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Physicochemical parameters of water in earthen ponds and concrete water storage reservoirs in Bakolori irrigation project, Zamfara state, north western Nigeria

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Abstract
Physicochemical Parameters of large Earthen Ponds and Concrete water storage reservoirs (CWSRs) of Bakolori Irrigation Project (BIP) were investigated from March 2019 to February 2020. Four sampling stations were randomly selected from the two water body types. Air and Water Temperature, Dissolved Oxygen (DO), pH, Electrical Conductivity (EC), Water Depth, Total Dissolved Solids (TDS), Transparency & Salinity were determined in situ, while water samples were collected monthly from the eight sampling stations and taken to the laboratory for analysis of Alkalinity, Hardness, Nitrate-N and Phosphate-P. The data collected were arranged on the bases of two seasons (dry & wet) and five sub-seasons, namely: Early dry (Oct - Dec); mid dry (Jan & Feb); late dry (March - May); Early rainy (June & July) and flood period (Aug & Sept), and subjected to T test analysis using Minitab statistical package. Results were compared with the water quality standards for Human consumption, aquatic life and fish production aquatic life and aquaculture. Results showed that with the exception of high Turbidity (low transparency) due to mud & debris in the water storage reservoir in some sub seasons, the water bodies were suitable for Aquatic life and Aquaculture. But partly unsafe for human consumption. The study recommends continuous assessment of the water bodies for physicochemical parameters. It further recommends the use of several water storage reservoirs for mudfish (Such as Clarias and Hetrobranchus species) production instead of leaving them redundant as observed during the study period.

Keywords: Physicochemical, ponds, storage reservoir, Bakolori, Nigeria

Introduction

The significance of water quality cannot be over emphasized as both plants and animals rely on good quality water for their survival. Therefore, water quality assessment is a most to ensure life sustainability. Water occupies a special place in natural resources of any nation and it is a valuable natural resource that is essential to human and ecosystems survival. Water is classified based on salinity as marine (sea, ocean), brackish (estuaries, lagoons) and freshwater (lakes, rivers, streams, groundwater, etc.). The freshwater environments cover less than one percent of the Earth's surface, but contain about 10% of all described species of fish (Strayer and Digeon, 2010) [32], this makes fresh water bodies global biodiversity hotspots. Globally aquatic ecosystems are negatively affected by human activities (Ani *et al.,* 2016; Amah-Jerry *et al.,* 2017) [5, 4], such as agriculture, mining, industries and human settlements. The resulting effect is water pollution that makes many regions in the world to have insufficient clean water to meet the demands for human survival (Kensa, 2012) [43]. Quality of water for human consumption, aquatic life, fish production and other uses depends on physicochemical and biological factors, which interrelate to produce some specific quality parameters that make the water either good or bad and hence influence the beneficial uses of the water. (Usali and Ismail, 2010; Nwankwoala and Ekpewerechi, 2017) [39, 26].

Aquatic ecosystems are highly dynamic and subject to pollution which may damage the environment and the living aquatic organisms (Martin and Hidayathulla, 2007). Good quality water availability is among the basic needs of living organisms and the quality of water for human consumption, aquatic life and for fish production depends on three major factors which interrelate to produce some specific quality parameters that make the water of either good or bad qualities (Aminu *et al.*, 2018) [44]. It is the web of physical, chemical and biological factors that constitute aquatic environment and influence the beneficial uses of water (Tchobanoglous and Schroeder, 1987) [35]. Water quality is defined as any physical, chemical and biological parameters of water which affect the survival, growth and reproduction of fish (Boyd, 1979) [10]. These parameters have ranges which fish can tolerate, below or above which can lead to stress, growth impairment or even mortality (Akegbojo, 1987) [3]. Water quality assessment involves collecting water samples from water bodies for determining the status of some relevant parameters, which indicate the suitability of the water for purposes such as human consumption, aquatic life and fish production (Delince, 1992) [11].

Where large reservoirs are formed, riverine fish may not find the new habitat suitable for all periods of their life cycle, hence their number will gradually decline with some species disappearing completely. In spite of this negative development, most irrigation managers are not exploring means of culturing fish in the water bodies of irrigation systems to balance the losses caused as a result of damming rivers for irrigation purposes (Petr, 2003) [28]. Fisheries can be integrated in irrigation systems, especially in major irrigation and drainage canals and water bodies established from residual irrigation water by the use of species with known preference for such water bodies (Nasim, 2004) [24]. However, these water bodies are sometimes characterized by elevated salinities and high concentrations of agrochemicals, such as fertilizers, hence the need for their water quality assessment (Petr, 1998) [29]. A number of inherent management problems exist in irrigation systems, such as poor or nil water quality assessment, which results in underutilization of the water for aquaculture developments (Nasim, 2004) [24].

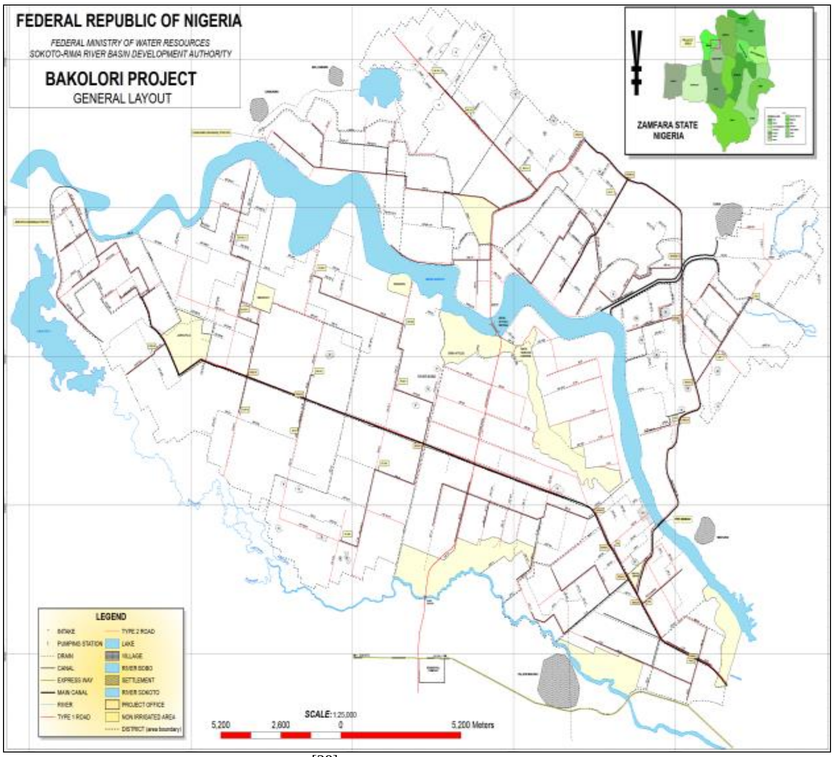
The Bakolori Irrigation Project is a multi-purpose dam and irrigation project designed to supply irrigation water to a net area of 23,000 hectares to boost food production, fisheries and livestock development, drinking water supply, forestry development as well as electricity power generation. There is paucity of information on water quality status of water bodies in irrigation systems of Nigeria and BIP in particular (FAO, 2004) [13]. Earthen fish ponds in BIP have not been surveyed for water quality parameters (USAID, 2010) [38].

It was therefore necessary to carry out this research, to examine some important physicochemical parameters of waters from numerous earthen ponds and CWSRs within the command area of BIP and compare them to water quality standards for human consumption, aquatic life and fish production. The findings of this research may provide the basis for further studies and utilization of the water bodies in the BIP for aquaculture and other purposes.

Materials and Methods

Study area

Bakolori Irrigation Project is located 110 km southeast of Sokoto city (USAID, 2010) [38], between latitude 12° 33'N to 12° 42'N and longitude 5° 57'E to 6° 07'E within the Sokoto river basin (FAO, 2004) [13]. The localities of Talata Mafara, Maradum, and Bakura (all in Zamfara state) North-Western Nigeria hold all the 23,000 hectares of the project (FAO, 2004) [13]. Almost 65% (15,000 hectares) of the land was designed for sprinkler irrigation which is now abandoned, while gravity fed surface irrigation was designed for the remaining 35% (8,000 hectares) (USAID, 2010). The mean annual rainfall is about 500mm (FAO, 2004) [13] which starts between April and June and ends around October when the dry season sets in, with an annual cold and dusty harmattan between November and February (Ita, 1993b). The temperature ranges between 25 °C – 35 °C (FAO, 2004) [13], and Extreme heat is experienced before the rainfall between March and April and may extend to late June or July with late rainfall (Yahaya, 2002) [42].



***Source*:** USAID (2010) [38]

Fig 1: Map of Bakolori Irrigation Project Showing its location in Zamfara State

The components of the gravity fed system include: A 15 km-long concrete lined supply canal; Two concrete lined main canals totaling 45 km of length; Concrete lined secondary canals totaling 200 km of length; Tertiary canals (earthen) totaling 300 km of length, and Field ditches (earthen) totaling 400 km of length (FAO, 2004) [13].

Sampling procedure
Eight sampling stations denoted by 1, 2, 3, 4, 5, 6, 7 and 8 were located within the study area.

- Station 1, 2, 3 and 4 were randomly selected from the several large earthen ponds
- Station 5, 6, 7 and 8 were randomly selected from the numerous CWSRs

Collection of water samples
Water samples were collected from each of the sampling stations monthly. Each sample was replicated three times. A total of twenty-four 500 ml capacity plastic bottles were used for sampling every first week of the month, for a period of 12 months (March 2019 to February 2020). A total of two hundred and eighty-eight (288) samples (500 ml each) were collected for the determination of the physicochemical parameters.

As described by (APHA, 2005) [6], water sample bottles were rinsed with the water at the sampling stations and lowered into the water body to collect water samples from about 15cm depth below the water surface at each of the eight sampling stations. The bottles were screwed tightly and transported immediately to the laboratory for analysis.

Water analysis
In situ measurements
Digital meters as shown in the table below, were used for the determination of the water temperature, pH, TDS, EC, Transparency, Dissolved Oxygen (DO) and Salinity according to the manufacturer's instruction and procedure. Water depth was measured using a calibrated chain and transparency was determined using a Secchi disk. The water samples collected were analyzed for the remaining physicochemical parameters in the Agric. Chemical Laboratory, Usmanu Danfodiyo University, Sokoto, following standard procedure of APHA, 2005.

Physicochemical and Heavy Metals Characteristics Data Collection Methods

Parameter	Methods, Instruments & Equipment Used	Units
Physicochemical Parameters (In Situ Measurements)		
Water Temperature	Digital Thermometer by Exteck Instruments	^{O}C
pH	Digital Multi Parameter meter (HI 9813-6)	
Dissolved Oxygen (DO)	Smart DO Meter (MW 600) by Milwaukee	mg/L
Water Depth	Graduated chain with heavy weight at the bottom	M
Transparency	Secchi Disk	cm
Electrical Conductivity (EC)	Digital Multi parameter meter (HI 9813-6)	µS/cm
Total Dissolved Solids (TDS)	Digital Multi parameter meter (HI 9813-6)	mg/L
Salinity Physicochemical Parameters (Laboratory Measurements)	Digital Master Refractor meter by ATAGO	g/L
Physicochemical Characteristics (Laboratory Measurements)		
Hardness	Smart 3 Colorimeter by Lamotte Instruments	mg/L $CaCO_3$
Alkalinity	Smart 3 Colorimeter by Lamotte Instruments	mg/L $CaCO_3$
Phosphate-P	Smart 3 Colorimeter by Lamotte Instruments	mg/L
Nitrate-N	Smart 3 Colorimeter by Lamotte Instruments	mg/L

Data Analysis
The data collected were arranged and analyzed for differences in the three water bodies on the bases of two seasons (dry & wet) and five sub seasons, namely: Early dry (Oct - Dec); mid dry (Jan & Feb); late dry (March - May); Early rainy (June & July) and flood period (Aug & Sept). T test analysis using Minitab statistics computer software (version 16) was used to analyze the data collected.

Results
The results of mean overall/seasonal and sub seasonal physicochemical parameters of the two water types are contained in table 1 and 2 respectively.

Table 1: Mean Seasonal and Overall Mean Values of Physico Chemical Parameters of Water in Earthen Ponds & CWSRs in BIP, Zamfara State, Nigeria

Parameter	Water Body	Day Season	Wet Season	Overall Mean
Water Temp (°C)	Ponds	25.3±3.8	26.2±1.6	25.6±3.3
	CWSRs	24.8±3.7	26.1±1.8	25.2±3.3
Transparency (cm)	Ponds	39.9±17.8^{a}	43.4±6.5^{a}	41.3±14.5^{a}
	CWSRs	12.6±6.5b	5.8±1.5^{b}	41.3±14.5^{a}
Depth (n)	Ponds	0.91±0.53^{b}	1.50±0.30^{b}	1.11±0.54^{b}
	CWSRs	2.98±1.03^{a}	3.00±0.64^{a}	2.98±0.91^{a}
TDS (mill)	Ponds	64.1±11.2^{a}	45.3±6.3^{b}	57.0±10.5^{a}
	CWSRs	53.2±9.6^{b}	49.2±5.6^{a}	52.1±9.5^{b}
DO (mv1)	Ponds	4.1±1.44	6.2±2.71	4.8 ±2.18^{b}
	CWSRs	4.8±1.49	6.1±3.39	5.3±2.41^{a}
EC (Asian)	Ponds	395.2±35.5^{b}	522.1±199^{a}	437.5±132^{b}
	CWSRs	532.1±172.6^{a}	451.7±91^{b}	503.7±153^{a}
Alkalinity (raga)	Ponds	18.32±2.09	22.25±4.86^{a}	21.31±5.05^{a}
	CWSRs	19.38±3.11	17.41±2.09^{b}	18.54±4.05^{b}
Hardness (mg4)	Ponds	20.77±4.69	17.61±3.72	19.72±4.70

	CWSRs	19.79±3.43	16.43±2.59	18.67±3.52
Salinity (g4)	Ponds	0.15±0.04^{b}	0.14±0.03^{b}	0.15±0.06^{b}
	CWSRs	0.23±0.05^{a}	0.22±0.02^{a}	0.23±0.04^{a}
NOs-N (mg/)	Ponds	1.69±0.80^{a}	2.57±0.36	1.98±0.80^{a}
	CWSRs	1.38±0.69^{b}	2.56±0.40	1.79±0.83^{b}
POtP (mg4)	Ponds	0.20±0.09	0.13±0.02	0.18±0.09
	CWSRs	0.21±0.11	0.14±0.01	0.19±0.10

Values are Means ± standard deviations
Means in a column with superscript are significantly different ($p<0.05$)

Table 2: Mean Sub Seasonal Physico Chemical Parameters Values of Water in Earthen Ponds & CWSRs in BIP, Zamfara State, Nigeria

Parameter	**Water Body**	**Sub season**				
		Late Dry (Mar-May) 2019	**Early Rainy (June-July)**	**Flood (Aug-Sept)**	**Early Dry (Oct-Dec)**	**Mid Dry (Jan -Feb) 2020**
Water Temp (°C)	Pond	27.8±2.20^{a}	26.1±1.41	26.2±1.74	26.6±1.39^{a}	19.4±0.92
	CWSRs	26.5±2.82^{b}	25.6±1.65	26.3±1.90	25.4±1.22^{b}	18.94±1.39
Transparency (cm)	Pond	52.1±2.48^{a}	43.0±7.95^{a}	43.7±4.91^{a}	27.7±18.23^{a}	26.8±0.12^{a}
	CWSRs	5.9±0.37^{b}	5.4±1.18^{b}	6.1±1.74^{b}	14.6±4.32^{b}	20.2±0.95^{b}
Depth (m)	Pond	1.4 ±0.15^{b}	1.7±0.11^{b}	1.2± 0.15^{b}	0.8±0.28^{b}	0.2±0.05^{b}
	CWSRs	3.1±0.15^{a}	3.1±0.13^{a}	2.9±0.91^{a}	1.9±1.22^{a}	3.9±0.26^{a}
TDS (mg/l)	Pond	47.3±6.10^{a}	38.5±4.01^{b}	52.05±7.03^{b}	59.3±5.11^{b}	80.5±9.4^{a}
	CWSRs	40.6±5.04^{b}	47.9±5.06^{a}	56.14±7.01^{a}	79.10±11.0^{a}	47.5±3.70^{b}
EC (μs/cm)	Ponds	397.6±53.6^{b}	657.7±205^{a}	386.4±24.5	383.2±12.4	409.2±13.4
	CWSRs	737.4±8.3^{a}	507.5±103^{b}	395.8±6.2	386.4±7.67	393.8±18.3
Hardness (mg/l)	Ponds	25.38±4.27^{a}	16.90±2.11	17.31±2.93^{a}	13.98 ±3.18^{b}	16.03±2.40
	CWSRs	22.11±3.21^{b}	17.91±2.19	12.05±1.44^{b}	14.22±2.11^{a}	16.99±0.12
PO_4-P (mg/l)	Ponds	0.12±0.01	0.11±0.01	0.15±0.00	0.20±0.07	0.35±0.02^{b}
	CWSRs	0.15±0.01	0.13 ±0.00	0.14±0.00	0.20±0.06	10.41±0.01^{a}
Alkalinity (mg/l)	Ponds	14.74±3.21	22.61±3.11^{a}	22.76±2.31^{a}	16.68±0.27^{a}	23.15±2.21^{b}
	CWSRs	15.5±2.10	19.6±3.89^{b}	11.93±2.12^{b}	12.21±1.67^{b}	27.91±3.62^{a}
DO (mg/l)	Ponds	5.3±1.66^{b}	8.3±1.26	4.0±1.90	3.2±0.44^{b}	3.4±0.17^{b}
	CWSRs	5.5±2.12^{a}	8.2±3.39	3.9±1.45	4.6±0.35^{a}	4.0±0.26^{a}
NO_3-N (mg/l)	Ponds	2.42±0.26^{a}	2.81±0.21^{a}	2.32±0.31^{b}	1.65±0.61^{a}	0.64±0.12^{a}
	CWSRs	2.00±0.22^{b}	2.31±0.32^{b}	2.79±0.32^{a}	1.31±0.49^{b}	0.43±0.06^{b}
Salinity (g/l)	Ponds	0.16±0.02^{b}	0.15±0.02^{b}	0.13±0.01^{b}	0.14±0.03^{b}	0.15±0.03^{b}
	CWSRs	0.25±0.06^{a}	0.22±0.04^{a}	0.20±0.03^{a}	0.20±0.5^{a}	0.21±0.04^{a}

Values are Means ± standard deviations
Means in a column with superscript are significantly different ($p<0.05$)

Discussion

In the study area, the rainfall season is usually from June to September with a peak in August, while the dry season last from October to May, and the zone which falls within the Sudan Savannah is noted for these two contrasting seasons within the year (Mamman *et al.*, 2000).

Water temperature of the two water bodies were lowest in mid dry sub season, the values are below the recommended temperature range of 25^{oC} to 35^{oC} for aquatic life, but very close to the optimum (20^{oC} to 25^{oC}) required for a tropical fish (common carp) *Cyprinus carpio* (Charkroff, 1976) [ ]. The highest water temperatures of the water bodies were recorded in late dry sub season, the values were within the recommended temperature range of 25^{oC} to 35^{oC} for aquatic life (Charkroff, 1976) [45]. Morever, with the exception of the mid dry sub season, sub seasonal water temperatures of BIP water bodies were within the recommended temperature range of 25^{oC} to 35^{oC} for aquatic life (Charkroff, 1976) [45]. The overall sub seasonal water temperature was significantly ($p<0.05$) highest in late dry sub season and significantly ($p<0.05$) lowest in mid dry sub season (Table 4.1). The highest water temperature recorded in the late dry sub season (March, April and May) could be due to hot weather usually associated with the sub season, while the lowest recorded in the mid dry sub season (January and February) could be attributed to the influence of the cold dry season or harmattan (Abohweyere, 1990) [46]. This agrees with the findings of Onaji *et al*. (2005) [27] and Mohammad (2012) [47] who recorded highest water temperature in late dry sub season and lowest in mid dry sub season in Kware lake and Sokoto Rima River system respectively in north-western Nigeria. Low specific heat capacity of the water bodies may be responsible for the lowering temperature of the water than the ambient air temperature around the water bodies across the seasons (Dupree and Hunner, 1984) [12].

Transparency of CWSRs water were lowest (5.4±1.18 cm) in early rainy and highest (20.2±0.9 cm) in mid dry sub season. Because the turbidity of the CWSRs water was observed to be due to suspended particulate matter, the lowest transparency (highest turbidity) in early rainy sub season could be attributed to the surface runoff that might have entered the reservoir feeding the CWSRs, as well as the canals system during the rainfall, which might have contained organic and inorganic matters which rendered the water less transparent and the highest transparency recorded in mid dry sub season could be due to high concentration of calcium and sodium ions which caused coagulation of aggregates and sedimentation of suspended particulate matters (Delince, 1992) [11]. Pond water mean transparency was lowest (27.7±18.23 cm) in early dry, probably due to the increase in the phytoplankton biomass, which impacted characteristic greenish colour in the pond water (Delince, 1992) [11]. It was however highest (52.1±2.48 cm) in late dry sub season, possibly as a result of settling of suspended particulate matter in the water fed from the Main Canal in that sub season, since the ponds were stagnant or due to high concentration of calcium and sodium ions which caused coagulation of aggregates and sedimentation of suspended particulate matters (Delince, 1992) [11].

The average transparency value (12.6±6.5 cm) recorded for CWSRs water in dry season was higher than 5.8±1.5 cm recorded in wet season and that of annual mean (10.1±6.2 cm), all these values are below the recommended Secchi Disk reading of (30-60cm) for fish production. Pond water had lower transparency (39.9±17.8 cm) in dry season and a higher value of 43.4±6.5 cm in rainy season, the annual mean value was 41.3±14.5 cm. All these values are within the recommended Secchi Disk reading of (30-60 cm) for fish production.

CWSRs water recorded lowest depth (1.9±1.22 m) in early dry and highest (3.9±0.26 m) in mid dry sub season. the lowest water level in early dry sub season could be attributed to the fact that water was not frequently released from the reservoir during the sub season, because the irrigation fields were being prepared ahead of the next dry season production. The reverse was the case in late dry sub season when the water level was highest because the irrigation activities were in full operation during the sub season. Pond water depth was lowest (0.2±0.05 m) in mid dry and highest (1.7±0.11 m) in early rainy. The lowest depth in mid dry sub season is likely because the ponds are usually partially drained for harvesting towards the end of the year in early dry sub season and refilled with water in late dry sub season for stocking. Hence it is very likely that the ponds are either shallow or even empty during the mid-dry sub season. The highest water level in early rainy sub season is however expected, because, the ponds are usually filled with water from the Main Canal in late dry sub season prior to stocking and subsequently replenished by some residual water from the surrounding irrigated fields as time goes on. The depth of the four water bodies were generally higher in wet season than in dry season. The two water bodies exhibited highest TDS in mid dry sub season, this could be due to the fact that all the water bodies had least amount of water in that sub season, because, there was no release of water from the dam since the plots have been harvested and most fields were being prepared for the next dry season operation. CWSRs water lowest TDS value (0.06±0.04mg/l) was observed in late dry sub season when the water level was high in the supply canal, while pond water had lowest TDS value in early rainy. The lowest TDS of CWSRs water in late dry sub season could be due to high evaporation experienced in the late dry sub season due to high sunshine, while that of other water bodies in early rainy sub season could be attributed to the large amount of water they contained in the sub season which might have diluted the dissolved solid content. Seasonal analysis indicated that the water bodies exhibited higher TDS values in dry season and lower values in wet season.

Dissolved oxygen (DO)

The highest DO concentration (8.2±3.39mg/l) of CWSRs water recorded in early rainy sub season might have been due to aeration because of high water turbulence as a result of high water velocity and/or due to lower temperature of the supply canal water in the sub season, while the lowest (3.9±1.45mg/l) in flood sub season could have been due to low water velocity of the canal water while flowing in to the CWSRs during flood sub season resulting in poor aeration of the water and/or relatively higher water temperature, because oxygen dissolves faster at low temperature and slowly at high temperature (Tchobanoglous and Shroeder, 1987) [35]. The earthen Ponds' water had highest DO (8.3±1.26 mg/l) in early rainy sub season, possibly due to presence of phytoplankton (e.g., algae and diatoms) as indicated by the light green color of the pond water which produces most of the DO in ponds during photosynthesis (Dupree and Hunner 1984) [12]. The lowest DO (3.2±0.44 mg/l) in early dry could have been due to lowest transparency (high turbidity) because Oxygen level decreases in turbid waters as they become warmer as a result of heat absorption from the sunlight by the suspended particles and with decreased light penetration resulting in decreased photosynthesis and consequently lowest DO (Barns and Mann, 1980; RRWSMB, 2004) [8, 30]. The DO levels of the ponds and CWSRs in wet season were higher than those recorded in dry season. The higher DO level during the rainy season could probably be due to influx of oxygen rich waters in to the water bodies from the surrounding land during torrential rainfall, while lower DO in the dry season could have been due to the oxygen utilization for aquatic respiration and decomposition of organic materials by microbial activities (Baijot *et al.*, 1997) [7]. However, with the exception of DO level recorded in flood for CWSRs water in early dry and mid dry for pond water, all other sub seasonal, seasonal and overall mean values of DO levels of the two water bodies were within the range of 4 to 6mg/l recommended for fish production in natural fresh water bodies (Mbagwu and Adeyini, 1994) [23], ≥5 mg/l (Swingle, 1969) [33] and minimum level of 4mg/l for aquatic life (Vezeau, 1989) [40], but lower than ≥15mg/l for human consumption (FEPA, 2003). The values were also close to the range of 5.8 to 6.6 mg/l recorded for Bakolori Reservoir (Adeniji, 1980) [2].

Electrical conductivity (EC)

The highest seasonal and sub seasonal EC value both recorded in the CWSRs' water in dry season (Table 1) and early rainy sub season (Table 2) respectively could be attributed to the influx of runoff water from the Bakolori reservoir catchment agricultural lands, which might contain high concentration of dissolved minerals resulting from fertilizers and other agro-chemicals used in the irrigated fields. This agrees with the findings of John (1986) that influx of dissolved minerals in the water bodies could result in high conductivity readings. While the lowest values recorded in Pond water (395.2±35.5µs/cm) in dry season could be due to decrease in dissolved ions concentration as a result of dilution (Delince, 1992) [11] caused by the impoundment of the pond with water from the main canal in the dry season prior to initial stocking of the ponds with fish. The sub seasonal (Table 2), seasonal and overall mean (Table 1) conductivity values recorded for the water bodies of BIP are lower than the recommended water quality standard (1,500µs/cm) for aquatic life (Vezeau, 1989) [40] and 1000 µs/cm for human consumption (NIS, 2007). However values recorded in this study are generally higher than 62.2µs/cm reported for River Niger (Imerbore, 1971) [19], 33-84 µs/cm for Kainji lake (Adeniji, 1980) [2] and 40-70µs/cm for Osun river (John, 1986), but close to 447.71±22µs/cm recorded for Kware lake (Onaji, *et al.*, 2005) [27].

Total alkalinity

Highest seasonal and sub seasonal alkalinity in the water bodies of BIP as found in the Ponds' water during the wet season (Table 1) and CWSRs during the mid-dry sub season (Table 2) could have been due to removal of carbon dioxide from water for photosynthesis by phytoplankton and aquatic macrophytes in the drainage canals. Other possible cause of the high alkalinity level in the water body include various biological and chemical processes such as de nitrification, sulphate reduction, and dissolution of lime or other calcareous rocks (Boyd, 1979) [10]. While the lowest seasonal and sub seasonal values recorded in CWSRs during the wet season (Table 2) and corresponding flood sub season (Table 2) could be due to nitrification, sulphate oxidation (Golterman, 1975) [17] and increase of acidic substances in the water body as a result of fermentation of indiscriminately dumped rice straws after harvesting, a common practice in BIP. With the exception of early dry, late dry and corresponding dry season alkalinity values of pond water, all the sub seasonal, seasonal and the overall alkalinity values of pond water are above the minimum acceptable level (20 mg/l) for catfish production (Lawson, 1995) [21], within the range of 5-500 mg/l for aquatic life (Lawson, 1995) [21] but below the (50-200 mg/l) required for fish production in the tropical natural water bodies (Dupree and Hunner, 1984) [12]. However, the alkalinity values recorded in this study are comparable with the values (18.0 to 54.6mg/l) obtained in Kainji lake (Adeniji, 1980) [2], but lower than 212.67±37.69 found in Lake Chad (Umeham, 1989) [37].

Total hardness

Highest seasonal and sub seasonal water hardness in the water bodies of BIP as found in the ponds' water during the dry season (Table 1) and corresponding late dry sub season (Table 2) could be due to increase of metallic salts of calcium and magnesium resulting from the influence of environmental factors (Halder *et al.,* 1989) [18]. While the lowest seasonal and sub seasonal values recorded in CWSRs' water during the wet season (Table 1) and corresponding flood sub season (Table 2) could be due to dilution caused by the rain and flood water that could lessen the concentration of the divalent cat ions (calcium and magnesium) in the water bodies. With the exception of late dry sub seasonal hardness values of the water bodies (Table 2) and dry seasonal values of pond waters (Table 1), all other values were lower than 20 mg/l to 200 mg/l considered to be adequate for fish production (Dupree and Hunner, 1984) [12]. Water hardness values for water bodies of BIP (Table 1 and 2) were lower than 100 mg/l standard for human consumption (WHO, 1993) [41], 120 mg/l for aquatic life (Vizeau, 1989) [4], as well as 54.8 to 58.2 mg/l reported for River Niger (Imerbore, 1971) [19] and 466.96±54.18mg/l for Kware Lake (Onaji, *et al.*, 2005) [27].

Salinity

Highest seasonal and sub seasonal salinity values found in the CWSRs water during the dry season (Table 1) and corresponding late dry sub season (Table 2) could be due to rapid evaporation of surface water, poor circulation of the water and decrease in the water volume (Barns and Mann, 1980) of the CWSRs during the late dry season which might have concentrated dissolved minerals in the water body (Tait, 1981). The lowest values recorded in the pond during the wet season (Table 1) and corresponding flood sub season (Table 2) can be attributed to the dilution caused by the rain and flood water that could lessen the concentration of dissolved minerals that constitute salinity in the water bodies. The overall mean salinity values recorded in the present study (Table 1) are however higher than 9.09±1.62ppm reported for Kware Lake (Onaji *et al.*, 2005), but closely comparable to the normal salinity level of 0.5ppt of natural fresh water bodies (Delince, 1992) [11], and are within the recommended level of <0.5ppt for fresh water aquaculture (Delince, 1992) [11].

Nitrate-nitrogen

Nitrate-N maximum levels recorded in the ponds water during the wet season (Table 1) and corresponding early rainy sub season (Table 2) can be attributed to the release of livestock excretory products in the ponds while drinking water, as have been observed severally during sample collection in the study area. It could also be due to inflow of fertilizers and organic materials from the irrigated fields and other surrounding farm lands through runoff during torrential rainfall (Delince, 1992) [11], and burning and clearing (Goldman and Horne, 1983) of irrigation fields for cultivation. The minimum values recorded in the CWSRs water during the dry season (Table 2) and corresponding mid dry sub season (Table 2) could be due to denitrification processes. The sub seasonal, seasonal and overall mean nitrate values recorded in the present study are higher than 0.5±0.4 mg/l for Kainji Reservoir (Adeniji, 1980) [2]. The values are however lower than 45 mg/l recommended for human consumption (WHO, 1993) [41], but within the water quality standard of 5 mg/l for aquatic life (Vizeau, 1989) [40].

Phosphate-phosphorus

The maximum phosphate-P values recorded in the CWSRs water during the dry season (Table 1) and corresponding mid dry sub season (Table 2) could be due to presence of detergents (Golterman, 1975) [17] used by herdsmen and inhabitants of the nearby settlements for washing clothes and bath in the drainage canals. It could also be as a result of influx of fertilizers (Boyd, 1979) [10] from the irrigated plots through the residual irrigation water in to the drainage canals. The minimum values recorded in the pond water during the wet season (Table 1) and corresponding early rainy sub season (Table 2) could be due to rapid uptake of the nutrient by algae, aquatic macrophytes and other phytoplankton, which frequently form blooms in the water body (Boyd, 1979) [10]. The overall mean values recorded in the present study (Table 1) were lower than 4.74±0.64 mg/l reported for Kware Lake (Onaji *et al.*, 2005) [27] and 5.75 mg/l for reservoir of International Institute for Tropical Agriculture, Ibadan south west rain forest zone of Nigeria (Adeniji, 1980) [2]. But higher than 0.13mg/l reported for River Niger in the middle belt savanna zone of Nigeria (Imerbore, 1971) [19], but comparable with 0.34mg/l found in Nyando River in Kenya (Tchobanoglous and Schroeder, 1987) [35]. However, the values recorded for the three water bodies in the sub seasons (Table 2), seasons and overall mean values (Table 1) are comparable to the water quality standard (0.1 mg/l) favourable for aquatic life and fish production (Vizeau, 1989) [40].

Conclusion

The research revealed levels of some important physicochemical parameters of main large earthen ponds and CWSRs waters in Bakolori Irrigation Project. Season, nature of the water bodies and agricultural activities, in and around the studied area and the catchment areas of Bakolori

Reservoir may have contributed to most of the variability in the concentration of the investigated parameters. Physicochemical parameters of the two water bodies are mostly within the acceptable levels for drinking water, aquatic life and fish production. It is therefore concluded that the earthen ponds and CWSRs waters of Bakolori Irrigation Project in Zamfara State, North Western Nigeria are of appreciable water quality status for human consumption, aquatic life and fish production.

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