Research Journal of Environmental and Earth Sciences 5(2): 67-77, 2013
ISSN: 2041-0484; e-ISSN: 2041-0492

Submitted: October 12, 2012 Accepted: December 06, 2012 Published: February 20, 2013

Spatio-Temporal Assessment and Water Quality Characteristics of Lake Tiga, Kano, Nigeria

[1]E. O. Akindele, [2]I.F. Adeniyi and [3]I.I. Indabawa
[1]Department of Biological Sciences, Bowen University, Iwo, Nigeria
[2]Department of Zoology, Obafemi Awolowo University, Ile-Ife, Nigeria
[3]Department of Biological Sciences, Bayero University Kano, Nigeria

Abstract: The physico-chemical water quality of Lake Tiga was monitored over a two-year period (March 2009-March 2011) in order to bridge the information gap on its limnology and assess its physico-chemical condition. Turbidity, Dissolved Oxygen (DO) saturation and organic matter were significantly higher ($p<0.05$) in the rainy season than in the dry season, while pH and Biological Oxygen Demand were significantly higher ($p<0.05$) in the dry season than in the rainy season. Apparent colour, Total Solids (TS), Total Suspended Solids (TSS), K^+, Cl^-, total acidity, total hardness, NO_3^- and PO_4^{3-} decreased ($p<0.05$) from the riverine section towards the dam site, while water transparency, Dissolved Oxygen (DO), SO_4^{2-} and Mg^{2+} showed an increase ($p<0.05$) from the riverine section towards the dam site. Apparent colour, TS, TSS, total acidity, total hardness, Ca^{2+}, NO_3^- and PO_4^{3-} increased ($p<0.05$) from the surface down to the bottom, while pH, Mg^{2+} and DO decreased ($p<0.05$) from the surface down to the bottom at the lacustrine section of the lake. Cluster analysis of the parameters showed major clusters between the major ions (Ca^{2+}, Na^+, K^+, Cl^-, HCO_3^-) and the general chemical characteristics (TDS, alkalinity, conductivity, acidity and hardness) and also between the nutrient compounds (Organic matter, NO_3^- and PO_4^{3-}) and the hydro-physical parameters (TS, TSS, apparent colour, true colour and turbidity). The water quality indices and sodium absorption ratio values in the sampled stations indicated that the water is most suitable for probable applications at the lacustrine section, towards the dam site.

Keywords: Dam site, lacustrine, limnology, riverine, season, water quality

INTRODUCTION

Dams, built to change natural flow regimes, are one of the most significant human interventions in the hydrological cycle (McCartney *et al*., 2001) and they can result in post-impoundment phenomena that are specific to reservoirs and not natural lakes (Dinar *et al*., 1995). The size of the dam, its location in the river system, its geographical location with respect to altitude and latitude, the detention time of the water and the source(s) of the water all influence the water quality (McCartney *et al*., 2001). Although oxygen demand and nutrient levels generally decrease over time as the organic matter decreases, some reservoirs require a period of more than twenty years for the development of stable water quality regimes (Petts, 1984). Eutrophication of reservoirs may occur as a consequence of large influxes of organic loading and/or nutrients (McCartney *et al*., 2001). This can result in water blooms of blue-green algae which can cause oxygen depletion and increased concentrations of iron and manganese in the bottom layer, as well as increased pH and oxygen in the upper layers of stratified reservoirs (Zakova *et al*., 1993).

Downstream, the water discharged from reservoirs can be of different composition and show a different seasonal pattern to that of the natural river (McCartney *et al*., 2001). The salinization of water below dams in arid climates (arising from increased evaporation) is problematic and has proved to be a problem on floodplain wetlands in the absence of periodic flushing and dilution by flood water. If sufficiently high and prolonged, elevated salinity will affect aquatic organisms (Hart *et al*., 1991).

Even without stratification of the storage, water released through dams may be thermally out of phase with the natural regime of the river (Walker, 1979). The quality of water released from a stratified reservoir is determined by the elevation of the outflow structure relative to the different layers within the reservoir. Water released from near the surface of a stratified reservoir will be well-oxygenated, warm, nutrient-depleted water. In contrast, water released from near the bottom of a stratified reservoir will be cold, oxygen-

Corresponding Author: Emmanuel O. Akindele, Department of Biological Sciences, Bowen University, Iwo, Nigeria, Tel.: +234-8036574615

depleted, nutrient-rich water which may be high in hydrogen sulphide, iron and/or manganese (ICOLD, 1994).

Lake Tiga is Nigeria's second largest artificial lake (based on volume) and was constructed in 1974 by the Water Resources and Engineering Construction Agency (Hadejia-Jama'are River Basin Development Authority, 1989). The dam of the lake is located at Tiga, about 70 km south of Kano city and 350 km north of the Federal Capital Territory, Abuja. Being 48m high (dam height), 6km long (crest length) and with a storage capacity of $1,974 \times 10^6 m^3$ (HASKONING Engineering Consultants Nigeria and HASKONING Nijmegen, 1978), the dam can be classified as a large dam based on the criteria used by the International Committee on Large Dams (ICOLD) i.e., dams higher than 15m from foundation to crest, crest length more than 500 m and more than one million cubic meters storage capacity (McCartney *et al*., 2001). The lake is being fed by two major rivers (River Kano and River Duku). Water from the lake drains into River Hadejia at a distance of about 40km downstream of the dam. River Hadejia formed a confluence (known as River Yobe) with River Jama'are. This confluence (R. Yobe) is one of the inflows of Lake Chad (Shettima, 1997; Barbier, 2003). Although the lake was created primarily for water supplies, it has served a wide range of other purpose. Aside fishing activities within the lake, a Federal Government-owned fish farm being fed by water from the lake is situated about a kilometre downstream of the dam. In view of the significance of the lake to the nation, this research assessed the spatial and temporal variability of its physico-chemical condition as well as its suitability for intended purposes; namely irrigation, fisheries and aquatic life.

MATERIALS AND METHODS

Description of the study area: Lake Tiga is located in Kano State, North-West, Nigeria. It lies within the Hadejia-Jamaa're River Basin and covers parts of Bebeji, Rano and Tudun-Wada Local Government Areas of the state. It lies roughly between longitudes 008°18^{1}E and 008°35^{1}E and latitudes 11°18^{1}N and 11°27^{1}N. The study area falls into the semi-arid equatorial tropical climate, characterised by an annual rainfall less than 44% of annual potential evapotranspiration, three humid months (June-September) and average daily maximum temperature of above 33.5°C (Papadakis, 1965). The expected annual date for onset of rainfall in Kano is May 30, although it could start as early May 15 or as late as June 14 every year. Rain is expected to cease in Kano on September 25 every year, although it could cease as early as September 10 or as late as October 10 of every year (Akintola, 1986). In this study, five representative sampling stations were established on the lake covering the upper basin (riverine), the middle basin and the lower basin (dam site) sections (Fig. 1).

Water samples collection and in-situ determinations: Water samples were collected from the five stations on monthly basis from March 2009 to March 2011. Sub-surface water samples were also collected at the established middle basin and lower basin stations of the lake where the lake was deep

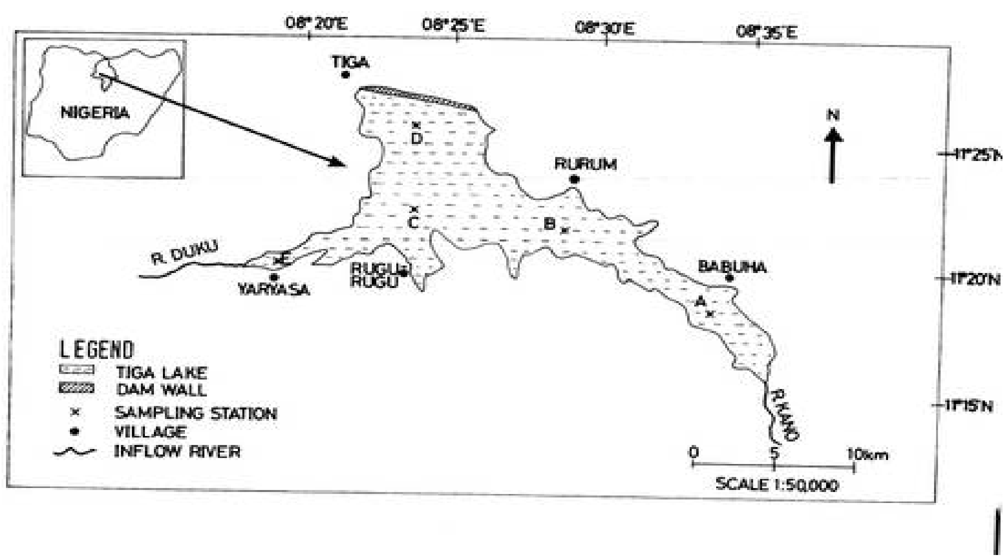

Fig. 1: Lake Tiga showing the water sampling stations (Inset: Nigeria showing the location of Kano State and Tiga Lake)

enough to stratify both thermally and chemically using a 2-litre Van Dorn water sampler. This was based on the need to give information on both horizontal and vertical variations in the physico-chemical water condition of the lake. Water temperature and pH were determined *in-situ* using a mercury-in-glass bulb thermometer and a field pH meter/lovibond comparator respectively, while transparency was determined with a Secchi disc. Electrical conductivity was determined using a JENWAY conductivity meter.

Laboratory analyses: Apparent colour (of unfiltered sample) and true colour (of filtered sample) were both determined by colorimetric method while turbidity was determined by nephelometric method (APHA *et al*., 1995). Total Solids (TS), Total Suspended Solids (TSS) and Total Dissolved Solids (TDS) were all determined by gravimetric method (APHA *et al*., 1995), while titrimetric (iodometric) method was used for Dissolved Oxygen (DO) and Biological Oxygen demand (Goltermann *et al*., 1978). Acid-base titrimetric method was employed for both alkalinity and acidity, Mohr titrimetric method for chloride ion and complexiometric titration for both calcium and magnesium ions (Goltermann *et al*., 1978). Sodium and potassium were analyzed using the flame emission spectrophotometer (Goltermann *et al*., 1978). Sulphate was determined by using a turbidity meter which was a function of the turbidity difference produced in the water sample after adding 0.15g of Barium chloride. Bicarbonate ion was estimated from the concentration of total alkalinity (Cole, 1975) as stated in the equation (alkalinity X 1.20) mg/l). Nitrate and phosphate were both determined by spectrophotometer (Goltermann *et al*., 1978). Water quality index was determined based on eight parameters (Dissolved Oxygen, pH, Biochemical Oxygen Demand, temperature change, total phosphate, nitrates, turbidity and total solids) (Oram, 2012). Sodium Absorption Ratio (SAR) in the lake was calculated using the formula:

$SAR = Na^+/\sqrt{(½Ca^{2+} + ½Mg^{2+})}$ (All concentrations are in meq/l).

Statistical analysis of data: All the data obtained were subjected to appropriate various methods including descriptive statistics, regression and correlation coefficient, analysis of variance (ANOVA) and cluster analysis.

RESULTS

Spatial Variation: The horizontal and vertical variation patterns in the physico-chemical water quality

Table 1: Horizontal variation of physico-chemical water parameters in Lake Tiga

	Basin			ANOVA	
Parameter	Upper Mean±s.e.m.	Middle Mean±s.e.m.	Lower Mean±s.e.m.	F	p
Water temperature (°C)	26.6±0.4	27.2±0.6	27.9±0.8	0.6572	0.552
Transparency (m)	0.20±0.03	0.47±0.04	0.58±0.05	15.66	0.004**
Apparent colour (Pt.Co)	974.8±138.9	486.0±64.4	372.6±77.6	4.953	0.054
True colour (Pt.Co)	94.6±14.4	51.1±6.28	32.0±7.4	7.007	0.027*
Turbidity (NTU)	80.2±12.7	30.1±4.50	18.6±4.5	4.837	0.056
Total solids (mg/L)	293±26	121±6	104±6	36.61	0.0004***
Total suspended solids (mg/L)	209±27	78±6	62±6	9.908	0.013*
pH	7.20±0.05	7.29±0.04	7.41±0.06	2.055	0.209
Conductivity (μS/cm)	150.5±22.8	73.9±1.23	73.0±1.7	3.797	0.086
Total alkalinity (mg$CaCO_3$/L)	56±9	24±1	26±2	4.837	0.056
Total acidity (mg$CaCO_3$/L)	23±2	14±1	14±1	9.615	0.013*
Total hardness (mg$CaCO_3$/L)	33.4±3.3	20.8±1.1	21.4±1.3	5.024	0.052
Total dissolved Solids (mg/L)	84±12	42±1	42±1	3.849	0.084
Ca^{2+}(mg/L)	10.68±1.40	6.34±0.13	6.32±0.21	3.953	0.080
Mg^{2+} (mg/L)	1.63±0.27	1.15±0.23	1.35±0.33	19.36	0.0024**
Na^+ (mg/L)	7.53±0.84	4.02±0.10	3.97±0.17	4.875	0.055
K^+ (mg/L)	7.76±1.62	3.29±0.06	3.28±0.11	9.737	0.013*
Cl^- (mg/L)	9.48±1.10	4.49±0.13	4.40±0.17	6.326	0.033*
SO_4^{2-} (mg/L)	3.90±0.39	4.98±0.08	5.80±0.80	11.99	0.008**
HCO_3^- (mg/L)	66.9±10.3	29.4±1.4	30.6±2.1	4.911	0.055
Dissolved oxygen (mg/L)	6.0±0.2	7.5±0.1	7.9±0.1	25.68	0.001***
Dissolved oxygen saturation (%)	75.2±2.6	95.6±1.9	101.2±2.1	14.65	0.005**
Biological oxygen demand (mg/L)	2.8±0.1	2.3±0.1	2.4±0.1	1.3	0.340
Organic matter (mg/L)	2.32±0.26	1.39±0.18	1.85±0.33	0.509	0.625
Nitrate (mg/L)	1.06±0.13	0.56±0.05	0.38±0.05	6.01	0.0001***
Phosphate (mg/L)	0.20±0.01	0.17±0.01	0.18±0.01	25.0	0.001***
Fe (mg/L)	0.149±0.012	0.329±0.024	0.368±0.039	51.93	0.0001***
Cu (mg/L)	0.030±0.002	0.030±0.001	0.028±0.001	0.4386	0.664
Mn (mg/L)	0.007±0.002	0.014±0.001	0.010±0.002	16.71	0.004**
Zn (mg/L)	0.005±0.002	0.002±0.001	0.001±0.001	0.509	0.625

s.e.m : Standard error of mean; *: significant; **: highly significant; ***: very highly significant

Table 2: Vertical variation of physico-chemical water parameters in the lacustrine section of Lake Tiga

	Mean±s.e.m.					ANOVA	
Parameter	0 m depth	5 m depth	10 m depth	15 m depth	20-30 m depth	F	p
Water temperature (°C)	27.4±0.5	26.4±0.49	26.2±0.83	25.1±0.83	23.5±0.80	3.032	0.071
Apparent colour (Pt.Co)	448.2±50.2	560.0±47.4	529.7±70.9	683.5±91.2	814.5±111.8	6.748	0.007**
True colour (Pt.Co)	44.7±5.0	70.2±6.8	71.3±10.8	102.5±15.0	126.2±15.3	64.61	4.17E-7***
Turbidity (NTU)	26.3±3.4	34.3±3.5	32.2±5.1	43.8±11.0	53.4±10.2	3.03	0.071
TS (mg/L)	115±4	124±4	122±7	143±9	162±17	4.816	0.02*
TSS (mg/L)	73±4	80±5	79±7	99±10	119±18	4.963	0.018*
pH	7.33±0.03	7.16±0.03	7.11±0.05	6.95±0.06	6.87±0.05	6.375	0.008**
Conductivity (μS/cm)	73.6±1.0	75.5±1.1	75.3±1.9	74.1±2.4	72.1±2.1	1.989	0.723
Total alkalinity (mg$CaCO_3$/L)	25±1	27±1	28±2	28±2	27±2	2.907	0.078
Total Acidity (mg$CaCO_3$/L)	14±1	15±1	16±1	17±1	19±1	7.239	0.005**
Total hardness (mg$CaCO_3$/L)	21.0±0.8	22.8±0.8	22.4±1.4	21.1±0.9	20.0±0.8	7.091	0.006**
TDS (mg/L)	42±1	44±1	44±1	44±1	43±1	1.833	0.199
Ca^{2+}(mg/L)	6.33±0.11	6.74±0.11	7.02±0.22	7.12±0.25	6.87±0.21	4.14	0.031*
Mg^{2+} (mg/L)	1.18±0.19	1.36±0.18	1.18±0.35	0.69±0.14	0.68±0.20	10.99	0.001**
Na^+ (mg/L)	3.99±0.08	4.26±0.09	4.21±0.14	4.20±0.26	3.99±0.16	2.375	0.122
K^+ (mg/L)	3.29±0.06	3.47±0.06	3.38±0.13	3.33±0.14	3.35±0.11	0.405	0.801
Cl^- (mg/L)	4.46±0.10	4.92±0.13	4.95±0.20	5.00±0.25	4.94±0.26	2.799	0.085
SO_4^{2-} (mg/L)	5.26±0.42	7.08±0.34	7.38±0.60	6.88±0.84	6.88±0.78	0.6411	0.645
HCO_3^- (mg/L)	29.8±1.1	32.3±1.2	34.1±2.5	33.2±2.3	32.8±2.0	3.2	0.062
Dissolved Oxygen (mg/L)	7.6±0.1	7.2±0.1	6.9±0.1	6.6±0.2	6.1±0.2	9.691	0.002**
Dissolved Oxygen Saturation (%)	97.5±1.5	90.7±1.5	87.8±2.0	80.9±2.6	72.6±2.5	11.45	0.001***
Biological oxygen demand (mg/L)	2.3±0.1	2.8±0.4	2.6±0.1	2.5±0.2	2.7±0.3	0.25	0.903
Organic Matter (mg/L)	1.80±0.19	1.95±0.14	2.22±0.18	2.11±0.18	2.39±0.23	0.0439	0.996
Nitrate (mg/L)	0.50±0.04	0.87±0.05	0.71±0.08	0.82±0.11	1.24±0.07	17.54	0.0001***
Phosphate (mg/L)	0.18±0.01	0.22±0.01	0.21±0.01	0.21±0.01	0.20±0.01	5.14	0.016*
Fe (mg/L)	0.342±0.021	0.469±0.027	0.575±0.069	0.549±0.063	0.517±0.072	17.7	0.0002***
Cu (mg/L)	0.029±0.001	0.034±0.001	0.034±0.001	0.039±0.002	0.041±0.001	21.62	6.557E-5***
Mn (mg/L)	0.013±0.001	0.017±0.001	0.022±0.003	0.015±0.002	0.017±0.003	5.38	0.014*
Zn (mg/L)	0.002±0.001	0.004±0.001	0.009±0.003	0.006±0.001	0.005±0.002	1.219	0.362

*: Significant; **: highly significant; ***: very highly significant

of the lake are provided in Tables 1 and 2. Secchi disc transparency, Dissolved Oxygen (DO) and iron showed an increase ($p<0.05$) from the riverine section towards the dam site. Water temperature and pH also increased towards the dam site, although they were not statistically significant ($p>0.05$) in their horizontal variation. Total Solids (TS), total suspended solids (TSS), K^+, Cl^-, SO_4^{2-}, NO_3^- and PO_4^{3-} generally decreased ($p<0.05$) from the riverine section towards the dam site. This pattern of horizontal variation was also observed for apparent colour, turbidity, conductivity, Ca^{2+} and Na^+ although not statistically significant ($p>0.05$). Water temperature, pH and DO all decreased from the surface down to the bottom in the lacustrine section, although water temperature was not statistically significant ($p>0.05$) in its vertical profile. Apparent colour, TS, TSS, NO_3^- and PO_4^{3-} generally increased ($p<0.05$) from the surface down to the bottom of the lake. Turbidity and organic matter also showed the same vertical profile pattern with the afore-mentioned ($p>0.05$). The general chemical characteristics and major ions also showed an increase in their vertical variation up to about 10-15m depth, beyond which they showed a slight decline down to the bottom. Total acidity, total hardness, Ca^{2+} and Mg^{2+} showed significant difference ($p<0.05$) in their vertical variation.

Temporal variation: Table 3 provides the descriptive statistics as well as the seasonal mean values of the investigated parameters. Most of the investigated parameters were higher in the dry season than in the rainy season, viz; water temperature, Secchi disc transparency, pH, conductivity, total alkalinity, total acidity, total hardness, Ca^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, HCO_3^-, BOD_5, NO_3^-, Fe and Cu. Although water temperature was generally higher in the dry season than in the rainy season ($p>0.05$), the lowest value was recorded in the middle of the dry season in January (data not shown). A different seasonal trend was observed for apparent colour, turbidity, TS, TSS, Mg^{2+}, organic matter, PO_4^{3-}, DO and Zn which were all higher in the rainy season than in the dry season. In these seasonal variation patterns, only pH, BOD_5, turbidity and organic matter showed significant difference ($p<0.05$).

Relationship among the investigated physico-chemical water parameters: Five major clusters were

Table 3: Descriptive statistics and seasonal mean values of physico-chemical water parameters in the sampled stations

Parameter	Descriptive Statistics: Min.	Max.	Mean	Seasonal variation: Rainy season	Dry season	ANOVA: F	P
Air temperature (°C)	20.0	42.0	30.5±0.5	28.9±0.5	31.5±0.7	27.49	0.039*
Water Temp. (°C)	19.1	34.5	26.5±0.3	26.3±0.3	26.6±0.3	0.2173	0.646
Transparency (m)	0.05	0.95	0.39±0.03	0.28±0.03	0.44±0.03	2.638	0.135
Apparent colour (Pt.Co)	8.8	2461.0	630.6±36.9	820.0±45.6	535.1±77.1	4.129	0.054
True colour (Pt.Co)	0.0	268.4	74.4±4.38	87.1±4.38	68.0±8.4	1.373	0.255
Turbidity (NTU)	1.5	240.9	42.4±3.20	66.0±7.8	30.5±2.1	5.007	0.036*
TS (mg/L)	58	654	157±7	183±16	143±7	1.27	0.272
TSS (mg/L)	16	620	106±7	139±16	90±5	2.382	0.137
pH	6.40	7.83	7.17±0.02	7.00±0.03	7.26±0.02	16.38	0.0005***
Conductivity (µS/cm)	51.9	695.0	88.3±4.7	76.7±1.5	94.9±7.0	0.9923	0.331
Total alkalinity (mgCaCO$_3$/L)	18	210	32±2	27±1	34±3	1.232	0.279
Total acidity (mgCaCO$_3$/L)	5	56	17±6	14±1	18±1	2.708	0.116
Total hardness (mgCaCO$_3$/L)	13.0	90.00	23.8±0.8	21.7±0.8	24.8±1.1	2.401	0.136
TDS (mg/L)	30	353	51±3	44±1	54±4	1.045	0.319
Ca^{2+} (mg/L)	4.76	36.00	7.41±0.28	6.54±0.14	7.85±0.41	1.708	0.206
Mg^{2+} (mg/L)	0	5.32	1.24±0.10	1.26±0.16	1.24±0.13	0.0248	0.877
Na^+ (mg/L)	2.24	28.47	4.77±0.19	4.12±0.13	5.09±0.27	2.281	0.147
K^+ (mg/L)	2.46	54.86	3.21±0.32	3.91±0.14	4.32±0.48	0.188	0.669
Cl^- (mg/L)	3.00	36.46	5.64±0.25	4.86±0.16	6.03±0.36	1.714	0.205
SO_4^{2-} (mg/L)	0.00	13.70	5.98±0.20	5.32±0.29	6.30±0.27	2.574	0.124
HCO_3^- (mg/L)	21.6	252.0	38.2±2.2	32.8±1.2	40.9±3.2	1.215	0.282
DO (mg/L)	2.8	9.6	6.9±0.1	7.3±0.2	6.8±0.1	2.216	0.152
DO saturation (%)	34.9	124.4	87.3±1.0	94.2±2.0	83.9±1.0	4.773	0.040*
BOD_5 (mg/L)	1.0	5.0	2.5±0.1	2.3±0.1	2.6±0.1	4.879	0.039*
Organic Matter (mg/L)	0.49	5.83	2.05±0.09	2.61±1.10	1.77±1.16	5.767	0.026*
NO_3^- (mg/L)	0.00	4.10	0.81±0.04	0.78±0.07	0.82±0.04	0.0008	0.934
PO_4^{3-} (mg/L)	0.08	0.39	0.21±0.004	0.22±0.01	0.20±0.01	3.087	0.093
Fe (mg/L)	0.005	1.413	0.401±0.018	0.401±0.028	0.403±0.021	0.1435	0.709
Cu (mg/L)	0.013	0.054	0.033±0.001	0.030±0.001	0.034±0.001	2.779	0.111
Mn (mg/L)	0.000	0.046	0.014±0.001	0.014±0.001	0.014±0.001	0.0015	0.970
Zn (mg/L)	0.000	0.057	0.005±0.001	0.005±0.001	0.004±0.001	0.2787	0.603

*: Significant; **: very highly significant

observed among the parameters as shown in Fig. 2 ($p<0.05$). The first cluster was among conductivity, total alkalinity, total dissolved solids, total acidity, total hardness, Ca^{2+}, Na^+, K^+, Cl^-, HCO_3^- and BOD_5. Organic matter, $NO3^-$, PO_4^{3-}, apparent colour, true colour, TS, TSS and turbidity formed the second cluster while the third one was between Mg^{2+} and Zn. The fourth cluster was among SO_4^{2-}, Fe, DO, DO saturation, water depth and water transparency, while pH and water transparency formed the last cluster. DO showed very highly significant inverse correlation ($p<0.001$) with organic matter, nitrate and phosphate and also showed very highly significant positive correlation ($p<0.001$) with DO saturation and sulphate. Very high significant correlations ($p<0.001$) were observed among some major ions and general chemical characteristics (conductivity, total alkalinity, total dissolved solids, total acidity, Ca^{2+}, Mg^{2+}, K^+, Cl^-, HCO_3^-). A similar observation ($p<0.001$) was made among some hydro-physical parameters (TS, TSS, apparent colour and turbidity). pH showed inverse correlations with three heavy metals (Cu, Zn and Mn), although only two were significant (Cu & Zn), respectively. A significant positive correlation ($p<0.05$) however existed between pH and Fe.

Sodium absorption ratio and water quality index: Sodium absorption ratio (SAR) values and water quality indices in the sampled stations are provided in Table 4. SAR values were generally less than 1 and typically decreased from the riverine section towards the dam site. Water quality index values were comparatively lower at the riverine section (Stations A and E) and increased along the horizontal axis of the lake to the highest value at both the dam site (Station D) and the nearer mid-basin station to the dam site (Station C).

Characterization of the lake in relation to the conventional standards of some physico-chemical water quality parameters: Table 5 compares some physico-chemical water quality parameters of the lake with conventional standards (World Health Organization, European Union and Nigerian Industrial Standard) and maximum limits for different uses i.e., drinking water and fisheries/aquatic life. Virtually all

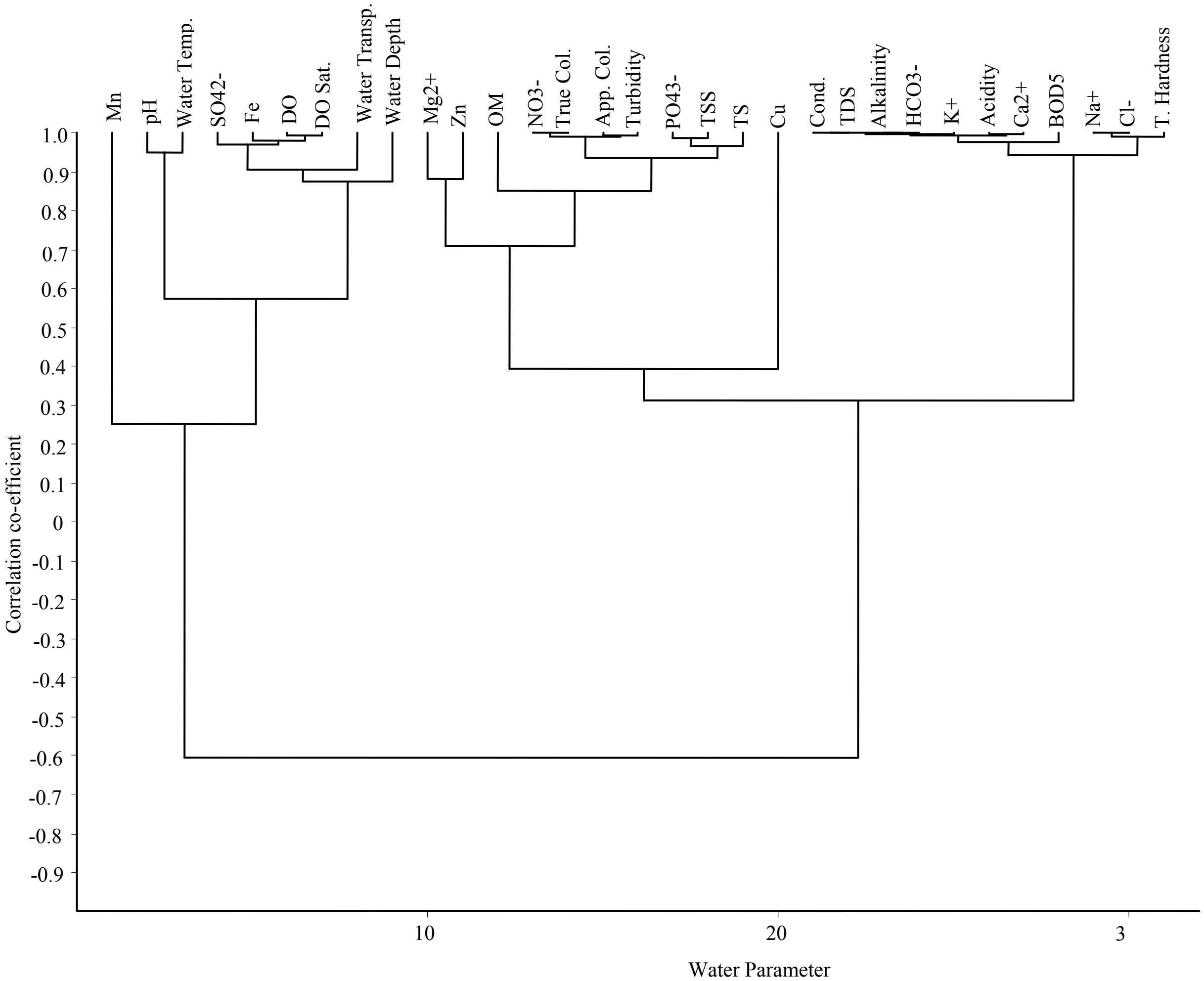

Fig. 2: Cluster analysis showing the relationship among the investigated physico-chemical water parameters ($p<0.05$, $r = 0.5529$; $p<0.01$, $r = 0.6835$; $p<0.001$, $r = 0.8010$)

Table 4: Sodium absorption ratio values and water quality indices in the sampled stations

		Sampling station/water quality index (Q)				
Factor	Weight	A	B	C	D	E
Dissolved oxygen saturation (%)	0.20	76	98	99	99	87
Biological Oxygen Demand (mg/L)	0.13	72	76	72	72	65
pH	0.13	89	92	93	93	93
Temperature change (°C)	0.12	36	36	36	36	34
Nitrate (mg/L)	0.12	96	96	96	97	96
Phosphate (mg/L)	0.12	82	93	93	93	91
Turbidity (NTU)	0.10	5	46	60	63	51
Total Solids (mg/L)	0.08	58	81	82	83	63
Overall water quality index (%)	1.00	67	80	81	81	75
Sodium absorption ratio		0.4953	0.3899	0.3828	0.3683	0.6370

Table 5: Comparison of the physico-chemical water quality of Lake Tiga with conventional standards

		Use			
		Drinking water		Fisheries/aquatic life	
Parameter	Value	W.H.O standard*	Nigerian standard**	*E.U. standard	W.H.O. standard*
Dissolved Oxygen (mg/L)	6.9	-	-	5.0-9.0	5.0-10.0
Biological oxygen demang (mg/L)	2.5	-	-	3.0-6.0	<2.0 (unpolluted)

Table 5: Continue

Nitrate (mg/L)	0.81	<50	<50	-	<1.0
Turbidity (NTU)	42.4	<5	<5	-	-
pH	7.17	<8.0	6.5-8.5	6.0-9.0	6.0-8.5
Total dissolved solids (mg/L)	51	<1000	<500	-	-
Total Alkalinity (mg$CaCO_3$/L)	32	-	-	-	>24
Total Hardness (mg$CaCO_3$/L)	23.76	-	<150	-	-
Ca^{2+} (mg/L)	7.41	-	-	-	<15.0
Na^{+} (mg/L)	4.77	<200	<200	-	<50.0
K^{+} (mg/L)	3.21	-	-	-	<10.0
Fe (mg/L)	0.401	<0.30	<0.30	-	-
Mn (mg/L)	0.014	<0.50	<0.20	-	-
Zn (mg/L)	0.005	<3.0	<3.0	0.03-2.0	-
Cu (mg/L)	0.033	<2.0	-	0.005-0.112	-
Cl^{-} (mg/L)	5.64	<250	-	-	<10.0
SO_4^{2-} (mg/L)	5.98	<250	<100	-	2-80

*: Chapman and Kimstach (1996); **: Standards Organization of Nigeria (2007)

the parameters complied with the above-mentioned standards except iron and turbidity in the case of drinking water quality.

DISCUSSION

The lowest ambient air temperature and water temperature were recorded in the middle of the dry season due to the characteristic cool dry North-East trade wind known as Harmattan between November and February. This pattern of seasonal variation has similarly been reported in Northern Nigeria by Balarabe (1989) in Makwaye Lake, Adakole *et al*. (1998) in Bindare stream, Ezra and Nwankwo (2001) in Gubi Reservoir, Ajibade *et al*. (2008) in the major rivers of Kainji Lake National Park and Adakole *et al*. (2008) in Kubanni Lake. Horizontal increase in surface water temperature was a function of the time of sample collection. Collection of water samples started early in the morning from the riverine section (Stations A and E), followed by the lacustrine section (Stations B, C and D) in the afternoon. This diel surface water temperature pattern of the lake is in agreement with Chapman and Kimstach (1996) who stated that water temperature is not only influenced by seasonality but also by time of the day. Water temperature determines the concentration of many variables. As water temperature increases, the rate of chemical reactions generally increases together with the evaporation and volatilization of substances. Increased temperature also decreases the solubility of gases, such as O_2, CO_2, N_2 and CH_4. The metabolic rate of aquatic organisms is also related to temperature and in warm waters, respiration rates increase leading to increased oxygen consumption and increased decomposition of organic matter (Chapman and Kimstach, 1996).

The on-set of the rain signals a radical change in the physico-chemical characteristics of tropical rivers (Chapman and Kramer, 1991), as evidenced in this study. Allochthonous sediments from run-off which have the capacity to further attenuate incident solar radiation could be the main reason for the lower values of water transparency recorded in the rainy season. Ayoade *et al*. (2006) in their study of Oyan and Asejire Lakes also observed lower water transparency in the rainy season and attributed this to decrease in sunlight intensity caused by the presence of heavy cloud in the atmosphere which in turn reduced the quantity of light reaching the water. Secchi disc transparency values (0.05 m-0.95 m) in this study put the lake in the eutrophic class, following Wetzel (1983) classification of lakes i.e., eutrophic lakes have 0.8 m-7.0 m Secchi disc readings, while oligotrophic and mesotrophic lakes have 5.4 m-28.3 m and 1.5 m-8.1 m, respectively. The highly significant positive correlation ($p<0.01$) between transparency and Dissolved Oxygen (DO) is further strengthened by the increase of both parameters from the upper basin down to the lower basin. This may be attributed to the sedimentation of suspended solids in the lower basin and the deeper layers. This must have consequently increased the penetration depth of incident solar radiation as well as the euphotic zone of the water body, hence the increased concentration of DO towards the dam site.

Biological respiration, including that related to decomposition processes, reduces DO concentrations. Waste discharges high in organic matter and nutrients can also lead to decreases in DO concentration as a result of increased microbial activity occurring during the degradation of the organic matter (Chapman and Kimsatch, 1996). Biological oxygen demand (BOD_5), a measure of biological activities taking place in the water was higher in the dry season than in the rainy season in spite of a higher organic matter in the rainy season. This was probably as a result of a high presence of inundated woody trees in the lake in addition to the accumulated detritus of the rainy season, whose rate of decomposition would be greatly favored by the relatively high temperature of the dry season. This also suggests that the BOD_5 is not only dependent on the concentration of organic matter in a water body but also on water temperature.

TSS contributed more to the TS load than the TDS (67.5 and 32.5% respectively). Olofin (1991) had also reported high sediment yield in the main rivers of Kano and a rapid siltation in the reservoirs. This could be attributed to the characteristic nature of the Sahel vegetation zone with widely-spaced trees and the consequent reduced capacity to check allochthonous run-off. McCartney *et al*. (2001) also opined that high suspended sediment load in the arid tropics could be as a result of sparse vegetation in the area, which fails to prevent erosion by intense seasonal rainfall. The role of rainfall and allochthonous input in the concentration of hydro-physical and nutrient parameters is underscored by the significant positive correlations ($p<0.05$) among apparent color, turbidity, NO_3^- and PO_4^{3-} and their higher concentrations (save NO_3^-) in the rainy season. Nitrate level in the lake was typical of freshwaters with the overall mean concentration <1.0 mg/L and the maximum concentration <5.0 mg/L (Chapman and Kimstach, 1996). Nitrate was the only nutrient compound with higher concentration in the dry season while its maximum concentration was also recorded just at the beginning of the rainy season (June 2010). This agrees with Wolfhard and Reinhard (1998) that nitrates are usually built up during dry seasons and that high levels of nitrates are only observed during early rainy season. Adeyemo *et al*. (2008) also stated that initial rains flush out deposited nitrates from near-surface soils and nitrate level reduces drastically as rainy season progresses.

Based on phosphate concentration, Tiga Lake can be categorized as a meso-eutrophic lake. Overall mean and range values of PO_4^{3-} concentration in the lake (0.21 mgL^{-1} and 0.08-0.39 mg/L respectively) exceeded the mean and range values of mesotrophic lakes (0.08 mg/L and 0.03-0.29 mg/L, respectively) but were less than the corresponding values in eutrophic lakes (0.25 mg/L and 0.05-1.18 mg/L) (Wetzel, 1983).

pH limits in the lake (6.40-7.83) exceeded the limits (6.9-7.6) reported by Adeniji and Ita (1977) in the preliminiary limnological study of the lake. They were however still within the EU recommended range of 6 to 9 for fisheries and aquatic life (Chapman and Kimstach, 1996) and the WHO pH guideline (<8.0) for drinking water for effective disinfections with chlorine (WHO, 1993). These pH values suggest that the water is suitable for drinking (after disinfections) and aquatic life. The disparity between pH readings in the upper basin stations and the lower basin stations suggests that the former are slightly acidic. This may not be unconnected with the higher concentration of organic matter in the upper basin stations and the consequent release of CO_2 gas during decomposition, as shown in the significant inverse correlation ($p<0.05$) between pH and organic matter. Low pH increases the solubility and toxicity of many chemical nutrients and heavy metals (DAWF, 1966; Chapman and Kimstach, 1996), which was the reason for the inverse relationships of pH with NO_3^-, PO_4^{3-} Cu, Zn and Mn. There appeared to be a strong relationship between metals, suspended solids, pH and organic matter as evidenced in the significant correlations ($p<0.05$) among these parameters. This shows that metals tend to be strongly associated with sediments in rivers, lakes and reservoirs and their release to the surrounding water is largely a function of pH, oxidation-reduction state and organic matter content of the water (Carr and Neary, 2006).

Conductivity values (51.9-695.0 μS/cm) in the lake were typical of a freshwater since the electrical conductivity of most freshwater ranges from 10-1,000 μScm^{-1} (Chapman and Kimstach, 1996). Virtually all the major ions were lower in the rainy season than in the dry season since conductivity declines in the wet periods as the concentration of salts becomes more dilute (Carr and Neary, 2006). There were inverse correlations between the major ions (save SO_4^{2-}) and water depth. This corroborates the claims of Schmidt (1973), Hamilton and Lewis (1987) and Vasques (1992) that water level fluctuation increases or decreases water transparency, pH, electrical conductivity, suspended matters, concentrations of nutrients and other variables. Concentration effects of salts at this period of the year when the water level was low (Holden and Green, 1960; Egborge, 1981; Moore, 1989; Michaud, 1991; Ovie and Adeniji, 1994) and water abstraction for dry season irrigation (Smakhtin *et al*., 2003) could have also contributed to the higher values of these ions in the season. The concentrations of Ca^{2+}, Mg^{2+}, Na^+ and K^+, Cl-, SO_4^{2-} and HCO_3^- were all typical of freshwaters (Chapman and Kimsatch, 1996), although relatively high concentrations of these parameters were recorded in an upper basin station (E) between December 2009 and March 2010. The lake can be categorized as a soft water since its total hardness was less than 120 mg $CaCO_3$/L (Renn, 1968). The mean total hardness (23.76 $mgCaCO_3$/L) however fell short of the optimal range (75-250 mg $CaCO_3$/L) for aquatic life, though above the minimum concentration of 20 mg $CaCO_3L^{-1}$ (Wurts, 1992). The mean total alkalinity concentration (32 $mgCaCO_3L^{-1}$) of the lake was also above the minimum of 20 $mgCaCO_3L^{-1}$ required for aquatic life and this will also prevent large swings in its daily pH values (Wurts and Masser, 2004). Conductivity, total alkalinity, hardness, total dissolved solids and most of the major ions (Ca^{2+}, Mg^{2+}, Na^+, K^+, SO_4^{2-}, HCO_3^-, Fe, Mn and Zn) showed an increasing trend up to about 10 m depth and then showed a decline. This is probably because water is being let out close to this depth since the main outlet of the dam is submerged 16 meters below the full supply level (Hadejia-Jama'are River Basin Development Authority, 1989).

Sodium Absorption Ratio values in all the stations were generally less than 1 and decreased from the upper basin (inflows) down to the lower basin (dam site), from where the water is being let out for the Kano River irrigation project. Water quality index (Q) increased from the inflow stations towards the dam site. The overall water quality index recorded in this study (76%) implies that Lake Tiga is still good for intended uses (Oram, 2012).

CONCLUSION

Lake Tiga is low in electrical conductivity and may also be categorized as a soft water. Comparatively, the physico-chemical nature of the lacustrine section of Lake Tiga was distinctively different from that of its riverine section. Water quality increased while sodium absorption ratio decreased from the riverine section towards the dam site. This also suggests that the lake undergoes self-purification process as water flows downstream towards the dam site and as suspended solids are deposited in the deep layers. This study has revealed that Lake Tiga is still suitable for intended applications, namely irrigation, fisheries and aquatic life.

The various physico-chemical indices of water quality in the lake suggest that it is less impacted by human activities, obviously because it is some distance (about 70 km) upstream of the commercial and industrial city of Kano. However, the sediment load of the reservoir was relatively high and successive loading can accelerate its aging process. Adequate monitoring of the water quality and regulation of anthropogenic activities in and around the basin are recommended in order to slow down the aging process of the lake and conserve it for a longer period.

ACKNOWLEDGMENT

We wish to thank the management and staff of Hadejia Jama'are River Basin Development Authority (HJRBDA) for granting us approval to work on Lake Tiga, and access to their library at HJRBDA Headquarters, Kano. The collaboration of the Department of Biological Sciences, Bayero University, Kano is also well appreciated, particularly Dr. Y. K. Mustapha and Messrs Hassan, Yusuf and Yakub.

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