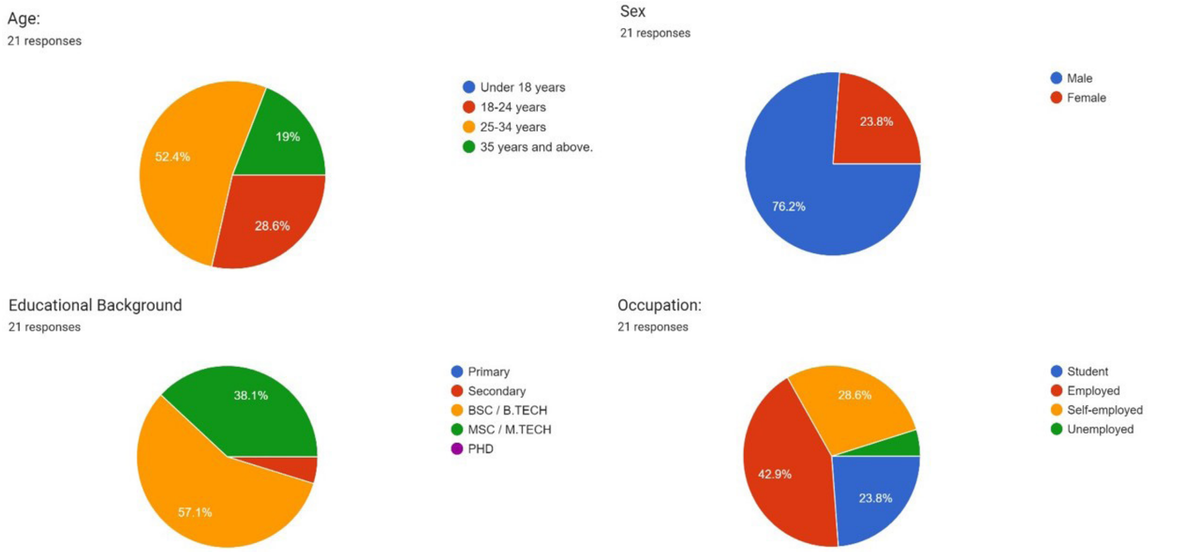

Figure 5: Image showing the Demographic data of the respondents in the study area

The analysis of the sustainability evaluation and conservation awareness data of the respondents displayed as Figure 6 shows that out of the 210 respondents, 66.7% have visited the study area, while 50% and 25% 'strongly agree' and 'agree' respectively that the conservation and preservation of forest ecosystems are important for the well-being of current and future generations. Furthermore, 52.4% 'strongly' believe that data-driven decision-making is essential for sustainable forest management practices, with 28.6% of respondents believing on average.

The current status assessment data of the study area (figure 7) revealed that 52.4% claimed they are aware of the potential threats and risks forest ecosystems face, such as deforestation, habitat loss, and climate change. Also, 57.1% believe that GIS and Artificial Intelligence technologies can effectively contribute to the evaluation and conservation of forest ecosystems. Similarly, among the 210 respondents, 55% think it is 'very important' to develop sustainable management strategies for the conservation and preservation while 30% of the respondents also think it is 'important' to develop sustainable management strategies for the conservation and preservation of the Olokemeji Forest Reserve.

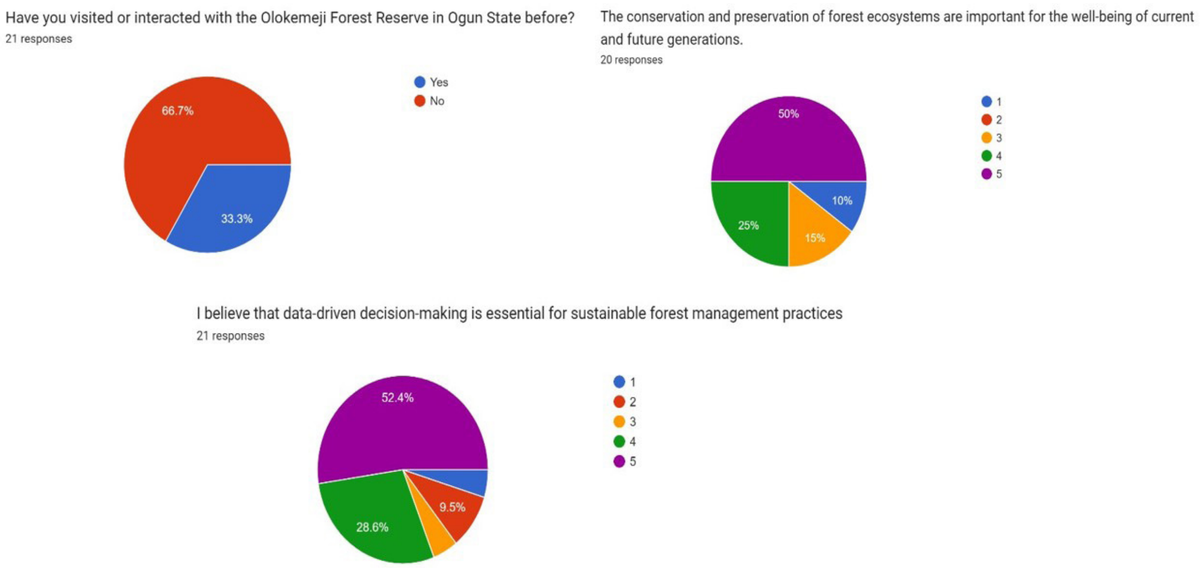

Figure 6: Image showing the Sustainability Evaluation and Conservation Awareness data

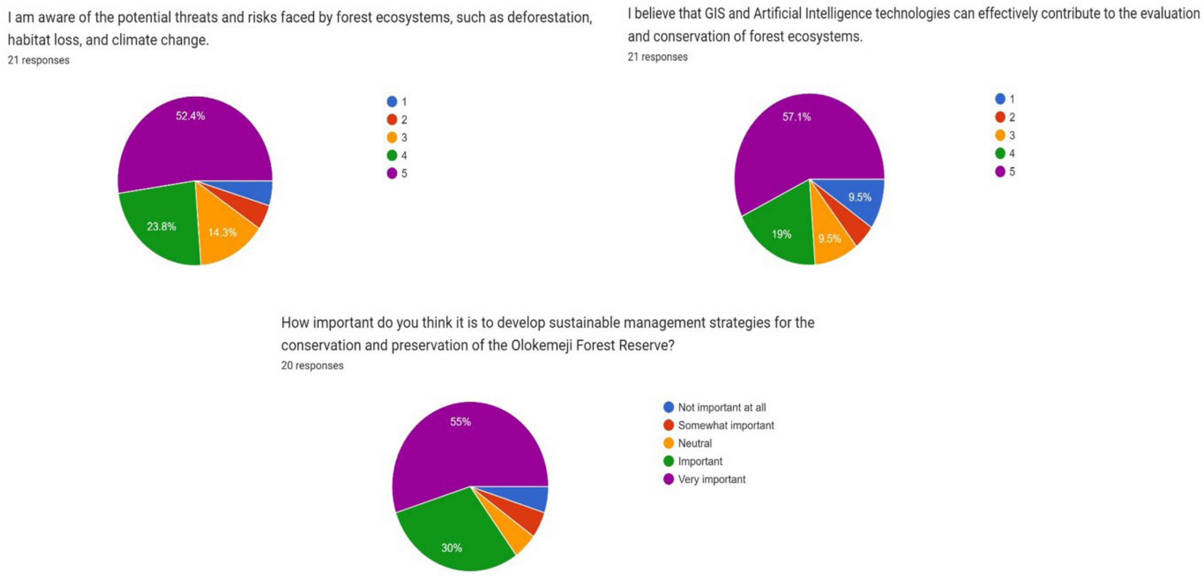

Figure 7: Image showing the Current State Assessment data of the study area

CONCLUSION

The study has effectively demonstrated the pivotal role of Geographic Information Systems (GIS) and Artificial Intelligence (AI) in the sustainable management of forest ecosystems. Through a rigorous analysis of the Olokemeji Forest Reserve, the study has revealed concerning trends in land cover change, with a notable reduction in forest area over the past decade. These findings are in line with those presented by Aigbokhan *et al.* (2022), which underscore the dynamic and often precarious nature of forest ecosystems. The application of Convolutional Neural Networks (CNNs) in land cover classification, coupled with the Normalized Difference Vegetation Index (NDVI) for assessing vegetation health, has provided compelling evidence of the forest's declining health. Such technological advancements in data processing and analysis have proven crucial in identifying subtle and overt changes within the ecosystem. Also, the integration of local community perspectives, gleaned from questionnaire responses, has enriched the study's insights, emphasizing the necessity of conservation efforts. Finally, the research articulates a clear and urgent call for the implementation of smart forest ecosystem monitoring systems that harness the power of AI and GIS. These systems provide a comprehensive and nuanced understanding of ecosystem dynamics, essential for the development of informed conservation strategies. The study's comprehensive methodology demonstrates the value of integrating advanced technologies in environmental management and conservation efforts which may be adopted in other forest reserves in Nigeria.

RECOMMENDATION

The study recommends the implementation of smart forest monitoring and evaluation systems that use artificial intelligence. Also, the Government and commercial groups should set regulations focused on reducing the escalating risks to forest reserves. Systematic tree felling techniques should be introduced as a matter of urgency, and continuous tree planting campaigns should be conducted to mitigate the effects of climate change and maintain healthy forest health for overall sustainable and revenue-driven management.

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