Assessment of the Water Quality of Oyun Reservoir, Offa, Nigeria, Using Selected Physico-Chemical Parameters

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Abstract

The variations in selected physico-chemical factors were investigated for two years to determine the water quality of Oyun Reservoir, Offa, Kwara State, Nigeria for drinking and fish production. Three stations were chosen on the reservoir to reflect the effect of human activities, lacustrine and lotic habitats. Temperature, transparency, pH, conductivity, total dissolved solids, dissolved oxygen, nitrate, phosphate, chemical oxygen demand, total alkalinity, total hardness, calcium, magnesium, silica, sulphate, carbon dioxide were analyzed monthly between January 2002 and December 2003 using standard methods and procedures. The ranges of these factors were found to be comparable to those reported for other African reservoirs except for nitrogen and phosphate which were found in higher concentration above freshwater limits. Run-off of nitro-phosphate and sulphate fertilizers from nearby farm lands and washing of cows dungs from the watershed into the reservoir were found to have caused cultural eutrophication in the reservoir. The eutrophication was pronounced at Station 1 due to impact of human activities on the watershed, and with time, it will affect the water quality and fish production in the reservoir. The study concludes that Oyun reservoir has excellent water quality, high ecological status and passes chemical status. Eutrophication which was noticed to be a threat to the water quality should be arrested at the nick of time through denitrification and nutrient control to halt the degradation of the water.

Key words: Eutrophication, Fertilizers, Ecology, Total Dissolved Solids, Fish production.

Introduction

Expanding human population brought about by the opportunities of good water supply, irrigation, fish production recreation and navigation offered by Reservoirs has put enormous pressure and stress on the quality of water impounded by the reservoir. The impact of human activities in and around the reservoir is felt on the unique physical and chemical properties of water on which the sustenance of fish that inhabit the reservoir is built as well as to the functions of the reservoir. Water quality is determined by the physical and chemical limnology of a reservoir (Sidnei *et al.*, 1992) and includes all physical, chemical and biological factors of water that influence the beneficial use of the water. Water quality is important in drinking water supply, irrigation, fish production, recreation and other purposes to which the water must have been impounded.

Water quality deterioration in reservoirs usually comes from excessive nutrient inputs, eutrophication, acidification, heavy metal contamination, organic pollution and obnoxious fishing practices. The effects of these “imports” into the reservoir do not only affect the socio-economic functions of the reservoir negatively, but also bring loss of structural biodiversity of the reservoir. Djukic *et al.* (1994) have used the physico-chemical properties of water to asses the water quality of a reservoir. The use of the physico-chemical properties of water to assess water quality gives a good impression of the status, productivity and sustainability of such water body. The changes in physical characteristics like temperature, transparency and chemical elements of water such as dissolved oxygen, chemical oxygen demand, nitrate and phosphate provide valuable information on the quality of the water, the source(s) of the variations and their impacts on the functions and biodiversity of the reservoir.

This study aimed at assessing the water quality of an African tropical reservoir for drinking and fish production using some selected physico-chemical properties. The results will form the baseline for monitoring and tracking changes in the water quality as a result of the reservoir’s natural dynamics over time or impact of men’s activities on the reservoir and its water shed.

Materials and Methods

Description of the Study Site

Oyun Reservoir is located at Offa, Kwara State, Nigeria, longitude 08°30' N and latitude 08°15' E. It’s a dam reservoir on Oyun River, created to supply portable water for domestic and industrial uses to an estimated population of about 300,000 people. Subsistence and commercial fishing activities are also carried out on the reservoir. The reservoir has a maximum length of 128 m, maximum width of 50 m and maximum depth of 8.0 m, mean depth of 2.6 m. The surface area is 6.9 x 10^5 m^2 while the water volume is 3.50 x 10^6 m^3. The net water storage capacity is 2.9 x 10^6 m^3. The water retention time is between 3–4 months in the raining season, while the water residence time in the dry season is few days due to high evaporation (Figure 1).

Stations and Sampling

Duplicate surface water samples were collected from 10 cm depth monthly from three stations for two years between January 2002 and December 2003. Station 1 was at the dam axis where a lot of human activities such as washing, bathing, fish landing take place. Station 2 was at the mid-section of the reservoir which represented the area of lentic water, while Station 3 was at the head water of the reservoir which represented the lotic section of the reservoir. Surface water temperature, pH, electrical conductivity (EC) and total dissolved solids (TDS) were measured *in situ* using Hanna portable pH/EC/TDS/temperature combined water proof tester model HI 98129. The following factors selected as water quality parameters were measured using the methods described for each factor as follows. Transparency was evaluated by extinction method using the secchi disc; dissolved oxygen was determined by Azide modification of the Winkler method; chemical oxygen demand was measured using the dichromate reaction method (Hach, 2003); carbon dioxide, total alkalinity, total hardness and calcium hardness were determined by titration method (APHA, 1995). Magnesium hardness was derived by subtracting calcium hardness value from total hardness value (Lind, 1979). Nitrate, phosphate, sulphate and silica were measured according to APHA (1995) standard procedures using Hach spectrophotometer model DR-EL/2. All the analyses were done at the water quality laboratory of Kwara State Utility Board, Ilorin, Nigeria.

Statistical Analyses

GLM procedure of statistical analysis system 9.1.3 (SAS Institute, 2003) was used to analyze the results. Monthly mean difference of each duplicate parameter was compared using two –way ANOVA at $P<0.05$ to see the variations due to stations, seasons and years.

Results

The mean monthly variation in the surface water temperature of the three stations is presented in Figure 2. The temperature ranged between the lowest value of 23.1±0.5°C obtained from Station 2 in September and the highest of 29.6±0.1°C obtained from Station 3 in March, 2003. Dry season temperature was significantly higher ($P<0.05$) than the wet season. No significant difference was seen among the stations and in two years. Secchi disc transparency was the highest at Station 1 with a mean value of 1.62±0.32 m obtained in March 2002. Station 3 recorded the least secchi disc transparency value with a mean of 0.62±0.8 m obtained in August of 2003 (Figure 3). During the dry season, Station 2 and year 2002 had

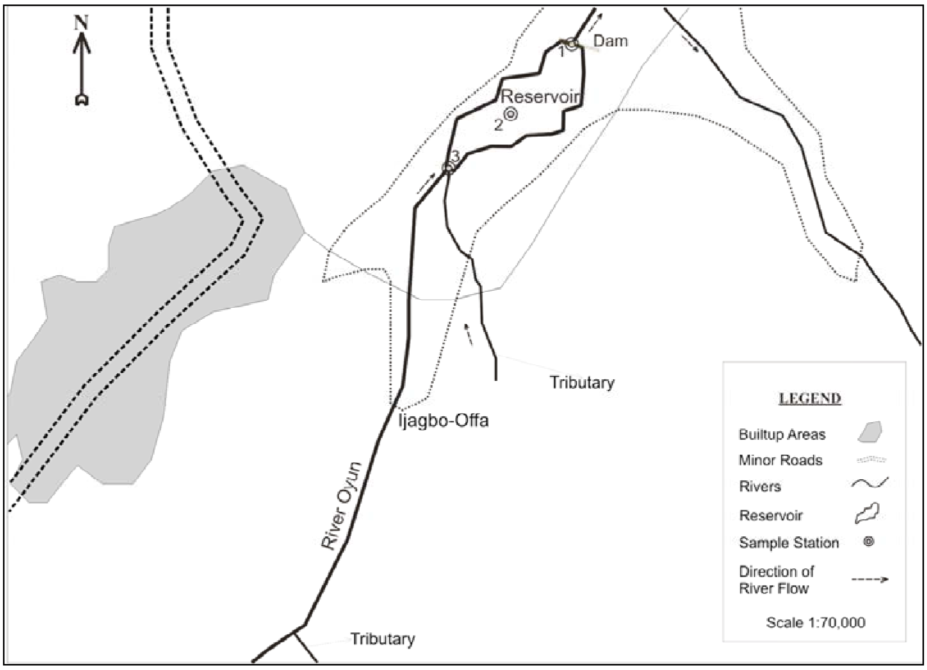

Figure 1. Map of Oyun Reservoir showing the sampling stations.

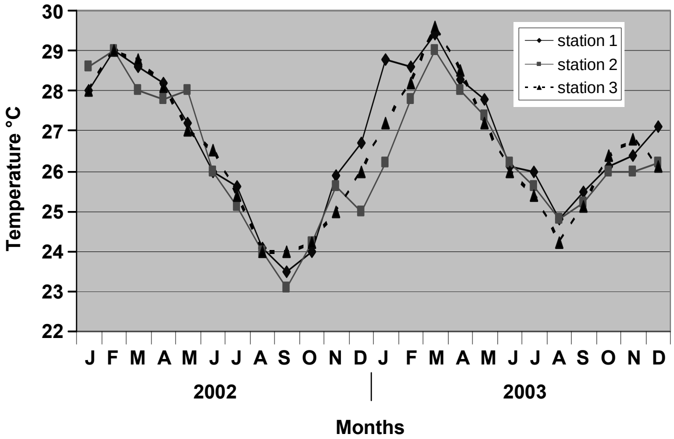

Figure 2. Monthly mean variations in the surface water temperature of Oyun Reservoir.

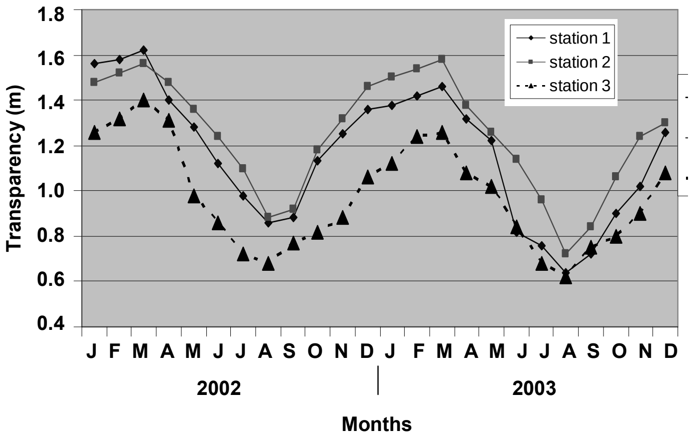

Figure 3. Monthly mean variations in Secchi disc transparency of Oyun Reservoir.

significantly higher transparency (P<0.05).

Dissolved oxygen fluctuated between the lowest monthly mean of 4.8±0.25 mg/L obtained in February and March 2003 from Station 1 and the highest monthly mean of 8.2±0.31 mg/L recorded in June 2002 from Station 2 (Figure 4). Statistical difference at P<0.05 was noticed in the dissolved oxygen concentration among the stations, (with Station 2 having the highest concentration) season, (the wet season values were significantly higher than the values of the dry season) and years (2002 had a higher concentration than 2003). Chemical oxygen demand (COD) varied between 1.2±0.1 mg/L and 2.6±0.2 mg/L COD was significantly higher in the dry season with Station 1 recording the highest concentration and Station 3 recording the lowest concentration in the wet season (Figure 5). There was no statistical difference in COD between the two years of study. Carbon dioxide and total alkalinity showed similar pattern in their concentration among the stations and in the seasons. The two factors were statistically higher in the dry season as well as at Station 3. Carbon dioxide ranged between monthly mean of 1.6±0.2 mg/L to 3.0±0.6 mg/L (Figure 6), while total alkalinity fluctuated between monthly mean of 30±2.6 mg/L and 55±3.4 mg/L (Figure 7).

The total hardness value in the reservoir, which is the sum of calcium and magnesium hardness concentrations, was found to be significantly higher in the wet season. This was the same for calcium and magnesium ions. Station 3 showed significantly higher concentration of total, calcium and magnesium hardness than the other stations. The mean monthly range of the total hardness (32±0.5 mg/L – 68±1.4 mg/L), calcium hardness (20±0.1 mg/L – 44±1.8 mg/L) and magnesium hardness (10±0.4 mg/L – 28±0.6 mg/L) are presented in Figures 8, 9 and 10 respectively. There was no significant difference in the concentration of these ions between the two years.

The highest monthly mean concentration of nitrate recorded was 6.4±0.3 mg/L which was obtained from Station 1 at the peak of the rains in August 2003. A decrease was observed in the dry season with the lowest concentration of 1.4±0.1 mg/L recorded from Station 3 in October 2003 (Figure 11). ANOVA at P<0.05 shows significant difference in the

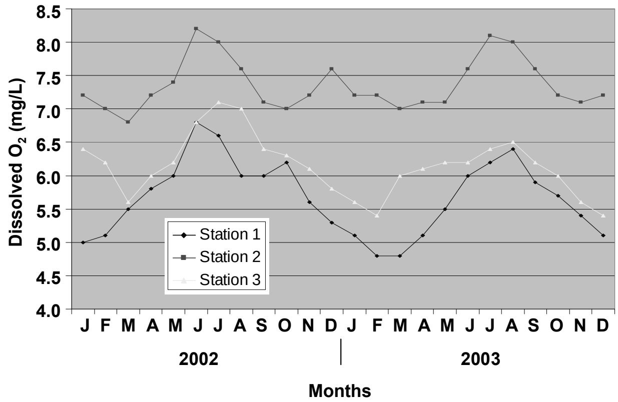

Figure 4. Monthly mean variations in dissolved oxygen concentration of Oyun Reservoir.

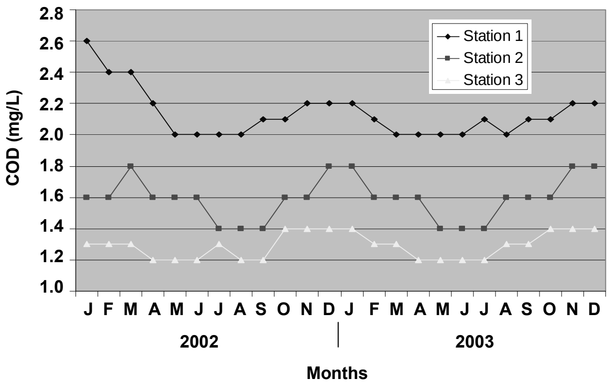

Figure 5. Monthly mean variations in COD of Oyun Reservoir.

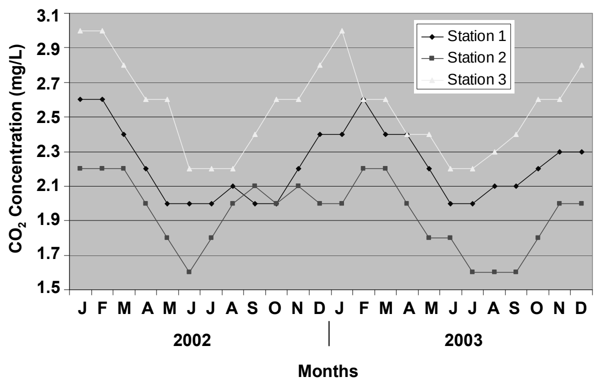

Figure 6. Monthly mean variations in carbon dioxide concentration of Oyun Reservoir.

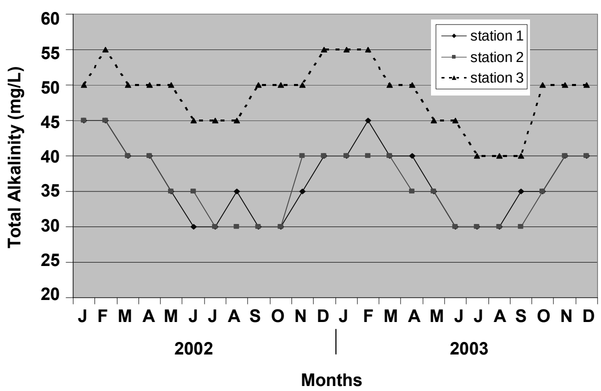

Figure 7. Monthly mean variations in total akalinity of Oyun Reservoir.

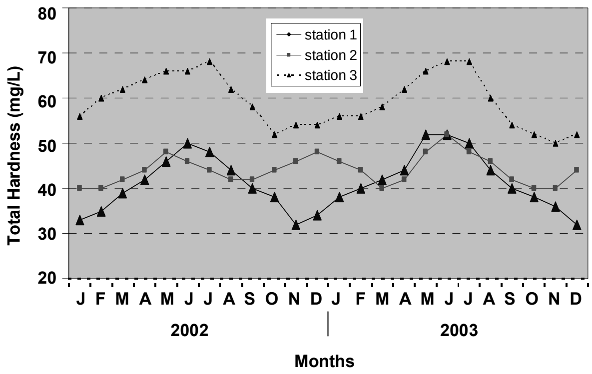

Figure 8. Monthly mean variations in total hardness concentration of Oyun Reservoir.

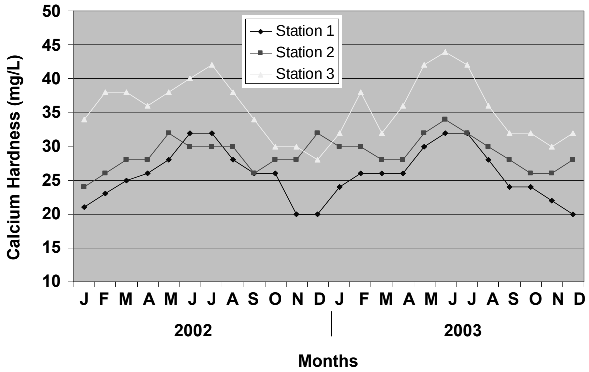

Figure 9. Monthly mean variations in calcium hardness of Oyun Reservoir.

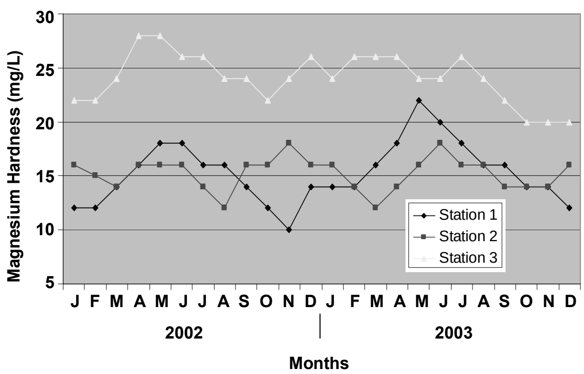

Figure 10. Monthly mean variations of magnesium hardness in Oyun Reservoir.

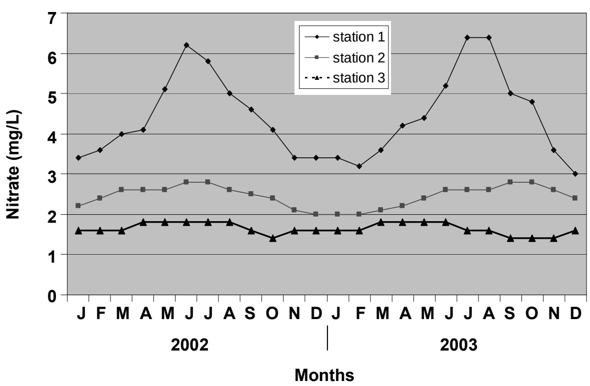

Figure 11. Monthly mean variations in nitrate concentration of Oyun Reservoir.

nitrate concentration during the seasons and within the stations. Nitrate was higher in the rainy season and the order of magnitude in the concentration among the stations was Stations 1 > 2 > 3. Phosphate had the least concentration among the ions. It ranged between 0.7±0.0 mg/L to 2.2±0.2 mg/L (Figure 12). Like nitrate, phosphate concentration was significantly higher in rainy season at Station 1 (P<0.05). No significant difference occurred between the years of study in nitrate and phosphate concentrations.

The fluctuations in sulphate concentration are shown in Figure 13. Sulphate concentration was the lowest at 9±0.2 mg/L at the beginning of the study at Station 1, it gradually increased until a maximum concentration of 16.9±0.45 mg/L was recorded at Station 3. Sulphate was significantly higher in the wet season, while the order of higher concentration among the stations was Station 3 > 2 > 1. No difference occurred within the years. The maximum monthly mean concentration of silica was 60±0.6 mg/L recorded from Station 3 in July 2003, while Station 1 recorded the lowest value of 30±0.2 mg/L in December 2002 (Figure 14). The silica levels were significantly different (P<0.05) among the stations and seasons. Silica was more abundant in the rainy season and Station 3 recorded the highest concentration among the stations. No difference was recorded among the years. The surface water pH fluctuated between slight acidity and moderate alkalinity. The lowest monthly mean pH was 6.8±0.05 obtained at Station 3 during the dry season in January 2002, while the highest was 8.2±0.2 obtained from Station 2 in August and September of 2003 (Figure 15). At Station 3, the pH was in the neutral range for most of the study period. No acidic pH was recorded from Station 2; it was either neutral or alkaline for most part of the study. ANOVA (P<0.05) showed pH to be statistically higher during the wet season than in the dry season and pH of Station 2 was significantly higher than the other stations. No difference was noted between the two years.

The monthly mean variations in electrical conductivity and total dissolved solids followed similar trend. There was slight variation in conductivity and TDS in Station 1, which recorded the lowest value of conductivity (80.4±0.8 μs/cm) and TDS (53.9±0.8 mg/L) in December 2002. And Station 3 recorded the highest variation and concentration of conductivity and TDS with the highest value of conductivity (178.8±2.0 μs/cm) and TDS (119.8±2.0 mg/L) obtained in July 2002 (Figures 16 and 17). Both electrical conductivity and TDS showed significant differences in their concentrations among the seasons and stations. The two factors were statistically higher during the rainy season, while the

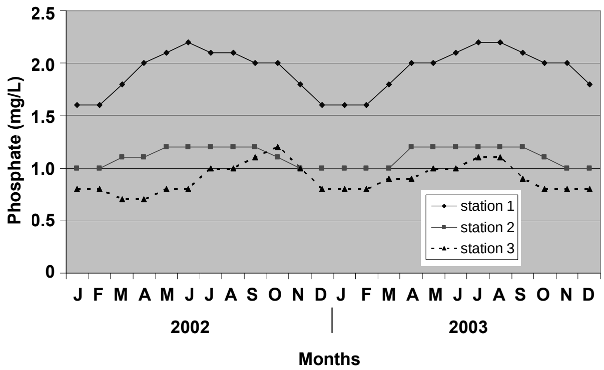

Figure 12. Monthly mean variations in phosphate concentration of Oyun Reservoir.

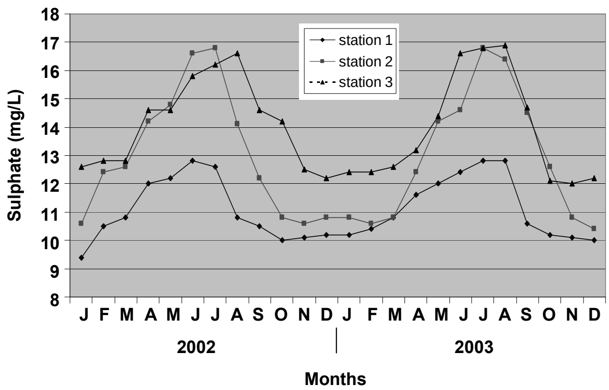

Figure 13. Monthly mean variations of sulphate concentration in Oyun Reservoir.

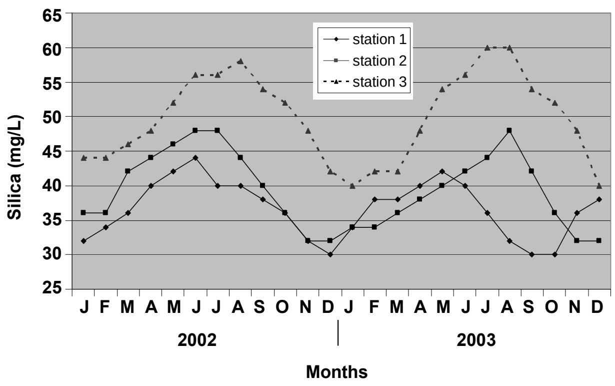

Figure 14. Monthly mean variations of silica in Oyun Reservoir.

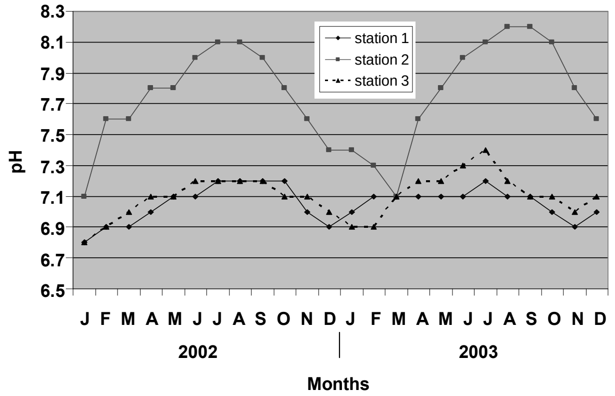

Figure 15. Monthly mean variations in pH of Oyun Reservoir.

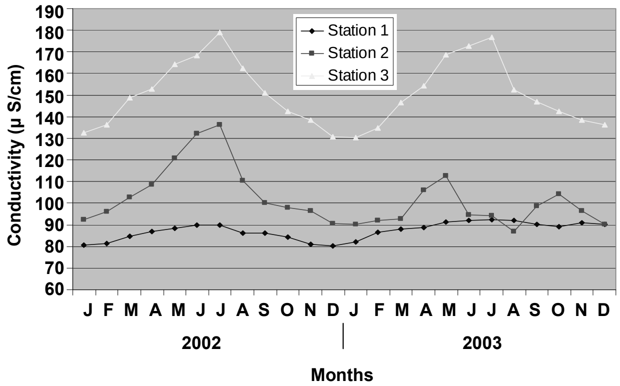

Figure 16. Monthly mean variations in conductivity of Oyun Reservoir.

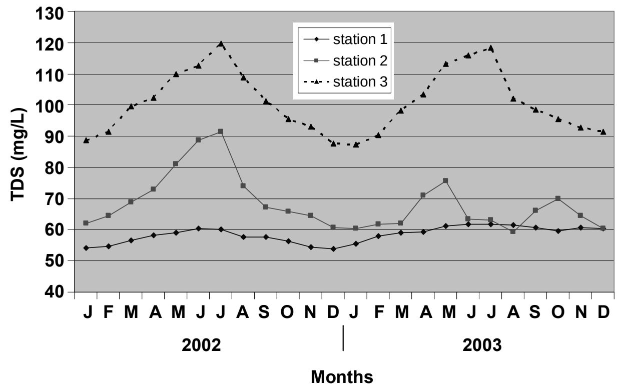

Figure 17. Monthly mean variations of TDS in Oyun Reservoir.

order of significant difference between the stations was Station 3 > 2 > 1.

Discussion

The physical and chemical factors investigated in this research have been used to assess the water quality of some African reservoirs (Nhiwatiwa and Marshall, 2007). The surface water temperature range was similar and compares well with the ranges reported for other African reservoirs (Talling, 1969). Meteorological conditions such as trade winds, sunshine durations and absorption of the solar radiation by the shallow reservoir water body might be responsible for the monthly variations and significant differences seen between the seasons. The temperature variations in the reservoir were normal for metabolic activities of organisms such as fish as reported by Boyd and Lichtkoppler (1979) and will not affect the water quality for drinking or fish production.

Secchi disc transparency was low in the rainy season at Station 3. This could be due to the washing of silts, sediments, debris, organic and inorganic suspended particles into the reservoir of which Station 3 (riverine) received the highest run-off of these particles. High flood water of 2003 which brought in more sediment may account for the significant difference in transparency of the two years. Gliwicz (1999) noted that increased turbidity is associated with rainy seasons that bring in clay and other particles from the water shed. Higher transparency in the dry season may be due to settling of the particles at the bottom of the reservoir, while the highest transparency recorded in Station 2 could be attributed to the stations' transition state between lentic and lotic habitations. The range of secchi disc visibility, 0.62 m to 1.62 m, reflects the depth of light penetration and this is good for a shallow reservoir as plankton and fish will thrive in this pelagic region, thus making food available to fish.

Dissolved oxygen is an important indicator of water quality, ecological status, productivity and health of a reservoir. This is due to its importance as a respiratory gas, and its use in biological and chemical reactions. Higher dissolved oxygen recorded in the rains could be as a result of low temperature and increased mixing of water. Tepe and Mutlu (2005) linked increase in dissolved oxygen in a reservoir in Turkey to high run-offs occurring during the rainy season. The highest dissolved oxygen concentration recorded at Station 2 was a good pointer to the fact that the station is the most productive, with the highest water quality parameters and will support diverse organisms. Significantly lower dissolved oxygen in 2003 might be due to higher turbidity and increased suspended materials which affected dissolution of oxygen. This occurred from the high flood water of 2003 which brought in so much sediment. Human activities and high rate of decomposition at Station 1 might be accountable for the low dissolved oxygen concentration of the station. High temperature coupled with high rate of decomposition in the dry season may explain the low dissolved oxygen concentration recorded in the dry season. The range of dissolved oxygen recorded 4.8mg/L – 8.2 mg/L shows the water to be of good quality and will support fish production. Boyd (1979) reported that dissolved oxygen concentration of 3 mg/L to 12 mg/L will promote the growth and survival of fish in reservoirs.

The mean range of chemical oxygen demand for (1.2 mg/L – 2.6 mg/L) fell within permissible level for drinking water and fish production (Hach, 2003). APHA (1995), however, recommended COD levels of <2 mg/L in drinking water. High COD has been linked with pollution (Tepe *et al*., 2005). The high COD level at Station 1 and in the dry season could have occurred due to high rate of organic decomposition resulting from human activities on the watershed which produce sewage and agricultural run-offs into the reservoir and this have negative impact on the water quality.

Organic decomposition, respiration, photosynthesis, diffusion and run-offs could account for the variations seen in the carbon dioxide levels. Higher CO_2 in the dry season agrees with Renn (1968) observation that CO_2 is released at high levels during low oxygen production. The mean range of CO_2 is within tolerable limit for fish production since it did not exceed 10 mg/L (APHA, 1995). The total alkalinity of the reservoir is a reflection of its carbonates and bicarbonate profiles (Wetzel, 2001) with the likelihood of silicates and phosphates contributing to it. This is so; because phenolphthalein alkalinity was absent in the reservoir (Campbell and Wildberger, 2001). Higher concentration of total alkalinity in the dry season and at Station 3 could be due to higher carbon dioxide concentration and release of bicarbonates ions by sediments. The mean range of the total alkalinity (30–55 mg/L) compared favourably well with the range given for lakes and reservoir by USEPA (1976), and is an indicator to the good quality of the reservoir water. Suguna (1995) reported that total alkalinity above 40 mg/L is indicative of high productivity. Thus the reservoir will support good fish production. Alkalinity is also a buffer for pH changes that helps stabilizing the pH of the reservoir. Alkalinity above 50 mg/L at Station 2 may be the reason why the station's water was in alkaline/neutral medium for most of the study period.

Oyun Reservoir water is soft going by the mean range of the total hardness (32–60 mg/L) which fell within the Hanna (2003) hardness scale classification for soft water. This range will support fish (Rottman and Shireman, 1990) and is ideal for drinking water supply (APHA, 1995). Higher river discharge which contains much inorganic nutrients into Station 3 may be the reason why total hardness of the station was higher. River – lake – reservoir continuum (Kalff, 2003) could be adduced for the decrease in total hardness concentration from Station 3 to Station 1.

The reservoir has low salinity and its total hardness is due to the presence of calcium and magnesium ions (Boyd, 1979). Higher total hardness levels in the rains could be due to higher concentration of calcium and magnesium ions. The utilization of these ions by organisms must have caused the decrease in the concentration of the total hardness in the dry season.

Like the "standard" freshwater in which calcium is the dominating cation (Golterman and Kouwe, 1980), the ionic composition of the water in Oyun Reservoir was also dominated by calcium followed by magnesium. The chemical denudation due to dilution from heavy rains coupled with the reservoir circulation and weathering from rock, and run-offs from surrounding water shed might have contributed to the availability of calcium and magnesium ions. This scenario has been reported by Lesack and Melack (1991) and probably explains why Station 3 had the highest concentration of the two ions. The flood of 2003 might have contained a high concentration of magnesium and this could be the reason for the significant difference in the concentration of the ion between the two years. The presence of calcium and magnesium ions in moderate levels classifies the reservoir as eutrophic which will support diverse plant and animal life including fish. According to Campbell and Wildberger (2001), waters with calcium levels of <10 mg/L are usually oligotrophic, while those above 25 mg/L are eutrophic.

Effects of human activities on the reservoir and its watershed are much reflected on the variations seen in nitrate, phosphate and possibly sulphate concentrations. The high concentration of nitrate (6.4 mg/L) and phosphate (2.2 mg/L) recorded in Station 1 and that of sulphate (16.9 mg/L) could have come from leaching and run-off of nitro-phosphate and sulphate fertilizers from nearby farmlands. The concentrations of these ions were higher during the rainy season; because the period is usually the peak of agricultural activities around the reservoir. Washing of cow dungs and bathing and washing with phosphate based detergents and soaps into the reservoir could have also caused the high concentration of the ions. These events led to cultural eutrophication of the reservoir with subsequent bloom in algae and changes to the water quality. Carpenter *et al.* (1998) and Carignan *et al.* (2000) reported that non-point source nutrients inputs from watershed are leading cause of eutrophication and water quality problems while Armengol *et al.* (1999) implicated sulphate in the eutrophication of reservoirs. Eutrophication is more pronounced in this reservoir due to its shallowness (Ekholm *et al.*, 1997). The eutrophication could affect the water quality of the reservoir by giving rise to unpleasant taste and odour, colours the water, and affects the dissolution of other gases, most especially dissolved oxygen as a result of algal bloom. The eutrophication could also pose threat to fish production in the reservoir, because it may destroy food web, decreases biodiversity at higher trophic levels (Hanson and Butler, 1994), lead to disappearance of population (Gliwicz and Warsaw, 1992) and induces changes in yield and species composition (Miranda, 2008).

Silica concentration which was the highest (60 mg/L) among the ions studied is in agreement with the report of Talling and Talling (1965) that concentration over 10 mg/L of silica is common in African water bodies. The high silica concentration could have come from washing of alumnio-silicate minerals present in the rocky substrate basement complex aided by dilution from the rains. The high silica concentration will be an advantage for fish production in the reservoir as it will promote high diatom population, an important food source for fish, thus making the reservoir to be productive and viable for fish production.

The fluctuations in surface water pH indicate the buffering capacity of total alkalinity. The slight acidicity (pH=6.8) in the dry season may be due to high carbon dioxide concentration occurring from organic decomposition. High water volume, greater water retention and good buffering capacity of total alkalinity may have been the reason why pH was in neutral or moderate alkaline medium during the wet season and for most part of the study. Using the pH as a water quality index, the Oyun Reservoir has good water quality with the pH range of 6.8–8.2, since most natural waters have pH between 6.5 and 8.5 (Tepe *et al*., 2005). The pH range will allow survival of fish and its use as drinking water. The conductivity of Oyun Reservoir is low and its range compared well with the reports of other reservoirs in Nigeria (Imevbore, 1970). The low conductivity might be responsible for the soft nature of the water. Increased concentration of cations such as calcium, magnesium and sulphate during the rains might be responsible for higher conductivity of the water at that period. Utilization of these salts by plankton, macrophytes might be the reason for the decrease noticed in the concentration while short water residence time in the dry season could also be the factor for the decrease concentration. Using electrical conductivity as water quality index (Moore, 1989), the reservoir has good water quality. Its range 80.40 µs/cm – 178.80 µs/cm will support diverse species of organisms. Dumont (1999) observed that species number decreases in water with high conductivity. TDS showed a positive concentration with conductivity. High values of TDS in the rains may be attributed to run-offs from sediment and catchments watershed. The settlings of dissolved salts coupled with uptake of ions may be adduced for the lower TDS values in the dry season. The range of TDS (53.9–119.8 mg/L) fell within tolerable limits for drinking water as it did not exceed 500 mg/L (EPA, 1976). The ranges of electrical conductivity and TDS values in the reservoir will support productive fisheries coupled with reservoirs shallowness. The two parameters could be used as morpho-edaphic index to estimate potential fish yields in reservoirs (Jenkins, 1982).

The surface water quality of Oyun Reservoir could be classified as excellent under class 1 of Prati *et al.* (1971) index and its ecological status of the reservoir is high, while its chemical status could be described as pass using the recently proposed Environmental Quality Standards (EQS) (WWI, 2005). Station 2 was the most productive one and its water quality was very high while Station 3 showed very high chemical status but with high turbidity and low transparency.

In all, the ranges of physico-chemical properties of Oyun Reservoir are comparable to those found in non-polluted African reservoirs, and are within the allowable limits recognized by WHO (1997) for drinking water supply as well as fish production. The only visible threat to the water quality and fish production is cultural eutrophication which was more pronounced at Station 1 as a result of human activities on the site. There is an urgent need to arrest the problem of cultural eutrophication in this reservoir to protect the water body, maintain its water quality and enhance fish production. This could be done through denitrification and nutrient control, which is one of today's focuses on applied limnology.

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