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Analysis of Land Use Change and Associated Implications on Soil Ecosystem Functions in South Eastern Nigeria

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Abstract

Land use change affects soil functions and its capacity to provide ecosystem services. Though much of the tropics are experiencing accelerated increases in land use change, associated impacts of such changes are poorly understood and studied. This study assessed the extent to which land use changes affect the soil ecosystem functions in a rainforest zone of south eastern Nigeria. Soil samples were collected from 24 sample locations in selected natural forest, cashew and palm plantations. Samples were analyzed in triplicate in the laboratory for geochemical analysis, after which the result was subjected to statistical analysis—ANOVA, correlation and regression. Forest carbon had higher % mean carbon content; though there was no significant difference ($F (2, 21) = .246$, $p = .784$) in carbon level across land uses. R value of .301 showed low correlation between % carbon, organic matter and % loss in ignition. Furthermore, R^2 value of 9.1% total variation in the dependent variable could only be explained by the independent variables. CEC, Nitrogen, Potassium and Phosphorus content of the land uses did not differ significantly: CEC ($F (2, 21) = .844$, p (.44); Nitrogen (.243), p (.79), Potassium (.140), p (.87), Phosphorus (.783), p (.47). This showed that there was no significant variation in soil fertility of the land uses, although natural forest had higher concentrations for these variables. Across the land uses, soil texture equally had no significant variations: % sand ($F (2, 21) = .320$, p (.729) % clay (.430), p (.656), % silt (.043), p (.958). Soil carbon was seen to be more enhanced in natural forest ecosystems than other land uses. Though plantations had reduced capacities to provide ecosystem functions, establishing such in modified landscapes is still advocated as they can coexist with such and yet ensure ecosystem functions.

Keywords

Climate Change, Ecosystem Services, Forest Loss, Modification, Soil Processes

1. Introduction

Land is used for different purposes and is targeted at meeting the varying needs of human populations. As the quest for land to meet varying purposes has steadily grown across the globe, much forest lands are converted into other uses (land use change) with far reaching consequences for global biodiversity and climate (Kaplan et al., 2011; Ruddiman et al., 2015; Boivin et al., 2016). This trend of modifying ecosystems to suit particular demands and fit into the models designed by different human societies is poised to increase with global population (estimated to be up to 11.2 billion by 2100; United Nations, 2015, medium scenario). Such disturbances and conversions of ecosystems and forest lands will escalate land use changes, and contribute directly to agricultural expansion due to an associated demand for more food preferences and dietary demands (Tilman et al., 2011; Lanz et al., 2017). These drivers of land use change and other proximate causes such as industrialization and infrastructural developments will equally grow in magnitude, and in totality, put more pressure on forest ecosystems and marginal lands. Consequently, important biodiversity that is found in such landscapes and vital ecosystem services such as carbon storage will be put at risk.

While the ecosystem services derived from land remain much relevant, the extent to which they could be harnessed and remain continually useful is dependent to a great extent on how the ecosystems are managed and how their lands are being used. Land use, which summarizes the totality of activities, management arrangements and human impacts on varying land cover types (Fedele et al., 2018), is incidentally modified at various times to suit perceived prevailing needs for different contexts. Understanding the drivers and impacts of land use changes and modifications in ecosystems are vital and topical concerns for different spatial scales. More insights are needed for tropical ecosystems which though undergoing accelerated changes in land use as other ecosystems, yet are still quite strategic for climate change mitigation. With a higher capacity to store carbon (Cuni-Sanchez et al., 2021), it craves conservation and should in reality be enhanced in a bid to address global climate change concerns. While this is well known and acknowledged at both regional and international scales, it is however hampered at local scales because much of its capacity to achieve this is relatively unknown and is not optimally conserved.

Ample information on land use change is hence needed on distinct biogeographic units (such as the rainforest ecosystem) and how they affect ecosystem services, particularly, supporting and regulatory services, elucidated. Rainforests are known for their vast number of species; and accommodate 70% of the flora and fauna in world's ecosystem even though they are found in only 7% of the world's terrestrial space (Lovejoy, 1997). It is however under intense pressure of exploitation of the biodiversity and largely deforested and degraded across the world. Across Nigeria, it only occupies 95,372 km^2 (9.7%) of Nigeria's land mass, yet it provides much of the timber need of the country (Onyekwelu et al., 2008). Expectedly, much of its landscapes across Nigeria are degraded and are found as relics. Information on how such dynamics and other degradation forcings emanating from changes to other land uses (mainly agriculture) are lacking and require concerted attention. Research on the ecosystem has focused more on land use change effects on soil fauna diversity (such as Kerfahi et al., 2016; Mueller et al., 2016), land use change effects on biodiversity, above and below ground carbon (Drescher et al., 2016) and soil fertility dynamics across land uses and microbial activity (Guillaume et al., 2016). Reference as to how changes in land use impacts soil functions is lacking across the rainforest belt of Nigeria and south east region in particular. This study hence explored the capacity of a rainforest zone to provide soil ecosystem services and showed the extent to which it could be affected by (agricultural) land use change. Information on such an issue is needed as it will provide insights on strategies that could be adopted to better address land use change concerns and yet promote better ecosystem resilience.

2. Materials and Methods

2.1. Study Area

The research was conducted in a rainforest zone in South East Nigeria (**Figure 1**). It is characterized by a humid tropical, tropical wet and dry climate, and marked with rainy and dry seasons. Annual rainfall ranges from 1400 mm in the North to 2500 mm in the South, and has a mean monthly temperature of 27.6˚C. Geology of the region comprises of ancient Cretaceous delta, with the Nkporo shale, the Mamu formation, the Ajali sandstone and the Nsukka formation as its main deposits (Ofomata, 1975). Natural vegetation in this region is a rainforest ecosystem; though much affected by degradation and forest cover loss.

Fieldwork was conducted in Inyi community in Oji River local government area, Enugu state.

2.2. Sample Collection and Analysis

A total of 24 soil samples were collected at 30 cm deep in a natural forest, palm and cashew plantations; being 8 samples per land category. These were air dried and analyzed in the laboratory. Organic carbon was derived with Walkey-Blacks titration method (Jackson, 1973) after which the Van Bemmelan factor was used to calculate the organic matter. Exchangeable aluminium (Al) and exchangeable cations, namely calcium (Ca), magnesium (Mg), sodium (Na) and potassium (K), were derived following Allen et al. (1974). Summer and Miller (1996) was employed for CEC determination; Semi-micro kjedahls distillation method (Mishra, 1970) was used to get the nitrogen while pH employed the H_2O and 0.1

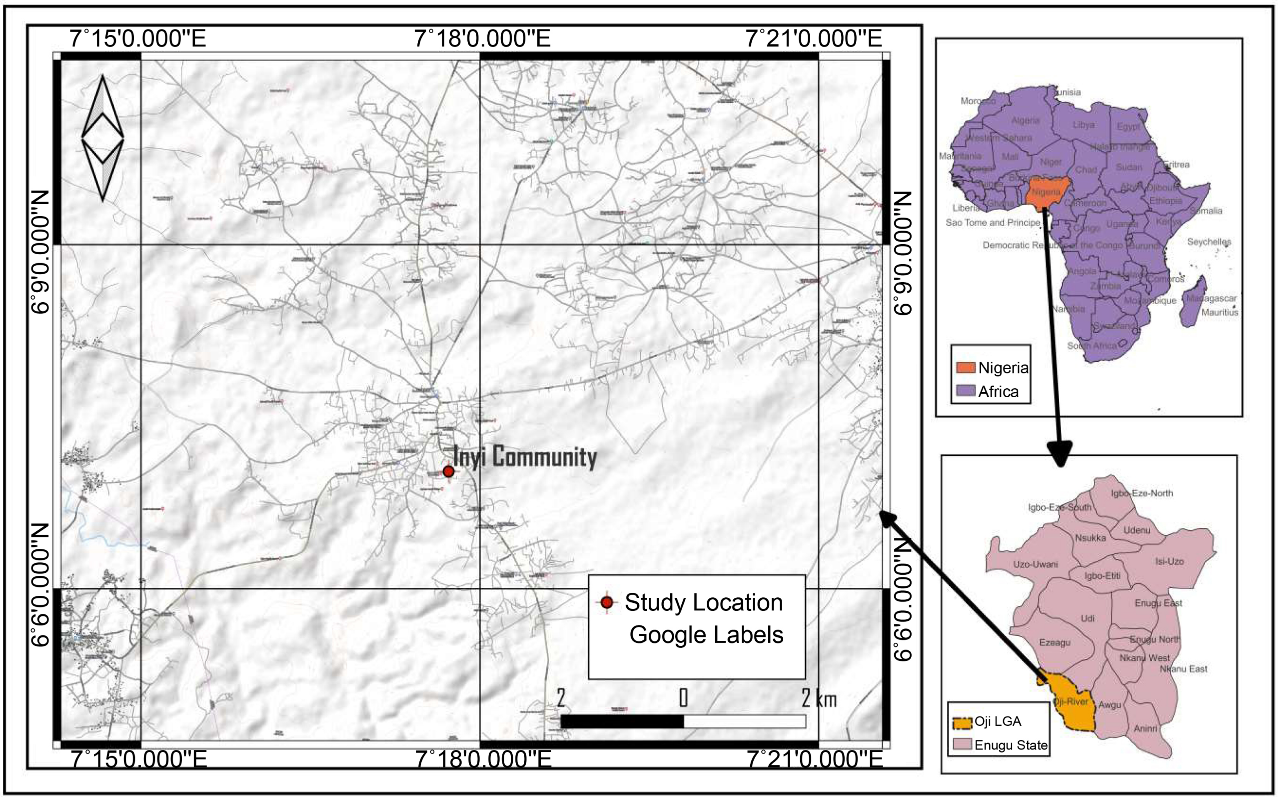

Figure 1. Map of the study area.

M KCl methods of Rowell (1994). Other heavy metals were analyzed with EDTA and titrimetric methods.

2.3. Data Analysis

Descriptive statistics were used to summarize the mean average of the % carbon of each of the land categories. Analysis of variance (ANOVA) was used to verify how varied the soil carbon was for the different land categories/land uses. Relationship between % carbon and other carbon indices (loss on ignition and organic content) was verified with a linear regression. Significant variations in soil fertility and texture across the land uses were equally verified with ANOVA and a Tukey post hoc test.

3. Results

Mean of the carbon content of the land categories showed that natural forest had the highest % carbon content (4.938) and was followed by cashew and palm plantations (4.818 and 4.39), respectively.

There was no statistical significance difference between the amount of carbon across the land uses: (F (2, 21) = .246, p = .784) (**Table 1**).

Regression to establish relationship between percentage carbon and other carbon indices-loss on ignition and organic carbon content showed an R value of .301, which implied that there was low correlation between % carbon, organic

Table 1. ANOVA for the different land uses.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.320	2	.660	.246	.784
Within Groups	56.399	21	2.686		
Total	57.718	23			

matter and % loss in ignition. R^2 value of 9.1% total variation in the dependent variable could only be explained by the independent variables.

CEC, Nitrogen, Potassium and Phosphorus content of the land uses did not differ significantly: CEC (F (2, 21) = .844, p = .44; Table 2); Nitrogen (F (2, 21) = .243, p = .79); Potassium (F (2, 21) = .140, p = .87); Phosphorus (F (2, 21) = .783, p = .47) and showed that there was no significant variation in soil fertility of the land uses. However, the natural forest had higher concentrations for the variables as shown by the post hoc test (Table 1).

Analysis of variance to verify if the soil texture differed across the land uses were not significant: % sand (F (2, 21) = .320, p = .729); % clay (F (2, 21) = .430, p = .656); % silt (F (2, 21) = .043, p = .958).

4. Discussion

Ecosystems sequester vast amounts of carbon especially in its natural environment. This was visible from the results of the study which recorded higher percentage of soil carbon, compared to agricultural land use (palm and cashew plantations). Indeed, the conversion of forests to woody plantation agriculture has grown in magnitude in tropical landscapes and impacts on its carbon budgets (Ali et al., 2022). Natural forest landscapes are expected to sequester more carbon since they have sufficient amounts of litter falls and biogeochemical processes from trees, herbs and grasses, as well as a relatively undisturbed carbon cycle and processes. Equally, the soil in forest ecosystems is relatively less disturbed and exposed than would be the case in the other land use category and so, has a higher tendency to retain and conserve carbon in the soil. Anthropogenic activities such as agriculture generally degrade the soil and affect its ability to provide ecosystem services such as carbon storage (Kopittke et al., 2019). Though plantation agriculture of tree crops (such as palm or cashew) could protect the soil against direct impacts of sunshine and carbon loss, natural forests have higher capacities for such and have more under-canopy covers. As demographic pressure is increasing, so that the demand of food crops and agricultural land use are in turn escalating, there is need to initiate strategies that would ensure that the forests are not completely lost.

Though loss on ignition (a crude measure of the organic content of the sediment) and organic matter are correlates of carbon and contribute to the carbon pool in ecosystems, they however take longer periods of time to reflect in the percentage soil carbon; hence their weak relationship with percentage carbon (R = .301). This suggests that while organic matter could be increased by having

Table 2. ANOVA of CEC for the land uses.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.000	2	.000	.844	.444
Within Groups	.002	21	.000		
Total	.002	23			

ample vegetation cover with sufficient leaf falls, enhanced soil microbial activities and carbon cycle, they do not immediately influence the soil carbon in ecosystems. Change in the litter production (which obviously varies according to climatic conditions) affects changes in soil organic content (Kotroczó et al., 2012). This would on the other hand undergo decomposition processes, and the rate at which this is done equally dependent on temperature conditions as well as time. Guarding against forest loss is hence an important step to ensuring continual soil carbon storage. Interrupting this cycle through cutting down forests with the intention of reforestation at a later time, would, in turn, affect the carbon pool and would require time to build it up.

Indices for soil fertility: CEC, Nitrogen, Potassium and Phosphorus though varied across the land uses, did not differ significantly. Natural forest had higher concentrations for the variables (**Tables 2-4**) and showed tendencies of better fertility as expected, and hence, a better way to preserve soil fertility in landscapes. However, with the reality of land use change emanating from population pressure and need to provide nutrition, energy and sustenance for a vast majority, ecosystems are being altered significantly. While changes to other land uses that are non-agricultural (such as built-up areas) are equally expected to reflect in the land use change, they could be initiated alongside monocultures; which may be more easily achievable or accommodating than for forest landscapes. Such strides would help to preserve the fertility of ecosystems as well as other similar ecosystem functions such as its wetness index, soil microbial activities and ability to regulate its microclimate. Soil texture was equally seen not to be significantly varied among the land uses. Being occupied with tree stands (of either natural species or planted tree crops), forest landscapes and monoculture experience similar processes and so were seen to possess likely soil textures. This would not be the case with agricultural activities that engage in (non-tree) crops, which when practiced over time may still maintain some similarities of the texture, but will now have a modified soil structure. As crop farming is what is normally practiced at both subsistence and commercial scales to address hunger concerns in most tropical landscapes, environmental challenges emanating from such anthropogenic activities would likely become more exacerbated over time.

Table 3. ANOVA for nitrogen, potassium and phosphorus according to the land uses.

		Sum of Squares	df	Mean Square	F	Sig.
Nitrogen %	Between Groups	2.790	2	1.395	.243	.787
	Within Groups	120.785	21	5.752		
	Total	123.575	23			
Potassium mg/kg	Between Groups	39.993	2	19.996	.140	.870
	Within Groups	3001.155	21	142.912		
	Total	3041.147	23			
Phosphorus mg/kg	Between Groups	20.726	2	10.363	.783	.470
	Within Groups	277.775	21	13.227		
	Total	298.501	23			

Table 4. Summary of Tukey HSD post hoc for % carbon content of the land categories.

Land use category	Nitrogen %	Potassium mg/kg	Phosphorus mg/kg
Cashew	5.57	17.85	10.70
Palm	5.72	20.33	12.96
Forest	6.36	20.78	11.99

Subset for alpha = 0.05.

5. Conclusion

Land use changes are not inherently evil, but are realities of population dynamics and preferences that require moderations. However, it affects ecosystem services and functions at different scales, depending on the land cover that replaced the initial ecosystem. Forest landscapes were found to store soil carbon and equally facilitate other ecosystem services such as soil fertility and texture better than other land use/forest cover. Agricultural land use change, however, has potentials for maintaining similar services; though at a reduced scale. Appropriate strategies and policies that would enable its combination with other land use change to maximize such benefits in the face of the reality of land use change are advocated. Further research that will utilize other plants (monocultures) apart from the ones used in the research is needed to provide more refined responses on land use impacts on soil functions and better food security and climate change mitigation nexus.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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