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Health implications of selected heavy metals around hydrocarbon impacted sites in the Niger Delta: A preliminary investigation

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Abstract

This study appraises the levels of Heavy metals and health implications in Khana and Gokana LGAs of Rivers State, Nigeria. A random sampling approach was employed for groundwater sampling and samples were collected from a total of twenty-two (22) boreholes in the area. A total of ten (10) residential boreholes were sampled in Khana LGA and twelve (12) in Gokana LGA. Iron (Fe) in Khana area showed concentration exceeding WHO and NSDWQ regulatory limits of 0.3mg/l in BH2, BH4, BH5, BH7, BH8, BH9 and BH10 while in Gokana area, BH11, BH12, BH14, BH17, BH19 and BH20 had Fe concentration exceeding the regulatory requirements. The result shows that Fe concentration in groundwater in the study area is significantly high to render the groundwater unsuitable for oral ingestion. Manganese concentration in samples from Khana showed concentrations above WHO standard in BH3, BH6 and BH9 while only BH16 exceeded the regulatory limit in Gokana area and then all other samples concentrations were within WHO regulatory limit for potable drinking water. Copper (Cu) and Lead (Pb) concentration showed levels below permissible limits in all samples analyzed. The results of hazard index from oral ingestion of water from boreholes in the area ranged from 0.30 to 1.13, with an average of 0.69. Based on USEPA classification, apart from BH9 and BH16 where harmful effect from groundwater consumption is recognized, there is no non-carcinogenic harmful effect that may arise from oral ingestion of most of the groundwater sources in the area. The spatial map revealed that the southern central area is a hot spot that needs urgent attention. The results of hazard index from dermal contact with groundwater in the area ranged from 0.02 to 0.36, with an average of 0.18. Carcinogenic health risk from oral ingestion of groundwater in the area ranged from 1.07 to 16.69, with an average of 8.69. Similarly, cancer risk from dermal contact with groundwater in the area ranged from 0.02 to 0.25 with an average of 0.13. Based on USEPA guidelines as revealed in this study, oral ingestion or dermal contact with groundwater from any borehole cited in Gokana and Khana areas are associated with possible cancer risk. The results and of this study will serve as a baseline data in the investigation of the suitability of groundwater in oil producing areas of Khana and Gokana LGAs of Rivers State for human consumption. Thus, the study has revealed the need of an urgent remediation of oil impacted areas in the study area to mitigate further impact on human health.

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1. Introduction

Heavy metals are naturally occurring elements that have a high atomic weight and a density at least five (5) times greater than that of water [1]. Their multiple industrial, domestic, agricultural, medical and technological applications have led to their wide distribution in the environment; raising concerns over their potential effects on human health and the environment. The assumption that heaviness and toxicity are inter-related, heavy metals also includes metalloids, such as arsenic, that are able to induce toxicity at low level of exposure [2].

Metals constituting important class of the toxic substances encountered day to day life during occupational and environmental circumstances. The impact of such toxic agents on human health is presently an area of passionate interest because of ubiquity of its exposure, by increasing the use of wide verity of the metals in industry and in daily life work hood [3, 4]

Heavy metals are significant environmental pollutants and toxicity of theirs is major problem for ecological, evolutionary, nutritional and environmental balances [5].In recent years, there has been an increasing ecological and global public health concern associated with environmental contamination by these metals. Also, human exposure has risen dramatically as a result of an exponential increase of their use in several industrial, agricultural, domestic and technological applications [6].

Reported sources of heavy metals in the environment include geogenic, industrial, agricultural, pharmaceutical, domestic effluents, and atmospheric sources (He et.al 2005). Environmental pollution is very prominent in point source areas such as mining, foundries and smelters, and other metal-based industrial operationsas earlier reported by [1, 6, and 7].

Heavy metal contamination refers to the excessive deposition of toxic heavy metals in the soil caused by human activities. Heavy metals in the soil include some significant metals of biological toxicity, such as mercury (Hg), cadmium (Cd), lead (Pb), chromium (Cr) and arsenic (As),They also include other heavymetals of certain biological toxicity, such as zinc (Zn), copper (Cu), nickel (Ni), stannum (Sn), vanadium (V),and so on. In recent years, with the development of the global economy, both type and content of heavy metals in the soil caused by human activities have gradually increased, resulting in the deterioration of the environment as earlier reported by [8, 9, 10, 11, 12, and 13]. Heavy metals are highly hazardous to the environment and organisms. It can be enriched through the food chain. Once the soil suffers from heavy metal contamination, it is difficult to be remediated.

1.1. Source of Contamination of heavy metal in Water

1.1.1. Natural sources

In nature excessive levels of trace metals may occur by geological phenomena like volcanic eruptions, weathering of rocks, leaching into rivers, lakes and oceans due to action of water. Anthropogenic Sources: Small amounts of heavy metals are released while mining and uncontrolled smelting of large quantities of metal, ores in open fires. With the industrial revolution, metals were extracted from natural resources and processed in the industries from where heavy metals passed on into the atmosphere. Similarly traces of heavy metals get into the environment through discharge of waste - both domestic ,agricultural and from auto exhausts. Following list shows the various human activities through which heavy metals get into the environment ; Smelting or processing of ores of metals ,mining,burning of fossil fuels such as coal, petrol, kerosene oil, Discharging Agricultural waste, Discharging Industrial and Domestic waste, wastes from Auto exhaust and pesticides containing compounds (salts) of heavy metals [14].

1.2. Location and Geology of the Area

1.2.1. Description of the Study Area

The study area is the oil producing communities within Khana and Gokana LGAs in Rivers State. The area is located geographically within Latitude $4^0\ 36^I\ 36.51^{II}$ N -- $4^0\ 43^I\ 42.21^{II}$ N and Longitude $7^0\ 15^I\ 12.00^{II}$ E -- $7^0\ 26^I\ 42.97^{II}$ E. The climate of an area plays a major role in determining the vegetation of the locality. The vegetation of Niger Delta can be described by two major regions, namely the swampy forest region (coastal environment) and the rain forest region (fluvial environment). The swamp forest region can further be subdivided into the mangrove or saltwater swamp forest and the freshwater swamp forest. The saltwater swamp forest is characterized by the presence of several varieties of mangrove trees. This region forms the zone of brackish water i.e. the mixture of salt water and fresh water. The freshwater swamp forest is formed from the influence of the tidal water. This region is characterized by raffia palms that cover the whole of the central portions of the Delta.

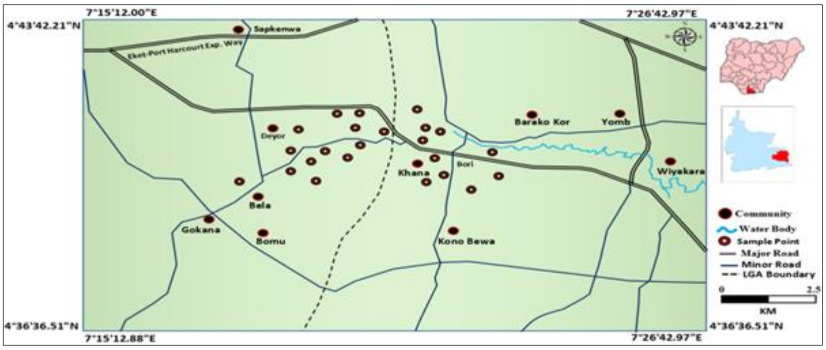

Figure 1 Map showing sample points in the study locations

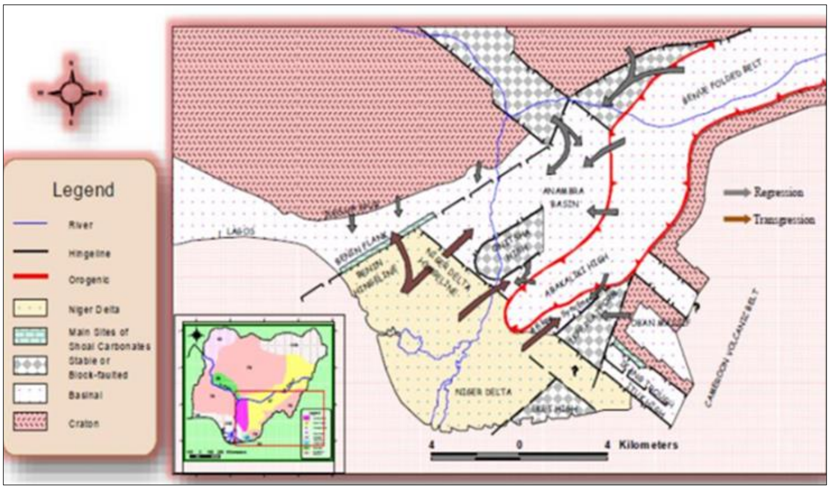

Figure 2 Tectonic Map Showing the Niger Delta

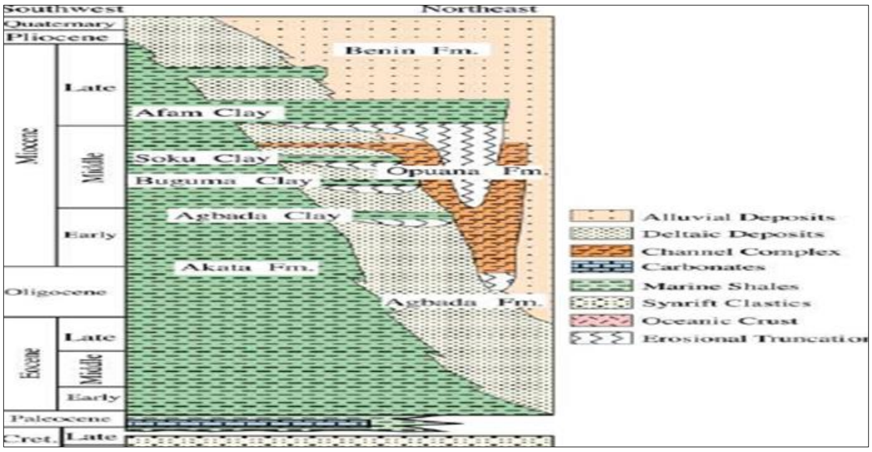

Figure 3 Stratigraphic Column of Niger Delta Formations[15]

The study area is Khana and Gokana L.G.A. of Rivers State (figure 1), located within the Niger Delta region of Nigeria, situated in the Gulf of Guinea, therefore, has same geology as the Niger Delta. The Niger Delta Basin is perhaps the most prolific basin in Sub-Saharan Africa with respect to its petroleum resources (figure 2). The Niger Delta is composed of marine shale as the base of its stratification, (figure3) overlying it is an intercalation of sand and shale as the intermediate layer, then the topmost layer is sandstone. The groundwater occurrence is a multi-aquifer system because of the presence of certain clayey strata in formations of various thicknesses that acts as confining layer between two distinct aquiferous rock strata. The present-day Niger Delta was formed during the Tertiary period as a result of the interplay between subsidence and deposition arising from a succession of transgression and regression of the three-tertiary subsurface litho-stratigraphic units of Akata, Agbada, and Benin Formations [16]. Further studies and evidence from deep wells drilled in the Niger Delta has also proven that the Niger Delta has a three litho-stratigraphic depositional succession (Akata, Agbada and Benin Formations) with an approximate average thickness of over 5000m of sediment body.

2. Material and methods

2.1. Groundwater Sampling

Table 1 Sampling location and geographic references for the sampled boreholes

Location	Borehole ID	Easting	Northing
Khana L.G.A.	BH1	318428.88	515856.14
	BH2	317976.04	516741.85
	BH3	320007.51	517190.53
	BH4	318200.19	517703.40
	BH5	319181.86	515201.95
	BH6	320215.87	516128.46
	BH7	317566.83	517306.79
	BH8	317724.13	518146.85
	BH9	317774.02	515758.14
	BH10	317370.54	518766.95
Gokana L.G.A	BH11	311415.80	515607.34
	BH12	314641.10	518751.29
	BH13	316157.97	517409.62
	BH14	315540.04	518848.68
	BH15	315304.79	517898.21
	BH16	315401.34	516504.62
	BH17	313590.93	515734.83
	BH18	313148.27	516222.46
	BH19	313803.46	516453.13
	BH20	313094.83	517074.10
	BH21	314237.74	517104.54
	BH22	313385.94	518168.20

A random sampling approach was adopted in groundwater sampling in Khana and Gokana local government areas of Rivers State. Groundwater samples were collected from a total of twenty-two (22) boreholes in the area (Table 1). Ten (10) residential boreholes were sampled in Khana while 12 boreholes were sampled in Gokana local government area. At each borehole where water samples were to be collected, the sterilized sample bottles were thoroughly rinsed with the water to be sampled before actual samples were collected. The water was allowed to flow freely for about 5 minutes in order to clear all dissolved solids that may be stuck to the walls of the pipes and tap. The sample bottles were allowed to fill to the brim and corked immediately to minimize escape of dissolved oxygen.

Samples were collected in duplicates for analysis of heavy metals. Samples for heavy metal analysis were collected in plastic bottles. Water samples for the determination of heavy metals were stabilized by adding few drops of diluted hydrochloric acid to them after collection. All sampling bottles were neatly labelled after sample collection and stored in an ice tight chest for onward transport to the laboratory for analysis. All sampling locations were noted with the aid of a global positioning system.

2.2. Heavy Metals

The heavy metals were determined in accordance with APHA3030B/3114B, APHA 3111B, APHA 3112B, and ASTM D3859 using an atomic absorption spectrophotometer (AAS). This method involves direct aspiration of sample into an air/acetylene flame generated by a hollow cathode lamp at a specific wavelength peculiar only to the metal under investigation. The minimum acceptable absorbance from which metal concentrations were calculated was 0.004 and values below this equipment detection limits for the various heavy metals analysed were as follows in mg/l: cadmium (Cd) = 0.002mg/L; chromium (Cr) = 0.01mg/L; copper (Cu) = 0.05mg/L; iron (Fe) = 0.05mg/L and lead (Pb) = 0.01mg/L.

Table 2 Analytical methods used for heavy metal samples

Class	Parameter	Symbol	Unit	Type of Test	Laboratory Standard
Heavy Metals	Iron	Fe	mg/L	Laboratory	APHA 3111B
	Zinc	Zn	mg/L	Laboratory	APHA 3111B
	Manganese	Mn	mg/L	Laboratory	APHA 3111B
	Chromium	Cr	mg/L	Laboratory	APHA 3111D
	Lead	Pb	mg/L	Laboratory	APHA 3111B
	Nickel	Ni	mg/L	Laboratory	APHA 3111B
	Cadmium	Cd	mg/L	Laboratory	APHA 3111B
	Copper	Cu	mg/L	Laboratory	APHA 3111B

2.3. Estimation of Degree of Metal Contamination

The degree of contamination (Cd) method used as reference for the estimation of the extent of metal pollution [17]. In this method, the quality of water is evaluated by computing the extent of contamination using the sum of the contamination factors of each metal component exceeding the upper permissible limit [18]. The Cd method thus, summarizes the combined effects of a number of quality parameters considered to be unsafe in drinking water [18]. [19] Proposed that, the degree of toxic heavy metal contamination (Cd) may be presented as in Eqn. 1:

$$C_d = \sum_{i=1}^{n} C_f \qquad (1)$$

where, C_f is the contamination factor calculated using Eqn. 2:

$$C_f = \frac{CMi}{CSi} \qquad (2)$$

where, *CMi*, and *CSi*, are the analytical value and upper permissible concentration for the ith component respectively. The degree of toxic heavy metal contamination in any water resource have been categorized as, low (Cd < 1), medium (Cd =1-3), and high (Cd > 3) [17].

2.4. Carcinogenic and Non-Carcinogenic Health Risk Assessment

The health risk from groundwater consumption was assessed in the study area. The adverse health effect due to exposure to heavy metal over a period of time is quantified in order to determine the magnitude of risk, which could be expressed in terms of carcinogenic and non-carcinogenic health effects [20]. The toxicity risk factors estimated are the reference dose (RfD) for non-carcinogenic risk and slope factor for carcinogenic risk characterizations [21]. In order to adequately characterize these risks, the average daily dose (ADD) for the metals must be properly estimated. Average daily dose (ADD) is the estimations of the magnitude, frequency, and duration of human exposure to each heavy metal or metalloid in the environment. Exposure of human beings to the metals could occur via three main pathways including direct ingestion, inhalation and dermal absorption through skin; however, ingestion and dermal absorption are common routes for water exposure. According to the [22] as proposed in the Risk Assessment Guidance for Superfund (RAGS) methodology, the numeric expressions for risk assessment may be presented as in Eqns. 3 and 4 as follows;

$$D_{ingestion} = \frac{C_{water} \times IR \times EF \times ED}{BW \times AT} \quad (3)$$

$$D_{dermal} = \frac{C_{water} \times SA \times IR \times K_p \times EF \times ED \times CF}{BW \times AT} \quad (4)$$

where, $D_{ingestion}$: exposure dose through ingestion of water (μg/(kg day)); D_{dermal}: exposure dose through dermal absorption (μg/(kg day)); C_{water}: concentration of metals estimated in groundwater (μg/l); IR: ingestion rate (2.2 l/day); EF: exposure frequency (365 days/year); ED: exposure duration (30 years); BW: average body weight (70 kg); AT: averaging time (25,550 days); SA: exposed skin area (18,000 cm^2); ET: exposure time (0.58 h/day); CF: unit conversion factor (0.001 l/cm^3); and K_p(cm/h): dermal permeability coefficient. The Kp for the metals utilized in this study are as follows (Cd, Fe, Cu, Mn = 0.001 cm/h; Pb = 0.004 cm/h; Zn = 0.0006 cm/h; Cr = 0.002cm/h) [22]. Oral reference dose (RfD) of the various heavy metals from dermal absorption used for the determination of toxicity responses as proposed by [22] are presented as follows; (Fe = 140, Zn = 60, Mn = 1.84, Cr = 0.015, Pb = 0.42, Cd = 0.025, Cu = 8), and (Fe = 700, Zn = 300, Mn = 14, Cr = 3, Pb = 1.4, Cd = 0.5, Cu = 40) through oral ingestion.

Potential non-carcinogenic risks for exposure to contaminants were assessed by comparison of the calculated contaminant exposures with respect to each exposure route and the reference dose (RfD) so as to produce the hazard quotient (HQ). The HQ may be defined as in Eqn. 5 [22]:

$$HQ_{ingestion/dermal} = \frac{D_{ingestion/dermal}}{RfD_{ingestion/dermal}} \quad (5)$$

Where, $HQ_{ingestion/dermal}$ is defined as the hazard quotient via ingestion or dermal contact and is unitless, and $RfD_{ingestion/dermal}$ is defined as the oral/dermal reference dose in μg/kg-day. The $RfD_{ingestion}$ and RfD_{dermal} values were obtained from USEPA [23 and 24]. The hazard quotient (HQ) is a numeric estimate of the systemic toxicity potentially posed by a single element within a single route of exposure. According to[25 and 26], the toxic risk due to potentially hazardous substances in the same environmental media is presumed to be additive and the arithmetic sum of individual target hazard quotient and is equal to the hazard index (HI). To estimate the overall potential for non-carcinogenic effects posed by potentially hazardous substances, the computed HQs for each element are integrated and expressed as a hazard index (HI) as defined by Eqn. 6:

$$HI_{HQ_{ingestion/dermal}} = \sum_{i=1}^{n} HQ_{ingestion/dermal} \quad (6)$$

where, $HI_{HQ_{ingestion/dermal}}$ is defined as the hazard index via ingestion or dermal contact (unit less). According to the [22] where, HI < 1, there is no concern for potential human health risks caused by exposure to non-carcinogenic elements and where, HI >1, there may be a concern for potential human health risks caused by exposure to non-carcinogenic elements.

Environmental Protection Agency defined carcinogenic or cancer risks (CR) as “the incremental probability of an individual to develop cancer, over a lifetime, as a result of exposure to a potential carcinogen”. Equation 3.17 was used to estimate the carcinogenic risks. The cancer slope factor (CSF) value (μg kg^{-1} day^{-1}) is only available for Cd (6.1 μg kg^{-1} day^{-1}), Pb (8.5 μg kg^{-1} day^{-1}), and Cr (41 μg kg^{-1} day^{-1}) [23], which were adopted from USEPA screening levels [23]. A risk level of 1×10^{-6} has been considered as the point of excess cancer risk, indicating 1 per 1,000,000 chance of getting cancer via consumption of drinking water containing arsenic and toxic metals, estimated in μg L^{-1} for 70 years. The safe point for carcinogenic risks must be lower than this level. The range of risks borderline by the EPA is 1×10^{-4} to 1×10^{-6} and unacceptable if the risks are surpassing 1×10^{-4}. A carcinogenic risk of 1×10^{-4} poses health hazards; therefore, it is sufficiently large, poses health hazards, and need some sort of intervention and remediation [27].

$$CR = D \times CSF \quad (7)$$

3. Results and discussion

Heavy metals, Fe ranges from 0.01 mg/l to 0.70 mg/l with mean and SD of 0.37 ± 0.19 mg/l in Khana area, whereas in Gokana, Fe ranged from 0.18 to 063 mg/l with mean and SD of 0.32 ± 0.13 mg/l respectively. In Khana area, BH2, BH4, BH5, BH7, BH8, BH9 and BH10 had iron concentration exceeding WHO and NSDWQ regulatory limits of 0.30 mg/l; whereas in Gokana area, BH11, BH12, BH14, BH17, BH19 and BH20 had iron content exceeding the regulatory requirement. These results show that iron concentration in groundwater within the study area is significantly high to render the groundwater unsuitable for oral ingestion.

Zinc concentration ranges from 0.40 to 3.76 mg/l with mean and SD of 1.23 ± 1.27 mg/l in Khana, and from 0.23 to 0.95 mg/L with mean and SD of 0.59 ± 0.20 mg/L in Gokana area. Generally, WHO standard for Zn in potable drinking water is set at 5.0 mg/l. All the groundwater samples revealed Zn concentrations which are within the regulatory guideline. These results show that zinc is not a possible source of contamination of groundwater in the area.

Manganese ranged from 0.02 to 0.39 mg/l and from 0.01 to 0.43 mg/l in Khana and Gokana areas. The WHO standard for Mn in potable drinking water is set at 0.20 mg/l. In Khana area, only BH3, BH6 and BH9 exceeded this limit, while only BH16 exceeded the regulatory limit in Gokana area. All other boreholes had Mn concentrations within WHO regulatory limit for potable drinking water.

Chromium and Lead ranged from 0.0t to 0.08 mg/l and from 0.001 to 0.02 mg/L in Khana, while in Gokana, Cr and Pb ranged from <0.001 to 0.04 mg/l. The average Cr and Pb concentrations are 0.04 ± 0.03 mg/L and 0.009 ±0.008 mg/l in Khana L.G.A. and 0.04 ± 0.02 mg/l and 0.025 ± 0.01 mg/l in Gokana L.G.A. respectively. The WHO and NSDWQ regulatory limit for Cr and Pb in potable groundwater are 0.05 mg/l and 0.01 mg/l. Based on these guidelines, the average Cr and Pb concentrations in groundwater samples from Khana area are within regulatory requirements. Only Lead exceeded WHO regulatory limit at Gokana area. Nickel was below the detectable limit of the measuring instrument at all sampled boreholes.

Cadmium concentration ranges from 0.001 to 0.006 mg/l with mean and SD of 0.003 ± 0.0015 mg/L in Khana, and from 0.002 to 0.005 mg/l with mean and SD of 0.003 ± 0.001 mg/L in Gokana area. Generally, WHO standard for Cadmium in potable drinking water is set at 0.003 mg/L. Apart from BH3, BH6 and BH10 in Khana, and BH14, BH16, BH17, BH20 and BH22 in Gokana which exceeded WHO limit, all other groundwater samples revealed Cadmium concentrations which are within the regulatory guideline for potable drinking water.

Copper concentration ranges from 0.06 to 0.66 mg/L with mean and SD of 0.34 ± 0.020 mg/l in Khana, and from 0.09 to 0.62 mg/l with mean and SD of 0.38 ± 0.17 mg/l in Gokana area. Generally, WHO standard for copper in potable drinking water is set at 1.0 mg/l. Hence, all the groundwater samples revealed copper concentrations which are within the safe limit for oral ingestion.

3.1. Groundwater Contamination Degree

The groundwater contamination degree was evaluated to determine the level of groundwater contamination from heavy metals in the area. The metals utilized included Fe, Zn, Mn, Cr, Pb, Cd and Cu. The results of contamination degree ranges from 2.98 to 8.37 (Table 3), indicating moderate to high contamination degree as proposed by Rubio et al., (2000). The map showing the degree of contamination revealed that the north central part of the study area is most deteriorated with heavy metal contamination (Figure 4.). The results also show that lead and cadmium are the most significant heavy metals contributing to the high degree of contamination in the area (Table 3).

3.2. Health Risk Assessment

Health risk assessment was conducted in terms of non-carcinogenic and carcinogenic risk for adult's resident in the area. The results of hazard index from oral ingestion of water from boreholes in the area ranged from 0.30 to 1.13, with an average of 0.69 (Table 4). Based on [22] classification, apart from BH9 and BH16 where harmful effect from groundwater consumption is recognized, there is no non-carcinogenic harmful effect that may arise from oral ingestion of most of the groundwater sources in the area. The spatial map showing the health risk areas from ingesting groundwater in the area (Fig. 6) revealed that the southern central area is a hot spot that needs urgent attention.

The results of hazard index from dermal contact with groundwater in the area ranged from 0.02 to 0.36, with an average of 0.18 (Table 5). Based on [22] classification, all the water sources have no harmful non-carcinogenic risk from dermal contact with groundwater in the area. Hence, the residents of the area can bathe and wash with these water sources without any associated health risk.

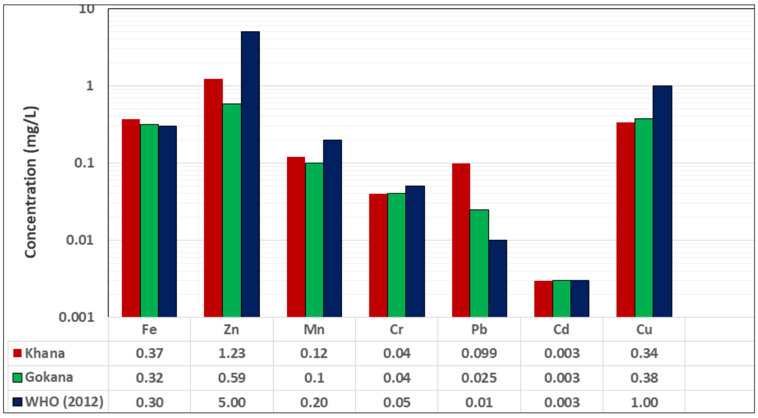

Figure 4 Histogram showing the average concentration of heavy metals in groundwater from the study area compared with WHO regulatory guidelines

Table 3 Contamination factors and degree of contamination for heavy metals in groundwater from the study area

Symbol	Contamination Factors							Contamination Degree (CD)	CD Interpretation
	Fe	Zn	Mn	Cr	Pb	Cd	Cu		
BH1	0.77	0.09	0.30	1.00	0.10	0.67	0.17	2.98	Moderate Contamination
BH2	1.47	0.11	0.40	1.20	0.70	1.00	0.64	5.52	High Contamination
BH3	0.03	0.15	1.05	0.80	0.30	1.33	0.34	4.00	High Contamination
BH4	1.37	0.08	0.45	0.00	1.00	0.67	0.12	3.68	High Contamination
BH5	1.07	0.12	0.25	1.20	0.90	1.00	0.06	4.59	High Contamination
BH6	0.73	0.09	1.10	0.60	0.20	1.67	0.32	4.71	High Contamination
BH7	1.43	0.29	0.10	1.60	2.00	0.67	0.41	6.50	High Contamination
BH8	1.70	0.75	0.25	0.00	0.70	1.00	0.27	4.67	High Contamination
BH9	1.37	0.11	1.95	0.80	2.00	0.33	0.66	7.22	High Contamination
BH10	2.33	0.67	0.15	0.40	2.00	2.00	0.43	7.98	High Contamination
BH11	1.47	0.11	0.65	1.20	3.00	0.67	0.32	7.41	High Contamination
BH12	2.10	0.11	0.25	1.00	1.00	1.00	0.52	5.98	High Contamination
BH13	0.70	0.17	0.50	0.60	3.00	0.67	0.11	5.75	High Contamination
BH14	1.07	0.05	0.30	1.20	4.00	1.67	0.09	8.37	High Contamination
BH15	0.73	0.09	0.15	1.40	2.00	1.00	0.34	5.71	High Contamination
BH16	0.60	0.13	2.15	0.80	2.00	1.33	0.62	7.63	High Contamination
BH17	1.43	0.09	0.05	0.40	0.00	1.67	0.48	4.12	High Contamination
BH18	0.93	0.16	0.15	0.60	1.00	1.00	0.33	4.17	High Contamination
BH19	1.23	0.10	0.30	1.00	3.00	1.00	0.38	7.02	High Contamination
BH20	1.13	0.12	0.60	0.40	2.00	1.33	0.58	6.17	High Contamination
BH21	0.70	0.19	0.55	0.00	4.00	0.67	0.46	6.57	High Contamination
BH22	0.63	0.10	0.25	0.00	2.00	1.67	0.31	4.96	High Contamination

Carcinogenic health risk from oral ingestion of groundwater in the area ranged from 1.07 to 16.69 (Table 6), with an average of 8.69. Similarly, cancer risk from dermal contact with groundwater in the area ranged from 0.02 to 0.25 with an average of 0.13 (Table 7). Based on [22] guidelines as presented in this study, oral ingestion or dermal contact with groundwater from any borehole cited in Gokana and Khana areas are associated with possible cancer risk. The maps presented in Figure 6 and 7 all show that the north central part of the area is the most significantly affected area and needs urgent remediation actions.

Table 4 Results of non-carcinogenic health risk assessment arising from ingesting groundwater in the area

Symbol	Hazard Quotient							Hazard Index (HI)	HI Interpretation
	Fe	Zn	Mn	Cr	Pb	Cd	Cu		
BH1	0.0044	0.0202	0.0577	0.2245	0.0096	0.0539	0.0572	0.4276	No Harmful Effect
BH2	0.0085	0.0251	0.0770	0.2694	0.0673	0.0808	0.2155	0.7436	No Harmful Effect
BH3	0.0002	0.0328	0.2020	0.1796	0.0289	0.1078	0.1145	0.6657	No Harmful Effect
BH4	0.0079	0.0180	0.0866	-	0.0962	0.0539	0.0404	0.3029	No Harmful Effect
BH5	0.0062	0.0265	0.0481	0.2694	0.0866	0.0808	0.0202	0.5377	No Harmful Effect
BH6	0.0042	0.0193	0.2117	0.1347	0.0192	0.1347	0.1078	0.6316	No Harmful Effect
BH7	0.0083	0.0651	0.0192	0.3592	0.1924	0.0539	0.1381	0.8362	No Harmful Effect
BH8	0.0098	0.1688	0.0481	-	0.0673	0.0808	0.0909	0.4658	No Harmful Effect
BH9	0.0079	0.0242	0.3752	0.1796	0.1924	0.0269	0.2222	1.0285	Harmful Effect
BH10	0.0135	0.1504	0.0289	0.0898	0.1924	0.1616	0.1448	0.7814	No Harmful Effect
BH11	0.0085	0.0247	0.1251	0.2694	0.2886	0.0539	0.1078	0.8779	No Harmful Effect
BH12	0.0121	0.0251	0.0481	0.2245	0.0962	0.0808	0.1751	0.6620	No Harmful Effect
BH13	0.0040	0.0391	0.0962	0.1347	0.2886	0.0539	0.0370	0.6536	No Harmful Effect
BH14	0.0062	0.0103	0.0577	0.2694	0.3848	0.1347	0.0303	0.8934	No Harmful Effect
BH15	0.0042	0.0193	0.0289	0.3143	0.1924	0.0808	0.1145	0.7544	No Harmful Effect
BH16	0.0035	0.0292	0.4137	0.1796	0.1924	0.1078	0.2088	1.1349	Harmful Effect
BH17	0.0083	0.0198	0.0096	0.0898		0.1347	0.1616	0.4238	No Harmful Effect
BH18	0.0054	0.0350	0.0289	0.1347	0.0962	0.0808	0.1111	0.4921	No Harmful Effect
BH19	0.0071	0.0233	0.0577	0.2245	0.2886	0.0808	0.1280	0.8101	No Harmful Effect
BH20	0.0065	0.0274	0.1155	0.0898	0.1924	0.1078	0.1953	0.7347	No Harmful Effect
BH21	0.0040	0.0427	0.1058	-	0.3848	0.0539	0.1549	0.7461	No Harmful Effect
BH22	0.0037	0.0233	0.0481	-	0.1924	0.1347	0.1044	0.5066	No Harmful Effect
Minimum	0.0002	0.0103	0.0096	0.0898	0.0096	0.0269	0.0202	0.3029	
Maximum	0.0135	0.1688	0.4137	0.3592	0.3848	0.1616	0.2222	1.1349	
Average	0.0066	0.0395	0.1041	0.2020	0.1691	0.0882	0.1218	0.6868	No Harmful Effect

Results of non-carcinogenic health risk assessment arising from ingesting groundwater in the area is presented in Table 4. Similarly, the results of non-carcinogenic health risk assessment arising from dermal contact with groundwater in the area is presented in Table 5. The spatial variation maps showing the distribution of non-carcinogenic health risk from oral ingestion of groundwater and from dermal contact with groundwater in the area is presented in Figures 6 and 7 respectively. Meanwhile, results of carcinogenic health risk assessment arising from ingesting groundwater or from dermal contact with groundwater in the area is presented in Tables 6 and 7. Figure 6 is a map showing areas likely to be affected by carcinogenic health risk arising from ingesting groundwater in the area, while Figure 7 shows areas likely to be affected by cancer from dermal contact with groundwater in the area.

Table 5 Results of non-carcinogenic health risk assessment arising from dermal contact with groundwater in the area

Symbol	Hazard Quotient							Hazard Index (HI)	HI Interpretation
	Fe	Zn	Mn	Cr	Pb	Cd	Cu		
BH1	0.0001	0.0003	0.0021	0.2131	0.0006	0.0051	0.0014	0.2226	No Harmful Effect
BH2	0.0002	0.0004	0.0028	0.2557	0.0043	0.0077	0.0051	0.2761	No Harmful Effect
BH3	0.000005	0.0005	0.0073	0.1704	0.0018	0.0102	0.0027	0.1930	No Harmful Effect
BH4	0.0002	0.0003	0.0031	-	0.0061	0.0051	0.0010	0.0157	No Harmful Effect
BH5	0.0001	0.0004	0.0017	0.2557	0.0055	0.0077	0.0005	0.2716	No Harmful Effect
BH6	0.0001	0.0003	0.0076	0.1278	0.0012	0.0128	0.0026	0.1524	No Harmful Effect
BH7	0.0002	0.0009	0.0007	0.3409	0.0122	0.0051	0.0033	0.3633	No Harmful Effect
BH8	0.0002	0.0024	0.0017	-	0.0043	0.0077	0.0022	0.0185	No Harmful Effect
BH9	0.0002	0.0003	0.0135	0.1704	0.0122	0.0026	0.0053	0.2045	No Harmful Effect
BH10	0.0003	0.0021	0.0010	0.0852	0.0122	0.0153	0.0034	0.1197	No Harmful Effect
BH11	0.0002	0.0004	0.0045	0.2557	0.0183	0.0051	0.0026	0.2867	No Harmful Effect
BH12	0.0003	0.0004	0.0017	0.2131	0.0061	0.0077	0.0042	0.2334	No Harmful Effect
BH13	0.0001	0.0006	0.0035	0.1278	0.0183	0.0051	0.0009	0.1562	No Harmful Effect
BH14	0.0001	0.0001	0.0021	0.2557	0.0243	0.0128	0.0007	0.2959	No Harmful Effect
BH15	0.0001	0.0003	0.0010	0.2983	0.0122	0.0077	0.0027	0.3223	No Harmful Effect
BH16	0.0001	0.0004	0.0149	0.1704	0.0122	0.0102	0.0050	0.2132	No Harmful Effect
BH17	0.0002	0.0003	0.0003	0.0852	-	0.0128	0.0038	0.1027	No Harmful Effect
BH18	0.0001	0.0005	0.0010	0.1278	0.0061	0.0077	0.0026	0.1459	No Harmful Effect
BH19	0.0002	0.0003	0.0021	0.2131	0.0183	0.0077	0.0030	0.2446	No Harmful Effect
BH20	0.0002	0.0004	0.0042	0.0852	0.0122	0.0102	0.0046	0.1170	No Harmful Effect
BH21	0.0001	0.0006	0.0038	-	0.0243	0.0051	0.0037	0.0377	No Harmful Effect
BH22	0.0001	0.0003	0.0017	-	0.0122	0.0128	0.0025	0.0296	No Harmful Effect
Minimum	0.000005	0.0001	0.0003	0.0852	0.0006	0.0026	0.0005	0.0157	
Maximum	0.0003	0.0024	0.0149	0.3409	0.0243	0.0153	0.0053	0.3633	
Average	0.0002	0.0006	0.0038	0.1918	0.0107	0.0084	0.0029	0.1828	No Harmful Effect

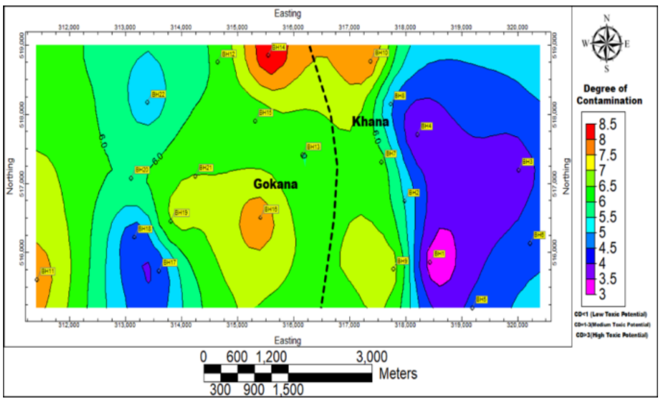

Figure 5 Map showing the degree of heavy metal contamination within the study area

Table 6 Results of carcinogenic health risk assessment arising from ingesting groundwater in the area

Symbol	Hazard Quotient			Cancer Risk (CR)	CR Interpretation
	Cr	Pb	Cd		
BH1	9.204082	0.081778	0.328653	9.61451312	Possible Cancer Risk
BH2	11.0449	0.572449	0.49298	12.1103265	Possible Cancer Risk
BH3	7.363265	0.245335	0.657306	8.26590671	Possible Cancer Risk
BH4	-	0.817784	0.328653	1.14643732	Possible Cancer Risk
BH5	11.0449	0.736006	0.49298	12.2738834	Possible Cancer Risk
BH6	5.522449	0.163557	0.821633	6.50763848	Possible Cancer Risk
BH7	14.72653	1.635569	0.328653	16.6907522	Possible Cancer Risk
BH8	-	0.572449	0.49298	1.06542857	Possible Cancer Risk
BH9	7.363265	1.635569	0.164327	9.16316035	Possible Cancer Risk
BH10	3.681633	1.635569	0.985959	6.30316035	Possible Cancer Risk
BH11	11.0449	2.453353	0.328653	13.8269038	Possible Cancer Risk
BH12	9.204082	0.817784	0.49298	10.5148455	Possible Cancer Risk
BH13	5.522449	2.453353	0.328653	8.30445481	Possible Cancer Risk
BH14	11.0449	3.271137	0.821633	15.1376676	Possible Cancer Risk
BH15	12.88571	1.635569	0.49298	15.0142624	Possible Cancer Risk
BH16	7.363265	1.635569	0.657306	9.65613994	Possible Cancer Risk
BH17	3.681633	-	0.821633	4.50326531	Possible Cancer Risk
BH18	5.522449	0.817784	0.49298	6.83321283	Possible Cancer Risk
BH19	9.204082	2.453353	0.49298	12.150414	Possible Cancer Risk
BH20	3.681633	1.635569	0.657306	5.97450729	Possible Cancer Risk
BH21	-	3.271137	0.328653	3.59979009	Possible Cancer Risk
BH22	-	1.635569	0.821633	2.45720117	Possible Cancer Risk
Minimum	3.6816	0.0818	0.1643	1.0654	
Maximum	14.7265	3.2711	0.9860	16.6908	
Average	8.2837	1.4370	0.5378	8.6870	Possible Cancer Risk

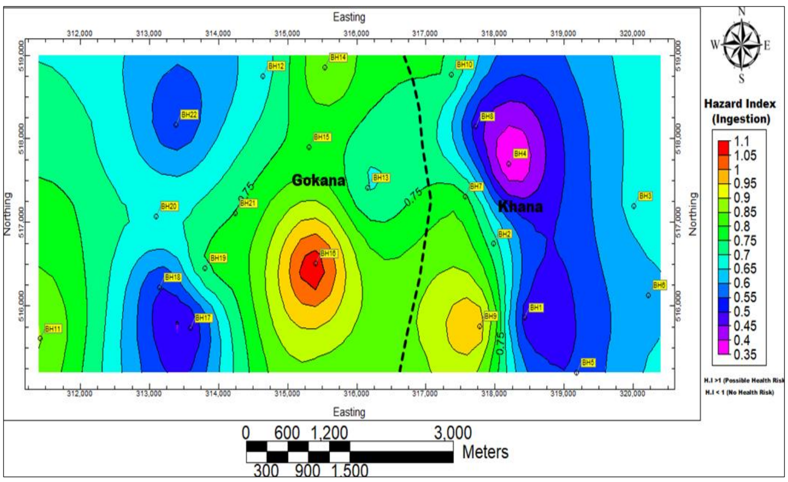

Figure 6 Map showing areas likely to be affected by non-carcinogenic health risk arising from ingesting groundwater in the area

Table 7 Results of carcinogenic health risk assessment arising from dermal contact with groundwater in the area

Symbol	Hazard Quotient			Cancer Risk (CR)	CR Interpretation
	Cr	Pb	Cd		
BH1	0.1310	0.0022	0.0008	0.1340	Possible Cancer Risk
BH2	0.1572	0.0152	0.0012	0.1736	Possible Cancer Risk
BH3	0.1048	0.0065	0.0016	0.1129	Possible Cancer Risk
BH4	-	0.0217	0.0008	0.0225	Possible Cancer Risk
BH5	0.1572	0.0196	0.0012	0.1780	Possible Cancer Risk
BH6	0.0786	0.0043	0.0019	0.0849	Possible Cancer Risk
BH7	0.2097	0.0435	0.0008	0.2539	Possible Cancer Risk
BH8	-	0.0152	0.0012	0.0164	Possible Cancer Risk
BH9	0.1048	0.0435	0.0004	0.1487	Possible Cancer Risk
BH10	0.0524	0.0435	0.0023	0.0982	Possible Cancer Risk
BH11	0.1572	0.0652	0.0008	0.2232	Possible Cancer Risk
BH12	0.1310	0.0217	0.0012	0.1539	Possible Cancer Risk
BH13	0.0786	0.0652	0.0008	0.1446	Possible Cancer Risk
BH14	0.1572	0.0869	0.0019	0.2461	Possible Cancer Risk
BH15	0.1834	0.0435	0.0012	0.2281	Possible Cancer Risk
BH16	0.1048	0.0435	0.0016	0.1499	Possible Cancer Risk
BH17	0.0524	-	0.0019	0.0544	Possible Cancer Risk
BH18	0.0786	0.0217	0.0012	0.1015	Possible Cancer Risk
BH19	0.1310	0.0652	0.0012	0.1974	Possible Cancer Risk
BH20	0.0524	0.0435	0.0016	0.0974	Possible Cancer Risk
BH21	-	0.0869	0.0008	0.0877	Possible Cancer Risk
BH22	-	0.0435	0.0019	0.0454	Possible Cancer Risk
Minimum	0.0524	0.0022	0.0004	0.0164	
Maximum	0.2097	0.0869	0.0023	0.2539	
Average	0.1179	0.0382	0.0013	0.1342	Possible Cancer Risk

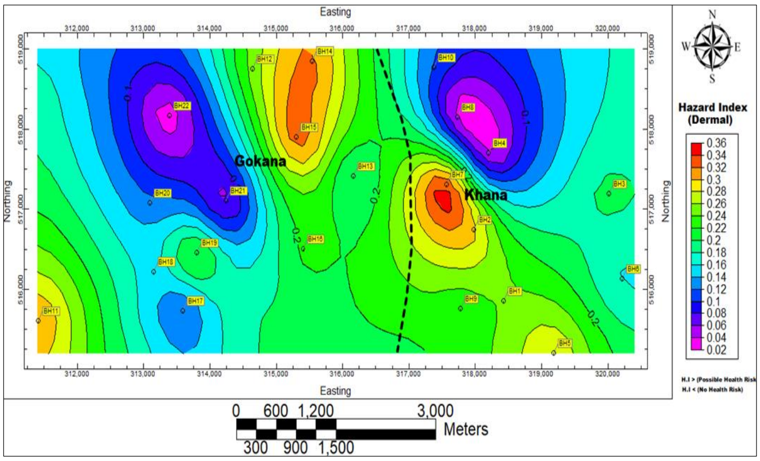

Figure 7 Map showing areas likely to be affected by non-carcinogenic health risk arising from dermal contact with groundwater in the area

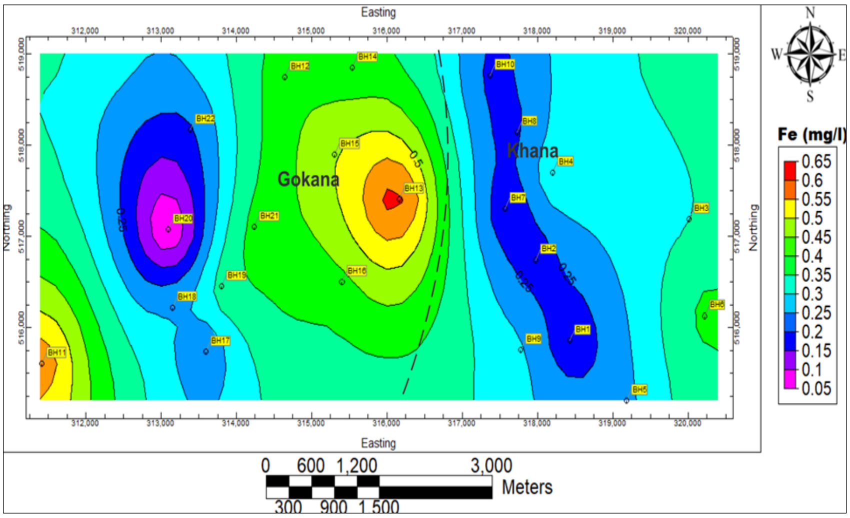

Figure 8 Map showing spatial variation in iron concentration across the study area

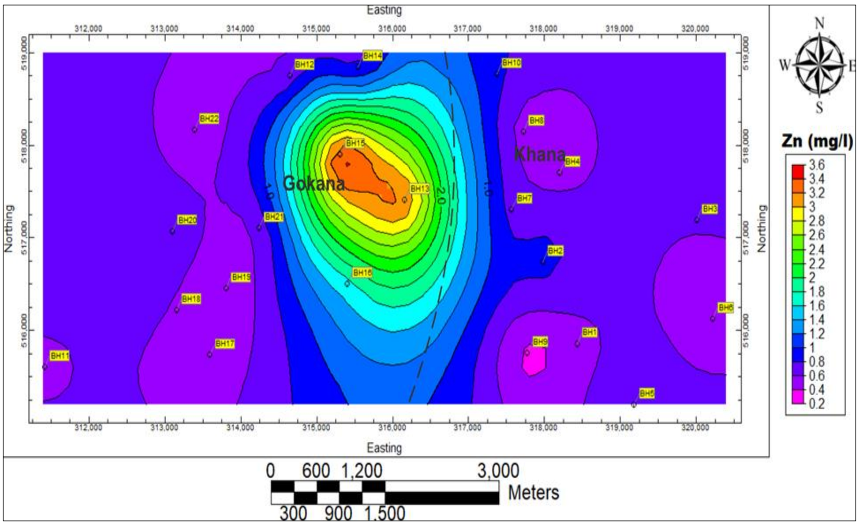

Figure 9 Map showing spatial variation in zinc concentration across the study area

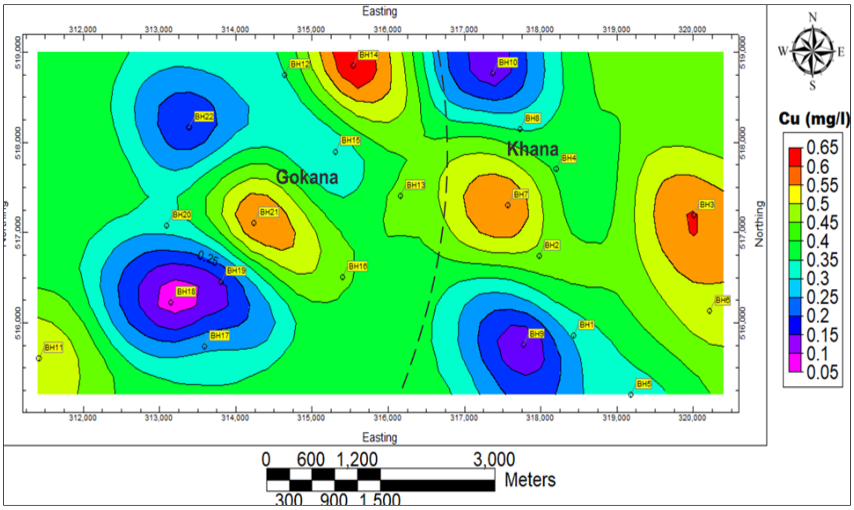

Figure 10 Map showing spatial variation in copper concentration across the study area

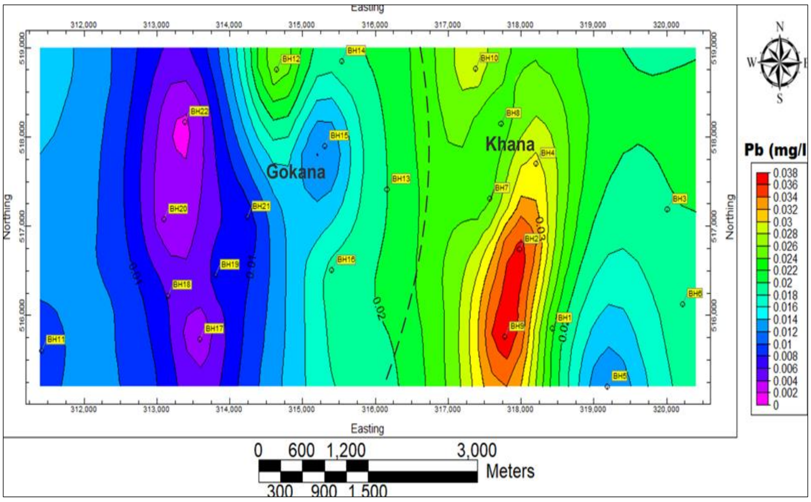

Figure 11 Map showing spatial variation in Lead concentration across the study area

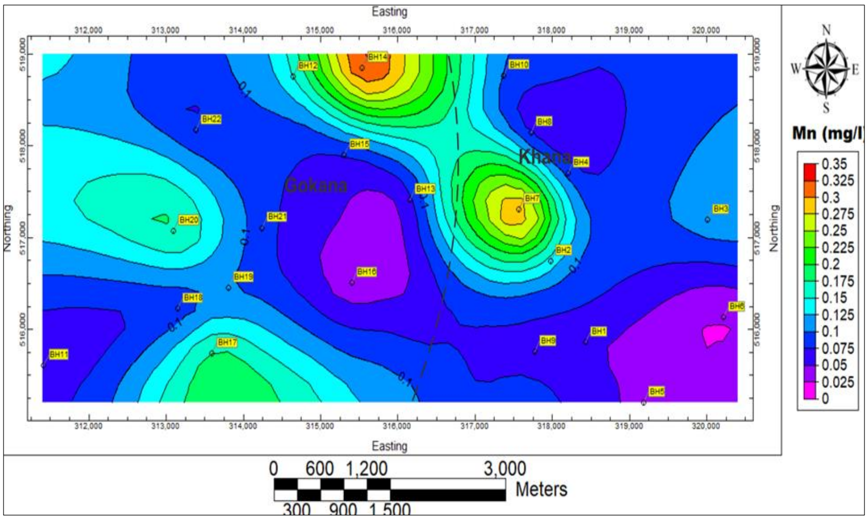

Figure 12 Map showing spatial variation in manganese concentration across the study area

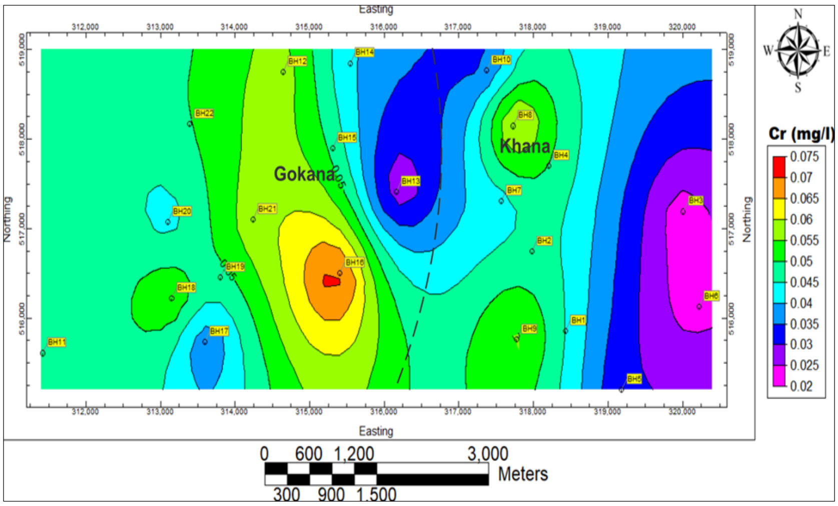

Figure 13 Map showing spatial variation in chromium concentration across the study area

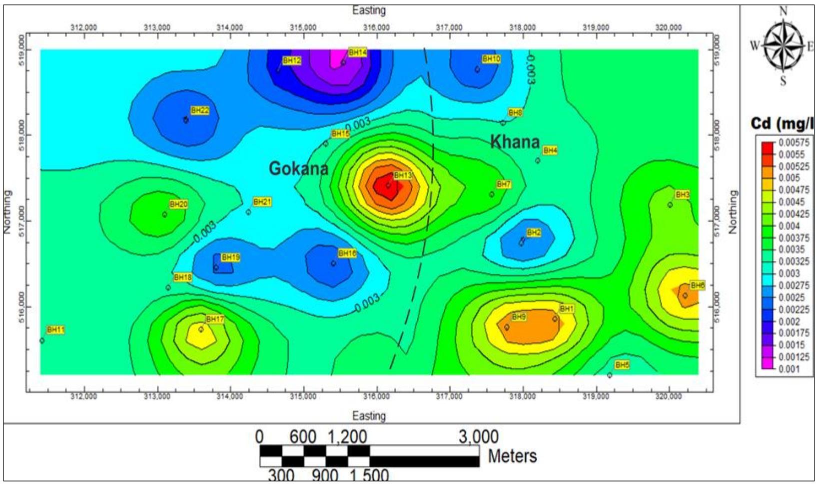

Figure 14 Map showing spatial variation in cadmium concentration across the study area

4. Conclusion

Iron (Fe) in Khana area showed concentration exceeding WHO and NSDWQ regulatory limits of 0.3mg/L in BH2, BH4, BH5, BH7, BH8, BH9 and BH10 while in Gokana area, BH11, BH12, BH14, BH17, BH19 and BH20 had Fe concentration exceeding the regulatory requirements. The result shows that Fe concentration in groundwater in the study area is significantly high to render the groundwater unsuitable for oral ingestion. Manganese concentration in samples from Khana showed concentrations above WHO standard in BH3, BH6 and BH9 while only BH16 exceeded the regulatory limit in Gokana area and then all other samples concentrations were within WHO regulatory limit for potable drinking water. Cupper (Cu) and Lead (Pb) concentration showed levels below permissible limits in all samples analyzed.

The results and of this study will serve as a baseline data in the investigation of the suitability of groundwater in oil producing areas of Khana and Gokana LGAs of Rivers State for human consumption. Thus, the study has revealed the need of an urgent remediation of oil impacted areas in the study area to mitigate further impact on human health.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The Authors declares that there is no conflict of interest.

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