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Water Quality Assessment by Pollution Indices in Eastern Obolo Coastline Communities of Nigeria

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Abstract The investigation of water quality is crucial for the protection of health. This study assesses water quality, using pollution indices, within the coastline communities of southern Nigeria by examining a total of 48 samples of domestic water sources from 12 communities in Eastern Obolo for one year from November, 2017 to October, 2018. GPS was used to identify the sampling points and Geostatistical technique was used to visualize the risky communities. Water pollution status of the coastline communities was determined using three pollution indices: Water Quality Index (WQI), Heavy metal Evaluation Index (HEI) and Heavy metal Pollution Index (HPI). Result revealed a 66.7% acidification of the sampled domestic water sources with seasonal variation. High Turbidity in 66.67% of surface water during the wet season. Domestic water sources were generally low in Dissolved Oxygen with the highest mean value of 2.13 ± 0.45mg/L for surface water. The mean concentration of Lead (Pb), Iron (Fe) and Cadmium (Cd) were as high as 0.24±0.06 mg/L, 1. 40±0.46 mg/L and 0.68±0.08mg/L, respectively in some water sample. Greater than 50% of the sampled water was not safe for drinking based on water quality index. Water quality was poorer in the wet season than the dry season. Quality rating based on HEI showed that 91.7% of the sampled water had low heavy metal pollution and 8.3% was moderately polluted with heavy metals in both seasons. The total heavy metal pollution index revealed highly polluted domestic water sources. The spatial pollution distribution maps showed a more polluted urban and semi- urban communities than the remote rural communities, demonstrating the influence of urbanization and industrialization on water pollution.

Keywords: *water pollution indices, heavy metals, coastline communities, Eastern Obolo*

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1. Introduction

The environment is constantly being polluted either naturally or through the activities of man in technology and economic advancement. Environmental pollution has tremendous negative effect on vegetation and humans. All pollutants, atmospheric and land-based eventually enter water environment by direct discharge, precipitation and run-offs. Therefore, water bodies' serves as sink and also as carrier of waste and pollutants [1]. “Water pollution has wide ecological impacts as water is an important raw material in photosynthesis and hydrological processes” [1].

Pollution of drinking water with infective organism is a major cause of infant mortality through diarrhea diseases in the developing world. The regular monitoring of water to ensure quality serves to control water pollution as well as a measure of monitoring environmental pollution [2,3]. Information generated from such monitoring is necessary for protection of health through efficient water treatment and management planning. Trace elements pollution has become the main source of global environmental pollution and constitutes risk to drinking water [4,5]. Koki [6] described the investigation of water contaminated by heavy metal as a prime focus of environmental scientist. Their release into the environment is harmful not only to ecosystems, but also poses a threat to human health because of refractory characteristics of bioaccumulation [7].

Essential trace elements are critical for life processes and sustainability, but are only needed in very small amount [8]. Excess intake of essential trace elements in drinking water may lead to adverse health effects [9]. Copper (Cu), is a macro nutrient, and a necessary trace element for the human body, it is involve in many enzyme system activities, but if its concentration goes above the necessary amount, it is harmful to the liver, kidney, digestive system, and brain [10]. Non-essential elements have no usefulness in humans but are harmful in low dose. Elements such as cadmium (Cd), chromium (Cr), arsenic (As), and lead (Pb) have significant biological toxicity and are harmful to human health [11,12]. For example, Cadmium (Cd) mainly accumulates in the human hepatic system and kidneys, disturbing estrogen secretion, and is also carcinogenic by inducing malignant changes in the arteries [13]. Cadmium (Cd) has been implicated in high blood pressure by its ability to replace Zinc (Zn) in biochemical reaction [14]. Lead (Pb) disturbs gonad secretion [15], it is also associated with negative pregnancy outcomes like premature rupture of membrane, spontaneous abortion, cardiovascular diseases and erectile dysfunction in men [14].

Environmental pollution has become an unavoidable consequence of economic development through industrialization, it is therefore necessary to control pollution to a level where it is not hazardous to man and vegetation but at the same time not compromise the gains of industrialization [16].

The Niger Delta region of Nigeria which occupies the southeastern part of the country sustains the economy of Nigeria through crude oil exploration. It is very prone to pollution from the activities of multinational oil companies operating in the region and also from illegal crude oil refining by the operation of oil bunkering. The coastal environments are adversely affected by anthropogenic activities leading to eutrophication, heavy metals, organic, oil spills and microbial pollution. It is imperative to establish adequate coastal water resource management programme, which is lacking in many coastal communities in Nigeria. To do this, it is necessary to characterize the coastal ecosystem in terms of pollution index to determine the degree of contamination [5].

Eastern Obolo coastline communities occupy the extreme corner of the Eastern Niger Delta [17]. There are many small-to-medium fishing settlements scattered around coastlines where environmental help and support from central bodies is meager and very time-consuming. There is no water treatment plant in the Local Government; therefore the people depend on surface and groundwater as their source of drinking water supply. The suitability and adequateness of these water sources for drinking and other domestic uses has generated public health concern leading to some studies on the physicochemical and microbial parameters of surface water, limiting more to the semi-urban part of the local Government Area which are less difficult to access. The findings of such studies were mainly discussed based on the individual water quality parameters, which were very good but such information generated are not easily understood by many none technical people who should benefit from such information. There are very limited studies that provide information on the composite effect of the different water quality parameters, and currently there is none such study that combined the different water quality indices to determine and characterized domestic water pollution in these communities.

A major step in controlling the pollution of the coastal communities in the Niger Delta is to characterize the communities based on their pollution indices. There are several indices that have been used to assess water quality in different parts of the world. In this study, a combination of Weighted Arithmetic Water Quality Index (WQI), Heavy metal Pollution Index (HPI) and Heavy metal Evaluation Index (HEI) is used to identify polluted risky communities based on domestic water pollution. Water quality index combines different water quality parameters into a non-dimensional number that is easy to communicate information on water quality to generality of people. It takes away the cumbersomeness and complexity of discussing individual quality parameter and makes it easy for policy makers to understand the challenges of water pollution [18].

Monitoring of drinking water quality has become imperative in order to ascertain the level and nature of pollutants, and to ensure that their permissible limits are not exceeded [3].

The aim of this study is to determine domestic water pollution of Eastern Obolo coastline communities in terms of Water Quality Index, Heavy Metal pollution Index and Heavy Metal Evaluation Index

2. Materials and Methods

2.1. Study Sites

Eastern Obolo Local Government Area of Akwa Ibom State is located at the eastern fringe of the Niger Delta between Imo and Qua Iboe River estuaries [17]. It is a rural coastal Local Government Area that lies between latitudes $4^{o}26$ and $4^{o}50$ North and longitudes $7^{o}30$ and $7^{o}55$ East with a land mass of about 259.6sq km and a shoreline of about 85km long (Figure 1). The Local Government Areas lies in an equatorial region, typically within the tropical mangrove belt with two main seasons; the wet season (April to October) and the dry season (November to March) in a year [19]. It has an average rainfall of about 3000mm with temperature between 26°C and 28°C [20]. Eastern Obolo has the Coastal Plain Sand, otherwise known as the Benin Formation, and the alluvial environment found within the Niger Delta region of southern Nigeria [20]. National population census, using Akwa Ibom State growth rate of 3.4% estimates the population to be 86,628 in 2017. The major economic activities of the people are farming and fishing and therefore are effected by pollution of the aquatic ecosystem. The Local Government Area has mineral resource and has the highest number of offshore oil wells in the state with a long history of crude oil exploration and exploitation.

2.2. Sample Collection and Analysis

2.2.1. Field Sampling

A total of 48 domestic water samples were collected from twelve communities in Eastern Obolo (Table 1). The sampling sites were purposively selected after field survey to suit the scope of the study. Four water sampling campaigns were carried out; two during the dry season (November and February) and two for the wet season (June and September)for one year from November 2017 to October, 2018. The water samples were collected and tested for physicochemical parameters, Heavy metals, and Total Hydrogen Content (THC), according to internationally accepted standard. The samples for physicochemical parameters and heavy metals were collected in polyethylene bottles. Samples for heavy metals were acidified with Nitric Acid. The samples for THC were collected in dark glass bottles with Teflon stoppers while samples for BOD/COD was collected in Amber glass bottles. These sample bottles were properly sealed and immediately stored in ice-packed coolers for transportation to the DPR certified laboratory for analysis.

2.2.2. Sample Treatment

On-site analysis of pH, Electrical Conductivity (EC), Dissolved Oxygen (DO), Total Dissolved Solids (TDS), Temperature and Salinity were carried out at the site of sample collection following the standard protocol and methods of American Public Health Association [21] and American Society for Testing and Materials (ASTM) using different calibrated standard Instruments.

pH, EC, TDS, and Temperature were measured with HANNA Instrument (model HI 9813-5, *USA*). Dissolved Oxygen was measured with a DO meter (Intron 550, *UK*), Salinity with salinity meter (Tecpel 850, *UK*), and location coordinates with a GPS (Etrek 10 Gasmin, *Taiwan*). All instruments were first standardized before taking three readings and the mean of each measured parameter recorded.

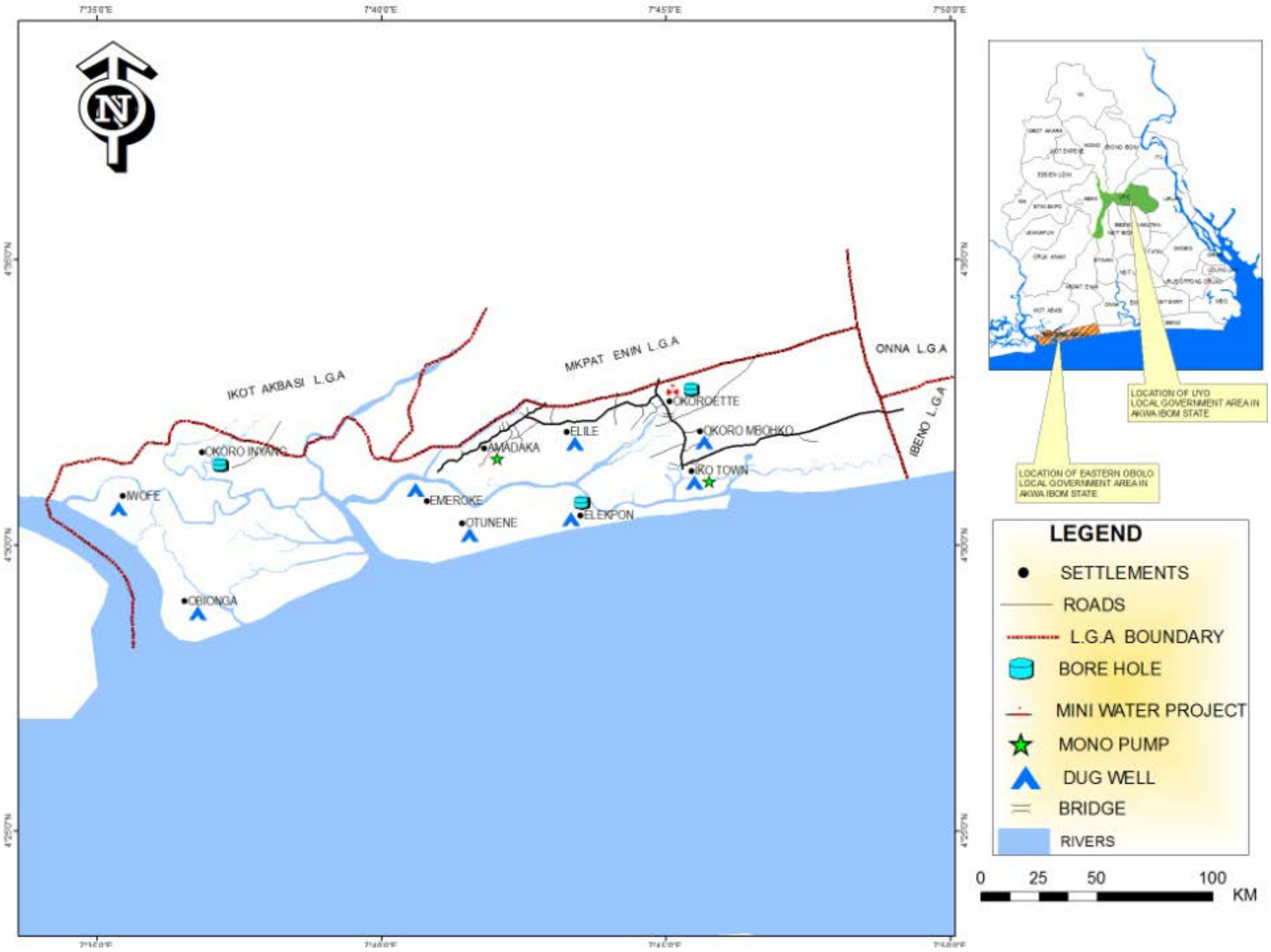

Figure 1. Map of the study area showing sampling points

Table 1. Global Positioning System (GPS) Coordinates for sampling sites

S/N	Site /community	Longitude	Latitude	Altitude (M)	No. of sampling
1	Elekpon(SW)	007° 73’ 15.9”E	04° 30’ 63.4”N	33.5	4
2	Iwofe (GW)	007°31’ 36.46”E	04° 31’15.25”N	6.5	4
3	Otunene(SW)	007° 69’ 50.1”E	04° 30’ 84.3”N	21.1	4
4	Emeroke(SW)	007°66’ 81.4”E	04° 30’68.9”N	11.5	4
5	Amadaka (GW)	007° 69’ 94.1”E	04° 33’ 14.9”N	23.5	4
6	Amadaka(GW)	007° 70’ 20.6”E	04° 33’34.8”N	12.5	4
7	Elile(SW)	007°71’ 09.5”E	04° 33’ 93.3” N	19.5	4
8	Okoromboko (SW)	007°75’ 65.4”E	04° 47’ 89.6”N	1.5	4
9	Iko (GW)	007°74’ 86.6”E	04° 46’ 83.8”N	13.5	4
10	Okoroette (GW)	007° 74’ 80.9”E	04° 48’ 47.1”N	15.5	4
11	Okoroinyong(SW)	007°37’22.80”E	04° 37’ 22.80”N	10.9	4
12	Obianga (SW)	007° 36’33.45”E	04° 29’ 0.97”N	10.5	4
	Total				**48**

SW - Surface Water; GW - Ground Water.

In the laboratory at the ministry science and technology, Uyo, the analyses of 6 heavy metals Cu, Zn, Fe, Cd, Pb, and Cr were carried out based on ASTM standards [22-27], using the Atomic Absorption Spectrometer (UNICAM 969AA, Japan). The standards for each metal were prepared. The meter was switched on and allowed to warm for 40minutes before inserting and aligning the appropriate lamps. "The deionised water was aspirated for zero absorbance and followed by the blank. The standards and already prepared samples in their sequence as identified were equally aspirated and the concentration values of each sample displayed was recorded". [[28], p. 15].

2.3. Water Pollution Assessment Indices

Three water quality indices, namely; weighted Arithmetic Water Quality Index (WQI), Heavy Metal Evaluation Index (HEI) and Heavy Metal Pollution Index (HPI) were used to estimate the level of pollution in the study area. The ability of indices to reduce the bulk of the information into a single value, and to express the data in a simplified and logical form is an advantage over the use of individual parameters in communicating information on water quality to decision makers and the general public [29].

2.3.1. Water Quality Index (WQI)

The overall quality of domestic water in the study area was determined using the weighted Arithmetic Water Quality Index (WAWQI) as cited in [18] Equations 1-4

$$WQI = \frac{\sum QiWi}{\sum Wi} \quad 1$$

Where Qi is the quality rating scale for each parameter and is calculated from

$$Qi = 100\left(\frac{V_i - V_o}{S_i - V_o}\right) \quad 2$$

V_i is the estimated concentration of the ith parameter in the analyzed water; V_o is the ideal value of this parameter ∴ pure water; $V_o = 0$ for other parameter except for pH = 7 and for; DO = 14.6mg/L; S_i is the recommended standard value of ith parameter; W_i is the unit weight otherwise known as the weighted factor for each water quality parameter and is calculated from.

$$Wi = \frac{K}{Si} \quad 3$$

Where K = proportionality constant and is calculated from

$$K = \frac{1}{\sum(\frac{1}{Si})} \quad 4$$

Table 2. Water quality rating using weighted Arithmetic water quality Index method

WQI value	Rating of water quality	Grading
0-25	Excellent Water Quality	A
26-50	Good water quality	B
51-75	Poor water quality	C
76-100	Very poor water quality	D
Above 100	Unsuitable for drinking purpose	E

Water quality index was calculated for both wet and dry seasons using 10 parameters; pH, Temperature, Turbidity, Electrical conductivity, Dissolved oxygen, Sulphate, nitrate, Total dissolved solids, Total hardness and iron.

2.3.2. Heavy Metal Pollution Index (HPI)

Heavy metal pollution Index (HPI) is calculated using the methods of [14,30]

$$HPI = \frac{\sum_{i=i}^{n} W_i Q_i}{\sum_{i=i}^{n} W_i} \quad 5$$

Where: W_i and Q_i are the unit weight and sub-index of the ith parameter respectively, and n is the number of parameters considered.

$$Wi = K / si \quad 6$$

$$K = \frac{I}{\sum_{i=1}^{n} \frac{1}{si}} \quad 7$$

Where K and S_i are the proportionality constant and the standard permissible limit in water for the ith parameter respectively

$$Qi = \sum_{i=1}^{n} \frac{M_i - I_i}{S_i - I_i} x100 \quad 8$$

Where M_i, I_i and S_i are the monitored value, ideal value and standard value of ithparameter.

2.3.3. Heavy Metal Evaluations Index (HEI)

Heavy metal evaluation index gives an overall quality of water with respect to heavy metal [31]. It is mathematically determined as follows using the method of [31]

$$HEI = \sum_{i=1}^{n} \frac{Hc}{Hmac} \quad 9$$

Where Hc = Analysed concentration of the respective parameter; Hmac = Maximum admissible concentration of the respective parameter.

3. Result and Discussion

3.1. Physicochemical and Heavy Metal parameters

Table 3 and Table 4 show the physicochemical and heavy metal parameters of water quality in Eastern Obolo. The mean pH of surface water varied between 5.28 ± 0.24 and 7.12± 0.10 for Wet and Dry seasons, respectively; while for groundwater, it was 6.13± 0.22 and 6.78± 0.29 for Wet and Dry seasons, respectively. The hydrogen-ion concentration [pH] of a solution determines the acidity or alkalinity condition of the solution. The pH of domestic water used for drinking in the study area was lower than the World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) permissible range of 6.5 to 8.5 in 66.67% of the sampled locations indicating acidification of drinking water sources.

The acidity was more during the Wet seasons and particularly so for surface water than groundwater.

Table 3. Variability in Physicochemical and Heavy metal parameters in Eastern Obolo domestic water

	Surface water		Ground water	
Parameters	**Dry season**	**Wet season**	**Dry season**	**Wet season**
pH	7.12±0.10	5.28±0.24	6.78±0.29	6.13±0.22
Temperature(0^c)	27.10±0.34	26.75±0.08	28.78±0.60	27.70±0.24
Turbidity (NTU)	2.43±0.61	7.09±0.61	2.06±0.12	0.02±0.69
Salinity (PPM)	0.68±0.23	0.02±0.02	0.47±0.17	19.67±0.02
Hardness (mg/l)	20.73±0.81	32.83±7.88	17.18±1.07	0.09±2.06
EC (us/cm)	0.41±0.18	0.72±0.72	0.38±0.14	2.00±0.03
DO (mg/l)	1.57±0.27	2.13±0.45	1.15±0.25	0.08±0.44
BOD (mg/l)	0.05±0.01	0.05±0.01	0.09±0.02	0.83±0.02
COD (mg/l)	0.34±0.18	0.12±0.01	0.66±0.23	0.002±0.22
THC (mg/l)	0.001±0.00	0.001±0.00	0.001±0.00	0.002±0.00
Phosphate (mg/l)	0.003±0.00	0.001±0.00	0.001±0.00	0.01±0.01
Sulphate (mg/l)	0.002±0.00	0.01±0.00	0.001±0.00	0.03±0.00
Nitrate (mg/l)	0.01±0.00	0.03±0.01	0.01±0.00	35.52±0.01
TDS (mg/l)	25.33±9.00	17.07±9.95	85.17±37.25	0.01±9.64
TSS (mg/l)	0.01±0.00	0.01±0.00	0.02±0.00	0.01±0.00
Cu (mg/l)	0.005±0.00	0.31±0.05	0.004±0.00	0.31±0.07
Fe (mg/l)	0.89±0.18	0.45±0.09	1.00±0.39	1.40±0.46
Pb (mg/l)	0.003±0.00	0.24±0.06	0.02±0.00	0.23±0.10
Zn (mg/l)	0.70±0.13	0.02±0.00	0.67±0.28	0.02±0.07
Cd (mg/l)	0.68±0.08	0.15±0.09	0.54±0.22	0.41±0.34
Cr (mg/l)	0.002±0.00	0.003±0.00	0.003±0.00	0.003±0.00

Table 4. Show the physicochemical and heavy metal parameters of water quality in Eastern Obolo for Wet and Dry seasons

	Wet season			Dry Season			WHO Std	NSDWQStd
	$\overline{X}$	SD	p-value	$\overline{X}$	SD	p-value		
pH	5.71	0.20	0.002**	6.95	0.13	0.005**	6.5-8.5	6.5-8.5
Temperature(0^c)	27.23	0.19	0.253	27.94	0.41	0.042*	27-28	27-28
Turbidity (NTU)	5.32	0.69	0.656	2.25	0.30	<0.001**	5.00	5.00
Salinity (PPM)	0.02	0.01	NA	0.57	0.14	NA	NA	NA
Hardness (mg/l)	26.25	4.36	<0.001**	18.96	0.83	<0.001**	100	150
EC (us/cm)	0.40	0.35	<0.001**	0.39	0.11	<0.0001**	NA	1000
DO (mg/l)	2.07	0.30	<0.001**	1.36	0.19	<0.0001**	6	5.00
BOD (mg/l)	0.07	0.01	<0.001**	0.07	0.01	<0.0001**	10	-
COD (mg/l)	0.47	0.15	NA	0.50	0.15	NA	NA	-
THC (mg/l)	0.00	0.00	0.147	0.00	0.00	<0.0001**	0.003	-
Phosphate (mg/l)	0.01	0.00	<0.001**	0.00	0.00	<0.001**	3.5	-
Sulphate (mg/l)	0.01	0.00	<0.0001**	0.00	0.00	<0.0001**	250	100
Nitrate (mg/l)	0.03	0.01	<0.001**	0.01	0.00	<0.0001**	10	50
TDS (mg/l)	26.29	7.17	<0.0001**	55.25	20.37	<0.001**	500	500
TSS (mg/l)	0.01	0.00	NA	0.01	0.00	NA	NA	
Cu (mg/l)	0.31	0.04	<0.001**	0.00	0.00	<0.001**	1	1
Fe (mg/l)	0.93	0.27	0.039*	0.94	0.20	0.009*	0.3	0.3
Pb (mg/l)	0.23	0.06	0.002**	0.01	0.00	0.539	0.01	0.01
Zn (mg/l)	0.02	0.00	<0.0001**	0.68	0.15	0.002**	3	3
Cd (mg/l)	0.28	0.17	0.135	0.61	0.12	<0.0001**	0.003	.0.003
Cr (mg/l)	0.00	0.00	<0.001**	0.00	0.00	<0.0001**	0.05	0.05

*= Significant at 5% (P<0.05); ** = Significant at 1% (P<0.01)

The Niger Delta has been reported to be high in acidity (low pH) particularly in the mangrove swamp area by other reseachers [32]. Inam [28] in their study of Okoroette community in Eastern Obolo noted the acidification of surface water in the wet season which they attributed to atmospheric carbon dioxide exchange. Beka [32] attributed the low pH in the Niger Delta region to the activities of gas flaring, which leads to the release of carbon dioxide that reacts with atmospheric precipitation to form carbonic acid, which percolates into ground water system and increases the acidity.

Ekpeyoung [33] attributed the acidic content of surface water in Ibeno to humic acid formed by decomposed vegetative materials. Acidification of domestic water sources impact bitter taste to drinking water which renders the water not potable. Acidification of water is known to increase the capacity of water to attack geological materials and leach toxic trace metals into the water which renders it harmful to health [34]. Acidic waters are known to favour iron bacteria to thrive and cause severe corrosion of iron containing metals. This has been observed in some parts of Niger Delta [32].

About 66.67% of surface water had mean turbidity value greater than 5 NTU with the highest mean value of 7.09$\pm$ 0.61 NTU occurring in surface water during the Wet season. All the groundwater samples (100%) had mean turbidity value of less than 5 NTU recommended by WHO. Turbidity, describes the cloudiness of water caused by suspended particles. Turbidity has both water safety and aesthetic implication. This could be attributed to storm runoff since turbidity was significantly higher during the wet season than dry season ($p \leq 0.05$). It has been argued that most of the constituents of turbidity (e.g. silt, soil, clay and natural organic matter) are harmless, but turbidity can indicate the presence of hazardous chemical and microbial contaminant. The implication of this finding is that though water may be abundant in the study area during the wet season much of it might not be acceptable aesthetically or health wise.

The Dissolved Oxygen (DO) concentration was generally low, the highest mean value of 2.13 $\pm$ 0.45 mg/L recorded for surface water in the Wet season is lower than the WHO recommended value of 6mg/L. The finding of low Oxygen content of drinking water is corroborated by [33] in Ibeno, [28] in Okoroette, and [34] in Uruan.

Inam [28] argues that the low DO value makes drinking water unacceptable as it may impact odour to the water and result in oxygen deficiency to sustain life. [34], however held a different view as they claimed that their values of 1.50 – 1.90 mg//l for public borehole in Uruan was acceptable though lower than the international recommended value of 6.00 mg/l. [33] attributed the low DO level to decomposed materials. Oxygen content of water is not known to have any direct toxic effect on man [32]. However, low Oxygen content of water affect aquatic organism and produce odour in drinking water. Low dissolved Oxygen in water could be an indication of the presence of biodegradable organic matter in water. Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) were both low in the study area as shown in Table 3 and Table 4. BOD and COD do not indicate water quality but potential for removing oxygen from water [34]. The low BOD in the presence of low DO in this study area could suggest that the low DO is not necessarily as a result of (high microbial load in the water samples) biodegradable organic pollution of water sources.

The mean values recorded for the heavy metals were generally low for Copper (Cu), Zinc (Zn) and Chromium (Cr) except for Lead (Pb), Iron (Fe) and Cadmium (Cd) which were as high as 0.24 $\pm$ 0.06 mg/L, 1. 40$\pm$ 0.46 mg/L and 0.68$\pm$ 0.08mg/L, respectively in some water sample. The concentrations of theses metals were found to be higher than the WHO and NSDWQ recommended permissible limit.

3.2. Pollution Assessment Indices

Table 5 indicates that only one site S10 (Okoroette) with 22.93 had excellent water quality during the dry season. The result obtained for WQI from the different sampling sites during the wet season varied from 27.51 to 314.48. About 41.7% of these were classified as good water quality, 8.3% were classified as poor water quality, 33.3% were of very poor quality and 16.7% were unsuitable for drinking. For the dry season, the WQI varied from 22.93 – 245.97, and of which 8.3% was of excellent quality, 41.7% were good water quality, 38.3% were very poor water quality and 16.7% were unsuitable for drinking. The result of water quality rating of the study area based on contamination with Heavy metals using Heavy Metal Evaluation Index (HEI) indicates that for the wet season the HEI varied from 13.58 to 756.33 with 91.7% below 400 (low heavy metal pollution) and 8.3% between 400 to 800 (moderate heavy metals pollution).

Table 5. Water Quality Index (WQI) and Heavy metal Evaluation Index (HEI)

SAMPLE ID	LOCATION	WATER TYPE	WQI		HEI	
			Wet	Dry	Wet	Dry
1	Etekpon	Surface water	97.01	75.44	13.58	4.52
2	Iwofe	Ground water	87.30	40.49	27.50	73.96
3	Otunene	Surface water	53.45	91.01	21.23	356.38
4	Emeroke	Surface water	92.64	81.76	14.70	135.34
5	Amadaka(PM)	Ground water	105.22	33.09	100.65	301.75
6	Amadaka(BH)	Ground water	35.52	245.97	21.51	486.00
7	Elile	Surface water	31.33	30.62	29.70	253.15
8	Okoromboko	Surface water	27.51	108.76	225.38	211.94
9	Iko	Ground water	314.48	87.39	60.53	20.24
10	Okoroette	Ground water	86.90	22.93	756.33	265.95
11	Okoroinyong	Ground water	31.33	30.62	33.95	253.06
12	Obianga	Surface water	27.51	30.41	133.70	211.95

PM = Monopump, BH = Borehole.

Table 6a. Total HPI for Wet Season

Parameter	Mean Conc. (mg/L)	S_i	W_i	Q_i	W_iQ_i
Cu	0.271	1	1	27.1	27.1
Fe	0.987	0.3	3.33	329	1095.6
Pb	0.188	0.01	100	1880	188,000
Zn	0.021	3	0.33	0.76	0.231
Cr	0.003	0.05	20.00	6	120
			124.66		189,242.931

$$\frac{\sum W_i Q_i}{\sum W_i} = 1,518.1$$

Table 6b. Total HPI for Dry Season

Parameter	Mean Conc. (mg/L)	S_i	W_i	Q_i	W_iQ_i
Cu	0.029	1	1	2.9	2.9
Fe	0.924	0.3	3.33	308	1025.64
Pb	0.022	0.01	100	220	22,000
Zn	0.559	3	0.33	16.63	5.4879
Cr	0.003	0.05	20	6	120
			124.66		23,034.03

$$\frac{\sum W_i Q_i}{\sum W_i} = 184.8$$

During the dry season, 91.7% of sampling site was low in heavy metal contamination and 8.3% had moderate contamination. Mean Heavy Metal pollution index (HPI) for wet and dry seasons were 1,518.1 and 184.8 respectively. Both were above the critical value of 100. The HPI for wet season was greater than 15 times the critical value. About 58% of domestic water used in the area of study was not safe for drinking during the wet season and 55% during the dry season based on WQI. Water quality rating based on Heavy metal content of domestic water sources showed serious metal pollution especially in the wet season.

3.3. Spatial Distribution Map

Geostatistical modeling for spatial distribution of the parameters using Geostatistical analyst extension of the Arc GIS software to identify the areas with high concentration of WQI and HEI are shown in Figures 2a-d. The distribution of water pollution by communities as shown on the pollution map revealed that semi-urban communities which are mainly located in the eastern part of the Local Government Area are more polluted especially with respect to Heavy metals indicating the influence of urbanization on the pollution of water resources.

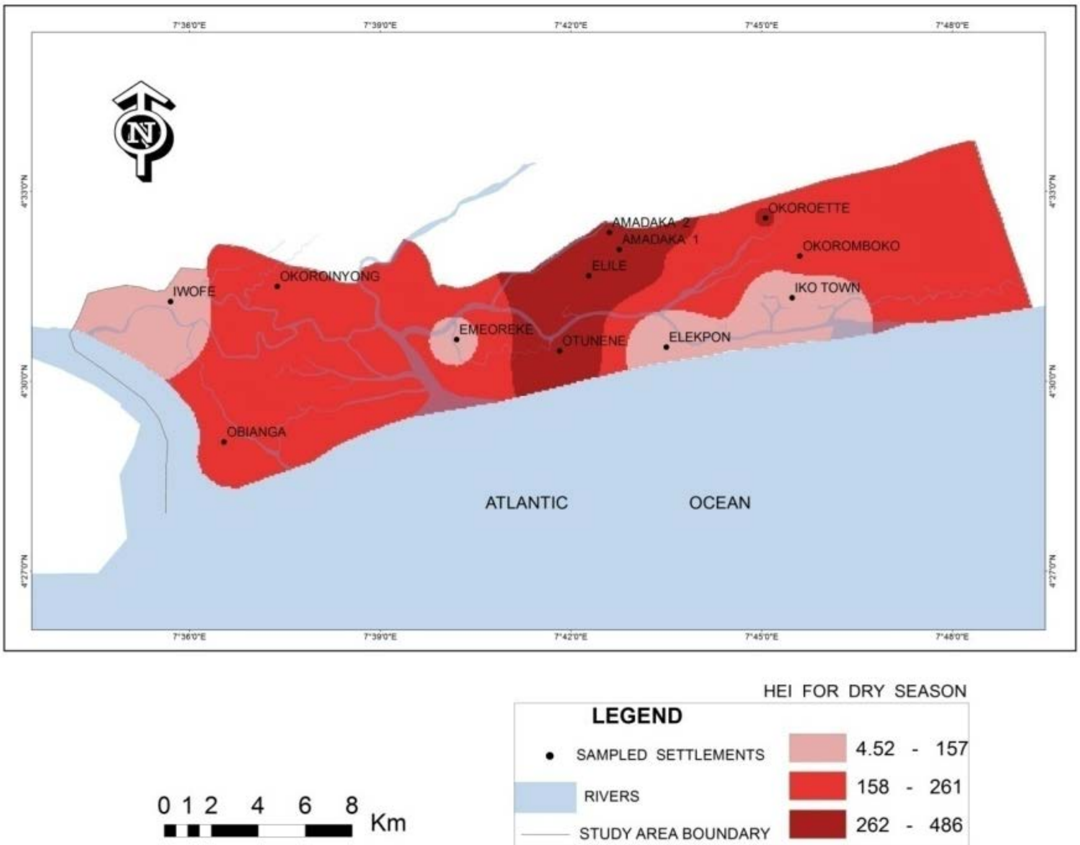

Figure 2a. Map showing the spatial distribution of Heavy metal Evaluation Index (HEI) score for dry season.

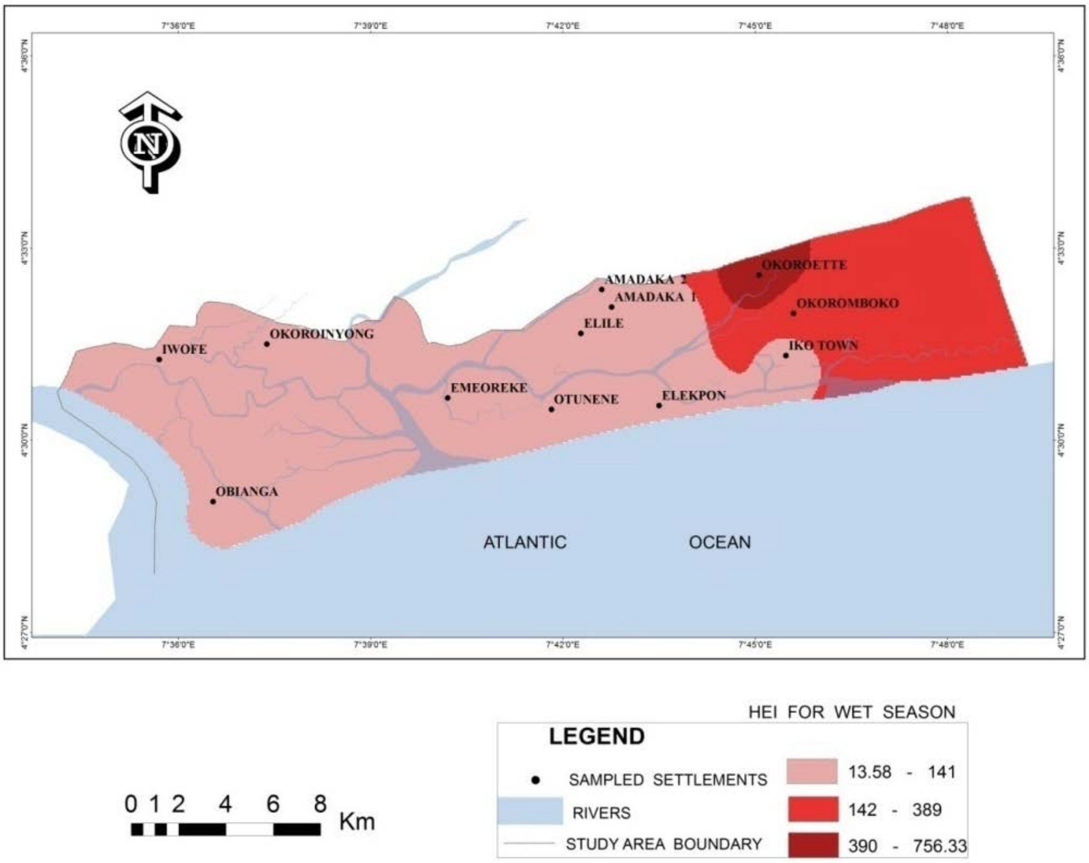

Figure 2b. Map showing the spatial distribution of Heavy metal Evaluation Index score (HEI) for wet season.

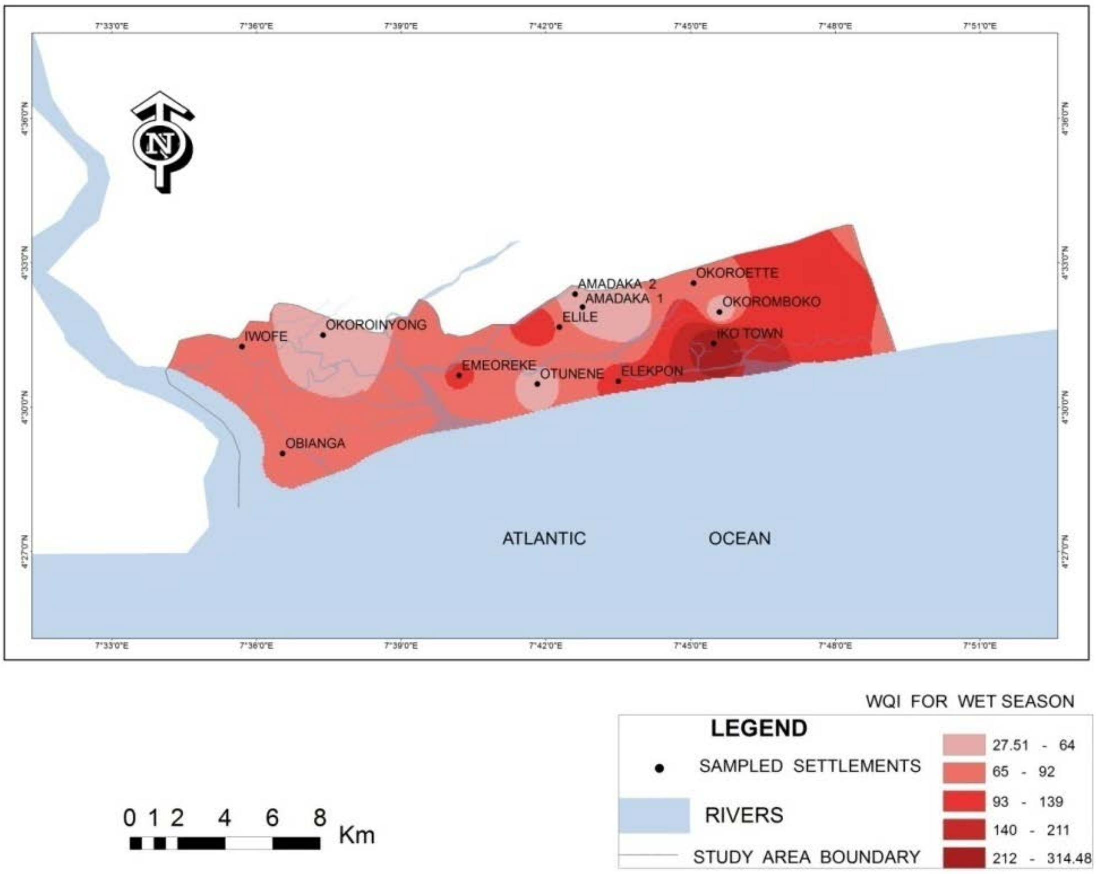

Figure 2c. Map showing the spatial distribution of Water Quality Index score for wet season

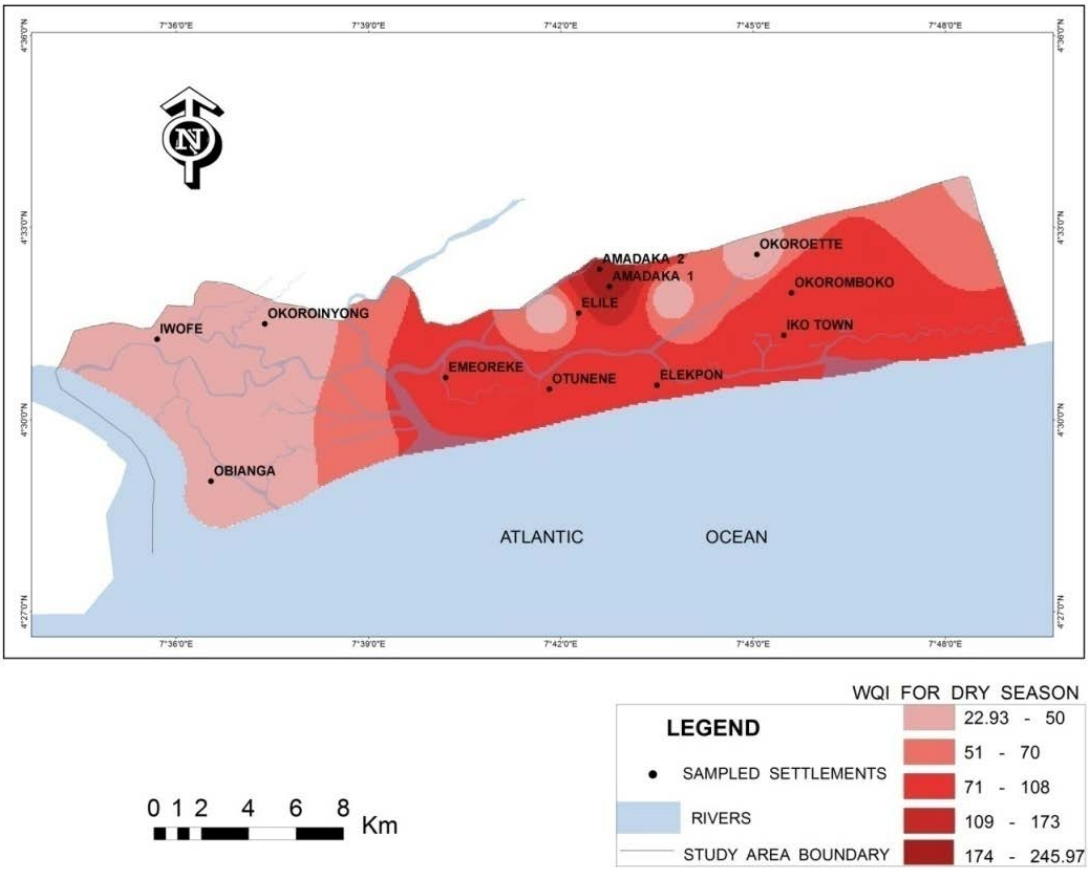

Figure 2d. Map showing the spatial distribution of Water Quality Index score for dry season

4. Conclusions

This study of water pollution has shown that the coastal communities of Eastern Obolo are at risk as revealed by the level of pollution of domestic water sources. There was high concentration of cadmium (0.68mg/L) and lead (0.24mg/L). These results are definitely above the WHO and NSDWQ permissible levels especially in the dry season. The water quality indices indicated that domestic water was not safe for drinking in both seasons in over 50% of the sampled communities. The overall assessment of the water quality with respect to heavy metals revealed a highly polluted water environment, which is risky to the health of the people in these communities.

The distribution of water pollution by communities as shown on the pollution map revealed that semi-urban and urban communities which are mainly located in the eastern part of the Local Government Area are more polluted especially with respect to Heavy metals indicating the influence of urbanization on the pollution of water resources. There is therefore the need to safeguard the health of the people by the provision of water treatment plants and the protection of the environment by instituting an appropriate coastal management plan to prevent a worsening situation.

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