Influence of Watershed Activities on the Water Quality and Fish Assemblages of a Tropical African Reservoir

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Abstract

Agricultural and fisheries activities around the watershed of an African tropical reservoir (Oyun Reservoir, Offa, Nigeria) were found to have contributed significantly to the eutrophication of the reservoir. This is evident from the high amount of nitrate (6.4 mg/L), phosphate (2.2 mg/L) and sulphate (16.9 mg/L) in the water body. These nutrients came from fertilizer run-offs from nearby farmlands and were found in higher concentrations in the rainy season, which was usually the peak of agricultural activities in the locality. The eutrophication altered the food web cycle with the bloom of filamentous algae and the decline in zooplankton population. The effect of this scenario affected the fish species composition and abundance with the dominance of cichlids (planktivorous group) in the fish population. Best management practices (BMP) to control and reduce the eutrophication and improve the fish assemblages should be adopted and adapted to suit the situation in the reservoir.

Keywords: eutrophication, nitrate, phosphate, cichlids, management.

Introduction

African tropical reservoirs are often constructed for one of the single purposes like provision of domestic and industrial water supply, irrigation/ hydroelectric power generation/ or fish production. With time, other functions like flood control, navigation, recreation/ and tourism are super imposed on them, making these as multi use reservoirs. The ability of the reservoir to deliver its function(s) effectively depends largely on its watershed activities. A watershed is the land from which rain and surface water drain into the reservoir. Reservoir characteristics are a reflection of its watershed (Holdren *et al*., 2001). The watershed land cover is a major determinant of water quality and fish community composition (Miranda, 2008). Therefore any alterations in the watershed will consequently affect the water quality and fish assemblages.

Various activities such as farming, fishing, forestry, construction, mining, urban development, pollution, municipal uses of water, sewage/ and industrial effluent discharge, in the watershed of a reservoir could bring about water quality problems and disruption in fish species composition. These activities could also affect habitat structure, flow regime, food web and biotic interactions in the reservoir (Karr, 1991). The effects of these activities produce on water quality and fish assemblages may vary with season, intensity of the activity and magnitude of discharge of the nutrients or sediments into the reservoir.

Effective reservoir management and sustainable fish production will depend on effective watershed use and management. A number of watershed management practices known as Best Management Practices (BMP) have been developed and in use over the years in many developed countries to protect and sustain both land use and the bodies of water that receive run off from the watershed. These practices however do not exist or are totally ignored in the management of many tropical African reservoirs which lead to the deterioration of water quality and inadequate fish assemblages in many of the reservoirs. The relationships between watershed inputs and fish assemblages in many tropical African reservoirs are not to be documented.

The goal of this paper is to look at various human activities occurring on the watershed of Oyun reservoir (a tropical African reservoir) and their effects on the water quality and fish species composition and abundance of the reservoir. This is with a view to helping in the management of the reservoir effectively and for sustainable exploitation of its fish.

Materials and Methods

Study Site Description

Oyun reservoir is located in Offa, Kwara State, Nigeria, longitudes 04°19'00" N and latitude 08°7'60" 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 and a 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 storage capacity is 2.9 x 10^6 m^3. The water retention time is between 3 and 4 months in the raining season, while the water residence time in the dry season is few days due to high evaporation (Figure 1).

Sampling and Sampling Stations

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/ and cassava fermentation took 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 and total dissolved solids were measured insitu 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 measured 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, and total alkalinity, were determined by titration method (APHA, 1995). Nitrate, phosphate, and sulphate 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.

Fish species composition and abundance were estimated through monthly collection of fish samples between January 2002 and December 2003. Gill nets, cast nets and lift nets of various mesh sizes ranging between 5.08 cm and 17.78 cm were used to sample the fishes. The fishes were identified using keys compiled by Holdeen and Reed (1972) and Reed *et al.* (1967), sorted into species and families, and each fishes were weighed to the nearest 0.1g using the mettler balance.

Statistical Analyses

GLM procedure of statistical analysis system 9.1.3 (SAS Institute, 2003) was used to analyze the results. Two-way ANOVA at $P<0.05$ was used to test for the effects of variations due to sampling error, stations, seasons and years.

Results

The mean monthly variations in the surface water temperature of the three stations was 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 the 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). The dry season, Stations 2 and year 2002 had significant 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

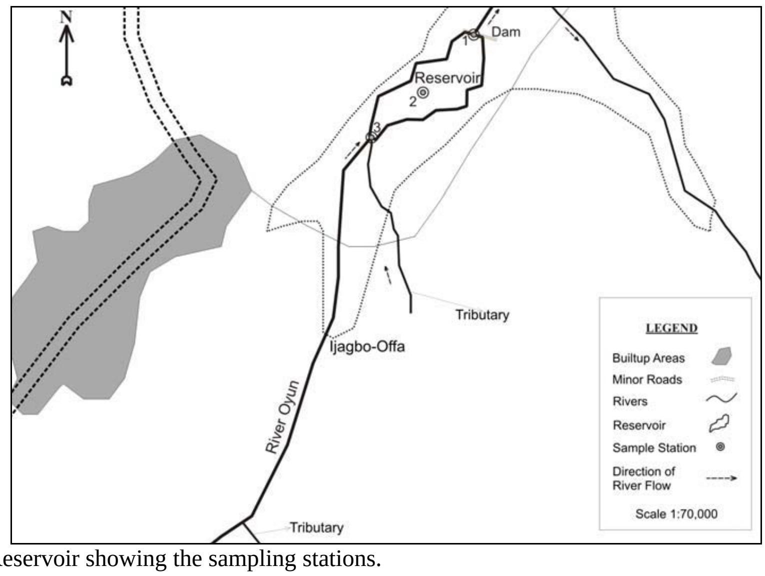

Figure 1. Map of Oyun Reservoir showing the sampling stations.

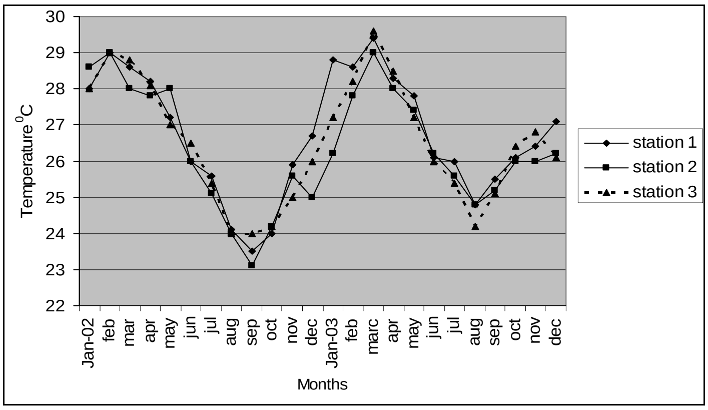

Figure 2. Monthly mean variations in surface water temperature of Oyun Reservoir.

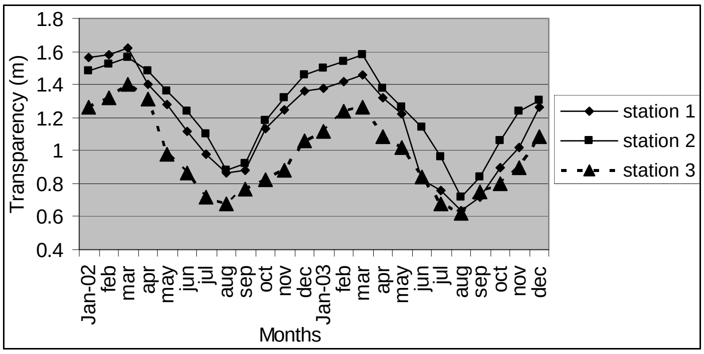

Figure 3. Monthly mean variations in secchi disc transparency of Oyun Reservoir.

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 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 concentrations among the stations and in the seasons. The two factors were statistically higher in the dry season as well as in Station 3. Monthly mean of carbon dioxide ranged between 1.6±0.2 mg/L to 3.0±0.6 mg/L (Figure 6), while monthly mean of total alkalinity fluctuated between 30±2.6 mg/L and 55±3.4 mg/L (Figure 7).

The highest monthly mean concentration of nitrate recorded was 6.4±0.3 mg/L 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 8). ANOVA showed significant difference P<0.05 in the nitrate concentration during the seasons and within the stations. Nitrate was higher in the raining season and the order of magnitude in the concentration among the stations was station 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 9). Like nitrate, phosphate concentration was significantly higher in raining season and in 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 10. Sulphate concentration was lowest at 9±0.2 mg/L at the beginning of the study in Station 1, it gradually increased until a maximum concentration of 16.9±0.45 mg/L was recorded in Station 3. Sulphate was significantly higher in the wet season while the order of higher concentration among the stations was stations 3>2>1. No difference occurred within 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 stations 2 in August and September of 2003 (Figure 11). In the 3 stations, 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

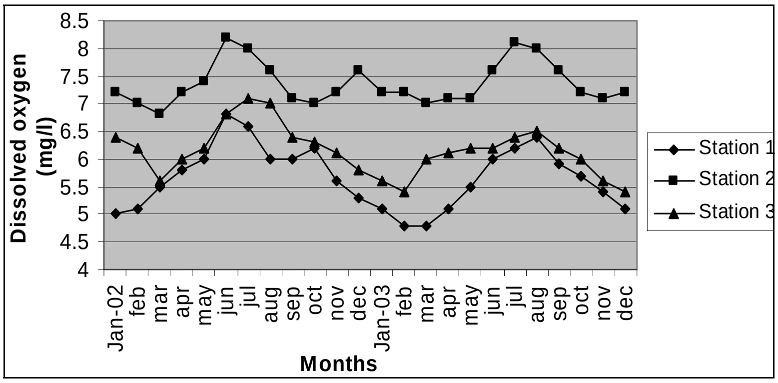

Figure 4. Monthly mean variations of dissolved oxygen concentration in Oyun Reservoir.

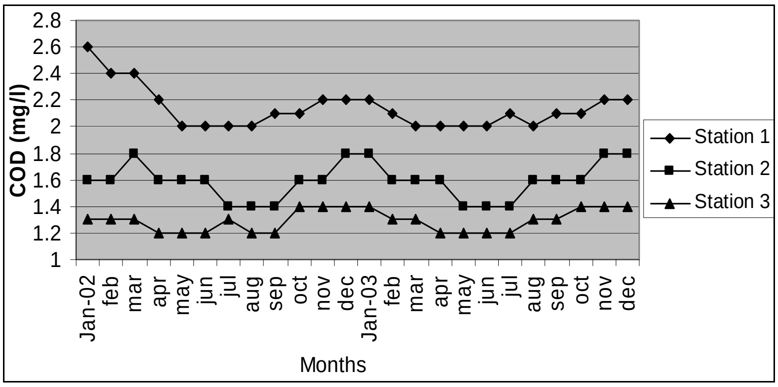

Figure 5. Monthly mean variations of COD in Oyun Reservoir.

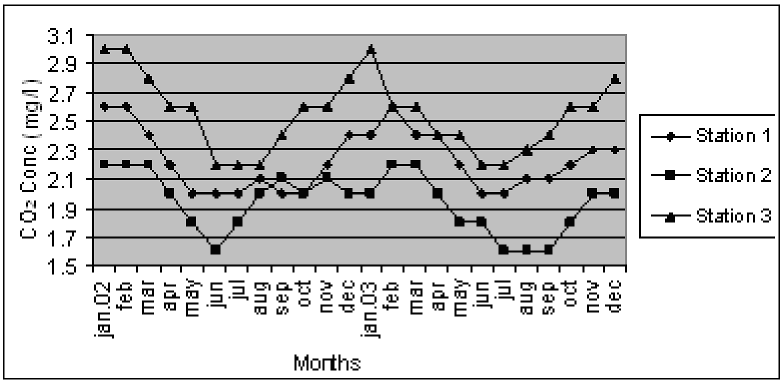

Figure 6. Monthly mean variations of carbon dioxide concentration in Oyun Reservoir.

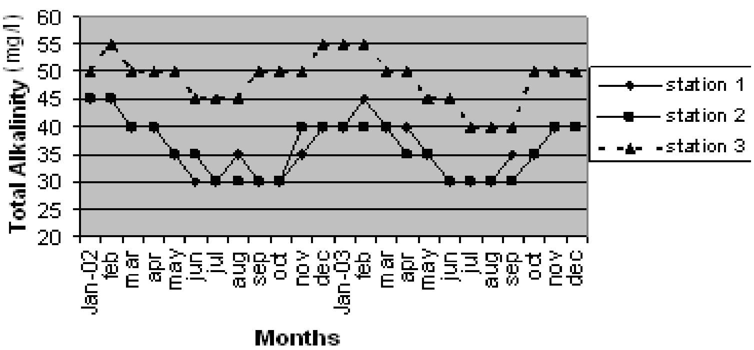

Figure 7. Monthly mean variations of total Alkalinity in Oyun Reservoir.

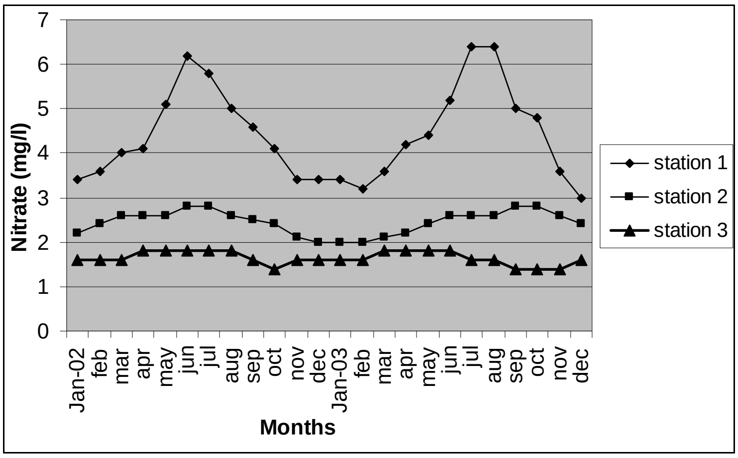

Figure 8. Monthly mean variations of nitrate concentration in Oyun Reservoir.

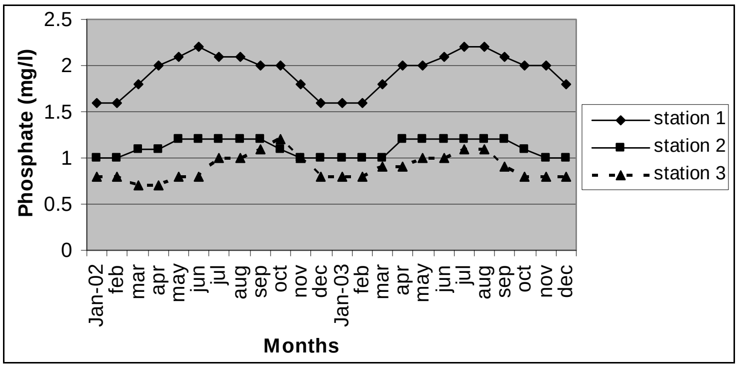

Figure 9. Monthly mean variations of phosphate concentration in Oyun Reservoir.

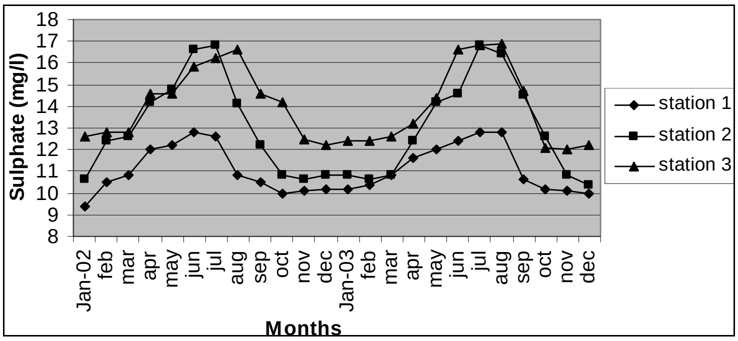

Figure 10. Monthly mean variations of sulphate concentration in Oyun Reservoir.

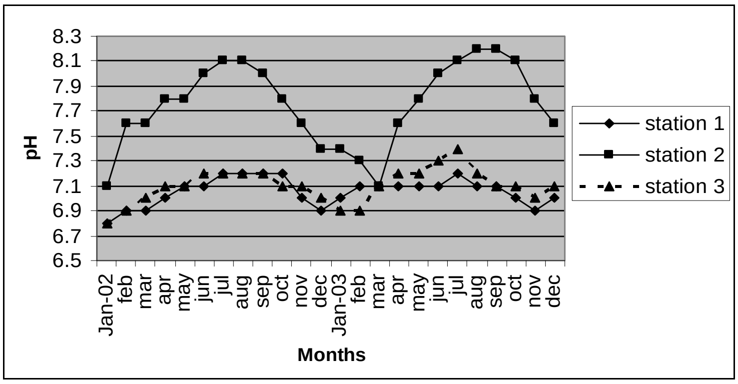

Figure 11. Monthly mean variations of pH in Oyun Reservoir.

noted between the years. The monthly mean variations in electrical conductivity and total dissolved solids (TDS) followed similar trend. There was slight variation in conductivity and TDS in Stations 1. The station 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 12 and 13). 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 order of significant difference between the stations was station 3>2>1.

A total of 7,713 samples comprising of eighteen species belonging to nine families were recorded from the reservoir (Table 1). The families Cichlidae and Momyridae were each represented by four species, but Cichlidae dominated the fish species in terms of number and weight with 64.56% and 69.31%, respectively. The families Mochokidae, Cyprinidae and Clariidae were each represented by two species, while Osteoglossidae, Characidae, Schilbeidae and Channidae had one species each. Osteoglossidae was the least abundant of all fish families with 0.22%; it also had the least weight of 0.82%. Among the individual fish species, *Tilapia zillii* constituting 30.0% and 28.55% by abundance and weight was the dominant species in terms of number and weight, while *Heterotis niloticus* constituting 0.22% by abundance and *Gnathonemus cyprinoides* having a weight percentage of 0.29% were the species with the lowest number and weight respectively. Majority of the fish species and families were caught all year round except for Osteoglossidae which was caught for only four months in a year (Figure 14). The species and families were highly abundant in the dry season between November and May, while in the rains and flood periods, between June and October, there was a decline in their population and diversity. *Heterotis niloticus* (Family Osteoglossidae), the least abundant species was also found in high numbers during the dry season. Significant higher weight was found in the dry season among the fish population.

Discussion

The variations observed in the physico-chemical parameters and fish species composition and abundance of Oyun reservoir could be linked to the various interactions of the human activities on the watershed and competing uses of the reservoir by

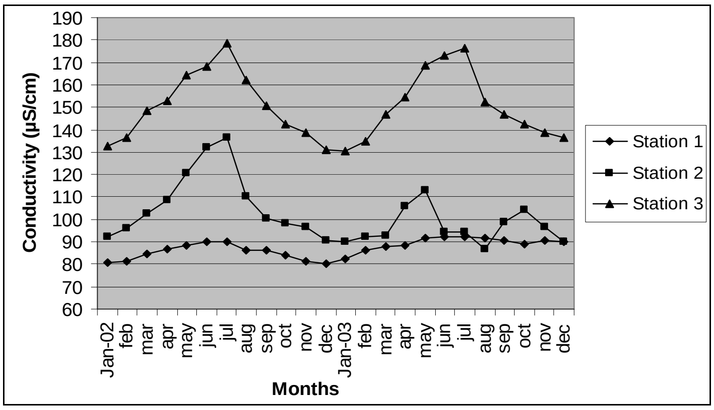

Figure 12. Monthly mean variations of conductivity in Oyun Reservoir.

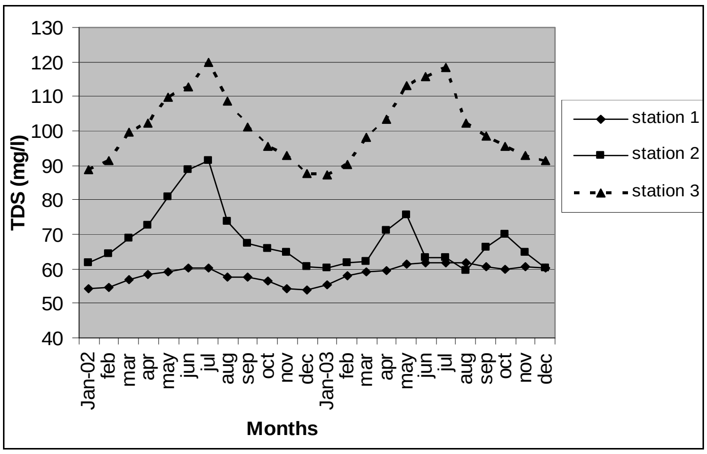

Figure 13. Monthly mean variations of TDS in Oyun Reservoir.

Table 1. Fish composition, relative abundance and average weight of species and families in Oyun reservoir, Offa, Nigeria

Family	Species	Number	Weight (g)	Sp% in family	Sp% in population	Sp% weight in family	Species % weight in population
Cichlidae	*Tilapia zilli*	2314	242650	46.47	30	41.63	28.85
	Oreochromis niloticus	1781	228180	35.76	23.09	39.15	27.13
	Sarotherodon galilaeus	790	103910	15.86	10.24	17.83	12.36
	Hemichromis fasciatus	95	8140	1.91	1.23	1.39	0.97
Total		4980	582880	100	64.56	100	69.31
Momyridae	*Momyrus rume*	168	14220	43.98	2.18	37.64	1.69
	Mormyrops deliciousus	132	13415	34.55	1.71	35.5	1.6
	Ganthonemus cyprinoides	21	2450	5.5	0.27	6.48	0.29
	Hyperopsis bebe	61	7700	15.97	0.79	20.38	0.92
Total		382	37785	100	4.95	100	4.5
Mochokidae	*Synodontis schall*	143	13960	33.49	1.85	42.9	1.66
	Synodontis gambiensis	284	18582	66.51	3.65	57.1	2.21
Total		427	32542	100	5.53	100	3.87
Cyprinidae	*Labeo coube*	218	49600	85.16	2.83	89.05	5.89
	Barbus occidentalis	38	6100	14.84	0.49	10.95	0.73
Total		256	55700	100	3.32	100	6.62
Clariidae	*Clarias gariepinus*	221	28200	72.46	2.87	70.07	3.35
	Clarias angularis	84	12045	27.54	1.09	29.93	1.43
Total		305	40245	100	3.96	100	4.78
Osteoglosssidae	*Heterotis niloticus*	17	6860	100	0.22	100	0.82
Characidae	*Brycinus nurse*	1032	48585	100	13.38	100	5.77
Schilbeidae	*Schilbe mystus*	123	11530	100	1.59	100	1.37
Channidae	*Channa obscura*	191	24860	100	2.48	100	2.96
Grand Total		7713	840887		100		100

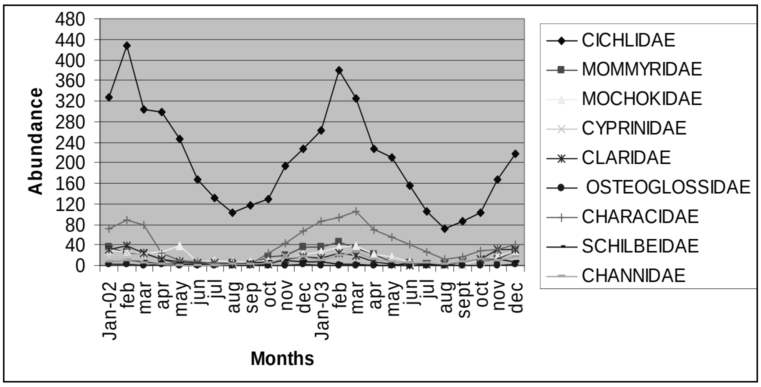

Figure 14. Monthly mean variations of abundance of fish families in Oyun Reservoir.

stakeholders. The high concentrations of nitrate, phosphate and sulphate during the rains possibly came from the run-off of nitrophosphate and sulphate fertilizers from nearby farmlands into the reservoir. This resulted in cultural eutrophication. The rainy season is usually the time of high fertilizer applications in the locality. Fertilizer application represents a major disturbance to the watershed (Novotny, 2003). Carpenter *et al*. (1998) reported that nutrients input from the watershed are a leading cause of eutrophication. Other watershed activities that could have caused the eutrophication include washing and bathing with phosphate based detergents and soaps as well as washing of cow dungs into the reservoir. The effects of the eutrophication were an increase in the blue green algae biomass with consequent decrease in zooplankton population. This scenario has been reported by Prepas *et al.* (2001), who observed that forest harvest impacted negatively on the water quality and plankton of Alberta reservoirs.

The presence of inedible blue green algae and decline in the population of edible phytoplankton and zooplankton might have contributed to the low fish species abundance in the rainy season. Pussey and Arthington (2003) noted that filamentous algae are favoured under high nutrients, but are not readily incorporated into aquatic food webs by invertebrate consumers. Eutrophication which brought large amount of filamentous algae might have favoured the feeding habits of Cichlids hence their dominance in the reservoir. This agrees with the observation of Miranda (2008) that eutrophication induces change in yield and species composition of fish population.

The watershed of Oyun reservoir is mainly agricultural with nutrient inputs coming from fertilizer run-off and cassava fermentation. Thus large amount of particulate organic matter was exported into the reservoir from sediments run-off. This is reflected in the high conductivity and total dissolved values of the water. The high TDS resulted in low transparency of the water. The high TDS levels could be responsible for the low fish species abundance in the rainy season through the reduction in light penetration and photosynthesis by plankton thereby reducing plankton growth and altering zooplankton communities. This eventually alters food web cycle and food availability to fishes. According to Kirk and Gilbert (1990), increase in turbidity driven by the sediments delivered by agricultural watersheds tends to interfere with the feeding of large zooplankton which is the food for fishes. High suspended solids have also been reported to reduce fish visibility, growth, health and could produce a shift in fish habitat use (Bruton, 1985), cover fish spawning sites, smoother their eggs and damage habitat for aquatic insects which are a major food source for the fishes (Holdren *et al.*, 2001).

Other watershed activities which often contribute non-point source inputs into the reservoir include fish landing, fish descaling, fish marketing and fishing net and canoe repairs. Many of these activities produced dissolved organic or particulate matter which when washed into the reservoir release carbon, consume dissolved oxygen, produce high concentration of carbon dioxide and increase the biological or chemical oxygen demand of the water. This is particularly more evident during the dry season when fisheries related activities are at their peak. Thus the low concentration of dissolved oxygen and the high concentration of carbon dioxide and chemical oxygen demand in the dry season could be attributed to this phenomenon. High concentration of carbon dioxide in the dry season might be responsible for the slight acidity of the water (pH 6.8), while total alkalinity acted as a buffer for the pH during most of the time. An important beneficial effect of the allochtonous carbon on fisheries is that population dynamics, predator-prey interactions and the reservoir ecosystems are enhanced (Polis *et al.*, 1997). The high fish production in the dry season could be explained by this factor.

The various human activities in the watershed of Oyun reservoir led to increase in the nutrient levels and inadequate assemblages of the fishes. The nutrient-induced eutrophication affected the water quality and fish species composition and abundance of the reservoir. In order to arrest further degradation of the water quality and inadequate fish assemblages in the reservoir, various practices that put in high amounts of nutrients and sediments into the reservoir should be halted. Good and safe agricultural practices in the watershed will protect the reservoir water quality and improve the fish diversity and abundance.

These activities identified as contributing to the eutrophication of the reservoir need to be eliminated. Best Management Practices (BMP) which is in use in many reservoirs of developed countries should be adopted and adapted to suit the situation in tropical African reservoirs. We should start to look beyond the traditional in-reservoir management to improve water quality and fish production and extend the scale of the management to the reservoir catchments area and watershed. This will enhance the managers' ability to impact reservoir fish population and communities (Miranda, 2008).

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