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Research Article

Land Use Land Cover Dynamics and Implications for Carbon Stock in the Savannah Agroecological Zone: A Case Study of Yamaltu-Deba LGA, Northeast Nigeria

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ABSTRACT
Unsustainable land-use management in Sub-Saharan Africa has been a major cause of soil-plant carbon instability, especially in savannah agroecological zones. About two-thirds of Nigeria's landmass is covered with savannah, especially northern region. This study aims to quantify carbon stock capacity per hectare with respect to vegetation classification in Nigeria's northeast agroecological zone, specifically the savannah. Five land use variables, made up of low forest, savannah, grassland, water body, and no vegetation, were adopted. Study area Landsat images with a periodic interval of ten (10) years were downloaded for four (4) decades: 1990, 2000, 2010, and 2020, respectively. Image calculations were used to generate a vegetation cover change map, and area coverage in hectares was multiplied by the previous estimated carbon stock of 60.01 Mg ha^{-1} for low forest, 32.66 Mg ha^{-1} for savannah, and 18.22 Mg ha^{-1} for grassland. While the low forest and grassland drastically reduced, the savannah tremendously increased. The study recommends afforestation policies, adoption of nitrogen fixing tree for farmland and boundary demarcation, and creation of a carbon stock sequestration database for the savannah agroecological zone.

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1 Introduction

While about one-third of the earth's surface is covered with land of different substrates and biomass, an average of 20% of it accounts for savannah and grassland, with their nature as determinant of the type of land use to be subjected to. Since the early existence of human settlement, the use of land has continued to evolve from one pattern to another, which ranges from agricultural land use to a diverse perspective as a result of development through man's interference, science, and technology, leading to industrialization, urbanization, the main causes of global warming, and climate change. Globally, about three-quarters of Earth's land surface has been altered by anthropogenic activities over the last millennium (Luyssaert, 2014).

The drivers of land use change are countless; some act slowly over a long time, while others trigger events quickly and visibly. In every case, several forces are at work; sometimes they operate simultaneously, sometimes independently, and at other times synergistically. Land use is primarily derived from land cover, which varies in carbon stocks across agroecological zones. The carbon sequestration stock rate is directly proportional to land-use patterns and the nature of vegetation cover. Land-use changes are a locally pervasive phenomenon with globally significant ecological implications (Agarwal, 2010) that may alter biogeochemical cycles and surface-atmosphere energy trade-offs, and influence regional climate (Turner, 2006).

The implications of land-use change for carbon sequestration is more pronounced in the northern part of the country, where grasslands and savannahs with sparse vegetation are prevalent. Savannas are widespread in sub-Saharan Africa and play a major role in the global carbon balance (Djagbletey et al., 2018). They can also be relied on generally as stable, enormous, and underappreciated areas with potential for carbon sequestration. Savannas may be managed as carbon sinks, primarily by protecting them from degradation and facilitating biomass accumulation over decades. Due to their extensive area and frequent burning, they influence the water and carbon balances (Santos et al., 2004). The composition of savannas is often heterogeneous, with various classifications as woodland, bushland, and grassland (Fisher et al., 2014). Carbon concentration in the savannah is a function of vegetation types, tree species, fire management strategies, and soil type.

Exposing savannahs to activities like logging, grazing, fire, and intermittent cultivation depletes carbon stocks, while protection from them increases savannah woodland with a closed canopy and high carbon stocks. In general, forests store most of their carbon in woody trunks and aboveground leaves, while in a savannah ecosystem, a significant amount of carbon is stored in the soil. In contrast, a significant portion of carbon in grassy ecosystems, such as savannas and grasslands, is stored in the soil, primarily within the extensive root systems of grasses and in decaying organic matter (Michael et al., 2017). The international concern with carbon emission and

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sequestration assessment requires adequate coverage of locally quantified carbon stocks (IPCC, 2006).

However, of significant concern is the dearth of spatial data on carbon stock in Nigeria's savannah agroecological zone, even though it accounts for more than 70% of the nation's vegetation. A lack of adequate data on spatial variation in carbon stocks across different land-use types and on the actual SOC in ecosystems affected by land-use change are two major sources of uncertainty in carbon estimates, particularly in developing countries (Keller et al., 2001). Nigeria, as a REDD+ signatory, stands to benefit from climate change mitigation gains but lacks spatial data on carbon stocks. Availability of spatial data on the savannah and the estimation of associated carbon may position Nigeria as one of the beneficiaries of REDD+ global finance. Financial mechanisms such as REDD+ (Reduced Emission from Deforestation and Forest Degradation) can produce an opportunity for SSA to alleviate poverty through conservation of its forestry resources (Djegbletey et al., 2018).

Carbon storage in terrestrial systems can be easily incorporated into each nation's National GHG inventories and be paid for, with Nigeria, a signatory to the Kyoto Protocol (Okon et al., 2021). Quantification and monitoring of carbon stocks have gained significant attention in international climate change mitigation and adaptation negotiations because verification and accounting of carbon stocks in forest ecosystems are recognized as potential strategies to reduce and stabilize atmospheric greenhouse gas concentrations (UNFCCC, 2010). Although more than half of Nigeria's vegetation is savannah, most studies on climate change mitigation strategies and carbon stock focus more on forests rather than savannah and grasslands. Contrary to Field et al. (2014) that sufficient work on the quantification of carbon stocks in savannas does not exist, the majority of previous studies on carbon stock estimation centred on forests (Saiz et al., 2012; Dintwe et al., 2015; Chiti et al., 2017) than on savannas. On this note, the study aims at quantifying carbon stock potential based on vegetation classification per hectare in Nigeria's northeast savannah agroecological zone.

2 Materials and Methods

2.1 Study Area

Yamaltu–Deba is one of the Local Government Areas (LGAs) in Gombe State, in northeastern Nigeria. The area lies approximately between Latitude 10°13′N and 10°23′N of the Equator and Longitude 11°23′E and 11°38′E of the Greenwich Meridian. It is bounded to the north by Kwami LGA, east by Borno State, south by Balanga LGA, and west by Akko LGA (Figure 1). According to the National Population Commission (NPC, 2006), Yamaltu–Deba LGA had a population of 255,726 in the 2006 national census. Based on an annual growth rate of 3.3%, the population is projected to reach approximately 473,894 by 2025. The LGA covers an area of about 1,857.33 km² and is located approximately 7 km east of Gombe, the state capital. The dominant ethnic groups in the area include Tera and Fulani, with other minority groups such as Kanuri, Hausa, Jara, and Waja. The area's economy is largely agrarian, with farming and livestock rearing as the main livelihood activities of its inhabitants.

The climatic conditions of the study area are characterized by high temperatures and seasonal rainfall typical of the Sudan Savanna ecological zone. The rainy season usually lasts five to six months, beginning in late May and ending in mid-October, while the dry season lasts six to seven months, though this may vary slightly from year to year. The mean annual rainfall ranges from 800 to 1,000 mm, the average temperature from 30°C to 32°C, and the relative humidity from 17% to 90% (Ibrahim & Abubakar, 2013).

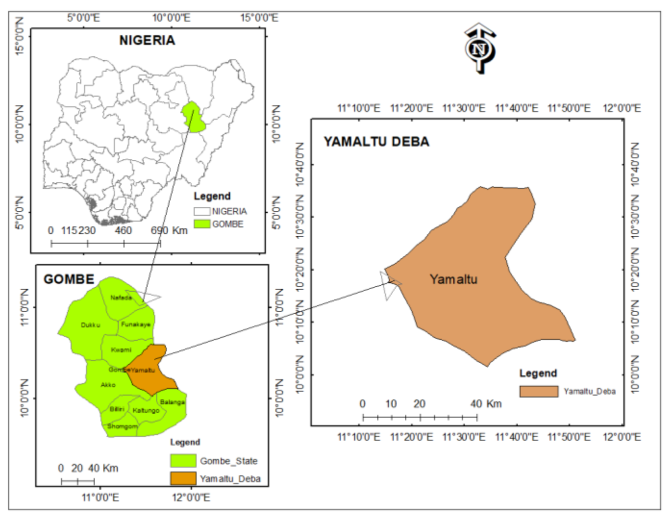


Figure 1: Map of Yamaltu-Deba

Vegetation in the study area falls within the Sudan Savanna belt, which is typically characterized by scattered trees, grasses, and shrubs. However, due to decades of anthropogenic activities such as farming, grazing, and fuelwood extraction, much of the natural vegetation has been degraded, resulting in the dominance of semi-desert shrubs and sparse savanna vegetation. The geomorphology of Yamaltu–Deba is mainly composed of gently undulating plains and pediments, which influence both land use and settlement patterns (Ibrahim & Abubakar, 2013). The predominant soil type in the area is Vertisol, which is generally dark in colour and rich in heavy clay content. These soils range from shallow to deep, clayey, loamy, and sandy Vertisols, commonly referred to as cracking clays due to their tendency to expand and contract with changes in moisture. Despite these physical characteristics, the soils are relatively fertile and capable of supporting intensive agricultural activities.

2.2 Data Sources

Satellite imagery from Landsat 7 ETM+ and Landsat 8 OLI with a spatial resolution of 30 m was used for the analysis. Multi-temporal satellite images were obtained at 10-year intervals over four decades, specifically in 1990, 2000, 2010, and 2020.

2.3 Data Analysis

Five major land-use/land-cover (LULC) classes were identified for the analysis: high vegetation (low forest), savannah, grassland, water bodies, and no vegetation (outcrop). To determine the areal extent and trend of vegetation cover changes, a temporal trend analysis approach was adopted. Image calculations were performed to generate vegetation cover change maps and quantify area coverage in hectares.

Furthermore, the estimated vegetation area was multiplied by the minimum estimated carbon stock value of 60.01 t C/ha for low forest (Djegbletey et al., 2018), 32.66 t C/ha for savannah (Awe et al., 2019), and 18.22 t C/ha for grassland (Ayina et al., 2025) to estimate the carbon stock associated with vegetation cover in the study area.

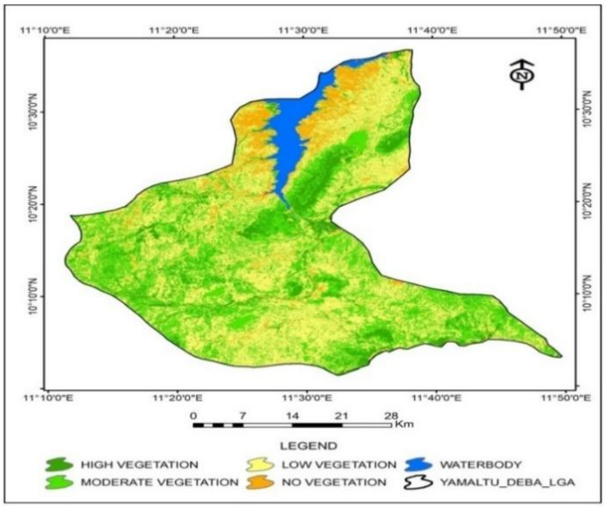
3 Results

The results presented in Table 1 reveal significant spatiotemporal changes in vegetation cover and corresponding carbon stock in Yamaltu–Deba LGA between 1990 and 2020. The total land area remained constant at 185,733 hectares throughout the study period, while total carbon stock was approximately 4.1 million tonnes. However, this apparent stability masks substantial internal shifts among vegetation classes. To estimate carbon stocks within the study area, five carbon sequestration categories were identified based on their carbon absorption and reflectance characteristics. These include low forest, savannah, grassland, no vegetation (bare land/outcrops), and water bodies.

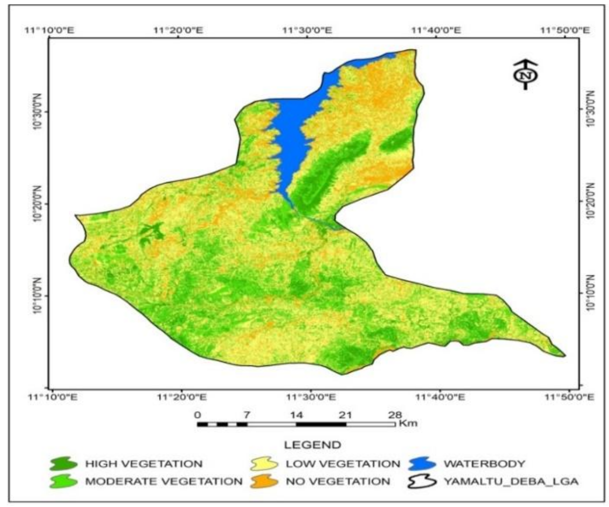
Table 1: Carbon Stock Estimation in Yamaltu–Deba LGA

Vegetation Class	1990 (ha)	2000 (ha)	2010 (ha)	2020 (ha)	%	Carbon Stock (t C)
Low forest	22,544	20,459	13,269	9,318	5.02	559,173.18
Savannah	84,172	87,614	101,782	103,096	55.51	3,367,115.36
Grassland	50,870	35,660	25,730	9,612	5.18	175,130.64
No Vegetation	19,074	31,993	35,513	51,115	27.52	
Water Body	9,073	10,007	9,439	12,592	6.77	
Total	185,733	185,733	185,733	185,733	100	4,101,419.18

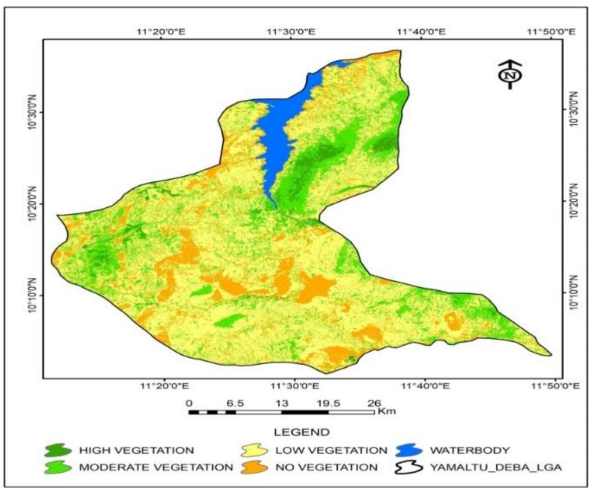
Land use distribution patterns were in order of savannah (55.51%), no vegetation (27.52%), water body (6.77%), grassland (5.18%), and low forest (5.02%), respectively (Table 1). Approximately about 66% area of the study account for 4,101,419.18 t C, while the remains area with 34% made up of water bodies and no vegetation, otherwise linked with either outcrop or built-up area. Low forest vegetation experienced a continuous and pronounced decline over the study period, with decreasing orders of 9.24%, 35.14%, and 29.77%. It decreased from 22,544 ha in 1990 to 9,318 ha in 2020, representing a loss of more than 50% of its original extent with consequential effects of 559,173.18 t C of carbon sequestration using 60.01 Mg ha^{-1} based on Djegbletey et al. (2018). This sharp decline suggests intense deforestation and degradation of dense vegetation, which are critical carbon sinks, thereby reducing the area's capacity for carbon sequestration. While low forests have been on the reduction side, savannah vegetation showed a steady increase in both area and carbon stock, with an increase of 4.08%, 16.17%, 1.29%. It expanded from 84,172 ha in 1990 to 103,096 ha in 2020, with a carbon stock of 3,367,115.36 t C using 32.66 Mg ha^{-1} according to Awe et al. (2019). This trend suggests a shift in land cover from higher-vegetation classes to more degraded or less dense vegetation types, possibly due to anthropogenic activities such as farming, grazing, and fuelwood extraction. Grassland vegetation exhibited a decline at a decreasing rate of 29.89%, 27.84%, 62.64% respectively. Its area reduced drastically from 50,870 ha in 1990 to 9,612 ha^{-1} in 2020, while carbon stock recorded 175,130.64 t C using 14.65 Mg ha^{-1} based on Ayina et al. (2025). This decline further reinforces the pattern of vegetation degradation, in which savannah vegetation is being converted to grassland or non-vegetated surfaces. The built-up area and water-body increased at the rate of 67.73%, 11%, 45.01% and10.29%, 5.67%, 33.40% between 1990 and 2020, respectively.



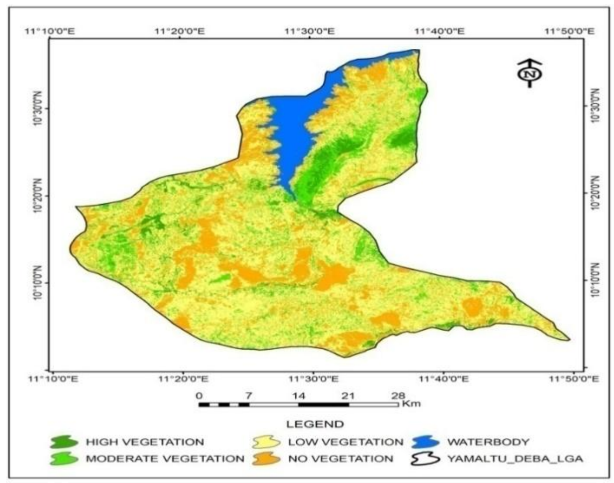
a) 1990



b) 2000



c) 2010



d) 2020

Figure 2: Land Use Change in Yamatu-Deba in 1990, 2000, 2010, and 2020

Estimation of carbon stock density is a fundamental step in carbon accounting and in evaluating land-use options and strategies to promote carbon sequestration (Lal, 2004). Apart from estimation, there is no universally accepted standard value for carbon stock across agro-ecological zones, making it difficult to determine the precise average rate of carbon sequestration in savanna ecosystems. Studies revealed that different vegetation sequesters carbon differently according to vegetation types and patterns. Abdulllahi et al. (2014) summarized the mean carbon stocks of plant communities in decreasing order of savanna woodland (127.30 Mg C ha^{-1}), tree savanna (114.44 Mg C ha^{-1}), scrubland (111.47 Mg C ha^{-1}), and grassland (106.72 Mg C ha^{-1}). Total carbon storage capacity of savanna ecosystems ranges from 39.85 ± 14.65 t C/ha for degraded areas to 152.18 ± 43.76 t C/ha for swampy areas (Awe et al., 2019). Natural forest of all the land use types has the greatest biomass carbon storage potential with an estimated standing stock of 155.61 Mg C ha^{-1}, while cropland has the least carbon storage with a measured standing stock of 35.33 Mg C ha^{-1} (Olorunfemi et al., 2019; Okon et al., 2019). The results showed that about 59% of reduction was recorded in the low forest and 81% of the savannah vegetation over 30 years of consideration. This indicates that the carbon stock of 559,173.18 t C for low forest and 175,130.64 t C for grassland represent 41% and 19% carbon sequestration as at 1990. More than 50% reduction in a particular vegetation type to the lower type signifies a tremendous amount of carbon reduction over a considerable period. Mohammed et al. (2022) evaluated the land use change from 1991 to 2022 in Selangor (Malaysia) and discovered a decrease in agricultural area (3.07%), forest (14.01%), and wetland (0.94%), respectively. Ayina et al. (2025) study on spatial assessment of carbon sequestration dynamics in the Southern guinea savannah agro-ecological zone of Taraba recorded 123.58 Mg C ha^{-1} in riparian forest, 97.71 Mg C ha^{-1} in savannah woodland, and 18.22 Mg C ha^{-1} in grassland, respectively.

By and large, findings indicate a clear trend of vegetation and land use cover transformation in Yamaltu–Deba LGA over three (3) decades of observation. The substantial reduction in low forest and grassland, coupled with the expansion of savannah and built-up area, evidenced anthropogenic pressure with consequential effect on the decrease in carbon sequestration in Nigeria's savannah.

4 Conclusion

Changes in land use are a global phenomenon and one of the most important processes altering the natural and human environment through many ecological and socio-economic mechanisms. The causes are local but have significant consequences for the biophysical environment and humans globally. The study observed that urbanization and acceleration in farmland encroachment are leading factors of low forest and grassland reduction in Yamatu-Deba. To address the identified problems and anticipated issues, the study hereby recommends an afforestation programme, the establishment of green spaces, parks, and gardens to reclaim lost vegetation via built-up areas, legislation against all forms of deforestation, and a modern farming system. The adoption of nitrogen-fixing perennial trees for farmland demarcation and boundary layout is an additional strategy for sustainable carbon sequestration and soil nutrient improvement in the savannah agroecological zone of Nigeria. Also, the domestication of dual-purpose trees in conjunction with physical planning policy needs to be integrated into building layout plans. Environmental impact assessment and monitoring of savannah agroecological variability should be a government priority to create a carbon stock database.

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References

Abdullahi, J., Suleman, M.Z., & Sakoma, J. K. (2014). Carbon sequestration potential of Kpasimi forest reserve and adjoining park area, Niger State, Nigeria. Journal of Geography and Earth Science, 2(1), 149-163.

Agarwal, C., Glen, M., Green, J., Morgan, G., Tom, P. E., Charles, M.S., & Charles, M. S. (2010). A review and assessment of land-use change models: dynamics of space, time, and human choice. General Technical Report, 297(1), 1–61.

Awe, D. V., Nohila, N. V. & Louis, Z. (2019). Carbon storage and emission factor of the savanna ecosystems in the Soudano-sahelian zone of Cameroon. Journal of Botany Research, 2(1), 60-70. https://doi.org/10.36959/771/562

Ayina, S. R., Oruonye, E. D, Bwadi, B. E., & Musa, H. (2025). Spatial assessment of carbon sequestration dynamics in southern guinea savannah agro-ecological zone of Taraba State, Nigeria. Journal of Plant Biota, 4(2), 24-32. https://doi.org/10.51470/JPB.2025.4.2.24

Chiti, T., Mihindou, V., Jeffery, K. J., Malhi, Y., De Oliveira, F. L., White, L. J., & Valentini, R. (2017). Impact of woody encroachment on soil organic carbon storage in the Lopé National Park, Gabon. Biotropica, 49(1), 9-12. https://doi.org/10.1111/btp.12369

Djagbletey, E. D., Logah, V., Ewusi-Mensah, N., & Tuffour, H. O. (2018). Carbon stocks in the Guinea savanna of Ghana: Estimates from three protected areas. Biotropica, 50(2), 225 - 233. https://doi.org/10.1111/btp.12529

Dintwe, K., Okin, G. S., D'Odorico, P., Hrast, T., Mladenov, N., Handorean, A., ... & Caylor, K. K. (2015). Soil organic C and total N pools in the Kalahari: potential impacts of climate change on C sequestration in savannas. Plant and soil, 396(1), 27-44. https://doi.org/10.1007/s11104-014-2292-5

Fisher, D. O., Johnson, C. N., Lawes, M. J., Fritz, S. A., McCallum, H., Blomberg, S. P., ... & Kutt, A. (2014). The current decline of tropical marsupials in Australia: is history repeating?. Global Ecology and Biogeography, 23(2), 181-190. https://doi.org/10.1111/geb.12088

Field, C. B., Barros, V. R., Dokken, D., Mack, K. J., Mastrandrea, M.D., Billir, J.E., Chatterjee, M.,

Ebi, K.L., Estrada, Y.O., Genova, R.C. et al. (2014). IPCC Climate change. Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspect.

Ibrahim, A. K. & Abubakar, B. (2013). Extractable micronutrient status in relation to other soil properties in Jangargari, Yamaltu-Deba Local Government Area, Gombe State. Asian Journal of Agriculture and Food Sciences, 1(5), 219-221.

Intergovernmental Panel on Climate Change (2006). Synthesis report summary for policy makers (www.ipcc-wg).

Keller, M., Silva-Dias, M. A., Nepstad, D. C., & Andreae, M. O. (2019). The large-scale biosphere-atmosphere experiment in Amazonia: analyzing regional land-use change effects. Ecosystems and Land Use Change Geophysical Monograph Series, 153, 321-334.

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. Science, 304(5677), 1623-7.

Luyssaert, S. (2014). Land management and land-cover change have impacts of similar magnitude on surface temperature. National Climate Change, 4, 389–393.

Michael, M., Michael, N., Harvey, H., Richard, L., Justin, S., Tor, U., & Joseph, O.O. (2017). Cotton and Consistent Land use/cover change estimate using socioeconomic data. Earth System Dynamics, 8, 55-77.

Mohammed, F. B., Mustafa, M. R. U., Baig, I., Takaijudin, H. B., & Zeshan, M.T. (2022). Assessment of land use land cover changes and future predictions using CA-ANN simulation for Selangor, Malaysia. Water, 14(3), 402–424.

National Population Commission (2006). Official Gazette of the Federal Republic of Nigeria.

Olorunfemi, I. E., Komolafe, A. A., Fasinmirin, J. T. & Olufayo, A. A. (2019). Biomass carbon stocks of different land use management in the forest vegetation zone of Nigeria. Acta Oecologica, 95(2), 45-56.

Okon, E. M., Falana, B. M., Solaja, S. O., Yakubu, S. O., Alabi, O. O., Okikiola, B. T. & Edeme, A. B. (2021). Systematic review of climate change impact research in Nigeria: implications for sustainable development. Heliyon, 7(9), 41–79.

Saiz, G., Bird, M. I., Domingues, T., Schrodt, F., Schwarz, M., Field-Pausch, T. R., Veenendaal, E., Djagbletey, G., Hien, F., Compaore, H., & Diallo, A. (2012). Variation in soil carbon stocks and their determinants across a precipitation gradient in West Africa. Glob. Change Biol. 18, 1670-1683.

Santos, A. J. B., Quesada, C. A., Silva, G. T., Malal, J. F., Miranda, H. S., Miranda, A. C. & Lloyd, J. (2004). High rate of net ecosystem carbon assimilation by Brachiara pasture in the Brazilian Cerrado. Global Change Biological, 10, 877-885.

Turner, B.L. (2006). Land change as a forcing function in global environmental change. In: H.J. Geist (Ed.) Our earth's changing land: An Encyclopedia of Land Use and Land Cover Change, 1 (A-K). Greenwood Press.