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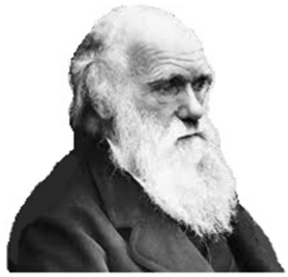

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Seasonal variation and health risk assessment of groundwater quality in the vicinity of dumpsites in Owerri, Southeastern Nigeria

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ABSTRACT

Human health risks associated with the consumption of water from groundwater sources in the vicinity of dumpsites in Orogwe, Nekede, and Ihiagwa in Owerri West were investigated for adults and children in this study. Groundwater samples were collected within 50-500 meters from solid waste dumpsites and subjected to *In-situ* analysis for fast-changing parameters such as temperature, pH, electrical conductivity, dissolved oxygen, and total dissolved solids using a Hanna multi-meter Probe. Heavy metals were measured using an Atomic absorption spectrophotometer while other parameters were examined using the American Public Health Association Method (APHA). Low pH levels were observed in the study area for wet and dry seasons. Conductivity levels and dissolved solids showed higher mean values in the wet season than dry season. The pollution index result was significant (≥1) for Nekede and Ihiagwa in the dry season. Exposure doses were higher in children than adults while the non-carcinogenic results ranged from medium to high risk in all samples except the control point in the wet season. Nickel, iron, and lead had a high percentage contribution to the hazard risks in both seasons. Significant carcinogenic risk ($>1.0E^{-4}$) for children recorded at Ihiagwa in the dry season is of great concern. In general, the groundwater quality in the vicinity of dumpsites was of poor quality (>100) and more vulnerable in the wet season than the dry season from the water quality index (WQI) result.

***Keywords*:** Groundwater quality, Human health risks, dumpsites, pollution index, heavy metals

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1. INTRODUCTION

In developing countries like Nigeria, waste management is an encompassing issue that adversely affects the environment and well-being of the populace. The increasing population index in municipal cities and constant waste generation have led to the proliferation of dumpsites very close to residential areas [1, 2]. These dumps usually are unlined borrow pits without any environmental impact assessment where industrial, commercial, and domestic wastes are constantly deposited [3, 4]. These solid wastes consist of metal scraps, used electrons, bad tyres, plastics, and organic and agricultural wastes. Open dumpsites are biologically and chemically active, exuding leachate which migrates to the surface and groundwater sources comprising their quality [5, 6].

In Owerri, groundwater sources are the primary source of water for drinking and other domestic activities due to the high contamination index of surface water sources [6, 8]. Also, the lack of a robust public pipe-borne water supply system in municipal cities has intensified the abstraction of the freshwater aquifer to satisfy the increasing need for water. This foresees the indiscriminate drilling of shallow boreholes close to the vicinities of dumpsites [1]. Leachate infiltration into groundwater is a serious environmental risk as a result of the difficulties involved in the treatment of contaminated groundwater sources especially in developing countries with limited technological and economic capacities [9].

An increase in precipitation further increases the corrosion of metals and the seepage of leachate into the groundwater by vertical and lateral migration [10, 12]. The rainy period in the area is controlled by the advance of northward maritime air which is linked to the Atlantic Ocean. There is usually an alternating period of sunshine and rainfall situations due to the conventional nature of the heavy downpour. About 89% of the rainfall is witnessed between May and October [23, 24]. The regularity and intensity of the rainfalls result in massive runoff occasioned by the presence of steep slopes which renders the area vulnerable to flooding. Sometimes, the intense rainstorm events go with enormous flooding which causes leaching of the topsoil that subsequently infiltrates into the underground water [25].

Heavy metal pollution in groundwater is a potential health risk and can be detrimental to humans and animals because of their ability to bioaccumulate and their high toxicity at low concentrations [13]. Several reports have indicated the presence of heavy metals at toxic levels in drinking water and groundwater sources from India, Nigeria, Iran, China, and Mexico. In rural areas of India, some percentage of drinking water was reported to exceed threshold values in heavy metal concentration [14].

In Owerri Nigeria, a high carcinogenic risk of chromium above the guideline limit was discovered in some areas [15]. The presence of Heavy metals in drinking water above standard limits can cause adverse health issues. According to the Centre for Food, 2013, Intake of aluminum in water above threshold limits can result in Alzheimer's and dementia. Manganese toxicity impacts negatively on the brain, and respiratory system, increasing the possibility of Parkinson's disease and bronchitis [15-16]. Also, Lead consumption can lead to neurological, kidney, and gastrointestinal disorders including poisoning [17, 18]. Therefore, pollution of drinking water sources with heavy metals is a global concern because it raises public health issues.

However, comparisons of metal and other contaminant concentrations in drinking water with standards are not enough to quantify and characterize the human health risks associated with the consumption of contaminated groundwater sources in both wet and dry seasons.

The Quantitative health risk assessment by the United States Environmental Protection Agency (USEPA) provides a model for risk characterization [19]. Health risks are analyzed by the concentration of the pollutant in the water source, the exposure doses of the water for children and adults, and the non-carcinogenic and carcinogenic risks of consumption of the pollutants. This method provides an inclusive quantifying chance for adults and children independently. Therefore, this study is aimed at quantifying the risk in the consumption of groundwater in the vicinity of dumpsites by identifying and determining the concentration of the individual pollutants in groundwater, assessing the risk of consumption in adults and children as well as the overall groundwater quality in wet and dry seasons using the water quality index.

2. Materials and Methods

2. 1. Study Area

The study was carried out in three municipal cities of Orogwe, Nekede, and Ihiagwa, in Owerri West Local Government Area in Imo State, Southeastern Nigeria. Owerri West Local Government Area lies between latitude 5º 16' 30"N and 5º 31' 30"N, longitude 6º 51' 00"E and 7º 5' 00"E. It has an area of 295 km^2 and a population of 199,265 [20]. These areas are densely populated with residential and few commercial buildings like tertiary institutions, hotels, and multiple stores, generating tons of waste collected and disposed of at the municipal dumpsites.

The dumpsites are unlined shallow excavations of abandoned burrow pits. Most residential and commercial buildings have private boreholes with overhead storage tanks very close to the dumpsites to provide water for domestic and commercial uses since there is no pipe-borne water supply in the areas.

The positioning of the dumpsites and borehole stations was determined using Garmin GPS facility and expressed in degrees, minutes, and seconds for latitude and longitude coordinates. The obtained positions were plotted out using the Google Earth software which gave a clear satellite image of the study area.

2. 2. Climate

Imo State of Southeastern Nigeria lies within the humid tropics. The area's weather condition is occasioned by the varying temperature which shows seasonally distributed rainfall. The study area has a bi-modal climate made up of dry and wet seasons. March signals the beginning of the wet season which ends in early October, while the dry period starts from the end of October up to the early part of March. The mean yearly rainfall is estimated at 2500 – 4000 mm. The months of July and September are the wettest seasons in the area, there is a "short dry season" in between known as "August break".

Intense sunlight is usually observed between November and December which lasts up to February as the Northeast trade wind blowing over the Sahara Desert extends its dehydrating influence progressively towards the equator, reaching the Southeast coast of Nigeria in late December or early January. The period is called "Harmattan". Daylight temperatures in the area ranged from 18 to 34 °C, with the average daily minimum and maximum temperatures of 19 and 28 °C, respectively [21]. The approximated evapotranspiration rate in the area is between 1450 and 1460 mm/year [22].

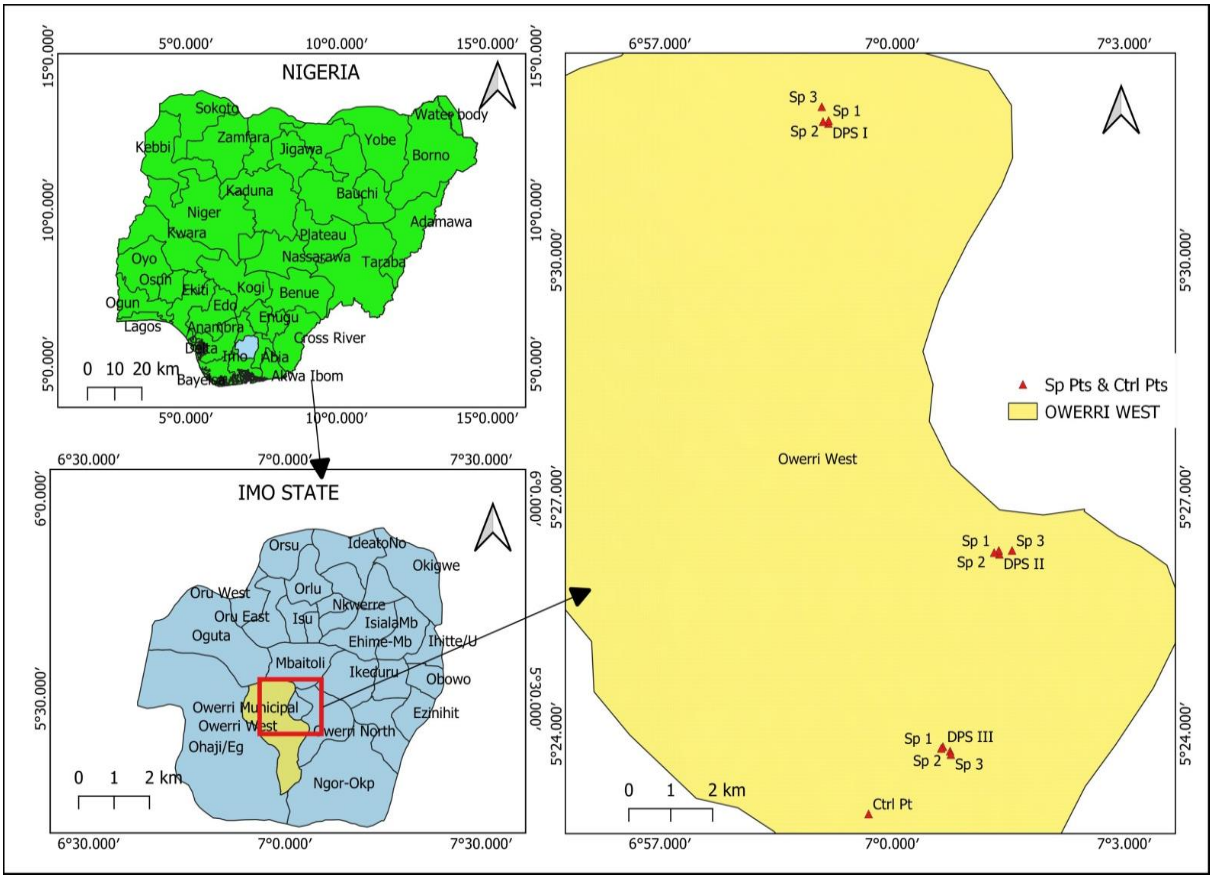

Plate 1. Map of the study area

Table 1. Dumpsites, Sampling points and Control point's GPS locations, and features

Dumpsites, Sampling and Control points	Northing (Y)	Easting (X)	Distance (m)	Area (m^2)
DPS 1 (OROGWE)	05° 31'43.92"	06° 59'10.57"	Perimeter 368	8009
Sample point 1(DPS I)	05° 31'46.10"	06° 59'10.72"	66.7	
Sample point 2(DPS I)	05° 31'45.31"	06° 59'6.40"	135	
Sample point 3(DPS I)	05° 31'56.61"	06° 59'5.41"	420	
DPS II (NEKEDE)	05° 26'16.58"	07° 1'23.11"	Perimeter 378	7340
Sample point 1 (DPS II)	05° 26'19.46"	07° 1'22.68"	89.1	
Sample point 2 (DPS II)	05° 26'17.84"	07° 1'19.98"	132	

Sample point 3 (DPS II)	05° 26'19.47"	07° 1'32.95"	315	
DPS III [IHIAGWA]	05° 23'50.39"	07° 0'39.35"	Perimeter 295	6205
Sample point 1 (DPS III)	05° 23'49.06"	07° 0'38.05"	57.48	
Sample point 2 (DPS III)	05° 23'47.00"	07° 0'44.92"	200	
Sample point 3 (DPS III)	05° 23'44.38"	07° 0'45.51"	265.36	
Control Point	5° 22' 59.23"	6° 59' 41.70"		

2. 3. Sample Collection

Groundwater samples from borehole well heads were aseptically collected for two seasons; the wet season in July 2022 and the dry season in January 2023, from sampling points near 50 - 500 m each from three solid waste dumpsites (Orogwe, Nekede, and Ihiagwa), located at municipal centers in Owerri West. Control samples were collected from a borehole at the Federal University of Technology, Owerri, the area has no history of dumpsites around the area.

The water samples were collected with two-liter plastic bottles after 20 minutes of electrical pumping. The bottles were washed, rinsed with distilled water, autoclaved, and rinsed again three times with the sample water at the site. Samples for heavy metals analyses were acidified with a few drops of conc. HNO_3 and collected in 100 ml bottles. Samples were collected in triplicates from each sampling point. The sampling containers were properly corked after filling and transported to the laboratory in an ice cooler at 4 ºC to avoid deterioration.

Fast-changing parameters such as temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), and dissolved oxygen were measured *in situ* using a calibrated HANNA (HI 9828) multi-parameter instrument. The turbidity of samples was determined using a turbidity meter (Hach 2100Q). For Total suspended solids (TSS), 100 ml of groundwater samples were well mixed and filtered through a vacuum filtration unit with a pre-weighed 0.45 µm millipore filter paper. The filter paper was dried at 105 ºC to constant weight. The TSS was then calculated as the difference in weight of filter paper before and after drying.

The amount of ammonia (NH_3) was determined using the Phenate spectrometric method, sulfate (SO_4^{2-}) by the turbidimetric method, Nitrate (NO_3), and Phosphate (PO_4^{3-}) by the spectrophotometric method using Hanna HI 83200 multi-parameter bench photometer. Total Alkalinity (T/A), and total chloride (Cl^-) were determined by titrimetric methods according to APHA standards. The concentration of heavy metals was determined using the Atomic Absorption Spectrophotometer (AAS) Buck Scientific-210 VGP.

2. 4. Pollution Assessment

Contamination factor (CF)

Contamination Factor (CF) was used to establish the extent of contamination by the individual metal in the groundwater samples according to Eq (1),

$$C_f = \frac{c_m}{c_b} \quad (1)$$

where; C_f represents the contamination factor, C_m is the concentration of a metallic element in the groundwater samples and, C_b *is* the background value of the metallic elements.

The Nigerian Standard for Drinking Water Quality (NSDWQ) was used as the background values for the groundwater samples. The observed contamination factor values were ranked according to $C_f < 1$ representing low contamination, $1 \leq C_f < 3$ for moderate contamination, $3 \leq C_f < 6$ representing high contamination, while $6 \leq C_f$ indicates very high contamination as earlier reported [15].

Pollution load index (PLI)

PLI was used to identify the level of heavy metal pollution in the groundwater sources. The pollution load index was established using Eq. 2.

$$PLI = \sqrt[n]{C_{f1} \times C_{f2} \times C_{f3} \times \dots C_{fn}} \quad (2)$$

where; n represents the number of metals analyzed and, C_f is as earlier described. PLI >1 is an indication of pollution.

2. 5. Health Risk Assessment

Human exposure to heavy metals could be from oral or dermal routes. The human exposure by oral consumption of groundwater was calculated using the USEPA risk assessment guidelines as shown in Eq. 3 [26]

$$Exp_{Oral} = \frac{\text{Cn X RI X EF X DE}}{\text{Bw X AT}} \text{ in mg/kg/day} \quad (3)$$

where; Cn is the mean concentration of the metal in groundwater sample [mg/l], RI is the rate of ingestion (2.5L/Day for adults and 1.5L/Day for Children), EF is the exposure frequency (365 day/year), DE is the duration of exposure (65 yrs -adults and 7 yrs-children), BW is the average body weight (70 kg for adults and 18 kg for children), AT is the average time.

Hazard Quotient

The non-carcinogenic risks due to the consumption of metallic pollutants present in the groundwater samples were estimated as the hazard quotient (HQ) and the cumulative risks of all assayed metals as the Hazard index (HI) with Equations 4 and 5

$$HQ_{Oral} = \frac{\text{Exp}_{\text{oral}}}{RFD} \quad (4)$$

$$HI = \sum HQ_{Cu} + HQ_{Mn} + HQ_{Fe} + HQ_{Pb} + HQ_{Ni} + HQ_{Zn} \quad (5)$$

where; HQ_{Oral} is the hazard quotient for consumption, HI_{oral} is the hazard Index, and Rfd is the reference dose of the metal [27]. HQ and HI values less than one (<1) are considered to be safe, but HQ or HI value >1 may be a major potential health concern.

Carcinogenic risk (CR) of using the groundwater

The carcinogenic risk (CR) of groundwater sources, as calculated using Eq. 6, refers to the lifetime exposure to carcinogens in the environment.

$$CR = \frac{Exp_{oral}}{\frac{1}{SF}} \quad (6)$$

where; SF represents the cancer slop factor.
The SF for Pb is 0.0085 mg/kg/day [26]. The tolerable range of carcinogenic risk is within $1.0e^{-06}$ - $1.0e^{-04}$.

2. 6. Water Quality Index (WQI)

The study assessed the water quality of groundwater sources in the study area using the weighted arithmetic WQI determination method, according to Eq. [7] - [10]

$$W_R = \frac{w_p}{\sum_{i=1}^{n} w_p} \quad (7)$$

$$Q_{Rating} = \frac{C_{mean}}{C_{sd}} x\ 100 \quad (8)$$

$$S_i = W_R x Q_{Rating} \quad (9)$$

$$WQI = \sum S_i \quad (10)$$

where; W_R is the relative weight of the parameters, Q_{Rating} is the quality rating, n is the number of parameters under investigation, w_p is the weight of each of the parameters, C_{mean} is the mean concentration of each of the parameters analyzed, C_{sd} is the standard value [Nigerian standard limit for safe drinking water] of the parameter analyzed, and S_i is the sub-index of the *i*th parameter.

The water quality was classified as reported by some studies [29, 30], where WQI < 50 represents excellent water quality, 50 < WQI ≤ 100 means good water quality, 100 < WQI ≤ 200 stands for poor water quality, 200 < WQI ≤ 300 means very poor water quality and WQI > 300 refers to water that is unsuitable for drinking.

3. RESULTS

The Physicochemical quality of the water samples in wet and dry seasons are shown in Tables 2 and 3. The temperature range in both seasons was from 27-30 °C. The mean temperature in the dry season was slightly higher than that observed in the wet season across the study area. pH of samples was acidic (Range 3.40 - 6.23) in both seasons. Conductivity mean values recorded in the wet season ranged from 34.97 - 66.87 µS/cm as against 23.97 - 61.22 µS/cm recorded in the dry season. Mean values of Alkalinity recorded, ranged from 8.63 - 15.92 mg/l in the dry season for sample points in the dumpsites' vicinity while a range of 5.00 - 9.24 mg/l was observed in the wet season.

The contamination factors in Table 4 show very high contamination values for Ni, Pb, and Fe in the range of 5.00 - 52.00, 0.30 - 21.00, and 0.02 - 4.40 respectively, for sampled sites in both wet and dry seasons. Low contamination was observed for Zn in the range of 0.01 - 0.22 except in the control points for wet and dry seasons. Control samples show low contamination for metals except Zn and Ni. Pollution Load index values showed pollution for Nekede and Ihiagwa groundwater samples in the dry seasons (Table 4).

Table 2. Mean values of groundwater physicochemical parameters during the wet season

Samples/ Parameters	FMEnv Standard	WHO	WET SEASON MEAN VALUES ± ST.DEV.			
			OROGWE	NEKEDE	IHIAGWA	CONTROL
Temperature	NS	NS	27.21 ±0.11	28.08±0.12	27.37±0.25	27.27±0.10
pH	6.50-8.50	6.50-8.50	3.40 ±0.74	4.66±0.09	4.65±0.96	5.77±0.12
EC (µS/cm)	1000	1000	66.87 ±5.35	39.41±11.73	40.78±8.01	34.97±0.54
Turbidity (NTU)	5.00	5.00	1.88 ±0.61	0.013±0.01	2.17±0.69	0.01±0.00
DO (mg/l)	>7.50	5.0	1.53±0.03	2.00±0.18	1.51±0.16	5.33±0.19
TDS (mg/l)	500	500	56.42±21.43	68.02 ±45.04	47.00±3.15	42.15±0.83
TSS (mg/l)	<10.00	<10.00	2.92 ±1.54	17.42 ±2.60	5.19±3.29	4.87±2.01
TS (mg/l)	500-1000	500-1000	59.34±22.30	95.50 ±45.30	51.20±4.59	47.02±1.97
T/A (mg/l)	150	100	5.00 ±0.34	5.08±0.32	9.24±2.01	5.56±1.66
Cl (mg/l)	250	250	2.13 ±0.21	2.79 ±1.48	10.82±5.53	1.98±2.67
SO_4^{2-} (mg/l)	100	100	1.17 ±2.34	1.17 ±2.34	1.17±0.00	0.10±0.01
NH_3 (mg/l)	0.30	0.50	0.64 ±0.15	0.74±0.09	0.64 ±0.02	0.67±1.48
NO_3^- (mg/l)	50.00	10	11.62 ±1.83	19.18±2.78	17.15±3.17	0.64±0.37
PO_4^{3-} (mg/l)	5.00	5.0	0.44 ±0.36	7.42±3.00	0.88±0.41	0.67±0.01
Cu (mg/l)	1.00	1.00	0.003±0.00	0.02±0.00	0.01±0.00	0.02±0.00
Ni (mg/l)	0.02	0.1	0.89±0.01	0.45±0.01	1.04±0.02	0.12±0.01
Mn (mg/l)]	0.20	0.40	0.01±0.00	0.02±0.00	0.008±0.00	0.00
Fe (mg/l)	0.30	0.30	0.92±0.01	0.33±0.01	1.15±0.01	0.02±0.00
Pb (mg/l)	0.01	0.05	0.14±0.01	0.003±0.00	0.018±0.00	0.00
Al [mg/l]	0.20	0.20	0.03±0.00	0.02±0.00	0.033±0.00	0.02±0.00
Zn [mg/l]	3.00	5.00	0.13±0.01	0.05±0.00	0.043±0.00	0.06±0.00

T/A = Total Alkalinity

Table 3. Mean values of groundwater physicochemical parameters during the wet season

Samples/ Parameters	FMEnv Standard	WHO	DRY SEASON MEAN VALUES ± ST.DEV.			
			OROGWE	NEKEDE	IHIAGWA	CONTROL
Temperature	NS	NS	29.21 ±0.17	29.15±0.31	28.36±0.75	29±0.09
pH	6.50-8.50	6.50-8.50	6.23±0.29	3.81±0.47	4.19±0.31	6.50±0.08
EC (µS/cm)	1000	1000	61.22±5.88	26.17±6.03	38.5±2.69	23.97±0.33
Turbidity (NTU)	5.00	5.00	6.23±0.31	8.02 ±1.84	8.63±1.77	0.01±0.00
DO (mg/l)	>7.50	5.0	6.17±0.37	6.09 ±0.99	7.24±0.26	7.56±1.67
TDS (mg/l)	500	500	39.80±3.88	44.92±18.88	32.21±1.92	18.05±2.03
TSS (mg/l)	<10.00	<10.00	7.32±1.69	23.58±5.69	8.93±0.44	7.01±0.33
TS (mg/l)	500-1000	500-1000	47.15±5.48	68.47±23.97	41.29±2.11	25.06±1.73
TA (mg/l)	150	100	15.92±8.54	8.63±3.80	8.70±2.85	6.58±2.01
Cl (mg/l)	250	250	26.75±3.76	27.13±4.51	59.86±5.72	27.79±2.78
SO_4^{-2} (mg/l)	100	100	8.80±5.87	0.01±0.00	2.92±2.34	3.67±0.10
NH_3 (mg/l)	0.30	0.50	1.37±1.35	1.69 ±0.36	1.09±0.14	0.56±0.06
NO_3^-(mg/l)	50.00	10	22.33±18.41	20.99±7.46	0.14±0.33	0.92±0.97
PO_4^{3-}(mg/l)	5.00	5.0	0.1±0.14	12.59±0.85	0.40±0.15	0.27±0.01
Cu (mg/l)	1.00	1.00	0.03±0.00	1.16±0.02	1.26±0.03	0.19±0.01
Ni (mg/l)	0.02	0.1	0.11±0.00	0.10±0.01	0.26±0.01	0.00
Mn (mg/l)]	0.20	0.40	0.08±0.00	0.04±0.00	1.14±0.04	0.03±0.00
Fe (mg/l)	0.30	0.30	0.34±0.01	0.30±0.00	1.32±0.02	0.23±0.01
Pb (mg/l)	0.01	0.05	0.06±0.00	0.07±0.00	0.21±0.01	0.04±0.00
Al [mg/l]	0.20	0.20	0.03±0.00	0.00	0.02±0.00	0.00
Zn [mg/l]	3.00	5.00	0.33±0.00	0.57±0.01	0.67±0.01	0.39±0.02

T/A = Total Alkalinity

Table 4. Contamination factor and pollution load of studied metals in groundwater

Sites	Contamination factors							PLI	Remark
	Cu	Ni	Mn	Fe	Pb	Al	Zn		
Orogwe Wet Season	0.003	44.50	0.05	3.07	14.00	0.15	0.04	0.4074	Not Polluted
Orogwe Dry Season	0.03	5.50	0.4	1.13	6.00	0.15	0.11	0.4415	Not Polluted
Nekede Wet Season	0.02	22.50	0.10	1.10	0.30	0.10	0.017	0.2198	Not Polluted
Nekede Dry Season	1.16	5.00	0.20	1.00	7.00	ND	0.19	1.0639	Polluted
Ihiagwa Wet Season	0.01	52.00	0.04	3.83	1.80	0.17	0.014	0.3194	Not Polluted
Ihiagwa Dry Season	1.26	13.00	5.7	4.4	21.00	0.10	0.22	2.1203	Polluted
Control Wet Season	0.01	6.00	ND	0.02	ND	0.10	6.00	0.1099	Not Polluted
Control Dry Season	0.095	ND	0.60	0.23	0.80	ND	39.00	0.4084	Not Polluted

ND = Not Detected

Nickel and iron exposure levels are highest in the wet season, while Copper, Iron, and Zinc are high in the dry season (Tables 5 and 6). The Hazard Index shows high to medium risks for water consumption, with Fe, Ni, and Pb being major contributors (Figures 1 and 2). Lead carcinogenic risk is within the standard limit by USEPA, except in Ihiagwa (Figures 3 and 4).

The water quality index (Table 7) shows increased pollution during the wet season, with poor quality (>100) observed near dumpsites, while good quality (<100) was observed at the control point in both seasons.

4. DISCUSSION

From the physicochemical results in Tables 2 and 3, the observed slight increase in groundwater temperature trend in the dry season is assumed to be a consequent effect of the hotter temperature associated with dry seasons. Fluctuations can also exist, depending on the period of the day sampling was carried out. The temperature results were within the WHO and NSDWQ acceptable range. Similar results were obtained in a study of groundwater quality near landfills in Kumasi, Ghana [30]. pH across the sampled sites showed high acidity especially in the wet season below the benchmark by WHO and NSDWQ. The decrease in pH in the wet season may be as a result of infiltration of acidic leachate into groundwater as percolation increases in the wet season. The observed pH levels were similar to those obtained in a study of groundwater quality in Owerri [15]. The bedrock composition and shallow depth of wells may be contributing factors to the low pH of groundwater. Acidity affects the dissolution of solids and makes water sources vulnerable to heavy metal pollution and unsafe for consumption [28].

Table 5. Exposure dose (mg/kg BWd) to heavy metals at different locations for adults and children

Wet Season								
Sample Sites	Metals							Mean
	Cu	Ni	Mn	Fe	Pb	Al	Zn	
Orogwe (Adult)	0.000107	0.0318	0.000357	0.0329	0.0050	0.00107	0.00464	0.010839
Orogwe (Children)	0.00025	0.0742	0.000833	0.0767	0.0117	0.0025	0.0108	0.025283
Nekede (Adult)	0.000714	0.0161	0.000714	0.0118	0.000107	0.000714	0.00179	0.004563
Nekede (Children)	0.00167	0.0375	0.00167	0.0275	0.00025	0.00167	0.00417	0.010633
Ihiagwa (Adult)	0.00035	0.0371	0.000286	0.0411	0.000643	0.00118	0.00154	0.011743
Ihiagwa(Children)	0.000833	0.0867	0.000667	0.0958	0.0015	0.00275	0.00358	0.027404
Control (Adult)	0.000714	0.00427	0.00	0.000714	0.00	0.000714	0.002143	0.001222
Control (Children)	0.00167	0.01	0.00	0.00167	0.00	0.00167	0.005	0.002859
Dry Season								
Sample Site	Metals							Mean
	Cu	Ni	Mn	Fe	Pb	Al	Zn	
Orogwe (Adult)	0.00107	0.00393	0.00286	0.0121	0.00214	0.00107	0.0118	0.004996
Orogwe (Children)	0.0025	0.00917	0.00667	0.0283	0.005	0.0025	0.0275	0.011663
Nekede (Adult)	0.0414	0.00357	0.00143	0.0107	0.0025	0.00	0.0204	0.011429
Nekede (Children)	0.0967	0.00833	0.00333	0.025	0.00583	0.00	0.0475	0.02667
Ihiagwa (Adult)	0.045	0.00929	0.0407	0.0471	0.0075	0.000714	0.0239	0.024886
Ihiagwa(Children)	0.105	0.0217	0.095	0.11	0.0175	0.00167	0.0558	0.058096
Control (Adult)	0.006786	0.00	0.001071	0.008214	0.001429	0.00	0.013929	0.00449
Control (Children)	0.015833	0.00	0.0025	0.019167	0.003333	0.00	0.0325	0.010476

Table 6. HQ and HI (mg/kg) of the heavy metals at different locations for adults and children

Wet Season									
Sample Sites	Population Groups	Metals							ΣHQ
		Cu	Ni	Mn	Fe	Pb	Al	Zn	H1
	Reference dose	0.04	0.02	0.14	0.007	0.0035	NA	0.3	
Orogwe	*Adult*	0.00268	1.59	0.00255	4.70	1.43	NA	0.0155	7.74073
	Children	0.00625	3.71	0.00595	11	3.34	NA	0.036	18.0982
Nekede	*Adult*	0.0179	0.805	0.0051	1.69	0.0306	NA	0.00597	2.55457
	Children	0.0418	1.88	0.0119	3.93	0.0714	NA	0.0139	5.949
Ihiagwa	*Adult*	0.00893	1.86	0.00204	5.87	0.184	NA	0.00513	7.9301
	Children	0.0208	4.34	0.00476	13.7	0.429	NA	0.0119	18.50646
Control	*Adult*	0.0179	0.214	0.00	0.102	0.00	NA	0.00714	0.3413
	Children	0.0417	0.50	0.00	0.238	0.00	NA	0.0167	0.796485
Dry Season									
Sample Site	Population Groups	Metals							ΣHQ
		Cu	Ni	Mn	Fe	Pb	Al	Zn	HI
Orogwe	*Adult*	0.0268	0.197	0.0204	1.73	0.611	NA	0.0393	2.6245
	Children	0.0625	0.459	0.0476	4.04	1.43	NA	0.0917	6.1308
Nekede	*Adult*	1.04	0.179	0.0102	1.53	0.714	NA	0.068	3.5412
	Children	2.42	0.417	0.0238	3.57	1.67	NA	0.158	8.2588
Ihiagwa	*Adult*	1.13	0.465	0.291	6.73	2.14	NA	0.0797	10.8357
	Children	2.63	1.09	0.679	15.7	5.00	NA	0.186	25.285
Control	*Adult*	0.17	0.00	0.00765	1.17	0.408	NA	0.0464	1.8054
	Children	0.40	0.00	0.0179	2.74	0.952	NA	0.108	4.21244

NA = Not Available

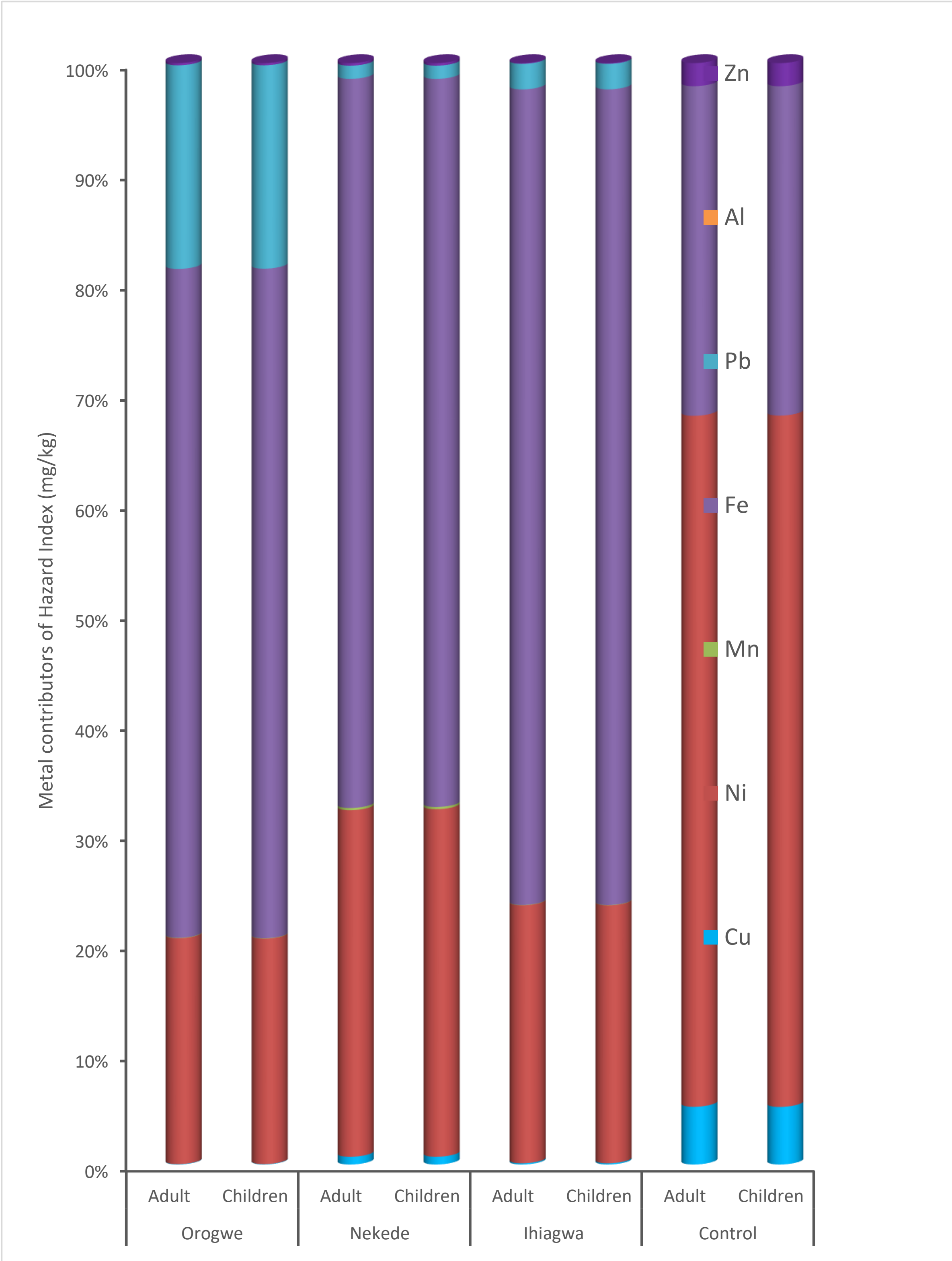

Figure 1. Metal contributors to hazard index in the wet season

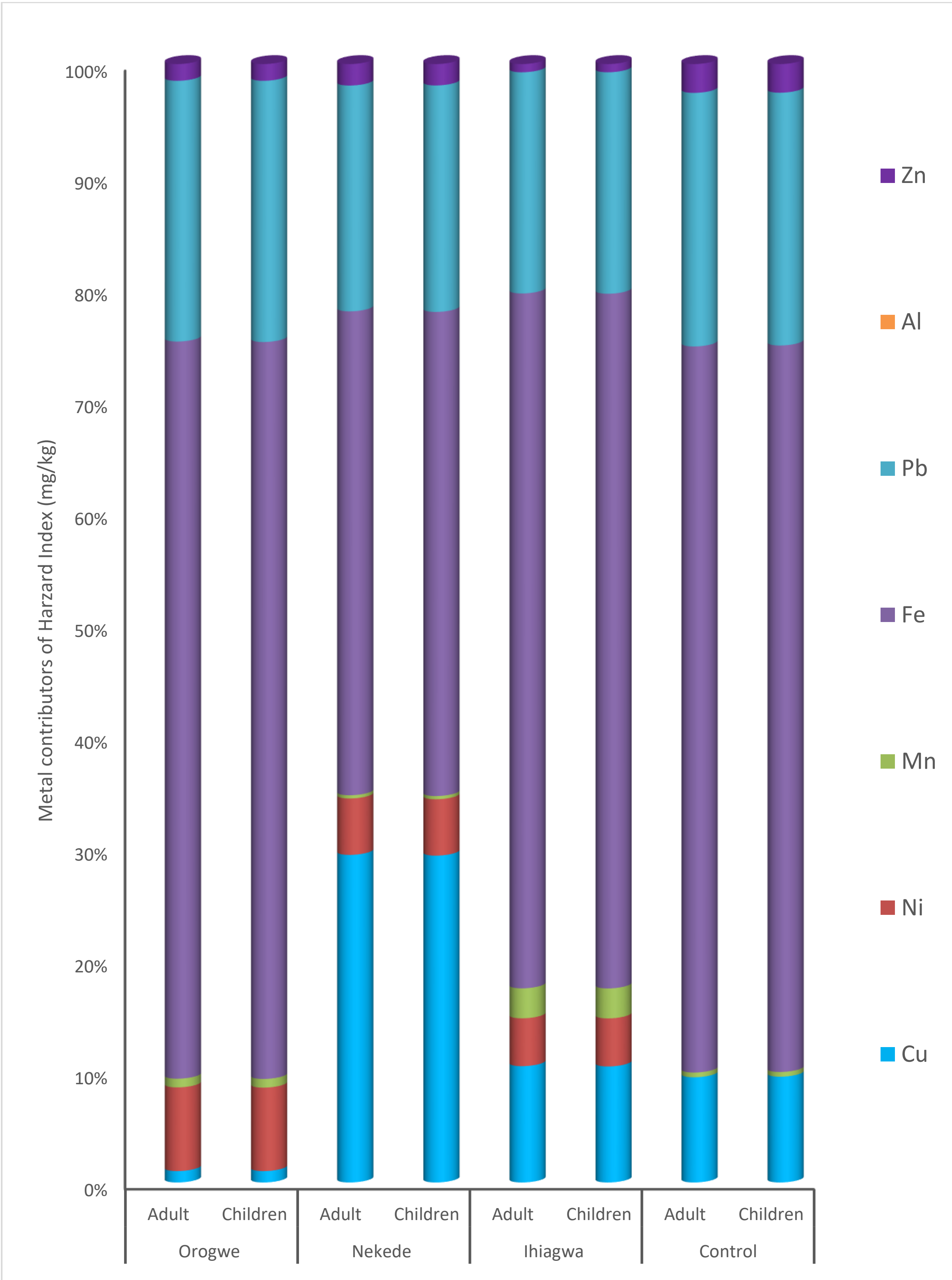

Figure 2. Metal contributors to hazard index in the dry season

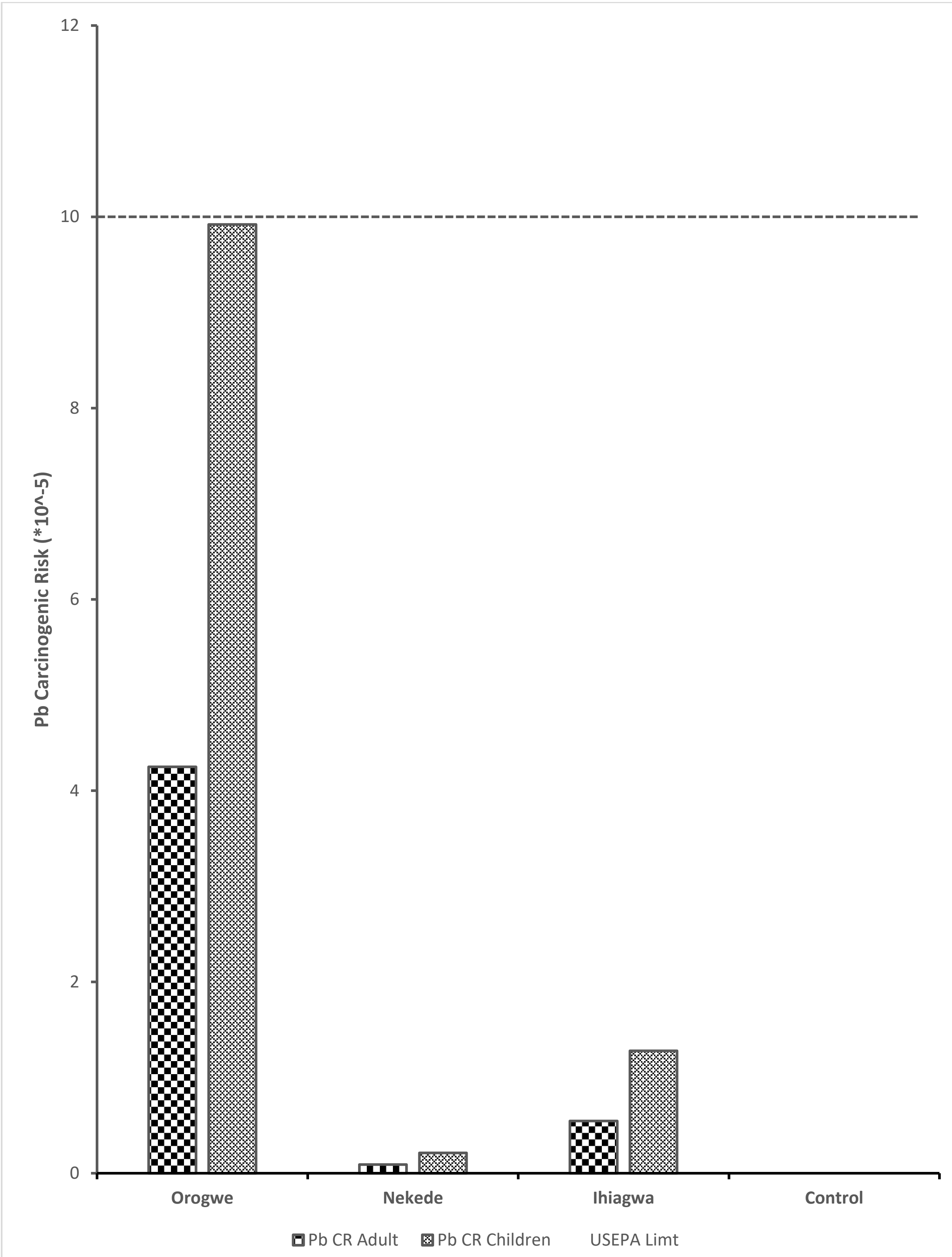

Figure 3. Carcinogenic risk of lead in the wet season

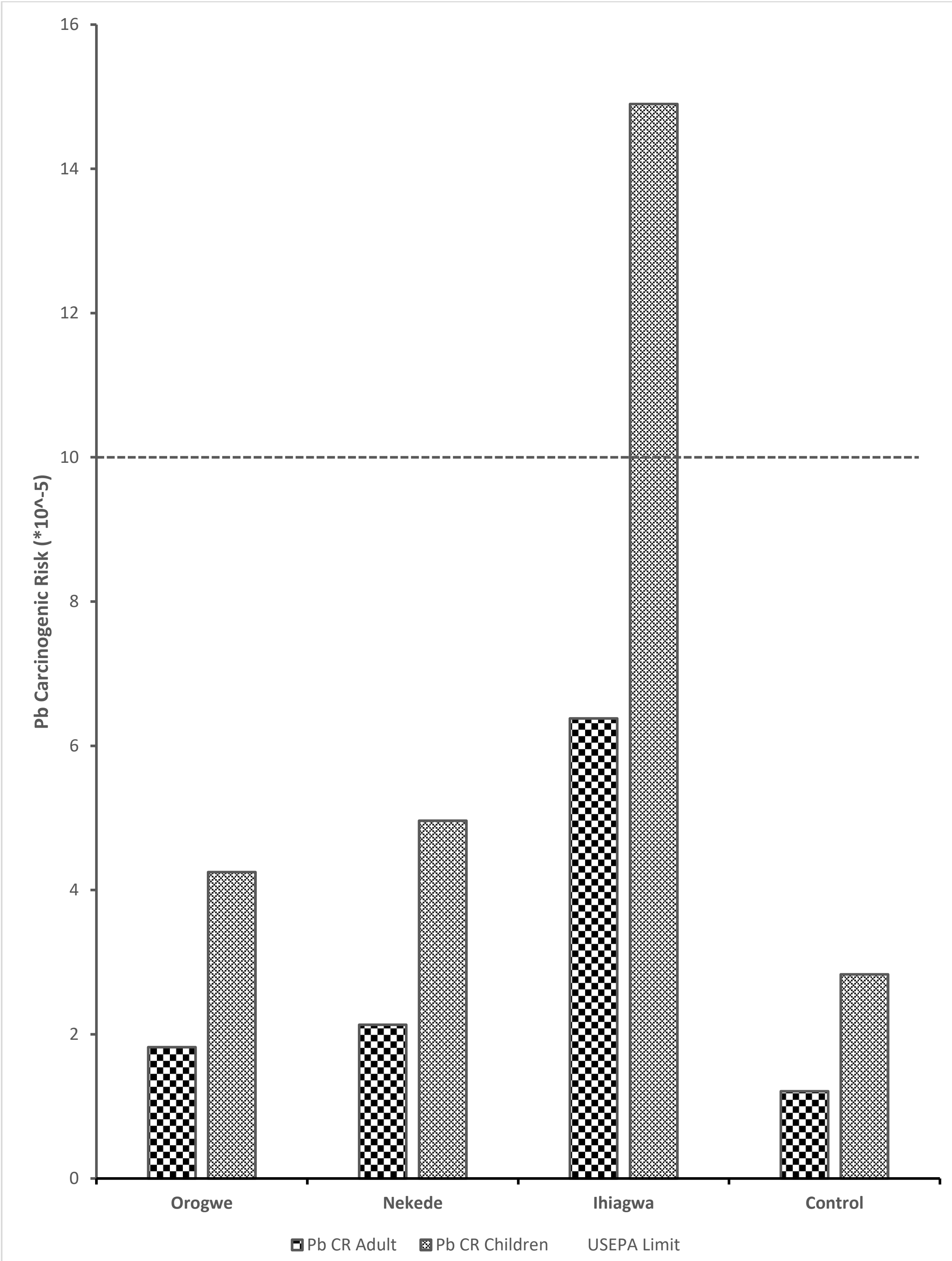

Figure 4. Carcinogenic risk of lead in the dry season

Table 7. Estimation of WQI of the sampled groundwater sources in wet and dry seasons

Parameters			$W_R \, x \, Q_{Rating}$							
			Wet Season				Dry Season			
	C_s	w_p	Orogwe	Nekede	Ihiagwa	Control	Orogwe	Nekede	Ihiagwa	Control
pH	7.50	4	2.833	3.883	3.875	4.808	5.608	3.175	3.492	5.417
EC	1000	4	0.418	0.246	0.255	0.219	0.383	0.164	0.241	0.150
Turbidity	10	1	0.588	0.004	0.678	0.003	1.947	2.506	2.697	0.003
DO	7.50	1	0.319	0.417	0.315	1.110	1.285	1.269	1.508	1.575
TDS	500	4	0.705	0.850	0.588	0.527	0.498	0.562	0.403	0.226
TSS	10	1	0.456	2.722	0.811	0.761	1.144	3.684	1.395	1.095
TS	500	1	0.185	0.298	0.160	0.147	0.147	0.214	0.129	0.078
TA	150	1	0.052	0.053	0.096	0.058	0.166	0.090	0.091	0.069
Cl	250	1	0.013	0.017	0.068	0.012	0.167	0.170	0.374	0.174
SO_4^{2-}	100	5	0.091	0.091	0.091	0.008	0.688	0.001	0.228	0.287
NH_3	0.30	4	13.333	15.417	13.333	13.958	28.542	35.208	22.708	11.667
NO_3^-	50.00	5	1.816	2.997	2.680	0.100	3.489	3.280	0.022	0.144
PO_4^{3-}	5.00	5	0.688	11.594	1.375	1.047	0.156	19.672	0.625	0.422
Cu	1.00	3	0.014	0.094	0.047	0.094	0.141	5.438	5.906	0.891
Ni	0.02	4	278.125	140.625	325.000	37.500	34.375	31.250	81.250	0.000
Mn	0.20	4	0.313	0.625	0.250	0.000	2.500	1.250	35.625	0.938
Fe	0.30	3	14.375	5.156	17.969	0.313	5.313	4.688	20.625	3.594
Pb	0.01	5	109.375	2.344	14.063	0.000	46.875	54.688	164.063	31.250
Al	0.20	4	0.938	0.625	1.031	0.625	0.938	0.000	0.625	0.000
Zn	3.00	3	0.203	0.078	0.067	0.094	0.516	0.891	1.047	0.609
$\sum w_p$		64								
WQI			424.840	188.137	382.751	61.384	134.876	168.197	343.053	58.586

The electrical conductivity values were higher in the wet season than the dry season for all the sampled groundwater, but within WHO limit for drinking water quality. Higher conductivities in the result can be attributed to the seepage and accumulation of leachate anions and cations. High conductivity has no obvious effects on health; however, excess conductivity has a detrimental influence on water quality since it leads to an increase in contaminants. The results were consistent with the findings of Oki and Ombu [31].

Elevated TDS values in the wet season from the study area can result from the infiltration of leachate from the dumpsite to the groundwater, the porosity and solubility of the bedrock components, and the depth of the aquifer [21]. Additionally, Unlined dump sites may result in a rise in the TDS levels in the groundwater around their vicinity. However, all sampled groundwater in both seasons was within the WHO recommended standard (500 mg/l) for portable water.

Total Dissolved Solids (TDS), Total Chloride (Cl), Nitrate (NO_3^-) and phosphate (PO_4^{2-}) mean concentrations were within standard limits in the wet and dry season across the study area. Also, higher mean levels of ammonia (NH_3) above the standard limit were observed in the dry season for sample points around dumpsites.

The high pollution Load Index (PLI>1) at Ihiagwa and Nekede in the dry season, is an indication of pollution of the groundwater sources by metallic elements. This could be associated with the shallow depth of aquifers and the porous nature of the soil in the study area which could allow easy penetration of contaminants from the waste dump sites and the acidic pH of groundwater [15, 28].

The high contamination factors and hazard quotient recorded for nickel, lead, and iron across the study areas may suggest corrosion of metal scraps and batteries disposed of in the dumpsites and their infiltration to the freshwater aquifer since the control was not polluted based on the result. Also, bedrock composition could influence metal concentration in groundwater. This may have resulted in elevated HQ values (>1) and suggests that the prolonged consumption of this groundwater can result in serious health effects for adults and children.

The non-carcinogenic risks and carcinogenic risks were higher in children than in adults from the result. This suggests that children are more susceptible to hazard risks of consumption of contaminated water sources since their immune system, nervous system, and digestive system are still developing. Exposure to heavy metals can cause chronic neurological disorders in children at this developmental stage because of their high sensitivity to metal toxicity on exposure to products with elevated metal concentrations. Especially at Ihiagwa in the dry season where the carcinogenic risk is above the USEPA limit ($1.0E^{-4}$) for children in that area [16, 28]. High cumulative exposure doses of all studied metals and low carcinogenic risk of lead for adults in drinking water sources might not be encouraging as a study posits that short time but reasonable dose exposure to heavy metals may not be the only cause of cancer but persistent low dose exposure possibly plays key roles in tumor formation. This can be particularly dangerous for the aged as reports of cognitive reduction with osteoporotic effects are associated with the presence of lead in the bloodstream [13]. This development calls for concern and poses health risks to the inhabitants whose primary water source is groundwater if it becomes contaminated by its proximity to unsanitary solid waste dumps.

The result in Table 7 shows that all the sampled groundwater sources near dumpsites were of poor and very poor quality according to the WQI classification. This suggests that the analyzed groundwater sources are unsuitable for human consumption and will require some level of purification before usage. The observed very poor quality of the analyzed water samples could be attributed to the nearness of the water sources to waste dump sites [15]. High levels of nickel, lead, and iron contributed greatly to the reduction of groundwater quality in both seasons. The observed elevated metal ion levels of the groundwater sources could be attributable to the low pH. In general, groundwater quality was observed to be more polluted in the wet season than in the dry season.

There could be uncertainties in the result arising from limitations in the estimation of daily dose and body weights of individuals as adults in the area most likely weigh more than 70 kg and consume more water. Also, the water quality estimated was only inclusive of some investigated parameters.

5. CONCLUSION

According to the study, the infiltration of leachate, which increases during the wet season, could affect groundwater sources near dumpsites. Also, the disposal of metal scraps, batteries, and spoilt electronic parts alongside organic waste in dumpsites contributed to elevated metal concentration. The protection of groundwater calls for effective waste management in the area. Consumption of water from these sources poses a health risk, especially for vulnerable populations, and immediate remediation and treatment is needed.

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