CHALLENGES AND PROSPECTS OF REMOTE SENSING AND GIS TECHNOLOGY FOR FOREST RESOURCES MANAGEMENT IN NIGERIA

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Abstract
Forest resources are indispensable to man because of the number of essential goods and services they provide. Forest management is becoming more complex because of the paradigm shift in the way the forest is managed in recent time. Effective and sustainable management therefore requires accurate, reliable and up-to-date information. However, in Nigeria, one of the notable problems of forest management is paucity of data on forest resources and this has negatively impact forest management planning and monitoring. Insecurity and insurgency have further heightened the problem, making it difficult to collect field data directly from the forest. This article highlighted some of opportunities remote sensing (RS) and Geographic Information System (GIS) technology present in overcoming this challenge. Remote sensing and GIS provide tools for capturing, storing, analysing and displaying spatial data on forest resources. Some of the contributions of RS/GIS technology to sustainable forest management were highlighted. They included land use and land cover classification, GIS map production, development of forest management information system and spatial analysis. Some challenges hampering the adoption RS/GIS technology were discussed and recommendations were made on how to address them.

Keywords: Forest data, Forest management, Forest resources, Geographic Information System (GIS), Remote sensing

Introduction

Forest ecosystems play a vital role in the survival of humans because of the number of essential goods and services they provide (Njana *et al*., 2016; Sabogal *et al.*, 2013; Usman *et al.*, 2020). Some of these include recreation, timber production, biodiversity conservation, habitat for some wildlife species, water production, soil protection, carbon sequestration, oxygen production, *etc.* (BGCI, 2021; Sabogal *et al.*, 2013). Sustainable and effective management of forests are very key to ensure the continuous production of these goods and services (Bhandari and Lamichhane, 2020). The forests are sometimes managed for a single purpose and at other times for multiple purposes depending on the management objective. Meanwhile, traditional forest management planning has shifted from sustainable timber management to ecosystem-based multipurpose forest management (Sheppard *et al.*, 2020). Sonti (2015) noted that with increasing demand for forest products and services, forest management is becoming very complex.

Effective and sustainable forest management therefore requires a sound knowledge of the structure, composition and dynamics of the forest as well as deployment of the right strategy and plan using reliable data and tools (Cillis *et al*., 2021). This is important because some forest management decisions when taken might be irreversible (Abildtrup *et al.*, 2012). Therefore, tools that can help a forest manager foresee and predict consequences of planned actions are indispensable in forest management. Several tools have been employed in recent time in ensuring sustainable management of the forest, among which are Remote Sensing (RS) and Geographic Information System (GIS) technology.

Remote sensing in this context is defined as the "science of acquiring information about the earth using instruments which are remote to the earth's surface, usually from aircraft or satellites" (Lwin, 2018). Data can be collected on relatively large geographic area very quickly using remote sensing technology. Geographic Information System on the other hand is a "powerful set of tools used for collecting, storing, retrieving, analysing and displaying spatial data from the real world" (Burrough and McDonnell, 1998). These capabilities, when properly harnessed, helps forest managers make well-informed decision on the forest they are managing. These tools have been used in many parts of the world and have been proven to be very effective (Bolstad, 2016; Bratu, 2017; Cillis *et al*., 2021; Picchio *et al*., 2019; Sonti, 2015).

In Nigeria, despite several research studies illustrating the effectiveness of GIS technology in monitoring and managing forests, its benefit is yet to be harness for the management of most public forests (Abiodun, 2018; Adedeji *et al*., 2015; Akinola and Akindele, 2020; Njungbwen and Mbakwe, 2013; Oke *et al*., 2020; Suleiman *et al*., 2017). Sustainable forest management in Nigeria has been faced with a lot of challenges, some of which are poor management, inadequate funds, outdated forest management plans, inadequate manpower, and outdated information on the size and extent of forest estate in Nigeria (Edu *et al*., 2011; Ogbodo *et al*., 2017; Olukwu-Kalu *et al*., 2022). Some of these can be solved by adopting RS and GIS technology. However, there seems to be a gap between research findings, recommendations and actual implementation. This article therefore seeks to review the importance of RS and GIS technology in solving some forest management problems and likely challenges encountered in the adoption of such technology in public forest management in Nigeria.

Sustainable Forest Management and GIS/Remote Sensing Technology

Forest management is defined as "the process of planning and implementing practices for the stewardship and use of forests to meet specific environmental, cultural, social, and economic objectives" (FAO, 2020a). It is "the art and science of making decisions with regard to the use, organization, and conservation of forests and related resources" (Buongiorno and Giless,

2003). The focus of forest management has shifted from just timber to include other goods and services (both tangible and intangible). The unending demand for forest goods and services has brought the forest under intense pressure necessitating the concept of sustainable management. Sustainable forest management was defined as "the management of forests to achieve optimum yield and continuous flow of desired forest products and services, enhancing forest productivity and maintaining economic, social and environmental values of forests" (Bhandari and Lamichhane, 2020).

Sustainable forest management focuses on ensuring that the present use of forest does not hamper the future benefit. For a forest entity to be sustainably managed, sound knowledge on the available resources as well as adequate planning is required. Accurate and up-to-date information is an essential part of management (Alo *et al*., 2014; Oke *et al*., 2020). Information about forests is traditionally obtained through forest inventories. Forest inventory is an activity purposefully designed for data collection to generate information base on size, shape, as well as qualitative and/or quantitative information on the growing stock of the forest resource within an area of interest (Asrat and Tesfaye, 2013). It provides qualitative and quantitative information on the extent, state and use of forests (Dau *et al*., 2015).

Traditional method of forest inventory involves actual field work where data are collected by direct field measurement. A field team will often visit the forest with relevant equipment for data collection. Obtaining information about the forest using traditional measures can be challenging and cumbersome because of the vastness of the forest, difficulties in accessibility, insecurity problems, *etc.* (Shuaibu and Dagba, 2013). Field work for collection of data cannot be completely jettisoned in forest inventory, however, GIS and remote sensing technologies help in mitigating some of these challenges encountered and provide more information in a relatively shorter period of time. In other words, GIS enhances more effective forest inventory.

Geographic Information System and remote sensing technology have helped foresters by providing detailed information about vast areas of forest without necessarily having physical contact with the forest. They have helped in facilitating the management, analysis, manipulation, modelling, representation and display of geo-referenced data to solve complex problems regarding planning and management of forest resources (Cillis *et al*., 2021; ESRI, 2006; McKendry and Eastman, 2002). Raw and analysed data obtained through remote sensing and GIS provides important tools for forest resources assessment, inventory and monitoring. It has also helped in modelling and forecasting to support planning and decision geared towards sustainable forest management. Some of the advantages of GIS include its ability to produce thematic and interactive maps while at the same time integrating data from different sources (Bolstad, 2016; ITC, 2009). GIS and remote sensing technology has proven useful in forest management because they help provide relevant data and information to answer the questions regarding the location of forest resources, their condition, as well as established trends and patterns, which can help in predicting and planning for the future.

Prospects of GIS/Remote Sensing Technology for Sustainable Forest Management in Nigeria

There are several areas GIS/Remote Sensing technology had been aiding sustainable forest management, some of which are listed below.

Land Use and Land Cover (LULC)

Land use and Land cover (LULC) refers to the classification or categorization of human activities and natural elements on the landscape within a specific time frame based on established scientific and statistical methods of analysis of appropriate source materials (Singh, 2017). It helps in land cover identification which provides baseline information for activities such as change detection analysis and thematic mapping. GIS and remote sensing technology makes it possible to monitor and quantify changes in forest cover over time by comparing multi-temporal images. Remotely sensed satellite imagery can help provide information on forest type, extent of the spatial cover and the biophysical properties of the forest. Examples of satellite imagery that have been used for LULC include Landsat Thematic Mapper (TM), Landsat Enhanced Thematic Mapper plus (ETM+), ALOS ANVIR-2, Sentinel -2 (S2) and Landsat 8 series (Fonji and Taff, 2014; Lwin, 2018; Nasiri *et al*., 2022). These satellite imageries are major source data used by GIS for detailed analysis.

A number of studies has been carried out using remote sensed data and GIS software such as IDRIS, ArcView, ArcGIS for LULC of forest reserves in Nigeria (Adedeji *et al*., 2015; Akinola and Akindele, 2020; Olokeogun *et al*., 2014; Suleiman *et al*., 2017; Wachiye *et al*., 2013). The first large-scale remote sensing application to forestry in Nigeria was the Nigeria Radar (NIRAD) project commissioned by the Federal Government of Nigeria in 1976 to procure Side Looking Airborne Radar (SLAR) images for Nigeria (Akindele, *et al.*, 2022). The images were used to produce the first comprehensive wall-to-wall vegetation and land cover maps for Nigeria in 1978. In 1994, the Federal Government of Nigeria commissioned a second project tagged Land Use and Vegetation (LUV) project to carry out an assessment of Vegetation and Land Use changes in Nigeria between 1978 and 1993. The maps produced formed the basis for land use planning in many states of the country. They were also the basis for planning the national Forest Resources Study (FRS), which involved a large-scale inventory of Nigeria's high forests and plantations covering 28 States. In a recent FAO REDD+ study on carbon stock assessment in Nigeria, remote sensing and GIS techniques were used to identify field clusters for data collection and determine the extent of

the various land use and land cover classes (FAO, 2020b, FAO, 2020c). In addition to all these applications of remote sensing techniques in forestry in Nigeria, QGIS software is being used to calculate forest cover, forest loss, and gain from derived data obtained from Google Earth Engine platform. This is done by research scientists in the Remote Sensing laboratory of the Forestry Research Institute of Nigeria (Akindele, *et al.,* 2022).

Forest Management Information System

Accurate and up-to-date information is key to achieving sustainable forest management *(Alo et al.*, 2014). In Nigeria, paucity of data on forest resources is a major challenge facing forest management. Available information in most cases are in paper format and they are in multiple files and platforms, which in most cases are not properly integrated or accessible. Updating these information poses another challenge. Forest Management Information System (FMIS) are management information system designed specifically for forestry applications to support planning, analysis and reporting map design (Oke *et al*., 2020). Information systems helps to generate accurate, timely and organized information so managers and other users can make decisions, solve problems, supervise activities, and track progress (Hasan, 2018). It is an integrated system which will be used to support the planning, monitoring and implementation of multi-objective forest management activities (Robak and Murty, 2009). Forest management information systems can incorporate both spatial and non-spatial data from varied sources for easy assessment, monitoring, reporting activities (Wellving, 2010). Some FMIS are designed solely based GIS Software like ArcGIS while others work with other software such as SQL and Microsoft Assess as done in study by Alo *et al.* (2014) and Oke *et al*. (2020). At the national level in Nigeria, a Forest Information System (FIS) was designed and set up as part of the deliverables of the Forest Resources Study in 1999. It was warehoused in the Remote Sensing laboratory at the Federal Department of Forestry, Abuja. It has all the spatial and non-spatial data collected during the Forest Resources Study. The spatial data were in ArcView and Landsat formats while the database was set up in Oracle. PowerBuilder was used to design the frontend, and training was conducted for selected staff of the Federal Department of Forestry to manage the system. Unfortunately, the system could not be maintained because the civil service in Nigeria is not set up for such services. Within a few years of no maintenance, the system broke down and became abandoned. If the system had been warehoused within a University, it would have survived and experienced several updates.

Map production

Geospatially accurate maps showing different forest type and their spatial distribution are essential to forest management. Traditional maps used for the management of public forest in Nigeria are sometimes obsolete, inaccurate and do not contain the necessary information required for management. GIS software help produce intelligent maps that are suitable for planning and management purpose using remote sensed imagery. A major advantage of GIS maps is their ability to combine both spatial data and their non-spatial attribute of geographic data. Each feature on the map has a unique value which helps to differentiate it from other features. The maps are usually interactive and the user has the ability to zoom in and out to highlight the specific feature of interest (ESRI, 2006). GIS software can also help store and organize information as a collection of thematic layer with each layer containing features of similar attribute like roads, houses and street that are located within the same geographic extent. The dataset can then be managed as a layer and combined graphically using overlay analysis operators available in the software (ESRI, 2018). This makes it possible to produce maps showing all the features on a single map or produce the map of each of the feature as separate maps depending on the data layer included, depending on the desire objective (ESRI, 2021a). Working with these layers helps the forest manager to explore critically important management questions and find answers to those questions (ESRI, 2018). A major advantage of GIS technology is its ability to work with different types of data to produce maps and to update them easily. Snow *et al.* (2008) describes GIS as a highly effective information and communication technology due to its ability to graphically convey knowledge through the universal language of maps.

In Nigeria, GIS technology has been used to produce series of maps for various purposes. The Land Use and Vegetation maps of the LUV project in the 1990s were produced with GIS technology. Similarly, the field maps used during the forest inventory exercise under the Forest Resources Study were produced with ArcView, a prominent GIS software in the 1990s. In recent times, several individuals and groups have used GIS software such as ArcGIS, QGIS, etc. to produce forest thematic maps used for various purposes. Examples include Alo (2018), Oke, et al., (2020) and Akinola and Akindele (2020).

Spatial Analysis

One of the major attribute that set GIS apart is its ability to perform certain types of spatial analysis. Spatial analysis is defined as a process in which problems are modelled geographically, results derived by computer processing, and the results explore and examined (ESRI, 2018). Spatial analysis can help find best locations and paths, determine relationship and make predictions. It works by combining information from many independent sources to derive new set of information using sophisticated set of spatial operators (ESRI, 2021a). Spatial analysis helps in determining the suitability of a site for a planned activity. Site suitability models are very critical in forest management planning. This is done by identifying certain criteria that suit a planned activity, after which available dataset are analysed in GIS environment to determine the best location that meets such criteria (Felicısimo *et al*., 2002). This ensures that forest and related resources are optimally used. Suitability of certain site/location for specific purposes can be evaluated using spatial analysis features such as proximity, network analysis and

density analysis. Proximity analysis examines the relationship between features in terms of nearness or connectivity while network analysis examines connectivity of linear features and how easily resources flow through them (Bhutani, 2020; ESRI, 2021b). Important hidden patterns can be detected, interpreted and the outcome predicted. Quantum GIS (QGIS), ArcGIS, SAGA are examples of GIS software that can be used for such analysis as used in the study by Alo (2018).

Challenges hindering the adoption RS/GIS technology for Forest Management in Nigeria

In spite of the several advantages of using remote sensing and GIS technology in forestry, and the past efforts of the Federal Government in this direction, there are still some challenges as enumerated below:

Inadequate skilled manpower and expert in RS/GIS technology : In Nigeria, one of the major problems hampering sustainable management of the forest is inadequate manpower (Shuaibu and Dagba, 2013). Government are not recruiting enough skilled manpower to manage the country's forest estate (Olaitan and Nosiru, 2022). Most forest reserves and national parks in Nigeria do not have remote sensing/GIS units and most still rely on crude tools to manage the forest, which are generally not effective, especially with the issue of insecurity and insurgency.

Poor Funding: Investment in RS and GIS technology requires a lot of funding. Funding available for the running of most forest reserves in Nigeria is grossly inadequate (Ogbodo *et al*., 2017). Most department managing the country's forest estate cannot afford to purchase Information and Communication Technology (ICT) equipment that support RS and GIS. Budget, in most cases, is only able to cater for salaries of staff and no other major project needs (Olaitan and Nosiru, 2022).

Lack of willingness of forest managers to embrace new technologies: A number of forestry staff are not open to adopt new technology for the management of the forest. Most will rather stick to the old conventional method they are familiar with, even when there is opportunity to be trained. According to Innes (2009), most difficult step in any innovation process is the actual implementation on the ground. In some cases, there are concerns that new technology would lead to loss of traditional jobs, especially for those involve in manual labour (Morrison-métois and Lundgren, 2016).

Obsolete and non-functioning Information Communication Technology (ICT) Department: In most forestry department in Nigeria, there are no modern ICT equipment that can be used for forest management and planning purpose. Most available equipment are either damaged or obsolete. In few departments where there are modern equipment, available staff lack the technical know-how to do any meaningful spatial analysis to solve forest management problems.

Knowledge gap between research institutions and public forest management institutions: A lot of research work is done in various forest-related educational and research institute but the findings, results and recommendations are not being implemented in the management of public forests. There seems not to be integration and proper communication of research findings within different forest institutions (Universities, Government research Institutes, NGOs), between forest research groups and among other research institutes (Byron and Sayer, 1999).

Conclusion and Recommendations

Sustainable forest management requires that a manager is well-equipped with the right data and tools to make well-informed decisions about scarce forest resources. Remote sensing and GIS technology provides resources and tool which can help achieve the ultimate goal of sustainable forest management. Many countries (both developing and developed) are already taking advantage of these tools and Nigeria should not be left out. In this era of growing insecurity and insurgency in the nation, remote sensing and GIS technology should be harnessed for forest stand inventory, monitoring, planning and decision making. In view of this, Government and forestry staff should be properly sensitized on the importance of remote sensing and GIS technology to forest management and planning. More so, there must be a forum where research findings by the various academic, research and Government institutions are properly communicated and integrated for the advancement of sustainable forest management in Nigeria.

In addition, adoption and implementation of new technology should take the bottom-top approach rather that the top-bottom approach, that is, there should be adequate consultation from the grassroots. Focus group discussions that focus on the identification of areas of need and proposed actions should be organised for all stakeholders. In addition, other stakeholders should put more pressure on the Government to properly fund forest management in Nigeria. Training and re-training opportunities should be explored by all forest stakeholders. Free and open source land monitoring tool like System for Earth Observation Data Access, Processing and Analysis for Land Monitoring (SEPAL), Google Earth, Quantum GIS (QGIS)and other relevant software should be explored for management of public forest.

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