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Occurrence and risk assessment of phenolic endocrine disrupting chemicals in shallow groundwater resource from selected Nigerian rural settlements

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Abstract. To date, limited information exists on the distribution of endocrine disrupting compounds in groundwater resources from African rural settlements. In view of this knowledge gap, the present study investigated the concentrations and potential health risks of phenolic endocrine disrupting chemicals (EDCs) in underground water samples obtained from eight rural settlements in Nigeria, West Africa. The water samples were obtained from domestic drinkable communal wells at Anambra (Mgbaukwu and Umudioka), Lagos (Bariga, Itire and Mushin), and Delta (Agbarho, Ikweghwu and Orhokpokpor) states representing the South-East, South-West and South-South Nigeria respectively. Samples were analyzed for 10 selected chlorinated, nitrogen-containing and alkyl phenolic compounds using gas chromatography coupled with flame ionization detector technique. At all understudied sites, selected phenolic compounds with the exception of 2-chlorophenol which was below detectable limits at 4 sites (Agbarho, Mgbaukwu, Umudioka site 1 and Mushin) were detected. The concentrations of the phenolic compounds in the samples from the different sites ranged between below detectable limits to 0.0904 ppm. Nonylphenol, 2,4-dinitrophenol and 2,4,6-trichlorophenol were predominant at EDCs in most sites when compared with the other phenolic contaminants. The calculated chronic daily intake (CDI) results for the exposed populations at the communities implies that the level of occurrence and daily intake of 2-nitrophenol, 2,4-dimethylphenol, 4-nitrophenol, 2-chlorophenol and bisphenol A were still below their respective oral reference doses. Nonylphenol and 2,4,6-trichlorophenol (risk quotient, RQ > 1) were identified as the major EDC contributors to potential health risk for exposed populations at the communities.

Keywords: endocrine disrupting chemicals, phenolic compounds, water, risk assessment.

1. Introduction

Endocrine disrupting compounds (EDCs) have been the subject of critical research interest in the last three decades because they have been reported to interfere with the normal functioning of the endocrine system and cause a wide range of health issues from growth and developmental disorders [1], abnormalities in sex organs [2], endometriosis [3], respiratory issues to metabolic and neurological problems [4]. Most of these chemical compounds are used in the industries for the production of pesticides, cosmetics, personal care products, plastics, pharmaceuticals, etc. These chemicals have the potential of leaching into various ground waters, surface water bodies, air and soil and eventually make their way into the human endocrine system where they cause harm [5].

Phenolic compounds are among the several endocrine disrupting compound which has attracted the interest of the scientific community due to its increasing production and consumption rates. 4-nonylphenol (NP), 4-*t*-octylphenol (OP) and bisphenol A (BPA) are among the most frequently reported and ecotoxicologically significant EDC's in Nigeria [6 - 9]. BPA is used in epoxy resin and polycarbonate plastics in food and drink packaging [10]. OP and NP are used as precursors to produce non-ionic surfactants [11].

Currently, the pollution of the global water cycle with persistent organic contaminants remains one of the major challenges of the 21st century. The majority of these organic substances are only partially removed by conventional wastewater treatment plants. Many of these contaminants escape into the environment and spread across different ecological compartments thus increasing the exposure risk of citizens [12, 13]. In developing countries like Nigeria, many rural communities depend on shallow groundwater sources for domestic water use. While groundwater is considered the most resilient source of drinking water across much of Africa, improper management of household and agricultural waste in rural areas is a growing concern [14]. There is very little information on studies monitoring the levels of micro-organic pollutants in African groundwater systems. Where such studies have been conducted, the focus has been on the urban areas.

Regulation of endocrine disrupting compounds is still at its infant stage in many African countries [15, 16]. There is urgent need for consistent monitoring and strict regulatory frame work by environment protection agencies to formulate laws in order to reduce the level of environmental pollution by these organic pollutants in rural as well as urban areas. Considering the scarcity

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of data on the occurrence and potential health risks of phenolic EDCs in shallow groundwater from Nigerian rural areas, this study aimed to monitor phenolic compounds in drinking well water samples obtained from selected rural settlements located in three Nigerian states (Delta, Lagos and Anambra) to ascertain the levels of concentration and possible health implications.

2. Experimental

2.1. Description of study locations (Delta, Lagos and Anambra states)

Three rural settlements (Agbarho, Ikweghwu and Orhokpokpor) located in Ughelli North local government area of Delta state, South-south Nigeria were selected for this study. Ughelli North is one of the oil producing locations in the state, and farming is the predominant occupation for the dwellers. Several oil spillages have been reported in this region, with the recent one which occurred in Warri North council area in 2018, which within 112 km away from the study area [17]. In Lagos state South-west Nigeria, Mushin, Itire and Bariga were selected as study locations. Lagos is the major hub of industrial and commercial activities in Nigeria and the largest city in West Africa. Mgbakwu and Umudioka rural settlements located in Anambra, South East Nigeria. These villages have smaller population size compared to the other study areas. Farming is the major preoccupation of the people. In all the eight communities selected (Table 1), the populace relies majorly on shallow groundwater for domestic use.

Table 1. Location of sampling sites.

	Site	State	Latitude	Longitude
1	Agbarho	Delta	05º47' N	05º52' E
2	Ikweghwu	Delta	05º 34' N	05º 53' E
3	Orhokpokpo	Delta	05º 36' N	05º 51' E
4	Mushin	Lagos	06º31' N	03º21' E
5	Itire	Lagos	06º 30' N	03º 19' E
6	Bariga	Lagos	06º 32' N	03º 51' E
7	Umudioka	Anambra	06º 13' N	07º 3' E
8	Mgbakwu	Anambra	06º 16' N	07º 3' E

2.2. Sample collection

Between June and July 2019, a total 8 shallow groundwater samples were collected. Samples were collected from the eight selected study areas. The samples were isolated from insect repellants, pharmaceutical products, colognes and other personal care products to avoid possible incidence of contaminations. All 8 samples were collected in a pre-cleaned glass bottle and immediately transported in a cooler box with ice chests to the laboratory for analysis.

2.3. Materials

Except specified all reagents used in this study are of analytical grade purchased from Sigma Aldrich, UK.

2.4. Sample extraction, clean-up and GC-FID analysis

Liquid-liquid extraction technique was performed based on a slightly modified work [28]. 100 mL of each sample was measured into a separatory funnel and 2 mL of concentrated sulfuric acid (H_2SO_4) was added to the measured sample.

Another 50 mL of acetone (CH_3COCH_3) was added, shaken and vented for five minutes. The sample was allowed to separate into organic and aqueous layer. Then the organic layer was immediately transferred into a rotary evaporator and concentrated to 2 mL. Activated sodium sulfate (Na_2SO_4) was used to clean up the extract in a packed column and was concentrated to 1 mL, and 1 µL of the clean extract was injected into the Gas chromatograph - Flame Ionization Detector (GC/FID, Varian CP3800) for the separation of the phenol components in the column. Standard stock solutions of 4-nonylphenol (Sigma) and EPA 604-M phenols were prepared in methanol from pure analytical standards (Sigma-Aldrich).

The analytes were detected using the GC/FID peak identification software. The detection was enabled by identification of the appropriate retention time window for each compound in the calibration solutions. The quantification of the phenolic compounds of interest was possible from analytical calibration curves and the limits of detection for each analyte obtained according to the published procedure [8, 29]. The limits of detection (g/L) are as follows: 2-chlorophenol 0.041; 2-nitrophenol 0.044; 2,4-dimethylphenol 0.034; 2,4-dichlorophenol 0.046; 4-chloro-3-methyl phenol 0.042; 2,4,6-trichlorophenol 0.024, 2,4-dinitrophenol 0.22, 4-nitrophenol 0.18; bisphenol A 0.001; nonylphenol 0.002.

2.5. Chromatographic conditions

Split less mode injection method was deployed and DB-5 ms capillary chromatographic columns of 30 m × 0.25 mm (inner diameter) × 0.25 µm (film thickness) was used. The injection port temperature was maintained at 260 ºC, while the column temperature was initially set at 100 ºC for 3 min, and was later increased to 270 ºC at 10 ºC/min interval, and maintained for 2 min; it was finally increased to 300 ºC at 10 ºC/min intervals and maintained for 2 min. The detector temperature was 280 ºC. The carrier gas was hydrogen while the make-up gas was air with flow rate of 10 mL/min.

2.6. Human health risk assessment

For the assessment of health risks through oral ingestion of the phenolic endocrine disrupting compounds in the drinking water, the chronic daily intake (CDI) and risk quotient (RQ) for each of the phenolic EDCs were calculated using the following mathematical relationships [18]:

$$\text{CDI} = \frac{Cn \times IR}{BW} \quad (1)$$

where *Cn* (mg/L) represents the concentration of each EDC in the water sample at test site; BW represents the average body weight (kg) assumed to 70 kg for an adult and 10 kg for a child; IR is the drinking water ingestion rate (L/day) (assumed to be 1 and 2 for children and adults respectively);

$$\text{RQ} = \frac{Cn}{DWEL} \quad (2)$$

where DWEL is the Drinking Water Equivalent Level [19].

$$\text{DWEL} = \frac{(ADI \times BW \times HQ)}{(DWI \times AB \times FOE)} \quad (3)$$

where *ADI* is the acceptable daily intake (mg/kg/day); *HQ* is the hazard quotient, assumed to be 1; *DWI* indicates the drinking water intake (L/day); DWI rate of 1 L/day for infants and children (< 10 years of age) ad 2 L/day for adults (≥ 10 years of age) was assumed. AB is the gastrointestinal absorption rate, assumed to be 1, and FOE represents the frequency of exposure (days/365 days), assumed to be 0.96 (350 days/365 days = 0.96) [20, 21].

An RQ value of > 1 indicates there is a potential health risk to those exposed.

Table 2. Estimated drinking water equivalent derivatives for the selected phenolic endocrine disruptors for risk quotient evaluation in the study [19, 21].

Phenolic EDCs	Acceptable daily intake (mg/kg/day)	Drinking Water Equivalent Level (mg/L)	
		adult	child
2-nitrophenol	0.008	0.292	0.083
2,4-dimethylphenol	0.02	0.729	0.208
2,4-dichlorophenol	0.003	0.109	0.031
4-chloro-3-methylphenol	NA	ID	ID
2,4,6-trichlorophenol	0.0003	0.011	0.003
2,4-dinitrophenol	0.002	0.073	0.208
4-nitrophenol	20	729.167	208.333
Nonylphenol	0.0005	0.002	0.005
Bisphenol A (BPA)	0.05	1.823	0.521
2-chlorophenol	0.005	0.182	0.052

NA- no available data
ID- Insufficient data to derive value

3. Results and discussion

3.1. Levels and distribution of phenolic EDCs in the shallow groundwater samples

The concentrations and distribution of phenolic EDC's in the various well water samples from the eight communities in this study are presented in Tables 3 to 5. The frequency of detection was 50% for 2-chlorophenol and 100% for the other phenolic contaminants in the shallow groundwater samples. The results from Table 3 showed that the concentrations of the phenolic compounds ranged from below detectable limits to 0.0904 ppm in the samples from the Delta study location. Nonylphenol (0.0903 ppm), 2,4,6-trichlorophenol (0.0904 ppm) and 2-nitrophenol (0.0087 ppm) were the predominant EDCs in the samples from Agbarho, Ikweghwu and Orhokpokpor villages respectively. The high levels of 2-nitrophenol and 2,4,6-trichlorophenol in the water source could be attributed to the agricultural activities and the usage of pesticides by the local resource farmers in this community who majorly cultivate cassava and fluted pumpkins. These pesticides leach through the soils into the ground water over time. The incessant use of pesticides for agricultural purposes has led to the increased level of organic pollution in the soil, water and air [22]. Nonylphenol has attracted attention due to its prevalence in the environment and its potential role as an endocrine disruptor and xenoestrogen, due to its ability to act with estrogen-like activity. It functions as a primary intermediate in the production of the non-ionic surfactants, nonylphenol exthoxylates used in the production of pesticides, paints and personal care products. The ground water samples investigated at some sites in the Hamdan city of western Iran revealed that nonylphenol and bisphenol A were found to be in the ranges of 0.001 ng/L to 0.9 ng/L [23]. Samples from Mgbaukwu and Umudioka (Table 4) did not yield 2-chlorophenol in detectable levels. 4-nitrophenol was the highest occurring phenolic contaminant with values of 0.0774 ppm and 0.2040 ppm at Mgbaukwu and Umudioka respectively. 4-Nitrophenol is an intermediate in the synthesis of paracetamol. It is also used as the precursor for the preparation of phenetidine and acetophenetidine, which serve as indicators, and raw materials for fungicides [24]. Human exposure to 4-nitrophenol can result to irritation of the skin, eyes and the gastrointestinal tract [25].

At the three study sites from Lagos, 2,4-dinitrophenol (0.0554 ppm), 2-nitrophenol (0.0077 ppm) and 2,4-dichlorophenol (0.0111 ppm) were the phenolic contaminants with the highest concentration in the groundwater from Mushin, Itire and Bariga sites respectively. Nonylphenol (0.0409 ppm) was the second predominant phenolic contaminant at the Mushin site. Other phenolic EDCs were at much lower concentrations in Itire and Bariga sites. Agricultural activities are almost nonexistent in the rural areas of Lagos state due to increased urbanization. So the presence of these phenolic contaminants can be attributed to the heavy industrial presence scattered all around Lagos and its environs. Some of these industries makes use of phenols and its derivatives in the production of various items. Lagos is the major commercial hub in Nigeria. Phenols are known to be released in the air via its production and use in phenolic resins and organic synthesis which eventually settle on soil surfaces and leach into underground water. A similar study [26] at some underground water sites in Aurangabad city in India revealed much lower concentrations of 4-nitrophenol, 4-chloro-3-methylphenol, 2-chlorophenol, 2,4-dinitrophenol and 2,4,6-trichlorophenols and the values ranged from 3 ng/L to 17 ng/L when compared to the present study. In the light of the present result, it is suggested that proper measures for the management of agricultural and industrial wastes be adopted to preserve the groundwater resource especially in rural areas.

Table 3. Concentrations (ppm) of selected phenolic contaminants in underground well water samples collected from Agbarho, Ikweghwu and Orhokpokpor villages in Delta state.

Sample sites/ Contaminants	Agbarho	Ikweghwu	Orhokpokpor
2-nitrophenol	0.0257	0.0125	0.0087
2,4-dimethylphenol	0.0258	0.0239	0.0001
2,4-dichlorophenol	0.0251	0.0492	0.0084
4-chloro-3-methylphenol	0.0267	0.0559	0.0000
2,4,6-trichlorophenol	0.0194	0.0904	0.0002
2,4-dinitrophenol	0.0870	0.0231	0.0037
4-nitrophenol	0.0185	0.0224	0.0002
Nonylphenol	0.0903	0.0213	0.0001

Sample sites/ Contaminants	Agbarho	Ikweghwu	Orhokpokpor
Bisphenol A (BPA)	0.0810	0.0032	0.0027
2-chlorophenol	BDL	0.0046	0.0009

BDL=below detectable limit.

Table 4. Concentrations (ppm) of phenolic contaminants in underground well water samples collected from Mgbaukwu, and Umdioka villages in Anambra state.

Sample sites/ Contaminants	Mgbaukwu	Umudioka
2-nitrophenol	0.0111	0.0106
2,4-dimethylphenol	0.0248	0.0130
2,4-dichlorophenol	0.0205	0.0189
4-chloro-3-methylphenol	0.0231	0.0265
2,4,6-trichlorophenol	0.0739	0.0493
2,4-dinitrophenol	0.0509	0.0478
4-nitrophenol	0.0774	0.2040
Nonylphenol	0.0570	0.0037
Bisphenol A (BPA)	0.0122	0.0118
2-chlorophenol	BDL	BDL

BDL= below detectable limit

Table 5. Concentrations (ppm) of phenolic contaminants in underground well water samples collected from Mushin, Itire and Bariga villages in Lagos state.

Sample Sites/ Contaminants	Mushin	Itire	Bariga
2-nitrophenol	0.0188	0.0077	0.0003
2,4-dimethylphenol	0.0248	0.0004	0.0001
2,4-dichlorophenol	0.0201	0.0056	0.0111
4-chloro-3-methylphenol	0.0222	0.0012	0.0001
2,4,6-trichlorophenol	0.0336	0.0003	0.0001
2,4-dinitrophenol	0.0554	0.0072	0.0042
4-nitrophenol	0.0360	0.0006	0.0002
Nonylphenol	0.0409	0.0001	0.0002
Bisphenol A (BPA)	0.0084	0.0018	0.0004
2-chlorophenol	BDL	0.0012	0.0019

BDL= below detectable limit

3.2. Human Health risk assessment of the phenolic EDCs

Tables 6-8 show the CDI via oral exposure for children and adult populations of the eight selected communities in the study. The calculated CDI results for the exposed populations at the communities implies that the level of occurrence and daily intake of 2-nitrophenol, 2,4-dimethylphenol, 4-nitrophenol, 2-chlorophenol and bisphenol A were still below their respective oral reference doses [21]. CDI values ranged from BDL to 0.02040 and BDL to 0.00258 mg/kg/day for children and adult populations respectively. For the adult population, nonylphenol (0.00258), 2,4,6-trichlorophenol (0.00258), 2-nitrophenol (0.00025), 4-nitrophenol (0.00221), 2,4-dinitrophenol (0.00158), 4-nitrophenol (0.00538), 2-nitrophenol (0.00022), 2,4-dichlorophenol (0.00032) had the highest CDI among the selected phenolic contaminants in the groundwater from Agbarho, Ikweghe, Orhokpokpo, Mgbaukwu, Mushin, Umudioka, Itire and Bariga communities respectively. Higher CDI values were observed for children. This is a future health concern as children have longer exposure duration [18].

Table 6. Chronic daily intake (CDI) for Agbarho, Ikweghe and Orhokpokpo communities.

Phenolic EDCs	Agbarho		Ikweghe		Orhokpokpor	
	child	adult	child	adult	child	adult
2-nitrophenol	0.00257	0.00073	0.00125	0.00036	0.00870	0.00025
2,4-dimethylphenol	0.00258	0.00074	0.00239	0.00068	0.00001	0.00000
2,4-dichlorophenol	0.00251	0.00072	0.00492	0.00141	0.00084	0.00024
4-chloro-3-methylphenol	0.00267	0.00076	0.00559	0.00160	0.00001	0.00001
2,4,6-trichlorophenol	0.00194	0.00055	0.00904	0.00258	0.00002	0.00001
2,4-dinitrophenol	0.00870	0.00249	0.00231	0.00066	0.00037	0.00012
4-nitrophenol	0.00185	0.00053	0.00224	0.00064	0.00002	0.00001
Nonylphenol	0.00903	0.00258	0.00213	0.00061	0.00001	0.00001
Bisphenol A	0.00810	0.00231	0.00032	0.00009	0.00027	0.00008
2-chlorophenol	BDL	BDL	0.00046	0.00013	0.00009	0.00003

Table 7. Chronic daily intake (CDI) for Mgbaukwu and Umudioka communities.

Phenolic EDCs	Mgbakwu		Umudioka	
	child	adult	child	adult
2-nitrophenol	0.00111	0.00032	0.00106	0.00030
2,4-dimethylphenol	0.00248	0.00071	0.00130	0.00037
2,4-dichlorophenol	0.00205	0.00059	0.00189	0.00054
4-chloro-3-methylphenol	0.00231	0.00066	0.00265	0.00076
2,4,6-trichlorophenol	0.00739	0.00211	0.00493	0.00141
2,4-dinitrophenol	0.00509	0.00145	0.00479	0.00137
4-nitrophenol	0.00774	0.00221	0.02040	0.00583
Nonylphenol	0.00570	0.00163	0.00037	0.00011
Bisphenol A	0.00122	0.00035	0.00118	0.00034
2-chlorophenol	BDL	BDL	BDL	BDL

Table 8. Chronic daily intake (CDI) for Mushin, Itire and Bariga communities.

Phenolic EDCs	Mushin		Itire		Bariga	
	child	adult	child	adult	child	adult
2-nitrophenol	0.00188	0.00054	0.00077	0.00022	0.00003	0.00001
2,4-dinitrophenol	0.00248	0.00071	0.00004	0.00001	0.00001	0.00001
2,4-dichlorophenol	0.00201	0.00057	0.00056	0.00016	0.00111	0.00032

Phenolic EDCs	Mushin		Itire		Bariga	
	child	adult	child	adult	child	adult
4-chloro-3-methylphenol	0.00222	0.00063	0.00012	0.00003	0.00001	0.00001
2,4,6-trichlorophenol	0.00336	0.00096	0.00003	0.00001	0.00001	0.00001
2,4-dinitrophenol	0.00554	0.00158	0.00072	0.00021	0.00042	0.00012
4-nitrophenol	0.00360	0.00103	0.00006	0.00002	0.00002	0.00001
Nonylphenol	0.00409	0.00117	0.00001	0.000003	0.00002	0.00010
Bisphenol A	0.00084	0.00024	0.00018	0.00005	0.00004	0.00001
2-chlorophenol	BDL	BDL	0.00012	0.00003	0.00019	0.00005

Table 9. Risk quotient for Agbarho, Ikweghwu and Orhokpokpor communities

Phenolic EDCs	Agbarho		Ikweghwu		Orhokpokpor	
	adult	child	adult	child	adult	child
2-nitrophenol	0.0880	0.3096	0.0428	0.1506	0.0298	0.1048
2,4-dimethylphenol	0.0354	0.1240	0.0328	0.1149	0.0001	0.0005
2,4-dichlorophenol	0.2303	0.8097	0.4514	1.5871	0.0771	0.2709
4-chloro-3-methylphenol	N/A	N/A	N/A	N/A	N/.A	N/A
2,4,6-trichlorophenol	1.7636	6.4667	8.2100	30.1333	0.0182	0.0667
2,4-dinitrophenol	1.1912	0.3164	1.7769	0.1111	0.0507	0.0178
4-nitrophenol	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000
Nonylphenol	45.1500	18.0600	10.6500	4.2600	0.0500	0.0200
Bisphenol A	0.0444	0.1555	0.0018	0.0061	0.0015	0.0052
2-chlorophenol	BDL	BDL	0.0253	0.0885	0.0049	0.0173

Table 10. Risk quotient for Mgbaukwu and Umudioka sites.

Phenolic EDCs	Mgbaukwu		Umudioka	
	adult	child	adult	child
2-nitrophenol	0.0380	0.1337	0.0363	0.1277
2,4-dimethylphenol	0.0340	0.1192	0.0178	0.0625
2,4-dichlorophenol	0.1881	0.66513	0.1734	0.6097
4-chloro-3-methylphenol	N/A	N/A	N/A	N/A
2,4,6-trichlorophenol	6.7182	24.6333	4.4818	16.4333
2,4-dinitrophenol	0.6973	0.2447	0.6548	0.2298
4-nitrophenol	0.0001	0.0004	0.0003	0.0009
Nonylphenol	28.5000	11.4000	1.8500	0.7400
Bisphenol A	0.0067	0.0234	.0065	0.0234
2-chlorophenol	BDL	BDL	BDL	BDL

Table 11. Risk quotient for Mushin, Itire and Bariga communities.

Phenolic EDCs	Mushin		Itire		Bariga	
	adult	child	adult	child	adult	child
2-nitrophenol	0.0644	0.2265	0.02645	0.0928	0.0010	0.0036
2,4-dimethylphenol	0.0340	0.1192	0.0005	0.0019	0	0
2,4-dichlorophenol	0.1844	0.6484	0.0514	0.1806	0.1018	0.3581
4-chloro-3-methylphenol	N/A	N/A	N/A	N/A	N/A	N/A
2,4,6-trichlorophenol	3.0545	11.2000	0.0272	0.1000	0	0
2,4-dinitrophenol	0.7589	0.2663	0.0986	0.0346	0.0575	0.0202
4-nitrophenol	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000
Nonylphenol	20.4500	8.1800	0.0200	0.0200	0.1000	0.0400
Bisphenol A	0.0046	0.0161	0.0009	0.0002	0.0002	0.0008
2-chlorophenol	BDL	BDL	0.0231	0.0104	0.0104	0.0365

The results for the calculated risk quotients for the children and adult populations at the communities in the study are presented in Tables 9-11. It was observed that at the Agbarho, Ikweghe, Mgbaukwu, Umudioka and Mushin sites, the children and adult population may be at potential risk of nonylphenol and 2,4,6-trichlorophenol related toxicity. The risk quotient values for both phenolic contaminants were greater than 1 in all cases. This indicates that drinking the raw groundwater from these sites without any form of treatment is unsafe. The risk quotient for the children was higher for children at all eight communities. This is similar to other reported results [27] that in early life stage (infants and children, birth to < 12 months and 1 to < 11 years of age, respectively) RQs could be approximately 6 times greater than the RQs for adulthood (≥ 21 years of age). The present results thus indicate that nonylphenol and 2,4,6-trichlorophenol are the major EDC contributors to potential health risk for exposed populations at the communities.

4. Conclusions

This study has shown the groundwater quality in the selected rural areas was seriously threatened by the presence of significant concentrations of phenolic EDCs. Although CDI for some of the phenolic EDCs (2-nitrophenol, 2,4-dimethylphenol, 4-nitrophenol, 2-chlorophenol and bisphenol A) at the communities fell below the USEPA oral reference dose, the RQs for nonylphenol and 2,4,6-trichlorophenol were above 1 for the exposed children and adult populations. This result raises serious concern over the status of EDC pollution in Nigerian groundwater resource. Thus, there is need for strict environment regulations by various health and environment agencies on the production and use of phenolic compounds and also to continuously monitor the levels of phenolic chemicals in the underground water as long term exposure may cause serious health hazards.

Conflict of interest

The authors declare that there is no conflict of interest.

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