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Research Article

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Sedimentation and Contamination Level in a Surface Water used as Drinking Water Supply: A Case Study of Okpara Dam in Benin

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Abstract The dams are now affected by the phenomenon of sedimentation that lead not only to its progressive filling but also the deterioration of water quality. The study aims to identify the origin of sedimentation observed at the dam Okpara, and to see its influence on the physico-chemical water quality. The methodology consisted in the sampling of water and sediment, the survey of sediment sub surface, the determination of the physico-chemical parameters of water and sediment; and the granulometry of the sediment analysis. The average concentrations of iron and manganese in the sediment are respectively 1120mg/kg and 228.89mg/kg. Those recorded in water are 3.24mg/L for iron and 0.91mg/L for manganese. It appears that iron is 345 times more concentrated in the sediment than in the water and that manganese is 251 times more concentrated in the sediment than in the water. The analysis of the chemical parameters measured in water, coupled with those measured in sediments confirms the influence of the sedimentation on the water quality. The granulometric study of sediments shows that they are mainly composed of silt and remains of plants; and borehole has revealed that the deposited layers are mainly clay and sand. The results of the study indicate contamination of the water dam Okpara by iron and manganese and its filling with sediment.

Keywords Deterioration, contamination, granulometry, sedimentation, physico-chemical parameters

1. Introduction

Drinking water suppliers around the world have always preferred groundwater to surface water. In fact, since surface waters are opened to the atmosphere, they are exposed to several types of pollution such as chemical pollution, eutrophication and sedimentation phenomena [1-4]; while, in contrast, groundwater enjoys the protection against these pollutions from atmosphere, since there are covered by geological formations [5]. In some areas, access to groundwater is difficult due to the crystalline nature of the geological substratum in place. This may force the water stakeholders to turn to the use of surface water for drinking water production [6]. Thus, the Government of Benin has implemented the construction of dams to reinforce drinking water supply in difficult geology areas. However, as in general, the management of these structures is confronted to the problems of sedimentation and water contamination [7]. Okpara dam, which is the only source of drinking water of the town of Parakou, meets with this situation. Existing studies on Okpara dam water's [8] does not provide information on the evolution of sedimentary deposits layers. Thus, this study determined the order of deposition of sedimentary layers on the reservoir of Okpara dam and measured the physico-chemical parameters of its water. It helps to appreciate the importance of the filling and its impact on the quality of the water in the dam.

2. Material and Methods

Study area

Okpara catchment is located in the North-East of Benin, in Parakou, with a 2070 km^2 area with a perimeter of 217 km. The dam is located in the Eastern part of the city of Parakou and overflow to the townships of Tchaourou, Pèrèrè, Nikki, N'Dali then on a small part to the South-East of Bembérêkê Township (figure 1).

The concerned area is characterized by a tropical climate, with the alternation of one rainy season from May to October and one dry season from November to April. The temperatures are variable in the area. During the rainy seasons, the thermal amplitude is low and oscillates around 25°C. The maximal extremes oscillate between 35°C and 38°C (March to April) and the minimal between 18°C and 21°C (December to January) [9]. This last period corresponding to the Harmattan is characterized by low relative humidity that can decrease to 20% and strong sunstroke of eight hours per day.

Soils in the study area are tropical ferruginous, ferralitic, sandy - clayey or clayey - sandy. The Okpara river is situated on a Precambrian basement formed of calco - alkalic granites with muscovite and biotite most often leucocratic and of gneiss [10].

Contributions of water from the Okpara River to the dam are estimated to be approximately 269 million m^3 in a year. This quantity is reduced to 220 million m^3 during a dry ten-year and to 50 million m^3 during one very dry year. The water flow direction is imposed by the topography where the altitude decreases progressively from the North to the South with values between 500 m and 250 m [11]. According to local inhabitants interviewed, the dam dries up from day to day during the period of low water level [9]. This observation could be linked to the progressive filling of the dam by sediments and organic materials.

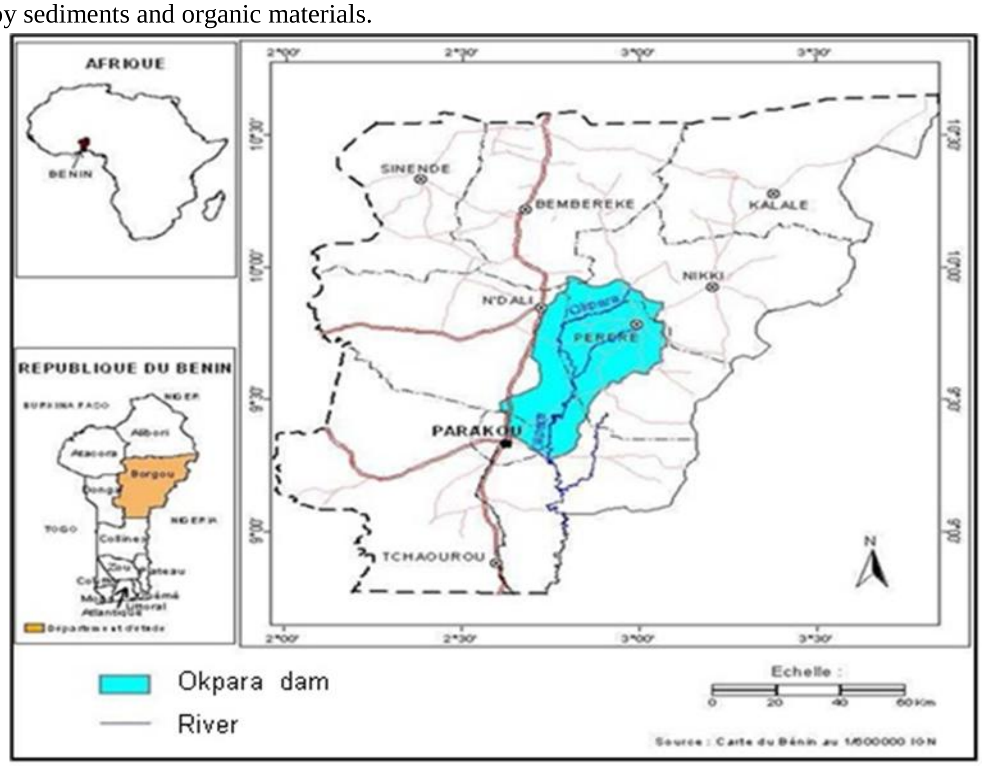

Figure 1: Localisation of Okpara catchment and dam [14]

Sampling

Water and sediment samples were collected in the reservoir of the Okpara. The survey of sedimentary layers was made on the edges of the dam. Chemical analyzes were performed at the Laboratory of Applied Hydrology (LHA) and particle size analysis was performed in the laboratory of the Department of Earth Sciences, Faculty of Science and Technology (FAST).

Water and Sediment

Water and sediments were sampled from ten different stations around the dam (figure 2). Water samples were collected at appropriated depth with an automatic sampler, in plastic bottles that were first rinsed with water from Okpara lac at the sampling point. The top 20 cm of sediment were collected from each sampling station using the Eckman bottom sampler device [12-15]. Samples for chemical analysis were kept in polypropylene containers (20g) and the one for texture analysis were kept in glass bottles (at least 150 g). At each site, one random sample of water and two random samples of sediment were collected whereas the sediments for texture analysis were mixed, to ensure that the sample was representative for this site. All the samples were kept at 4^{o}C from the study field to the laboratory. During their transportation to the laboratory, precautions were taken (cold storage on ice, complete filling containers, use of plastic materials for storage, avoidance of undue agitation) to minimize any kind of disturbances [16-18]. Sample containers, sampling devices, glass and plastic material were carefully cleaned before use, by soaking in 10% nitric acid [19]. The different sites were located using the global positioning system (Garmin GPS 12 _ L).

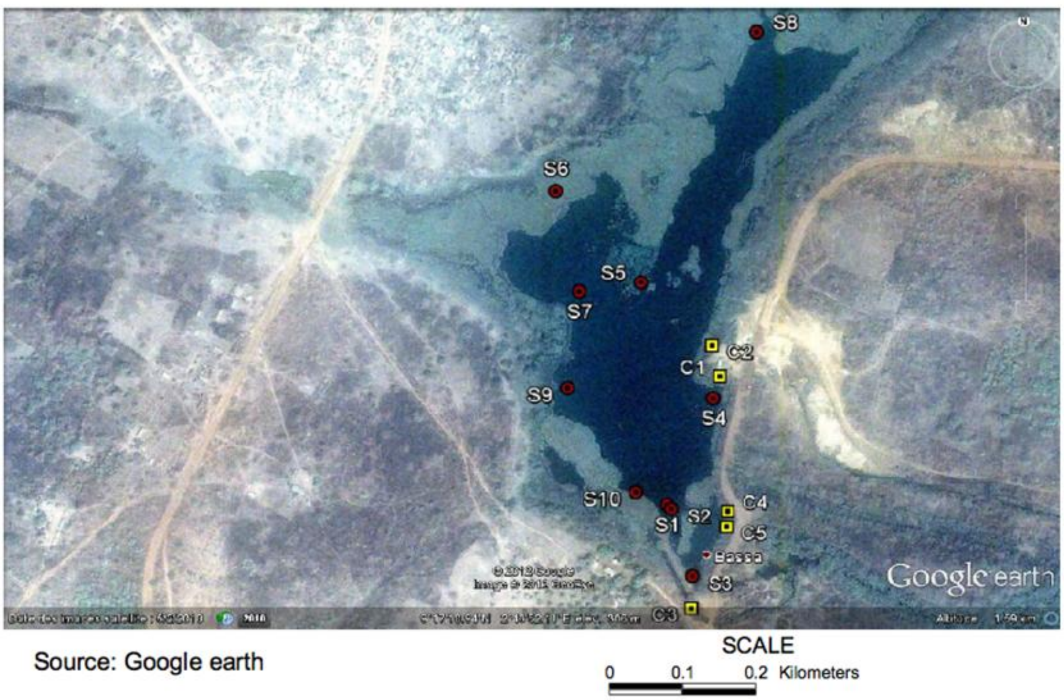

Figure 2: Localization of water collection stations and borehole points at the Okpara dam

Boreholes

For better understanding of sedimentary deposits in terms of their nature, five (5) boreholes (figure 2) with depth from 55 to 103 cm were drilled on the edge of the dam by a hand auger, and different sediments taken at different levels. Two boreholes were drilled in front of the tower collection, two in front of the lateral spillway and one in front of the central spillway.

Laboratory Analysis

Physical Parameters

Physical parameters such as temperature, pH, conductivity, turbidity and color were analyzed in the water samples. The temperature and the conductivity were measured by the conductivity-meter WTW 340i, the pH by pH meter pH /oxi, the turbidity and color by the Colorimeter HACH DR890. The parameters were measured by submersing the sensor in the water at the depth of 10 cm from the water surface. All parameters were displaced on the screen of the apparatus.

Chemical Parameters

The chemical parameters analyzed in water samples were calcium, magnesium, bicarbonate ions, iron and manganese.

The analysis of calcium, magnesium and bicarbonate were carried out using the titrimetric method according to (NF T 90-003) guidelines. The different materials used were burette, pipette, Erlenmeyer flask and bottle. The reagents used were standard ETDA titrate (0.01M) and ammonia buffer. Additionally, as all metal EDTA salts are colorless and require an indicator to tell when the reaction is over, the appropriate indicator was used according to the chemical to be titrated. The procedure is as follows: After the dilution of 25 mL of sample (V) to about 50 mL with distilled water in an Erlenmeyer flask, 1mL of buffer solution was added followed by two drops of indicator solution. Then the slow addition of standard EDTA titrates with continuous stirring until the disappearance of the last color tinge from the solution was carried out. The volume used to reach titration was noted down and the proper calculation gives the concentration of the titrated chemical.

The method used for the determination of iron and manganese is the spectrophotometry. The spectrophotometer used type Spectoquant NOVA 60.

Sediment and Boreholes Analysis

Two types of analysis were carried out in the sediment samples: chemical analyses and granulometry.

In respect of chemical analyses, 5g of sediment was weighted and put in Erlenmeyer. 100 mL of distilled water was added to the sediment and the mixture was stirred until homogenous solution was reached. Then the mixture was filtrated and the filtrate was used for chemical analyses. Iron and manganese were analyzed by the means of atomic absorption spectrophotometer.

The granulometric distribution study was carried out on dried sediments fractions. The sampled sediment was sifted with water to rid of the coarse particles (< 0.05 mm). The dried greater fraction is dry sifted on a column of seven sieves with stitches ranged between 2mm and 0,050mm set (French standard), [18]. The sifting has been done with the help of Rotap device during 10mn. Each of the fractions (recovered like refusal by sifter) has been weighed to the hundredth of gram and the respective percentages are calculated in relation to the totality of the sediment treated. The very fine fraction (< 0,05 mm) is represented by silt and its size distribution has not been studied.

With regards to boreholes, five boreholes were made on the edge of the dam have depth varying from 55 cm to 103 cm and samples were collected for sedimentologic analyses.

Statistical Analysis

A descriptive statistical analysis (average, minimum and maximum) was carried out on the results which were presented in the form of tables and graphs (histogram).The statistics related to the significant differences between the averages of the samples.

Results

At station 3, fragments of bedrock only had been taken. So, this sample has not been analyzed.

Iron and manganese in the sediments

The contents of iron (Fe^{2+}) in the sediments vary from 260 mg/kg to 2900 mg/kg with an average of 1120 mg/kg, while manganese (Mg^{2+}) in the sediment vary from 140 mg/kg to 320 mg/kg with an average of 229 mg/kg. The highest concentration has been observed at station 1 and the lowest has been obtained at the station 7 for both iron and manganese.

The spatial distribution of concentrations of iron and manganese (figure 3), the direction of the flow of water at the dam Okpara shows that the North and South of the water retention areas are most polluted with concentrations in the southern area being double registered in the North zone concentrations. However, the values recorded at stations 7 and 10 depart from the trend of the distribution of Iron.

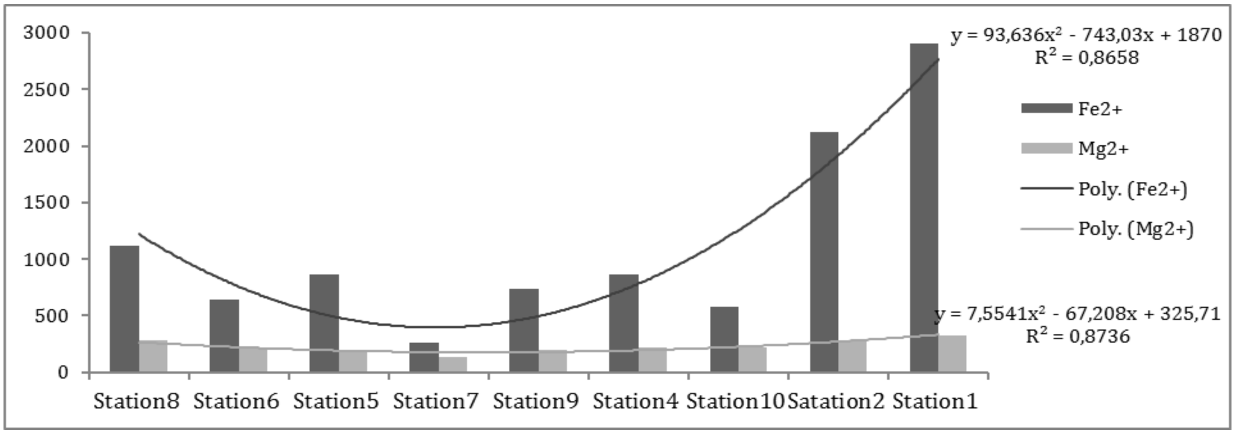

Figure 3: Spatial variations of the content of iron and manganese in the sediments

Physical Parameters of Water

Analysis of the results shows that the temperature value obtained varies between 26.9°C and 28.1°C with an average of 27.66°C and the pH between 6.45 to 6.89 with an average of 6.63. Higher values have been obtained at stations 7, 9 and 10 for the temperature and at the station 7 for the pH. The lowest is recorded at the station 8 for the temperature and station 2 for the pH.

The conductivity varies from 66.8 to 84.1µs/cm with an average of 78.45µs/cm and the turbidity from 13 to 56 NTU with an average of 28.3 NTU. The highest value was observed at the station 4 for the conductivity and at stations 7, 9 and 10 for the turbidity. The lowest value was observed at station 1 for the conductivity and at station 5 for the turbidity.

The salinity in this dam is very low and varies from 0.013 to 0.017g/L with an average of 0.015g/L. The maximal value was observed at stations 4, 5 and 6, and the minimal observed at station 3. The color varies from 125 to 383 Pt- Co with an average of 209.2 Pt-Co. Highest values were obtained at station 7 (383 Pt- Co), station 9 (296 Pt - Co) and station 10 (276 Pt - Co), and lowest at station 6 (125 Pt-Co) and at station 5 (127 Pt-Co).

Table1: Physical parameter measured in Okpara dam water

Parameters Stations	Temperature (°C)	pH	Conductivity (µs /cm)	Salitiny (g/L)	Color (Pt-Co)	Turbidity (NTU)
station 1	27.6	6.50	66.8	0.015	160	16
station 2	27.5	6.45	76.7	0.015	177	22
station 3	27.6	6.63	81.0	0.013	175	23
station 4	27.6	6.75	84.1	0.017	224	20
station 5	27.7	6.62	79.4	0.017	127	13
station 6	27.6	6.50	78.4	0.017	125	19
station 7	28.0	6.89	79.3	0.015	383	56
station 8	26.9	6.80	80.0	0.015	149	21
station 9	28.0	6.50	79.0	0.015	296	48
station 10	28.1	6.63	79.8	0.015	276	45
Average	27.66	6.63	78.45	0.015	209,2	28,3

Chemical Parameters of Water

The calcium and magnesium content varies from 6.41 to 9.62 mg/L for calcium with an average of 7.37 mg/L and from 3.39 to 5.82 mg/L for magnesium with an average of 4.17 mg/L. Highest values were obtained at station 7 for calcium and at station 9 for magnesium. The lowest values were observed at stations 3, 5 and 6 for the calcium and at stations 3, 4, 5 and 6 for magnesium. The content of bicarbonate varies from 53.68mg/L to 68.32mg/L with an average of 55.14 mg/L. The highest values were obtained at stations 4 and 10, and the lowest - at station1. The contents of iron and manganese varied from 1.21 to 5.6 mg/L with an average of 3.24mg/L for the iron and 0.48 to 1.8 mg/L with an average of 0.91 mg/L for the manganese. The highest value was observed at station 2 for the iron and at station 1 for the manganese.

Table 2: Chemical parameters of water in Okpara dam

Parameters (mg/L)	**Ca^{2+}**	**Mg^{2+}**	**HCO_3^-**	**Fe^{2+}**	**Mn^{2+}**
Station1	7.21	3.88	53.68	3.6	1.8
Station 2	7.21	4.85	58.56	5.6	1
Station 3	6.41	3.39	63.44	4.85	0.9
Station 4	7.21	3.39	68.32	4.85	1.1
Station 5	6.41	3.39	63.44	4.05	0.65
Station 6	6.41	3.39	63.44	1.95	0.55
Station 7	9.62	3.88	58.56	3.3	0.81
Station 8	8.02	4.36	58.56	2.97	1.02
Station 9	7.21	5.82	63.44	1.21	0.77
Station 10	8.02	5.34	68.32	1.89	0.48
Average	7.37	4.17	55.14	3.24	0.91

Boreholes Water Analysis

The borehole (C_1) realized in front of the central spillway shows from the bottom to the top, a clayey - sandy layer with a thickness of at least of 35cm and containing particles of quartz and feldspar. This is surmounted by reddish sandy clay with thickness of 23 cm which contains pebbles of quartz of about 5mm.

The first borehole (C_2) made in front of the lateral spillway shows from the bottom to the top, a brown clayey-sand with a thickness of at least of 28 cm and a pocket of iron oxide. This level is surmounted by a dark sand-clayey with quartz pebbles.

The second borehole (C_3) made in front of the lateral spillway shows from the bottom to the top, a dark clayey-sand with 52 cm thickness containing rare pebbles of quartz. This level is surmounted by a brownish sandy-clay of 51 cm thickness, containing grains of feldspar and sub - angular quartz grains.

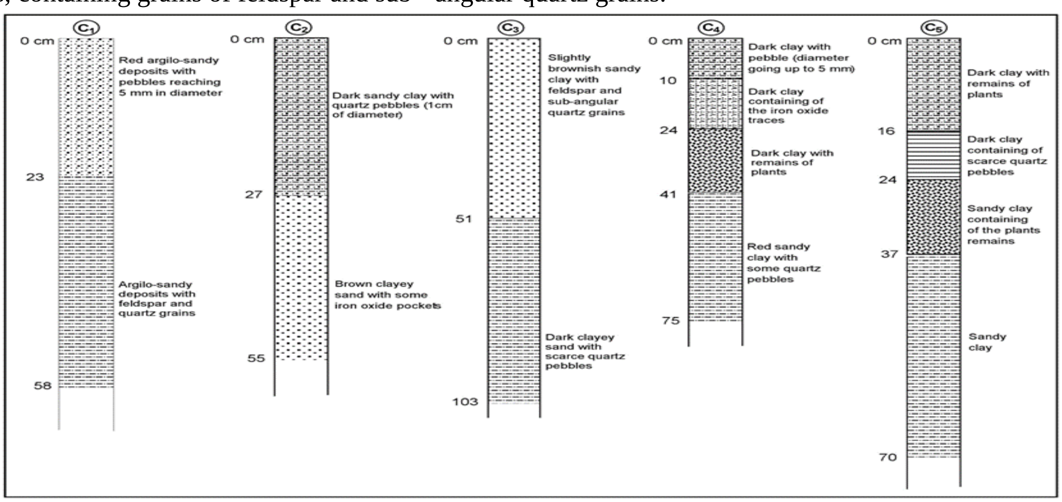

Figure 4: Boreholes logs realized at the edge of Okpara dam

Size repartition of the superficial sediment

Sediments taken from the water dam could not be studied in terms of granulometry because vase and remains plants exclusively constitute them. Only the sediment from station 7 was studied in terms of its granulometric repartition. However, the cumulative curve (figure 5) of this thin sediment didn't permit to calculate the granulometric parameters since the cumulated percentage of sandy fraction is lower than Ø50.

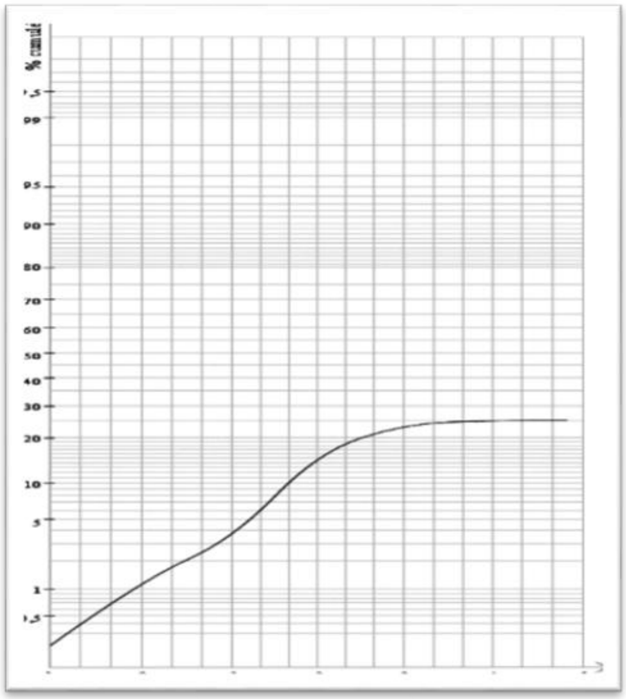

Figure 5: Cumulative granulometric curve of the sediment of station 7

4. Discussion

The actual sedimentation in the dam reveals a dominance deposit of sandy-clay at the bottom and clay deposits at the summit alternated by plant fragments under the effect of a streamlined current of weak to hopeless energy. These detritus materials come from the erosion of the alternated crystalline rocks and the erosion of altered soil due to agriculture and pasture activities. This sedimentation of detritus particles is especially inducted by river contributions. In flood period, the sediments coming from the zone upstream of the dam are drained by the Okpara river. These sediments put down at the bottom of the dam result in clayey bars observed in it. The muddy sands put down close to the bank reveal the slowing of the water current. This slowing allowed the deposit of sandy vases and vases in the central part of the dam.

These vessels contain a mineral phase, an organic phase and a liquid phase. Vases in general can be anthropogenic or natural origin [20-21]. Natural particles can be endogenous to the lake (consisting of organic material derived from plants or aquatic organisms animals) or exogenous him (mainly mineral from wind and water erosion of soil or organic catchment basins from plant debris and / or animals carried by runoff or windblown) [20-21].

The results of physical analysis of the water sample have showed that the temperature, the conductivity, the turbidity and the color don't exactly conform to the guidelines of drinking water [22] which is 25°C for the temperature, 2000µS/Cm for the conductivity, 5 NTU for the turbidity and 15 Pt-Co for the color. These values have proved that the water of the Okpara dam is favorable to the activity of photosynthesis, which promotes the increase, and development of the aquatic plants. It should be noted that a water temperature of between 25 ° C and 28°C is a good culture medium for environmental microorganisms, which means that these water temperatures create conditions favorable to the Bacteriological contamination[23]. The value of the turbidity and the color are linked to waters from the upstream charged more in detritus matter. Detritus matters come from soil eroded in direction to the dam. The conductivity values are very low showing that water are less charged.

Among chemical parameters measured in the water, only magnesium and calcium contents are within the guideline of drinking water set by World Health Organization [22] which is 100 mg/L for the calcium and 50 mg/L for the magnesium. Iron and manganese content were found to be above the guidelines of drinking water WHO Standards which are 0.01mg/L for the iron and 0.3 mg/L for the manganese. This is the same for sediments in which iron and manganese are respectively 345 and 251 times more concentrated than in water. These observations reveal the origin of the sediments observed in the Okpara dam. Sediments come from the ferruginous soils, ferralitic soils, and from the granitic and gneissic formations presented in the Okpara catchment; therefore, from the degradation of soil, rich in iron and manganese. These sediments at the bottom of the dam increase the eutrophic state of the water; and justify the invasion of the water surface by the aquatic plants and deteriorate the physico-chemical quality of the water in the dam.

5. Conclusion

Okpara dam bottom is constituted of fine detritus sediments (clays and fine sands) indicating that sedimentation in a process of streamlined current to weak and sometimes hopeless energy. These sediments come from the alteration of rocks alternated by crystalline rocks and erosion of altered soil due to agricultural and pastoral activities near the dam.

Agricultural and pastoral activities are thus the main sources of pollution of the dam. The dam is under a strong metallic contamination (high content in iron and manganese) because of the sedimentation influences, which concentrates these metals in water and much more in the sediment. The bottom sediment of the water dam, result from erosion of the surrounding soils and rocks causing the modification not only on the quality of the water of this dam, but also affects its capacity Combined action of these two phenomena could result later to the total loss of the dam capacity as well as to serious health problems linked to the high content in iron and manganese in water.

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