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Physico-Chemical Parameters and Heavy Metal Contents of Water from the Mangrove Swamps of Lagos Lagoon, Lagos, Nigeria

E.O. Lawson

Department of Fisheries, Faculty of Science, Lagos State University, Ojo, Lagos, Nigeria

Abstract: A study was conducted on physico-chemical parameters and heavy metal contents of water from the mangrove swamps of Lagos lagoon, Nigeria. The study was aimed at assessing its suitability for fish production and as well as its safety for drinking purpose in man. In all eleven (11) physical and chemical parameters and six (6) heavy metals were investigated for water quality assessment of the lagoon between January and December 2001. Data on temperature and pH were obtained from the field using mercury-in-glass thermometer and pH metre. Salinity, dissolved oxygen and carbon dioxide, total alkalinity and acidity, total suspended and dissolved solids were determined in the laboratory by titrimetric method. The concentrations of Fe, Zn, Mn, Cd, Cr and Pb in water were determined by Atomic Absorption Spectrophotometer (AAS). Air temperature varied between 26-31.75 (28.34±0.17°C); water temperature, 20.0-30.50 (28.07±0.18°C); pH, 1.89-8.50 (6.97±0.06); salinity, 0.2-16.75 (8.995±0.01%o); dissolved oxygen, 0.58-10 (9.97±0.03 mg L^{-1}); dissolved carbon dioxide, 9-29-25.97 (17.40±0.04 mg L^{-1}); total alkalinity, 20.5-90.0 (43.33±18.67 mg L^{-1}); total acidity, 11.0-22.5 (16.26±0.27 mg L^{-1}) and rainfall, 2.4-460.9 (149.53±37.39 mm). The concentrations of heavy metals were above the maximum contaminant level (MCL) recommendations of USEPA. The water parameters favoured the production of brackish water fish. However, it is highly contaminated and therefore not suitable for drinking purpose in man. In conclusion, this study is baseline data toward future ecological study, conservation and management of the resources of this economically important wetland in Nigeria.

Key words: Allochthonous materials · Atomic absorption spectrophotometer · Anion · Cation · Winkler solution

INTRODUCTION

Based on the discoveries of our satellites, it appears that water is a unique substance in our discovered universe. The presence of water on earth is in itself unique, for the planet earth has few natural liquids. Water is the prime resource of man's food supply and his most important household and industrial tool. But most important is the fact that water is a major constituent of all living matter, comprising up to two-thirds of the human body. Next to the air we breathe, water is mankind's most important substance. Water freezes at 32°F and boils at 212°F. This indicates another characteristic of the compound: a pure compound has a definite freezing and a definite boiling point.

Water quality is defined in terms of the chemical, physical and biological contents of water. The water quality of rivers and lakes changes with the seasons and geographic areas, even when there is no pollution present. Water quality guidelines provide basic scientific information about water quality parameters and ecologically relevant toxicological threshold values to protect specific water uses. Important physical and chemical parameters influencing the aquatic environment are temperature, rainfall, pH, salinity, dissolved oxygen and carbon dioxide. Others are total suspended and dissolved solids, total alkalinity and acidity and heavy metal contaminants. These parameters are the limiting factors for the survival of aquatic organisms (flora and fauna). Poor water qualities may be caused by low water flow, municipal effluents and industrial discharges [1].

Temperature is a limiting factor in the aquatic environment [2, 3]. Water temperature is probably the most important environmental variable. It affects metabolic activities, growth, feeding, reproduction, distribution and migratory behaviours of aquatic organisms [4-6]. It affects solubility of gasses in water, gas solubility decreases with increased temperature.

Corresponding Author: O.E. Lawson, Department of Fisheries, Faculty of Science, Lagos State University, Ojo, P.O. Box: 001, LASU Post Office Box, Lagos, Nigeria. E-mail:ollulawson@yahoo.com.

Temperature is affected by time of the day, high temperatures may be recorded in daytime and become low at night. Temperature may cause thermal stratification occurs in the oceans.

Hydrogen ion concentration or pH as one of the vital environmental characteristics decides the survival, metabolism, physiology and growth of aquatic organisms. Ramanathan *et al*. [7] recommended optimum range of pH 6.8-8.7 for maximum growth and production of shrimp and carp. pH is influenced by acidity of the bottom sediment and biological activities. High pH may result from high rate of photosynthesis by dense phytoplankton blooms. pH higher than 7 but lower than 8.5 according to Abowei [8] is ideal for biological productivity, but pH at <4 is detrimental to aquatic life. pH may be affected by total alkalinity and acidity, run off from surrounding rocks and water discharges.

Salinity is a dynamic indicator of the nature of the exchange system. It is expressed as the total concentration of electrically charged ions (cations) in water in part per thousand (%o). The cations include CO_3-, SO_4^{2-}, Cl^-, HCO_3^-, NO_3^-, NH_4^{2-}, PO_4^{2-}. It is expressed either as a mass of these ions per unit volume or as milli-equivalent of the ions per volume of water. It determines distribution of organisms in aquatic environments. The salinity of the water within the estuary tells us how much fresh water has mixed with sea water. Oxygen solubility decreases slightly as salinity increases, but oxygen solubility decreases more as temperature goes up regardless of salinity. The solubility of oxygen in seawater is 21% less than that of freshwater at 32 degrees Fahrenheit and 17 % less than that of freshwater at 100 degrees Fahrenheit. Oxygen solubility in freshwater decreases from 14.6 to 8.24 mg/L as temperature rises from 32 to 100 degrees. This is a 46.3% decrease. On the other hand, oxygen solubility in seawater decreases from 11.5 to 6.75 mg/L for this same temperature increase, a decreased oxygen solubility of 41.3%.

The salt concentration directly affects the salinity which impacts circulation with estuaries and coastal regions can derive from or be strongly influenced by the density variation associated with salinity. In effect, dense saline water tends to flow under fresh water. Salinity is an important ecological parameter in its own right; and it is important in some chemical processes.

Dissolved oxygen (DO) affects the solubility of and availability of nutrients. Its low levels can result in damages to oxidation state of substances from the oxidized to the reduced form thereby increasing the levels of toxic metabolites. Dissolved carbon dioxide in aquatic environment increases with decreased dissolved oxygen. It is important parameter in primary production and phytoplankton biomass. Water Acidity increases with increased dissolved carbon dioxide. High rate of dissolved carbon dioxide is detrimental to survival, physiology and metabolic activities of aquatic animals including fish.

Alkalinity of a water body is a measure of its capacity to neutralize acids to a designated pH [9, 10]. Alkalinity is an indirect measure of the concentration of anions in water. The dissolved anions according to McNeely *et al*. [11] may be sourced from bicarbonates, carbonates, hydroxides, phosphates borates or silicates which may be derived from industrial wastes, dissolved rocks, salts, soils or bottom sediments. Alkalinity between 30 and 500 mg L^{-1} is generally acceptable to fish and shrimp production [11, 12], between 20 and 50 mg L^{-1} according to Boyd [13] will permit plankton production for fish culture. High alkalinity results in physiological stress on aquatic organisms and may lead to loss of biodiversity.

Total suspended and dissolved solids affect metabolism and physiology of fish and other aquatic organisms. They are products of run offs. They increase with increased rainfall and have adverse effects on dissolved oxygen and carbon dioxide. Suspended solids in water are directly proportional to dissolved solids. Dissolved solids could directly influence water conductivity, the higher the dissolved solids the higher the conductivity.

Rainfall is an important factor in aquatic environment. Substances present in the air affect rainfall. Dust, volcanic gases and natural gases (such as carbon dioxide, oxygen, sulphur dioxide and nitrogen) are all dissolved or entrapped in rain. Toxic chemicals or lead when in the air are also collected in the rain as it falls to the ground. Rain reaches the earth's surface and, as runoff, flows over and through the soil and rocks, dissolving and picking up other substances. For instance, if the soils contain high amounts of soluble substances, such as limestone, the runoff will have high concentrations of calcium carbonate. Urban runoff worsens the water quality in rivers and lakes by increasing the concentrations of such substances as nutrients (phosphorus and nitrogen), sediments, animal wastes (feacal coliform and pathogens), petroleum products and road salts.

Industrial, farming, mining and forestry activities also significantly affect the quality of water. Farming increases concentration of nutrients, pesticides and suspended sediments. Industrial activities also increase concentrations of metals and toxic chemicals, add suspended sediment, increase temperature and lower dissolved oxygen in the water. Each of these effects can have a negative impact on the aquatic ecosystem and/or make water unsuitable for established or potential uses. Metals and in distinction heavy metals have one special importance in pollution of surface waters and concentrations of some of them are beneficial, where as some of them are harmful and toxic. Toxicity of heavy metals depends of kind of metal, compound, from the amount which are deposited in organism and from time extension action of metal.

The presence of toxic metals in environmental matrices is one of the major concerns of pollution control and environmental agencies in most parts of the world [14]. This is mainly due to the health implications of these toxic metals since they are non-essential metals of no benefit to humans [15]. Their presence in aquatic ecosystems, mainly due to anthropogenic influences has far-reaching implications directly to the biota and indirectly to man. Trace metals have been referred to as common pollutants, which are widely distributed in the environment with sources mainly from the weathering of minerals and soils [16]. However, the level of these metals in the environment has increased tremendously during the past decades as a result of human inputs and activities [17, 16].

The pH of a water body influences the concentration of many metals by altering their availability and toxicity. Metals such as zinc (Zn) and cadmium (Cd) are most likely to have increased detrimental environmental effects as a result of lowered pH [18]. Temperatures at which environmental samples are collected and at which physico-chemical measurements are made are important for data correlation and interpretation. For instance, for domestic use, high temperatures may increase the toxicity of many substances such as trace metals in water. In addition to microbial activities within an aquatic medium, temperature and pH are two important factors that govern the methylation of elements such as lead (Pb) and mercury (Hg) [19].

Trace metals have been determined in potable water [20] and fresh and marine waters [21].

The wetlands including the mangrove swamps of Lagos lagoon are one of the most productive ecosystems in the world. They are very important economically in fishing, agriculture, husbandry, reed production, ecological tourism and educational and scientific researches. Therefore, the accurate determinations of heavy metals and other physical and chemical parameters in aquatic environment are of ultimate important for controlling their pollution, this study aims at providing additional information to existing data on water quality assessments of this important water body.

MATERIALS AND METHODS

Study Area: Lagos lagoon in Nigeria (Figure 1) is located between longitudes 3°20' and 3°50'W and latitudes 6°24' and 6°36'N. It is the largest lagoon system in the West African coast, covering 208 km^2. The lagoon is an open tidal estuary; it is fed in the north by Ogun River, Majidun, Agoyi and Ogudu creeks. The southern margin is bounded by Five Cowries and Badagry creek and in the east by Lekki and Epe lagoons. Ogun River remains the major source of water to the lagoon, discharging a large volume of water into the lagoon. The lagoon opens into the Atlantic ocean via Lagos habour. It is shallow in depth and in most places; it is little more than 1.5 metres deep. The lagoon is surrounded by marshy ground which is permanently white mangrove forest. The dominant plants are *Rhizophora racemosa, Drepanocarpus lunatus, Avecennia nitida, Dalbergia ecastaphyllum, Typha australis* and *Phoneix reclinata.* The sedges include: *Cyperus articulatus, Paspalum vaginatum* and *Cyperus papyrus.* The prominent ferns are *Achrosticum sp., Marsilead sp., Cylosorus sp.* and *Ceratopleris sp.* Palms are mainly *Pandanus candelabrum* and *Raphia hookeri*. Lagos lagoon has several species of fishes, some abound in large numbers and serves as breeding and feeding grounds for some of them. The fresh water fishes include Tilapias (*Oreochromis niloticus*, *Tilapia melanotheron* and *T. zillii*) and Catfishes (*Clarias* and *Chrysichthys* sp). Marine fish species are Mullets (*Mugil* and *Liza* sp), Ten pounder (*Elops lacerta*), Clupeids (*Ilisha africana*, *Ethmalosa fimbriata*) and Sciaenids (*Pseudotolithus typus* and *P. senegalensis*). The indigenous species are mudskipper (*Periophthalmus papilio*) and gobiid (*Bathygobius soporator*). Common shellfishes include *Cardisoma armatum*, *Callinectes amnicola*, *Goniopsis pelli* and *Macrobranchium vollenhoveni*.

Due to seasonal distribution of rainfall, Lagos lagoon experiences seasonal flooding which introduces a lot of detritus and pollutants from the land. The lagoon presently serves as a major drainage channel receiving domestic wastes as well as industrial effluents from industries in the area.

The experimental stations (Figure 1) used for this study are located in University of Lagos (UNILAG), marked (Xa) situated in the west; Offin station (Xb) in the north and Ikoyi station (Xc) in the south of lagoon.

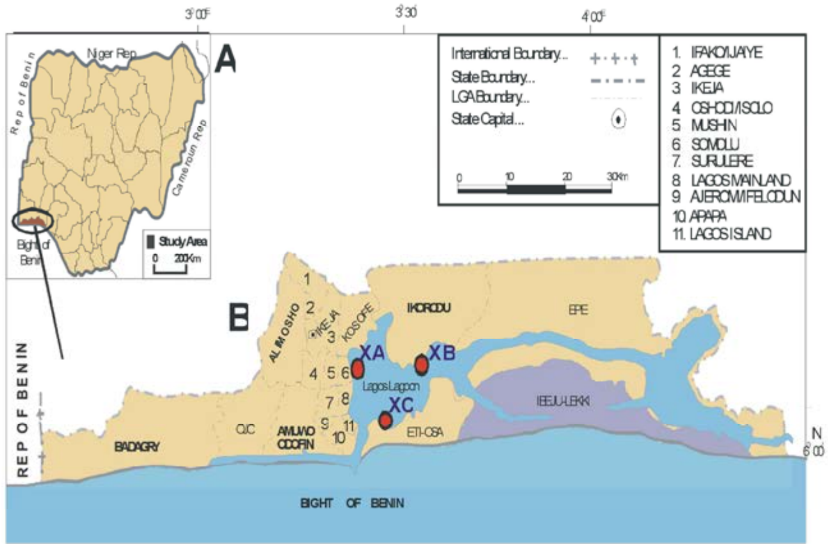

Fig. 1: (A) Administrative Map of Nigeria (B) Insert Lagos Map showing Lagos lagoon

Field Activities: The study was carried out between January and December 2001. The period corresponds to low water levels and peak flooding in the lagoon. Samples of water were collected from the experimental stations of the mangroves swamps. Collections were carried out fortnightly using 4 litre plastic kegs and 250 ml reagent bottles. The kegs and bottles were immersed below the water surface and filled to capacity, brought out of the water and properly closed. All the analyses were based on standard methods as appropriate to each water quality parameter, as prescribed in the APHA *et al*. [22].

The air and water temperatures were measured at the sampling sites with mercury-in-glass thermometer. For air temperature, the thermometer was held up right in the air with the fingers and with the lower part exposed to the air for about four to five minutes. For water temperature, the thermometer was immersed in water 6 cm below the water surface and left to stabilize for about five minutes. The average values for air and water temperatures were recorded in degrees centigrade (°C).

The pH was determined with Griffin pH meter (model 400). The electrodes were immersed in water samples and the potential difference between them was measured. Standardization was done using buffer solutions of pH values of 4 and 9.

Fixing of dissolved oxygen was carried out in the field. 100 ml. of water was measured into a clean oxygen bottle and flushed several times until all air bubbles escaped. Two (2) millimetres of Winkler's solution I ($MnSO_4$ solution) and another 2 ml of Winkler's solution II (KI + NaOH solution) were added to the bottle using a pipette. The bottle was closed and thoroughly shaken to ensure proper mixing. A brown precipitate forms at the bottom of the bottle after this process. The bottle was then, transported to the laboratory for further analysis.

Data on rainfall for Lagos area was obtained from Department of Meteorology, Federal Ministry of Aviation, Oshodi, Lagos, Nigeria.

Laboratory Procedures: Each sample was analyzed for the hydrochemistry parameters such as total alkalinity and acidity; salinity; dissolved oxygen and carbondioxide; total suspended and dissolved solids were determined in the laboratory following APHA *et al*. [22] and APHA [23]. The concentrations of iron (Fe), zinc (Zn), manganese (Mn), cadmium (Cd), chromium (Cr) and lead (Pb) in the samples of water were determined with Atomic Absorption Spectrophotometer (AAS). The wave lengths used for measurements were 213.9 nm for Zn, 220 nm for Mn, 228. 8 nm for Cd, 214.5 nm for Cr and 217.0 nm for Pb with detection limits of 48, 35, 32, 15, 24 and 41 µg/L, respectively. Data provided were the average of three replicates. The analyses were executed by SPSS (version 9) package. The values of these parameters were compared to the WHO standard for unpolluted or clean water.

RESULTS

Physical and Chemical Parameters: The results of physical and chemical parameters of water samples from the three stations in mangrove swamps of Lagos lagoon are presented in Table 1.

Table 1: Physical and chemical parameters of water from the mangrove swamps of Lagos lagoon

	Station A (UNILAG)			Station B(Offin)			Station B(Ikoyi)		
Parameters	Min	Max	Mean±SE	Min	Max	Mean±SE	Min	Max	Mean±SE
Air temperature (°C)	28.44	31.75	28.44±1.94	26.00	31.25	28.22±1.73	26.00	31.20	28.37±1.60
Water temperature (°C)	25.25	30.50	28.35±1.74	25.50	30.00	28.05±1.66	25.00	29.60	27.80±1.40
pH	1.97	8.36	7.03±1.83	1.89	8.35	6.92±1.93	1.90	8.50	6.97±1.94
Salinity in part–per-thousand (‰)	0.20	16.75	6.00±0.79	0.30	16.56	6.01±0.77	0.25	16.65	5.98±0.77
Dissolved oxygen (mg L^{-1})	0.58	10.00	4.95±3.15	1.00	10.00	4.97±3.09	0.78	9.90	4.91±3.11
Dissolved carbon dioxide (mg L^{-1})	9.29	25.97	17.58±5.13	9.30	25.78	17.34±5.16	9.50	25.56	17.29±5.20
Total alkalinity (mg L^{-1})	21.50	90.00	43.33±18.67	21.50	90.00	43.32±18.71	20.50	89.50	43.13±18.61
Total acidity (mg L^{-1})	11.00	22.40	16.36±4.28	11.00	22.00	16.10±3.93	11.40	22.50	16.33±3.74
Total suspended solids (mg L^{-1})	221.00	22094.00	4783.83±672.02	220.00	22003.00	4761.58±692.26	221.00	21899.00	4713.25±688.71
Total dissolved solids (mg L^{-1})	91.00	2560.00	841±753.63	90.00	2456.00	838.25±770.27	88.00	2459.00	831.08±773.30

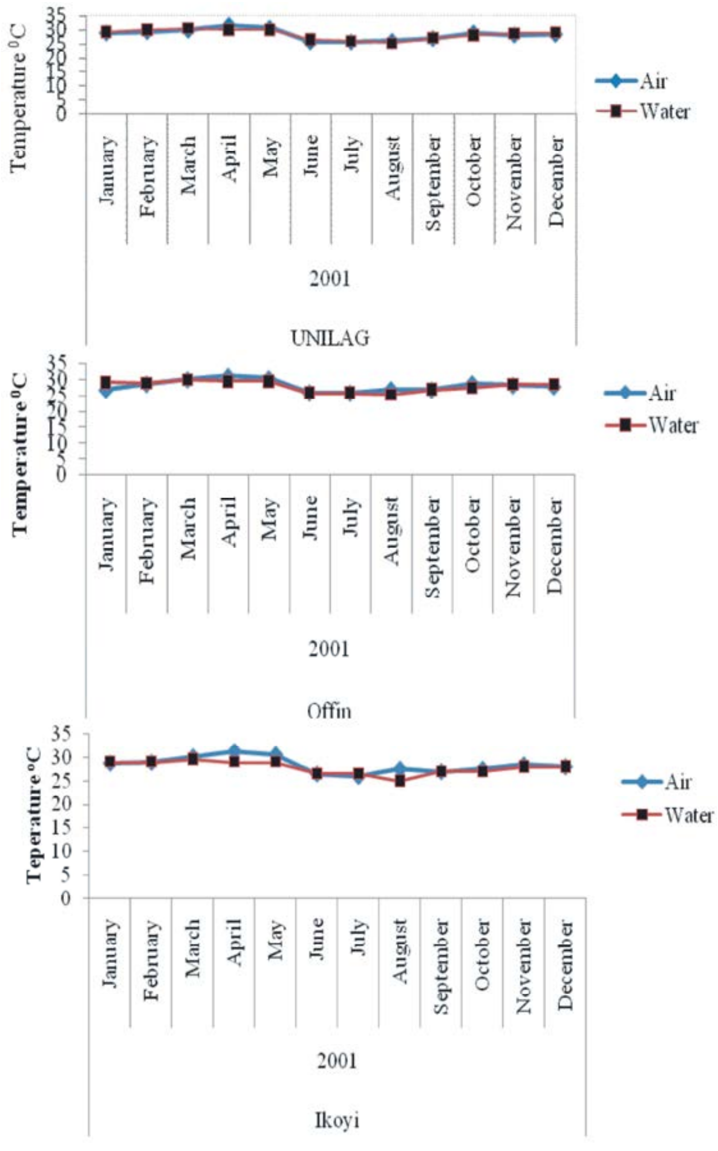

Fig. 2: Monthly air and water temperature variations in mangrove swamps of Lagos Lagoon

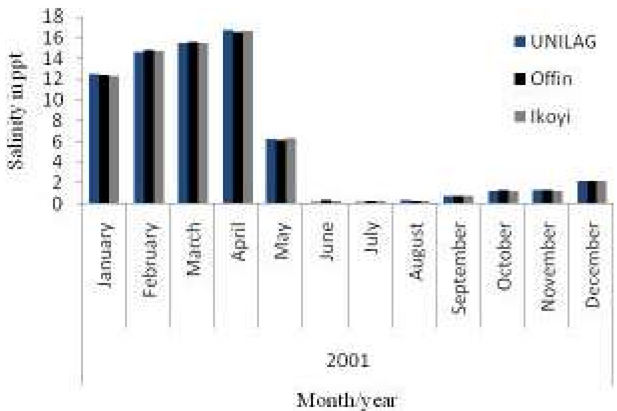

Fig. 3: Histograms of the monthaly mean water salinity in the mangrove swamps of Lagos lagoon

Temperature: Air temperature varied from 26.0 to 31.75 °C with overall mean value of 28.34±0.17 °C. The water temperature ranged between 20.0 and 30.50 (28.07±0.18°C). The air and water temperature polygons are given in Figure 2. There were variations in air and water temperatures across the three stations, however these variations were not significantly different (P>0.05) across the stations.

pH: The hydrogen ion concentration of pH was both acidic and slightly basic in Lagos lagoon. The pH ranged between 1.89 and 8.50, obtained from Offin and Ikoyi, respectively with overall mean value of 6.97±0.06. pH varied with seasons and variations were statistically different at 5% level (P<0.05) across the stations.

Salinity: Salinity of the mangrove swamps of Lagos lagoon showed it as a brackish water environment. It ranged from 0.20 to 16.75 (6.00±0.79%o) off UNILAG, 0.30 - 16.56 (6.01±0.07%o) in Offin and between 0.25 and 16.65 (6.97±1.94%o) in Ikoyi. The overall mean salinity for the study period was 8.995±0.01 %o. Histograms of monthly water salinity in the mangrove swamps of Lagos lagoon for the three stations are presented in Figure 3. The histograms showed variations in salinities, however they were not significantly different (P>0.05) across the three stations. Similar patterns of distribution in salinity were observed in all the stations. There was gradual increase between January and April and from June to December 2001 but a drastic drop in salinity was recorded in May. The least salinities of 0.2, 0.4 and 0.3 was recorded in June, the highest values were 16.75, 16.56 and 16.65 in April for UNILAG, Offin and Ikoyi, respectively.

Dissolved Oxygen: In this study, dissolved oxygen was as low as 0.58 and as high as 10.00 mg L^{-1}, the overall mean values was 9.97±0.03 mg L^{-1}. The mean values of 4.95±3.15, 4.97±3.09 and 4.91±3.11 mg L^{-1} were recorded for UNILAG, Offin and Ikoyi respectively. The variations did not differ significantly (P>0.05) across the stations.

Dissolved Carbon Dioxide: Dissolved carbon dioxide varied between 9.29 and 25.97, 9.30 and 25.78 and 9.50 and 25.56 mg L^{-1} in UNILAG, Offin and Ikoyi stations respectively, the overall mean dissolved carbon dioxide was 17.40±0.04 mg L^{-1}. The highest mean of 17.58±5.13 mg L^{-1} was recorded in UNILAG.

Total Alkalinity: Total alkalinity ranged from 20.50 to 90.00 mg L^{-1}. The mean values were 43.33±18.67, 43.32±18.71 and 43.13±18.61 mg L^{-1} for UNILAG, Offin and Ikoyi stations respectively. The overall mean was 43.26±0.05 mg L^{-1} for the lagoon. The values were significantly indifferent (P>0.05) across the stations.

Total Acidity: The total acidity values ranged between 11.00 and 22.50, the lowest and highest mean values of 16.10±3.93 and 16.36±4.28 mg L^{-1} were observed in Offin and UNILAG, respectively. However, the overall mean was 16.26±0.27 mg L^{-1}.

Total Suspended Solids: The total suspended solids were high varying from 220 to 22094 (4752.89±10.59 mg L^{-1}). Within the stations, the values of suspended solids were of significant difference. However, the variations across the three stations were not by different significant (P>0.05).

Total Dissolved Solids: The total dissolved solids ranged between 88 and 2560 mg L^{-1} The mean dissolved solids were 841±753.63 (UNILAG), 838.25±770.27 (Offin) and 831.08±773.30 mg L^{-1} (Ikoyi). The overall mean was 836.78±10.81 mg L^{-1}. The differences in means were not significant across the stations.

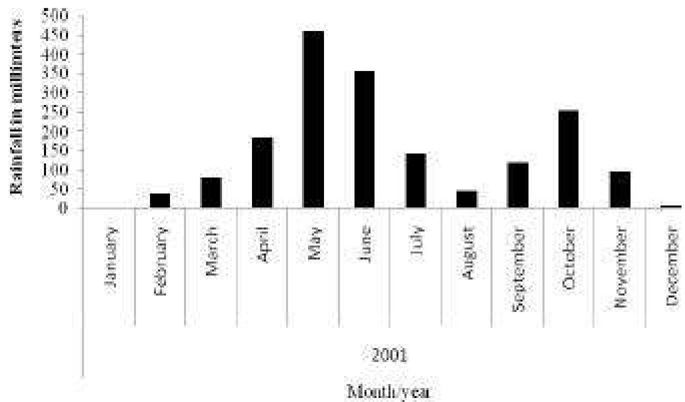

Fig. 4: Histogram showing rainfall in Lagos area (January-December 2001) Data obtained fron Department of Meteology, Ministry of Aviation, Oshodi, Lagos, Nigeria

Table 2: Mean values of some heavy metals in water from mangrove swamps of Lagos lagoon

	Heavy metal in $mg\ L^{-1}$					
Station	Fe	Zn	Mn	Cd	Cr	Pb
UNILAG	8.065±1.99	1.055±0.21	0.975±0.12	0.074±0.05	0.116±0.03	BDL
Offin	6.067±1.98	1.267±0.05	1.075±0.34	0.174±0.03	0.12±0.01	BDL
Ikoyi	7.67±1.34	1.167±0.78	0.678±0.21	0.142±0.02	0.115±0.05	BDL

BDL, below detectable level

Rainfall: Data on rainfall during the study period is presented in Figure 4. The patterns of rainfall in Lagos lagoon revealed eight (8) months of wet and four (4) months of dry seasons. The wet season sprang from April and November with light shower or less rain in August 2001, while dry season was in January to March and December 2001, with 2.40 mm of rain recorded in January. The highest rain (460.9 mm) was recorded in May. The mean rainfall for the period of study was 149.53±37.39.

Heavy Metal Contents: The mean values of some heavy metals in water from the mangrove swamps of Lagos lagoon are presented in Table 2. Overall results of water samples showed variations in the distributions of Fe, Zn, Mn, Cd and Cr. The variations were not significant across the experimental stations, however Pb was found below detectable level. The mean Fe ranged between 6.067±1.98 in Ikoyi and 8.065±1.99mg/l UNILAG stations. Zn between 1.055±0.21 and 1.267±0.05 and Mn from 0.678±0.21-1.075±0.34. Others included Cd (0.074±0.05-0.174±0.03) and Cr (0.115±0.05-0.12±0.01) mg/l.

In this study Fe and Pb were the most and least concentrated of the metals. They were concentrated in water from these stations in the following orders:

UNILAG : Fe>Zn>Mn>Cr>Cd>Pb
Offin : Fe>Zn>Mn>Cd>Cr>Pb and
Ikoyi : Fe>Zn>Mn>Cd>Cr>Pb.

DISCUSSION

In the present study, air temperature varied between 26-31.75 (28.34±0.17)°C and water temperature ranged from 20.0-30.50 (28.07±0.18)°C. These values were within the acceptable levels for survival, metabolism and physiology of aquatic organisms. Water temperature has some positive and negative effects on plant growth. The most suitable water temperature for plant growth is 20-35°C, Temperature over 30°C can cause regression in growth and decay in plants [24].

The pH values of between 1.89 and 8.50 (6.97±0.06) recorded in the study fell within ranges reported for rivers flowing through areas with thick vegetation [25,26]. pH has direct or indirect effects on photosynthesis and growth of water plants. In water with low pH, solution dissociation of iron phosphate decreases and vice versa. High pH causes more carbonate and bicarbonate in water [24]. Pidgeon and Cains [27] observed that organic acids resulting from decaying vegetation might be responsible for the low pH in most aquatic ecosystems.

Our drinking water pH level varies between 6.5 and 9.5. The safest pH level of drinking water would be 7 which is the pH level of Pure water. Based on this, water from the mangrove swamps of lagos lagoos is not suitable for drinking.

Salinities 0.2-16.75 (8.995±0.01) %o observed in this study was slightly brackish and fell within the range reported by Edokpayi *et al*. [28, 29]. Higher salinities were recorded across the stations during the dry months (December -April) than wet months (May-November) this may be due to dilution of the water by the increase freshwater input during these wet months. This was in agreement with reports of Edokpayi *et al*. [29] on the adjacent Ogbe creek that drains Lagos lagoon.

The dissolved oxygen values of 0.58 to 10.0 (9.97 ±0.03 mg L^{-1}) in this study was similar to those reported for many other polluted Nigerian waters including 6.9 - 8.8 mg/l for Lagos lagoon [30], 4.00-7.50 mg/l for Luubara creek in Niger Delta [31,32] and 1.20 - 9.40 mg/l documented in Victor and Onmivbori [33] and Edokpayi and Osimen [34] for some polluted water bodies in Nigeria. All the values recorded fell outside the "no effect" range of 0–0.3 mg/l for drinking water use [35]. The values, however, fell within the 0.1–10 mg/l range for which slight adverse health effects can be expected in children and sensitive individuals [36, 37]. High organic content from human faeces, decayed plant materials and domestic and sawmill wastes that found their ways into the lagoon may responsible for low dissolved oxygen. According to USDA [38], the level of oxygen depletion depends primarily on the amount of waste added, the size, velocity, turbulence of the stream and the temperature of the water. Frequent deaths of fish in water in fact don't come from toxicity of matters, but from deficit of consumed oxygen from biological decomposition of pollutants. Various studies suggested that maintaining minimum daily dissolved-oxygen concentrations above 3 mg/L in channel catfish and penaeid shrimp ponds assures better feed consumption and growth than possible in ponds with lower concentrations. Tilapia can tolerate lower dissolved- oxygen levels than catfish and shrimp, but concentrations should not fall below 1 mg/L in tilapia ponds [39]. Dissolved oxygen in waters depend water temperature, partial pressure of oxygen in atmosphere and salt contents in waters.

Dissolved carbon dioxide values varied between 9-29 and 25.97 (17.40±0.04) mg L^{-1}. These values were within acceptable levels for survival, metabolism and physiology of aquatic organisms. Carbon dioxide is a poisonous gas to most animals, levels of 30 ppm (parts per million) are harmful to most organisms. Levels greater then 35 ppm are considered limiting to all aquatic organisms. During respiration oxygen is used up as carbon dioxide is produced, the quantities of these gases are usually opposite in quantities. This means if there is a high carbon dioxide amount there is going to be a low oxygen amount. High levels of carbon dioxide will make the pH more acidic. In aquatic ecosystem, a high level of carbon dioxide usually indicates that there is a lot of dead material undergoing decomposition. This may occur naturally, but could be the result of different types of water pollution or water treatment.

Alkalinity values ranged from a minimum of 20.50 to a maximum of 90.0 mg/L (mean value of 43.26±0.05 mg/L). Concentrations less than 100 ppm are desirable for domestic water supplies. The recommended range for drinking water is 30 to 400 ppm. A minimum level of alkalinity is desirable because it is considered a "buffer" that prevents large variations in pH. Alkalinity is not detrimental to humans. Moderately alkaline water (less than 350 mg/L), in combination with hardness, forms a layer of calcium or magnesium carbonate that tends to inhibit corrosion of metal piping. High alkalinity (above 500 mg/l) is usually associated with high pH values, hardness and high dissolved solids Water with low alkalinity (less than 75 mg/l), especially some surface waters and rainfall, is subject to changes in pH due to dissolved gasses that may be corrosive to metallic fittings. Boyd [13] recommended suitability of alkalinities between 20 and 50 mg/l for plankton production for fish culture. It is used in the classification of waters especially lakes according to nourishments [24]. In the absence of sufficient carbonic acid, the bicarbonate ion in the water dissociates to form additional carbon dioxide [40]. Algae readily exploit this carbon dioxide for their photosynthetic needs, at the cost of allowing a build-up of hydroxide ions to such an extent that the water becomes quite alkaline. Lagos lagoon in this study is classified as rich in terms of nourishments. The nourishments are necessary for photosynthetic activity and plant growth.

Total acidity values of 11.0-22.5 (16.26±0.27) mg L^{-1} were within the acceptable levels. Total acidity was lower in dry period. Increase in acidity during the rainy months may be attributed to the allochthonous and anthropogenic inputs from the catchments of the lagoon.

Acidity and alkalinity are related to pH, they should not be confused with pH, nor should the terms be used interchangeably. Acidity is a measure of a solution's capacity to react with a strong base (usually sodium hydroxide, NaOH) to a predetermined pH value. Alkalinity is the measure of a solution's capacity to react with a strong acid (usually sulphuric acid H_2SO_4) to a predetermined pH.

In this study the total suspended solids (TSS) ranged from 220 to 22094, the overall mean was (4752.89±10.59 mg L^{-1}). TSS are solid materials, including organic and inorganic, that are suspended in the water. These would include silt, plankton and industrial wastes. Source of total suspended solids include erosion from urban runoff and agricultural land, industrial wastes, bank erosion, bottom feeders, algae growth or wastewater discharges. High concentrations of suspended solids can lower water quality by absorbing light. Waters then become warmer and lessen the ability of the water to hold oxygen necessary for aquatic life. Because aquatic plants also receive less light, photosynthesis decreases and less oxygen is produced. The combination of warmer water, less light and less oxygen makes it impossible for some forms of life to exist. Suspended solids clog fish gills, reduce growth rates, decrease resistance to disease and prevent egg and larval development. Particles that settle out can smother fish eggs and those of aquatic insects, as well as suffocate newly-hatched larvae. The material that settles also fills the spaces between rocks and makes these microhabitats unsuitable for various aquatic insects, such as mayfly nymphs, stonefly nymphs and caddis fly larva.

Total dissolved solids (TDS) varied between 88 and 2560 mg L^{-1} (mean=836.78±10.81 mg L^{-1}). The EPA Secondary Regulations advise a maximum contamination level (MCL) of 500mg/liter for TDS. When TDS levels exceed 1000mg/L it is generally considered unfit for human consumption. A high level of TDS is an indicator of potential concerns and warrants further investigation. Most often, high levels of TDS are caused by the presence of potassium, chlorides and sodium. These ions have little or no short-term effects, but toxic ions (lead arsenic, cadmium, nitrate and others) may also be dissolved in the water. High TDS indicates hard water. High TDS results in undesirable taste which could be salty, bitter, or metallic. It could also indicate the presence of toxic minerals. Some dissolved solids come from organic sources such as leaves, silt, plankton and industrial waste and sewage. Others include runoff from urban areas, road salts used on street and fertilizers and pesticides used in farms; inorganic materials such as rocks and air that may contain calcium bicarbonate, nitrogen, iron phosphorous, sulfur and other minerals. Many of these materials form salts, which are compounds that contain both a metal and a nonmetal. Salts usually dissolve in water forming ions. Ions are particles that have a positive or negative charge.

The higher the suspended solids in water, the higher the total dissolved solids. There is correlation between TSS and TDS. The more salts are dissolved in the water; the higher is the value of the electric conductivity. High purity water that contains no salts or minerals has a very low electrical conductivity.

The water temperature affects the electric conductivity, its value increases from 2 up to 3 % per 1 degree Celsius.

Water can be classified according to Ela [41] by the amount of TDS per litre: fresh water < 1500 mg/L TDS, brackish water 1500 to 5000 mg/L TDS and saline water > 5000 mg/L TDS. This is an indication that water in the mangrove swamps can switch between fresh and brackish waters. Spawning fishes and juveniles appear to be more sensitive to high TDS levels. For example, it was found that concentration of 350 mg/l TDS reduced spawning of Striped bass (*Morone saxatilis*) in the San Francisco Bay-Delta region and that concentrations below 200 mg/l promoted even healthier spawning conditions [42]. According to Boyd [43] most aquatic ecosystems involving mixed fish fauna can tolerate TDS levels of 1000 mg/l.

The rainfall recorded in this study was 2.4-460.9 (149.53±37.39) mm. Rainfall greatly affects the dynamics of the environments, transports nutrients and allochthonous materials and alters the water's visual, physical and chemical characteristics. Rainfall regimen according to Landa [44] in shallow systems is a major activity which affects the concentration and distribution of inorganic and dissolved nutrients, heat throughout the water column and suspended materials and consequently, transparency and depth.

Ingestion of lead can post a series health risk to humans. For Adults, lead exposure is usually limited to certain occupational and recreational sources. The major source of lead exposure for children is deteriorating lead-based paint and the accompanying dust and soil contamination. In babies and children, exposure to lead in drinking water above the action level can result in delays in physical and mental development, along with slight deficits in attention span and learning abilities. In adults, it can cause increases in blood pressure and fertility problems such as miscarriages, premature births, low birth-weight. Adults who drink this water over many years could develop kidney problems or high blood pressure. Most of the metals are introduced into the lagoon system through industrial processes, sewage disposal, soil leaching and rainfall.

Metal are reported to be well concentrated in the water [45,46] and sediments [47,48]. Bioaccumulation of these metals in many fish species and their organs have been variously reported by Kumada *et al*. [49], Westernhagen *et al*. [50], Osborne *et al*. [51], Norris and Lake [52] and Evans [53]. These metals in trace amount may play important role in the biochemical life process of the fish [54], some as enzyme co-factor [55, 56]. However, their sublethal concentrations become lethal to fish or other aquatic organisms when the duration of exposure to these metals is prolonged [57 - 61].

The mean Fe concentrations in water from the Lagos lagoon varied between 6.067±1.98 (in Ikoyi) and 8.065±1.99 mg/l (in UNILAG) (Table 2). The values were above the maximum contaminant level (MCL) of <0.3 mg/l which is an acceptable level [62]. However, 0.3 - 1.0 mg/l are satisfactory level but may cause staining and objectionable taste. Fe values of 1.0> are unsatisfactory in drinking water. This result indicates that Lagos lagoon is highly contaminated with Fe. The differences in levels of Fe in water across the stations were not significant (P>0.05). The geochemical and biochemical processes in the aquifers within the catchments according to Tay *et al*. [14] may be responsible for the differences.

Fe is an important metal in both plants and animals, especially in the cellular processes [56]. The insoluble Fe^{3+} is reduced to soluble Fe^{2+} in water by bacterial reduction. Fe is found in natural fresh- and groundwater, but have no health-based guideline value, although high concentrations give rise to consumer complaints due to its ability to discolour aerobic waters at concentrations above 0.3 mg/l [63].

The mean Zn concentrations of 1.055±0.21 and 1.267±0.05 mg/l (Table 2) were below the MCL of 5 mg/l recommended by USEPA [62]. Zn is present in large amount in natural water and next to Fe in terms of concentrations in this study. The relatively high Zn level is suggestive of the influence of refuse dump and domestic sewage sources. It could also be attributed to industrial effluents. The level of concentrations of Zn in this study did not significantly different across the stations (Table 2). This suggests the intense anthropogenic influence due to industrialization and urbanization within the catchments of the lagoon.

Zn is an enzyme co-factor in several enzyme systems including carbonic anhydrase found in red blood cells. Chance of being poisoned with Zn is rare because salts of alkaline earth element reduce toxicity of Zn. High temperature and low dissolved oxygen concentration lead to increase in toxicity of Zn. Its toxicity to fish according to Alabaster and Lloyds [64] and Everall *et al*. [46] can be greatly influenced by both water hardness and pH. It is one of the earliest known trace metals and a common environmental pollutant, which is widely distributed in the aquatic environment. Studies have also shown that it could be toxic to some aquatic organisms such as fish [64]. It has been found to have low toxicity effect in man. However, the prolonged consumption of large doses can result in some health complications such as fatigue, dizziness and neutropenia [65].

The mean Mn concentrations in water in this study ranged from 0.678±0.21 to 1.075±0.34 mg/l, though there were variations across the stations that were not significantly different (P>0.05). The Mn levels from this study were above the recommended or acceptable level for unpolluted water. The recommended MCL for Mn in water is 0.05 mg/l [62]. Mn in nature is found in form of oxides, silicates and carbonates. It functions as co-factor in the synthesis of urea from ammonia, amino acid and fatty acid metabolism and glucose oxidation. Inhalation of high dose of Mn leads to death. The health based guideline value is 0.4 mg/l [63]. The symptoms in man include problems with central nervous system, euphoria, insomnia, serious headache and palsy of feet.

Mn is an element of low toxicity having considerable biological significance and one of the more biogeochemical and active transition metals in aquatic environment [66]. It occurs in surface waters that are low in oxygen and often does so with Fe. It accumulates in certain species of fish [67]. A probable source of airborne inorganic Mn pollutant in urban centres is the combustion of methylcyclopentadienyl manganese tricarbonyl (MMT), particularly in areas of high traffic density [68]. Combustion of MMT in hot car engine leads to the emission of manganese phosphates, manganese sulfate and manganese oxides that include manganese tetroxide as a minor component [63, 69]. The high Mn levels in the swamps of Lagos lagoon could, therefore, be due to MMT, an anti-knocking agent present in petroleum products which has Mn as an active component.

The Concentrations of Cd in large amount constitute a serious health hazard. Cd is very soluble in water and it is important in several enzyme systems. Cadmium (Cd) is one of the most toxic elements with widespread carcinogenic effects in humans [70]. It is widely distributed in the aquatic environment. The mean Cd concentrations in this study varied from 0.074±0.05 in UNILAG to 0.174±0.03 mg/l in Offin stations (Table 2). These values were below the MCL of 0.005 mg/l [62]. This is an indication that the water from the mangrove swamps was contaminated, but not polluted with Cd. Sources of Cd in water include weathering of minerals and soils, discharge of domestic effluents and urban storm-water runoff containing Cd-laden materials. The possible accumulation of Cd in man is mainly in the kidney and liver. Its high concentrations lead to chronic kidney dysfunction, inducing cell injury and death by interfering with calcium (Ca) regulation in biological systems in man, fish and other aquatic organisms [71]. Its involvement in endocrine disrupts activities, which could pose serious health problems. However, its concentrations in water are only likely to be of health concern in environments where *p*H is less than 4.5 [63].

In this study the concentrations of Cr were as low as 0.115±0.05 in Ikoyi and as high as 0.12±0.01mg/l in Offin stations. These values were higher than the maximum contaminant level (MCL) of 0.1 mg/l recommended by USEPA [62] for unpolluted water.

Cr oxidizes easily from trivalent to hexavalent. Cr^{3+} ion is not toxic, but an essential nutrient, but Cr^{6+} ion is very toxic and damages adrenals, livers and lungs. Exposure of man to high concentration of Cr^{6+} may cause dermatitis, ulcer, destruction of mucus of nose and cancer of the stomachs. The major source of Cr in water is via industrial effluents.

The concentrations of Pb in this study were below the detectable level (BDL). The recommended MCL for Pb was 0.0015mg/l [62]. The study showed that the concentrations of Pb were very low and could not be detected in water from the swamps of Lagos lagoon. The United States Environmental Protection Agency has classified Pb as being potentially hazardous and toxic to most forms of life [72]. It has been found to be responsible for chronic neurological disorders in foetuses and children especially when it is greater than 0.1 mg/l. A probable source of Pb to aquatic environment could be from used dry-cell batteries and tyres from dump sites. Absence of dry cell battery manufacturing industry from catchment areas of the lagoon might probably responsible for non detectable level of Pb in water from Lagos lagoon.

Conclusively, in this study the water quality properties in terms of its physico-chemical parameters from the mangrove swamps of Lagos lagoon were assessed. Values obtained for the temperatures, pH, salinity, dissolved oxygen and carbon dioxide, total alkalinity and acidity, total suspended and dissolved solids were within the recommended values of World Health Organisation (WHO) and United State Environmental Protection Agency (USEPA) for survival, metabolism and physiology of aquatic organisms. However, data obtained for heavy metals such as Fe, Zn, Mn, Cd and Cr were dangerously higher than the maximum contaminant levels (MCL) recommended for unpolluted or drinking water. Therefore the water was highly contaminated and polluted with heavy metals and not recommended as a drinking water for human consumption. This study was an additional data and information to already existed reviews on some Nigerian waters with high pollution rate and contaminants. The findings will assist our relevant agencies on the need to protect our water bodies and make it safe for drinking purpose.

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