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Sustainable Water Quality: Effects of Habitat Types and Disturbance regimes in Afrotropical Wetlands

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ABSTRACT

The protection and sustainable utilization of wetlands are vital for existence, but they face challenges of exploitation and pollution that lead to deterioration. Hence the study aimed to assess the water quality in different types of habitats and disturbance regimes in Afrotropical wetlands. The study was conducted across twenty-eight sites which cuts across four major habitat types (Streams, Lakes, Ponds and Creeks), with varied degree of human activities in the Niger Delta wetland complex. Physicochemical parameters were determined across various habitat types and anthropogenic regimes using standard methods. The principal component analysis was used to characterize environmental variables across habitat types and disturbance regimes, while linear models were used to examine the variation of physicochemical data across a bi-spatial scale of habitat types and disturbance regime with physicochemical data acting as the response while habitat types and disturbance regime acting as the predictors. The PCA result revealed Electrical conductivity (EC), Phosphate (P), Total Dissolved Solids (TDS), Hydrogen ion concentration (pH) and Turbidity as the source of variation across habitat types and disturbance regimes. Linear model results also revealed variations of physicochemical variables across habitat types and disturbance regimes. This study had revealed the level of perturbation of the Niger Delta wetland complex and what the conditions of the habitat types in this complex system of networks tend to face, if necessary, measures are not put in place. Thus, resources planners should ensure that management actions are put in place that will prioritize site-specific and stress-specific actions that will improve the water quality of the Niger Delta wetlands.

Keywords: Water quality, Habitat types, Anthropogenic factors, Afrotropical wetlands

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INTRODUCTION

One of the most vital resources available to all life forms is water. However, more than 50% of water used is emptied untreated, reducing water quality and adversely impacting biodiversity [8,25]. The global consequence of such an act is an upsurge in scarcity, which has been identified by international policies with the dual aim of facilitating protection and resource utilization and reducing anthropogenic disturbance [8].

The protection and sustainable utilization of wetlands is vital for existence but faced with challenges of exploitation and pollution that leads to their deterioration [4]. There are unprecedented studies on wetlands because of the unique role they play and vital ecosystems services they render which range from tourism to hotspot for important and endemic biodiversity [41], water quality improvement through transformation and retention of pollutants [54], and as an important source of water to all life forms [4]. However, these systems are recipient of anthropogenic disturbance which threatens their role in environmental sustainability and further economic development especially in the impoverished sub-Saharan region of Africa [22, 6]. It is speculated that bulk of wetland systems would had disappeared in about a century from now, due to stochastic events that are heavily linked to human disturbances at a spatial-temporal scale [49].

For instance, it has been reported that pH, water temperature, conductivity, TDS, total alkalinity, Orthophosphates and nitrate and dissolved oxygen are vital water quality determinants in wetlands [7, 33]. However, these parameters are not only vital as determinants of water quality but also influence presence of biodiversity [7, 17, 32, 57]. Unfortunately, activities like laundry, mining, irrigation and other land use [6] coupled with a surge in rural-urban migration and a rapid increase in human population [18] on wetland ecosystem have facilitated their deterioration by altering physicochemical conditions [18]. This persistent deterioration in the quality of wetlands is more pronounced in the Afrotropical region most especially in Nigeria [6, 17] and is attributable to the rapid decline in aquatic biodiversity [25]. For instance, in sub-Saharan Africa, farming around wetlands makes such ecosystem liable to pollution from pesticides which negatively impacts organisms that depend on them through bioaccumulation [12]. This abnormality can threaten the health of closely integrated micro-communities and even that of higher animals [25]. In addition to the anthropogenic influence, deterioration of the physical, chemical, or biological water quality parameters in surface waters is also due to natural processes such as the wearing of rocks, run-off, and ion exchange, which often makes the water resource unsuitable for its intended use [8]. Also, water pollution assessment and control are also major and widespread challenges in developing countries because water can indirectly favour the transmission of many diseases [22]. Issues of these sorts are intensified by challenges in governance such as poor water resources management, inappropriate institutional organization and socio-economic and political predispositions leading to poor enforcement of laws and regulations that will facilitate wetland management [17].

Therefore, it is imperative to monitor potential trends in water quality in order to comprehend such changes and to properly implement water management [8]. To achieve this goal, it is the responsibility of stakeholders to implement appropriate monitoring programs involving a holistic inclusion of necessary parameters to phantom the natural and anthropogenic processes driving water quality [18]. Reports of water quality monitoring have been on large datasets across varied sampling frequencies and disturbance regimes [28, 18, 42] unfortunately such studies have failed to reveal how different water quality parameters respond to different habitat types and disturbance regimes especially in Afrotropical wetland systems. It is in the light of this problem that this study intends to assess water quality across habitat types and disturbance regime in the Niger Delta wetland complex in order to establish possible effects of anthropogenic activities on the physicochemical parameters and establish the preferential availability of these parameters across habitat types.

MATERIALS AND METHODS

Study area and sampling station

The Niger Delta Wetland (NDW) complex is the largest wetland complex in Africa covering an area of approximately 4235.54Sqmiles [29]. The wetland complex which extends from the lower reaches of the Niger River lies between latitudes 4° and 7°N and longitudes 3° and 9°E [10]. It experiences a mean monthly temperature of 80.6°F and rainfall of 3000mm to about 5000mm [10]. The wetland complex comprises of dense networks of rivers, streams, lakes, ponds, estuaries, creeks and stagnant swamps with various degree of excessive siltation and regularly subjected to various forms of disturbances which expose its fragile nature [10, 1]. The formation of the wetland complex is linked to the build-up of sedimentary deposits facilitated by the dynamic meandering of the Niger and Benue Rivers [10], serving as the basis for local livelihoods and important hotspots for diverse and endemic biodiversity [29]. The wet and dry seasons are two distinct seasons associated with the NDW complex. A predominant short period of dry season is observed from November to March while the wet season starts in April and extends till September [10]. The activities of the oil and gas industries are prominent within the NDW complex, with obvious pollution activities and massive degradation of forest [21]. Some parts of the landscape have witnessed land conversion from excessive logging and farming, construction of seismic trails for the exploration of oil have opened up once pristine habitats for hunters to exploit forest resources for food and income generation [21].

This study was conducted across twenty-eight sites which cut across four major habitat types (Streams, Lakes, Ponds and Creeks), with varied degree of human activities (Table 1). Sites were randomly distributed within two Niger-Delta states of Bayelsa and Delta with the ArcGIS software programme and ground-trothed with the aid of a handheld GPS were sampled during the study [9]. The minimum distance between points was 400 m apart. Each waterbody had its unique feature.

Table 1: Site description and spatial information of surveyed wetlands

STN	STN Code	Location	N	E	Habitat Type
Asaba	RF_1	Delta	6.20637	6.73313	Lake
Asaba	RF_2	Delta	6.21058	6.72847	Lake
Asaba	RF_3	Delta	6.21375	6.72416	Lake
Anwai	RF_4	Delta	6.29575	6.70118	Lake
Anwai	RF_5	Delta	6.28785	6.70572	Lake
Anwai	RF_6	Delta	6.28086	6.70721	Lake
Anwai	RF_7	Delta	6.27505	6.7104	Lake
Anwai	RF_8	Delta	6.27059	6.71412	Lake
Utagba-Uno	RF_9	Delta	5.88147	6.41152	Pond
Utagba-Uno	RF_10	Delta	5.88229	6.41243	Pond
Utagba-Uno	RF_11	Delta	5.90471	6.3999	Stream
Ubeji	RF_12	Delta	5.5644	5.70253	Creek
Ubeji	RF_13	Delta	5.59175	5.82002	Creek
Osubi	RF_14	Delta	5.58404	5.80558	Lake
Osubi	RF_15	Delta	5.59175	5.82002	Lake
Warri	RF_16	Delta	5.58336	5.84896	Stream
Warri	RF_17	Delta	5.65247	5.92176	Stream
Swali	RF_18	Bayelsa	4.90684	6.2805	Lake
Swali	RF_19	Bayelsa	4.90678	6.28027	Lake
Opulabor	RF_20	Bayelsa	5.09982	6.38454	Lake
Abanudu	RF_21	Bayelsa	5.12707	6.37663	Lake
Abarigina	RF_22	Bayelsa	5.08752	6.37694	Lake
Sam	RF_23	Bayelsa	5.13208	6.38123	Lake
Sam	RF_24	Bayelsa	5.13672	6.38575	Lake
Sam	RF_25	Bayelsa	5.14088	6.38807	Lake
Asa	RF_26	Bayelsa	5.243	6.49777	Lake
Asa	RF_27	Bayelsa	5.23144	6.48583	Lake
Esiribi	RF_28	Bayelsa	5.28347	6.51915	Lake

Physicochemical Variables

Water samples were taken every season over a period of two years (June 2019 and May 2021) at each station. During each sampling period, sub-surface temperature, Dissolved Oxygen (DO), Total Dissolved Solids (TDS), Electrical Conductivity (EC), Hydrogen ion Concentration (pH), Turbidity (TUR), Depth (Dp) and flow velocity were determined on-site. However, composite water samples were stored in a flask filled with ice cubes to weaken the growth of microorganisms and then taken to the laboratory for analysis of Phosphate (P) and Nitrate (N) using standard methods [3]. Multi-parameter water quality meter (Hanna HI 991300/1) was used for in-situ analysis of temperature, pH, DO, TDS and EC and TUR [3]. Water depth for each wetland was estimated with a rule calibrated at an accuracy of 0.1cm. The calibrated rule was vertically held and randomly placed at the shore and middle of the waterbody, with the average of these measurements recorded for the sampling area [50]. Flow velocity was estimated by programming the movement of a float (usually a tennis ball) over a predetermined distance [6].

Anthropogenic Activity

Anthropogenic activity was classified based on the activities observed around the study site. A Land-Based classification standards (LBCS) model which simply provides a classification of land use into dimensions like activities, functions, building, ownership, site development and character was used to map out various anthropogenic activities along study sites [2]. However, these measures were adjusted to suit the purpose of this study. Observed activities were recorded and distance to the nearest activity was measured from the water body to the point of activity using GPS [52]. Anthropogenic activities observed during the study were grouped under the following categories: Farming (FM), Fishing (FH), Human settlement (HS), Lumbering (LB), Mining (MN), Organic waste (OW).

Data Analysis

Data analysis was performed using R software [43]. Environmental data were evaluated across various habitat types and disturbance regimes. The principal component analysis was used on environmental variables to examine their responses to various habitat types and disturbance regimes [8]. The PCA was used in order to reduce the multidimensionality in the dataset while retaining vital information [30]. The first and second PCA axis were used in habitat types and disturbance regimes since they both explained 26.7% and 18.8% respectively of the variation in the explanatory variables [13]. The results of the principal component analysis were visualized using the biplot to reveal the existing relationship between the predictors and responses. The PCA ordination was performed using the vegan package [38].

Furthermore, to examine the variation of physicochemical data across a bi-spatial scale of habitat types and disturbance regime, a linear model was conducted with physicochemical data acting as the response while habitat types and disturbance regime acting as the predictors. Prior to modeling, all response variables were subjected to normality test, a Shapiro-Wilk normality test to check if they had a unimodal distribution. Since the response data skewed, they were all log-transformed to ensure the assumed normality [11]. The significant effects of habitat types and anthropogenic activities on physicochemical variables were separately analyzed. The output from the analysis gave the mean and standard error difference across the different categories of response variables, while the F-values, p-values and square values were all calculated. The outputs of the relationship were visualized using boxplots.

RESULTS

Characterizing Physicochemical Variables across habitat types and anthropogenic regime

The relationship between water quality variables and habitat types were examined by PCA. All variables had their original data used. Across habitat types, the lakes were strongly correlated more with Nitrate and pH and weakly correlated with dissolved oxygen and depth. Phosphate, turbidity, conductivity, flow velocity, water temperature as well as total dissolved solids were correlated with creeks, streams were correlated with phosphate, turbidity, dissolved oxygen and nitrate, while ponds showed no obvious correlation with environmental variables (Figure 2a). Across various disturbance regimes, fishing and lumbering activities were correlated with pH and depth, while farming activity was correlated with dissolved oxygen and nitrate. Sites with human settlement were correlated with all variables except nitrate, while mining activity was correlated with nitrate, dissolved oxygen, phosphate and turbidity. However, nitrate, dissolved oxygen, phosphate, turbidity, conductivity, flow velocity and water temperature were associated with organic waste (Figure 2b). Despite these correlations, 45.50% of variability in the dataset was explained by first two principal components and also provided a clear separation of the variables across habitat types and anthropogenic activities.

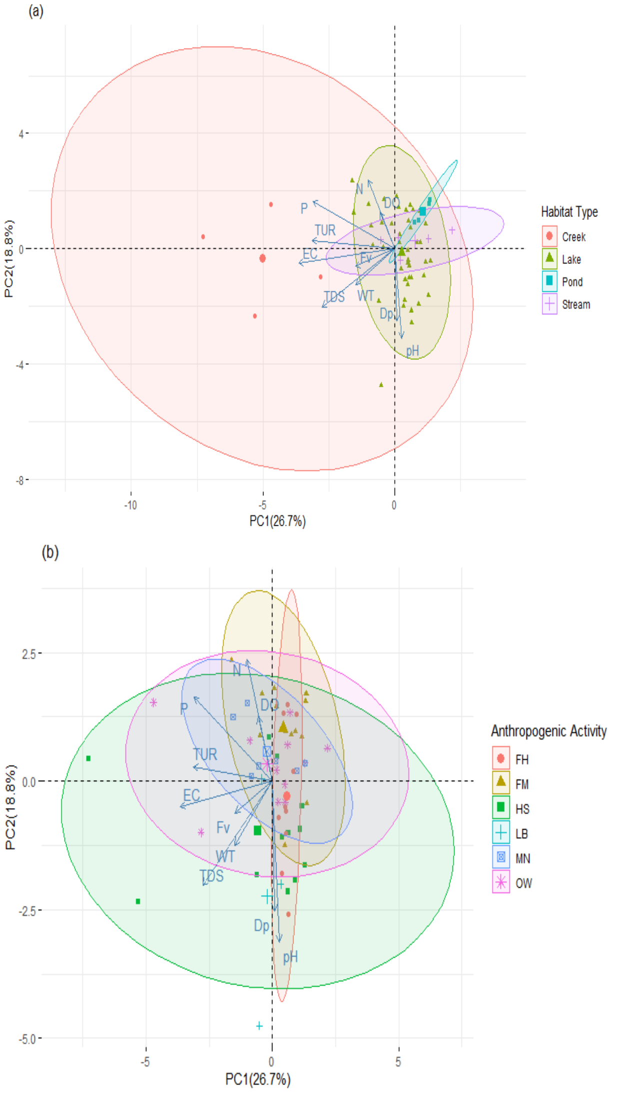

Figure 2: A PCA biplot indicating the alignment structure based on the variability of physicochemical variables across habitat types (a) and anthropogenic activity (b). **Abbreviated physicochemical variables: DO (Dissolved Oxygen); N (Nitrate); P (Phosphate); TUR (Turbidity); EC (Electrical Conductivity); Fv (Flow Velocity); WT (Water Temperature); TDS (Total Dissolved Solids); Dp (Depth) and pH (Hydrogen ion Concentration).**

Also, across principal components 1 and 2, electrical conductivity, phosphate, total dissolved solids, hydrogen ion concentration and turbidity were the variables explaining significant variation in the dataset, with each of these variables contributing more than 10% of the variation in the dataset (Figure 3).

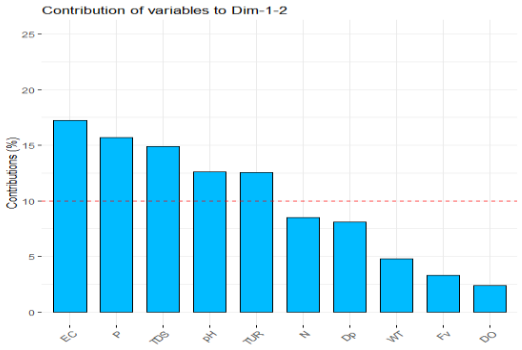

Figure 3: Percentage contributions of physicochemical variables to both Principal components 1 and 2.

Variation of physicochemical variables across habitat types

The results of linear models to ascertain the variation of physicochemical variables across habitat types indicated that depth, flow velocity, water temperature, hydrogen ion concentration, electrical conductivity, total dissolved solids, turbidity and phosphate showed significant variation ($p<0.05$) across habitat types, while dissolved oxygen and nitrate did not revealed any significant variation ($p>0.05$) across habitat types (Table 2). Furthermore, the mean values of Dissolved oxygen, hydrogen ion concentration, electrical conductivity, total dissolved solids, turbidity, phosphate and nitrate reported in this study were below the recommended global and national standards for drinking water (Table 2).

Table 2: Unnormalized values of environmental variables across habitat types in Niger-Delta, Nigeria (June 2020 - July 2022)

Variables	**Habitat Types**				**p-value**	**WHO***	**FEPA****
	Creek	Lake	Pond	Stream			
Dp (m)	0.57±0.16	0.67±0.16	0.22±0.22	0.65±0.20	0.06366		
WT (^{o}C)	30.60±0.96	28.41±1.00	27.96±1.36	26.43±1.24	0.01385		
DO (mg/l)	3.83±0.46	3.51±0.48	3.90±0.65	3.03±0.59	0.4295		
pH	6.15±0.39	6.71±0.41	5.86±0.56	5.94±0.51	0.03519	6.5-8.5	6.0-9.0
EC (µS/cm)	411.88±20.62	39.22±21.58	17.38±29.16	15.84±26.62	< 2.2e-16	1000	
TDS (mg/l)	197.50±20.51	58.42±21.46	40.82±29.00	32.78±26.48	1.75E-07	500	2000
TUR (NTU)	25.00±2.62	12.88±2.74	10.81±3.70	11.85±3.38	0.000402	5	
P (mg/l)	0.28±0.04	0.08±0.04	0.06±0.06	0.08±0.05	0.000187		5
N (mg/l)	1.49±0.60	1.50±0.63	1.15±0.86	0.56±0.78	0.3477	10	20
Fv (ms^{-1})	0.12±0.02	0.09±0.02	0.03±0.03	0.13±0.03	0.000969		

Values are mean±SD=Mean±Standard Deviation **World Health Organization (WHO) Standard for Drinking Water Quality. **Nigerian Water Quality Standard for Inland Surface Water. Dp=Depth; WT=Water Temperature; DO=Dissolved Oxygen; pH=Hydrogen ion Concentration; EC=Electrical Conductivity; TDS=Total Dissolved Solids; TUR=Turbidity; P=Phosphate; N=Nitrate; Fv=Flow Velocity

However, across habitat types, stream had the highest mean depth followed by lakes and creeks, while the lowest depth was recorded in ponds (Figure 4a). High values of water temperature (30.60 °C) were observed in creeks, while low temperatures (26.43°C) were noted in streams (Figure 4b). Despite no sharp variation in pH across habitat types, high pH values (6.71) were recorded in lake and low pH values (5.86) were recorded in Pond (Table 2, Figure 4d). There was a sharp variation in conductivity and across sites; creeks had the highest conductivity (411.88 µS/cm) while the lowest conductivity (15.84 µS/cm) was recorded in streams (Table 2, Figure 4e). Similarly, high values of TDS (197.50mg/l) and turbidity (25.00NTU) were recorded in creeks, while low TDS (32.78mg/l) reported streams and low turbidity (10.81NTU) recorded in ponds (Table 2). The creeks also had high levels of phosphate (0.28mg/l), while low levels of phosphate (0.06mg/l) were found in ponds (Table 2, Figure 4h). Furthermore, the mean flow velocity was highest in creeks ($0.12 ms^{-1}$) and streams ($0.13 ms^{-1}$) and lowest ($0.03 ms^{-1}$) in ponds (Table 2, Figure 4j). Despite the non-significant variation recorded for dissolved oxygen and nitrate across habitat types, the highest dissolved oxygen (3.90mg/l) was recorded in ponds while the lowest values (3.03mg/l) was recorded in streams (Table 2, Figure 4c). However, nitrate was highest (1.50mg/l) in lakes and lowest (0.56mg/l) in streams (Table 2, Figure 4i).

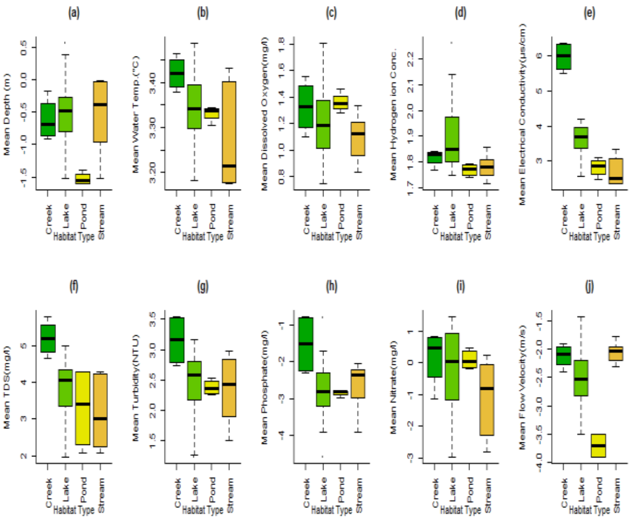

Figure 4: Variation in log-transformed environmental factors across various habitat types in Afrotropical wetlands

Variation of physicochemical variables across anthropogenic activity

The variation of physicochemical parameters across different disturbance regimes indicated that depth, flow velocity and hydrogen ion concentration were significantly different ($p<0.05$) across various levels of anthropogenic activities, while water temperature, dissolved oxygen, electrical conductivity, total dissolved solids, turbidity, phosphate and nitrate did not revealed any significant variation ($p>0.05$) across anthropogenic activities (Table 3). However, values of Dissolved oxygen, hydrogen ion concentration, electrical conductivity, total dissolved solids, turbidity, phosphate and nitrate reported in this study were below the recommended global and national standards for drinking water (Table 3).

Table 3: Unnormalized values of environmental variables across anthropogenic activities in Niger-Delta, Nigeria (June 2020 - July 2022)

Variables	**Anthropogenic Activities**						**p-value**	**WHO***	**FEPA****
	FH	FM	HS	LB	MN	OW			
Dp (m)	0.67±0.10	0.47±0.13	0.85±0.13	0.79±0.20	0.55±0.15	0.54±0.14	0.0539		
WT(°C)	27.50±0.63	27.92±0.84	29.51±0.85	29.15±1.31	27.30±0.98	28.70±0.87	0.119		
DO(mg/l)	3.29±0.29	3.69±0.38	3.35±0.39	2.67±0.60	3.51±0.45	3.91±0.40	0.3072		5
pH	6.72±0.22	6.16±0.29	6.65±0.30	8.38±0.46	6.21±0.34	6.34±0.30	0.000336	6.5-8.5	6.0-9.0
EC(µS/cm)	39.72±33.25	35.98±44.22	121.51±45.02	29.55±69.21	31.29±51.81	75.32±45.94	0.309	1000	
TDS(mg/l)	61.84±16.77	40.25±22.30	92.44±22.70	118.50±34.90	51.31±26.13	57.99±23.17	0.1014	500	2000
TUR(NTU)	12.88±1.97	12.84±2.62	13.49±2.67	17.62±4.10	14.60±3.07	12.97±2.72	0.8665	5	
P (mg/l)	0.07±0.03	0.10±0.04	0.09±0.04	0.04±0.06	0.11±0.05	0.10±0.04	0.852		5
N (mg/l)	0.96±0.38	1.96±0.50	0.85±0.51	1.24±0.78	1.75±0.59	1.42±0.52	0.2128	10	20
Fv (ms^{-1})	0.07±0.01	0.06±0.01	0.10±0.01	0.09±0.02	0.16±0.02	0.11±0.02	3.75E-06		

Values are mean±SD=Mean±Standard Deviation
**World Health Organization (WHO) Standard for Drinking Water Quality.
**Nigerian Water Quality Standard for Inland Surface Water.
Dp=Depth; WT=Water Temperature; DO=Dissolved Oxygen; pH=Hydrogen ion Concentration; EC=Electrical Conductivity; TDS=Total Dissolved Solids; TUR=Turbidity; P=Phosphate; N=Nitrate; Fv=Flow Velocity; FH=Fishing; FM=Farming; HS=Human Settlement; LB=Lumbering; MN=Mining; OW=Organic Waste

However, across anthropogenic activity, the highest depth was reported in wetlands close to human settlement and lowest in sites around farming activity (5a). Highest values of pH were recorded in sites with predominant lumbering activity and lowest in sites with mining activity (Figure 5d). However, sites close to mining activities recorded the highest flow velocity, while the lowest flow velocity was reported for sites close to farmland (5j). Despite the non-significant ($p>0.05$) variation of other variables across anthropogenic activities, water temperature was highest (29.51°C) in wetlands impacted by human settlement and lowest (27.30°C) in wetlands impacted by mining activities (Table 3; Figure 5b). Also, high values of dissolved oxygen (3.91mg/l) were associated with wetlands impacted by organic waste, while low values of dissolved oxygen (2.67mg/l) were obtained in wetlands impacted by lumbering activity (Table 3; Figure 5c). Electrical conductivity was revealed to be highest (121.51µS/cm) in wetlands impacted by human settlement and lowest (29.55µS/cm) in wetlands impacted by lumbering activity (Table 3; Figure 5e). Furthermore, wetlands impacted by lumbering activity recorded high TDS values(118.50mg/l), while low TDS values (40.25mg/l) were reported from wetlands impacted by farming activities (Table 3; Figure 5f). Highest turbidity values (17.62 NTU) were recorded in wetlands impacted by lumbering activity, while lowest turbidity value (12.84) was reported from wetlands impacted by Farming (Table 3; Figure 5g). Wetlands impacted by mining activity had high values for phosphate (0.11mg/l) while low phosphate values (0.04mg/l) were obtained from wetlands impacted by lumbering activity (Table 3; Figure 5h). Nitrate was however highest(1.96mg/l) in wetlands impacted by farming activity and lowest(0.85mg/l) in wetlands impacted by human settlement (Table 3; Figure 5i)

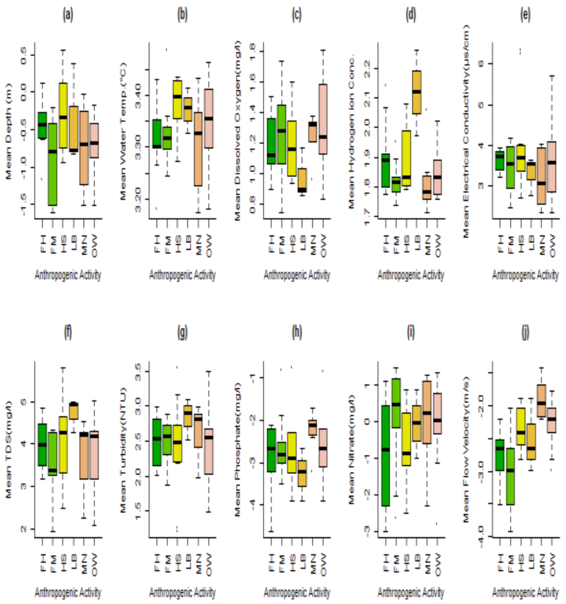

Figure 5: Variation in environmental factors across various anthropogenic activities in Afrotropical wetlands

DISCUSSION

The Niger Delta wetland complex, one of the largest wetland complexes in Nigeria, has a significant impact on water quality, and as such has been explored in this study. The findings established a strong variation in physicochemical parameters across habitat types and disturbance regimes. As revealed from the PCA, correlations of Phosphate, turbidity, conductivity, flow velocity, water temperature as well as total dissolved solids to the creeks might be indicative of the vulnerability of these habitats to soil-runoffs that are heavily silted and also the presence of mangrove vegetation within this habitat [56]. These findings were in congruence to the outcomes from studies conducted in Oproama Creek in the Niger Delta were it was asserted that mangrove facilitates nutrient flow in creeks through the production of leaf liters [56]. Also, the correlation of streams with phosphate, turbidity, dissolved oxygen and nitrate is unanticipated as such habitats might be recipients of high inorganic inputs which have been reported by previous studies [6-8]. The correlation of lakes with nitrate, pH and dissolved oxygen clearly indicated the response of this habitat to pollution from activities such as fishing and farming. As revealed from previous studies, the presence of pH might regulate the photosynthetic process in these systems, thereby reducing or increasing levels of dissolved oxygen [8]. Also, the correlations of depth to lakes in this study have been reported in previous studies where it has been related to substrate types and particle size of the lake [51]. However, this study did not analyze this relationship between depth, substrate types and particle size and as such assertions of this sort may be subjective. Furthermore, activities like mining of silica might influence the availability of dissolved oxygen and nutrient level of the wetlands [26]. Around human settlements, wetlands may be the recipients of discharges from laundry and other domestic activities which may likely impact dissolved oxygen, phosphate, turbidity, conductivity, water temperature, TDS and pH [15].

The variation in environmental factors across various habitat types in Afrotropical wetlands have revealed that pond had shallow depth across habitat types and is in congruence to the findings of [45] in the United States. Similarly [36] reported low depths for ponds in a lowland rainforest system in Southern Nigeria and attributed the shallow nature of the ponds to the complete dryness experienced by this habitat when there is minimal or no rainfall, while it retains water as the rain sets in. Highest depths recorded in streams in this study contrasted with those reported by [5] from a stream in Southern Nigeria. However, the high depths in stream might be due to an increase in water level which is typically connected with the precipitation pattern of the drainage basin of such habitat in the Afrotropical landscape [36]. Previous studies had highlighted the importance of inundation, hydrogeochemical processes and climatic conditions as drivers of water quality in Afrotropical wetlands [12, 39]. In this study high flow velocity reported in creeks and streams (lotic) when compared to lakes and ponds (lentic) was like the findings of [12] in Agbede wetlands were primarily governed by the degree of inundation associated with these wetlands. Several studies have showcased the importance of leaf litter decomposition and low vegetation cover in increasing temperatures of lentic systems [5, 56]. This assertion is in congruence with this study were high temperatures were recorded in the creeks were deforestation had decreased vegetation cover and exposed such habitats directly to sunlight [29]. Despite dissolved oxygen not being significant across habitat types, the high levels of dissolved oxygen recorded in ponds were in contrast to the findings of [36] from ponds in a lowland rainforest in Southern Nigeria and that of [23] in Kenya. The high levels of dissolved oxygen might be attributed to the sparse vegetation cover which could increase diffusion of oxygen into the habitat and photoperiod [31]. However, the low levels of oxygen reported in streams in this study might be because most of the streams are recipients of organic waste and high level of degradation from microbial activities [19]. The acidity recorded from all habitat types in this study have been previously reported to be typical for tropical wetlands [40] and might be due to the canopy effect and the poor macrophytes conditions in these waterbodies [12].

Electrical conductivity is the extent to which aquatic systems conduct current due to the presence of dissolved ions [36-37]. It is a measure of the ground water run-offs [28] and an indicator of the salt content [37]. The highest conductivity values recorded in the creeks does not conform to brackish water salinity trend reported by [56] in Oporoma creek, Southern Nigeria. Furthermore, the high conductivity reported in the creeks might be influenced by tidal inflow of salt water from the sea [19, 34]. The low conductivity values reported in streams were like the findings of [5] from a highly sandy site in a Southern Nigeria stream and this may be an indicative of the low mineralization associated with minimal human impact in this habitat type [40] and the fact that they are farther away from receiving sea water. The combination of these variables in the creeks can be utilized in identifying and addressing multi-scale stressors of this habitat [6]. The high TDS recorded in the creeks may be an indication of the presence of toxicants that might have originated from dissolved solids of organic origin, possibly petroleum effluent discharged into these habitats [28]. Furthermore, the elevated levels of TDS in the creeks may negatively impact the quality of water in the creeks and potentially affect the physiology of the biota through osmoregulatory processes and a reduction in oxygen solubility [37]. Furthermore, the high turbidity in the creeks might be related to anthropogenic stressors operating within the habitat [37], tidal flows [28] and the influence of run-offs [12]. The implication of the high turbidity in the creek is reduced photosynthetic rate due to low light penetration, thereby increasing difficulty in the availability of food by organisms [37]. However, the findings for turbidity and TDS was not in conformity to the findings of [12] in Agbede wetlands where higher values were reported in lentic systems rather than lotic systems.

Phosphates and nitrates are often used as surrogates for productivity in lakes, ponds, reservoirs and rivers [12]. In this study, the mean phosphate concentration reported in the creeks was similar to the findings of [28] in Egbeni station of Sagbama creek in Bayelsa. The creek recorded the highest value of phosphate when compared to other habitat types and might be due to agricultural waste discharge [19] and possibly as a result of nutrients released from microbial activities into the water column for macrophytes [6]. Furthermore, previous studies had revealed that the metabolic demands of phytoplankton during development reduce nitrate concentration in water, while the decomposition of plants and dry leaf litter in aquatic systems add to the level of nitrate [36]. For instance, the high levels of nitrates found in lakes (lentic habitat) when compared to other habitat types was similar to the findings of [12] in Agbede wetlands and have been attributed to the level of litter decomposition and submerged and submerged aquatic plants, and the possible influence of waste from agricultural activities around these habitats [19]. However, low nitrates observed in streams (lotic habitats) might be an indication of the less significant stress on this habitat [12]. Overall, the low concentration of nitrates across wetlands in the Niger Delta complex are below national and global standard limits, which clearly indicates that these habitats are not highly polluted. Similar assertion had been documented in Elechi creek in the Upper Bonny Estuary of Southern Nigeria [34].

Furthermore, reports of anthropogenic threats on water quality in aquatic systems are rife, with such studies identifying varied level of activities that contribute to degradation of aquatic systems and reductions in water quality [25, 58]. For instance, the high depth reported for wetlands impacted by human settlement was in contrast to the findings from South Africa which has been linked to the frequent deposition of sediments carried by run-off into these habitats [24]. Farming activities around wetland systems may loosen soil particles which are washed into the habitat basin during periods of rainfall thereby making the habitat shallow [15]. Also, the high temperatures observed in wetlands impacted by human settlement could be attributed to the direct exposure of such habitats to sunlight due to deforestation [14]. The accretion of organic waste in aquatic habitats facilitates microbial development, leading to oxygen depletion and disturbance of the entire wetland ecosystem [53]. For instance, the high level of dissolved oxygen reported in this study was similar to the findings of [16] in Woji creek in Southern Nigeria but contradicts the findings of [5] from an Afroropical stream impacted by abbatoir effluents. While organic effluents have been identified to deplete dissolved oxygen [5], the contradicting findings from this study might have been influenced by season as it has been previously reported that during the wet season there is usually an increase in dissolved oxygen [16]. Lumbering activities have been reported to reduce oxygen levels [48], and this was similar to the findings of this study where low oxygen levels were reported in wetlands impacted by lumbering activity. Lumbering activities which stem from deforestation have always been linked to alterations in pH [35] which can affect the concentrations, fractions, fluxes, and cycles of other nutrient elements [58]. The high pH, TDS and turbidity reported in wetlands impacted from lumbering activities is an indication of the potential of such activities to increase the toxicity of wetlands [46]. However low pH, TDS and turbidity reported in wetlands close to farms have been reported in previous studies and attributed to possibly precipitation and run-offs from farmland [47].

The high conductivity values reported in wetlands impacted by human settlement in this study is within the recommended standards for freshwater habitats to support aquatic life [24]. Furthermore, the high conductivity values might be due to the discharge of waste from such activity in the habitats thereby making the water unsuitable for domestic use and irrigation purposes [27]. Silica mining is a common activity within the Niger Delta wetland complex and such activity have been reported to impact water quality by regulating nutrient contents of the system [55]. The high phosphate level found in wetlands impacted by mining activities had also been reported in wetland habitats of the Niger Delta [26]. Also the high nitrate concentrations associated with wetlands impacted by farmlands in this study have also been reported in KwaZulu-Natal, South Africa [47]. Similarly in South America it has been reported that farming activities increased nitrate levels of surface water which facilitates eutrophication and increased risk to human health [44] due to increased toxicity levels of these aquatic systems that are used domestically.

Disclosure of Conflict of Interest

The authors declare no conflict of interests or personal relationships that could have appeared to influence the work reported in this paper.

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