EXAMINING THE PROCESS OF DECOMPOSITION AND CARBON CYCLING IN 'FADAMA' COASTAL WETLANDS: A CASE STUDY OF HEAPING WETLANDS ECOSYSTEM

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ABSTRACT

Wetlands provide several ecosystem services including carbon capture and storage, water filtration, nutrient cycling, and support agriculture among others. The biogeochemical process and decomposition parameters in 'Fadama' wetland soils comprising of Gada biyu, Pwomol and Kpang referred to as sites A, B, and C respectively all of Heipang District in Barkin Ladi, Plateau State was investigated using standard operating procedures (SOP). Results of investigations revealed that soils from Kpang had slightly higher water content (34.52%) than those from Pwomol (33.48%) and Gada biyu (32.03%). While soils from Gada biyu had the highest solid organic matter (SOM) (10.79%) followed by Pwomol (8.15%) as Kpang had the least (7.85%). Gada biyu soils had the lowest Phenol oxidases activity (1536.56 nmol dicq g^{-1} h^{-1}) while those from Pwomol (5340.44 nmol dicq g^{-1} h^{-1}) was highest. All sites had similar concentrations of soil phenolics (76.58 µg g^{-1}, 79.98µg g^{-1}, and 83.25µg g^{-1}). The activity of hydrolyses (β-glucosidase) in Gada biyu soil (2.93 nmol g^{-1} min^{-1}) was lower than those from Pwomol (6.13 nmol g^{-1} min^{-1}). These parameters indicate the level of biogeochemical processes in the soil at each site. Gada biyu had the highest rate of CH_4 (0.84 ug $g^{-1}h^{-1}$) flux. Decomposition of organic matter, carbon cycling and greenhouse gas storage in wetland soil, is due to the anoxic condition comprising of low oxygen availability, cool temperatures, anaerobic conditions, reduced microbial activity, and the quality of organic matter substrates in such soils. Anthropogenic disturbances affecting wetlands must be discouraged to promote vital ecosystem services.

Keywords: Wetland, Carbon, Sequestration, Enzyme activity, Decomposition.

INTRODUCTION

Wetlands are biologically complex environments due to the biogeochemical and physical processes associated with such soil settings (Mitsch & Gosselink, 2015). Wetlands are therefore one of the world's most valuable habitat types, due to the numerous ecosystem services they provide, including water filtration, protection from coastal erosion, soils for agriculture purpose, supporting biodiversity, fishing for food and economy, trees for various purposes and carbon sequestration (Shange *et al.,* 2013; Mitsch & Gosselink, 2015; Adame & Fry, 2016).

The unique soil property of waterlogging places a constraint on the breakdown of organic matter, thereby promoting the sequestration and burial of carbon as sediments, making these ecosystems valuable tools against climate change (Freeman *et al.,* 2001, Adame & Fry, 2016). Thus, carbon sequestration is the process of confiscating atmospheric carbon dioxide and burying the same as soil sediments (Whiting & Chanton, 2001; IPCC,2007, 2014).

The capture and storage of atmospheric CO_2 and other greenhouse gases (GHGs) in wetlands soil for a very long period has been encouraged through the build-up of biomass or soil organic matter (Mer & Roger, 2001). Therefore, wetlands globally account for the storage of up to 500Pg of soil carbon which is about two-third of total terrestrial soil carbon (Bridgham, *et al,* 2006, Zheng *et al.,* 2013; Suratman, 2017). This unique condition provides support and nourishment to diverse biodiversities, they also serve as living filters which process pollutants from terrestrial runoffs and atmospheric deposition (Reddy & De Laune, 2008).

The discharge of sequestered greenhouse gases (GHGs) from wetland soil is due to increased microbial activities which could be attributed to several varying environmental conditions resulting in high decomposition of soil organic matter. Such environmental conditions could include water table, soil texture, presence of atmospheric oxygen, pH, temperature, leaf litter materials, and availability of microbes (Limpens *et al.,* 2008; Kayranli *et al.,* 2010).

Updegraff *et al.* (2001) posited that several climate change models forecast warmer and drier climatic conditions globally. This scenario could result in a serious water drawdown thereby influencing the biogeochemical processes in the soil resulting in high rates of organic matter decomposition. A dryer atmospheric condition could turn wetlands from carbon sinks into net sources (Freeman *et al.,* 2001). Freeman *et al.* (2004) conducted both laboratory and field investigations with the outcome suggesting that drier climatic conditions could compromise many wetland biogeochemical processes vital ecosystem services. Mcleod *et al. (*2011) and Adame *et al*. (2015) noted that rising level of CO_2 in the atmosphere is as a result of increased deforestation which has resulted in degrading vital ecosystem services.

Nigeria's wetlands

Nigeria is endowed with both coastal and inland wetlands

ecosystem accounting for about 3% of the total land area (Nwankwoala, 2012) (These wetlands are mostly found in the Niger River, Benue River, Chad basin and the Niger Delta, with the latter being the most important wetlands in Nigeria, the largest in Africa and third largest area in the world (Ajibola & Oni, 2015). Furthermore, in Nigeria, wetland comprises inland swamps, mangrove, and freshwater swamps, and shallow to deep water 'fadama' (Zaccheaus 2011). Unfortunately, (Chidi & Ominigbo, (2010) opined that most of Nigeria's wetland sites are not well documented and gazetted, as only 11 out of over 70 are recognised as Ramsar sites.

Nigeria's wetlands support many biodiversities as they are home to most of the country's endangered species including microbes, plants, insects, amphibians, reptiles, birds, fish, and mammals. Furthermore, Nigeria's wetlands are a very important source of natural resources upon which many rural economies depend (Uluocha & Okeke, 2004).

The value and resources of Nigeria freshwater wetlands could produce about 510,000 tonnes of fish, support over 14 reptile species, over 70 mammal species, 5 amphibian species, about 72 bird species, and over 200 species of fish. Some of these species especially the birds are endemic to Nigeria (Olalekan *et al.,* 2004).

Despite this importance, Nigeria's wetlands are threatened by both natural and anthropogenic factors such as marine and coastal erosion, desertification, population pressure, urbanization, mining, oil, and industrial waste pollution, uncontrolled agricultural practices, overgrazing, logging, land reclamation and construction of dams. Such anthropogenic activities could release buried ancient GHGs with negative implications for the global atmosphere. These primary GHGs have been implicated with climate change (Malmer *et al.,* 2005; Liikanen *et al*., 2006; Mander *et al.,* 2008). Nwankwoala, (2012) opined that Nigeria contributes less to the global greenhouse effect, this notwithstanding, the country remains the most vulnerable to the adverse effects of global warming and climate change.

Additionally, (Adewumi & Ujoh (2012) stated that previous studies on the extent of wetlands in Nigeria indicated that extensive areas of wetland ecosystems are increasingly being wiped and suggested effective management to preserve the same. Similarly, the Lake Chad basin has been identified as a major 'climate catastrophe' which is partly responsible for the current uprising in the West African sub-region, affecting over 10.7 million people.

METHODOLOGY

Sampling site
Sampling was performed in January in three wetland sites (Gada biyu, Pwomol and Kpang designated as sites A (0487420 E, 1071830 N), B (0487825 E, 1067345 N) and C (0494304 E, 1066203 N) respectively in Heipang District of Barkin Ladi LGC, Plateau State.

Sample collection
Soil samples weighing about 200g devoid of unwanted materials were collected from a depth of 10-12 cm in replicates of five with the aid of a trowel and placed in labelled sealed bags and further in cooler boxes containing ice packs. Samples were stored at 4°C in the laboratory before analyses within two weeks. Average field soil temperatures were 10°C in site A, and 9.5°C in sites B (Pwomol) and C (Kpang).

Laboratory Analyses
Soil samples, enzyme substrates, and all reagents used in these analyses were incubated at field temperatures for 24 hours. All laboratory analyses, preparation of enzyme substrates, calibration solutions for phenolics, and other reagents were done according to the procedure described by Box (1983), Frogbrook *et al.* (2009), and Dunn *et al.* (2014).

Water Extraction
A 5g subsoil sample was transferred to a 50 ml falcon tube, after which 40 ml deionised water was added and placed on a shaker at 300 rpm for 24 hours. This was followed by centrifuging at 5000 rpm for 30 minutes in a microcentrifuge and 20 ml of sample filtered through 0.45 μm cellulose nitrate filters.

Soil Water and Organic Matter Contents (SOM)
Previously weighed crucibles containing about 10g soil samples were placed in an oven at 105°C for 24 hours for effective evaporation of water content. After weighing again, crucibles containing the soil were ashed in a muffle furnace for 60 minutes at 550°C and weighed thereafter. The weights were used to calculate the water and organic matter contents as a percentage of the original sample using Microsoft Excel spreadsheet.

Phenol Oxidase Enzyme Assay
Two sets of soil samples weighing 1g were placed into two separate stomacher bags labelled blank (B) and substrate (S). Then, 9 ml of deionised water was added, homogenised in a stomacher machine. To the bags labelled S, 10 ml of substrate phenolic amino acid L-3, 4-dihydroxyphenylalanine (L-DOPA) solution was added while the same volume of deionised water was added to bags B. All bags were homogenised and incubated at field temperature for 10 minutes.

A set of three 1.5 ml tubes were filled with solutions from each bag and centrifuged at 10000 rpm for 5 minutes. 300 μL of the supernatant was pipetted into wells of a clear 96 well microplate and the absorbance determined at 475 nm using SpectraMaxM2e spectrophotometer plate reader. Soil enzyme activity was thereafter determined and expressed as nmol of product formed.

Hydrolyses
The activity of soil hydrolyses enzymes was determined by placing 1 g of the soil sample in labelled stomacher bags, followed by the addition of 7 ml of the relevant substrate solution previously prepared. After analyses was done as for Phenol oxidases above.

Phenolic Assay
To determine the concentration of soil phenolics, calibration standards of 0, 0.25, 0.5, 0.75, 1, 2, 3 ppm was chosen from the previously prepared phenolic stock solution. For each calibration standard and sample, 1ml was pipetted into separate labelled 1.5 ml microcentrifuge tubes and 50μl of Folin-Ciocalteau Phenol Reagent and 0.15 ml of Na_2CO_3 solution added to all tubes, mixed and incubated at room temperature for 1 hour 15 minutes, a gradual colour change to blue indicates phenolics presence. Phenolic concentration was determined as for Phenol oxidase assay above.

Gas Fluxes.

GHGs (CO_2, CH_4 N_2O) in the soil were done by placing 10 g of soil into a 50 ml falcon tube and incubated at field temperature for 1 hour. Gas samples were extracted with 10ml needle and syringe an analysed on a Varian Model 450 gas Chromatograph (GC) following procedure described by), Frogbrook *et al*. (2009) and Dunn *et al*. (2014).

Statistical Analysis

Data generated were analysed by one-way ANOVA to determine the effect of the measured parameters. SPSS v22 (IBM Corporation, New York, USA) was used for all analyses.

A p-value of <0.05 was used to indicate significance for the ANOVA analysis, on the other hand <0.01 for the correlation analysis.

RESULTS

Investigations of parameters of microbial soil decomposition in this study revealed a slow rate of biogeochemical processes across the three sites as it was characterised by low soil water and SOM contents, soil enzymes activity, soil phenolics as well as greenhouse gas (GHG) fluxes (Figures 1-5) making these wetlands an excellent medium for moderating the effects of rising climatic temperatures.
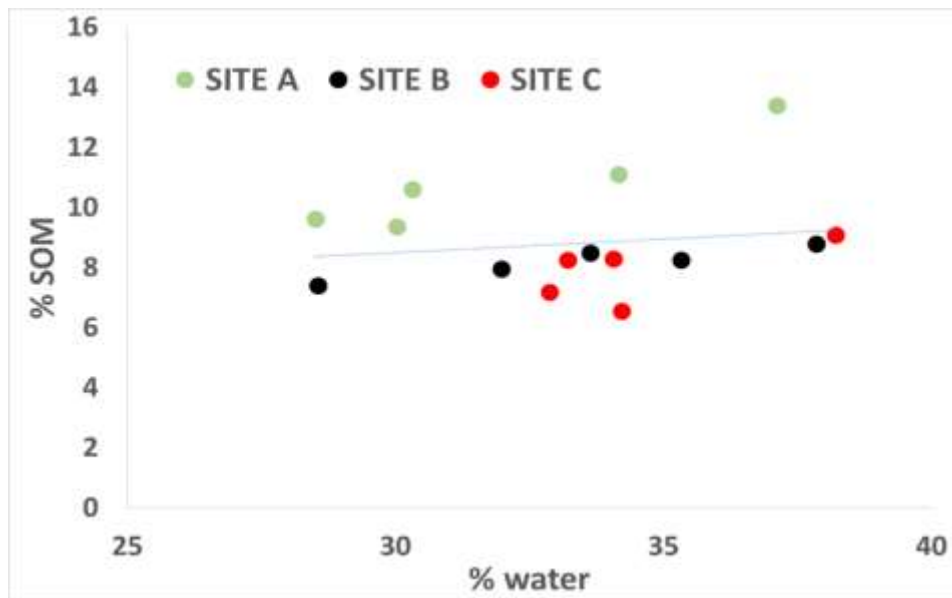

Figure 1: Scatterplot presentation indicating association between % water and % soil organic matter across the 3 wetland sites. The trendline shows an exponential relationship
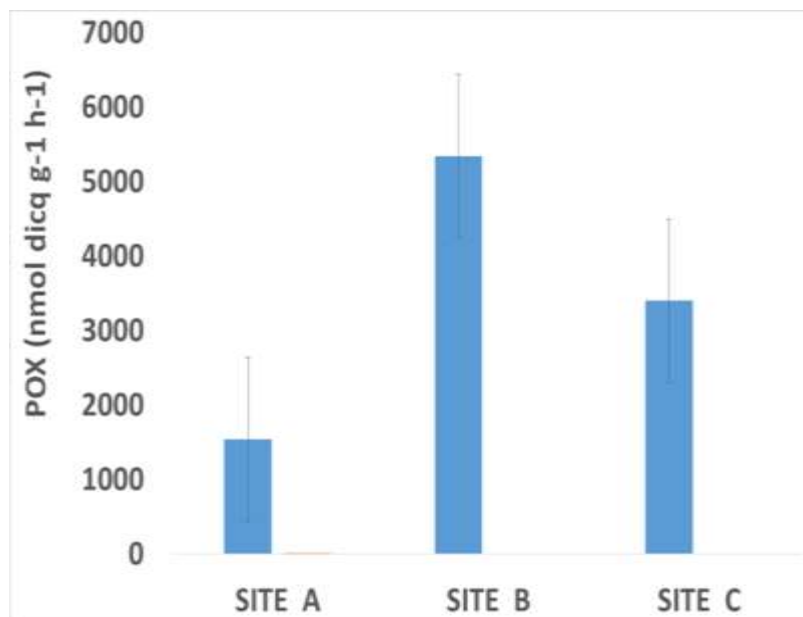
Figure 2: Bar chart indicating average phenol oxidase activity at the three wetland sites
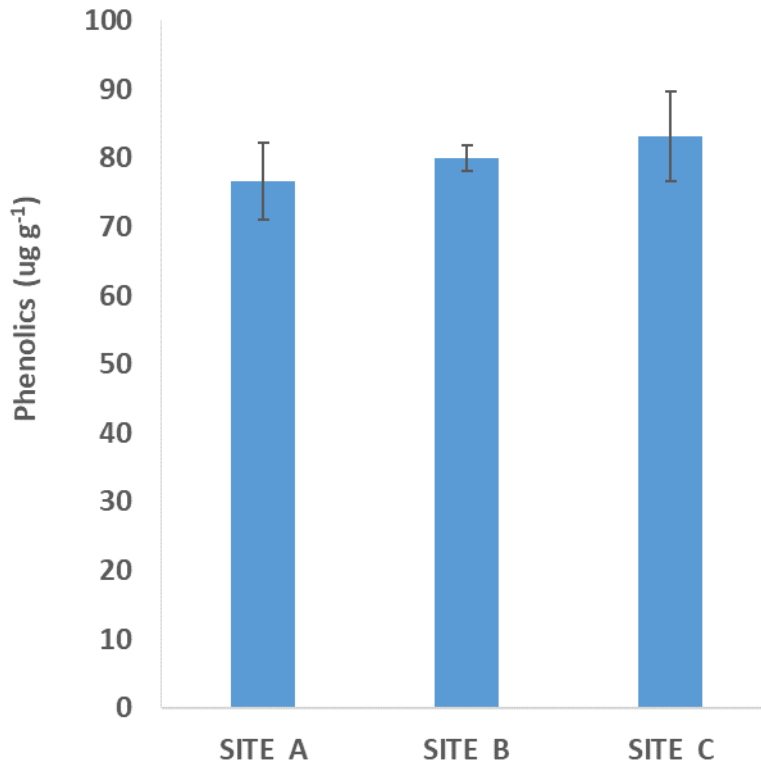(n=5, error bars + SD)

Figure 3: Bar chart showing the mean concentration of soil phenolics in three different wetland sites (n=5, error bars + SD)
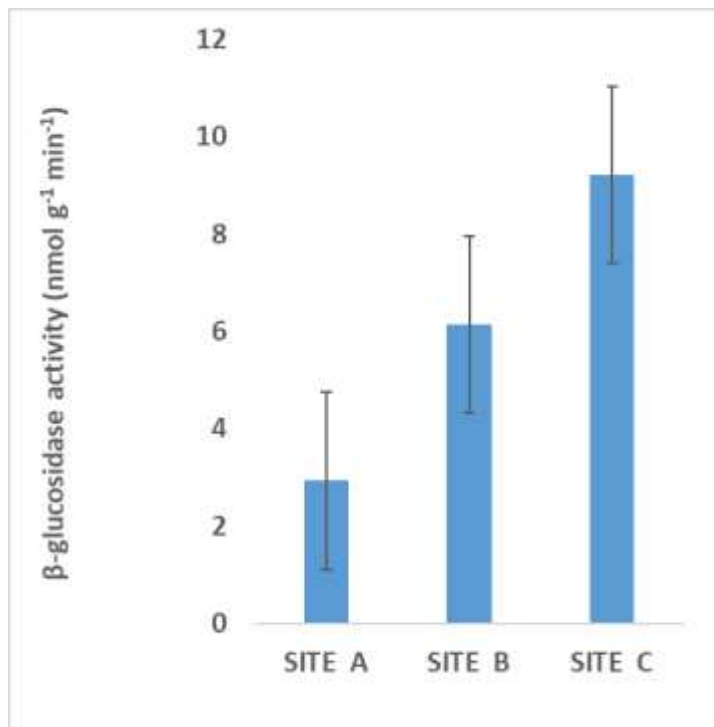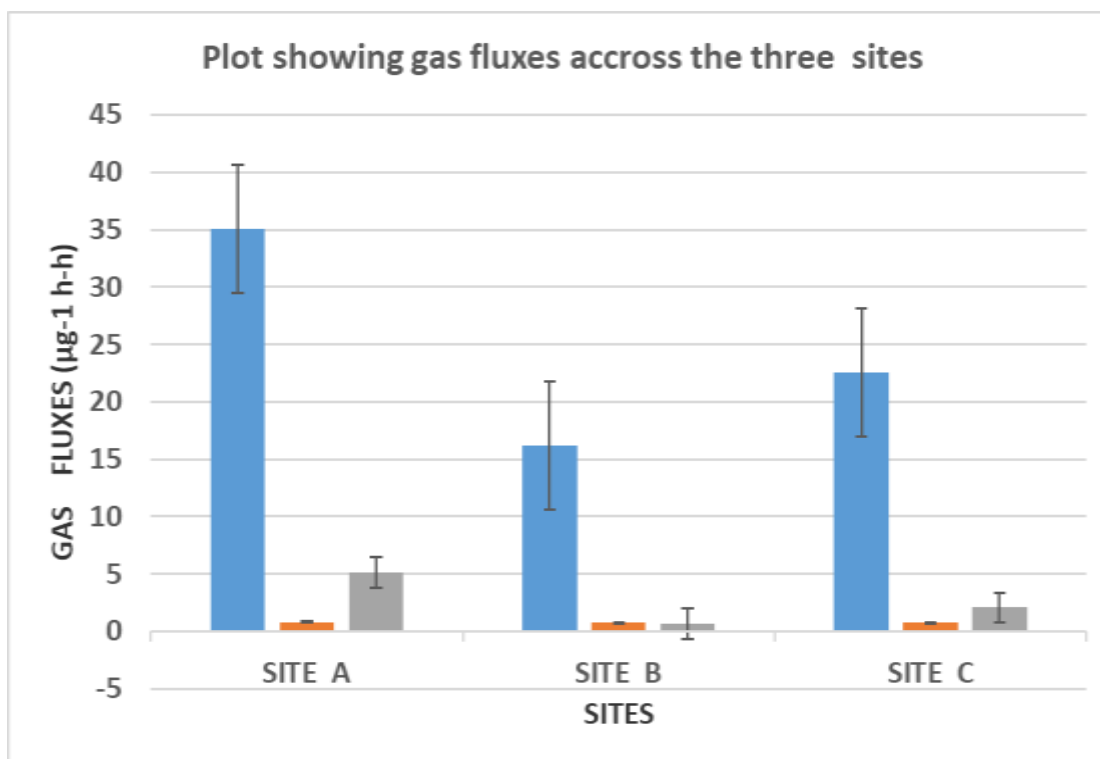

Figure 4: Bar chart of mean hydrolase enzyme activities at the three wetland sites

(n=5, error bars + SD)

Figure 5: Gas fluxes for CO_2, CH_4 and N_2O across the three sites

DISCUSSION

Results of analyses revealed that soils from Kpang (Site C) had slightly higher water content (34.52%) than Pwomol (site B) (33.48%) and Gada biyu (site A) (32.03%) while soils from Gada biyu had the highest SOM content of 10.79% followed by Pwomol (8.15%). Kpang (site C) had the lowest SOM content of 7.85% as indicated in Figure 1.0. The differences in both parameters are not statistically significant across the three sites (p>0.05) with a slight positive correlation in the first two sites (p<0.01). High water and organic matter contents in wetland soils indicates a low microbial activity which encourages huge storage of SOM as well as high storage of GHGs over the years. This occurs usually as a result of the anoxic condition in such ecosystems due to low oxygen availability, thereby reducing decomposition and encouraging massive carbon deposit as well enhancing burial of GHGs (Foster *et al.,* 2012, Saraswati *et al.,* 2016).

Soils from site A (Gada biyu) had the lowest Phenol oxidase enzyme activity (1536.56 nmoldicq g^{-1} h^{-1}) this was followed by site B (Pwomol) which had slightly more than two-fold activity (3397.31nmoldicq g^{-1} h^{-1}) while site B had a statistically significantly higher phenol oxidase activity (5340.44nmoldicq g^{-1} h^{-1}) (p<0.05) in comparison with the other two sites (Figure 2). It is also observed that the activity of hydrolases enzyme (β-glucosidase) in site A (2.93nmol g^{-1} min^{-1}) is significantly lower than soils from site B (6.13nmol g^{-1} min^{-1}) while the rate of enzyme activity in site C (9.22nmol g^{-1} min^{-1}) (p<0.05) was a significantly high (Figure 4).

Extracellular enzymes are key to the wetland carbon cycle as they are used by microbes to access nutrients and energy present in complex organic substrates, making enzymes the proximate agents of decomposition.

The concentration of soil phenolics was similar in sites A (76.58µg g^{-1}) and B (79.25µg g^{-1}) but site C had a slightly higher phenolics (83.25µg g^{-1}) these differences are however not statistically significant (p>0.05) (Figure. 3). It is hereby speculated that the presence of phenolic compounds could be the reason in part responsible for low microbial activities across the three sites, hence the low varying activities of hydrolyses which are the main suits of bacterial enzymes involved with the breakdown of organic matter in wetland soils (Pind *et al.,* 1994; Freeman *et al.,* 2004; Saraswati *et al.,* 2016). Figure 5 shows GHGs fluxes across the three sites with CO_2 (35.09 ug g^{-1} h^{-1}) and $_2O$ (5.14 ug g-1 h-1) having higher emissions in site A which is statistically significant (p<0.05). There appears to be no significant difference between the rate of emissions of other gases across the three sites (p>0.05). Therefore, this investigation suggests low emissions of GHGs across the three sites, though soils from site A (Gada biyu) have a significantly higher amount of CO_2, CH_4 and N_2O released into the atmosphere (Figure 3). The release of these GHGs into the atmosphere could produce negative feedback for global warming (ICPC, 2007) and could have a negative consequence on wetlands ecosystem services (Allen *et al.,* 2010; Zhang *et al.,* 2017).

In similar studies involving soils obtained from red, black and white mangrove sites and a salt marsh zone encroached by black mangroves in northern Florida, USA, Dasat (2018)

established that soil water contents positively correlates with SOM in all sites and further reported varying rates of low microbial activity and emissions of GHGs notably CO_2, CH_4 and N_2O across the three sites examined.

Forster *et al.* (2007) investigated the biogeochemistry of some wetland soils in Nigeria's' Niger delta wetlands and revealed that such wetlands could be greatly impacted in response to draining because of warming alternations. These changes could lower the water table, thereby stimulating significant releases of GHGs as a result of an increase in microbial activities which could deplete available soil nutrients (Freeman *et al.*, 1993; Martikainen *et al.,* 1993). Friesen *et al.* (2018) investigated decomposition in mangrove soils and identified tidal inundation, vegetation types, faunal community, and microbial processes as factors that could influence organic matter accretion in such ecosystems.

Wetland ecosystems globally play a major role in atmospheric carbon seizure, thereby serving as a considerable blue carbon pool with a vast potential to mitigate the effect of climate change (Mcleod *et al.,* 2011; Siikamäki *et al.,* 2013).

In Nigeria, wetlands perform some vitally important hydrological functions such as flood protection, maintain stream flow during the dry season in the semi-arid region of northern Nigeria. Importantly, they also help in regulating surface water quality and volume, as well as in replenishing and sustaining groundwater hence their destruction could trigger more environmental problems.

Unfortunately, Nigeria's wetlands just like others across the globe are diminishing at an alarming rate. In particular, wetlands destruction is affecting water supply and water resources management in various parts of the country. Furthermore, the destruction of the wetlands implies the release of ancient buried carbon into the atmosphere which could further increase the impact of global warming.

The numerous ecosystem services offered by wetlands notwithstanding, these important ecosystems are increasingly coming under stress due to natural and anthropogenic factors. These anthropogenic disturbances if sustained could compromise the carbon sequestration potentials of the Country's wetlands turning them from carbon pools into net sources of GHGs (Alongi, 2011; Everard *et al.,* 2018).

CONCLUSION AND RECOMMENDATIONS

The biogeochemical activities in the wetland soils across the three sites (Gada biyu, Pwomol and Kpang) investigated were adjudged to be low because of the low rates of decomposition of organic matter and emissions of GHGs. These wetlands could therefore serve as pools of GHGs and could be a vital tool for mitigating the effect of global warming. The loss and degradation of these vital ecosystems could also compromise vital ecosystem services.

Anthropogenically induced degradation of wetland ecosystems in Nigeria could increase the task of water resources management. Thus, the country's wetland resources need to be properly identified and mapped. Moreover, the right legislation and policy framework has to be put in place and enforced to safeguard the remaining wetlands from going into extinction.

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