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Baseline physico-chemical and bathymetry assessment of Mahin Lake, Southwestern, Nigeria

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Assessment of baseline physico-chemical parameters and bathymetry mapping of Mahin Lake has been carried out for effective and sustainable utilization, management, conservation, and exploitation of its resources. pH, temperature, dissolved oxygen, electrical conductivity, resistivity, total dissolved solid (TDS), salinity, and surface pressure were determined *in situ*; while concentrations of calcium, magnesium, sodium, potassium, chloride, nitrate, and phosphate in water samples were determined in the laboratory. Bathymetry map revealed that the deepest portion of the lake is 4.3 m, while surface area and estimated volume of water were 1.82×10^6 m^2 and 4.48×10^6 m^3, respectively. The parameters measured shows considerable spatial variations. Mahin Lake is classified as a freshwater lake, indicating little interaction with the Atlantic Ocean; while its water is classified as 'soft' and weakly mineralized considering Ca^{2+} (0.46 to 1.69 mg/L), Mg^{2+} (0.55 to 1.83 mg/L), pH (5.05 to 5.5) and electrical conductivity (72.75 to 95.75 µS/cm). With these result, growth, biodiversity, and productivity of marine organisms within the lake are at risk. The low dissolved oxygen concentration (DO, 0.04 to 0.91 ppm) tends towards anoxia status and can possibly cause fauna depletion. Trace anthropogenic impact were identified on the western flank of the lake. The status of the lake provides a guide to further research in determination of its tectonic evolution. Sustainable environmental management system is required to prevent possible anthropogenic activities which can further reduce the quality of Mahin Lake and its associated ecosystem.

Key words: Mahin Lake, physico-chemical, bathymetry, anthropogenic, anoxia.

INTRODUCTION

Lake water contains dissolved minerals which can be measured by its physico-chemical properties just like other water bodies. The concentration of constituent minerals can become hazardous to human beings and life forms, when it exceeds recommended values (WHO, 1989; Hespanhol, 1994; WHO, 2008; Patil et al., 2012). Hazardous water pollutants include substances which are toxic at low concentrations, carcinogenic, mutagenic, teratogenic and/or can be bioaccumulated; especially when they are persistent (Enderlein, 1996). Therefore

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quality of water in any ecosystem provides significant information about the available nutrients supporting life within and around that ecosystem and determines the trophic dynamics of the water (Leena, 2007; Manikannan et al., 2011; Usman et al., 2014).

Lake water provides important multistage uses which include source of drinking water, irrigation, navigation, aquaculture, hydroelectric power generation and recreation (Kahl, 1991; Mastran et al., 1994; Beachler and Hill, 2003; Soeprobowati, 2014; Kumar et al., 2015; Doreen et al., 2015; Querijero and Mercurio, 2016). Although, various research works have been carried out to assess the water quality of estuaries, rivers, and other water bodies in Nigeria (Adeniji et al., 1984; Kolo, 1996; Mustapha 2003; Mustapha and Omotosho, 2005; Adakole et al., 2008; Nkwoji et al., 2010, Dan et al., 2014; Francis et al., 2014; Makinde et al., 2015); few information is available on the bathymetry and physico-chemical properties of Mahin Lake.

Water quality is usually measured using organoleptic, physico-chemical properties, toxic compound concentration, excess cations, anions and bacterial levels. Change in physico-chemical properties can be a result of several factors which include anthropogenic activities, climatic variability, and eutrophication (Psenner and Schmidt, 1992; Hamilton et al., 2001; Smith and Schindler, 2009; Kernan et al., 2010; Rinke et al., 2010; Read and Rose, 2013; Omotoso et al., 2015). Hence, chemistry of lake water is a cumulative reflection of catchment geology, weathering and erosional processes as well as anthropogenic inputs (Fezeu et al., 2009; Mushatq et al., 2013). Pollution arising from anthropogenic substances is capable of altering a lake ecosystem and reduces its economic productivity. Organic wastes and other nutrient inputs from sewage and industrial discharges, agricultural and urban runoff can result in low oxygen level (Yadav et al., 2005, 2007; Bobmanuel et al., 2006; Ho et al., 2012). Nutrient input often leads to excessive algal growth; when the algae die, the organic matter is decomposed by bacteria, a process which consumes a great deal of oxygen that could lead to oxygen sag (Aiyesanmi et al., 2006). Low concentration of dissolved oxygen is known to be one of the major problems of faunal and floral survival in the aquatic environment (Erkk et al., 1996), because it creates anoxic condition (Kamer and Stein, 2003).

Temperature is the most important physical variables which affect metabolic activities, growth, feeding reproduction distribution and migratory behaviours of aquatic organisms and water quality attributes in aquaculture (IEPA, 2001; Crillet and Quetin, 2006). High water temperature is known to enhance the growth of micro organisms. However, changes in temperature can have critical effect on living organisms. Relative depth of water at a particular site in a water body is one of the major physical factors controlling the water quality (Nõges, 2009; Stefanidis and Papastergiadou, 2012). Therefore, temperature and water depth relationship can provide vital information on lake ecosystem.

By reason of the fishing activities carried out in the study area, Mahin Lake can be said to be a productive water body that supports diverse number of organisms from phyto and zooplanktons, benthos to fishes and macrophytes (Bisht et al., 2013). However, the abundance of chemical ions needed for interconversion of energy and production of organic minerals present in a lake (Mushatq et al., 2013) can provide information on health status of a lake (Usman et al., 2014). Thus, determination of the physico-chemical properties of a lake contributes to knowledge required for optimum utilization. This study is carried out to assess and document the bathymetry and physico-chemical baseline aspects of the water quality indicators in Mahin Lake. This is essential because no previous research work has been carried out on the lake. Comparison of results obtained with published water quality parameters for lakes will assist to evaluate possible impact of the physico-chemical parameters upon the ecological habitat, health status of the ecosystem and if the lake could maintain a flourishing fishing hub. Spatial variation of parameters measured will provide information required to guide in monitoring, management and further research, should there be any future alteration of the water quality.

METHODOLOGY

Study area

Mahin Lake is located between Latitude 6.175989 °N – 6.206869 °N and Longitude 4.810944 °E – 4.823770 °E in Ilaje Local Government Area, Southwestern Nigeria (Figure 1a). It is approximately 2.3 ×1 km, and at a distance of 9 km from the Atlantic Ocean. The lake is famous as a fishing hub. Communities are sited around it for economic purposes, and a section of it serve as transportation route from Igbokoda to communities on the coastline (Figure 1b). Mahin Lake represents a mixed and dynamic ecosystem, considering its proximity to the ocean and associated tidal influences. It is fed by Mahin canal connected to a 29 km long river channel which drains to the sea. The western flank of the lake used to be the major transportation route from Igbokoda to the coastal communities. The rehabilitated road infrastructure connecting Igbokoda to Ugbo has reduced the pressure on water transportation in the study area. During the peak of the raining season, algal blooms are usually noticeable in the lake. The decay of this plant material as they die off also alters the physico-chemical properties and by implications the ecosystem. This has a potential of causing seasonal migration of organisms and modify the food chain within the lake and its environment.

A motorized survey boat, Hanna multi-parameter auto water analyzer with an in-built Global Positioning System (GPS) was used to determine station coordinates and sample points. Furuno 6 single beam echosounder, model LS-6100 (dual frequency 50 and 200 kHz) with pole-mounted transducer was used for depth measurement. One hundred and twenty-eight evenly spaced sample stations were occupied. Surface water samples of the lake were collected into plastic bottles, packed in a cooler and was refrigerated prior to laboratory analysis. Some physico-chemical parameters (temperature, salinity, pH, total dissolved solid (TDS), dissolved oxygen (DO), resistivity, surface pressure, and electrical

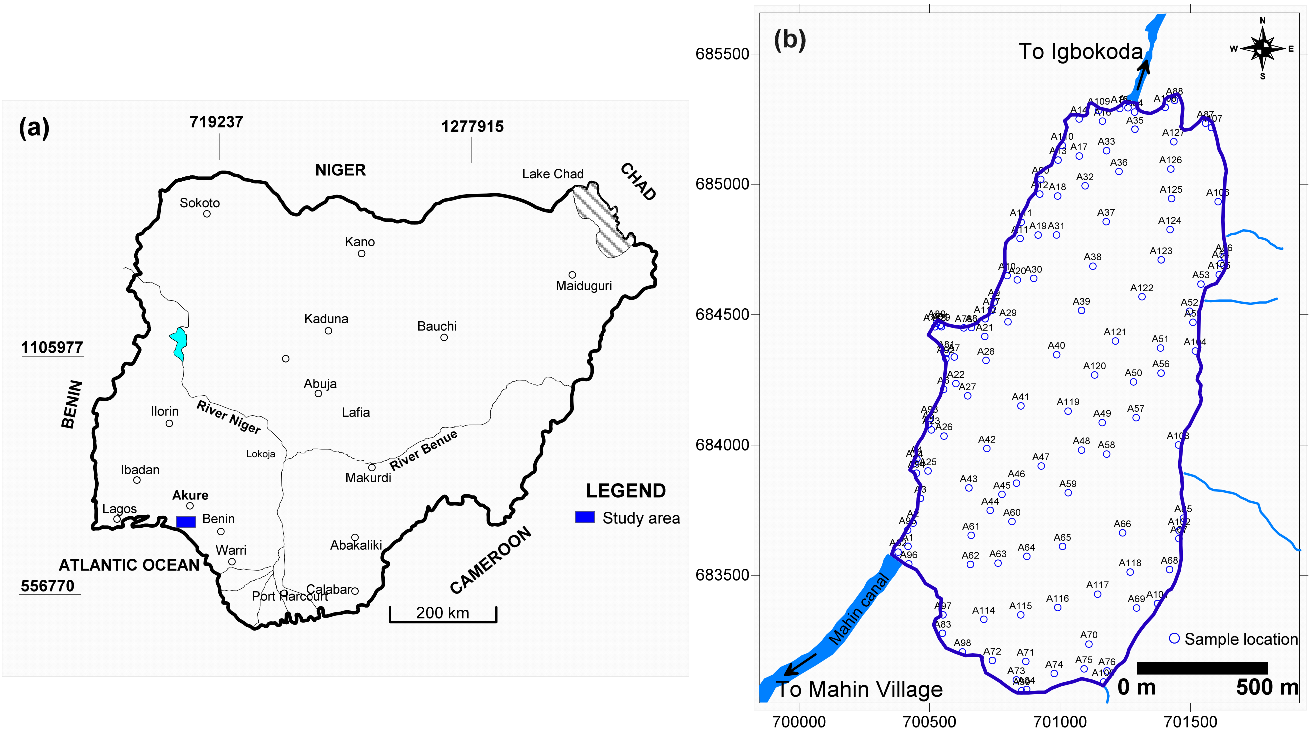

Figure 1. (a) Map of Nigeria indicating the study area; (b) Location map of Mahin Lake indicating the sample stations.

conductivity (EC) were determined *in situ* using Hanna multi parameter auto water analyzer. Calcium and magnesium were measured using Buck Scientific Atomic Absorption Spectro-photometer Model 210 VGP. Sodium and potassium were determined using Atomic flame photometer PfP7. Nitrate, phosphate and chloride were determined using Shimadzu 1800 UV spectrophotometer.

The sample stations occupied were georeferenced to produce the bathymetry of the lake using ordinary point kriging algorithm, which produces exact data interpolations. Maps of various properties measured and analyzed were produced using Surfer 12.0 terrain modeling package (Cressie, 1991; Köck et al., 2012).

RESULTS

Bathymetry study revealed that the depth of Mahin Lake is within the range of 1.5 and 4.3 m, with an average value of 2.26 m (Table 1). The surface area of the lake is 1.82×10^6 m^2, while its volume is estimated to be 4.48×10^6 m^3 using Simpson’s second rule (also known as Simpson's 3/8 rule, calculated based on cubic interpolation for better accuracy). Electrical conductivity values ranges between 72.75 and 95.75 µs/cm, with an average value of 83.46 µs/cm (Table 1). Resistivity values obtained has the same trend as that of the electrical conductivity (Figure 2b and d). This is expected, considering the inverse relationship which exists between the two parameters. The lowest resistivity value of 0.01 Mohm.cm (Table 1) was obtained at the north-western flank.

TDS values obtained ranges between 36.25 and 47.75 ppm, with an average value of 41.74 ppm. Dissolved oxygen is within the range of 0.05 and 0.91 ppm, with an average value of 0.46 ppm (Table 1). Water surface temperature in Mahin Lake ranges from 25.7 to 31.2°C, with an average value of 28.35°C. Surface pressure in Mahin Lake ranges between 758.8 and 767.2 mmHg with an average of 762.23 mmHg (Table 1).

A summary of the analysis conducted for some nutrients is presented in the Table 1. Chloride concentration ranges from 5.0 to 439.86 mg/L, with an average value of 59.50 mg/L. Potassium ion concentration has values in the range of 7.1 and 27 mg/L, with an average value of 9.63 mg/L. Magnesium ion concentration in Mahin Lake ranges between 0.55 and 1.83 mg/L, with an average value of 1.10 mg/L. The values of sodium ions obtained for the lake ranges from 5.3 to 23 mg/L, with an average value of 7.71 mg/L. The value of calcium ion concentration obtained ranges from 0.46 to 1.69 mg/L, with an average value of 0.85 mg/L. Nitrate concentration ranges from 4.4 to 57.74 mg/L, with an average value of 24.88 mg/L. Phosphate concentration ranges from 13.1 to 69.8 mg/L, with an average value of 26.46 mg/L.

Correlation coefficient of the physico-chemical para-meters, anions and cations in Mahin Lake was determined. In the physico-chemical parameter group (Table 2), significant positive correlation exists between conductivity and TDS (0.99), pH and temperature (0.51), while conductivity and resistivity (-0.95), resistivity and

Table 1. Summary of physico-chemical parameters measured in-situ and result of laboratory analysis carried out on water samples collected; with some recommended values for aquaculture and freshwater.

Parameter	Minimum	Maximum	Average	Remark	Recommended values
Depth (m)	-1.5	-4.4	-2.26	Relatively shallow lake	
pH	5.05	5.5	5.29	Slightly acidic	[a]6.5 - 9.0
Temperature (°C)	25.69	31.18	28.35	Within optimum productivity range	-
Dissolved Oxygen (ppm)	0.04	0.91	0.46	Hypoxic status	[a]6 - 9
Electrical conductivity (µS/cm)	72.75	95.75	83.46	Mineralised water	[b]1000
Resistivity (MOhm·cm)	0.0105	0.0154	0.01	Freshwater	-
Total dissolved solid (ppm)	36.25	47.75	41.74	-	[b]2000
Salinity (ppt)	0.035	0.045	0.04	Freshwater	[c]50 - 2000
Surface pressure (mmHg)	758.8	767.2	762.23	-	-
Calcium ion (mg/l)	0.46	1.69	0.85	'Soft' base on water hardness	[c]5 - 100
magnesium (mg/l)	0.55	1.83	1.10	'Soft' base on water hardness	[c]5-100
Sodium (mg/l)	5.3	23	7.71	-	[c]2 - 100
Potassium (mg/l)	7.1	27	9.63	-	[c]1 - 10
Chloride (mg/l)	5	439.86	59.50	-	[c]1 - 100
Nitrate (mg/l)	4.4	57.74	24.88	-	[c]0.2 – 10
Phosphate (mg/l)	13.1	69.8	26.46	-	[c]0.005 – 0.2

Sources: [a]South African Water Quality Guidelines (1996); [b]WHO (2008); [c]Boyd (1998).

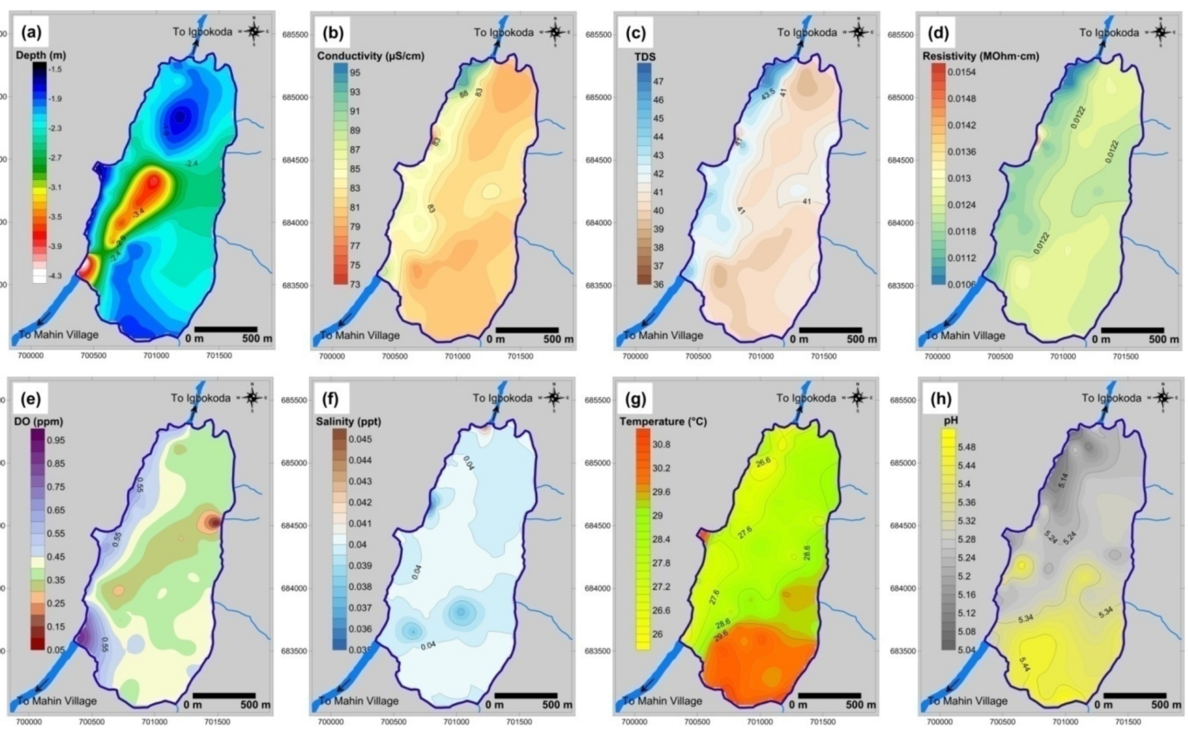

Figure 2. Two-dimensional map of parameters measure *in-situ* (a) Depth, (b) Electrical conductivity, (c) Total dissolved solid, (d) Resistivity, (e) Dissolved oxygen, (f) Salinity, (g) Temperature, and (h) pH.

TDS (-0.95), resistivity and salinity (-0.59), pH and temperature, temperature and conductivity (-0.50) are negatively correlated. The cation-anion group (Table 3) shows significant positive correlation in the following: sodium and potassium (0.99), magnesium and potassium (0.76), magnesium and sodium (0.74), calcium and magnesium (0.57), and calcium and potassium (0.54). Constructed two-dimensional maps (Figures 2 and 3)

Table 2. Correlation coefficient between physico-chemical parameters in Mahin Lake.

Correlation	Depth	pH	Temperature	DO	Conductivity	Resistivity	TDS	Salinity	Surface pressure
Depth (m)	1								
pH	-0.0744	1							
Temperature (°C)	0.2664	0.5090	1						
DO (ppm)	-0.1577	-0.1207	-0.3847	1					
Conductivity (µS/cm)	-0.0942	-0.4150	-0.5007	0.4679	1				
Resistivity (MOhm·cm)	0.0455	0.3933	0.3921	-0.3696	-0.9515	1			
TDS (ppm)	-0.0214	-0.4507	-0.4460	0.4221	0.9858	-0.9490	1		
Salinity (ppt)	0.0609	-0.0367	-0.0908	-0.0002	0.4708	-0.5934	0.4883	1	
Surface pressure (mmHg)	-0.3060	0.1703	-0.1396	0.3336	-0.0283	-0.0338	-0.0476	0.0047	1

Table 3. Correlation coefficient between anions and cations in Mahin Lake.

Correlation	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	NO^{3-}	PO^{3}
Ca^{2+}	1						
Mg^{2+}	0.5733	1					
Na^{+}	0.4940	0.7373	1				
K^{+}	0.5398	0.7613	0.9906	1			
Cl^{-}	0.1350	-0.1113	-0.1180	-0.1087	1		
NO^{3-}	0.2214	-0.2238	0.2614	0.2216	0.2718	1	
PO^{3}	-0.2411	-0.1333	-0.0133	-0.0328	-0.2857	-0.0925	1

reveal the spatio-temporal distribution of physico-chemical parameters, anions and cations in Mahin Lake.

DISCUSSION

The highest depth value was obtained at the south-western flank, having a northeast-southwest orientation. The lake is found to be made up of three main compartments: the deepest part with depth of 4.3 m, a relatively shallow north and south compartments, and the intermediate eastern flank. The deepest segment is understood to be as a result of dredging activities. The western boundary is characterized by relatively shallow depth (Figure 2a).

The highest values of electrical conductivity were obtained at the north-eastern flank of the lake, while the western boundary of the lake is characterized by relatively high electrical conductivity. A relatively high conductive plume is observed to originate on the eastern flank, migrating south-westward. TDS has the same trend as electrical conductivity and resistivity (Figure 2c). This is expected as the electrical conductivity depends upon the quantity of dissolved substance present in the water (Gupta et al., 2008). The highest values of electrical conductivity were obtained at the north-western flank of the lake. Electrical conductivity is an index of total ionic content and therefore, in water, it reflects the degree of salinity of the water (Nkwoji et al., 2010). The relatively low electrical conductivity and resistivity values are within the limits recommended for freshwater (Boyd, 1979), therefore indicating there is little interaction with the Atlantic Ocean. Hence, Mahin Lake is classified as a freshwater lake.

Based on the dissolved oxygen distribution, Mahin Lake is once again segmented into three compartments for ease of description. The

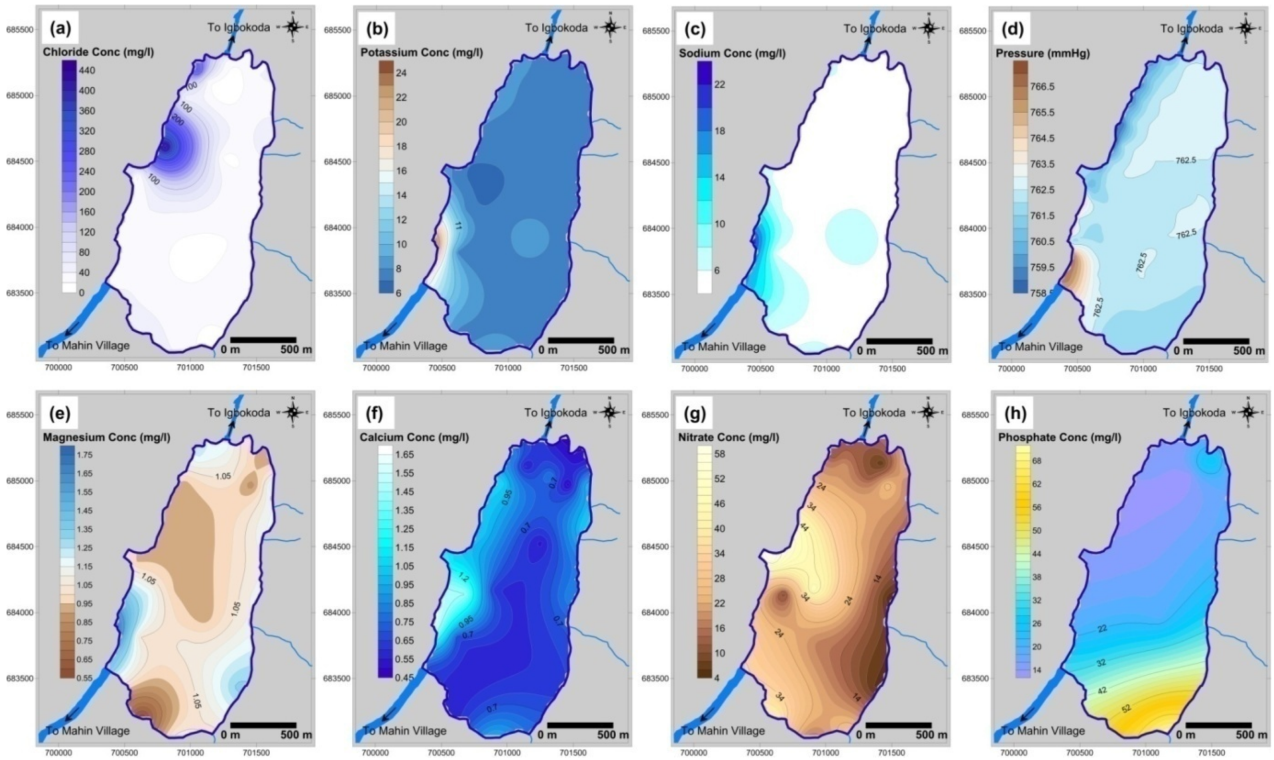

Figure 3. Two-dimensional map of parameters measure in-situ and from laboratory analysis of water sample (a) chloride, (b) potassium, (c) sodium, (d) surface pressure, (e) magnesium, (f) calcium, (g) nitrate, and (h) phosphate.

western flank along the lake boundary, characterized by relatively high dissolved oxygen; the eastern flank with relatively low dissolved oxygen which ranges between 0.35 and 0.45 ppm; and the very low dissolved oxygen (below 0.25 ppm) plume which originate from the eastern flank, migrating south-westward. The dissolved oxygen concentration in Mahin Lake is generally low. According to Boyd (1979) and Abdus-Salam et al. (2010), dissolved oxygen concentration of 4 to 9 ppm will support a large diverse fish population, while 5 ppm concentration is considered as optimal to support life and desirable for fish survival (Howell and Simpson, 1994; US EPA, 2000). Low dissolved oxygen concentration result in anoxia status (Erkk et al., 1996; Saiz-Salinas, 1997) and causes fauna depletion in the ecosystem. Hence, Mahin Lake ecosystem is at risk considering the dissolved oxygen concentration.

Fishes may migrate from this lake, more sensitive species may die, while the present status may limit the growth of others and reduce biodiversity. DO values obtained can be identified as a contributing factor to reduction in productivity of Mahin Lake. Generally, DO is below the recommended limit required for fish survival. According to Srivastava et al. (2009), depletion of dissolved oxygen is the most frequent result of certain forms of water pollution. The southern flank with high temperature values corresponds to areas with low dissolved oxygen, while the western boundary with low temperature is characterized by high dissolved oxygen. Hence, at lower temperature, higher concentration of dissolved oxygen is retained. This is the relationship between water temperature and gas saturation. According to Michaud (1991), water at lower temperature holds more of any gas than at higher temperature.

Electrical conductivity, dissolved oxygen, resistivity, and TDS distributions were found to have similar trend. The salinity values ranges between 0.04 and 0.05 ppt, with almost uniform distribution throughout the lake (Figure 2f). However, 0.037 ppt was obtained at some few locations. The relatively low salinity value is in consonance with the classification of Mahin Lake as freshwater. Egborge (1994) classified waters with salinity value above 1 ppt as brackish/marine. This result is reflected in the low concentration of calcium, magnesium, potassium, sodium, and chloride which contribute to the salinity of water.

Based on surface temperature distribution, the lake is also segmented into three compartments. The southern compartment has the highest temperature values. The western flank, along the lake boundary is characterized by relatively low temperature trending north-south, which is attributed to mixing as a result of the connected canals. Base on pH distribution, the lake is segmented into two compartments. High readings were obtained at the southern compartment, while the lowest value on the northwestern flank. Generally, the lake is slightly acidic. Areas characterized by high temperature were also associated with high pH values and relatively shallow depth. Temperature values obtained are within recommended guidelines, within which optimum growth rate, efficient food conversion, best condition of fish, resistance to diseases and tolerance to disease and toxins (metabolites and pollutants) can be achieved (South African Water Quality Guidelines, 1996). pH values between 6.0 and 8.5 indicate productive nature of water body, while values less than 4.0 is detrimental to aquatic life (Garg et al., 2010; Abowei, 2010). This suggests that pH values obtained in Mahin Lake is not within the range for optimum productivity. Hence, may not support growth, biodiversity and productivity of marine organisms.

The characteristic pattern of EC, TDS, resistivity, DO, temperature and pH on the western flank along the lake boundary is attributed to possible anthropogenic activities carried out in the lake area and mixing facilitated by the connected canals. This result reveal trace anthropogenic impact on the western flank Mahin Lake, and has the potential of spreading to other parts.

Surface pressure is highest at the southwestern flank of the lake, just at the connection with Mahin canal, and lowest at the northwestern flank. Water generally flows from high to low pressure areas. Hence, as evident in the surface pressure distribution, the spread of the pressure plume at the southwestern flank shows that water flows from Mahin canal into the lake at this time of study. This introduces relatively high dissolved oxygen, potassium, sodium, and magnesium ions into the lake (Figures 2e, 3b, c and e). The northwestern flank is characterized by high chloride ion, electrical conductivity, TDS, low resistivity and low pH, attributed to sludge floating on the water surface. Surface pressure also contributes to mixing and distribution of physico-chemical parameters in the lake.

A relatively high concentration of chloride is obtained at the western flank of the lake. This pattern is also observed in electrical conductivity. Mahin Lake is characterized by a generally low chloride concentration with values less than 40 mg/L. The potassium ion concentration has similar trend with that of the sodium ion concentration across the lake, having the highest values at the south-western flank. Generally, the values of potassium ion concentration are between 6 and 8 mg/L. The highest values for sodium were obtained at the south-western flank, just around the connecting Mahin canal. Relatively high concentrations were obtained on the southwestern and eastern flanks, as well as the northwestern flank. A relatively low magnesium concentration plume is identified on the western flank which migrates towards the centre and southwards. The western boundary of the lake is characterized by relatively high values of calcium above 0.95 mg/L. Relatively low concentration of nitrate is observed on the eastern and northern flanks respectively. The western and southern flanks are characterized by relatively high concentration above 24 mg/L. Calcium and magnesium ions concentration in water are the major determinant of total hardness.

From the result obtained, Mahin Lake can be classified as ‘soft’ water based on IEPA (2001) classification for waters with up to 50 mg/L $CaCO_3$. Nitrate concentration in Mahin Lake is found to be higher than that obtained in some other lakes studied in Nigeria, e.g. 4.0 mg/L in Jebba Lake (Adeniji et al., 1984), 0.5 mg/L in Shiroro lake (Kolo, 1996), 5.1 mg/L in Oyun Lake (Mustapha, 2003) and 22.4 mg/L in Moro Lake (Mustapha and Omotosho, 2005). According to Manikannan et al. (2011), natural waters in their unpolluted state contain only minute quantities of nitrates. Therefore, relatively high concentration of nitrate is an indicator of pollution. High nitrate concentration can affect osmoregulation, oxygen transport, eutrophication and algal bloom (Lawson, 1995). This result corroborates other parameters obtained on the western flank of the lake which expresses trace anthropogenic impact. The southern flank is characterized by high concentration of phosphate which decreases northward. Generally, phosphate concentration is less than 38 mg/L.

Conclusion

This study has developed the first bathymetry map of Mahin Lake, which will be valuable for further research on the lake. The average depth, area extent and volume of water have been determined. Physico-chemical results obtained can be used as baseline and reference when assessing further changes caused by natural or anthropogenic influences on the lake. It would also form a useful tool for ecological assessment and monitoring of the lake resources. Mahin Lake is a freshwater lake with little interaction with the Atlantic Ocean based on the physico-chemical results obtained. Trace anthropogenic impact were identified on the western flank of the lake, which has the potential of spreading eastward. Low dissolved oxygen concentration obtained tends towards anoxia condition, which can possibly cause fauna depletion in Mahin Lake ecosystem. Thus, fishes may migrate, more sensitive species may die, reduce biodiversity, while the growth of others is hampered. Water in the lake is characterized by relatively low electrical conductivity and may thus be classified as weakly mineralized water. Surface temperature values obtained is within recommended guidelines for optimal growth rate, efficient food conversion, best condition of fish, resistance to diseases and tolerance to disease and toxins. Mahin Lake is characterized by pH values which are lower than recommended values required for optimum productivity. Hence, growth, biodiversity and productivity of marine organisms within the lake are at risk. Based on the calcium and magnesium ions concentration, the lake is made up of 'soft' water. Nitrate concentration is found to be higher than that obtained in some other lakes studied in Nigeria. Further studies to determine the tectonic evolution of the lake is suggested.

Conflict of Interests

The authors have not declared any conflict of interests.

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