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HEALTH RISK ASSESSMENT OF HEAVY METALS IN DOMESTIC WATER OF EASTERN OBOLO COMMUNITIES OF NIGERIA.

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ABSTRACT
The investigation of chemical contaminant of domestic water sources and the determination of Human Health Risk due to six Heavy metals (Fe, Cu, Pb, Cd and Cr) in Eastern Obolo coastline communities was carried out by testing 48 water samples from 12 communities for the concentration of 21 chemical parameters and 6 Heavy metals. Internationally accepted procedures were observed in the collection and testing of water samples from November, 2017 to October, 2018 across Wet and Dry seasons. The United States Environmental Protection Agency model was used to estimate Human Health Risk from exposure to heavy metals. Result showed acidification of water sources with mean pH as low as 5.8 in some surface water, particularly during the wet season. A generally low Dissolved Oxygen content of water was observed with the highest value of 2.5mg/L. The concentrations of Lead (Pb), Iron (Fe) and Cadmium (Cd) were as high as 0.29 ± 0.29 mg/l, 2.36 ± 1.27mg/l and 1.42 ± 0.66mg/l, respectively in some groundwater sources with significant seasonal variation ($p<0.05$). The incremental cancer risk associated with exposure to carcinogenic heavy metals through drinking water was above $1x10^{-4}$ for Cd, predisposing children and adults to the risk of cancer from Cd. Cluster analysis demonstrated similarities in chemical parameters in some communities which could suggest similar source of contamination requiring similar measure of control or treatment.

KEYWORDS: Chemical contaminants, Heavy metals, Human Health Risk Assessment, Eastern Obolo communities.

INTRODUCTION
Water is vital to all living organisms. It is by far the most abundant component of the human body, consisting 60% of body weight on average but ranging from 40% to 80%.[1] Water is needed for homeostasis, transport of substances in the body, metabolism, and temperature regulation. It is also necessary for the maintenances of the integrity of cells and for photosynthesis in plants.

There has been a growing interest in the chemical contamination of domestic water sources around the world because chemicals have direct and indirect effect on the quality of water. Low pH, for example, impact a sour test to water and also increases the dissolution of chemicals from rocks and soil. Sulphates affect the test, smell and odour of water. The colour and turbidity of water is affected by chemicals such as Iron (Fe) and Manganese (Mn). Therefore, the determination of the chemical content of natural water gives some explanation to some physical characteristic of water.

Bicarbonate ($HC0_3^-$) is the most abundant inorganic chemical in water, it is very important in the Carbonate-Bicarbonate system which is the most important chemical system in natural water.[2] This system provides the buffering capacity essential for maintaining the pH of natural water system in the range required by bacteria and other aquatic species.[2]

Chemicals such as the heavy metals in natural water have generated concern in science and technology because of toxic, carcinogenic and teratogenic effect attributable to some of them.[3,4] Cd, Pb and Cr are among the non essential elements but are toxic to the body at very low concentrations. The concern about metal contamination of the environment goes beyond the immediate multiple organ system effect caused by high concentration above the permissible limits but the bioaccumulative and biomagnifications produced by the non-biodegradation and the persistence of these chemicals in the ecosystem once released.[5]

Chemicals enter the environment through natural processes such as weathering, erosion and precipitation from the atmosphere or through human activities like mining, industrial waste, agriculture and improper solid waste disposal method. Combustion of petroleum products, forest burning for agricultural activities and open burning of solid waste are common practices in Eastern Obolo communities. These activities generate some toxic chemical into the atmosphere. Acid rain occurs as a result of the conversion of chemical pollutants such as sulphate and nitrate ions to their respective acids. The effects of acidification of surface water can be seen in the destruction of vegetation, leaching of some important nutrients from the soil and the mineralization of water bodies.[6]

Eastern Obolo communities, located in the Niger Delta region of Nigeria have long history of crude oil exploration and exploitation.[7] They are also prone to natural and man-made disasters such as flooding, erosion and oil spills as a result of their location along the coast of the Atlantic Ocean. These communities source domestic water from streams, ponds, shallow wells, rain and a few bore holes because there are no water treatment plants. The peculiarity of the situation has generated some interest in researchers in the area of environmental contamination, particularly in surface water and sediments.[7] gave the historical account of oil pollution and its impact on the human ecology. Studies on surface water and estuaries have reported the pollution of the water environment.[8,9,10] There is a dearth of knowledge on human health risk assessment posed by chemical pollutants in these communities. Therefore this study analyzed the chemical pollutants in domestic water and estimated the non-cancer and the cancer risk of heavy metals in adults and children using such water for drinking.

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.[7] 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 1.1). The Local Government Area` 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.[10] It has an average rainfall of about 3000mm with temperature between 26^{o}C and 28^{o}C.[11] 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.[11] 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 resources and has the highest number of offshore oil wells in the State with a long history of crude oil exploration and exploitation.

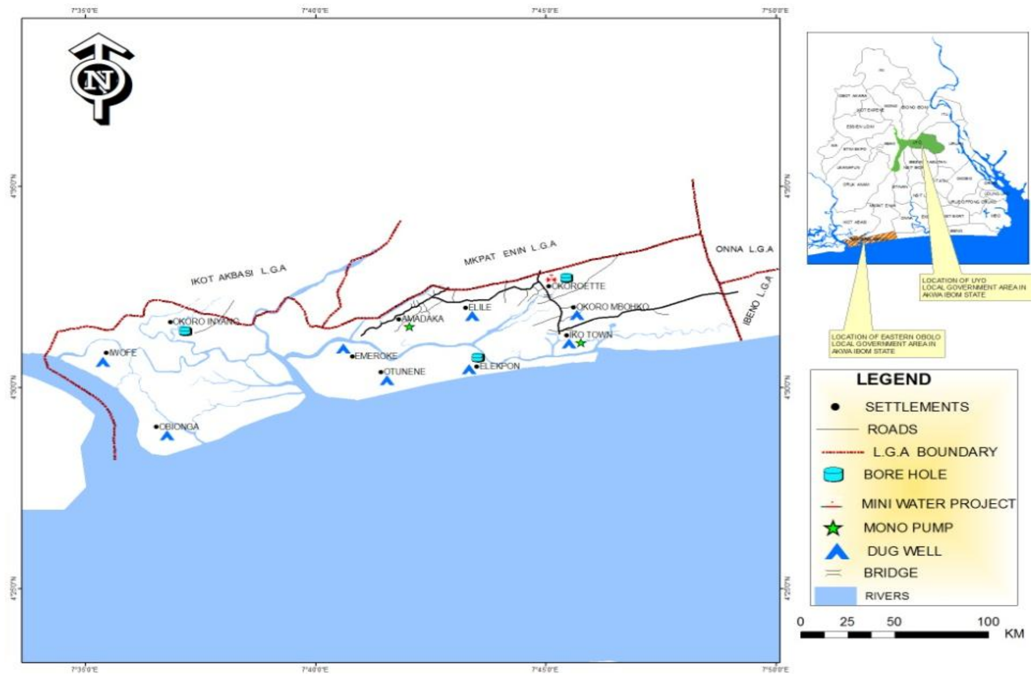

Fig 1: Map of the study area showing sampling points.

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 exercises 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, total hydrocarbon content, 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 and microbes were collected in Amber glass bottles. These sample bottles were properly sealed and immediately stored in ice-packed coolers for transportation to the Department of Petroleum Resources (DPR) certified laboratory for analysis.

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

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[12] 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.

In the Laboratory at the Ministry of Science and Technology, Uyo, the analyses of 6 heavy metals Cu, Zn, Fe, Cd, Pb, and Cr were carried out based on ASTM standards[13,14,15a-d] 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 40 minutes 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".[9] Finally quality control check was performed by aspirating a known concentration of the metal being determined (ASTM, 2012).

2.3. Human Health Risk Assessment

Risk is a measure of the probability of an adverse effect in a particular situation. The United State Environmental Protection Agency in 1989 outlined a four-step procedure for assessing human health risk[16] to include hazard identification through data collection and evaluation, dose-response assessment, exposure assessment and risk characterization. The human health risk can be non-carcinogenic or carcinogenic.

2.3.1. Non-carcinogenic effect

This is estimated by comparing an exposure level over a specified time period (e.g. lifetime) with a reference dose derived for a similar exposure period. This ratio of exposure to toxicity is the Hazard Quotient (HQ).

Using the modified Equations (1 to 5) from the United States environmental protection Agency[16] for drinking water, the non- cancer risk can be estimated (Equation 1)

$$HE_{DW} = \frac{CxIR}{BW} \quad (1)$$

Where HE_{DW}, C, IR and BW are the human exposure risk through drinking water pathway (mg /kg /day), concentration of the heavy metal in water (mg /L), ingestion rate of water (L / day) and body water (kg) respectively.

The hazard quotient (HQ) for non-carcinogenic risk for each heavy metal is calculated using the Equation 2

$$HQ = \frac{HE_{DW}}{RFD} \quad (2)$$

Where RFD is the oral reference dose for heavy metal that an individual can be exposed to (in mg /kg/day)

HQ is calculated for each heavy metal and the sum of HQ gives the Hazard Index (HI)

$$HI = \sum HQ \quad (3)$$

Hazard Index (HI) gives the total risk through health exposure pathway. Values of HQ and HI under unity are considered safe for the non-carcinogenic exposure.

2.3.2 Cancer Risk

This is based on incremental probability.[16] The slope factor (SF) converts estimated daily intake averaged over a lifetime of exposure directly to incremental risk of an individual developing cancer. It is generally assumed that the dose- response relationship will be linear in the low- dose portion of the multistage model dose- response curve. Therefore, slope factor is a constant and risk will be directly related to intake. Thus, linear form of the carcinogenic equation is applicable and is given as;

$$Risk = CDI \times SF \quad (4)$$

Where,
Risk = A unitless probability of an individual developing cancer.
CDI = chronic daily intake average over 70 years (mg/kg-day).
SF = Slope Factor (mg/kg-day)$^{-1}$

$$CDI = \frac{EDI \times EF \times ED}{AT \times BW} \quad (5)$$

Where:
EDI = Estimated Daily Intake;
EF = Exposure Frequency;
ED = Exposure Duration;
AT = Average Time; and
BW = Body Weight

Table 2: Parameters Used for Estimating Exposure Assessment in Water.

Risk exposure	Values	Unit
Ingestion Rate (IR)	2.2	L/day
Exposure Frequency (EF)	360	Days/Year
Exposure Duration (ED)	30	Year
Average Time (AT)	0.6	h/day
Average body Weight (BW)	70	Kg
Slope Factor (SF)	Pb=0.0085, Cd=6.3, Cr=0.5	(mg/kg/day)$^{-1}$

Source:[5]

2.4 Statistical Analysis

Descriptive statistical techniques, such as mean, standard deviation, percentages were employed to analyze the physiochemical parameters and heavy metals. Student's t- test was used to compare mean and establish statistical significance at 5% and 1%. A Multivariate statistical tool (Agglomerative Hierarchical Cluster Analysis) was used to statistically establish similarities in water quality characteristics amongst communities within the coastline. SPSS Statistical software, version 20.0 was employed to achieve speed and accuracy. Results were presented in tables, figures, and graphs.

3. RESULT

3.1. Chemical characteristic of domestic water in the study area

The general characteristics of physiochemical parameters and heavy metals for the study area are summarized in Tables 3a and 3b for surface and groundwater, respectively.

The mean pH of the water ranged from 5.8 ± 1.2 to 6.6 ± 1.0 for surface water and 6.15 ± 0.75 to 6.75 ± 0.65 for the ground water. The least value of 5.8 ± 1.2 was recorded for surface water while the highest value of 6.75 ± 0.65 was for groundwater. In both surface and groundwater, 66.7% of sampled water had pH less than WHO minimum recommended pH of 6.5 for drinking water. The highest mean value for Total Hardness of 35.8 ± 16.20mg/l was for surface water while the least value of 14.85 ± 2.6mg/l was recorded for ground water. Total hardness values were generally low in the area under study. Similar low mean values were recorded for; Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Phosphate (PSO_4), Sulphate (SO_4), and Nitrate (NO_3).

The mean value for Dissolved Oxygen (DO) was generally low with the highest mean value of 2.5mg/l recorded for surface water. Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) were also found to be low in the area. Total Hydrocarbon Contents (THC) was below detectable limit for both surface and groundwater except for one groundwater sample (GW3) where it was found to be 0.01mg/L.

3.2 Heavy Metals

The mean values recorded for the heavy metals were generally low for Copper (Cu), Zinc (Zn) and in Chromium (Cr) except for Lead (Pb), Iron (Fe) and Cadmium (Cd) which were as high as 0.29± 0.29 mg/l, 2.36 ± 1.27mg/l and 1.42 ± 0.66mg/l, respectively in ground water.

The seasonal distribution of Cadmium (Cd) and Lead (Pb) in the communities is shown in Figures 2a and 2b. Cadmium was more widely distributed in domestic water sources in Eastern Obolo especially during the wet season.

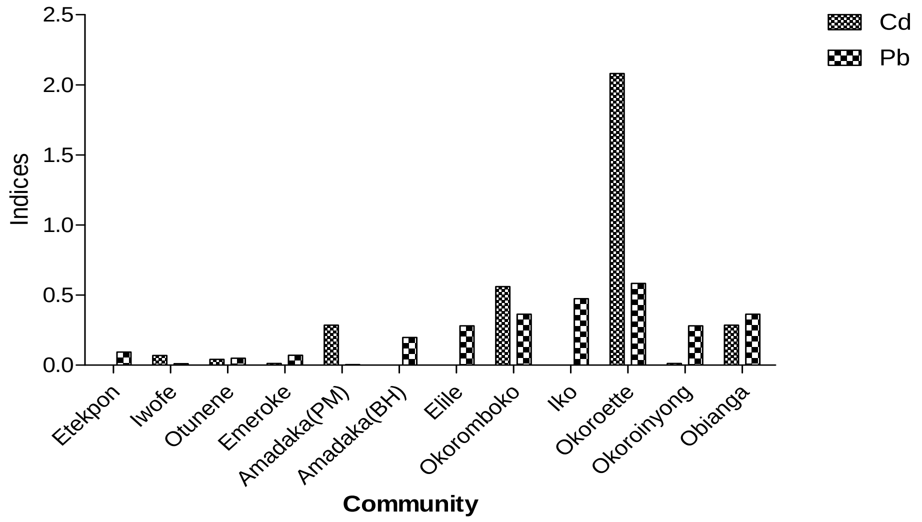

Figure 2a: Wet season distribution of Cd and Pb.

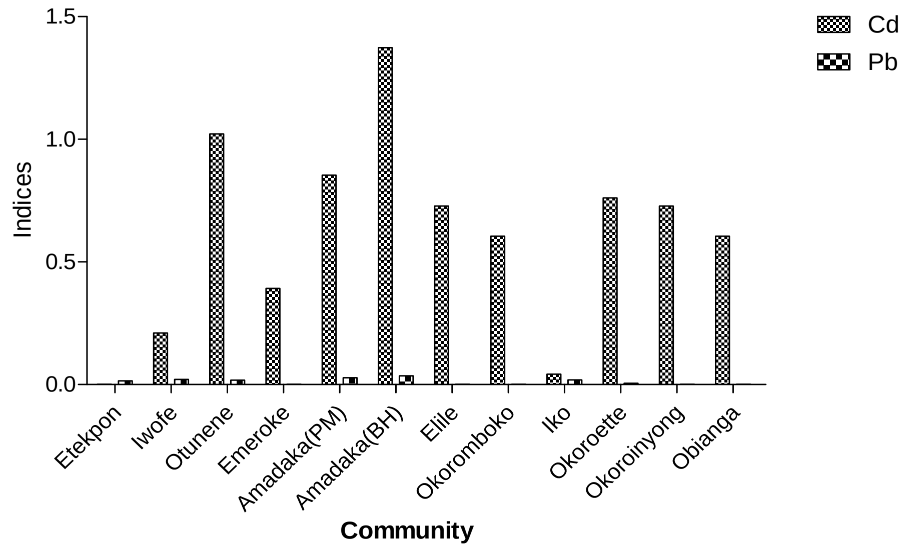

Figure 2b: Dry saeson distribution of Cd and Pb

Table 3a: Descriptive statistics for surface water.

	Sites											
	SW1		**SW2**		**SW3**		**SW4**		**SW5**		**SW6**	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
pH	6.50	0.40	6.60	1.00	5.80	1.20	6.25	0.85	5.80	1.20	6.25	0.85
Temperature	26.65	0.05	26.10	0.50	27.15	0.55	27.25	0.25	27.15	0.55	27.25	0.25
Turbidity	4.15	2.99	2.95	1.93	5.32	3.43	5.40	1.10	5.32	3.43	5.40	1.10
Salinity	0.60	0.60	0.70	0.60	0.00	0.00	0.40	0.40	0.00	0.00	0.40	0.40
Hardness	21.10	3.10	32.80	14.20	35.80	16.20	17.60	3.60	35.80	16.20	17.60	3.60
EC	0.41	0.40	2.17	2.13	0.00	0.00	0.40	0.40	0.00	0.00	0.40	0.40
DO	1.70	1.30	2.10	0.70	2.50	0.30	1.15	0.45	2.50	0.30	1.15	0.45
BOD	0.08	0.04	0.08	0.04	0.04	0.01	0.04	0.01	0.04	0.01	0.04	0.01
COD	0.14	0.04	0.66	0.56	0.14	0.02	0.15	0.02	0.14	0.02	0.15	0.02
THC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Phosphate	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sulphate	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrate	0.06	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
TDS	46.00	20.00	49.50	13.50	9.00	3.00	6.85	6.15	9.00	3.00	6.85	6.15

TSS	0.01	0.00	0.01	0.00	0.02	0.00	0.01	0.00	0.02	0.00	0.01	0.00
CU	0.10	0.10	0.05	0.05	0.17	0.17	0.22	0.21	0.17	0.17	0.22	0.21
Fe	0.83	0.31	0.92	0.05	0.30	0.04	0.83	0.44	0.30	0.04	0.83	0.44
Pb	0.03	0.02	0.04	0.04	0.14	0.14	0.18	0.18	0.14	0.14	0.18	0.18
Zn	0.52	0.49	0.08	0.06	0.48	0.45	0.31	0.29	0.48	0.45	0.31	0.29
Cd	0.53	0.49	0.20	0.19	0.36	0.36	0.58	0.02	0.37	0.36	0.45	0.16
Cr	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

SEM= Standard Error of Mean; SW = Surface Water

Table 2b: Descriptive statistics for ground water.

	GW1		GW2		GW3		GW4		GW5		GW 6	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
pH	6.40	0.40	6.40	0.20	6.75	0.65	6.70	0.50	6.35	0.65	6.15	0.75
Temperature	27.15	0.35	27.65	0.45	28.55	0.25	28.70	1.50	28.15	0.15	29.25	1.45
Turbidity	1.70	0.10	2.75	0.80	4.16	2.34	2.91	0.33	3.17	0.95	2.17	0.15
Salinity	0.10	0.00	0.35	0.35	0.03	0.03	0.50	0.50	0.07	0.07	0.40	0.40
Hardness	19.20	0.80	15.20	1.20	14.85	1.85	20.88	2.13	22.60	2.40	17.83	5.18
EC	0.30	0.06	0.07	0.02	0.43	0.38	0.09	0.02	0.10	0.05	0.41	0.40
DO	1.45	1.25	1.95	0.75	0.95	0.35	2.25	0.45	1.70	1.00	1.15	0.55
BOD	0.10	0.04	0.07	0.03	0.04	0.04	0.13	0.01	0.14	0.02	0.05	0.04
COD	0.67	0.54	0.67	0.53	0.60	0.46	1.21	0.01	1.16	0.06	0.15	0.01
THC	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Phosphate	0.00	0.00	0.01	0.01	0.02	0.02	0.00	0.00	0.01	0.01	0.00	0.00
Sulphate	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.00
Nitrate	0.01	0.01	0.04	0.03	0.03	0.02	0.01	0.01	0.01	0.00	0.01	0.00
TDS	140.85	123.15	29.70	22.30	56.00	6.00	77.50	10.50	32.50	18.50	25.50	5.50
TSS	0.02	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.02	0.01	0.03	0.00
Cu	0.07	0.06	0.03	0.03	0.20	0.20	0.16	0.16	0.24	0.23	0.24	0.24
Fe	0.98	0.12	0.75	0.23	0.83	0.44	1.59	1.25	2.36	1.27	0.70	0.42
Pb	0.05	0.04	0.02	0.01	0.02	0.01	0.12	0.08	0.25	0.23	0.29	0.29
Zn	0.00	0.00	0.05	0.05	0.66	0.64	0.74	0.71	0.05	0.01	0.55	0.54
Cd	0.00	0.00	0.14	0.07	0.57	0.28	0.69	0.69	0.02	0.02	1.42	0.66
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

SEM= Standard Error of Mean; GW = Ground Water

Cluster Analysis

Agglomerative Hierarchical Cluster (AHC) analysis was performed by Ward's method, using squared Euclidean distance to measure similarity group in terms of water quality characteristics in the 12 coastline communities. The dendrogram in Figure 3c for the wet season identified three significant clusters. Cluster 1 revealed similarities in water quality characteristics of six different communities (Elile (S_3), Okoro Inyong (S_5), Amadaka community pump (G_3), Otunene (S_1), Okoroette (G_6) and Elekpon community well (G_1)). Cluster 2, identified three communities: Okoromboko (S_4), Obianga (S_6), Iwofe (G_2) and cluster 3 had the following three; Amadaka community pump (G_3), Iko (G_5) and Emeoreke (S_2) during wet season. The dendrogram for dry season only had two clusters as shown in Fiqure 3d.

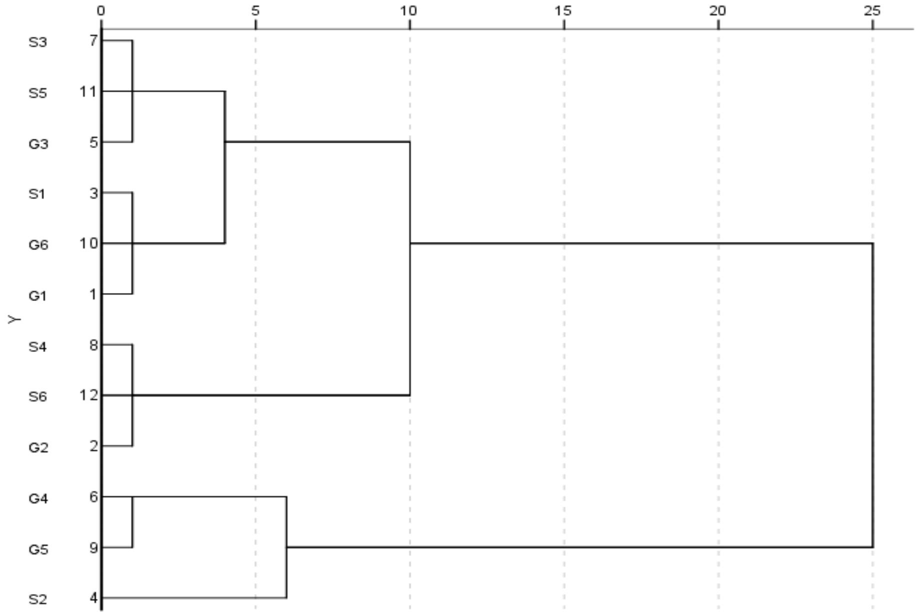

Figure 3c: Dendogram showing clustering of sampling communities according to water quality characteristics during wet season.

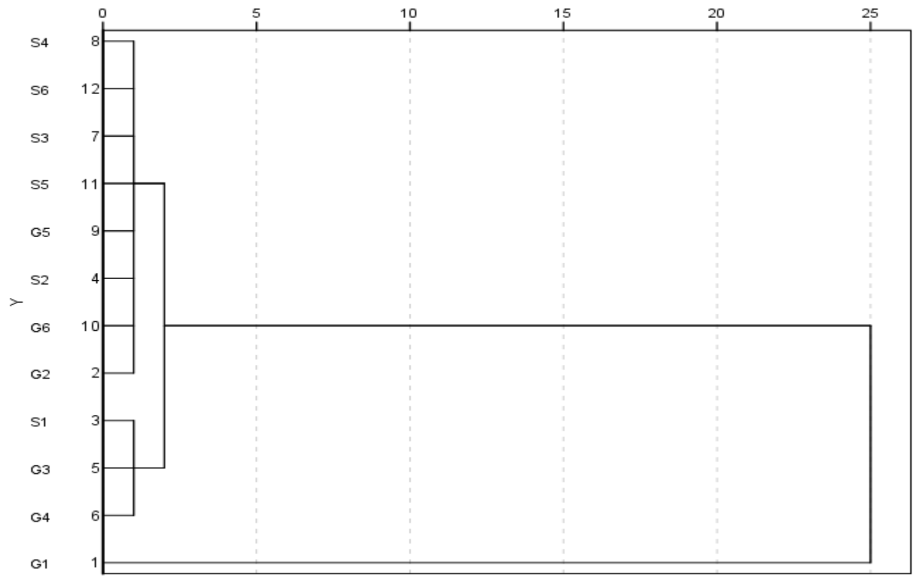

Figure 3d: Dendogram showing clustering of sampling communities according to water quality characteristics during dry season

Cancer and Non-Cancer Risk

(i) Non-Cancer Risk

The risk characterization of trace metals in the study area was quantified by carcinogenic and non-carcinogenic risk at the different seasons. The levels of health hazard risk for the population caused by oral ingestion of trace metal in two groups: adult and children are shown in Tables 4a-d. The non-cancer risk for individual metal, determined by Hazard Quotient (HQ) and the total for all metals determined by Total Hazard Index (HI) were all below unity, (HQ and HI < 1), for both adult and children indicating low risk. However, among all the metals, HQ oral for Cadmium (Cd) was calculated the highest for adult and children in both seasons.

(ii) The Cancer Risk

The cancer risk for surface and groundwater in both seasons were below 1 x 10^{-6} for Pb and Cr. Therefore Lead (Pb) and Chromium (Cr) posed no cancer risk for the individuals using these sources of water within these communities. The estimated cancer risk for Cadmium (Cd) for adult and children were generally higher than 1 x 10^{-4} except for surface water during the wet season where it was within the satisfactory range of 1 x 10^{-5} to 1 x 10^{-6}. The use of these sources of water within these communities exposes the individuals to the risk of development of cancer due to Cadmium in the water environment.

Table 4a: Chronic daily intake and hazard quotient for each metal in surface water for dry season.

Metal	RfD	CDI child	CDI Adult	HQ Child	HQ adult
Cu	0.01	0.000004543	0.000002419	0.00011	0.00006
Fe	0007	0.000065604	0.000034932	0.00094	0.0005
Pb	0.02	0.000001694	0.000000902	0.00049	0.00026
Zn	0.3	0.000029876	0.000015908	0.000029	0.00002
Cd	0.10	0.0000308	0.0000164	0.031	0.016
Cr	0.003	0.000000231	0.000000123	1.20E-07	6.00E-08
HI				0.033	0.017

Table 4b: Chronic daily intake and hazard quotient for each metal in ground water for dry season.

Metal	RfD	CDI child	CDI Adult	HQ Child	HQ adult
Cu	0.01	0.000000308	0.000000164	0.0000078	0.000004
Fe	0007	0.00007854	0.00004182	0.0012	0.0006
Pb	0.02	0.00000154	0.00000082	0.0005	0.0002
Zn	0.3	0.00006083	0.00003239	0.000061	0.000032
Cd	0.10	0.00005005	0.00002665	0.05	0.026
Cr	0.003	0.000000231	0.000000123	1.15E-07	6.00E-08
HI				0.052	0.027

Table 4c: Chronic daily intake and hazard quotient for each metal in surface water for wet season.

Metal	RfD	CDI child	CDI Adult	HQ Child	HQ adult
Cu	0.01	0.000016786	0.000008938	0.00042	0.0002
Fe	0007	0.000049665	0.000026445	0.00071	0.0004
Pb	0.02	0.000010703	0.000005699	0.0031	0.0016
Zn	0.3	0.00000154	0.00000082	0.000002	0.00000008
Cd	0.10	0.000007392	0.000003936	0.0074	0.0039
Cr	0.003	0.00000308	0.00000164	1.55E-07	8.00E-08
HI				0.012	0.006

Table 4d: Chronic daily intake and hazard quotient for each metal in ground water for wet season.

Metal	RfD	CDI child	CDI Adult	HQ Child	HQ adult
Cu	0.01	0.000026488	0.000014104	0.0007	0.0004
Fe	0007	0.000112882	0.000060106	0.0016	0.0009
Pb	0.02	0.000019558	0.000010414	0.0056	0.0029
Zn	0.3	0.000001617	0.000000861	0.000061	0.0000009
Cd	0.10	0.000037576	0.000020008	0.0376	0.02
Cr	0.003	2.618E-07	1.394E-07	1.30E-07	7.00E-08
HI				0.046	0.024

Table 5a: Incremental lifetime cancer risk (ILCR) of surface water for dry season.

	DI Child	DI Adult	ILCR Fraction	CDI Child	CDI Adult	CSF	ILCR Child	ILCR Adult
Pb	0.000001694	0.0000009	1.01	1.71094E-06	0.000000909	0.0085	1.4543E-08	7.7265E-09
Cd	0.00005	0.0000267	1.01	0.000031108	0.000016564	6.3	0.00019598	0.000104353
Cr	0.000000231	0.00000012	1.01	0.00000023	0.000000124	0.5	0.00000012	6.2115E-08

Table 5b: Incremental lifetime cancer risk (ILCR) of ground water for dry season.

	DI Child	DI Adult	ILCR Fraction	CDI Child	CDI Adult	CSF	ILCR Child	ILCR Adult
Pb	0.0000154	0.00000082	1.01	1.5554E-06	8.282E-07	0.0085	1.32209E-08	7.0397E-09
Cd	0.00005	0.0000267	1.01	0.0000505	0.000026967	6.3	0.00031815	0.000169892
Cr	0.00000023	0.00000012	1.01	0.00000023	0.00000012	0.5	0 .00000012	6.2115E-08

Table 5c: Incremental lifetime cancer risk (ILCR) of surface water for wet season

	DI Child	DI Adult	ILCR Fraction	CDI Child	CDI Adult	CSF	ILCR Child	ILCR Adult
Pb	0.0000107	0.000005699	1.01	0.00001807	5.75599E-06	0.0085	9.1855E-08	4.89259E-08
Cd	0.000007392	0.000003936	1.01	7.46592E-06	3.97536E-06	6.3	4.70353E-05	2.50448E-05
Cr	0.00000031	0.00000016	1.01	0.00000031	0.00000017	0.5	0.00000016	8.282E-8

Table 5d: Incremental lifetime cancer risk (ILCR) of ground water for wet season.

	DI Child	DI Adult	ILCR Fraction	CDI Child	CDI Adult	CSF	ILCR Child	ILCR Adult
Pb	0.0000197	0.000011	1.01	0.000019897	0.00001111	0.0085	1.69125E-07	9.4435E-08
Cd	0.0000376	0.00002	1.01	0.000037976	0.0000202	6.3	0.00023949	0.00012726
Cr	0.00000026	0.00000014	1.01	0.00000027	0.00000014	0.5	0.00000013	7.0195E-8

4. DISCUSSION

There were variations in the concentration of the different chemicals between sampling stations and also between surface and groundwater. Domestic water sources were generally acidic, degrading the water quality in the coastline communities. Acidic water has been reported in other study conducted in the Niger Delta.[17, 9] Surface waters, with a mean pH of 6.2 were more acidic than groundwater (pH: 6.46). This has been attributed mostly to deposition from acidic gases present in the atmosphere from combustion of petroleum products[17], and partly from the present of fulvic and humic acid from decaying organic matters.[8] The concentrations of Phosphate, Sulphate and Nitrate, which are commonly referred to as nutrients were generally low suggesting lower rate of eutrophication of the water bodies in these communities. These chemicals commonly contaminate water bodies from agricultural activities, particularly the use of chemical fertilizers. Less agricultural activities were indeed observed in these coastline communities as the people were mostly engaged in fishing activities from the rivers and Atlantic Ocean. Equally low was the Dissolved Oxygen (DO), depreciating domestic water quality. The concentrations of Pb, Fe and Cd in water were significantly higher than the local and international maximum permissible limits ($p<0.05$), exposing the users of such water to the negative health effect of metal contamination of drinking water sources.

Agglomerative Hierarchical Cluster (AHC) analysis for both seasons identified 3 clusters for wet season and 2 clusters for the dry season. The differences in the number of clusters for the different seasons suggest some dissimilarity in the route of contamination of domestic water in these coastline communities for each season. Each of the 3 clusters in Fiqure 3c contains water drawn from both surface and groundwater sources which indicate similarities in the route of contamination in each of the clusters. AHC analysis has, therefore, demonstrated the effect of seasonal variability in the water quality characteristics of these communities.

From the values of HQ and HI calculated, HQ and HI were below unity (HQ <I and HI < I). The area though polluted with heavy metals, has little or negligible non-cancer hazard as a result of heavy metal pollution. This is however different for cadmium (Cd) which had estimated cancer risk higher than 1 x 10^{-4}, thereby exposing adult and children to risk of developing cancer due to cadmium.[18] also observed an increase in the concentration of cadmium in ground water and spring of Zanzibar in Tanzania. However, the toxicity of cadmium is governed by other factors such as nutrition, dose, age and lifestyle.

5. CONCLUSION

The study revealed a general acidification of domestic water sources in the different communities, but more in surface water during the wet season (mean pH of 6.2). The concentration of phosphates, Sulphate and Nitrate, commonly referred to as nutrients were significantly low especially during the dry season signifying low eutrophication of the water bodies.

The concentration of heavy meals in the water environment showed spatial and seasonal variability. Cadmium (Cd) and Lead (Pb) with concentration as high as 1.42mg/L and 0.29mg/L respectively in some locations during the wet season, showed contamination of water environment with toxic heavy metals. Cluster analysis identified similarities in chemical contamination of domestic water sources among some communities which could suggest similar sources of contamination in each season that was different from the other season therefore demonstrating the effect of seasonal variability in the route of pollution of domestic water sources in Eastern Obolo coastline communities.

Human health risk assessment of people exposed to heavy metal through drinking water, using exposure assessment model revealed Cd (Cancer Risk greater than 1x 10^{-4}) as the most important chemical pollutant with the potential of causing cancer over time in both adult and children in these communities. The non-carcinogenic risk from heavy metals through the oral route was however negligible.

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