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SPATIAL ASSESSMENT OF GREEN INFRASTRUCTURE FOR ENHANCING SUSTAINABLE BUILDING MATERIALS PRODUCTION IN OYO, NIGERIA

ABSTRACT
Green infrastructure is a cornerstone of sustainable development, offering a pathway for providing renewable and environmentally friendly building materials that are becoming practically unavailable in Oyo localities. The study was conducted through analysis of land use patterns, resource availability and ecosystem services using geospatial techniques. The

ARC. R. S. BUSARI (PhD)[1]; & A. F. BUSARI[2]

[1]Department of Technical Education (Building), Emmanuel Alayande University of Education, Oyo.
[2]Architecture and Building Unit, ARKRAS Consultancy Services, Oyo.
Corresponding Author: sekorerasheed@gmail.com
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INTRODUCTION

The construction relies heavily on the provision of renewable and environmentally friendly building materials for building production. Green infrastructure, defined as a network of natural and semi-natural areas that deliver ecosystem services (Jato-Espino *et al.*, 2023; Isola *et al.*, 2024; Ferreira *et al.*, 2021; Mirici, 2022; Sokolova *et al.*, 2024), offers a sustainable alternative in the production of renewable building materials such as timber, bamboo, clay and others. Green infrastructure provides a wide range of ecosystem services (Van Oorschot *et al.*, 2024,

analysis employed landscape images of 2000, 2005, 2010, 2015 and 2020 to evaluate the spatial growth that affected the green infrastructure in Oyo, Nigeria. Also, field observations were employed to gather information on the availability of timber and bamboo harvested from these green spaces. The land use, land cover analysis showed a decrease of 76.48% in 2000 to 50.40% in 2020. The Normalized Difference Vegetative Index (NDVI) varies from – 0.46 to 0.06 in 2000 to 0.00 to 0.28 in 2020, showing a decline in the vegetation. The field observation also revealed a decrease in the availability of timber and bamboo in the community for construction purposes. The study therefore recommends that the government and the entire populace should make efforts to protect and maintain green infrastructure for the sustainable provision of these materials for building construction.

Keywords: Green Infrastructure, Biodiversity, Normalized Difference Vegetative Index, Ecosystem Services, Urbanization, Remote Sensing, Timber, Bamboo.

Escobedo *et al*., 2019, Young *et al*., 2014 and Romanosvka *et al*., 2023) to man and contributes significantly to urban sustainability on which the productions of building materials depend.

Ecosystem services are the functions provided by green infrastructure and natural systems that are beneficial to society and the economy (Fairbrass *et al.*, 2018, Heckwolf *et al.*, 2021 and Sangha *et al.*, 2022). These services are arranged into provisioning, regulating, cultural and supporting (MEAS, 2005 and Hassan *et al*., 2005). Provisioning services include timber, food, medicines, fibers, fuels and other products. Regulating services include water filtration, climatic regulation, crop pollination, disease control, and waste decomposition, which provide a healthy environment for people to live in and cultural services provide spiritual, psychological, educational, and aesthetic values. Supporting services are ecological functions that maintain ongoing processes such as soil formation, evolution, nutrient cycling and primary production. Provisioning services are responsible for the production of various building materials which are the benefits the building industry receives from the availability and provision in the environment.

Provisioning services of these primary materials in the local environment and serving various choices in building construction that is predominantly dedicated by local availability, durability, renewability and ease of use (Ruuska and Hakkinen, 2014). Majority of these materials are often regarded as environmentally friendly because they reduce environmental cost of making and using buildings (Suhamad and Martana, 2020; Saleh *et al.*, 2023; Rousseau, 2018) and they are sourced directly from green infrastructure fields with little processing and chemical treatment (Firoozi et al, 2024). These are materials that are used for the production of grey infrastructure (buildings, bridges, drainage, etc.) sourced from the provisioning ecosystem.

Green infrastructure such as forests, wetlands, grasslands and urban green spaces provides renewable materials such as timber and bamboo, which are natural materials that offer a pathway to sustainable grey infrastructure development. Timber is readily available, sustainable, affordable, flexible, in usage and durable (Abumaje and Baba 2014, Kumar *et al.,* 2022, Avila and Blanca, 2022; Woodard and Mulner, 2016) and bamboo as a natural building material is available, renewable and sustainable (Yadav and Malthur, 2021; Adier *et al*., 2023; Boity *et al.*, 2022 Bredenoord, 2024 and Manandhar *et al.*, 2019) in green space in Oyo and Southwestern Nigeria. Timber is being used mainly for several purposes, such as roofing, finishing, furniture, scaffolding and several others in building construction, while bamboo is also efficient for scaffolding, formwork, finishes and others. Bamboo is also a fast-growing-renewable with a high strength – to – weight ratio, making it ideal for construction as reinforcement (Tripathi *et al.*, 2021, Kumal *et al*., 2021, Karthile *et al*., 2017; Prasad and Khan, 2022).

With increasing urbanization, the need for sustainable treatment of green infrastructure in the town has become more pressing. Oyo has been presently dominated by unplanned neighbourhoods with poor infrastructure and services, as well as other environmental issues (Oyeleye,

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2013 and Salam *et al.*, 2023). Extensive land use changes and green destruction are witnessed due to an increase in the population. It therefore becomes necessary to monitor the green infrastructure in the town to improve the availability and sustainability of the mentioned building materials. This requires measurement of land, land cover and health of green infrastructure using remote sensing images that would be analyzed using geospatial tools and provide spatially explicit and temporally continuous ground truth information (Chen *et al.*, 2017; CrousBou *et al.*, 2020; Mears *et al.*, 2020). This study therefore aims to assess how Oyo green infrastructure can serve as a source of sustainable materials that promote environmental sustainability in the building construction practice using geospatial tools and observation of the materials in various communities in the town.

Materials and Methods

Study Area

Oyo is a city in Oyo State founded as the capital of Oyo Kingdom in the 1830s and known to its people as "New Oyo" (Oyo Atiba) to distinguish it from the former capital to the worth, 'Old Oyo'. Oyo is a remarkable Yoruba city with its ceremonial ruler as Alaafin of Oyo. Oyo is the most populous state in Nigeria with a population of about 736,072 (Word Population Review, 2019). The city has three local government areas: Atiba, Oyo East and Oyo West. The city has approximately between 3°54' to 3°59'E and latitudes of 7°49' N and 7°55' longitude and is situated 298 meters above sea level (Rafiu *et al.*, 2018), Oyo is also located between the rainforest and savannah region and has moderate rain which starts around April and ends by October or November each year. Oyo people mainly trade in farm produce (Morton, 2018) within the geographical areas now encounter expansion in the built areas in different directions. The soil type is mainly sand mixed with gravel (Adeboboye *et al.*, 2015).

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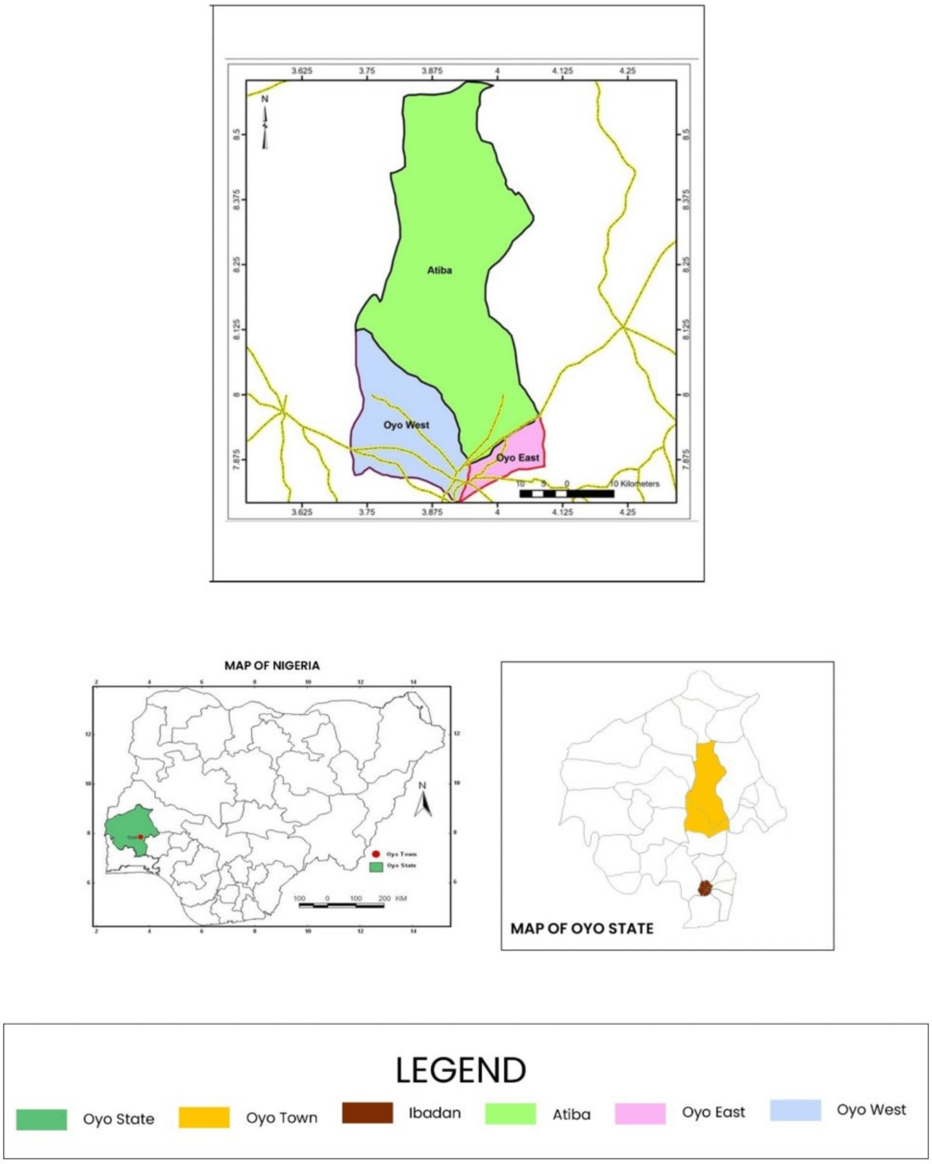

Figure 1: Oyo land use for the year 2000

Data and Pre-Processing

Land cover data collected at a 5-year interval were used for the study. This covered the years 2000 to 2025, sourced from remote sensing monitoring data. For year 2000, 2005 and 2010, Landsat thematic was used while year 2015 and 2020 made use of Operational Land Imager (OLI) which were obtained from United States Geological Survey Global Visualization Views (USGS – GLOVIS) with spatial resolution of 30m which has been validated and widely applied in different scientific research (Zhang *et al.*, 2023, Friedl *et al.*, 2022). These images were connected for radiometric and geometric errors and pre-referenced using the Universal Transverse Mercator Projection system and Arc GIS 10.5 with SPSS 22 Software were employed in the land use land cover analysis.

Classification

Land use land cover changes analysis was carried out using supervised image classification with the maximum likelihood method. This was applied using supervised maximum likelihood classification in ENVI 4.5 software environment. Accordingly, the images were classified into four different land cover classes adapted from Anderson *et al.*, (1976) which resulted in generating five land cover maps of the study area. The land cover classes are built-up, green area, image surface and water bodies. The study used image differencing to determine changes between the images. This was calculated as subtracting the imagery of one date from that of another, and generating an image based on the result (Busari and Adedeji, 2024).

$$\% \text{ change (Trend)} = \frac{\text{Observed change}}{\text{Sum of change}} \times 100$$

Normalized Difference Vegetative Index (NDVI) was also to measure reflective properties of leaves in red and near infrared wavelengths (*Haung et al*., 2020 and Jinru and Su, 2017). The formula is stated below:

$$NDVI = \frac{\rho NIR - \rho RED}{\rho NIR + \rho RED}$$

where NDVI is the Normalized Difference Vegetative Index, ρNIR is the Surface Reflectance of band 4, and PRED is the surface reflectance of band 3 in Landsat 5 and 7, and band 5 and band 4 in Landsat 8. Vegetated areas will yield high near-IR reflectance and low visible reflectance. The NDVI values were classified into three categories: low, moderate and high, which coincide with 2000, 2010 and 2020 respectively.

The three local government areas were also surveyed through visits to production areas, for examination of the availability of timber and bamboo in building construction processes in the town. Efforts were made to visit

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urban forests and agroforestry zones to determine the possible sources of cultivating timber and bamboo for different operations in building. Sawmills and other places of selling these materials were also visited in the town and interaction was made with the sellers on the availability of the products.

Results and Discussion

Land Use/Land Cover Analysis

The statistics of land use and land cover distribution for each in the study area and dynamics of change between the years are presented in Table 1 and the figures below. Various components of green infrastructure in Gedu Scheme, Ayetoro area, Boroboro area and road extensions to towns and villages have also been converted to residential and other settlements which is accountable for the reduction in green areas from 76.48% in 2000 to 50.41% in 2020 shown in figures 2 to 6. The result is also in line with the previous studies such as Afonja (2015) and Rafiu *et al.* (2018) where GIS was used to study the urban growing expansion in Oyo with the findings that urban green spaces are being converted to developmental projects This clearly shows that GI in Oyo is on decrease due to developmental projects that are taking up the available space. Oyo, with its largest percentage of land predominantly for green areas is also losing spaces to built area as a result of urbanization. Oyo is expanding along the major roads such as Iseyin, Ibadan, Ogbomoso, and other minor roads such as Aawe, Ilora, Jobele, Bale Agbe and others. The results of the land use change in the two study areas corroborate the findings of Abubakar *et al.* (2021) and Taiwo (2021), that the expansion of settlements, roads, offices, commercial and educational areas means an increase in human activities on the land while the vegetation that produces building materials depreciates.

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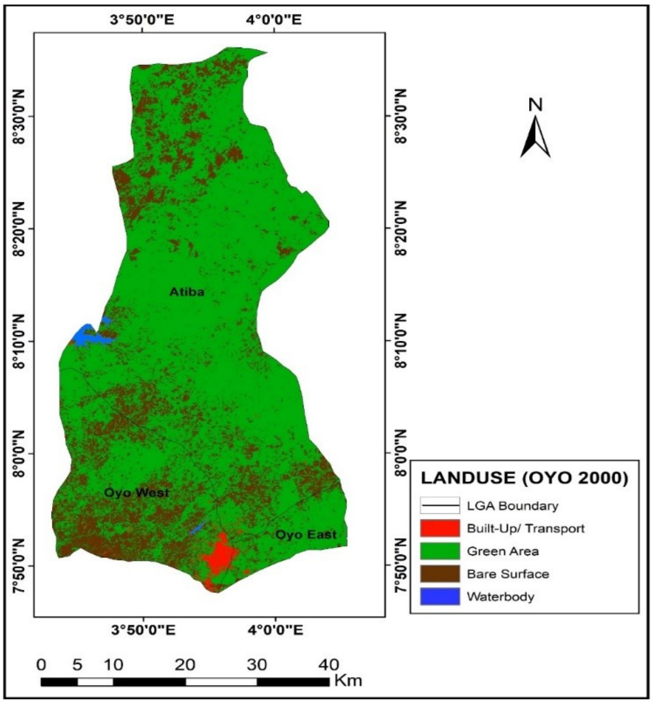

Figure 2: Oyo land use for the year 2000

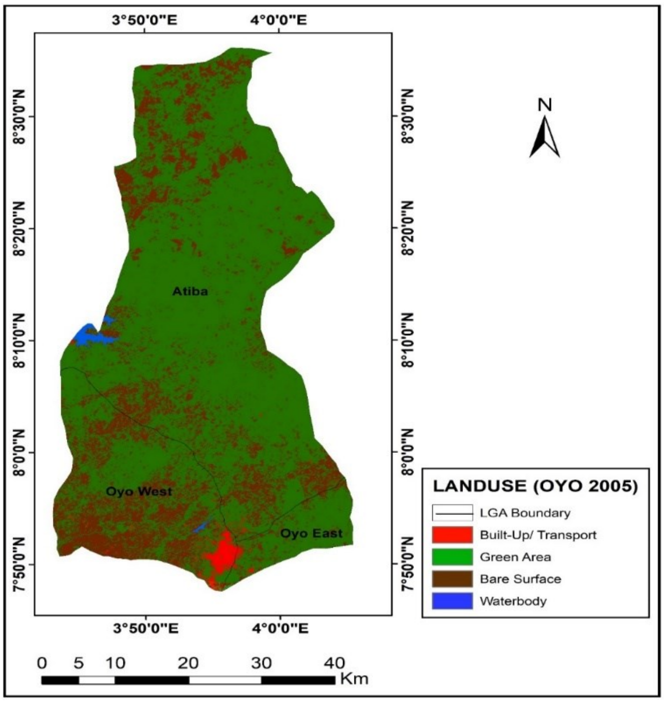

Figure 3: Oyo land use for the year 2005

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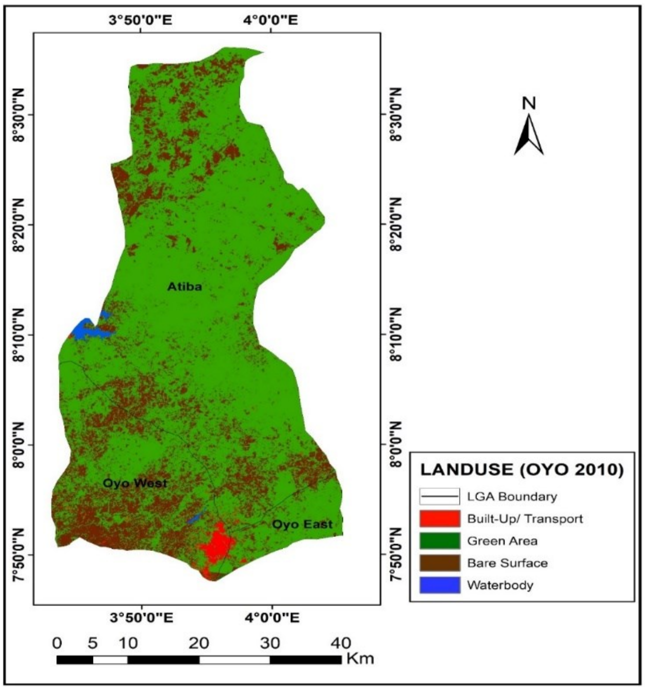

Figure 4: Oyo land use for the year 2010

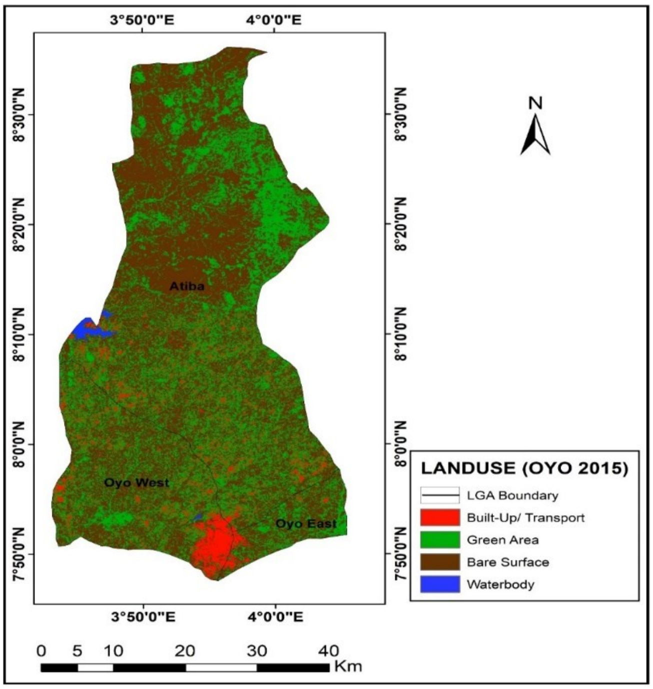

Figure 5: Oyo land use for the year 2015

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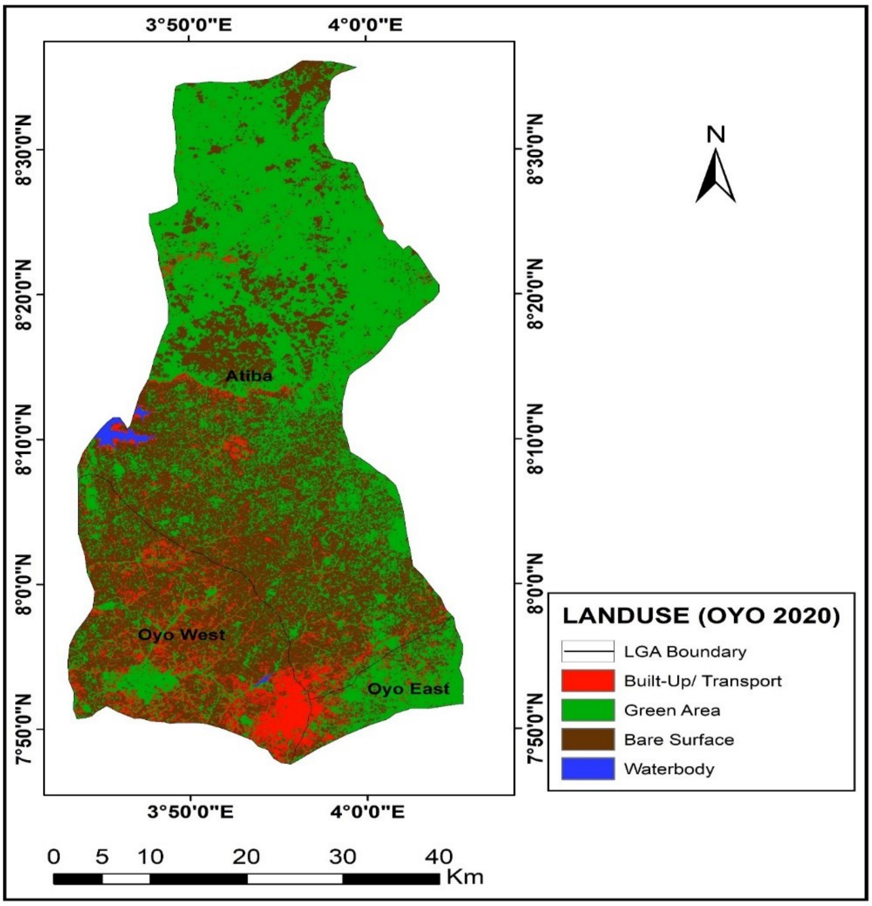

Figure 6: Oyo land use for the year 2020

Table 1: Oyo combined land use

Year	2000		2005		2010		2015		2020	
Land use	Area (km²)	Area (%)	Area (km²)	Area (%)	Area (km²)	Area (%)	Area (km²)	Area (%)	Area (km²)	Area (%)
Built-up Area/Transport	27.692	1.20	67.75	2.92	92.78	4.00	143.79	6.20	200.78	8.66
Green Area	1770.28	76.48	1805.80	77.88	2001.14	86.30	840.19	36.23	1168.96	50.41
Bare surface	502.29	21.71	427.83	18.45	212.80	9.18	1324.85	57.13	938.43	40.47
Waterbody	18.56	0.63	17.45	0.75	12.10	0.52	9.99	0.43	10.65	0.46
TOTAL	**2318.83**	**100.00**	**2318.83**	**100.00**	**2318.83**	**100.00**	**2318.82**	**100.00**	**2318.83**	**100.00**

Normalized Difference Vegetative Index

The NDVI is a dimensionless index that describes the differences between visible and near-infrared reflectance of vegetation cover and can be used to estimate the density of green on an area of land. It is an indicator of

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vegetation greenness. The NDVI of the study areas revealed the categories of vegetation; it shows the vegetative area from the highest point to the lowest point (non-vegetative) area. In years 2000, 2010 and 2020 in Oyo, The NDVI of Oyo for year 2000, 2010 and 2020 as shown in figures 7, 8 and 9 respectively showed the changes that have happened in categories of vegetation between year 2000 and 2020, the result revealed that vegetation index varies from -0.46 to 0.06 in the year 2000 (Figure 7), -0.03 to 0.34 in the year 2000 (Figure 8), and -0.00 to 0.28 in the year 2000 (Figure 9) which have had adverse effects on provision of natural building materials. This means that vegetation in the study areas is declining due to some anthropogenic or natural factors. This same view was expressed by Bayode *et al.* (2014) on the decreased values of NDVI across the epochs. The study of Meerah Ghandi (2015) with the finding that NDVI decreased consistently between 2001 and 2006 in the analysis with decreased vegetation.

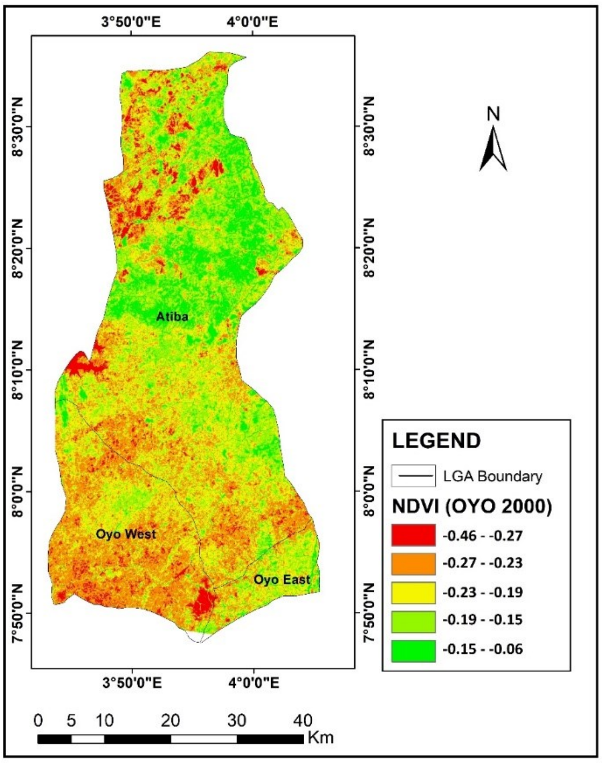

Figure 7: Oyo NDVI for year 2000

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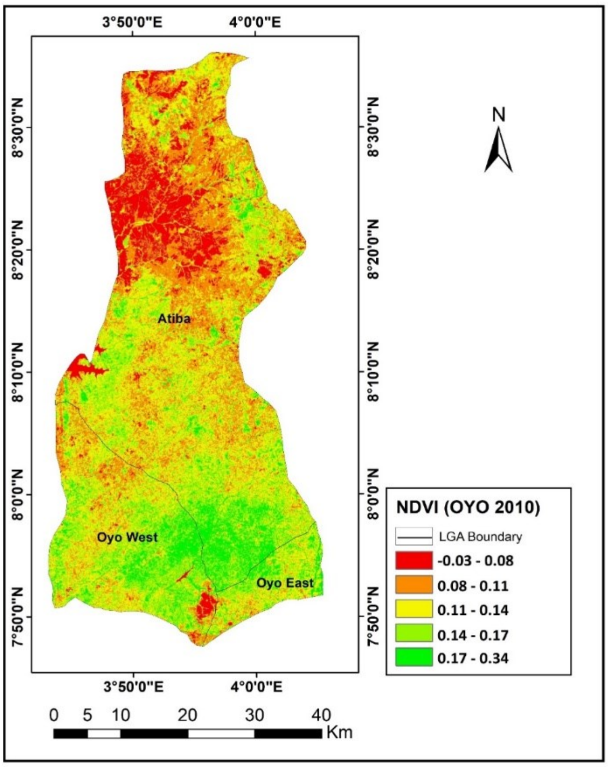

Figure 8: Oyo NDVI for year 2010

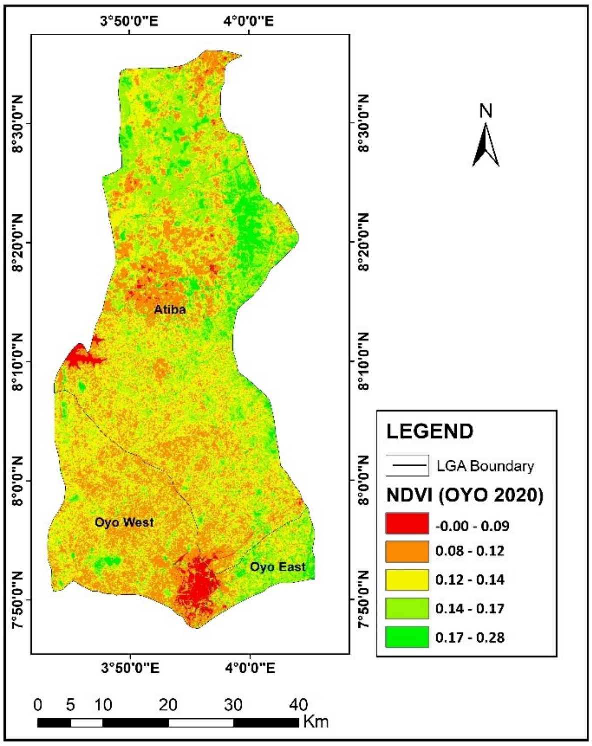

Figure 9: Oyo NDVI for year 2020

Market Survey of Availability of the Materials

The two materials under the study were available at different locations in the town because of the importance roles they played in the construction activities. Timber provision in the town for construction purposes are sourced from far places like the boundary of Republic of Benin and Nigeria due to deforestation of the forest that produced these planks in Oyo town. It is evidently clear that majority of the forests in the town have been cleared as a result of rapid urban growth in Oyo to create space for housing, infrastructure and industrial activities. Clear evidence of these are destruction of Gedu forest, Soro forest, Oko-Oba forest, Agodongbo forest etc. that supplied timber to the town in the past years. Table 2 shows the areas where planks are available in Oyo for construction activities. Majority of these vendors source the timber from far and wide to produce planks for various sizes and applications. Also, the sizes of timber produced in the Oyo Sawmills are far below the standards obtained some years ago. This falls in line with the land use/land cover analysis earlier conducted in this research, with marked increase in the destruction of the vegetal cover in the town. Agricultural expansion and conversion of forested area into farmlands through slash-and-burn practices also reduces the availability of timber resources in the locality. This is confirmed by the study of Adedokun *et al.* (2017) that availability of timber for construction purposes is now becoming scarce in Oyo and its environ due to a result of logging and overexploitation. The popular timber materials that were available freely in the markets are no longer in existence and decreasing availability will have an adverse effect on the quality of building construction.

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Table 2: Availability of Planks in Oyo Town

S/N	Plank Seller/Factory	Location	Types of plank	Source
1.	Atiba Sawmill	Old Ibadan Road, Oyo	Big industrial layout of woodworking machines for processing different sizes of wood for local use and supply to other cities	From the Republic of Benin and Oke-Ogun Area of Oyo State
2.	Saabo Sawmill	Saabo, Oyo	Medium-sized sawmill industry for timber processing into local and other uses	✓
3.	Oroki Sawmill	Oroki, Oyo	Selling and processing of wood produced by movable machines	✓
4.	Plank Retail Shops	Mabolaje, Araromi, Mogaji, Kosobo	Selling of wood for local and immediate use in the neighbourhood	Local Sawmills

Bamboo, which is also another sustainable material suitable for construction activities in the locality is also being impacted negatively and degraded faster. Bamboo is available in different villages in the town, but the rate of harvesting is higher and to the extent that they are supplied to cities like Lagos and Ibadan for construction purposes. Also, they are supplied to manufacturing companies for the production of different articles for human needs as well. The harvesting of bamboo for these purposes is carried out daily without any investment for planting that could serve as renewal in future. The bamboo of different sizes and shapes are loaded into various trucks to highly urbanized centres for various construction purposes. This unsustainable extraction of these materials has severely affected its natural ecosystems for the supply of the materials and provision of benefits from the green infrastructure. In Oyo town, increasing deforestation, land conversion and unsustainable resource extraction have led to a decline in green infrastructure, directly affecting the supply of timber and bamboo for construction. Encroachment of green spaces has significantly reduced the availability of bamboo for building construction purposes. Bamboo materials are only available in farthest villages which require efforts to get them harvested and transported to the town. Since they are mostly supplied to other towns and cities, heavy logs of these bamboos are stacked along Oyo Ibadan Expressway and Old Ibadan Road

The results above have shown that the destruction of green infrastructure in Oyo would continue to have adverse effect on the availability of sustainable materials in the area. The land use land cover affect the availability of timber by directly impacting the amount of forested land, the health of existing forests, and the rate of tree growth (Abdul Aziz *et al.*, 2024 and Liu *et al.*, 2024). Also Mgalula *et al.*, 2024 also concurred with this study that various benefits received by humans from trees in the form of food provision and other ecosystem services were distorted by the drives of land use land cover changes that were being experienced in the study area. Land use/land cover significantly impact availability of bamboo as conversion of the forests to other land uses limits its production (Bessie *et al.*, 2016 and Yirsaw and Nigussie, 2024).

Conclusion

Green infrastructure plays a crucial role in promoting sustainability in the built environment by integrating natural system with urban development. The land use land cover and NDVI analyses were used to conduct a spatial assessment of green infrastructure in Oyo town in order to evaluate its potential for enhancing sustainable building materials production. The study supports how these natural and renewable assets can support the production of sustainable building materials, which is timber and bamboo, which contribute to reducing the environmental impact of construction activities. The findings reveal that Oyo town possesses significant green infrastructure potential; its integration with the local construction industry remains limited due to poor spatial planning, inadequate policies and urban sprawl. The study highlights the need for strategic land use planning, investment in green infrastructure networks, and policy intervention to

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optimize the benefits of green infrastructure in sustainable building materials production. The destruction of green infrastructure in Oyo town has significantly affected the availability of timber and bamboo for building production. Without urgent intervention, the depletion of these materials will continue to threaten sustainable construction, local economics, and environmental stability. Oyo can adequately ensure the sustainable availability of timber and bamboo for building construction while protecting its natural ecosystems.

Recommendations

Based on the findings of this study, the following recommendations are proposed to enhance the integration of green infrastructure into sustainable building materials production in Oyo town. Strengthening of spatial planning and land-use policies in the planning sectors needs to be given special consideration and local authorities should incorporate green infrastructure into urban and regional planning frameworks to ensure its sustainable management and utilization. This also requires revision of zoning regulations to protect and expand areas designated for green infrastructure, such as urban forests, wetlands, and agricultural lands that can support eco-friendly material production. Government should also promote the use of sustainable building material by providing incentives such as tax reliefs, grants and subsidies to encourage local and industries and builders to adopt sustainable materials derived from green infrastructure.

Also, efforts should be made by the people at the community levels to expand and maintain green infrastructure assets, including reforestation projects, agroforestry, and green urban belts, to ensure a steady supply of raw materials for sustainable construction. The integration of green infrastructure systems should be prioritized to improve environmental sustainability and urban resilience. A dedicated task force or agency should be created to oversee the implementation and monitoring of green infrastructure development and its role in material production. Training

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programs should be organized for architects, engineers and construction professionals to enhance their knowledge of green infrastructure and sustainable materials. This should be followed by educating the communities on the benefits of using locally sourced, eco-friendly building materials and the importance of preserving green infrastructure. Geographic information system tools and remote sensing should be used to regularly assess and map the availability, distribution and health of green infrastructure assets and digital platforms should be developed to provide real-time data on green materials resources and their sustainable harvesting potential. These will enhance the role of green infrastructure in supporting sustainable building materials production, thereby reducing environmental degradation and promoting a resilient built environment in Oyo town.

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