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SEASONAL VARIATIONS IN PHYSICOCHEMICAL PROPERTIES OF WATER IN SOME SELECTED LOCATIONS OF THE LAGOS LAGOON

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ABSTRACT
The seasonal and spatial distributions of physicochemical parameters that determine water quality was studied in the Lagos Lagoon. Nine locations were selected according to the activities that take place in the areas. Parameters that determine water quality were measured during the months of February and July that represent dry and rainy season. Physical water quality parameters such as salinity, EC and TDS showed strong seasonal variation amongst stations and evaporation seem to be a major controlling force for these parameters in the lagoon. Generally, the data obtained suggests that anthropogenic disturbances and the establishment of several types of activities with increased point and non-point storm water runoff shunted directly into Lagos Lagoon has negatively affected the water quality and made relationships between most of the parameters and the different locations complex.

Keywords: water quality, pollution, relationship between parameters, Lagos Lagoon

INTRODUCTION
The Lagos lagoon consists of three main segments namely the Lagos Harbour Segment, the Metropolitan and the Epe Division Segment. This aquatic resource of multiple usages receives inputs of domestic sewage, solid waste, industrial effluents, sawdust and particulate wood wastes, petroleum hydrocarbon, cooling water from thermal power station and emissions from automobile exhausts. Boats and marinas also have a significant impact on the environment through oil and fuel leakages and vessel maintenance (Ajao *et al*., 1991).The lagoon is located in a tropical coastal savannah ecosystem influenced by a bimodal rainfall pattern averaging 700 mm per annum. The lagoon's hydrology is influenced by surface runoff, inflow from rivers, several streams, groundwater flow, overwash of seawater and direct precipitation.

There is, however, a paucity of information on the spatiotemporal distributions of physicochemical parameters that determine water quality, and how these are influenced by external factors such as rainfall. This study seeks to address these gaps in knowledge and focused on nine locations of the lagoon once acknowledged as the most productive sector in terms of fish catch. Specifically, the study tried to describe the spatiotemporal distribution of water physicochemical parameters, ascertain the extent of spatiotemporal heterogeneity of the parameters and identify the parameter(s) that most influence the distributions observed.

MATERIALS AND METHODS
The study was conducted between July 2007 and February 2009. Surface water was collected from nine sampling stations located within the lagoon. These locations were selected based on the different activities carried out in the areas (Table 1). The positions of the sampling stations were accurately located by using Geographical Positioning System (GPS). The physicochemical parameters sampled were dissolved oxygen (DO), salinity, pH, water depth, nutrients (nitrates and orthophosphates), conductivity, total dissolved solids (TDS), total suspended solids (TSS), turbidity and alkalinity, utilizing a combination of *in situ* and laboratory methods (APHA, 1999).

TABLE 1. SAMPLING STATIONS FOR THE STUDY

Sampling Stations	Station Code	Average depth (m)	Average Transparency	No. of Sampling Points
University of Lagos	L1	3.25	2.1	3
Ajah	L2	2.75	1.9	3
Okobaba	L3	2.6	1.5	3
Iddo	L4	3.25	2.08	2
Apapa	L5	2.5	1.6	3
Atlas Cove	L6	4.0	1.35	3
McGregory Creek	L7	0.8	0.8	3
Ibeshe	L8	2.8	1.3	3
Odo-Iyaalaro	L9	0.4	0.4	3

Statistical Treatment of Data: Statistical analyses performed on the data sets were non-parametric tests based on ranks of data rather than absolute values, since water physicochemical parameters usually exhibit log-normal distributions (Sanders *et al*., 1987).

RESULTS AND DISCUSSION
The results obtained for all the physicochemical parameters in locations studied are presented are presented in Fig 1. The values obtained for pH at all the locations reflected little influence of season with slightly higher values during the dry seasons (F08 and F09) than the wet seasons (J07 and J08) in all the locations (Fig 2). Generally in this study the pH varied from slightly acidic to slightly alkaline except for location L9. These pH changes may be conducive for fish since they usually live at pH levels between 6.0 and 9.0, although they may not tolerate a sudden change within this range (Adefemi *et al*., 2007). The variation of pH showed from calculation of one sample analysis of variance test analysis (Friedman Test) that it did not vary significantly ($p < 0.05$, 95%, CV 4.6%) in all the locations throughout the periods of sampling. However, Dun's Multiple Comparison Test showed except for location pairsL3/L9 and L6/L9 some similarity in the way the pHvaried. This little variation in pH might have been influenced by a number of factors, such as the deposition of some organic matters into the water from run-off during wet seasons and subsequent decomposition by bacteria and fungi thus producing organic acids capable of lowering pH (Bowen, 1979), photosynthetic activity of submerged plants, respiration and the buffering capacity of the water body (Schult & Welch, 2006).

The almost neutral pH in many of the locations was also accompanied by relatively high alkalinity which did vary significantly ($p > 0.05$, 95%, CV 28.6%) in all the locations throughout the sampling events. The comparison test showed similarities in the way alkalinity varied in all locations. This indicates a consistent buffering capacity of water in the different locations of the lagoon (Schult & Welch, 2006). The alkalinity values obtained during the J07 and F08 did not vary much in all the locations (Fig 1). The highest values were recorded during the

F09 sampling period for all the locations (between 96.8 mg/L in location L5 and 133.3 mg/L in location L1). This means that during this period the water had high buffering capacity and may explain why pH during this period did not vary much (Chagas & Suzuki, 2005).

The lagoon can therefore be described as being buffered since relatively large quantities of acid or base are added to water without causing much change to its pH.

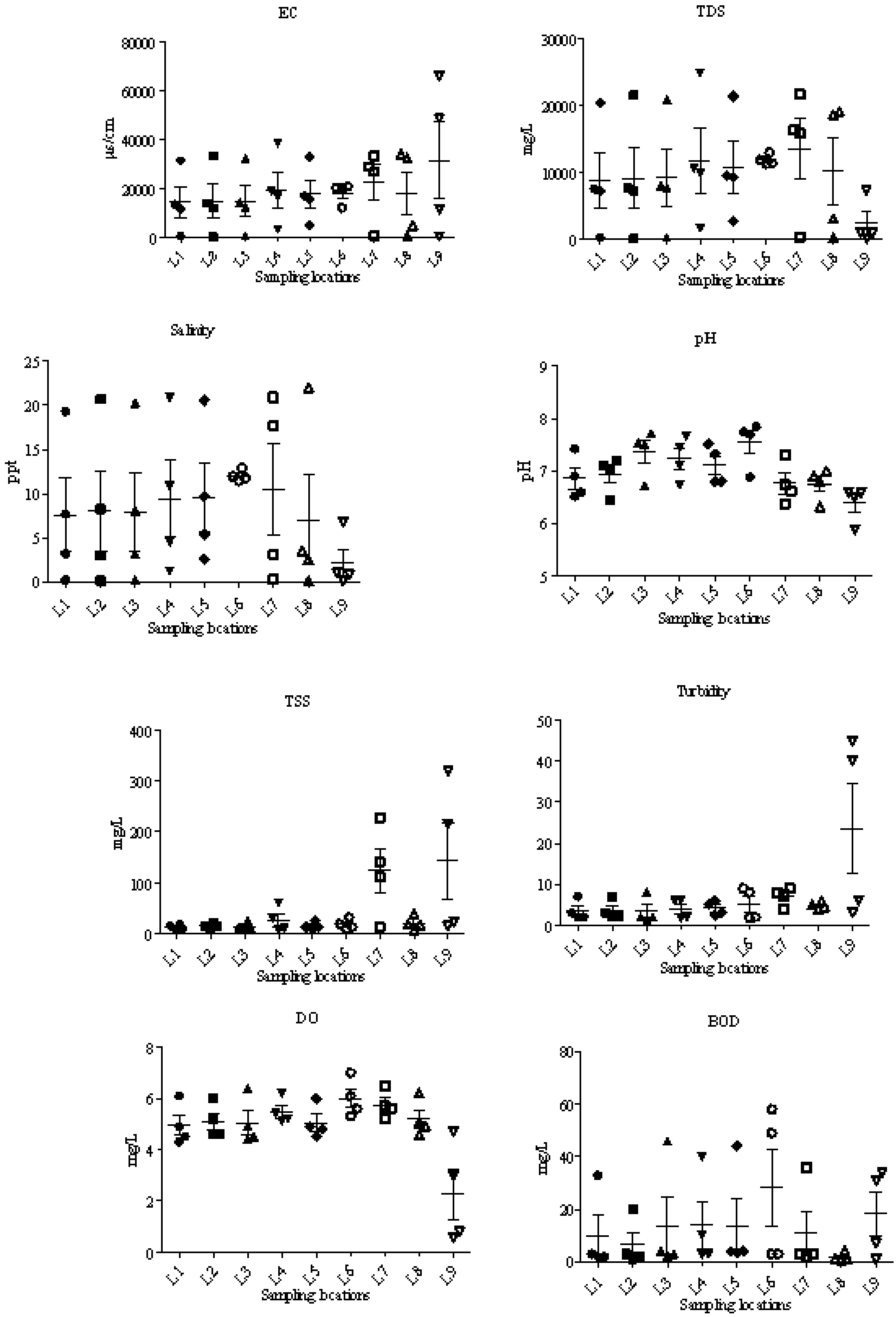

FIG 1. SPATIOTEMPORAL DISTRIBUTION OF PHYSICOCHEMICAL PARAMETERS DURING THE SAMPLING PERIODS.

Fig. 1 cont…

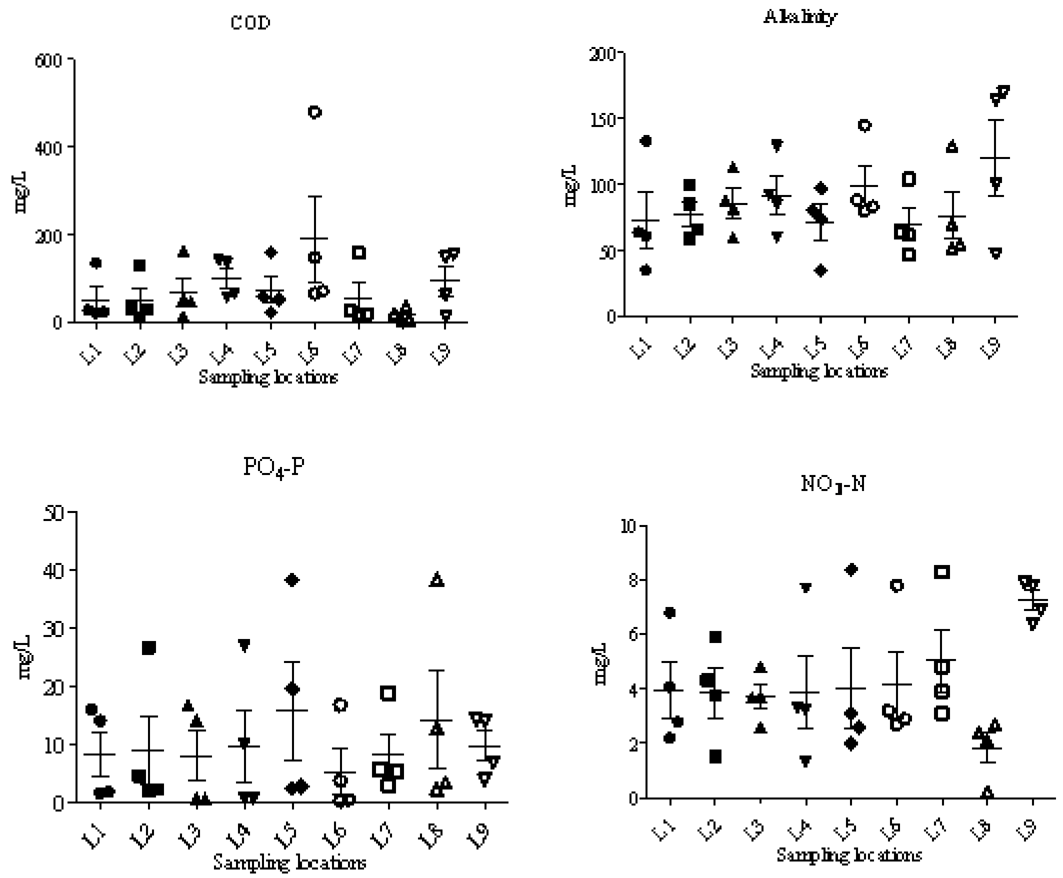

FIG 1 (cont). SPATIOTEMPORAL DISTRIBUTION OF PHYSICOCHEMICAL PARAMETERS DURING THE SAMPLING PERIODS.

The Electrical conductivity values were relatively high in all the locations during F08 and F09 sampling periods, because the lagoon was undergoing drying and salts were accumulating through evaporation. During drying phases EC concentrations can become high to impact on biota (Merz, 2006). This is also an indication of high dissolved solids in the water during this period of dry season. By J07 and J08 (the wet season) sampling periods EC levels decreased because the lagoon had refilled and salts had been diluted or flushed out of the system (Fig 1). The EC levels recorded during the J08 season were exceptionally low because of the high amount of rainfall during that month. The variation of EC among the different locations within the lagoon was significant suggesting that dissolved inorganic salts are not evenly distributed within the lagoon. However, location L6 showed consistently high EC throughout the period of this investigation because of it nearness to the sea.

The variation in total dissolved solids followed a similar pattern as EC. TDS values were high during the dry season (F08 and F09) for locations L1 to L8 reaching up to 24896 mg/L during the F09 sampling period at location L4 (Fig 1). Relatively low TDS were observed for samples collected during the J08 sampling period for same reason as EC. Samples collected from location L6 were consistent throughout the period under investigation also showing some relationship with the EC results. This parameter which was found to vary substantially in time and space might be due to shallowness of the lagoon, macroclimatic conditions, and inputs of sea and fresh water (Chagas & Suzuki, 2005).

Salinity of the different locations of the lagoon varied according to season and values obtained during this investigation together with EC values is indicative of a brackish environment. The fluctuations in salinity values indicate that there was some fresh water input from land and are as subject to strong freshwater discharge from rivers in the surroundings recorded low salinity (L8 and L9) and this might have resulted in the stratification between the locations primarily in the wet season (Stickney, 1984). In all the locations except L6 salinity varied substantially probably due to shallowness, macroclimatic conditions, and inputs of sea and fresh water (Chagas & Suzuki, 2005). The samples collected from L6 did not vary much throughout the period of investigation because of its closeness to the sea suggesting continuous sea-water infiltration through the sand land separating the lagoon from the sea (Chagas & Suzuki, 2005).There was also a trend of increasing salinity at times of the year when little or no rainfall occurred; showing that the rate of evaporation exceeded fresh water input. The Friedman test showed that there was significant variation among the different locations of the lagoon ($p < 0.05$, 95%, CV 77.9%) and in all cases the same reason could be attributed to the cause of this variation. All the values obtained during the periods of sample collection had salinity lower than that typical for marine environment i.e. 35 ppt.

Of critical importance to marine organisms are the fate and behaviour of dissolved oxygen and the factors affecting fluctuations in dissolved (DO) levels. The principal anthropogenic activity resulting in changes in dissolved oxygen concentrations in the marine environment is the addition of organic matter (Cole *et al*., 1999). Dissolved oxygen (DO) levels were generally high but variable, between different locations of the lagoon with no discernable seasonal pattern. The presence or absence of submerged aquatic vegetation may have contributed to the observed variability (Merz, 2006). DO did not vary significantly recording values that were fairly consistent in most locations ($p < 0.05$, 95%, CV 15.6%) during the period of study in all the

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locations. However, there was a significant difference in the way L6/L9 and L7/L9 varied. In location L9 the DO values were relatively low (0.55 mg/L to 4.7 mg/L). The J08 samples from the different locations have the highest DO values (Fig 2). The highest value during this period was found in L6 (7.0 mg/L). Since the lagoon is extremely shallow, DO levels may have been high due to wind-assisted surface mixing and not necessarily the influx of fresh water during the wet season. It is also possible that high the readings may have been generated by photosynthesising algae. All the samples except L9 collected during the periods of investigation are within those found for tropical estuaries (Thangaraj *et al*., 1979; Sivasankar & Jayabalan, 1994; Chineah *et al*., 2001). In L9 very low DO values were obtained 0.55 and 0.80 mg/L for J07 and F08 sampling periods respectively. Low dissolved oxygen concentrations that were below standards commonly in marine water could be indicative of shallow water and/or higher water temperatures typical to the area and, therefore, may not be indicative of impaired water quality (EPA, 2000). Alternatively, instances of low dissolved oxygen readings during the wet season could be indicative of heavy algal concentrations or vegetative decomposition of plants that has been exacerbated by heavy point source freshwater inflows carrying excess nutrients into this system (EPA, 2000). However, dissolved oxygen value which varied from 4.3 to 7.0 mg/L in many of the locations (L1 to L8) indicated a good aeration or quick re-aeration of water as a result of strong winds (Chagas & Suzuki, 2005).

COD and BOD values showed that organic matter contents in the lagoon were low in several locations of the lagoon (Fig 1). The BOD exhibited high degree of variation in all the locations and did not show any seasonal pattern. The values of BOD ranged from 0.75 mg/L in location L8 to 58 mg/L in location L6 suggesting high variation in dissolved organic matter concentration from one location to another. This further suggests periodic discharge of sewage containing varying amounts of substances with high BOD in the different locations. The values obtained in this study were in many cases lower than the average values reported by Bawa *et al.,* (2007) for Lomé's Lagoon (BOD 40 mg/L).COD also did not vary significantly in all the locations and did not show any seasonal pattern. The values obtained in this study were in many cases slightly lower than the average values reported by Bawa *et al.,* (2007) for Lomé's Lagoon (110 mg/L).

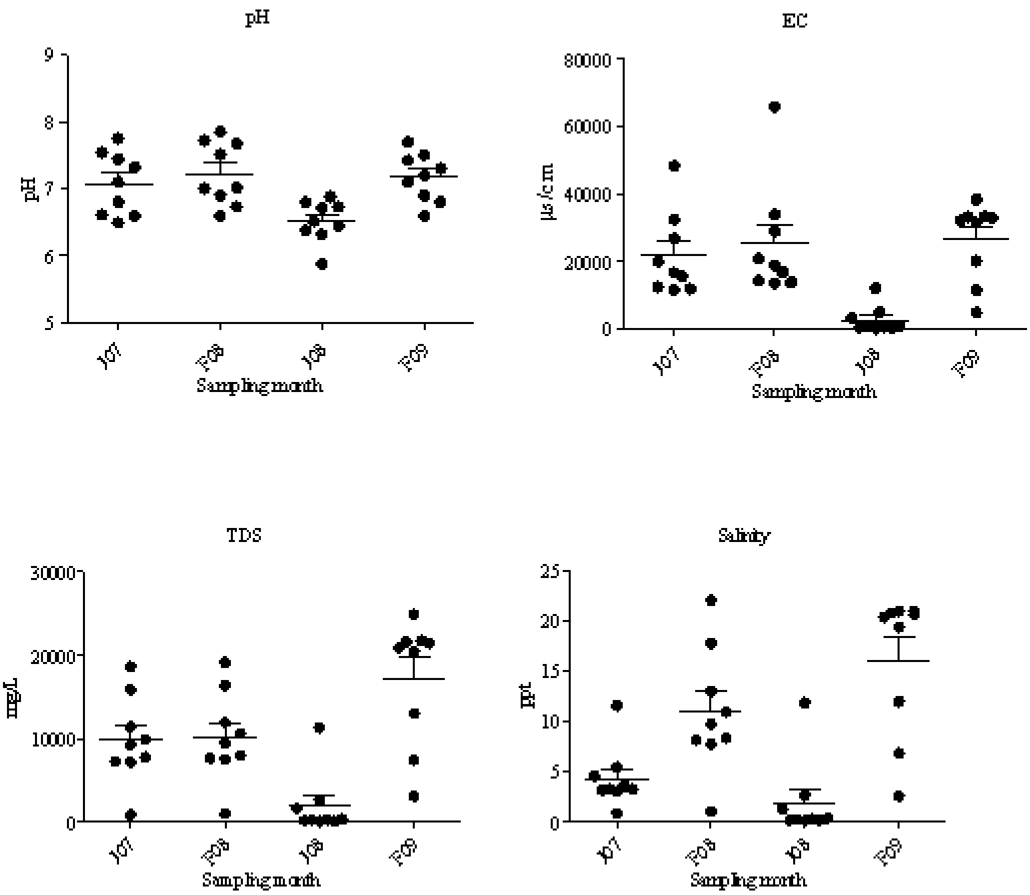

FIG. 2. SEASONAL VARIATION OF WATER QUALITY PARAMETERS IN THE SELECTED LOCATIONS OF THE LAGOON DURING EACH SAMPLING PERIOD.

Fig. 2 cont…

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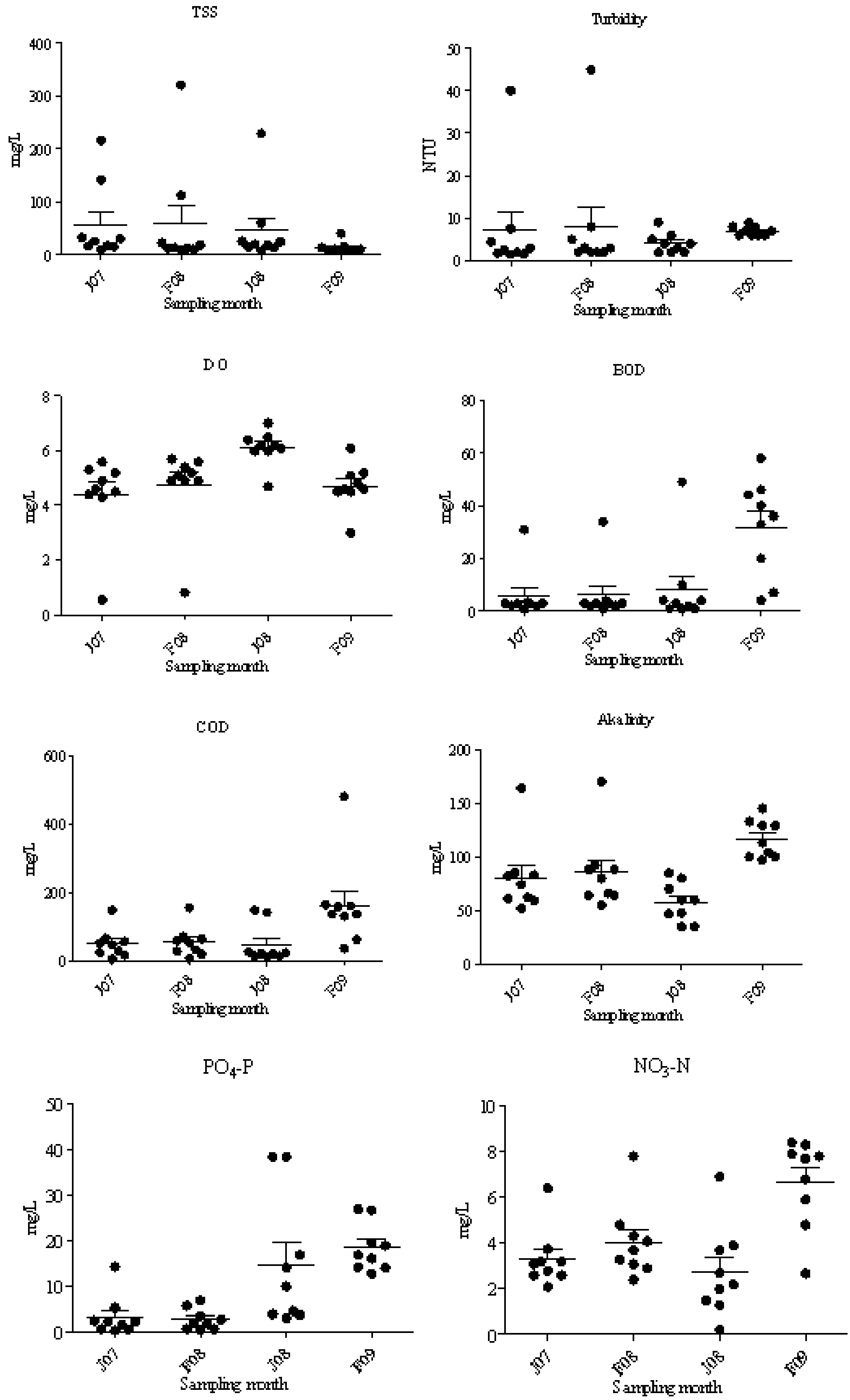

FIG. 2 (cont). SEASONAL VARIATION OF WATER QUALITY PARAMETERS IN THE SELECTED LOCATIONS OF THE LAGOON DURING EACH SAMPLING PERIOD.

Turbidity and suspended solids are important variables relative to transport and bioavailability of contaminants (Castane *et al.*, 2006). Turbidity results from the scattering and absorption of incident light by particulate matter in the water and can often be related to solids (Chapman & Kimstach, 1992). In this study the turbidity values obtained did not show any seasonal pattern (Fig 2). The values ranging from 1.5 NTU at location L3 to 9.0 NTU at L8 were recorded throughout the sampling periods. The relatively high consistent values for turbidity were obtained at all the locations during the F09 sampling periods and this may be as a result of waste discharge or earth-disturbing activities are occurring near the lagoon. Generally, a high turbidity value indicates a high concentration of total suspended solids. The higher TSS concentrations may be attributed to accidental discharges entering the lagoon from local drainages. The level of suspended solids have been found to depend on a variety of factors including: substrate type, river flow, tidal height, water velocity, wind reach/speed and depth of water mixing (Parr *et al*.,1998). The level of suspended solids can also be enhanced by anthropogenic activities in the river catchment as well as within the river and the estuary. Changes in river flow as a result of abstraction can influence suspended solids concentrations reaching estuaries. The values obtained in this work were relatively low and did not vary significantly in locations L1, L2, L3, L5 and L6 ($p < 0.05$, 95%). Locations L4, L7, L8 and L9 varied significantly during the periods of sampling. High values ranging from 112 to 228 mg/L were recorded in locations L7 during the J07, F08 and J08 sampling periods and in L9 during J07 and F08 sampling periods (Fig. 2). Higher solids observed in locations L9 during these periods might have decreased the passage of light through water, thereby slowing photosynthesis by aquatic plants and in turn reducing the dissolved oxygen content of the water. it has also been reported that high amount of TSS will cause water to heat up more rapidly and hold more heat; this, in turn, might adversely affect aquatic life that has adapted to a lower temperature regime (Chagas & Suzuki, 2005). Total suspended solids values obtained during this period did not have direct bearing on the turbidity of the water samples taken during the periods of investigation. Turbidity levels may have been low in most locations during the survey suggesting that the lagoon sediments were able to flocculate and settle out. The salinity levels in the lagoon may have promoted the aggregation of sediments and therefore hastened deposition (Merz, 2006). This may also be explained in terms of the materials that constitute the suspended solids. If they are colloidal in nature then they are small enough to pass through a filter paper. Turbidity like TSS did not show any seasonal variation and locations L4, L5, L7 and L8 is variation turbidity not significantly different during the sampling periods. However, significant variations in turbidity were observed in locations L1, L2, L6 and L9. Sources of total solids include industrial discharges, sewage, fertilizers, road runoff, and soil erosion.

The micronutrient content did not show distinct seasonal variation but did show spatial variation. Higher phosphate value than nitrate is a noteworthy feature during this study which could be due to addition of phosphate along with the land drainage and detergent rich sewage effluents or may be attributed to the input of freshwater as evidenced by the salinity and pH at some stations (Chineah *et al*., 2001). The concentration of phosphate found at L6 during J07 was the lowest (0.25 mg/L) and the concentration found at L5 and L8 during the J08 sampling period was the highest (38.4 mg/L).The concentration of nitrates in all the locations did not show significant variation but showed no relationship with season (Fig 2). The nitrate levels in location L9 was consistently higher than other locations investigated ranging from 6.4 mg/L during F07 sampling period to 7.9 mg/L during the F09 period. The highest values for each location were obtained during the F09 sampling season with 4.8 mg/L at L3 and 8.4 mg/L L5. This means that in these locations incidences of pollution by NO_3 containing substances were mainly from non-point sources. Much of the nitrogen was likely coming from agricultural fields or deposition of raw sewage into the lagoon and because nitrate is very soluble, it flows and disperses easily into the water body. The relationship between PO_4 and NO_3 was almost always positive except in location L1 where it was negative and L5 where there seem to be no relationship at all. In locations L2, L6, L7 and L8 the relationship was significant.

For the purpose of further discussion, correlation analyses (Spearman Rank Correlation) were performed on some of the water physicochemical parameters to see how they all relate with each other during the period of this study. Statistically, for samples where $n = 4$, $p < 0.05$, the critical correlation coefficient, r was found to be 0.81.The values found to be significant are in bold and presented in Table1. Correlation between two parameters provides a strong indication for a single reason for their variation. The pH of marine and brackish water system is always taken as the function of salinity. The result of the present study showed that the increase and decrease in pH followed the same trend as that of salinity as reported elsewhere (Lakshman & Durga, 2005). Salinity and pH have positive relationship in all the locations but only in locations L1 and L7 is this relationship significant. pH and dissolved oxygen showed significant negative relationship in all the locations except at L1, L4 and L5. pH and alkalinity showed positive correlation only at locations L1, L7 and L9.

Dissolved oxygen values also had negative relationship with and salinity, however none of the relationship is significant. The result established is similar to those obtained in tropical estuaries (Thangaraj *et al*., 1979; Sivasankar & Jayabalan, 1994). BOD and DO as would be expected showed negative correlations and this relationship was only significant in location L9. Electrical conductivity was positively correlated with salinity and total dissolved solids in all the locations. The relationship between EC and salinity was only significant at locations L1, L2, L3, L4 and L5 while EC and TDS gave very high correlation values except at location L6 and L9.

In conclusion, the results from this study showed that physical water quality parameters such as salinity, EC and TDS showed strong seasonal variation amongst stations. The only identifiable source of water loss from the lagoon is by evaporation and freshwater inflow and evaporation seem to be a major controlling force for these parameters in the lagoon. The effects of season and runoff are the two major causes of variation in water quality but human activities have interfered with this cycle and have exacerbated both wet and dry period extremes. The data obtained suggests that anthropogenic disturbances have affected the water quality of the Lagos Lagoon. The establishment of several types of activities with increased point and non-point storm water runoff shunted directly into Lagos Lagoon has negatively affected the water quality and made relationships between most of the parameters complex. For example, total suspended solids did not show a similar pattern in all locations, but turbidity which in many cases is a function of TSS showed some similarity in how this parameter varied most locations; Biological oxygen demand (BOD) and chemical oxygen demand (COD) did not show a similar pattern in the way they both varied in all the locations. This means that the organic load carried in the different locations studied were not the same and the mixing force of the lagoon water is not strong enough to disperse the organic matter. In effect, three main parameters were identified as being principal in influencing the observed water physicochemical parameter distribution in the study area. These are salinity, pH and alkalinity.

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