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SPATIO-TEMPORAL TRENDS IN THE PHYSICOCHEMICAL PARAMETERS OF MID-LAGOS LAGOON WATER, SOUTH-WESTERN NIGERIA

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ABSTRACT
The spatio-temporal distributions of physicochemical properties of Mid-Lagos Lagoon water, South-western Nigeria were investigated by the division of the stations into three zones of 10km interval (Zones 1, 2 and 3) between January 2014 and December 2015. The observed ranges of physicochemical characteristics from the study area were: dissolved oxygen 3.2-7.1mg/L; pH: 6.6-8.5; temperature: 27.39-32°C; electrical conductivity: 11.06-51.46 μS/cm; salinity: 0.22-33.87ppt; turbidity: 27.09-32.71NTU. The nitrate and phosphate concentrations ranged from 0.08-1.71mg/L and 0.02-3.9mg/L respectively. The pH and temperature were within the desired values for healthy marine ecosystems when compared with the Federal Ministry of Environment (FMENV) Nigeria and World Health Organization permissible limits (pH:6.5-9 and temperature<40°C). Zone-1 had the highest pH, dissolved oxygen, electrical conductivity, salinity, nitrate and phosphate values, and lowest turbidity level. These values implied enhanced water quality at Zone-1, compared to Zones-2 and which reflected in the higher productivity at Zone 1 compared to Zones-2 and 3 respectively.
Keywords: Physicochemical characteristics, nutrients, water quality, marine ecosystems, productivity.

INTRODUCTION

Physicochemical conditions of lagoons and estuaries are the products of equilibrium between discharged continental run-off water, rivers, and marine intrusions (Kjerfve, 1994; Torregroza-Espinosa *et al.,* 2021). The coastal environments are habitats to dynamic ecosystems whose physical, chemical, and biological characteristics can greatly be influenced by anthropogenic activities taking place within their drainage basins (Tadese *et al.,* 2018). The majority of these anthropogenic activities are generated from the huge amounts of organic and synthetic wastes discharged from the urban centers with little or no treatment before their release into the nearby water bodies. The increasing population and industrialization of the urban areas tend to greatly alter the structure and function of coastal ecosystems such as, water quality, habitat structure, stream flow patterns, energy sources, nutrients availability, and biotic interactions (Tadese *et al.,* 2018).

The Lagos Lagoon and Estuaries (Figure 1) are amongst the world's most densely inhabited coastal provinces, with a high level of pollution generated mostly by domestic and industrial pollutants which are induced by series of anthropogenic effluents (Ajao, 1990; Ajao, 1996; Don Pedro *et al.,* 2004; Ajani *et al.,* 2015). These industrial effluents are not unconnected with changes in the physical and chemical status of the Lagos coastal waters and eutrophication (Shelle and Popoola, 2021, Ajani *et al.,* 2021). Several studies have been conducted on the physicochemical characteristics in Lagos Lagoon and environments, however, there is a paucity of information on the distinct water quality and variations in the physicochemical parameters of the mid-Lagos Lagoon waters. To bridge this gap, the Lagos lagoon system was divided into three zones of 10km intervals to understand its distinct physicochemical characteristics, nutrients status, water quality, and productivity.

This study aimed to monitor the spatio-temporal distribution of the physicochemical characteristics such as, pH, temperature, dissolved oxygen, salinity, pH, electrical conductivity, and nutrients such as, nitrate and phosphate loads of the mid-Lagos Lagoon waters of South-west Nigeria.

MATERIALS AND METHODS

Study Area

The Lagos lagoon is part of the continuous system of lagoons and creeks that are found along the coast of Nigeria from the border with the Republic of Benin to the Niger Delta. It is located between longitude 3º22' E and 3º4' E and latitude 6º17' N and 6º28' N. It spans around 257kilometres from Cotonou, Benin, to the Niger Delta's western boundary. The Lagoon borders the forest belt and receives inputs from several important sources. A reconnaissance survey was carried out on the lagoon to identify and determine fishing villages and landing sites to be surveyed with the aid of a digitized lagoon map at the Nigerian Institute for Oceanography and Marine Research (NIOMR). The Lagos lagoon system was divided into three zones of 10km intervals (Figure 1) for the study of its physicochemical characteristics and nutrients status.

Figure 1: Map of Lagos Lagoon showing the Stations/Zones; A (Zone-1); B (Zone-2) and C (Zone-3) (modified after Ajani e *et al.*, 2021).

Sample Collection

Water was sampled in two seasons (wet and dry) at the three designated zones *in-situ* and *ex-situ*. Parameters measured *in-situ* monthly using Hydrolab (HL 002066) water analysis meter were temperature, conductivity, dissolved oxygen, pH and salinity. The meter was standardized first with a buffer solution before use. Sampling was done monthly between January 2014 and December 2015, comprising of two dry seasons (November-April) and wet seasons (May-October) (FAO, 2004). For *ex-situ* measurements of nitrates and phosphates, water samples were collected monthly from each of the three sampling zones with the aid of a 2-litre Von-Don water sampler. The closed water sampler was released with a graduated rope at the sampling station. The water sampler was brought into the canoe and the water collected was emptied into plastic sample containers and labelled accordingly. The plastic containers were transferred to the laboratory and stored before the commencement of analysis. Samples were obtained randomly within the sampling zones in triplicates per zone. Water quality parameters of the lagoon were determined both in-situ using hydro lab HK 002066, made in the USA, and ex-situ on monthly basis during the study visits. The data obtained for each physiochemical parameter from the zones were tested for variations between stations and for correlation against the catch data.

Determination of Nitrates (NO_3^-)

This analysis was carried out using the method described by APHA (1985). Nitrate concentration was determined using phenyl di-sulphuric acid which was added and stirred with a glass rod until the solid residue was mixed thoroughly with the acid. About 35cm^3 of distilled water was added and the solution was made up to 50cm^3 in a standard flask. One absorption cell was filled with blank and inserted into the compartment of the spectrophotometer. Another cell was filled with the sample and inserted next to the blank. The lid was then closed and the meter set to zero. Using 420nm, the absorbance was extrapolated on a standard nitrate curve previously prepared to obtain the concentration of nitrate in mg/L. the value obtained was checked with a nitrate meter in the laboratory. The mean of the nitrate values at different locations within each zone was taken as the mean nitrate of the study area.

Determination of phosphates (PO_4^{3-})

Phosphate concentration was determined by the ascorbic acid method as described by APHA (1985). The unit of measurement of 700nm was mg/L. The value obtained was checked with a Nitrate meter in the laboratory. The mean of the phosphate values at a different locations within each zone was taken as the mean phosphate of the study area.

RESULTS

The values obtained for the physicochemical parameters from the analysis of water samples are presented in Figures 2-9.

Surface Water Temperature

The values of the water temperature in 2014 ranged from 28.60-30.30°C at Zone 1 (west of mid-Lagoon) during the dry season (January to April and November to December) to 29.20 - 30.90°C during the wet season (May-October) respectively. Whereas, the values ranged from 29.20-30.70°C during the dry season to 30.30-31.90°C during the wet seasons at Zone 2 (the centre-point of the study area) respectively (Figure 2). Zone 3 (the eastern part of the study area) ranged from 29.00-30.60°C during the dry season to 29.50-31.20°C during the wet seasons respectively. Zone-2 temperature had the highest level during the dry season, while, Zone 3 had a sharp increase during the end of the wet season (August-November). However, by 2015 the temperature level was higher in Zone 2 during the wet and dry seasons (Figure 2).

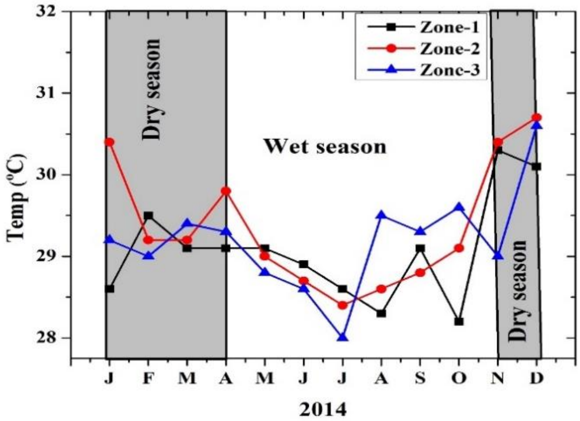

Figure 2: Spatio-temporal variation of Temperature in the study area in 2014

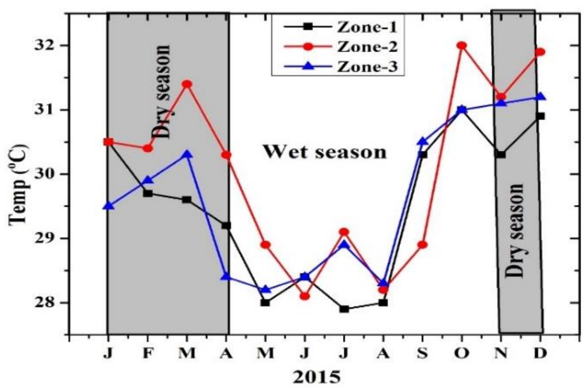

Figure 3: Spatio-temporal variation of Temperature in the study area in 2015

Turbidity

The turbidity at Zone 1 in 2014 ranged from 28.17 - 29.56NTU (Nephelometric Turbidity Units) during the dry season to 27.77-29.21NTU during the wet season respectively (Figure 4). Whereas, the values ranged from 30.47-32.36NTU during the dry season to 28.20-32.71NTU during the wet season at Zone 2 respectively. Turbidity values ranged from 31.21-32.53NTU during the dry season to 28.9-32.63NTU during the wet season respectively in Zone 3. The turbidity values of Zone 3 and Zone 2 had higher levels across the sampling stations (Figure 4), which suggested high concentrations of suspended particles at Zone 3 and Zone 2 respectively, and poor water quality compared to Zone 1. The turbidity values showed a slightly lower concentration in 2015, with increase in Zone 1 values in the wet season (Figure 5).

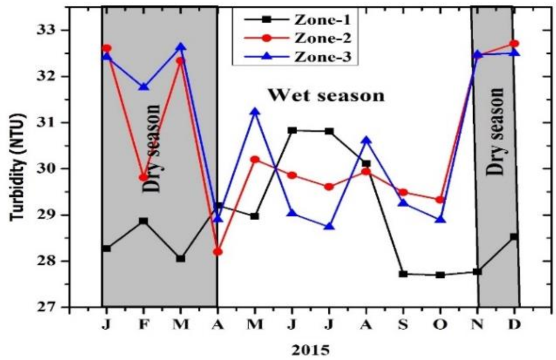

Figure 4: Spatio-temporal variation of Turbidity in the study area in 2014

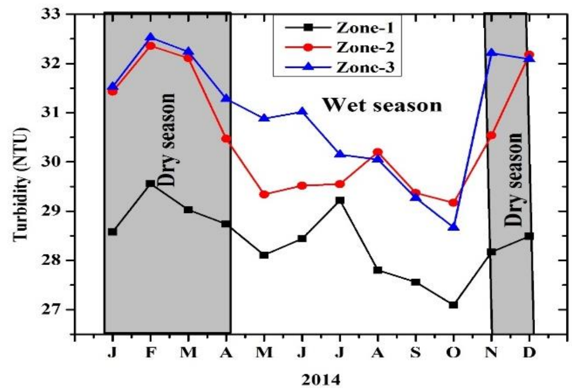

Figure 5: Spatio-temporal variation of Turbidity in the study area in 2015

Dissolved Oxygen (DO)

The value of DO in 2014 ranged from 5.5-6.7mg/L during the dry to 4.6-6.6 mg/L during the wet season at Zone 1 respectively (Figure 6), while the values ranged from 4.5 - 5.5 mg/L during the dry season to 3.4 - 5.2 mg/L during the wet season at the Zone 2. Zone 3 values ranged from 4.3-5.3 mg/L during the dry season to 3.5- 4.3 mg/L during the wet season. The DO values in Zone 1 displayed the highest spatio-temporal concentrations in 2014 (Figure 6) and 2015 (Figure 7) across the study area, whereas, Zone 3 displayed generally lower spatio-temporal concentrations in 2014 and 2015.

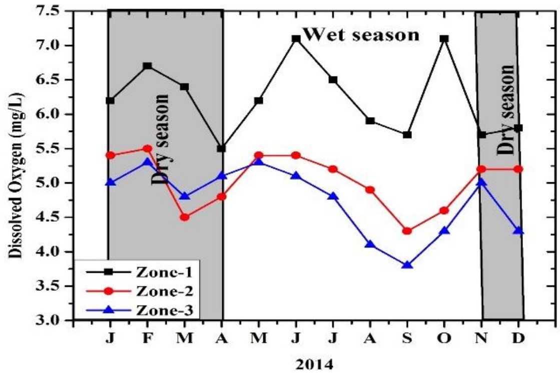

Figure 6: Spatio-temporal variation of dissolved oxygen in the study area in 2014

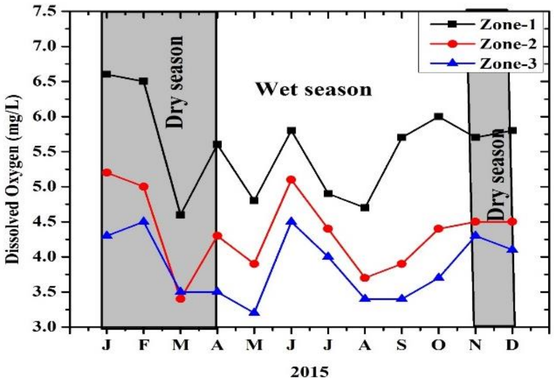

Figure 7: Spatio-temporal variation of dissolved oxygen in the study area in 2015

Electrical Conductivity

The values of the EC in 2014 ranged from 44.41- 47.78 µS/cm during the dry season to 43.34 - 47.78 µS/cm during the wet season at Zone 1, ranged from 28.42-43.61µS/cm during the dry season to 34.42-38.42 µS/cm during the wet season at Zone 2. Values in Zone 3 ranged from 24.29-38.18 µS/cm during the dry season to 34.29-36.5 µS/cm during the wet season respectively. Zone 1 EC values had the highest spatio-temporal concentrations in 2014 (Figure 8) and 2015 (Figure 9) across the study area.

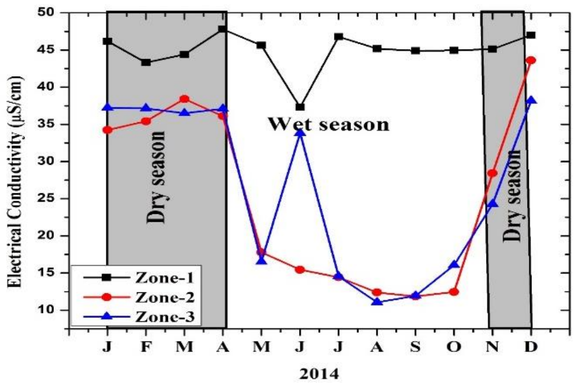

Figure 8: Spatio-temporal variation of electrical conductivity in the study area in 2014

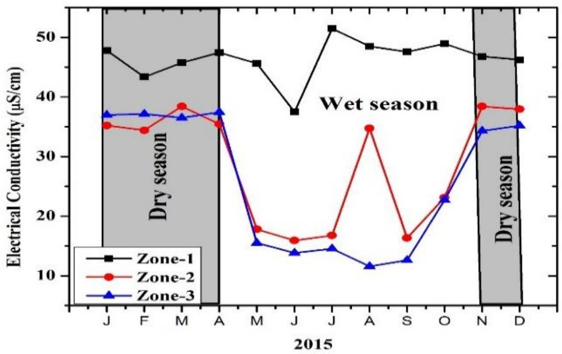

Figure 9: Spatio-temporal variation of electrical conductivity in the study area in 2015

Salinity

The salinity values in 2014 ranged from 23.17- 33.67 ppt during the dry season to 22.89 - 28.79ppt during the wet season at Zone 1 (Figure 9), and ranged from 13.66-17.50 ppt during the dry season to 12.17-14.80ppt during the wet season at Zone-2. Zone 3 values ranged from 8.27-16.58 ppt during the dry season to 9.56-13.23 ppt during the wet season respectively. The Salinity values at Zone 1 displayed the highest spatio-temporal concentrations in 2014 (Figure 10) and 2015 (Figure 11) across the study area, whereas, Zone 3 displayed generally lower spatio-temporal concentrations in 2015, with higher values in 2014 during the wet season.

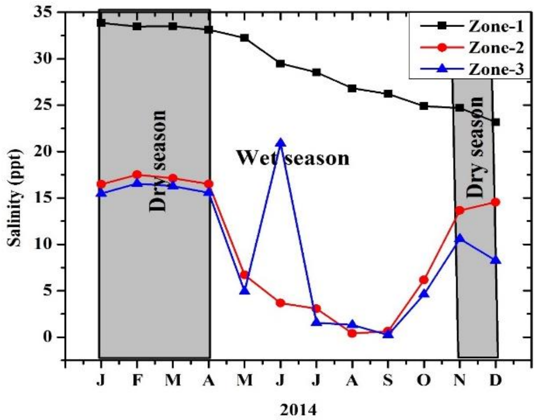

Figure 10: Spatio-temporal variation of salinity in the study area in 2014

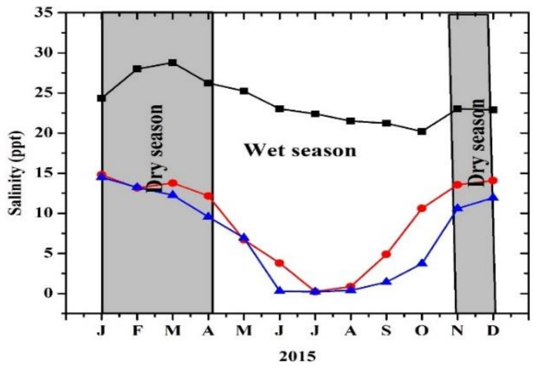

Figure 11: Spatio-temporal variation of salinity in the study area in 2015

pH

The values of the pH in 2014 ranged from 8.0-8.3 during the dry season to 7.8-8.5 during the wet season at Zone-1. Whereas, the values ranged from 6.5-7.6 during the dry season to 6.9-7.6 during the wet season at Zone-2. Zone 3 values ranged from 6.3-6.6 during the dry season to 6.0-6.3 during the wet season. The Zone-1 seasonal values displayed the highest spatio-temporal concentrations in 2014 (Figure 12) and 2015 (Figure13) across the study area.

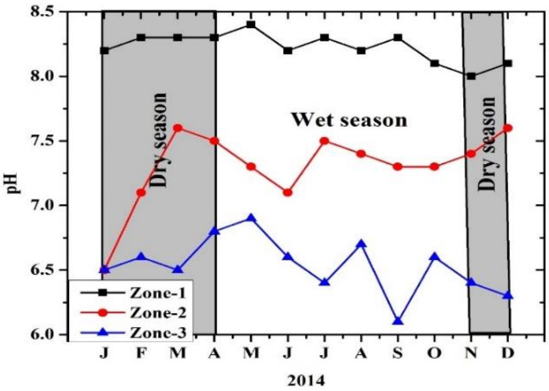

Figure 12: Spatio-temporal variation of pH in the study area in the year 2014

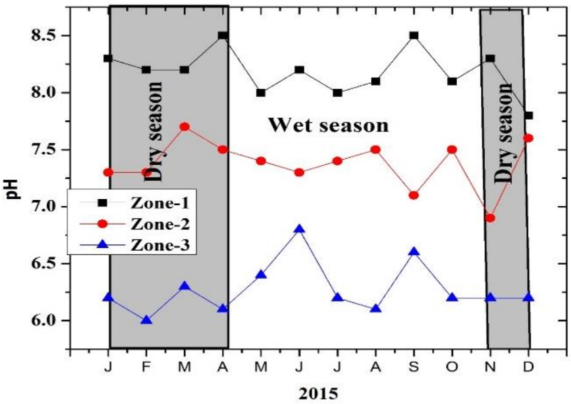

Figure 13: Spatio-temporal variation of pH in the study area in the year 2015

Nitrate

The values of nitrate in 2014 ranged from 0.08-0.65mg/L during the dry season to 0.08-1.71mg/L during the wet season respectively at Zone 1 (Figure 14), and ranged from 0.16-0.26 mg/L during the dry season to 0.14-0.23mg/L during the wet season respectively at Zone 2. The values at Zone 3 ranged from 0.15-0.49mg/L to 0.23-0.53mg/L, during the dry season and wet season respectively. The nitrate concentrations displayed similar trends as DO, EC, pH, and by the higher values at Zone 1. The nitrate concentrations showed slightly higher values at Zone 3 in September and November in 2014 and 2015 respectively.

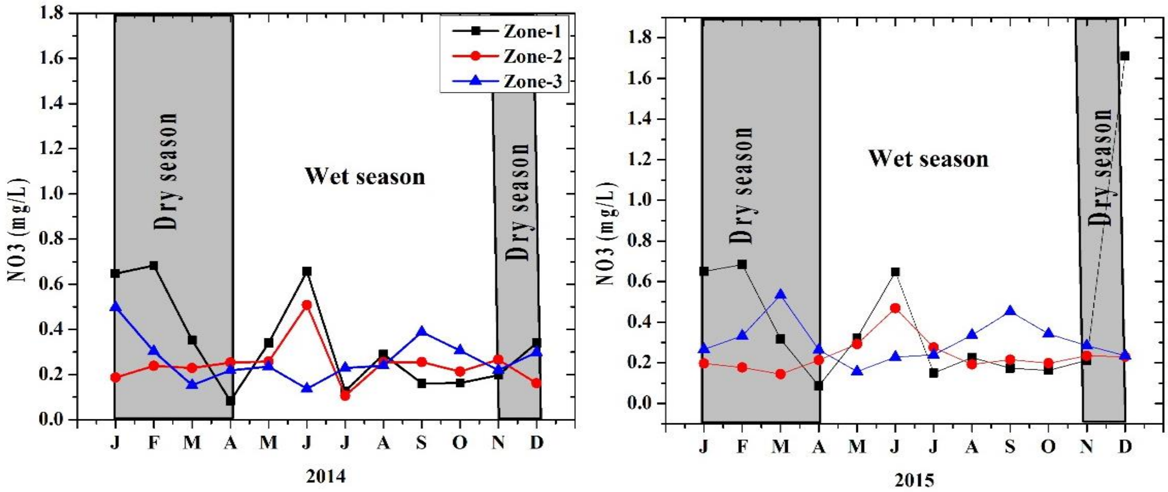

Figure 14: Spatio-temporal variation of nitrate concentrations in the study area in 2014 and 2015

Phosphate

The values of phosphate in 2014 ranged from 0.02-0.93mg/L during the dry season to 0.05-0.41mg/L during the wet season at Zone 1 (Figure 15), and ranged from 0.30-1.78mg/L during the dry season to 0.22-2.43mg/L during the wet season at Zone-2. Zone 3 values ranged from 0.13-1.15mg/L during the dry season to 0.11-1.18 mg/L. during the wet season respectively. Zone 1 had the highest phosphate concentrations during the wet season (July-August) in -2014 and 2015 respectively.

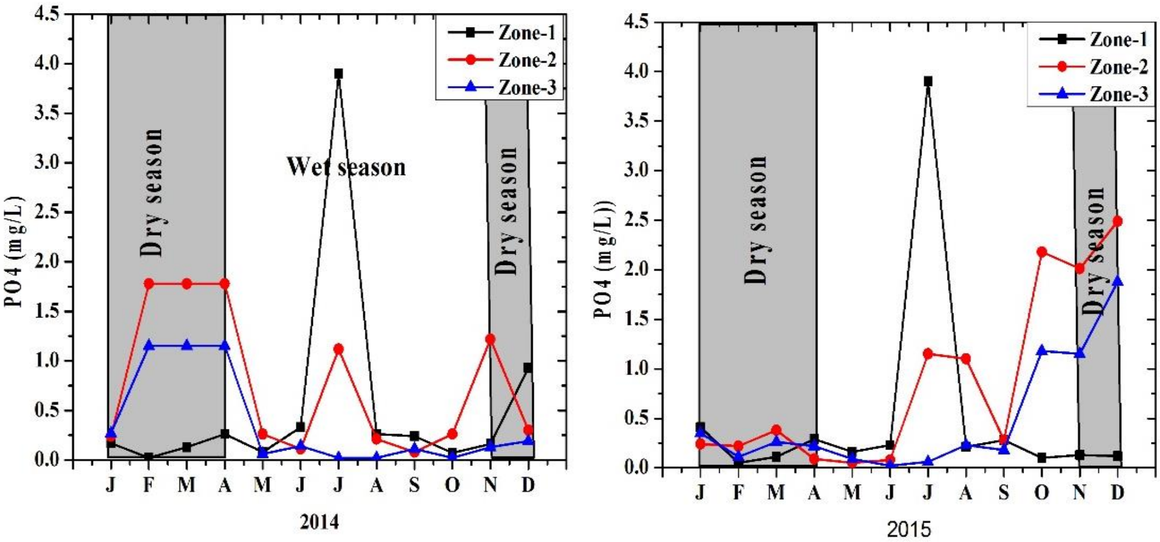

Figure 15: Spatio-temporal variation of phosphate concentrations in the study area in 2014 and 2015

DISCUSSION

Water temperature is one of the most important physical characteristics of aquatic ecosystems and affects several water quality parameters (Ajani *et al*., 2015; Popoola *et al*., 2015; Ajani *et al.*, 2021). It controls the rate of all chemical reactions and affects fish growth, reproduction, and immunity (Patil *et al*., 2012). The temperature values obtained in this study were within the range for a tropical climate and stipulated permissible limits (of < 40 ºC) by WHO (1997) and FMENV (2001).

Turbidity is an essential water quality measurement. It is the optical property that can be related to the cloudiness, light adsorption, and scattering in water. It can influence the penetration of sunlight into the water body (Rukeh *et al.*, 2013). It is an important parameter since it impacts how much sunlight penetrates the water.

The reduced rate of light transmission at Zone 3 and Zone 2 as determined in this study may alter the transmission of sunlight rays thereby affecting the bottom-dwelling phytoplankton in the area of study. The lower turbidity concentrations during the wet season compared to the dry season suggested a low rate of discharge of suspended particles during the rainy season (Rukeh, 2013). The recorded turbidity values were higher than the maximum permissible limit of 10NTU stipulated by WHO (1997) and FMENV (2001). The higher (>10NTU) turbidity values suggested the presence of humic substances resulting from decaying organic matter in the Mid-Lagos Lagoon water.

Dissolved oxygen (DO) is one of the important parameters in water quality assessment and reflects the biological and physical processes prevailing in the water (Dirican, 2015). Its correlation with the water body provides both direct and indirect information, such as, bacterial activity, photosynthesis, nutrients availability, stratification, and so on (Premlata, 2009; Patil and Sawant, 2012). The DO values at Zone-3 were generally lower than the stipulated minimum benchmark level of DO (5.0 mg/L) for normal survival of marine ecosystem (Popoola *et al.*, 2015). The DO concentrations at Zone-3 suggested a poor condition for the survival of aquatic life.

The Electrical conductivity (EC) of water (in µS/cm) is important in ecology and environmental management as an indicator of the total dissolved inorganic salts and other solids. It is roughly proportional to the concentration of inorganic salts in a water body (Rukeh, 2013). Zone 1 EC values displayed the highest spatio-temporal concentrations in 2014 and 2015 across the study area like the DO concentrations which can be related to seawater incursion, the higher concentrations of dissolved solids, or closer proximity of Zone 1 to the sea compared to Zone 2 and Zone 3. The sharp drop in EC concentrations across the sampling stations during the wet season was attributed to ebb-tidal phase periods when the tidal current moved freshwater seaward, and the ocean water diluted by the freshwater. The recorded seasonal EC range (11.06-51.46 µS/cm) fell within brackish-strong brackish water habitat (Rukeh, 2013).

Salinity concentrations influence the abundance and distribution of coastal and freshwater ecosystems. It controls biological diversity and acts as a limiting factor of aquatic organisms' distributions in coastal environments. The Zone 1 values displayed the highest spatio-temporal concentrations in 2014 and 2015 across the study area like the DO and EC concentrations which further supported the flood-tidal phases when the tidal currents moved seawater inland, enhanced productivity and proximity to the sea at Zone 1 compared to Zone 2 and Zone 3. Whereas, Zone 3 displayed a general low spatio-temporal salinity concentrations in 2015, with a higher values in 2014 during the wet season. The sharp increase in the values during this period was also not unconnected with the flood-tidal phases at that period. The sharp drop in electrical conductivity and salinity concentrations across the sampling stations during the wet season were because of the ebb-tidal phase periods when the tidal currents moved freshwater seaward, and the ocean water was diluted by the freshwater. A similar situation was reported by Nubi *et al.* (2022), in the Southwestern Nigeria coastal waters and estuaries The recorded seasonal SAL salinity range (1.55-33 μS/cm) fell within medium brackish-strong brackish water, except for some <1ppt recorded values during the wet season which was attributed to ebb-tidal phase periods when the tidal currents moved freshwater seaward, and the ocean water was diluted by the freshwater (Nubi *et al*., 2022).

Acidic pH permits toxic elements and compounds to become mobile and available for uptake by aquatic plants and animals. The Zone-1 seasonal pH values displayed the highest spatio-temporal concentrations in 2014 and 2015 across the study area like the DO, EC, and salinity concentrations which further supported the flood-tidal phases, enhanced productivity, and proximity to the sea at Zone 1 compared to Zone-2 and Zone 3. A pH of less than 6.5 may be harmful to many fish species (Dirican, 2015). The recorded seasonal pH range (6.0-8.5 unit) fell within the suitable pH range (6.5-9.0) for the protection of aquatic habitats (FEPA, 1991; FMENV, 2001)

The nutrients concentrations of a water body is an indication of the degree of sustainability and primary productivity of the water body. The high nitrate values at Zone 1 further corroborated enhanced productivity and flood-tidal phases at Zone 1 compared to Zone-2 and Zone-3 (Rukeh, 2013). The slightly higher nitrate values at Zone-3 by September- November 2014 and 2015 may be attributed to run-offs or discharges of anthropogenic effluents rich in NO_3^- during the periods. It can also be referred to as a situation of flood-tidal phase when the tidal current moved seawater rich in NO_3^- inland (Nubi *et al.,* 2022). The recorded seasonal NO_3^- fell within the suitable NO_3^- range (<20mg/L) for coastal water (FEPA, 1991; FMENV, 2001). High phosphate concentrations may promote the production of microbes and phytoplankton (Oyatola *et al.,* 2021). Other human-induced anthropogenic factors such as, chemical fertilizer, run-offs composed of dissolved and suspended phosphate, human or animal waste effluents, and effluents from detergents and laundries can trigger the high mean phosphate concentration at Zone 2.

CONCLUSION

The spatio-temporal distributions of the physicochemical characteristics (temperature, turbidity, dissolved oxygen, electrical conductivity, salinity, pH, nitrate~~,~~ and phosphate) of the west (Zone 1), central (Zone 2), and east (Zone 3) parts of the Mid-Lagos Lagoon showed that, the temperature and pH of the mid-Lagos Lagoon waters were within permissible limits for healthy marine ecosystems stipulated by the Federal Ministry of Environment of Nigeria and the World health organization. Except for the low DO (<5mg/L) at Zone 3 which suggested a poor condition for the survival for aquatic life. The recorded high turbidity values (>10NTU) at the Mid-Lagos Lagoon were further attributed to the presence of humic substances while the electrical conductivity and salinity values suggested a medium to strong brackish water ecological habitat.

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