IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

ANALYSIS OF ANTHROPOGENIC FACTORS AS CORRELATES OF SURFACE WATER QUALITY OF RIVER OTSORON, EGBOKODO ITSEKIRI COMMUNITY OF DELTA STATE, NIGERIA.

Akinwale Bukky Tosin[a]*, Duke Okoro[a]

[a]Department of Chemistry, Federal University of Petroleum Resources, Effurun, Delta State, Nigeria

Abstract

The surface water of the River Otsoron in Egbokodo Itsekiri Community, Delta State, Nigeria, is evaluated in this research for its physical, chemical, and heavy metal composition. From four (4) different locations along the river, fifteen (15) samples of water were taken and were analysed with the following physiochemical properties: pH, temperature, dissolved oxygen, oil and grease, electrical conductivity, total suspended solid, chemical oxygen demand, sodium, lead, iron, zinc, calcium, total hardness, biochemical oxygen demand, magnesium, ammonia, nitrate, total alkalinity, sulphate, salinity, turbidity and total dissolve solid. The result obtained from the analysis shows that the concentration of oil and grease is between 0.003mg/l and 0.01mg/l which are below the permissible concentration limit. The pH is between 5.93 and 6.40. The total suspended solid were between 2.0mg/l-6.90mg/l, temperature 26.2^{0}c –27.54^{0}c, concentration of salinity. The concentration chemical oxygen demand ranges from 96.0mg/l to 384.0mgl. The physiochemical parameters – Electrical Conductivity, Ammonia, Nitrate, Sulphate, Alkalinity, Total Hardness, Turbidity, Total Dissolved Solid and Salinity except for BOD concentration that fell below the permissible concentration limit (FEPA 1992) for environmental pollution control. Moreover, data obtained for metal analysis shows that concentration of Calcium, Magnesium, Zinc, Sodium and Chromium are within the acceptable limit. The concentration of Lead (Pb) from Point 1 to Point 4 are <0.001 which fall within the acceptable limit. All of the samples have an iron (Fe) content that varies from 0.006 to 3.433 mg/L. However, the concentrations of Lead (Pb) from Point 5 to Point 15 were above the maximum allowable limit (WHO), making the river water unfit for human consumption as this would result in Lead (Pb)-related illnesses like anemia and other similar conditions, as well as posing a risk of bio-accumulation to aquatic organisms and inhabitants who depend on the river water for drinking and another household uses. So before it may be utilised for anything, appropriate treatment is advised.

Keywords: Anthropogenic factors, Surface water, Quality, Analysis.

Introduction

Water (chemical formula H_2O) is an inorganic, transparent, tasteless, odorless, and nearly colorless chemical substance, which is the main constituent of Earth's hydrosphere and the fluids of all known living organisms in which it acts as a solvent. It is vital for all known forms of life, even though it provides neither food, energy, nor organic micronutrients. Man needs water for various other purposes apart from drinking and body functions. The other purposes include it is use in transportation, waste disposal and hydroelectric system. About 80% of the earth's surface is covered by water. This may be grouped into natural and artificial water. Natural water includes atmospheric water (rainfall, hail and snow), surface water includes (stream, lakes, rivers and ocean) and ground water (spring well, underground stream).

Artificial water on the other hand includes ponds. Surface water can be contaminated by some impurities like dust, smoke or gases etc from the atmosphere. Anthropogenic activities like dumping of waste on the river bank also results to the contamination of surface water quality, water may of these micro-organisms when present in large quantities and for prolonged period of time can cause health problem [1, 2]. There is a strong relationship existing between water, health and diseases causation [3].

Water is a very important element of human nature, yet a very dangerous element in the spread of diseases. A recent study of water related and water borne diseases are in one way or the other caused by surface water [4]. Water that is free of disease producing micro-organism and chemical substance that is dangerous to health is referred to as potable water. The two categories of the sources of surface water pollution based on their origin are point and non-point sources. The contaminants that enter a water way through discrete conveyance, such as pipe or ditch are called point source pollution. The non-point pollution is the diffused contamination that does not originate from a single discrete source. The cumulative effect of small number of contaminants gathered from a large area is as a result of non-point source pollution [5].

The contamination of water has been associated with sewage and sewage effluent. It has been generally accepted that surface water contains more harmful micro-organisms compared to other source, of water including ground water and rainfall water [3]. Consequently, high degree of sewage dumps, practices with domestic waste water may be sources of bacteria and other organisms capable of producing diseases in man and animals including livestock. Other source includes livestock manure and waste water from municipals, schools, feedlots and swamps. Consequently, the number of cases of water borne diseases has been seen to be the cause of many health hazards. The demand and pollution of level of water requires the basic monitoring on the quality [2, 6, 7]. Hence there is need to ascertain the physical, chemical and biological quality of this river to ascertain whether it is safe for human consumption.

Sampling

A total of 15 water samples were taken at various locations along the river, spaced 60 meters apart. Each sample of water was taken in a clean sampling container. Each sampling container was thoroughly rinsed with the water sample at the location where the water samples were collected, and each water sample was appropriately marked following collection. However, samples for Dissolved Oxygen (DO) analysis were collected with DO bottles and fixed with Winkler A and Winkler B solutions, samplesfor Biochemical Oxygen Demand (BOD) analysis were collected with BOD bottles (amber colour) while samples for metal analysis were collected with heavy metal analysis bottle and were preserved with 1:1 Nitric acid solution. All of the water samples obtained were put in a cooler with an ice chest and sent to the lab for examination.

Analytical Methods

Determination of pH by Electrometric Method

Determination of Electrical Conductivity by Electrometric Method

Determination of Total Dissolved Solid (TDS) by Electrical Conductivity

Determination of Alkalinity by Titrimetric Method

Determination of Nitrate by UV-VIS Spectrophotometer

Determination of Sulphate by Turbimetric Method

Determination of Total Hardness **by** EDTA Titrimetrc Method

Determination of Total Suspended Solids (TSS) by Photometric Method

Determination of Oil and Grease by Extraction/Photometric Method

Determination of Dissolved Oxygen (DO) using Winkler Azide Modification Titrimetric Method

Determination of Biochemical Oxygen Demand (Bod_5) Using Winkler Azide Modification Titrimetric Method

Determination of Ammonia by Direct Nesslerization Method

Determination of Salinity by Electrical Conductivity Method

Determination of Turbidity by Nephelometric Method

Determination of Heavy Metals by Atomic Absorption Spectrophotometer (Varian Spectraa-200)

Determination of Nitrite by Sulphanilamide Spectrophotometric Method

Source: APHA, 2012 [8].

The Study Area

L1 N05.578370, E005.681579 (Household Dump Site)
L2 N05.578555, E005.681886 (Abattoir Dump Site)
L3 N05.578504, E005.682227 (Dredging Site)

Figure 3.1: Map of Study Area

Results and Discussion

Analysis of Physicochemical Properties of Surface Water Quality of River Otsoron,

pH

The pH of the water in the study area falls within the range of 5.87 to 7.10 with an average value of 6.27 ± 0.44, indicating a slightly acidic to neutral nature. As seen in Table 1, the level of pH from dredging site, especially in sample 13 is the most acidic water sample more than any other sites. This is followed by Abattoir dumping site, which is more acidic than the household waste dumping site. In fact the effect of households' wastes dumped near the River did not worsen the level of water quality like wastes from Abattoir and dredging sites.

Temperature

The temperature obtained in the study area varied between 26.20 ^{0}C to 27.54 ^{0}C with an average value of 27.05 ± 0.40 ^{0}C. As shown in Table 1, the level of concentration of the water sample from the dredging site (27.54^{0}C), especially from water sample 12 is greater than water temperatures from other sample points in other sites. This is followed by the temperature in water sample point 7 (27.45^{0}C) from Abattoir dumping site. The temperature level in households' dumping sites at sample point 1 and the temperature of 26.20 ^{0}C is the least. This implied that dredging facilities the penetration of the sun and heat that raises the level of water temperature.

Electrical Conductivity (EC)

The research area's electrical conductivity values varied from 60.00 to 124.00 S/cm. It shows that there are dissolved minerals and salts in the water. Increased ion concentrations are suggested by higher conductivity values, which can impact water quality and the suitability of the habitat for certain species. The level of conductivity at Abattoir dumping site is averagely greater than those from households' dumping sites and the dredging site as seen in Table 1.

Turbidity, Total Dissolved Solids (TDS), Total suspended Solids

The turbidity, total dissolved solids (TDS), total suspended solids in the water ranged from 37.16 to 51.04 mg/L, 38.40 to 1500.00 mg/L, 2.55 to 7.75 mg/L with mean values of 43.01± 3.97 mg/L, 66.01 ± 12.84 mg/L and 5.90 ± 1.93 mg/L. As shown in Table 1, water samples from dredging site recorded higher level of turbidity, especially at sample points 11 and 12. This could be accounted for by the fact that the water samples were collected around an hour after the dredging operations. Thus, the unsettled water could make the water more turbid. Also, the levels of TDS from sample point 11 and 12 from dredging site are higher than other sites. This is followed by sample point 6 at the Abattoir dumping site, and sample point 1 at the household wastes dumping site at the least. Thus, more water solid particles are dissolved quickly as a result of dredging activities.

In terms of Total Suspended Solids (TSS), the result shows that on the average, solid particles are more suspended in the water samples obtained from households' dumping site than Abattoir and dredging sites.

This could be as a result of the fact that various types of waters dumped by households could contaminate the water than other wastes, especially from the abattoir.

Table 1: showing the result of analysis of the sample from Point 1 to Point 15

PARAMETERS	HOUSEHOLD DUMPING SITES					ABATTOIR DUMPING SITES					DREDGING SITES				
	PT 1	PT 2	PT 3	PT 4	PT 5	PT 6	PT 7	PT8	PT 9	PT 10	PT 11	PT 12	PT 13	PT 14	PT 15
Oil & Grease (mg/L)	0.0046	0.0044	0.0034	0.0032	0.004	0.004	0.007	0.007	0.008	0.007	0.01	0.009	0.009	0.005	0.006
pH	7.1	7.02	6.86	6.84	5.97	6.4	5.94	5.99	5.97	6.01	5.93	5.87	6.16	6.02	6
Electrical Conductivity (µS/cm)	120	110	110	110	60	124	113	106	113	89	115	119	62	89	111
Total Suspended Solid (mg/L)	5.795	5.055	6.72	5.61	5.795	6.165	5.425	3.205	4.685	2.095	6.905	3.575	3.575	5.795	2.465
Dissolved Oxygen (mg/L)	2.8	2.98	3.15	2.55	7.3	6.1	6.9	6.2	7	7.75	7.2	6.95	7.15	7.4	7.1
Temperature (0C)	26.2	26.5	26.3	26.9	27.21	27.21	27.45	27.31	27.12	27.26	27.12	27.54	27.15	27.31	27.27
Chemical Oxygen Demand (mg/L)	160	96	384	128	160	192	224	224	224	224	192	192	192	192	192
Sodium (mg/L)	7.6043	7.781	7.8298	7.283	5.6756	8.5596	4.874	5.2952	5.228	7.3976	5.303	1.8219	0.1604	6.2731	4.3029
Chromium (mg/L)	< 0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006
Lead (mg/L)	<0.001	<0.001	<0.001	<0.001	1.839	3.097	1.601	1.309	0.38	1.406	2.529	4.119	1.66	1.013	1.521
Iron (mg/L)	2.459	3.724	3.633	3.433	3.079	1.562	0.23	1.823	2.121	2.076	3.681	1.993	1.713	1.96	<0.006
Zinc (mg/L)	0.6036	0.3746	0.3074	0.3139	<0.001	0.004	0.012	0.0452	0.0465	<0.0010	0.0602	0.0749	0.0348	0.062	0.0019
Calcium (mg/L)	0.981	<0.001	<0.001	<0.001	0.574	2.133	0.421	1.319	<0.001	0.987	0.825	2.254	0.541	1.632	0.907
Total Hardness (mg/L)	20	38	24	24	19	17	17	18	18	19	18	19	18	19	21
Biochemical Oxygen Demand (mg/L)	1.7	0.1	1.25	2.35	1.5	0	1.4	1.9	1.7	1.6	1.4	1.7	1.4	1.2	1.6
Magnesium (mg/L)	2.2807	2.4498	2.3778	2.3701	2.3115	2.3897	2.5861	2.3204	2.3636	2.4055	2.2571	2.5074	2.38	2.4805	2.6006
Ammonia (mg/L)	0.659	0.643	0.672	0.649	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nitrate (mg/L)	1.152	1.152	0.91	1.514	1.568	0.765	0.563	2.011	0.581	0.378	0.581	0.765	1.679	1.899	1.974
Alkalinity (mg/L)	32	26	26	26	22	27	23	24	23	17	26	14	23	23	17
Sulphate (mg/L)	20.02	19.82	22.02	20.12	20.017	21.218	17.014	19.817	19.617	17.815	18.415	22.219	20.317	18.315	19.416
Salinity (mg/L)	0.09	0.06	0.06	0.07	0.03	0.06	0.06	0.05	0.06	0.04	0.06	0.06	0.03	0.04	0.06
Turbidity (NTU)	38.441	37.9272	43.583	40.755	44.365	45.38	42.812	42.555	42.297	37.156	51.039	50.268	40.498	44.612	43.583
Total Dissolve Solid (mg/L)	80	70	70	70	38.4	79.36	72.32	67.84	72.32	56.96	73.6	76.16	39.68	56.96	71.04

Dissolved Oxygen (DO), Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). The DO, BOD and COD levels ranged from 2.09 to 6.90 mg/L, 0.00 to 2.35 mg/L, 96.00 to 384 mg/L with mean values of 4.85 ± 1.51 mg/L, 1.39 ± 0.61 mg/L and 198.40 ± 63.07 mg/L. The low values of DO at all the sample points in households' dumping site could be as a result of frequent dumping of waste materials into the water thereby having chronic effects on aquatic lives as the available DO needed for healthy ecosystem is reduced. This corresponds with the findings of Aghoghovwia [9] on seasonal assessment of Warri River.

On the part of biochemical oxygen demand (BOD), the result shows that the level of BOD is higher in household dumping site because the level of DO is already low. Rivers that are moderately polluted may have a BOD value between 2 and 8 mg/L. When BOD levels approach 8 mg/L, rivers may be deemed extremely contaminated [10]. Thus, with BOD of 2.35 mg/L, the sampled river in this study is moderately polluted. Similarly, the level of chemical Oxygen demand at the sample point 3 from households' dumping site is the highest at 384 mg/L. Thus, the level of biochemical and chemical Oxygen demands are higher at sample points from households' dumping site where the level of DO is low.

Alkalinity, Salinity and Total Hardness

The alkalinity, salinity and total hardness concentrations ranged from 14.00 to 32.00 mg/L, 0.03 to 0.09 mg/L, 17.00 to 38.00 mg/L with mean values of 23.26 ± 4.52 mg/L, 0.05 ± 0.02 mg/L and 20.60 ± 5.28 mg/L respectively. Previous study has shown that, alkalinity value of 0-9 is strongly acidic, 10-50 is low alkalinity, and 50-200 is high alkalinity and 211-500 is optimum alkalinity [3, 10]. Based on this, the values of Alkalinity show that the river under study has low alkalinity.

In the same vein, the level of salinity of the sampled water is higher at the households' dumping site than other sites. This means that there is high salt content in dumped waters by households than other anthropogenic activities in Abattoir dumping sites and dredging sites. As a result of high salinity at the households' dumping sites, the level of hardness of the water also from samples points 1-5 from dumping sites of households and other mechanical and industrial waters made the water to be harder.

Nitrate, Ammonia and Sulphate

It can be seen in Table 1 that the levels varied between 0.37 to 2.01 mg/L, 0.64 to 0.67 mg/L, 17.01 to 22.22 mg/L with mean values of 1.17 ± 0.56 mg/L, 0.65 ± 0.01 mg/L and 19.74 ± 21.44 mg/L respectively for Nitrate, Ammonia and Sulphate.

These chemicals are among the anthropogenic elements that could have an impact on water quality. The results indicate that the highest level of nitrate concentration occurred at sample point 8 at Abattoir dumping site at 2.011 mg/L. The nitrates values of the sampled points were above the recommended values of the WHO and FEPA that ranged between 0.30 mg/L and 2.15 mg/L. The studied water body in this research is moderately contaminated.

Calcium, Sodium and Magnesium

Calcium, sodium, and magnesium concentrations ranged from 0.42 to 2.25 mg/L, 0.16 to 8.56 mg/L, 2.26 to 2.60 mg/L with mean values of 1.14 ± 0.62 mg/L, 5.69 ± 2.32 mg/L and 2.40 ± 0.10 mg/L respectively. From the result, sample point 6 and 12 from Abattoir and Dredging sites have the highest concentration level of calcium.

Analysis of Heavy metals/ Anthropogenic Properties of River Otsoron,

Lead, Iron, Zinc, and chromium

Chromium was below detection thresholds of 0.06 which depict the concentration of a few chosen heavy metals throughout the sample locations of the river. Lead, iron, and zinc concentrations ranged from 0.38 to 4.12 mg/L, 0.23 to 3.72 mg/L, 0.002 to 0.60 mg/L with mean values of 1.86 ± 1.03 mg/L, 2.39 ± 1.01 mg/L and 0.15 ± 0.18 mg/L respectively. Sample point 12 and point 6 from dredging and abattoir sites exhibit the highest level of lead concentration among other sample points.

Oil and Grease

In addition to Heavy metals, which are known for their anthropogenic effects, the introduction of Oil and Grease to the water can contaminate the water. Here, the level of concentration of Oil and Grease ranged from 0.003 to 0.01 mg/L with a mean and standard deviation values of 0.006 ± 0.002 mg/L across the entire 15 sample points studied. For this chemical substance, it can be seen that the dredging site contained the highest concentration level oil and grease.

Comparison of Physicochemical and Anthropogenic Characteristics of the Study Area with the Global Benchmark

The summary of the results is shown in Table 2. The concentration levels of the parameters of the water in relation to the existing global benchmarks. It can be seen from the results that the pH of River Otosoron, Egbokodo Itsekiri in Delta State is below the allowable benchmark of the World Health Organization [2] which is between 6.5 and 8.5. By implication, the water is averagely acidic, though it is still within the acceptable limit of WHO. Also, the average concentration of Total Dissolved Solid (TDS) obtained for this study is averagely below the benchmark of < 600 as reported by EGASPIN [11]. In fact, while the concentrations of all other parameters, including Heavy metals appear to be less than the global benchmark, it is only zinc, magnesium, and nitrate that have higher concentration range that are higher than the limit (see Table 2).

Principal Component Analysis

Principal Component is a statistical method employed to reduce dimensions and explore data. It enables the conversion of a dataset with many variables into a lower-dimensional form while retaining crucial information. This is accomplished by identifying principal components, which are new variables resulting from linear combinations of the original variables [12]. Figure 4.4 shows the screen plot which presents the principal components extracted. A total of 22 variables were examined, and four principal components were identified, explaining 83.89 % of the variance (eigenvalue). The primary principal component extracted encompasses most of the variation found in the original dataset, as it holds the highest eigenvalue. All significant variables are marked bold in table 4.3.

First Principal component (PC1): PC1 showed 33.18% of the total variance in the data set had showed strong positive loading of pH and Zinc. Total hardness (TH), iron, alkalinity, sodium, and salinity had moderate positive loading. DO and temperature had high negative loading while oil and grease had moderate negative loading.

Second principal component (PC2): PC2 accounted for 16.15 % of the total variance in the dataset. It exhibited a strong positive loading of TDS and demonstrated moderate positive loading of calcium, Lead, and turbidity.

The third principal component (PC3): PC3 explained 10.37% of the total variance in the dataset. It displayed a high positive loading for ammonia and COD and moderate negative loading for total hardness (TH).

Fourth principal component (PC4): PC4 accounted for 9.14 % of the total variance in the dataset. It exhibited a moderate positive loading of lead and sulphate.

Fourth principal component (PC4): PC4 accounted for 9.14 % of the total variance in the dataset. It exhibited a moderate positive loading of lead and sulphate.

Fifth principal component (PC5): PC5 accounted for 7.36 % of the total variance in the dataset. It showed a positive moderate loading of lead and negative moderate loading of TSS.

Sixth principal component (PC6): PC6 accounted for 6.63 % of the total variance in the dataset. It showed a positive moderate loading of BOD and EC, and a negative moderate loading of TSS.

Seventh principal component (PC7): PC7 accounted for 1.06 % of the total variance in the dataset. It showed a positive moderate loading of nitrate.

Table 2: Comparison of Physicochemical and Anthropogenic Characteristics of the Study Area

Physicochemical Parameters	**Range of the Study Area**	**Mean of the Study Area**	WHO, 2011	EGASPIN, 2018
Temperature (0C)	26.20 – 27.54	27.05 ± 0.40		
Ph	5.87 – 7.10	6.27 ± 0.44	6.5 – 8.5	
Electrical Conductivity (µS/cm)	60.00 – 124.00	103.40 ± 19.76	1000	
Dissolved Oxygen (mg/L)	2.09 – 6.90	4.85 ± 1.51		
Total suspended Solids (mg/L)	2.55 – 7.75	5.90 ± 1.93		
Total dissolved solids (mg/L)	38.40 – 1500.00	66.01 ± 12.84		< 600
Chemical Oxygen Demand (mg/L)	96.00 – 384.00	198.40 ± 63.07		
Biochemical Oxygen Demand (mg/L)	0.00 – 2.35	1.39 ± 0.61		
Sodium (mg/L)	0.16 – 8.56	5.69 ± 2.32	< 200	
Chromium (mg/L)	<0.006	<0.006		
Lead (mg/L)	0.38 – 4.12	1.86 ± 1.03	0.01	0.05
Iron (mg/L)	0.23 – 3.72	2.39 ± 1.01	0.3	
Zinc (mg/L)	0.002 – 0.60	0.15 ± 0.18	1.0	1.0
Calcium (mg/L)	0.42 – 2.25	1.14 ±0.62		
Total Hardness (mg/L)	17.00 – 38.00	20.60 ± 5.28		
Magnesium (mg/L)	2.26 – 2.60	2.40 ± 0.10	30	30

Ammonia (mg/L)	0.64 – 0.67	0.65 ± 0.01		
Nitrate (mg/L)	0.37 – 2.01	1.17 ± 0.56	50	50
Alkalinity (mg/L)	14.00 – 32.00	23.26 ± 4.52		
Sulphate (mg/L)	17.01 – 22.22	19.74 ± 21.44	< 250	< 250
Salinity (mg/L)	0.03 – 0.09	0.05 ± 0.02		
Turbidity (NTU)	37.16 – 51.04	43.01± 3.97	5	
Oil and Grease	0.003 – 0.01	0.006 ± 0.002		

WHO – World Health Organization, (2011). Environmental Guidelines and Standard for the Petroleum Industry in Nigeria – EGASPIN.

Table 3: Principal component analysis results

Parameters	PC1	PC2	PC3	PC4	PC5	PC6	PC7
pH	**.949**	-.143	-.116	-.230	.120	-.252	0.234
DO	**-.938**	-.230	-.259	-.236	-.199	-.103	.214
temp	**-.919**	.212	-.160	-.357		-.252	**.268**
zinc	**.862**	-.230	-.230	.339	.147	.230	.264
alkalinity	**.744**	-.148	.186	-.170	-.418	-.252	.101
Na	**.704**		-.239	-.220	-.252	-.385	.109
salinity	**.677**	.478	-.122	-.380	.143	.307	-.360
Oil and Grease	**-.665**	.245	.106	-.144	.592	.454	-.364
TH	**.592**	-.233	**-.524**	.249	.572		-.271
Iron	**.572**	-.180	-.230	.438	.430	.257	4.81
EC	.430	**.772**	-.198	-.356	.449	**.518**	.139
TDS	.449	**.760**	-.188	-.372	-.234	.333	.214
Ca	-.234	**.687**	-.208	.382	-.240	-.188	.325
Lead	-.240	**.680**	-.235	**.518**	**.592**	.150	1.06
turbidity	-.341	**.662**	.291	.333	-.277	.139	4.81
Ammonia	.441	.112	**.765**	.198	.349	-.232	.139
COD	-.236	.208	**.756**	-.154	.320	-.445	.214
Mg	-.357	.198	-.492	-.150	.415	-.405	239.
Sulphate	.339	.343	.198	**.694**	.352	.352	1.06
TSS	**.547**	.153	.346	.198	**-.598**	**-.598**	4.81
BOD	-.221	-.162	.340	-.245	.444	**.593**	.139
Nitrate	-.235	-.474	-.119	.349	.277	0.452	**629**
Total	7.30	3.53	2.28	2.01	1.62	1.46	.629
Initial Eigen value % variance	33.18	16.15	10.37	9.14	7.36	6.63	1.06
Cumulative %	33.18	49.33	59.70	68.84	76.19	82.82	4.81

Note: PC1- principal component analysis

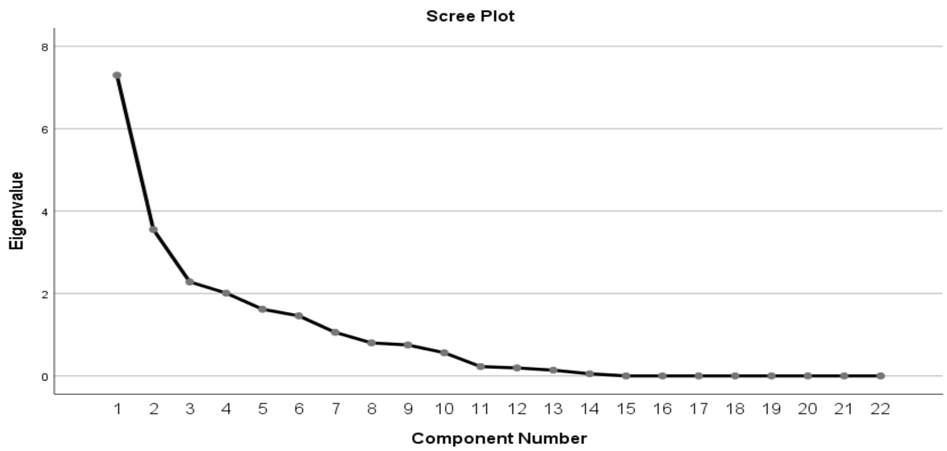

Figure 4: Screen plot showing the extractions of the principal components.

Pearson Correlation Matrix

In environmental studies, Pearson correlation analysis is a widely employed statistical method that assesses the linear connection between two continuous variables. By calculating the Pearson correlation coefficient (r), the degree and direction of the link between these variables are determined by it. If there is a positive correlation, it means that the two variables tend to rise together while one rises. A negative correlation, on the other hand, means that while one variable rises, the other tends to fall. The strength of the connection is indicated by the correlation coefficient's size, which is closer to 1 or -1 [13]. The findings in Table 4 support the rejection of null hypothesis one, which states that human causes have no impact on the quality of surface water.

Oil and grease: showed negative moderate correlation with pH, Na, Zn With r -value - 0.66, -+ 0.73, -0.53 respectively. Oil and grease also had positive moderate correlation with DO with r - Value of + 0.64.

pH: pH showed strong negative correlation with DO, Temp with r - Values of - 0.96, - 0.97. The connection between pH and Zn was similarly quite good, with an r-value of + 0.87. Contrarily, EC demonstrated a strong positive connection with salinity and TDS, with r-Values of 0.85 and 1, respectively.

DO: showed high positive correlation with temperature with r - Value of + 0.85. DO also showed negative moderate correlation between Fe, salinity, alkalinity, and TH, with r - Values of - 0.59, - 0.65, - 0.64, - 0.65 respectively. DO further Showed high negative correlation with Zn, with R- Value of -0.84.

Temperature: showed negative moderate correlation with Na, Fe, TH, Ammonia, Alkalinity and Salinity with r- Values of - 0.52, - 0.59, - 0.57, - 0.56, - 0.70 and -0.52 respectively. High negative correlation was also observed between Zn and temperature with r - Value of -0.88.

Sodium (Na): showed positive moderate correlation with Zn, alkalinity, with r – Values of + 0.50 and + 0.53 respectively. There was positive high correlation between COD and ammonia with correlation coefficient value r = 0.80.

Zn: strongly inverse relationships between DO, temperature, and Zn were found, with r values of -0.84 and -0.88, whereas there was a significant positive relationship between Zn and pH, with r values of 0.87. Zn Showed positive moderate correlation with alkalinity, salinity, TH with r - value of + 0.57, + 0.56 and + 0.55 respectively.

Testing for Significance Difference in Water Parameters across Sample Sites

In this investigation, water samples were taken at three primary locations: household waste disposal sites, abattoir waste disposal sites, and drilling sites. The purpose of this section is to test the null hypothesis that there are no statistically significant differences across the sample locations for the parameters of the surface water quality of the River Otosoron in the Egbokodo village of Itsekiri, Delta State, Nigeria.

To achieve this, an inferential statistical tool of Chi-square distribution is applied. It is calculated as:

$$X^2 = \sum \frac{(O-E)^2}{E}$$

Where

X^2 = Symbol for Chi - square

$\sum$ = Summation sign

O = Observed values from the lab results

E = Expected values from the lab results

The contingency table for the data obtained from the water samples are shown in Table 4.5 which is the average concentration for each of the parameter for the sample points in each site.

Table 4 : Correlation Matrix

Correlation Matrix																						
	oil /G	PH	EC	TSS	DO	temp	cod	Na	pb	Fe	Zn	Ca	TH	BOD	Mg	Ami	Nit.	Alk.	Sulp	Salin	Turb	TDS
oil /G	1																					
PH	-0.66	1																				
EC	-0.04	0.28	1																			
TSS	-0.37	0.39	0.20	1																		
DO	0.64	-0.96	-0.38	-0.40	1																	
Temp	0.52	-0.91	-0.20	-0.43	0.85	1																
COD	0.05	-0.13	0.07	0.08	0.09	-0.08	1															
Na	-0.73	0.57	0.37	0.44	-0.53	-0.52	0.02	1														
Pb	0.11	0.03	0.31	0.14	-0.06	0.12	-0.11	-0.14	1													
Fe	-0.31	0.49	0.00	0.35	-0.52	-0.59	-0.10	0.35	0.07	1												
Zn	-0.53	0.87	0.17	0.31	-0.84	-0.88	-0.18	0.50	-0.01	0.52	1											
Ca	-0.09	0.02	0.46	0.00	-0.04	0.16	0.00	0.15	0.54	-0.05	-0.10	1										
TH	-0.42	0.66	0.12	0.09	-0.65	-0.57	-0.32	0.35	-0.02	0.60	*0.55*	-0.01	1									
BOD	0.23	-0.23	-0.12	-0.29	0.06	0.16	0.10	-0.33	-0.24	-0.02	0.04	-0.28	-0.39	1								
Mg	0.02	-0.25	0.14	-0.39	0.24	0.41	0.02	-0.25	0.04	-0.47	-0.37	0.10	0.10	-0.13	1							
Ammonia	-0.29	0.36	0.14	0.35	-0.37	-0.56	0.80	0.23	0.00	0.20	0.37	-0.03	-0.12	0.14	-0.22	1						
Nitrate	-0.27	0.03	-0.39	-0.20	-0.05	0.04	-0.24	-0.21	-0.27	0.08	-0.03	-0.08	0.09	0.20	0.07	-0.12	1					
alkalinity	-0.43	0.69	0.22	0.71	-0.64	-0.70	-0.09	0.53	-0.17	0.26	0.57	-0.16	0.20	-0.23	-0.58	0.29	0.02	1				
Sulphate	-0.24	0.36	0.15	0.11	-0.39	-0.31	0.19	-0.07	0.53	0.32	0.22	0.54	0.17	-0.12	-0.19	0.40	0.10	0.04	1			
Saliniyty	-0.21	0.58	0.85	0.30	-0.65	-0.52	-0.08	0.39	0.20	0.16	0.56	0.19	0.20	0.07	-0.05	0.26	-0.26	0.46	0.17	1		
Turbidity	0.39	-0.51	0.21	0.31	0.40	0.45	0.17	-0.32	0.57	0.03	-0.50	0.37	-0.40	0.01	0.02	0.03	-0.12	-0.25	0.22	-0.04	1	
TDS	-0.04	0.30	1.00	0.21	-0.40	-0.23	0.06	0.37	0.31	0.00	0.21	0.45	0.11	-0.11	0.12	0.15	-0.39	0.24	0.15	0.88	0.19	1

Table 5: Chi-square contingency table for testing differential water parameters across sites

PARAMETERS	Households' Dumping site		Abattoir Dumping site		Dredging site		Total
	Observed	Expected	Observed	Expected	Observed	Expected	
pH	6.76	6.14	6.06	6.58	6.00	6.10	18.82
Electrical Conductivity (µS/cm)	102.00	101.24	109.00	108.42	99.20	100.54	310.20
Total Suspended Solid (mg/L)	5.80	4.76	4.32	5.09	4.46	4.72	14.57
Dissolved Oxygen (mg/L)	3.76	5.78	6.79	6.19	7.16	5.74	17.71
Temperature (0C)	26.62	26.49	27.27	28.37	27.28	26.31	81.17
Chemical Oxygen Demand (mg/L)	185.60	194.25	217.60	208.03	192.00	192.92	595.20
Total Hardness (mg/L)	25.00	20.17	17.80	21.60	19.00	20.03	61.80
Biochemical Oxygen Demand (mg/L)	1.38	1.36	1.32	1.45	1.46	1.35	4.16
Alkalinity (mg/L)	26.40	22.78	22.80	24.40	20.60	22.62	69.80
Salinity (mg/L)	0.06	0.05	0.05	0.06	0.05	0.05	0.17
Turbidity (NTU)	41.01	42.12	42.04	45.11	46.00	41.83	129.05
Total Dissolve Solid (mg/L)	65.68	64.92	69.76	69.53	63.49	64.48	198.93
Total	**490.07**		**524.81**		**486.70**		**1501.57**

Source: Author's computation from laboratory data

From the contingency table above, the expected values are obtained using this formula:

$$E = \frac{RT * CT}{GT}$$

Where

RT = Row total

CT = Column total

GT = Grand total

For the first value of pH, for instance, the expected value of 6.14 was obtained as:

$$E = \frac{18.82(490.07)}{1501.57} = 6.14$$

By applying the chi-square formula using to the data in the contingency table, the value of chi-square calculated is 5.96.

To determine the significant level, we need to find table value of chi-square at the applicable degree of freedom. The degree of freedom (DF) is obtained as DF = (R-1) (C-1) where R is the number of rows and C is the number of columns. From the contingency table, we have 12 rows and 3 columns for each of the sites. Thus, the DF = (12-1 3-1) = 22.

Checking for the value of 5.96 under 22 across 1%, 5%, and 10% level of statistical significance, the tabulated value of chi-square is 40.29@1%, 33.12@5%, and 30.81@10%. Since the value obtained (5.96) is less than the tabulated value at these 3 levels of statistical significance, the null hypothesis is accepted. By implication, there is no significance difference in the level of concentration of the parameters of surface water quality of River Otosoron in Egbokodo community of Itsekiri, Delta State, Nigeria across sample sites.

Testing for Significance Difference in Anthropogenic Factors across Sample Sites

In relation to anthropogenic activities in the sampled water, the null hypothesis of no significance difference in the level of Heavy metal concentration in River Otosoron in Egbokodo community of Itsekiri, Delta State, Nigeria across sample sites is tested. This is important in order to help identify the sample sites that may be more harmful in view of heavy metals and other anthropogenic activities around the River. Here, it is possible that the concentration of heavy metals may be significantly different from site to site.

To achieve this, statistical tool of Chi-square distribution is applied as well. The contingency table for the heavy metals and oil and grease obtained from the lab is shown in Table 6. The mean value of the concentration of the selected anthropogenic factors from each of the sites is shown in Table 6.

Table 6: Chi-square contingency table for testing differential Anthropogenic factors in water across sampling locations (sites)

PARAMETERS	Households' Dumping site		Abattoir Dumping site		Dredging site		Total
	Observed	Expected	Observed	Expected	Observed	Expected	
Oil & Grease (mg/L)	0.004	0.008	0.007	0.004	0.008	0.006	0.018
Lead (mg/L)	1.839	2.319	1.559	1.328	2.168	1.919	5.566
Iron (mg/L)	3.266	2.985	1.562	1.709	2.337	2.471	7.165
Zinc (mg/L)	0.400	0.197	0.027	0.113	0.047	0.163	0.473
Total	**5.508**		**3.154**		**4.560**		**13.222**

Source: Author's computation from laboratory data

Based on the chi-square formula applied, the calculated chi-square value is 9.35. Using the degree of freedom of 22 as earlier found and checking for the value of 9.35 under 22 across 1%, 5%, and 10% level of statistical significance, the tabulated value of chi-square is 40.29 at 1%, 33.12 at 5%, and 30.81 at 10%. Since the value obtained (9.35) is greater than the tabulated value at these 3 levels of statistical significance, the null hypothesis is rejected in favour of the alternative hypothesis. This implies that there is significance difference in the level of Heavy metal concentration in River Otosoron in Egbokodo community of Itsekiri, Delta State, Nigeria across sample sites.

This analysis further shows that the heavy metals and other antropogenic factors are more concentrated in water samples drawn from households' wastes dumping site than the dredging and the abattoir dumping sites.

Discussion

An important environmental factor that significantly affects aquatic creatures is pH. It gauges the quantity of hydrogen ions to determine whether the water is acidic or alkaline. The pH scale, which ranges from 0 to 14, classifies readings below 7 as acidic, above 7 as alkaline, and between 7 and 14 as neutral. The health and survival of aquatic species in aquatic habitats are greatly influenced by pH [10]. In order to control the speciation, mobility, and toxicity of metals in the environment, water's pH is a key factor. According to Saalidong *et al.* [14], when heavy metals become more soluble and bioavailable in water with a low pH, their toxicity tends to rise. pH measurements in the study region show a value that ranges from slightly acidic to neutral. This range was within the optimal range of 6.5 to 8.5 for the development and production of the majority of aquatic species in the research region [14, 15] reported comparable pH values in a related investigation.

The distribution, behaviour, growth, and reproductive habits of aquatic species are greatly influenced by temperature. Each species has its own temperature preferences and tolerances, with specific temperature ranges for their survival and optimal functioning. Changes in temperature may have an effect on an aquatic ecosystem's general ecological dynamics, feeding behaviour, oxygen availability, and metabolic rates [16]. The temperature measured in the study region is consistent with research done in the Niger Delta that was comparable to this one [17].

Alkalinity refers to the capacity of water to resist changes in pH and maintain a desired level [18]. For water bodies, total alkalinity is divided into five categories: low, moderate, high, and very high. Anything below 10 mg/L is considered to be very low alkalinity, followed by low (10–50 mg/L), moderate (50–150 mg/L), high (150–300 mg/L), and above 300 mg/L as very high alkalinity. Low levels of alkalinity may be found in the research region.

Oil and grease in water encompass a range of substances, such as motor oil, fuels, lubricating oil, cooking oil, hydraulic oil, waxes, and fats [12]. According to Meride and Ayenew [19], electrical conductivity measures how well water can carry electrical current. It depends on how dissolved particles (mineral salts) are broken down into ions and how electrically charged each ion is in the water. The research area's EC was within WHO's (2011) recommended drinking water quality guidelines. TSS stands for total suspended solids, which describes how many suspended solids are present in a given volume of water and describes how cloudy or hazy it is.

Turbidity and TSS are interconnected as turbidity are primarily influenced by the presence of suspended particles. TSS gives an estimate of suspended solids in water bodies, while turbidity reflects the degree of cloudiness caused by these particles [17]. The TSS levels found in this research are lower than those Ovonramwen reported [15]. The higher turbidity measurements made in this investigation are comparable to those made in a related study [20].

Turbidity levels in the study area exceeded EGASPIN, (2018) stipulated limits for domestic use and WHO, (2011) stipulated limits for drinking water quality. Sodium, nitrate, magnesium, nitrate, and sulphate were within EGASPIN, (2018) stipulated limits for domestic use and WHO, (2011) drinking water quality. Calcium and ammonia equally had lower values in the study area. According to Boyd [18], total dissolved solids (TDS) is the measurement of all dissolved inorganic and organic materials in water. The research area's TDS is within the limits set by EGASPIN (2018) for household use and the WHO (2011) recommended standards for the quality of drinking water.TDS levels in this research are lower than those reported by Ovonramwen [15], but they are comparable to those by Iwegbue et al. (2022). Quantifying the dissolved oxygen (DO) level, which is essential for aquatic creatures' existence, is a key factor in determining the quality of water in aquatic habitats. Fish mortality can occur when exposed to a DO concentration as low as 0.3 mg/L for extended periods [21]. The optimal DO level for aquatic bodies, according to Boyd [18], should be at least 5 mg/L. The DO levels found in this research were only a little bit below the values that are optimum in aquatic systems. When microorganisms break down organic materials in water, they need a certain amount of dissolved oxygen [22]. This is referred to as the biochemical oxygen demand. As bacteria decompose organic materials like sewage or decaying plants, they consume oxygen from the water, leading to a reduction in dissolved oxygen levels. Consequently, higher BOD levels typically correspond to lower levels of dissolved oxygen. The quantity of oxygen required to chemically oxidise both organic and inorganic molecules found in water is measured by chemical oxygen demand, on the other hand. In unpolluted water, the level of Biochemical Oxygen Demand (BOD) is typically low, usually below, or equal to 5mg/L [19]. The BOD results in this study suggest an unpolluted environment. The BOD and DO concentrations in this research agree with those found by Onojake *et al*. [17]. The high COD content indicates that the aquatic system contains oxidizable organic and inorganic materials. The COD levels in this study area agree with findings of previous study [20]

According to Sarmistha *et al*. [22], heavy metals are defined as elements having atomic numbers over 20 and densities more than 5g/cm3. They may be found naturally in soils, minerals, and rocks. Non-essential heavy metals lack biological relevance and may be harmful, while essential heavy metals are required for the regular operation of living things. While non-essential heavy metals like lead have no known biological purpose and may accumulate in tissues, causing health hazards, essential heavy metals like zinc, iron, and chromium are needed in modest levels for vital biological activities [23]. The amount of heavy metals found in this research region was of a certain order of magnitude Fe > Pb > Zn > Cr. Fe and Pb exceeded EGASPIN, (2018) stipulated limits for domestic use and WHO, (2011) recommended limits for drinking water quality. This implies a possible health hazard linked to consuming this water for drinking purposes.

Due to its pervasive usage, the extremely poisonous metal lead has contributed to severe environmental degradation and health issues around the world. Lead contamination often leads to lead poisoning, characterized by symptoms such as anemia, as lead interferes with hemoglobin production and hinders iron absorption. Long-term exposure to high amounts of lead may cause renal failure and lasting brain damage [24]. The most prevalent element in the crust of the planet is iron, yet when it is present at high concentrations in aquatic systems, it may affect how things taste, look, and feel [20].The Pb values determined in this research support Pb concentrations reported by Aghoghovwia *et al*. [9] from Nun River in Bayelsa State. Iron concentrations measured in the study area are comparable to levels reported by Aghoghovwia *et al*. (2018). No correlation was observed among the heavy metals. The considerable positive association between pH and Zn demonstrates that pH has a major impact on Zn concentrations in aquatic systems.

Pearson correlation matrix revealed that DO showed negative correlation with iron, zinc, alkalinity, and salinity which suggest that these maybe the variables contributing to the reduction of DO in the aquatic system. The considerable positive association between DO and temperature suggests that a rise in temperature has a major impact on how soluble oxygen is in a body of water. It is possible that pH has a significant impact on the surface water in the research region given the very positive pH loading and strongly negative DO loading in PC1. The negative correlation between DO and temperature indicates that temperature reduction results in the reduction of oxygen in the study area. The strong positive loading of zinc and the moderate loading of TSS, Fe, TH, salinity, alkalinity, and sodium may be due to natural origin such as weathering of rock or surface runoff or may potentially be brought on by residential garbage that is present in the research location [25].

The strong positive loading between EC and TDS, Ca, Lead, and turbidity in PC2 suggests that similar factor in contributing to their concentration in the aquatic system. The factor loading in PC3 indicates anthropogenic influence that may be attributed to domestic waste in the study area. The strong positive correlation between COD and ammonia in PC3 infers that similar factors may be contributing to their concentrations in the aquatic system. This observation is consistent with finding in Pearson correlation matrix which showed strong positive correlation between COD and ammonia. Ammonia may be from fertilizer, which suggests agricultural influence on the water quality in the study area [26]. This finding is consistent with correlation loading observed in Pearson correlation matrix (Table 4). Lead showed positive loading in PC2, PC4 and PC5 showed anthropogenic influence on the water quality and suggest that lead may be from different sources. Pb recorded in the study area may be linked domestic waste, agricultural waste or surface runoff. The negative moderate loading of TSS and the positive moderate loading of BOD in PC6 infers that TSS contributes moderately to the BOD values obtained in this study.

Conclusion

Water is a very important natural resource in the environment with multivariate usage in the homes, agriculture, industries etc. Unfortunately, it is contaminated at various points and causing pollution to the water body. This study revealed the current physical and chemical properties, as well as the heavy metals concentrations of the River Otosoron, Egbokodo Itsekiriin Delta State. Through this, it was discovered that some of the important elements affecting the water quality of the water body include local human activities, such as dredging, oil spills, and waste sites. The physical and chemical properties of the water body were compared to the standards set by national (FEPA) and international (WHO) regulatory agencies. The standards' acceptable ranges were fulfilled by some of the criteria, while they were exceeded by others. Since, not all the parameters agreed with the set standards by the regulatory agencies, the water cannot be said to be fit for human consumption and other organisms. As such, the water can be said not to be suitable for drinking. Appropriate treatment is therefore advised if it must be used for portability.

References

[1] Olu, U; Ugbomeh, A.P; BobManuel, K.N.O; Ekweozor, I.K.E. (2019) Levels of Selected Heavy Metals in Water and Sediment of the Soku Oil Field Area of the Niger Delta, Nigeria. J AquatPollut To 3 (1):19.

[2] World Health Organization (WHO), (2022). Guidelines for drinking-water quality: 4th ed. Geneva, Switzerland, ISBN 978-92-4-004506-4). Retrieved June 2022 from https://www.who.org

[3] Ajewole, G. (2005). Water an overview. Journal of Nigerian Institute of Food Science Technology, 4:15-33.

[4] Medema, G.S., Shaw, S. Waite, M., Snozzi, M., Morreay, A. and Grabow, W. (2003).Characterization and source of water, in: assessing microbial safety of drinking water, World Health Organization, Geneva, Switzerland, 4: 111-158.

[5] UNSD (2022) Statistics on Water (Introduction). Workshop on environment statistics (Addis Ababa, 16-20 July). Retrieved 2022 from https://www.unsd.org

[6] EPA, (2005). protecting water quality from agricultural runoff. United State Environmental Protection Agency, Fact Sheet no. epa-841-f-05-001. Retrieved in June 2022 from https://www.unepa.org

[7] EPA, (2002). Groundwater and drinking water. Current Drinking water standard united State Environmental Protection Agency. Retrieved in June 2022 from https://www.unepa.org

[8] American Public Health Association/American Water Works Association/Water Environment Federation. (2012). *Standard Methods for the Examination of Water and Wastewater*.22nd Edition, Washington DC, USA.

[9] Aghoghovwia, O. A. (2011). Physico-chemical Characteristics of Warri River in the Niger Delta Region of Nigeria. Journal of Environmental Issues and Agriculture in Developing Countries, 3(2): 40-461.

[10] Kumar, R., Grover, A. S., & Wats, M. (2018). Assessment of water quality status of lakes in Haryana, India. *International Journal of Recent Scientific Research*, *9*(7), 27831-27835.

[11] EGASPIN, (2018). Environmental Guidelines and Standard for the Petroleum Industry in Nigeria (EGASPIN). Lagos.

[12] Iyang, W; Zhao, Y; Wang, D; Wu, H; Lin, A; He, L. (2020). Using Principal Components Analysis and IDW Interpolation to Determine Spatial and Temporal Changes of Surface Water Quality of Xin'anjiang River in Huangshan, China. International Journal of Environmental Research and Public Health, 17(2942): 1 – 14. https:// doi. Org/10.3390/ijerph17082942

[13] Kothari, V; Vij, S; Sharma, S; Gupta, N. (2021). Correlation of various water quality parameters and water quality index of districts of Uttarakhand. Environmental and Sustainability Indicators, 9 (2021): 1 - 10. https://doi.org/10.1016/j.indic.2020.100093

14] Saalidong, B.M; Aram, S.A; Out, S; Lartey, P.O. (2022). Examining the dynamics of the relationship between water pH and other water quality parameters in ground and surface water systems. PLoS One 25;17(1):1 - 6. https://doi.org/10.1371/journal.pone.0262117.

[15] Ovonramwen, O.B. (2020). Physicochemical Analysis of Surface and Ground Water in Ugbomro and Iteregbi, Delta State, Nigeria. Journal of Applied Science and Environmental Management 24 (3): 511- 517.

[16] Ghosh, S., Chatterjee, S., Shiva Prasad, G., & Pal, P. (2021). Effect of Climate Change on Aquatic Ecosystem and Production of Fisheries. IntechOpen. https://doi.org/ 10.5772/intechopen.93784

[17] Onojake, M.C; Sikoki, F.D; Omokheyeke, O; Akpiri, R.U. (2017).Surface water characteristics and trace metals level of the Bonny/New Calabar River Estuary, Niger Delta, Nigeria. Applied Water Science 7:951– 959. https:// doi.org/ 10.1007/s13201-015- 0306 – y.

[18] Boyd CE (2015). Water quality: An introduction. 2nd Edition. Springer International Publishing.

[19] Meride, Y &Ayenew, B. (2016). Drinking water quality assessment and its effects on residents' health in Wondo genet campus, Ethiopia. Environmental Systems Research, 5(1): 1 – 7.

[20] Iwegbue, M.A.C; Faran, T.K; Faran, T.K; Iniaghe, P.O; Ikpefan, J.O; Tesi, G.O; Martincigh, B.S. (2022). Water quality of Bomadi Creek in the Niger Delta of Nigeria: assessment of some physicochemical properties, metal concentrations, and water quality index. Applied Water Science (2023) 13(36): 1 – 15. https://doi.org/10.1007/s13201-022-01804-2

[21] Ekubo, A.A; Abowei, J.F.N. (2011), Review of some Water Quality Management Principles in Culture Fisheries. Research Journal of Applied Sciences, Engineering and Technology 3(2): 1342-1357.

[22] Sarmistha, S.R; Paulami, P; Pratik, T; Apaala, B. (2021). Polyamines, metallothioneins, and phytochelatins—Natural defense of plants to mitigate heavy metals. In Atta, R. (Eds.). Studies in Natural Products Chemistry (pp. 227 – 261). Elsevier. https://doi.org/10.1016/B978-0-12-819487-4.00006-9

[23} Tchounwou, P.B; Yedjou, C.G; Patlolla, A.K; Sutton, D.J.(2012). Heavy metal toxicity and the environment. Exp Suppl. 101:133-64. doi: 10.1007/978-3-7643-8340-4_6.

[24] Philip Njoku Obasi, P.N; &Akudinobi, B.B. (2020). Potential Health Risk and Levels of Heavy Metals in Water Resources of Lead–Zinc Mining Communities of Abakaliki, Southeast Nigeria. Applied Water Science 10 (18): 1 – 23. https://doi.org/10.1007/s13201-020-01233-z

[25] Sangare, L.O; Ba, S; Toure, A; Samake, M; Zheng, T. (2023). Assessment of the Water Quality of the Niger River in Bamako, Mali Based on the Water Quality Index. Water Supply 23(2): 672 – 687.

[26] Hamed, M. A. R. (2019). Application of Surface Water Quality Classification Models Using Principal Components Analysis and Cluster Analysis. Journal of Geoscience and Environment Protection 7, 26-41. https://doi.org/10.4236/gep.2019.76003