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Physicochemical analysis of water and sediments of Usuma Dam, Abuja, Nigeria

Ifenna ILECHUKWU,[1] Tolulope Abisola OLUSINA[*],[2] and Odinaka Chidinma ECHETA[3, 4]

[1]*Environmental Chemistry Unit, Department of Industrial Chemistry, Madonna University, Elele Campus, Rivers State, Nigeria*
[2]*Civil Engineering Department, Imperial College London, SW7 2AZ, United Kingdom*
[3]*Civil and Environmental Engineering, Faculty of Engineering, University of Lagos, Akoka, Lagos State, Nigeria*
[4]*Regional Water and Environmental Sanitation Centre, Civil Engineering Department, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana*

Abstract. Usuma Dam is the major source of potable water in the Federal Capital Territory, Abuja, Nigeria. The physicochemical properties of water and sediment of the dam was assessed in this study to determine its quality. Electrical conductivity, pH, nitrate, phosphate, total dissolved solids, total suspended solids, turbidity, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, chloride, total hardness, phosphate, nitrate and sulfate were determined in the water samples. Total organic matter, total organic carbon and particle size were among the parameters analyzed in sediments. The parameters were within recommended limits except for biochemical oxygen demand and chemical oxygen demand which were more than the recommended limit of 10 mg/L and 30 mg/L respectively. The total organic matter and the total organic carbon in the sediment samples were between 1.56±0.27 – 2.85±0.20 % and 0.13±0.03 – 0.96±0.03 % respectively. The particle size was in the following order: sand > silt > clay. The results of this study confirmed the presence of high organic and inorganic matter in the dam from non-point pollution sources occasioned by storm water from poorly planned settlements around the dam and runoffs from agricultural practices.

Keywords: physicochemical parameter; pollution; Usuma Dam; sediment; water quality.

1. Introduction

The availability of water in sufficient quantity is as important as its quality. Water serves diverse needs for humans such as provision of seafood, water for agriculture and domestic activities, and psycho-social benefits for recreational purposes. Hence, water that comes in contact with humans directly or indirectly should meet certain standards to avoid causing harm. Water resource contamination remains a huge challenge in most regions of the world [1].

Most studies on water quality ignore the influence of sediments. The effect of anthropogenic activities compounded by longer residence time in dams enhances pollutants and organic matter sedimentation [2, 3]. Consequently, sediment composition gives a clearer view of the nature and sources of pollutants in a water body. Sediments act as a reservoir and source of pollutants in aquatic environments under favorable conditions [4, 5]. Sediment enriches the organic content of water and is the major site for organic matter degradation [6]. Furthermore, sediment–dwelling organisms can be adversely affected by water pollutants leading to loss of biodiversity [7]. Nutrients such as phosphates and nitrates are continuously interchanged between sediments and the overlying water. Moreover, only few water quality studies focus on dams as majority focus on streams, lakes, rivers and groundwater. This presents a knowledge gap considering that dams are man-made and have diverse tributaries which empties into them with municipal solid wastes and organic matter debris [8]. Structural design and dam operations may influence its water quality [9]. It has been reported that the presence of a dam modifies important habitat conditions such as dissolved oxygen, electrical conductivity, turbidity and nutrients such as nitrates and phosphates in sediment [10].

The Usuma Dam situated towards the North-Eastern part of the Federal Capital Territory of Nigeria, covers an area of approximately 2,500,000 m^2. Hence, it is greatly affected by anthropogenic activities. Major activities on the shores of the dam include fishing, animal husbandry, crop cultivation and trading. It is important to analyze the water and sediments of the dam to determine its quality considering that it is the major source of potable water in the Federal Capital Territory. Therefore, the aim of this study was to assess the physicochemical properties of water and sediments of Usuma Dam. Apart from comparing the parameters with standard guidelines, samples from tributary, shores and the mid water were analyzed for differences in their quality. The result of the study is expected to aid in the management of the dam and similar water reservoirs.

[*]Corresponding author. *E-mail address*: tolulope.olusina19@imperial.ac.uk (T. A. Olusina)

2. Experimental

2.1. Study area

Usuma Dam is located in Ushafa, Bwari, Abuja on latitude 9°0'12" N and longitude 7°25'16" E. It is built across River Usuma and serves as the source of water for irrigation, fishery and other daily essentials for the neighboring communities. The dam is the major receiving water body in the Federal Capital Territory. The main dam embankment is 1.3 km long, 47 m high and has a crest of 10 m. The saddle dam is 470 m long, 15 m high and has a crest size of 10 m. The total area used up by the dam is 2,500,000 m^2 [11]. Settlements around the dam include Payi, Jigo, Kwabwarra, Ushafa and Mpape communities.

2.2. Sample collection

Sediment samples were collected with Van-Veen grab sampler. Ten sediment samples were collected for the study, *i.e.* eight samples from the dam and two samples from the major tributary (Figure 1).

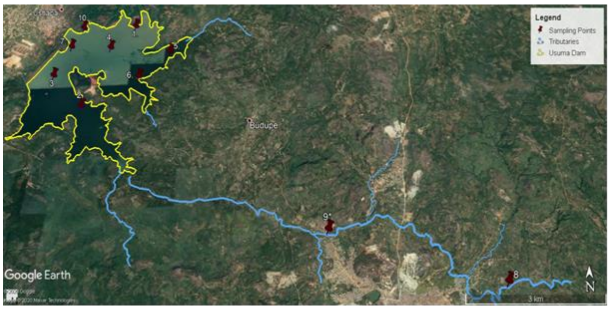

Figure 1. Sampling points within the Usuma Dam and tributaries

The sediment samples were wrapped with aluminum foil. Water samples were collected with 1.5 L plastic bottles. Samples were randomly collected multiple times at each sampling station and subsequently pulled together to form a composite sample. Samples were collected in November, 2019.

Table 1. Description of samples

Sample stations	Latitude	Longitude	Station
Sample 1	9°12'36.26"N	7°26'11.43"E	Mid-waters
Sample 2	9°11'16.20"N	7°25'35.94"E	Mid-waters
Sample 3	9°11'46.26"N	7°25'6.55"E	Mid-waters
Sample 4	9°12'13.81"N	7°25'51.94"E	Mid-waters
Sample 5	9°12'8.19"N	7°26'45.85"E	Shores
Sample 6	9°11'43.39"N	7°26'21.00"E	Shores
Sample 7	9°12'15.54"N	7°25'16.60"E	Mid-waters
Sample 8	9° 8'48.47"N	7°31'6.20"E	Tributary
Sample 9	9° 9'28.33"N	7°28'59.91"E	Tributary
Sample 10	9°12'35.45"N	7°25'24.14"E	Shores

2.3. Materials and equipment

Sodium hydroxide (NaOH), ethylenediaminetetraacetic acid (EDTA), silver nitrate ($AgNO_3$), potassium dichromate ($K_2Cr_2O_7$), iron (II) sulfate ($FeSO_4{\cdot}7H_2O$), manganese sulfate ($MnSO_4{\cdot}H_2O$), sodium hexametaphosphate ($(NaPO_3)_6$), concentrated sulfuric acid (H_2SO_4), barium chloride ($BaCl_2$), mercuric sulfate ($HgSO_4$), all of analytical grade, were purchased from Geochem Laboratories in Port Harcourt, Rivers State, Nigeria. Electrical conductivity and pH were determined with electrical conductivity meter (Labtech DDS-307) and pH meter (Hanna H1991300) respectively. Spectrophotometer (Apel PD300UV) was used for the determination of nitrate and phosphate.

2.4. Sample analysis

The values of pH, conductivity, hardness, total dissolved solids (TDS), total suspended solids (TSS), turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), chloride, sulfate, phosphate and nitrate were determined following standard methods [12]. Wet oxidation method and loss-on-ignition were used to determine total organic carbon (TOC) and total organic matter (TOM) respectively [13]. Particle size analysis was done with Bouyoucos hydrometer method. Sample analysis was done in triplicates.

2.5. Statistical analysis

Microsoft Excel Analysis ToolPak was used for the statistical analysis. Pearson's coefficient correlation was applied to ascertain the relationship between parameters. Additionally, a one-tailed *t*-test at 95% confidence limit ($p < 0.05$) was carried out to test for significant differences between the mean values of the analyzed parameters in the mid-waters, the shore, the tributaries and the dam (Table 1).

3. Results and discussion

The results of the physicochemical analysis of the water and sediments of the Usuma Dam are presented in Fig. 2 – 15.

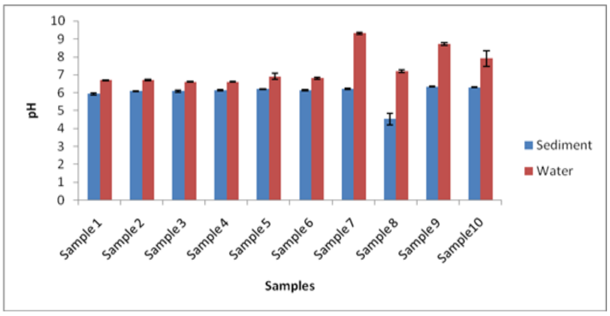

Figure 2. pH of water and sediment samples

pH is the measure of H^+ concentration in the samples. It is an important indicator of the chemical status of the dam. It regulates the biogeochemical reactions and processes in water bodies [14]. The pH values of the water were between 6.62±0.01 – 9.32±0.06 while the sediment pH was between 4.53±0.33 – 6.34±0.01 (Figure 2). The sediment pH was more acidic than the water pH in all sampling stations. Majority of the water samples except sample 7 and 9 were within the permissible range of values (6.5 – 8.5) prescribed by the Nigerian Standard for Drinking Water Quality [15]. Sampling station 9 corridors serve as a choice spot for washing of automobile. The increased pH value would have been from detergent used in washing of automobiles in the area. There was a significant difference (p = 0.01) between the pH of water samples from the mid-waters and the shores of the dam. There was also a significant difference (p = 0.0006) between pH of the sediment from the mid water and that of the shore samples. No significant difference was observed between the pH of water samples (p = 0.24) in the tributaries and that of the dam samples. The pH of the sediment samples from the tributaries and the dam also showed no significant difference (p = 0.07).

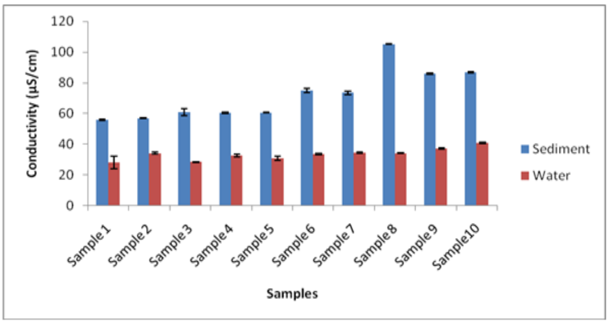

Figure 3. Electrical conductivity of water and sediment samples

The electrical conductivity of the samples was between 56.00±0.44 – 105.20±0.27 and 28.00±0.41 – 40.77±0.44 µS/cm for sediment and water respectively (Figure 3). The EC values were within the permissible limit of 1000 µS/cm [15]. The sediment samples recorded higher EC values than the water samples in all sampling stations. This is because sediment contains more electrolytes than water in water bodies. There were significant differences between the electrical conductivities of the water samples from the mid-waters and the shore samples (p = 0.02) and between the tributaries and the dam (p = 0.01). The sediment samples also showed significant difference between the mid - water and the shore samples (p = 0.001) as well as between the tributaries and the dam (p = 9.05E-05)

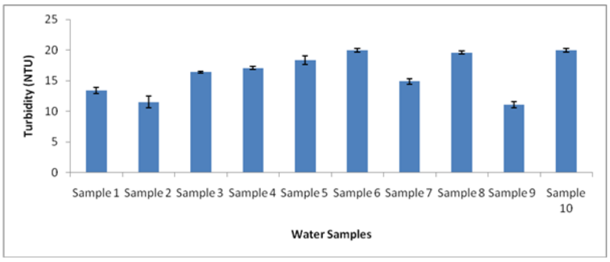

Figure 4. Turbidity of water samples

Turbidity is a measure of suspended minerals, bacteria, planktons, dissolved organic and inorganic substances [16, 17]. These suspended materials determine the clearness of water. The turbidity of the water samples was between 11.50±0.96 – 19.97±0.32 NTU (Figure 4). Shore samples (samples 10, 5 and 6) recorded high turbidity. There was a significant difference (p = 0.03) between the water samples from the mid-waters and the shore samples, but no significant difference (p = 0.31) was observed between the samples from the tributaries and the dam. Debris from influent water first settles on the shores due to decreased flow velocity. Anthropogenic activities around the dam also introduce organic and inorganic materials on the shores of the dam which lead to increased turbidity of water samples from the shores. The moderate positive correlation (+0.60) between turbidity and conductivity indicates the materials contributing to the turbidity of the samples may also be part of the electrolytes in the samples.

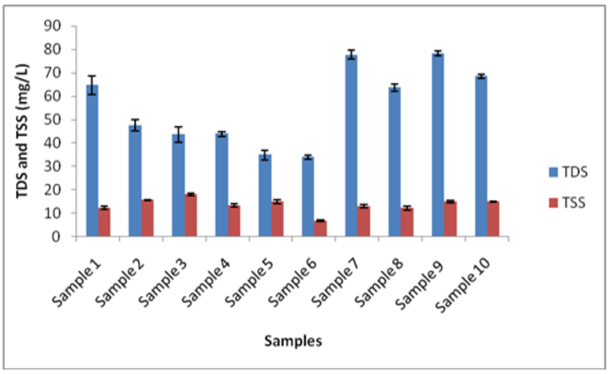

Figure 5. Total dissolved solids (TDS) and total suspended solids (TSS) in water samples

The total dissolved solids (TDS) of the water samples was 33.85±0.97 – 78.32±0.94 mg/L while the total suspended solids (TSS) was between and 6.73±0.33 – 17.89±0.59 mg/L (Figure 5). Both TSS and TDS were within the recommended limit by Department of Petroleum Resources [18]. No significant difference was observed between the mid-water TDS and the TDS of the shore samples (p = 0.14) and the TSS for mid-waters and the shores (p = 0.34). However, the mean differences between the TDS (p = 0.02) and TSS (p = 0.04) for the tributaries and the dam respectively were significant. Solids in the dam are from natural and anthropogenic activities such as industrial effluents, farming, construction, municipal solid wastes and urban runoff transported by the influent waters into the dam [19, 20]. Solids may be retained on the shores of the dam where they impede activities of aquatic animals [21]. Pearson correlation showed a weak positive correlation (+0.14) between TDS and TSS (Table 2) and a weak positive correlation (+0.48) between conductivity and TDS, indicating that TDS makes up part of the electrolytes in the dam.

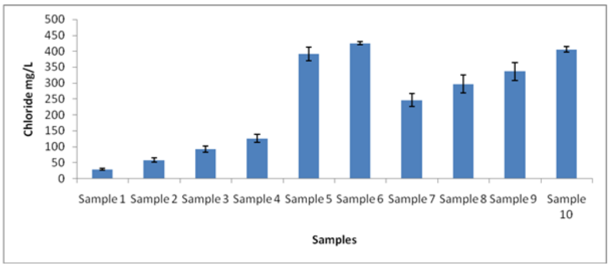

Figure 6. Chloride concentration in water samples

The chloride concentration of the water samples was between 28.67±3.21 – 425.33±10.07 mg/L (Figure 6). Chloride sources in surface water may include rocks containing chlorides, agricultural runoff, wastewater from industries, oil well wastes, industrial and waste water effluents and road salting [22, 23]. Samples from the tributaries and shores of the dam had higher chloride concentration than the mid-waters of the dam, confirming chloride sources are from runoffs into the dam but they all become diluted to lower concentration within permissible limit on settling in the dam [15]. Significant differences between chloride concentration in water samples from the tributaries and samples from the dam (p = 6.59E-05) and also between chloride concentration in the mid-waters and the shore samples (p = 5.25E-05) corroborate the chloride sources as runoffs into the dam. The strong positive correlation (+0.79) between chloride and water hardness and the negative correlation with phosphate (-0.86) and nitrate (-0.68) may be a confirmation that chloride sources in the dam are from surrounding rocks and runoffs from quarry sites as water hardness is due to magnesium and calcium salts in water. None of the sampling stations was higher than the recommended chloride limits (600 mg/L) for protection of aquatic life in freshwater [18].

Water hardness measures divalent cations mainly calcium and magnesium in a water body. The hardness of the water samples was between 39.33±3.06 – 440.00±34.00 mg/L (Figure 7). Samples from the tributaries had higher water hardness values than the shore samples. Samples from the tributaries and the dam showed significance difference (p = 0.0002) in their water hardness. There was also a significant difference between the hardness of mid-water samples compared to the shore samples (p = 0.0004).

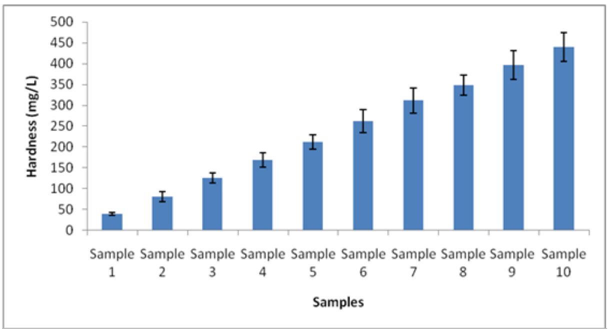

Figure 7. Hardness of the water samples

The total hardness for all samples was higher than the recommended limit of 150 mg/L except samples 1 and 2 [15]. The high values indicate high concentration of calcium and magnesium salts from runoffs into the dam [24, 25].

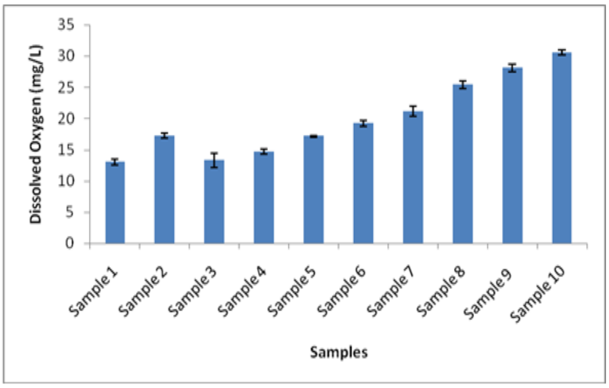

Figure 8. Disssolved oxygen (DO) in the water samples

Dissolved oxygen (DO) measures the amount of oxygen in water. The type of water body, temperature as well as biological and chemical processes taking place in the water determine the level of DO in the water and its ability to support aquatic life. It also affects algal bloom in surface waters [26]. Concentration below 5 mg/L will adversely affect the activities of aquatic organisms [27]. The DO of the samples was between 13.00±0.50 – 30.60±0.36 mg/L (Figure 8). Only samples 7-10 were up to DPR recommended value of 20 mg/L for DO. This could be attributed to the increased flow of water in these sample stations more than in the dam because flow increases dispersal of atmospheric oxygen into the water [28]. There was a significant difference between DO values for the mid-waters and the shore samples (p = 0.002) and between the tributaries and the dam (p = 4.48E-05).

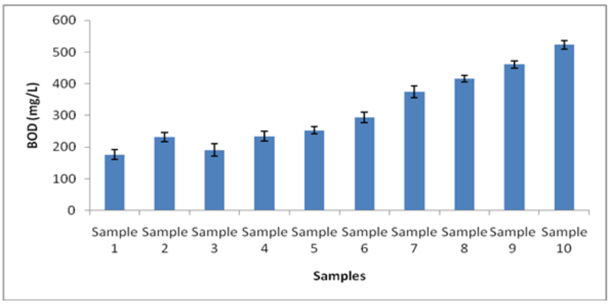

Figure 9. Biochemical oxygen demand (BOD) in the water samples

Biochemical oxygen demand (BOD) measures the level of oxygen needed for biological oxidation of organic wastes in water. It is dependent on temperature, nutrient concentrations, organic content and enzymes available to the indigenous microbial populations [29]. The BOD of the samples was between 176.00±15.62 – 523.33±13.61 mg/L (Figure 9). Large quantity of organic wastes in water attracts lots of microrganisms to decompose the wastes. In such case, the demand for oxygen will be high invariably increasing BOD levels [30]. The BOD levels of the samples were higher than the DPR recommended value of 10 mg/L indicating high organic waste content of the dam [21]. There was a significant difference between the BOD values of the mid-waters and the shore samples (p = 0.004) and between the tributaries and the dam samples (p = 0.004).

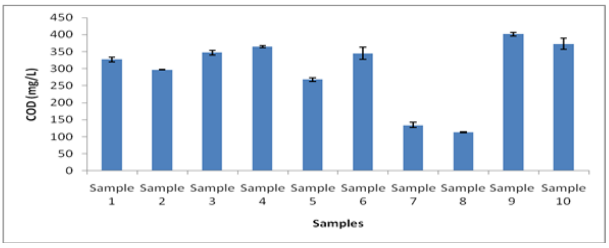

Figure 10. Chemical oxygen demand (COD) in water samples

Chemical oxygen demand (COD) assesses the depletion of oxygen in a water body during the decomposition of organic matter and the oxidation of inorganic chemicals. The COD of the samples was between 113.42±1.34 – 401.53±5.32 mg/L (Figure 10). All samples were higher than the recommended limit of 30 mg/L for surface water [18]. Sample 9 with the highest COD value is not surprising considering that the station is a choice spot for automobile wash with detergents and other ancillary chemicals. No significant difference was observed between the COD values of the mid-waters and the shore (p = 0.18) and between the tributaries and the dam (p = 0.49).

The sulfate concentration in the water samples was between 69.2±8.74 – 123.80±3.14 mg/L (Figure 11). Sulfate concentration in the samples did not exceed the recommended limit of 50 – 200 mg/L for surface water [18].

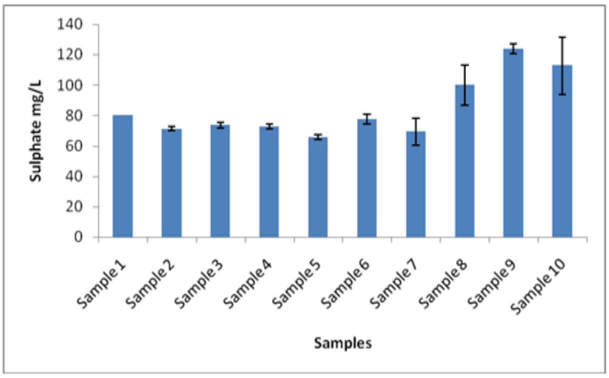

Figure 11. Sulfate concentration in water samples

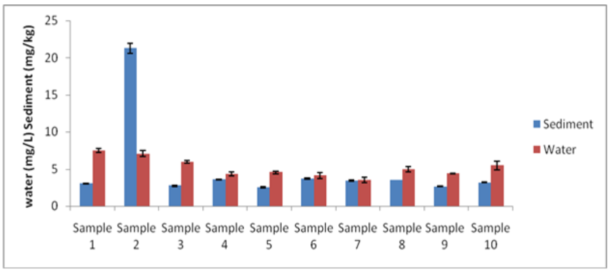

Figure 12. Nitrate concentration in water and sediment samples

Nitrate concentration indicates the nutrient level and the extent of organic matter pollution in a water body [31]. The concentration of nitrate in the samples was between 2.54±0.07 – 21.29±0.66 mg/kg and 3.55±0.37 – 7.47±0.28 mg/L for sediment and water respectively (Figure 12).

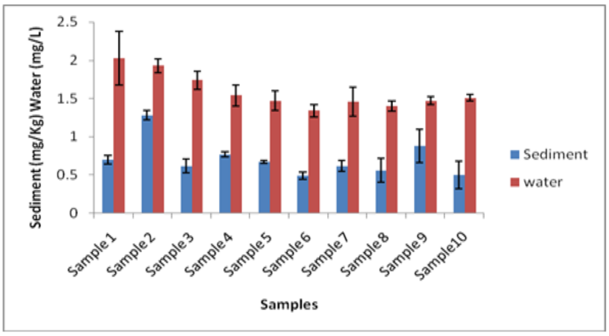

Figure 13. Phosphate concentration in water and sediment

The concentration of phosphate in the samples was between 0.49±0.05 – 1.28±0.06 mg/kg and 1.34±0.08 – 2.03±0.35 mg/L for sediment and water respectively (Figure 13). All samples were within the DPR recommended limit of 20 mg/L and 5.0 mg/L for nitrate and phosphate respectively in surface water except sediment sample 2 which has higher nitrate concentration [18].

There was no significant difference between the nitrate concentration of the mid-waters and the shore (p = 0.08), and there was also no significant difference between the tributaries nitrate concentration and that of the dam samples (p = 0.08). There was a significant difference between the phosphate in the mid-waters and in the shores (p = 0.03) and between phosphate values of the tributaries and the dam (p = 0.004). There was no significant difference between nitrate concentration (p = 0.21) in the mid water sediment and sediment samples from the shores but there was a significant difference (p = 0.04) between nitrate concentration in the sediments of the dam and that of the tributaries. Both nitrate and phosphate showed a strong positive correlation in water (+0.91) and sediment (+0.84) (Tables 2 and 3). This is an indication that the sources of nitrates and phosphates as well their interactions in the dam may be similar. Open defecation and farming activities in the corridors of the dam and its tributaries are likely sources of nitrates and phosphates in the dam. Fertilizers from farms, industrial effluents and wastes from human settlements are significant sources of nitrates and phosphates in surface water [31, 32]. These nutrients are usually retained in sediments of the dams due to impoundments [33]. The presence of these nutrients may result in eutrophication and toxic algae bloom [34].

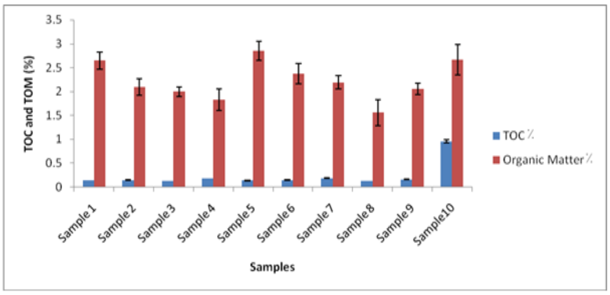

Figure 14. Total organic carbon and total organic matter in sediment samples

TOC concentation in the sediment was between 0.13±0.03 – 0.96±0.03 % while the total organic matter was between 1.56±0.27 – 2.85±0.20 % (Figure 14). The concentration of TOM and TOC were high in the sediment samples. The dam being a recieving water body, is a sink for organic matter from domestic, municipal, agricultural and industrial wastes. Unlike the TOC concentration in sediments of the dam and the tributaries, sediment samples from mid-waters and shores showed significant difference (p = 0.05). TOM showed significant difference (p = 0.05) between tributaries and dam samples but there was no significant difference (p = 0.06) between mid-water and shore samples. The slow water exchange in the dam is optimum for accumulation of organic matter in the sediments [35]. TOC and TOM showed a weak positive correlation (+0.37) (Table 3). Perhaps, some of the organic carbon may have been generated from the decomposition of organic matter [36].

The particle size analysis showed dominance of sand particles (50.17±1.77 – 75.17±2.16%) followed by silt (11.61±6.15 – 31.83±1.05%) and then clay (7.86±1.68 – 25.77±1.16%) in all samples except sample 2 where clay dominated the silt (Figure 15). Particle size affects nutrient accumulation especially if it consists of huge fine particles that provide large surface area for pollutant adsorbtion and organic matter deposition [31, 37].

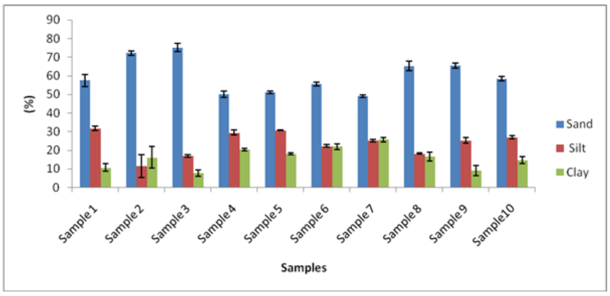

Figure 15. Particle size analysis of the sediment samples

Significant difference ($p = 0.008$) was observed only between the silt concentration in the mid - water and the shores. Silt has strong negative correlation with sand (-0.78) and clay (-0.70) confirming the variations in the particle sources. While the sand and the clay particles may have been as a result of dam construction and runoffs, most of the silt may be as a result of decomposition of organic matter in the dam as shown from the moderate positive correlation (+0.56) between the silt and TOM (Table 3).

Table 2. Pearson correlation of physicochemical parameters of water samples from Usuma Dam

	pH	Turbidity	Conductivity	Chloride	Hardness	COD	Nitrate	Phosphate	Sulfate	DO	BOD_5	TDS	TSS
pH	1												
Turbidity	0.08	1											
Conductivity	0.59	0.60	1										
Chloride	0.37	0.55	0.56	1									
Hardness	0.69	0.53	0.83	0.79	1								
COD	-0.26	0.23	0.07	-0.05	-0.12	1							
Nitrate	-0.52	-0.08	-0.35	-0.68	-0.63	0.23	1						
Phosphate	-0.41	-0.32	-0.49	-0.86	-0.78	0.22	0.91	1					
Sulfate	0.44	0.35	0.68	0.39	0.72	0.26	-0.07	-0.27	1				
DO	0.65	0.54	0.91	0.66	0.94	-0.07	-0.36	-0.56	0.84	1			
BOD_5	0.68	0.63	0.91	0.66	0.95	-0.17	-0.43	-0.61	0.73	0.97	1		
TDS	0.80	0.01	0.48	-0.01	0.50	-0.22	-0.06	-0.01	0.63	0.60	0.60	1	
TSS	0.05	-0.06	-0.04	-0.41	-0.13	0.16	0.33	0.39	0.06	-0.05	-0.08	0.14	1

Table 3. Pearson correlation of physicochemical parameters of sediments from Usuma Dam

	pH	Conductivity	Nitrate	Phosphate	TOC (%)	TOM (%)	Sand (%)	Silt (%)	Clay (%)
pH	1								
Conductivity	-0.57	1							
Nitrate	0.04	-0.31	1						
Phosphate	0.20	-0.41	0.84	1					
TOC %	0.23	0.31	-0.11	-0.30	1				
TOM %	0.56	-0.37	-0.15	-0.19	0.37	1			
%Sand	-0.22	0.07	0.44	0.40	-0.10	-0.39	1		
%Silt	0.31	-0.14	-0.66	-0.41	0.19	0.56	-0.78	1	
%Clay	-0.01	0.05	0.05	-0.17	0.05	-0.01	-0.70	0.11	1

4. Conclusions

The physicochemical parameters assessed in this study were within recommended limits except for biochemical oxygen demand (BOD) and chemical oxygen demand (COD). The high BOD and COD confirm the presence of high organic and inorganic materials in the dam from non-point pollution sources occasioned by poorly planned settlements around the dam, runoffs from agricultural practices and disposal of municipal and domestic wastes washed into the tributaries. While routine monitoring is recommended to always ascertain the water and sediment quality of the dam, it is important to ensure organic and inorganic debris do not drain into the dam in order to protect aquatic life.

Acknowledgements

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Conflict of interest

The authors declare that there is no conflict of interest regarding this research article.

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