Carcinogenic and Non-Carcinoginic Health Risk Assessment of Organic and Inorganic Contaminants within Three Major Metropolies in Enugu

Ezeh Uchechukwu A and D. C Ozoko
Department of Geology and Mining, Faculty of Applied Natural Sciences
Enugu State University of Science and Technology

Abstract
This study assessed the carcinogenic and non-carcinogenic health risks and within three major metropolis in Enugu, namely Abakpa, Emena, and Independence Layout by analyzing 60 water samples. Phthalate and PAHs organic contaminants, which is linked mostly to plastics and cosmetics at refuse dumps as well as open waste burning, oil spills and underground tank leakage, were most predominant in most of the analyzed water samples collected from the three settlement areas. Leaching of these domestic and commercial wastes could also be responsible for the high BPA values recorded in some groundwater samples in Abakpa and Independence Layout. Boracol and TOH contaminated groundwater is more severe in Emene and Independence Layout. High concentration values of Total kjheldhal were observed in some water samples in Emene and Independence Layout, with sewage and failing septic tank as the major sources. HQ dermal values calculated for all the analyzed water samples in the three settlement areas were within acceptable limits. However, HQ oral values obtained for some of the samples exceeded the approved threshold values indicating that water consumers are more likely to contract non-cancer related ailment through drinking of contaminated water than through skin contact. Moreover, more samples had HI oral values that exceeded the allowable limit when compared to HI dermal values. ILCR values obtained for more than 75% of all the analyzed samples in the three settlement area exceeded the allowable limit of 0.000001-0.0001 indicating a high risk of contracting cancer from groundwater consumption in the areas. As and Mn poses the greatest threat of cancer related diseases in the settlement areas. The simulation results showed that plume movement was from northwest to east/northeast. It was also inferred that the overall groundwater flow gradient is easterly, which is approximately same with the contaminant particle movement.
Keywords: Carcinogenic, Enugu metropolis, Health risk, plume movement, Water Quality
DOI: 10.7176/JEES/13-4-05
Publication date: June 30th 2023

1.0 INTRODUCTION
Human life depends on the availability of clean drinking water, and the health of people shouldn't be significantly put at risk by safe drinking water (Adelekan and Abegunde 2011). Water scarcity is on the rise, which has a number of detrimental effects on global environmental quality, human livelihoods, and economic growth. Water can be contaminated by a wide range of substances, including heavy metals, organic and inorganic chemicals, etc. Heavy metals are among the dangerous and persistent contaminants present in water that receive special attention (Ekwe et al., 2006; Eze, 2011). High levels of heavy metal contamination in the soil, followed by surface and groundwater, have been caused by the rapid economic development and industrialisation of many cities, including Enugu State Nigeria Flyhammar (1995), Christensen et al. (2001), Kjeldsen et al. (2002), Oygard et al. (2004), Mor et al. (2006), Oman and Junestedt (2008), Vasanthavigar et al. (2010), Cumar and Nagaraja, (2011), Edet and Offiong (2002), Ezugwu et al. (2019) and Egbueri (2020. This study assessed the impact of increased industrialization and population within three major metropolis in Enugu, namely Abakpa, Emena, and Independence Layout by analyzing 60 water samples and 10 shale samples on the health of the inbitants. Determining the type and scope of negative health impacts on people who may be exposed to harmful substances in a contaminated environment constitutes human health risk assessment. Risk and exposure assessments were performed in the current work using the USEPA approach.

1.1 LOCATION OF THE STUDY AREA
The study area, covering 191.19 km^{2}is located within Enugu metropolis in southeastern Nigeria (Fig. 1). The area is bounded by latitudes 6°24' and 6°31' north of the equator and longitudes 7°29' and 7°37' east of the Greenwich meridian. It has a network of both secondary and primary roads. The primary roads connect major towns within the metropolis while the secondary roads link the local communities to the primary roads. There are minor pathways and access routes that traverse the area. A major railway, which links the southwestern part of the area to the northeastern region, is seen passing through Independence Layout and Emene. Generally, the area is accessibile through major paved roads that link the study area to the southern part of the country through

Awka and Onitsha, and the northern part through Nsukka and Obollo-Afor. Other major paved roads connect the study area to the commercial areas in Ninth Mile. Majority of the roads are seasonal, and several of them are relatively passable in the heart of the rainy season (June - September). The surrounding villages and towns are Nsude, Oji River, Obioma and Udi to the south; Nsukka, Ameke Ngwo to the north; Abaja Ngwo, Ngwo Uno, Uwani Uborji to the northeast, and Eke to the northwest.

The Enugu Formation, which consists of blue to dark grey and soft grey shales and mudstones, underlies the city in the majority. The shale units also contain interbedded sandstones and sandy shales (Reijers, 1996). The fractured shales have a history of weathering into grayish and blackish laterites that operate as a cap over the bedrock and, in certain places, can reach a thickness of roughly 20 m. (Onwuka et al., 2004). One of the known aquifers in the city that is normally continuous but occasionally interrupted by new bedrock is made up of the fractured parts of the shale. The sandstone aquifers in Agbani and Owelli are two others (Ezeh, 2020). Precipitation provides aquifer replenishment.(Fig 1).

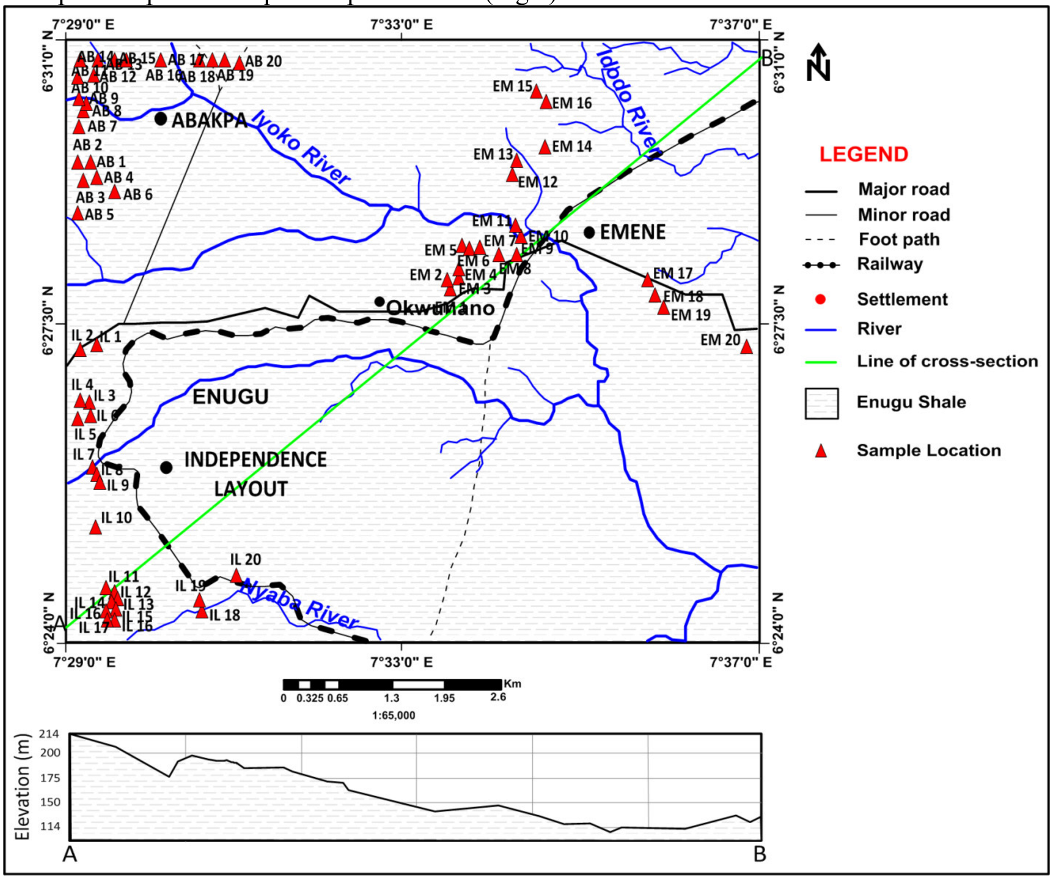

Fig. 1 Geologic map of the study area showing the drainage pattern and sampled locations

2.0 MATERIALS AND METHODS

This study started with a desk study and reconnaissance survey. A reconnaissance field study was conducted between 12th and 14th of March, 2022 to identify the locations of dumpsites, sewage systems, timber markets, and oil spill zones in three settlement areas (Abakpa, Emene and Independence Layout) within the metropolis prior to the sample collection. The focus of the field study is to identify and sample groundwater which are proximal to dumpsites, sewage systems, timber markets and oil spill zones (Fig 2). Groundwater samples were collected from hand dug wells and boreholes at sixty (60) different points within the three settlement of the 60 samples, three (3) samples (one (1) from each area), collected away from the source points, were designated as control samples. The concentrations of heavy metals and the presence of organic compounds in water samples collected from three settlement areas (Abakpa-Nike, Emene and Independence Layout) in Enugu metropolis, Nigeria has been assessed using physicochemical, HPLC-MS (High Performance Liquid Chromatography coupled to Mass Spectrometry) and contaminant transport modeling techniques. The values were used to calculate the cancerous and non cancerous health risks, as well as the contaminant transport model.

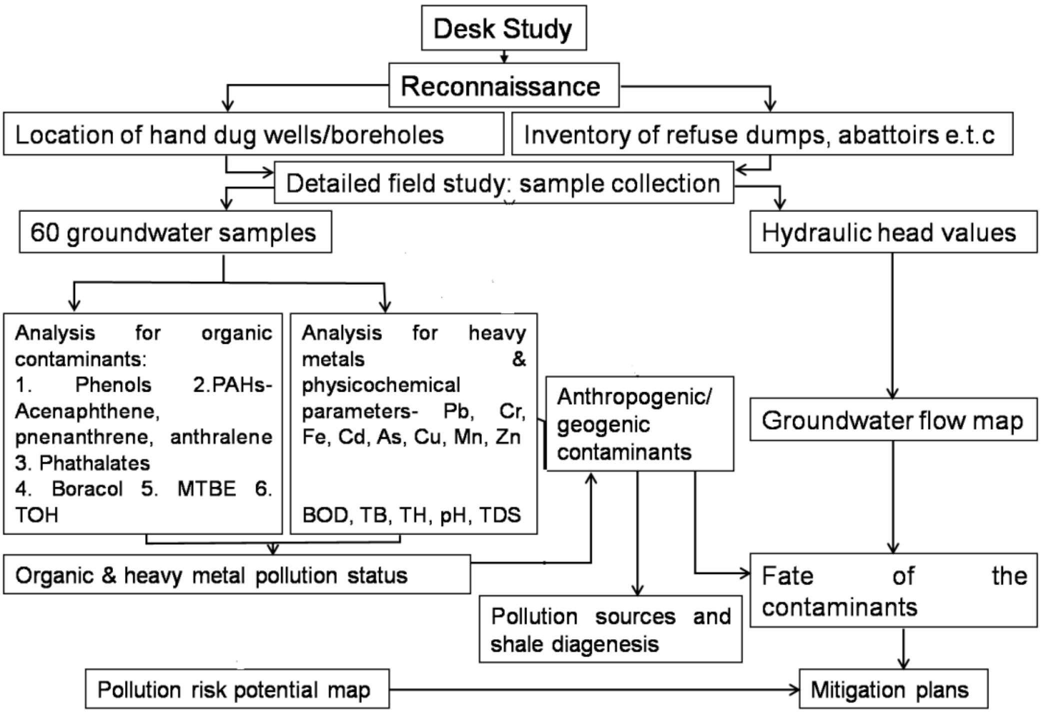

Fig 2 The work flow summarizes the systematic steps taken in this research

3.0 RESULT AND DISCUSSIONS

3.1 Assessment of Health Risks

The non-carcinogenic and carcinogenic human health risks were measured by evaluating the health index (HI), health quotient (HQ) and carcinogenic risk (CR) were calculated according to Egbueri 2022.

3.2 Assessment of non-carcinogenic health risks in Abakpa settlement area

The results of the HI and HQ for oral ingestion and dermal absorption of ground water in Abakpa are presented in Tables 14 and 15. For oral ingestion, the HQ_{oral} for the studied heavy metals are in the order Pb>Cd>Cr>Zn>Cu>As>Mn>Fe. Their values ranged from 0.1074-1.8046, -0.8247-0.7890, 0.0064-0.0505, -0.0004-0.0195, 0.0053-0.0242, -0.019-2.72, 0.006-2.745, and -0.0007-0.1418 for Pb, Cd, Cr, Zn, Cu, As, Mn and Fe respectively with corresponding average values of 0.56236, 0.32885, 0.30385, 0.20606, 0.04802, 0.02466, 0.01238 and 0.00444 (Table 1).

HQ values greater than one (HQ>1) suggests adverse non-carcinogenic health impact while those less than one (HQ<1) implies safe limits for drinking and domestic activities (Zakir et al., 2020). Consequently, the following heavy metals with their respective sampling points yielded HQ_{oral} values above the safe limits for drinking purposes: Pb (AB 1, AB 2 and AB 10), Mn (AB 10 and AB 13) and As (AB 10 and AB13). Others fall within the allowable limit for drinking water (Table 14). The HQ values for dermal absorption of groundwater in Abakpa ranged from 0.0154-0.0311, 0.013-0.0203, -0.2760-0.3012, 0.0689-1.0483, 0.00694-0.005104, 0.0309-0.0380, 0.0608-0.1118 and 0.1102-0.7110 for Cu, Zn, Pb, Cd, Cr, As, Mn and Fe, respectively, in their order of increasing trend. The mean values are 0.26684, 0.18437, 0.09276, 0.07823,0.03265, 0.02520, 0.02189 and 0.01551. On the basis of the obtained HQ_{dermal} values, all the samples fall below the limit recommended for non-carcinogenic health impacts except Cd in sample AB 13, which also exceeded the boundary limit for HQ_{oral} in Mn and As.

The resulting HI values ranged from -0.2547-6.5855 and 0.12744-1.66694 for oral ingestion and dermal absorption respectively (Tables 2). The average value for HI-oral is 1.4906, while that of dermal absorption is 0.71742. Based on oral ingestion of ground water in Abakpa, samples AB 1, AB 2, AB 3, AB 4, AB 5, AB 6, AB 9, AB 10, AB 13 and AB 18, which constitute about 50% of the sampled water has its HI values greater than one and thus, predisposes the inhabitants to greater risks of contracting non-carcinogenic ailments during their lifetime, whereas on the basis of dermal absorption, only 20% of the samples (AB 1, AB 2, AB 10 and AB 13) has HI values greater than one.

Table 1 Calculated Hazard Quotient (HQ) and Hazard Index (HI) as a result of oral ingestion of water from Abakpa settlement area and their basic statistics (* represents control sample)

Sample	Hazard Quotient (HQ-oral)								HI-oral
	Cd	Cr	Cu	Fe	Pb	Mn	Zn	As	
AB 1	0.756	0.0073	0.0063	0.1045	1.6773	0.325	0.0111	0.3	3.1875
AB 2	0.228	0.0064	0.0053	0.092	1.4633	0.435	0.008	0.41	2.648
AB 3	0.459	0.0505	0.0134	0.013	0.5864	0.05	0.0027	0.025	1.2
AB 4	0.6768	0.0337	0.0259	0.0118	0.3856	0.061	0.0024	0.036	1.2332
AB 5	0.327	0.0453	0.009	0.0041	0.6185	0.039	0.0006	0.014	1.0575
AB 6	0.162	0.043	0.0084	0.0036	0.4214	0.27	-0.0004	0.245	1.153
AB 7	0.096	0.0373	0.0187	0.0048	0.2941	0.028	0.0018	0.003	0.4837
AB 8	0.327	0.0348	0.0068	0.0028	0.3893	0.006	0.0014	-0.019	0.7491
AB 9	0.096	0.0204	0.0209	0.0106	0.3959	0.435	0.0013	0.41	1.3901
AB 10	0.789	0.012	0.0083	0.1045	1.8046	1.095	0.0123	1.07	4.8957
AB 11	-0.003	0.0211	0.0117	0.054	0.4289	0.061	0.0038	0.036	0.6135
AB 12	0.162	0.0222	0.0109	0.0628	0.2177	0.193	0.003	0.168	0.8396
AB 13	0.327	0.0162	0.0145	0.1309	0.6147	2.745	0.0172	2.72	6.5855
AB 14	0.129	0.0184	0.006	0.0941	0.1338	0.105	0.001	0.08	0.5673
AB 15	0.228	0.0237	0.0061	0.0317	0.1244	0.05	-0.0001	0.025	0.4888
AB 16	0.129	0.0212	0.0151	0.1418	0.3158	0.105	0.0004	0.08	0.8083
AB 17	-0.8247	0.018	0.0123	-0.0007	0.1338	0.215	0.0016	0.19	-0.2547
AB 18	0.063	0.0154	0.0172	0.0357	0.808	0.215	0.0195	0.19	1.3638
AB 19	-0.003	0.0368	0.0066	0.0033	0.3262	0.105	0.0003	0.08	0.5552
AB 20*	-0.003	0.0094	0.0242	0.055	0.1074	0.039	0.0009	0.014	0.2469
Average	0.32885	0.30385	0.04802	0.00444	0.56236	0.01238	0.20606	0.02466	1.4906

Table 2 Calculated Hazard Quotient (HQ) and Hazard Index (HI) as a result of dermal absorption of water from Abakpa settlement area and their basic statistics (* represents control sample)

Sample	Hazard Quotient (HQ-dermal)								HI-dermal
	Cd	Cr	Cu	Fe	Pb	Mn	Zn	As	
AB 1	0.183	0.00784	0.0157	0.6655	0.2894	0.0984	0.0133	0.035	1.30814
AB 2	0.2223	0.00694	0.0154	0.5890	0.1006	0.0940	0.013	0.0339	1.07514
AB 3	0.0847	0.05104	0.0311	0.2754	0.1832	0.0657	0.0159	0.032	0.73904
AB 4	0.0886	0.03424	0.0251	0.2036	0.2611	0.0653	0.0203	0.0319	0.73014
AB 5	0.0807	0.04584	0.0293	0.2869	0.1360	0.0625	0.0143	0.0313	0.68684
AB 6	0.1633	0.04354	0.0285	0.2164	0.0770	0.0624	0.0141	0.0309	0.63614
AB 7	0.0768	0.03784	0.0264	0.1709	0.0534	0.0628	0.0178	0.0317	0.47764
AB 8	0.0689	0.03534	0.0255	0.2050	0.1360	0.0621	0.0135	0.0316	0.57794
AB 9	0.2223	0.02094	0.0204	0.2073	0.0534	0.0648	0.0186	0.0315	0.63924
AB 10	0.4583	0.01254	0.0174	0.7110	0.3012	0.0984	0.014	0.0355	1.64834
AB 11	0.0886	0.02164	0.0206	0.2191	0.0180	0.0804	0.0153	0.0324	0.49604
AB 12	0.1358	0.02274	0.021	0.1436	0.0770	0.0835	0.015	0.0322	0.53084
AB 13	1.0483	0.01674	0.0189	0.2856	0.1360	0.1079	0.0163	0.0372	1.66694
AB 14	0.1043	0.01894	0.0196	0.1136	0.0652	0.0947	0.0132	0.0314	0.46094
AB 15	0.0847	0.02424	0.0216	0.1102	0.1006	0.0724	0.0132	0.031	0.45794
AB 16	0.1043	0.02174	0.0206	0.1787	0.0652	0.1118	0.0165	0.0312	0.55004
AB 17	0.1437	0.01854	0.0195	0.1136	-0.276	0.0608	0.0155	0.0316	0.12744
AB 18	0.1437	0.01594	0.0186	0.3547	0.0416	0.0738	0.0172	0.038	0.70354
AB 19	0.1043	0.03734	0.0262	0.1824	0.0180	0.0622	0.0134	0.0312	0.47504
AB 20*	0.0807	0.00994	0.0164	0.1042	0.0180	0.0807	0.0197	0.0314	0.36104
Average	0.07823	0.03265	0.26684	0.01551	0.09276	0.02189	0.18437	0.02520	0.71742

Thus, implying that the inhabitants of the study area stand a greater risk of contracting non-cancer related ailments through drinking of contaminated groundwater water than through bathing or skin contact. The values for oral ingestion and dermal absorption of groundwater in Abakpa were represented in a bar graph and the plot presented in Fig. 3. The green line drawn across the figure indicates the threshold value of one. HI values above this line suggests samples whose consumption might pose adverse health impact to the water consumers.

Evidence from the spatial distribution maps previously discussed shows that most of the affected samples were collected in vicinities where moderate to high concentration values of some heavy metals (Cd, Cr, Zn, Mn and As) in the groundwater were recorded.

3.3Assessment of carcinogenic health risks in Abakpa settlement area

The potential risk of settlers in Abakpa contracting cancer as a result of prolonged exposure to heavy metals is high. According to USEPA (2010). The acceptable range for Σ*ILCR* is 1.0×10^{-6} to 1.0×10^{-4} for multi-element carcinogens and single carcinogenic element and, implying a probability of one (1) person contracting cancer in 1000000 populations for a single carcinogen to one (1) in 10000 for multi-element carcinogen (USEPA, 2010; Mohammadi et al., 2019; Zakir et al., 2020). Based on this proposition, the chances that one may develop cancer as a result of consumption of contaminated water in the Abakpa area through dermal absorption or oral ingestion of heavy metals are high (Table 3).

For groundwater in this area, with the exception of samples AB 7, AB 9, AB 13, AB 16 and AB 17 that falls within the safe range of carcinogenic risks, other sampled points (AB 1, AB 2, AB 3, AB 4, AB 5, AB 6, AB 8, AB 10, AB 11, AB 12, AB 14, AB 15, AB 18, AB 19 and AB 20) predisposes one to a high risk of developing cancer over a life time (Table 16).From the foregoing, the main threat to human health in Abakpa as a result of exposure to heavy metals is associated mostly with copper, cadmium, arsenic. Toxicity from these heavy metals through drinking water could be acute and chronic after a long-term exposure and can lead to damages of several body organs such as kidney, brain, lungs and liver (Engwa et al., 2018; Obasi et al., 2020).

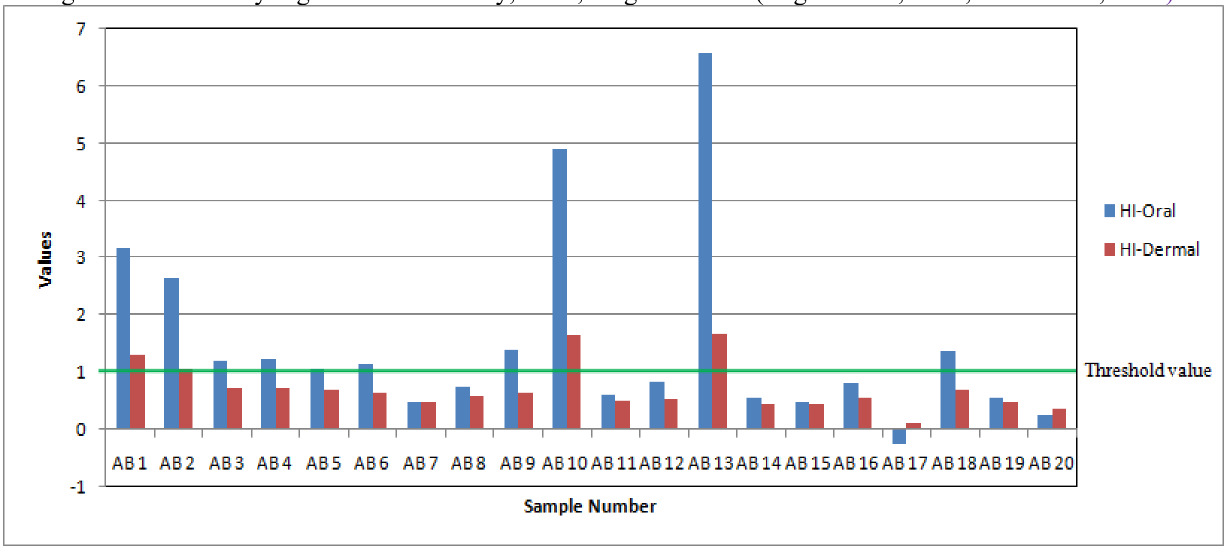

Fig. 3 Graphical representation of HI values of analyzed metals for oral ingestion and dermal absorption in Abakpa settlement area

Table 3 Calculated incremental lifetime cancer risks (ILCR) of the heavy metals for ingestion and dermal absorption of water in Abakpa

Location	Mn		As		Fe		Zn		Pb		Cu		Cd		Cr		
	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	∑ILCR
AB 1																	
AB 2	0.0024	0.000089	0.00335	0.00275	0.00231	0.000086	0.000068	8.32E-05	0.003284	6.02E-05	0.003194	5.72E-05	0.003284	0.003096	0.005703	0.014604	0.044419
AB 3	-0.0007	0.000027	0.00681	0.00621	-0.00079	0.000024	0.00081	0.000488	0.006744	0.000802	0.006654	0.000799	0.006744	0.006556	-0.00598	0.002923	0.038124
AB 4	-0.006	0.000022	0.01008	0.00948	-0.00609	0.000019	0.000527	0.000333	0.010014	0.000519	0.009924	0.000516	0.010014	0.009826	-0.00019	0.008713	0.05771
AB 5	-0.0063	0.000025	0.00483	0.00423	-0.00639	0.000022	0.000721	0.000439	0.004764	0.000713	0.004674	0.00071	0.004764	0.004576	0.003812	0.012713	0.034304
AB 6	-0.0081	-2.4E-05	0.00236	0.00176	-0.00819	-2.7E-05	0.000683	0.000419	0.002294	0.000675	0.002204	0.000672	0.002294	0.002106	-0.00299	0.005913	0.002053
AB 7	-0.0091	-2.4E-05	0.00137	0.00077	-0.00919	-2.7E-05	0.000586	0.000366	0.001304	0.000578	0.001214	0.000575	0.001304	0.001116	-0.00641	0.002493	-0.01307
AB 8	-0.0069	-8.3E-06	0.00483	0.00423	-0.00699	-1.1E-05	0.000545	0.000343	0.004764	0.000537	0.004674	0.000534	0.004764	0.004576	-0.00791	0.000993	0.008973
AB 9	-0.0073	0.000034	0.00137	0.00077	-0.00739	0.000031	0.000304	0.000212	0.001304	0.000296	0.001214	0.000293	0.001304	0.001116	-0.00327	0.005633	-0.00408
AB 10	-0.0074	0.000028	0.01178	0.01118	-0.00749	0.000025	0.000162	0.000135	0.011714	0.000154	0.011624	0.000151	0.011714	0.011526	-0.00835	0.000553	0.047509
AB 11	0.0036	-4.9E-05	-0.00012	-0.00072	0.00351	-5.2E-05	0.000315	0.000218	-0.00019	0.000307	-0.00028	0.000304	-0.00019	-0.00037	0.005612	0.014513	0.026416
AB 12	-0.0049	-8E-05	0.00236	0.00176	-0.00499	-8.3E-05	0.000334	0.000228	0.002294	0.000326	0.002204	0.000323	0.002294	0.002106	-0.01035	-0.00145	-0.00762
AB 13	-0.0057	-8.2E-05	0.00483	0.00423	-0.00579	-8.5E-05	0.000233	0.000173	0.004764	0.000225	0.004674	0.000222	0.004764	0.004576	-0.00696	0.001943	0.012019
AB 14	0.0085	-9.2E-05	0.00186	0.00126	0.00841	-9.5E-05	0.000269	0.000193	0.001794	0.000261	0.001704	0.000258	0.001794	0.001606	-0.00374	0.005163	0.029149
AB 15	-0.0077	-9.4E-05	0.00335	0.00275	-0.00779	-9.7E-05	0.000359	0.000242	0.003284	0.000351	0.003194	0.000348	0.003284	0.003096	-0.00774	0.001163	-0.002
AB 16	-0.0088	-9.1E-05	0.00186	0.00126	-0.00889	-9.4E-05	0.000316	0.000219	0.001794	0.000308	0.001704	0.000305	0.001794	0.001606	-0.00558	0.003323	-0.00896
AB 17	-0.0083	-9.3E-05	0.01218	0.01158	-0.00839	-9.6E-05	0.000263	0.00019	0.012114	0.000255	0.012024	0.000252	0.012114	0.011926	-0.00766	0.001243	0.049604
AB 18	-0.0071	-9.5E-05	0.00087	0.00027	-0.00719	-9.8E-05	0.000219	0.000166	0.000804	0.000211	0.000714	0.000208	0.000804	0.000616	0.006312	0.015213	0.011925
AB 19	0.0108	-9.4E-05	-0.00011	-0.00071	0.01071	-9.7E-05	0.000578	0.000361	-0.00018	0.00057	-0.00027	0.000567	-0.00018	-0.00037	-0.00913	-0.00023	0.012225
AB 20	-0.0084	-9.4E-05	-0.00011	-0.00071	-0.00849	-9.7E-05	0.000118	0.00011	-0.00018	0.00011	-0.00027	0.000107	-0.00018	-0.00037	-0.00994	-0.00104	-0.02943

3.4 Assessment of carcinogenic health risks in Emene settlement area

Similarly, 80% of sampled locations (EM 3, EM 4, EM 5, EM 6, EM 7, EM 8, EM 9, EM 10) in Emene show ILCR values that exceed the allowable range of 1.0×10^{-6} to 1.0×10^{-4} for multi-element carcinogens and single carcinogenic element, with a range of 0.001206-0.03714 (Table 4). Only samples EM 1, EM 2 and EM 11, which constitutes 15% of the total samples, have ILCR values that falls within the permisible range. This indicates a high carcinogenic risk for most residents in Emene who consume groundwater from boreholes or hand dug wells. In this case, the main threat to human health arises mostly from the consumption of manganese, iron and arsenic. The HQ values for dermal absorption of groundwater in Emene varies from 0.00075-0.01465, 0.00201-0.00931, -0.0215-0.9579, -0.0467- -0.0035, 0.01412-0.06512, -0.0258-0.5810, -0.0765-0.2067 and 0.0121-0.0192 in the order Cu>Zn>Cd>Cr>Mn>Fe>Pb>As (Table 17). Accordingly, the average values are 0.13684, 0.09397, 0.03155, 0.01385, 0.00724, 0.00452, -0.001765 and -0.02935. The HQdermal values obtained from all the samples fall within the limit approved for non-carcinogenic health impacts (Tables 4).

HI values of the heavy metals varies between -0.3529-4.7975 (average = 1.3924) and -0.331-1.18 (average = 0.25686) for oral ingestion and dermal absorption respectively (Tables 4 and 16). The results of HI obtained for the samples shows that 45% of the samples (EM 1, EM 2, EM 3, EM 4, EM 6, EM 9, EM 10 and EM 13) have HI values above one (1), which suggests that settlers in Emene are at considerable risk of contracting non-carcinogenic illnesses by oral ingestion during their lifetime. On the other hand, only 10% of the samples (EM 10 and EM 13) indicate HI values for dermal absorption that exceeds the boundary limit. This is also an indication that water users in Emene are more likely to contract non-cancer related ailments through drinking of contaminated groundwater water than through bathing or skin contact. A similar conclusion was reached for water samples collected in Abakpa. The values for oral ingestion and dermal absorption of groundwater in Emene are presented in a bar graph shown in Fig. 4.

Journal of Environment and Earth Science www.iiste.org
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.13, No.4, 2023

Table 4 Calculated Hazard Quotient (HQ) and Hazard Index (HI) as a result of oral ingestion of water from Emene settlement area and their basic statistics (* represents control sample)

Sample	Hazard Quotient (HQ-oral)								HI-oral
	Cd	Cr	Cu	Fe	Pb	Mn	Zn	As	
EM 1	0.7476	-0.0014	-0.0022	0.0958	1.6213	0.3345	0.0024	0.2913	3.0893
EM 2	0.2196	-0.0023	-0.0032	0.0833	1.4073	0.4445	-0.0007	0.4013	2.5498
EM 3	0.4506	0.0418	0.0049	0.0043	0.5304	0.0595	-0.006	0.0163	1.1018
EM 4	0.6684	0.025	0.0174	0.0031	0.3296	0.0705	-0.0063	0.0273	1.135
EM 5	0.3186	0.0366	0.0005	-0.0046	0.5625	0.0485	-0.0081	0.0053	0.9593
EM 6	0.1536	0.0343	-1E-04	-0.0051	0.3654	0.2795	-0.0091	0.2363	1.0548
EM 7	0.0876	0.0286	0.0102	-0.0039	0.2381	0.0375	-0.0069	-0.0057	0.3855
EM 8	0.3186	0.0261	-0.0017	-0.0059	0.3333	0.0155	-0.0073	-0.0277	0.6509
EM 9	0.0876	0.0117	0.0124	0.0019	0.3399	0.4445	-0.0074	0.4013	1.2919
EM 10	0.7806	0.0033	-0.0002	0.0958	1.7486	1.1045	0.0036	1.0613	4.7975
EM 11	-0.0114	0.0124	0.0032	0.0453	0.3729	0.0705	-0.0049	0.0273	0.5153
EM 12	0.1536	0.0135	0.0024	0.0541	0.1617	0.2025	-0.0057	0.1593	0.7414
EM 13	0.3186	0.0075	0.006	0.1222	0.5587	2.7545	0.0085	2.7113	6.4873
EM 14	0.1206	0.0097	-0.0025	0.0854	0.0778	0.1145	-0.0077	0.0713	0.4691
EM 15	0.2196	0.015	-0.0024	0.023	0.0684	0.0595	-0.0088	0.0163	0.3906
EM 16	0.1206	0.0125	0.0066	0.1331	0.2598	0.1145	-0.0083	0.0713	0.7101
EM 17	-0.8331	0.0093	0.0038	-0.0094	0.0778	0.2245	-0.0071	0.1813	-0.3529
EM 18	0.0546	0.0067	0.0087	0.027	0.752	0.2245	0.0108	0.1813	1.2656
EM 19	-0.0114	0.0281	-0.0019	-0.0054	0.2702	0.1145	-0.0084	0.0713	0.457
EM 20*	-0.0114	0.0007	0.0157	0.0463	0.0514	0.0485	-0.0078	0.0053	0.1487
Average	0.33835	0.29515	0.03932	-0.00426	0.50636	0.00388	0.19766	0.01596	1.3924

Table 5 Calculated Hazard Quotient (HQ) and Hazard Index (HI) as a result of dermal absorption of water from Emene settlement area and their basic statistics (* represents control sample)

Sample	Hazard Quotient (HQ-dermal)								HI-dermal
	Cd	Cr	Cu	Fe	Pb	Mn	Zn	As	
EM 1	0.0926	-0.0467	0.00105	0.53550	0.1949	0.05172	0.00231	0.0162	0.84759
EM 2	0.1319	-0.0476	0.00075	0.45900	0.0061	0.04732	0.00201	0.0151	0.61458
EM 3	-0.0057	-0.0035	0.01645	0.14540	0.0887	0.01902	0.00491	0.0132	0.27848
EM 4	-0.0018	-0.0203	0.01045	0.07360	0.1666	0.01862	0.00931	0.0131	0.26958
EM 5	-0.0097	-0.0087	0.01465	0.15690	0.0415	0.01582	0.00331	0.0125	0.22628
EM 6	0.0729	-0.011	0.01385	0.08640	-0.0175	0.01572	0.00311	0.0121	0.17558
EM 7	-0.0136	-0.0167	0.01175	0.04090	-0.0411	0.01612	0.00681	0.0129	0.01708
EM 8	-0.0215	-0.0192	0.01085	0.07500	0.0415	0.01542	0.00251	0.0128	0.11738
EM 9	0.1319	-0.0336	0.00575	0.07730	-0.0411	0.01812	0.00761	0.0127	0.17868
EM 10	0.3679	-0.042	0.00275	0.58100	0.2067	0.05172	0.00301	0.0167	1.18778
EM 11	-0.0018	-0.0329	0.00595	0.08910	-0.0765	0.03372	0.00431	0.0136	0.03548
EM 12	0.0454	-0.0318	0.00635	0.01360	-0.0175	0.03682	0.00401	0.0134	0.07028
EM 13	0.9579	-0.0378	0.00425	0.15560	0.0415	0.06122	0.00531	0.0184	1.20638
EM 14	0.0139	-0.0356	0.00495	-0.0164	-0.0293	0.04802	0.00221	0.0126	0.00038
EM 15	-0.0057	-0.0303	0.00695	-0.0198	0.0061	0.02572	0.00221	0.0122	-0.00262
EM 16	0.0139	-0.0328	0.00595	0.04870	-0.0293	0.06512	0.00551	0.0124	0.08948
EM 17	0.0533	-0.036	0.00485	-0.0164	-0.3703	0.01412	0.00451	0.0128	-0.3331
EM 18	0.0533	-0.0386	0.00395	0.22470	-0.0529	0.02712	0.00621	0.0192	0.24298
EM 19	0.0139	-0.0172	0.01155	0.05240	-0.0765	0.01552	0.00241	0.0124	0.01448
EM 20*	-0.0097	-0.0446	0.00175	-0.0258	-0.0765	0.03402	0.00871	0.0126	-0.09952
Average	0.03155	0.01385	0.13684	0.00452	-0.00175	0.00724	0.09397	-0.02935	0.25686

Table 6 Calculated incremental lifetime cancer risks (ILCR) of the heavy metals for ingestion and dermal absorption of water in Emene

Location	Mn		As		Fe		Zn		Pb		Cu		Cd		Cr		
	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	∑ILCR
EM 1	-0.0078	-7.9E-05	-0.00012	-0.00072	-0.00789	-8.2E-05	0.000187	0.000148	-0.00018	0.000179	-0.00027	0.000176	-0.00018	-0.00037	-0.01066	-0.00176	-0.02941
EM 2	0.00231	-9.3E-05	-0.00012	-0.00072	0.00222	-9.6E-05	0.000306	0.000139	-0.00018	0.000298	-0.00027	0.000295	-0.00018	-0.00037	-0.00851	0.000393	-0.00458
EM 3	0.00201	-9.6E-05	-0.00012	-0.00072	0.00192	-9.9E-05	0.0009	0.000351	-0.00018	0.000892	-0.00027	0.000889	-0.00018	-0.00037	0.004714	0.013615	0.023254
EM 4	0.00491	-9.1E-05	-0.00012	-0.00072	0.00482	-9.4E-05	-0.00009	-3E-06	-0.00018	-9.8E-05	-0.00027	-0.0001	-0.00018	-0.00037	-0.00608	0.002825	0.004161
EM 5	0.00931	-9.7E-05	-0.00012	-0.00072	0.00922	-1E-04	0.00239	0.000882	-0.00018	0.002382	-0.00027	0.002379	-0.00018	-0.00037	-0.00029	0.008615	0.032853
EM 6	0.00331	-9.7E-05	-0.00011	-0.00071	0.00322	-1E-04	0.000356	0.000156	-0.00018	0.000348	-0.00027	0.000345	-0.00018	-0.00037	0.003714	0.012615	0.022051
EM 7	0.00311	-9.5E-05	-0.00011	-0.00071	0.00302	-9.8E-05	-0.00009	-3E-06	-0.00018	-9.8E-05	-0.00027	-0.0001	-0.00018	-0.00037	-0.00309	0.005815	0.006555
EM 8	0.00681	-9.7E-05	-0.00011	-0.00071	0.00672	-1E-04	0.00338	0.001237	-0.00017	0.003372	-0.00026	0.003369	-0.00017	-0.00036	-0.00651	0.002395	0.018789
EM 9	0.00251	-8.9E-05	-9.3E-05	-0.00069	0.00242	-9.2E-05	0.00437	0.001587	-0.00016	0.004362	-0.00025	0.004359	-0.00016	-0.00035	-0.00801	0.000895	0.010617
EM10	0.00761	-9.4E-05	-0.00011	-0.00071	0.00752	-9.7E-05	0.000405	0.000174	-0.00017	0.000397	-0.00026	0.000394	-0.00017	-0.00036	-0.00337	0.005535	0.016693
EM 11	0.00301	-9.7E-05	-0.00011	-0.00071	0.00292	-1E-04	0.0009	0.000351	-0.00018	0.000892	-0.00027	0.000889	-0.00018	-0.00037	-0.00845	0.000455	-0.00105
EM 12	0.00431	-9E-05	-9.6E-05	-0.0007	0.00422	-9.3E-05	0.000121	7.23E-05	-0.00016	0.000113	-0.00025	0.00011	-0.00016	-0.00035	0.005514	0.014415	0.026976
EM 13	0.00401	0.001141	0.00335	0.00275	0.00392	0.001138	0.000121	7.23E-05	0.003284	0.000113	0.003194	0.00011	0.003284	0.003096	-0.01045	-0.00154	0.017594
EM 14	0.00531	0.002381	0.00022	-0.00038	0.00522	0.002378	0.000164	8.77E-05	0.000154	0.000156	0.000064	0.000153	0.000154	-3.4E-05	-0.00706	0.001845	0.010818
EM 15	0.00221	0.003551	0.000228	-0.00037	0.00212	0.003548	0.000281	0.00013	0.000162	0.000273	0.000072	0.00027	0.000162	-2.6E-05	-0.00384	0.005065	0.013839
EM 16	0.00221	0.001671	0.000091	-0.00051	0.00212	0.001668	0.000266	0.000124	0.000025	0.000258	-6.5E-05	0.000255	0.000025	-0.00016	-0.00784	0.001065	0.001206
EM 17	0.00551	0.000786	0.000091	-0.00051	0.00542	0.000783	0.000049	4.66E-05	0.000025	4.12E-05	-6.5E-05	3.82E-05	0.000025	-0.00016	-0.00568	0.003225	0.009628
EM 18	0.00451	0.000432	0.000134	-0.00047	0.00442	0.000429	-4.4E-05	1.36E-05	0.000068	-5.1E-05	-2.2E-05	-5.4E-05	0.000068	-0.00012	-0.00776	0.001145	0.002708
EM 19	0.00621	0.001671	0.000251	-0.00035	0.00612	0.001668	-7E-05	4.3E-06	0.000185	-7.7E-05	0.000095	-8E-05	0.000185	-2.8E-06	0.006214	0.015115	0.03714
EM 20	0.00241	0.000432	0.000236	-0.00036	0.00232	0.000429	-7.6E-05	2.17E-06	0.00017	-8.3E-05	0.00008	-8.6E-05	0.00017	-1.8E-05	-0.00923	-0.00032	-0.00393

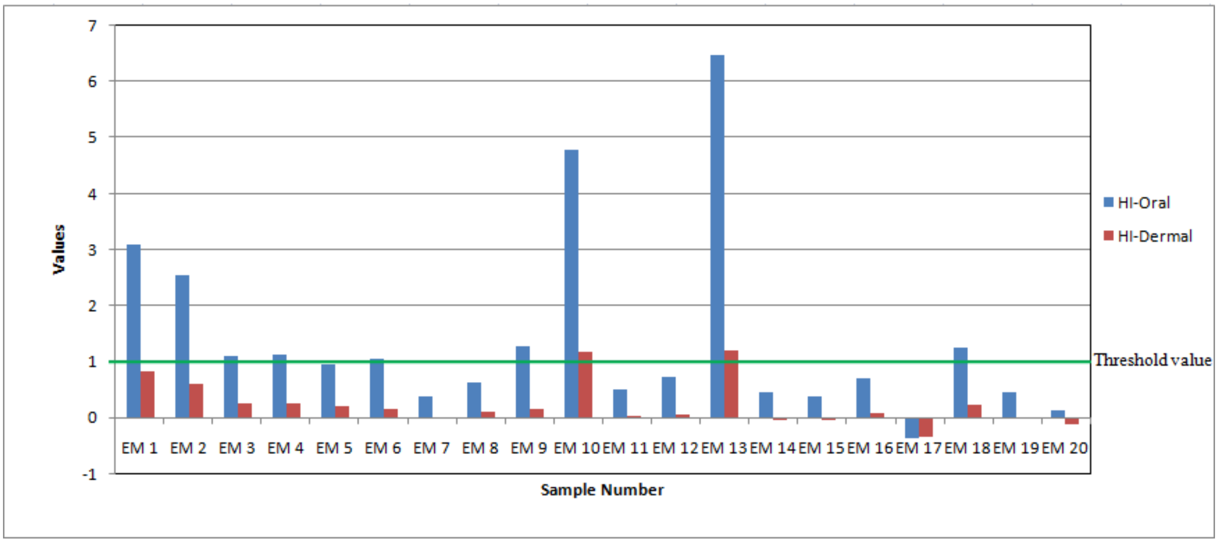

Fig. 4 Graphical representation of HI values of analyzed metals for oral ingestion and dermal absorption in Emene settlement area

3.5 Assessment of non-carcinogenic health risks in Independence Layout

The calculated results of the HI and HQ for oral ingestion and dermal absorption of ground water in Independce Layout are shown in Tables 7 and 8. Unlike Abakpa and Emene, HQ_{oral} values of the analyzed heavy metals in this settlement area are in the order Pb>Cd>As>Mn>Cu>Fe>Zn>Cr. Following same order, their values ranges from -0.8767-0.704, -0.00599-2.73301, 0.00138-0.02128, -0.01004-0.13246, 0.00741-0.05151, 0.00706-0.02766, 0.00676-0.02736 and -0.00844-0.13056, with average values of 0.15406, 0.03868, 0.03678, 0.02567, 0.01414, 0.01384, 0.013686 and 0.00622 . HQ_{oral} values of other heavy metals sampled in groundwater taken from Emene falls within the threshold value for safe drinking water excluding Cd in IL 10 and IL 13.

The HQ values for dermal absorption of groundwater in Independence Layout ranges between 0.00146-0.00876, -0.00032-0.00678, -0.3488-0.2282, -0.01154-0.03946, -0.01309-0.96631, 0.00141-0.01711, 0.00176-

0.00906 and 0.0045-0.0486 in the order Zn>As>Pb>Mn>Cd>Cu>Fe>Cr. The corresponding average HQ_{dermal} values of the heavy metals are 0.10238, 0.02276, 0.01976, 0.00790, 0.00589, 0.00427, 0.00397 and 0.00143. The HQ_{dermal} values obtained from all the samples fall within the limit approved for non-carcinogenic health impacts . Similar results were also obtained in the Emene settlement area.HI values of the heavy metals varies between -0.3529-4.7975 and -0.331-1.18 for oral ingestion and dermal absorption respectively (Tables 20 and 21). The results of HI obtained for the samples shows that only 15% of the samples (IL 1, IL 10 and IL 13) have HI values above one (1), which suggests that water consumers in Independence Layout are at a slight risk of contracting non-carcinogenic illnesses by oral ingestion during their lifetime.

On the other hand, only one sample (5%) show HI value for dermal absorption that exceeds the boundary limit. This suggests that inhabitants in Independce Layout are more likely to contract non-cancer related ailments through drinking of contaminated groundwater water than through bathing or skin contact. A similar conclusion was reached for water samples collected in Abakpa and Emene. Nothwithstanding, the risk of settlers contracting non-cancerous illnesses in Independence Layout is lesser when compared to other settlement areas. The values for oral ingestion and dermal absorption of groundwater in Emene are presented in a bar graph shown in Fig. 5.

Table 7 Calculated Hazard Quotient (HQ) and Hazard Index (HI) as a result of oral ingestion of water from Independence Layout and their basic statistics (* represents control sample)

Sample	Hazard Quotient (HQ-oral)								HI-oral
	Cd	Cr	Cu	Fe	Pb	Mn	Zn	As	
IL 1	0.31301	0.09326	0.00831	0.00806	0.704	0.09516	0.00776	0.01288	1.24244
IL 2	0.42301	0.08076	0.00741	0.00706	0.176	0.08266	0.00676	0.00978	0.79344
IL 3	0.03801	0.00176	0.05151	0.01516	0.407	0.00366	0.01486	0.00448	0.53644
IL 4	0.04901	0.00056	0.03471	0.02766	0.6248	0.00246	0.02736	0.00418	0.77074
IL 5	0.02701	-0.00714	0.04631	0.01076	0.275	-0.00524	0.01046	0.00238	0.35954
IL 6	0.25801	-0.00764	0.04401	0.01016	0.11	-0.00574	0.00986	0.00138	0.42004
IL 7	0.01601	-0.00644	0.03831	0.02046	0.044	-0.00454	0.02016	0.00358	0.13154
IL 8	-0.00599	-0.00844	0.03581	0.00856	0.275	-0.00654	0.00826	0.00318	0.30984
IL 9	0.42301	-0.00064	0.02141	0.02266	0.044	0.00126	0.02236	0.00308	0.53714
IL 10	1.08301	0.09326	0.01301	0.01006	0.737	0.09516	0.00976	0.01408	2.05534
IL 11	0.04901	0.04276	0.02211	0.01346	-0.055	0.04466	0.01316	0.00558	0.13574
IL 12	0.18101	0.05156	0.02321	0.01266	0.11	0.05346	0.01236	0.00478	0.44904
IL 13	2.73301	0.11966	0.01721	0.01626	0.275	0.12156	0.01596	0.01898	3.31764
IL 14	0.09301	0.08286	0.01941	0.00776	0.077	0.08476	0.00746	0.00278	0.37504
IL 15	0.03801	0.02046	0.02471	0.00786	0.176	0.02236	0.00756	0.00168	0.29864
IL 16	0.09301	0.13056	0.02221	0.01686	0.077	0.13246	0.01656	0.00218	0.49084
IL 17	0.20301	-0.01194	0.01901	0.01406	-0.8767	-0.01004	0.01376	0.00338	-0.64546
IL 18	0.20301	0.02446	0.01641	0.01896	0.011	0.02636	0.01866	0.02128	0.34014
IL 19	0.09301	-0.00794	0.03781	0.00836	-0.055	-0.00604	0.00806	0.00208	0.08034
IL 20*	0.02701	0.04376	0.01041	0.02596	-0.055	0.04566	0.02566	0.00268	0.12614
Average	0.03868	0.00622	0.01414	0.01384	0.15406	0.02567	0.013686	0.03678	0.60623

Table 8 Calculated Hazard Quotient (HQ) and Hazard Index (HI) as a result of dermal absorption of water from Independence Layout and their basic statistics (* represents control sample)

Sample	Hazard Quotient (HQ-dermal)								HI-dermal
	Cd	Cr	Cu	Fe	Pb	Mn	Zn	As	
IL 1	0.10101	0.0054	0.00171	0.00206	0.2164	0.02606	0.00176	0.00378	0.35818
IL 2	0.14031	0.0045	0.00141	0.00176	0.0276	0.02166	0.00146	0.00268	0.20138
IL 3	0.00271	0.0486	0.01711	0.00466	0.1102	-0.00664	0.00436	0.00078	0.18178
IL 4	0.00661	0.0318	0.01111	0.00906	0.1881	-0.00704	0.00876	0.00068	0.24908
IL 5	-0.00129	0.0434	0.01531	0.00306	0.063	-0.00984	0.00276	0.00008	0.11648
IL 6	0.08131	0.0411	0.01451	0.00286	0.004	-0.00994	0.00256	-0.00032	0.13608
IL 7	-0.00519	0.0354	0.01241	0.00656	-0.0196	-0.00954	0.00626	0.00048	0.02678
IL 8	-0.01309	0.0329	0.01151	0.00226	0.063	-0.01024	0.00196	0.00038	0.08868
IL 9	0.14031	0.0185	0.00641	0.00736	-0.0196	-0.00754	0.00706	0.00028	0.15278
IL 10	0.37631	0.0101	0.00341	0.00276	0.2282	0.02606	0.00246	0.00428	0.65358
IL 11	0.00661	0.0192	0.00661	0.00406	-0.055	0.00806	0.00376	0.00118	-0.00552
IL 12	0.05381	0.0203	0.00701	0.00376	0.004	0.01116	0.00346	0.00098	0.10448
IL 13	0.96631	0.0143	0.00491	0.00506	0.063	0.03556	0.00476	0.00598	1.09988
IL 14	0.02231	0.0165	0.00561	0.00196	-0.0078	0.02236	0.00166	0.00018	0.06278
IL 15	0.00271	0.0218	0.00761	0.00196	0.0276	6E-05	0.00166	-0.00022	0.06318
IL 16	0.02231	0.0193	0.00661	0.00526	-0.0078	0.03946	0.00496	-2E-05	0.09008
IL 17	0.06171	0.0161	0.00551	0.00426	-0.3488	-0.01154	0.00396	0.00038	-0.26842
IL 18	0.06171	0.0135	0.00461	0.00596	-0.0314	0.00146	0.00566	0.00678	0.06828
IL 19	0.02231	0.0349	0.01221	0.00216	-0.055	-0.01014	0.00186	-2E-05	0.00828
IL 20*	-0.00129	0.0075	0.00241	0.00846	-0.055	0.00836	0.00816	0.00018	-0.02122
Average	0.00589	0.00143	0.00427	0.00397	0.01976	0.00790	0.10238	0.02276	0.16833

3.6 Assessment of carcinogenic health risks in Independence Layout

All the samples in Independence Layout indicate a very high risk of contracting carncer related illnesses from ingestion or dermal contact with the groundwater, as their ILCR values far exceeds the required range stipulated for safety (Table 7). As, Mn and Fe poses the greatest threat of cancer associated diseases to settlers in Independence Layout.

3.7 General Interpretation of Organic Contaminants

Table 23 displays the concentration values of eight (8) organic compounds analyzed in water samples collected from the Abakpa settlement area. All analyzed water samples contained total organic halogen (TOH), boracol, phthalate, 2,4-dichlorophenol thioxate as well as PAHs, MTBE, BPA and total kjeldhal in varying concentrations. Of these compunds, TOH, Boracol, 2,4-dichlorophenol thioxate and MTBE, with concentration values that ranges from 10-59 mg/l, 7-58 µg/l, 4-44 µg/l, an 0.7-8.5 µg/l, have measured values that fall within the threshold concentration standard recommended by regulatory bodies (W.H.O (2017) and NSDWQ (2015)). These compunds show average concentration values of 25.60 mg/l, 26.55 µg/l, 23.85 µg/l, and 2.90 µg/l respectively. The boracol and MTBE concentration values was observed to be highest in sample AB 15 when compared to other samples. Conversely, phthalate, PAHs and BPA were detected in high concentrations in some of the sample sites.

Table 9 Calculated incremental lifetime cancer risks (ILCR) of the heavy metals for ingestion and dermal absorption of water in Independence Layout

Location	Mn		As		Fe		Zn		Pb		Cu		Cd		Cr		
	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	∑ILCR
IL 1	0.00871	0.004151	0.000019	-0.00058	0.00862	0.004148	-6.9E-05	4.64E-06	-4.7E-05	-7.6E-05	-0.00014	-7.9E-05	-4.7E-05	-0.00023	-0.01004	-0.00113	0.013211
IL 2	0.05172	-9.9E-05	-7.4E-05	-0.00067	0.05163	-0.0001	-7.5E-05	2.55E-06	-0.00014	-8.2E-05	-0.00023	-8.5E-05	-0.00014	-0.00033	-0.01076	-0.00185	0.088716
IL 3	0.04732	0.000786	-1E-04	-0.0007	0.04723	0.000783	-7.8E-05	1.19E-06	-0.00017	-8.6E-05	-0.00026	-8.9E-05	-0.00017	-0.00035	-0.00861	0.000295	0.085817
IL 4	0.01902	0.001671	-0.00011	-0.00071	0.01893	0.001668	-7.5E-05	2.21E-06	-0.00017	-8.3E-05	-0.00026	-8.6E-05	-0.00017	-0.00036	-0.01085	-0.00194	0.02648
IL 5	0.01862	0.000609	-9.9E-05	-0.0007	0.01853	0.000606	-7.5E-05	2.28E-06	-0.00016	-8.3E-05	-0.00025	-8.6E-05	-0.00016	-0.00035	-0.01063	-0.00173	0.024023
IL 6	0.01582	0.001141	-0.0001	-0.0007	0.01573	0.001138	-3.3E-05	1.73E-05	-0.00017	-4.1E-05	-0.00026	-4.4E-05	-0.00017	-0.00036	-0.01099	-0.00209	0.018884
IL 7	0.01572	0.000609	-0.00011	-0.00071	0.01563	0.000606	-7.4E-05	2.63E-06	-0.00017	-8.2E-05	-0.00026	-8.5E-05	-0.00017	-0.00036	-0.0101	-0.0012	0.01923
IL 8	0.01612	0.004311	-0.00011	-0.00071	0.01603	0.004308	-8.1E-05	3.8E-07	-0.00017	-8.8E-05	-0.00026	-9.1E-05	-0.00017	-0.00036	-0.01083	-0.00193	0.025978
IL 9	0.01542	0.000255	-0.00011	-0.00071	0.01533	0.000252	-6.9E-05	4.6E-06	-0.00017	-7.7E-05	-0.00026	-8E-05	-0.00017	-0.00036	-0.01099	-0.00209	0.016189
IL 10	0.01812	-9.9E-05	-6.3E-05	-0.00066	0.01803	-0.0001	-8.3E-05	-5.1E-07	-0.00013	-9.1E-05	-0.00022	-9.4E-05	-0.00013	-0.00032	-0.00975	-0.00085	0.023565
IL 11	0.05172	-9.9E-05	-0.0001	-0.0007	0.05163	-0.0001	-8.3E-05	-6.1E-07	-0.00017	-9.1E-05	-0.00026	-9.4E-05	-0.00017	-0.00036	-0.0094	-0.0005	0.091218
IL 12	0.03372	0.000432	-0.00011	-0.00071	0.03363	0.000429	-7.8E-05	1.42E-06	-0.00018	-8.5E-05	-0.00027	-8.8E-05	-0.00018	-0.00036	-0.01081	-0.00191	0.053435
IL 13	0.03682	-1.3E-05	-9.9E-05	-0.0007	0.03673	-1.6E-05	-8.3E-05	-5.1E-07	-0.00016	-9.1E-05	-0.00025	-9.4E-05	-0.00016	-0.00035	-0.00626	0.002645	0.067909
IL 14	0.06122	0.000392	-0.00011	-0.00071	0.06113	0.000389	-6.3E-05	6.66E-06	-0.00018	-7.1E-05	-0.00027	-7.4E-05	-0.00018	-0.00037	-0.00923	-0.00032	0.11156
IL 15	0.04802	0.000237	-0.00011	-0.00071	0.04793	0.000234	-7.7E-05	1.53E-06	-0.00018	-8.5E-05	-0.00027	-8.8E-05	-0.00018	-0.00037	-0.00774	0.001165	0.08778
IL 16	0.02572	0.000343	-0.00011	-0.00071	0.02563	0.00034	-8.4E-05	-7.9E-07	-0.00017	-9.2E-05	-0.00026	-9.5E-05	-0.00017	-0.00036	-0.00923	-0.00032	0.040425
IL 17	0.06512	0.000323	-0.00011	-0.00071	0.06503	0.00032	-6.6E-05	5.63E-06	-0.00018	-7.4E-05	-0.00027	-7.7E-05	-0.00018	-0.00037	0.001094	0.009995	0.139852
IL 18	0.01412	0.00027	-9.3E-05	-0.00069	0.01403	0.000267	0.01403	0.000267	-0.00016	0.014022	-0.00025	0.014019	-0.00016	-0.00035	-0.01022	-0.00131	0.057795
IL 19	0.02712	0.000247	-0.00011	-0.00071	0.02703	0.000244	-0.0002	-0.00072	-0.00017	-0.00021	-0.00026	-0.00021	-0.00017	-0.00036	-0.01013	-0.00123	0.040143
IL 20	0.01552	0.000116	-0.00011	-0.00071	0.01543	0.000113	-0.00019	-0.0007	-0.00018	-0.00019	-0.00027	-0.0002	-0.00018	-0.00037	-0.01085	-0.00195	0.015273

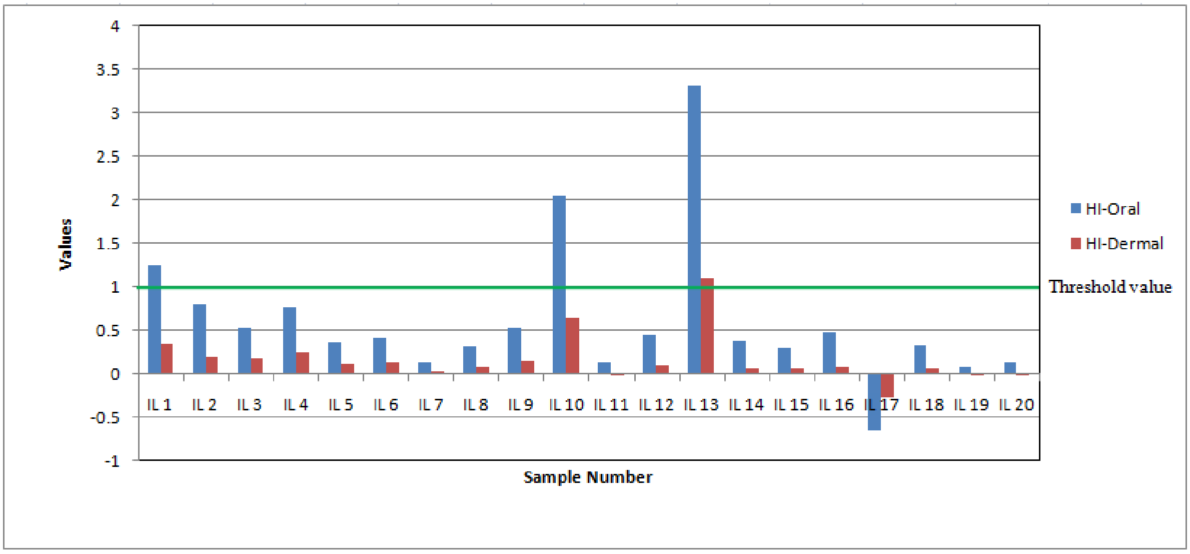

Fig. 5 Graphical representation of HI values of analyzed metals for oral ingestion and dermal absorption in Independence Layout

3.9 Water Quality Index (WQI)

The water quality index was employed to assess the suitability of the groundwater within the study area for consumption by integrating the individual and collective effect of all the physicochemical and organic parameters**.** This technique has been elaborately used by groundwater researches such as Olasehinde et al. (2015), Onwuka et al. (2018), Mama et al. (2020, 2021), Cumar and Nagaraja (2011), Edet and Offiong (2002), Ezugwu et al. (2019) and Egbueri (2020). WQI< 50 (Excellent) WQI 50-100 (Good water), WQI 100-200 (Poor water) WQI 200-300 (Very poor water) and WQI >300 (Unsuitable for drinking). None of the computed WQI fell within the excellent water quality within the study (Fig. 6). Generally 28.3% of the groundwater fell under the good water quality, 41.6% within the poor water quality, 20% within the very poor water quality and 10% within the unsuitable water condition Table 27. Fig. 6, which shows the spatial distribution of WQI values within the study area, shows that most of the water samples deemed very poor in quality or unsuitable for drinking are located within the Abakpa and Emene settlement areas.

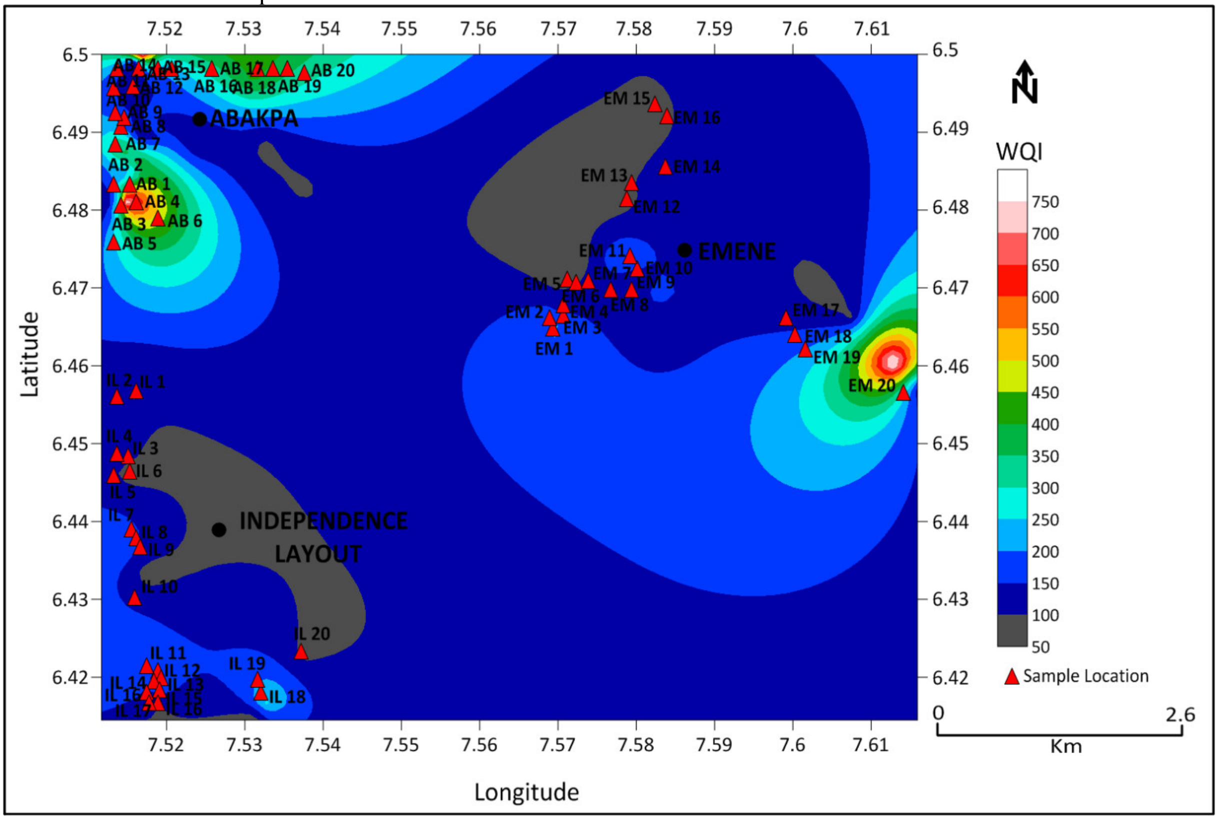

Fig. 6 Water quality index spatial distribution map of the study area

3.10Contaminant Transport Modeling

Data on well and borehole details, lithology, hydraulic conductivity, transmissivity, hydraulic head and aquifer thickness were all employed in flow model generation. Table 10 displays the borehole/well numbers and co-ordinates, calculated hydraulic head values and lithology. Values of hudraulic conductivity, transmissivity and aquifer thickness within the study area were obtained from electrical resistivity soundings, which is contained in the work of Nwachukwu et al. (2022). The conceptual flow model was developed in and around the study area using these parameters as shown in the flowchart below (Fig. 7). To generate a transport model, the concentration values of the various groundwater quality parameters (heavy metals and organic contaminants analyzed) and their respective dispersion coefficients (for each sample location), was employed. The dispersion coefficient for each location was computed using the equation below (Aulbur et al. (2000)):

$$\text{Coefficient of Dispersion} = \frac{\textit{Mean Deviation}}{\textit{Average Conc.}}$$

The mean deviation refers to the deviation of the value (or observations) from the control values.

The conceptual flow model and grids were developed using GIS software, which was further imported into the numerical model. A one-layer groundwater model covering 64 km2 (7,890 m × 8,110 m) was developed, simulating the contaminant transport and groundwater flow within the unconfined aquifer system. The prediction of contaminant plume was performed for five, ten and fifteen years from 2022.

Table 10 Some parameters used in groundwater and contaminant flow modeling (* represents control sample)

Well/Borehole Number	Latitude	Longitude	Hydraulic Head	Lithology
AB 1	6.4861°	7.5166°	33	Shale
AB 2	6.4861°	7.5117°	26	Shale
AB 3	6.4813°	7.5146°	41	Shale
AB 4	6.4814°	7.5140°	30	Shale
AB 5	6.4794°	7.5133°	34	Shale
AB 6	6.4847°	7.5154°	41	Shale
AB 7	6.4880°	7.5143°	20	Shale
AB 8	6.4895°	7.5174°	37	Shale

Well/Borehole Number	Latitude	Longitude	Hydraulic Head	Lithology
AB 9	6.4883°	7.5240°	31	Shale
AB 10	6.4883°	7.5184°	29	Shale
AB 11	6.4902°	7.5167°	27	Shale
AB 12	6.4915°	7.5191°	45	Shale
AB 13	6.4934°	7.5193°	28	Shale
AB 14	6.4911°	7.5181°	33	Shale
AB 15	6.5000°	7.5166°	27	Shale
AB 16	6.4991°	7.5160°	34	Shale
AB 17	6.4994°	7.5195°	25	Shale
AB 18	6.4963°	7.5311°	41	Shale
AB 19	6.4891°	7.5327°	32	Shale
AB 20*	6.4828°	7.5372°	28	Shale
EM 1	6.4653°	7.5698°	15	Shale
EM 2	6.4673°	7.5686°	20	Shale
EM 3	6.4679°	7.5686°	23	Shale
EM 4	6.4679°	7.5701°	17	Shale
EM 5	6.4737°	7.5721°	25	Shale
EM 6	6.4736°	7.5778°	19	Shale
EM 7	6.4718°	7.5785°	27	Shale
EM 8	6.4681°	7.5793°	30	Shale
EM 9	6.4665°	7.5828°	33	Shale
EM 10	6.4688°	7.5827°	18	Shale
EM 11	6.4714°	7.5809°	29	Shale
EM 12	6.4824°	7.5782°	25	Shale
EM 13	6.4832°	7.5799°	24	Shale
EM 14	6.4868°	7.5800°	15	Shale
EM 15	6.4963°	7.5808°	19	Shale
EM 16	6.4934°	7.5821°	24	Shale
EM 17	6.4675°	7.6022°	20	Shale
EM 18	6.4662°	7.6075°	20	Shale
EM 19	6.4603°	7.6130°	28	Shale
EM 20*	6.4573°	7.6159°	20	Shale
IL 1	6.4586°	7.5166°	40	Shale
IL 2	6.4569°	7.5117°	35	Shale
IL 3	6.4482°	7.5146°	28	Shale
IL 4	6.4488°	7.5140°	32	Shale
IL 5	6.4456°	7.5133°	43	Shale
IL 6	6.4466°	7.5154°	28	Shale
IL 7	6.4371°	7.5143°	35	Shale
IL 8	6.4333°	7.5174°	30	Shale
IL 9	6.4323°	7.5240°	25	Shale
IL 10	6.4293°	7.5184°	28	Shale
IL 11	6.4184°	7.5167°	38	Shale
IL 12	6.4153°	7.5191°	20	Shale
IL 13	6.4145°	7.5193°	25	Shale
IL 14	6.4159°	7.5181°	30	Shale
IL 15	6.4170°	7.5166°	28	Shale
IL 16	6.4182°	7.5160°	35	Shale
IL 17	6.4182°	7.5195°	28	Shale
IL 18	6.4148°	7.5311°	30	Shale
IL 19	6.4168°	7.5327°	28	Shale
IL 20*	6.4224°	7.5372°	18	Shale

If this continues, the contaminant plume could spread further and contaminate the downhill areas. Generally, the plume movement was from northwest to east/northeast. It was also inferred that the overall groundwater flow gradient is easterly, which is approximately same with the contaminant particle movement (Fig. 7). The magnitude of the contaminant particles depends on the values of the dispersion coefficients.

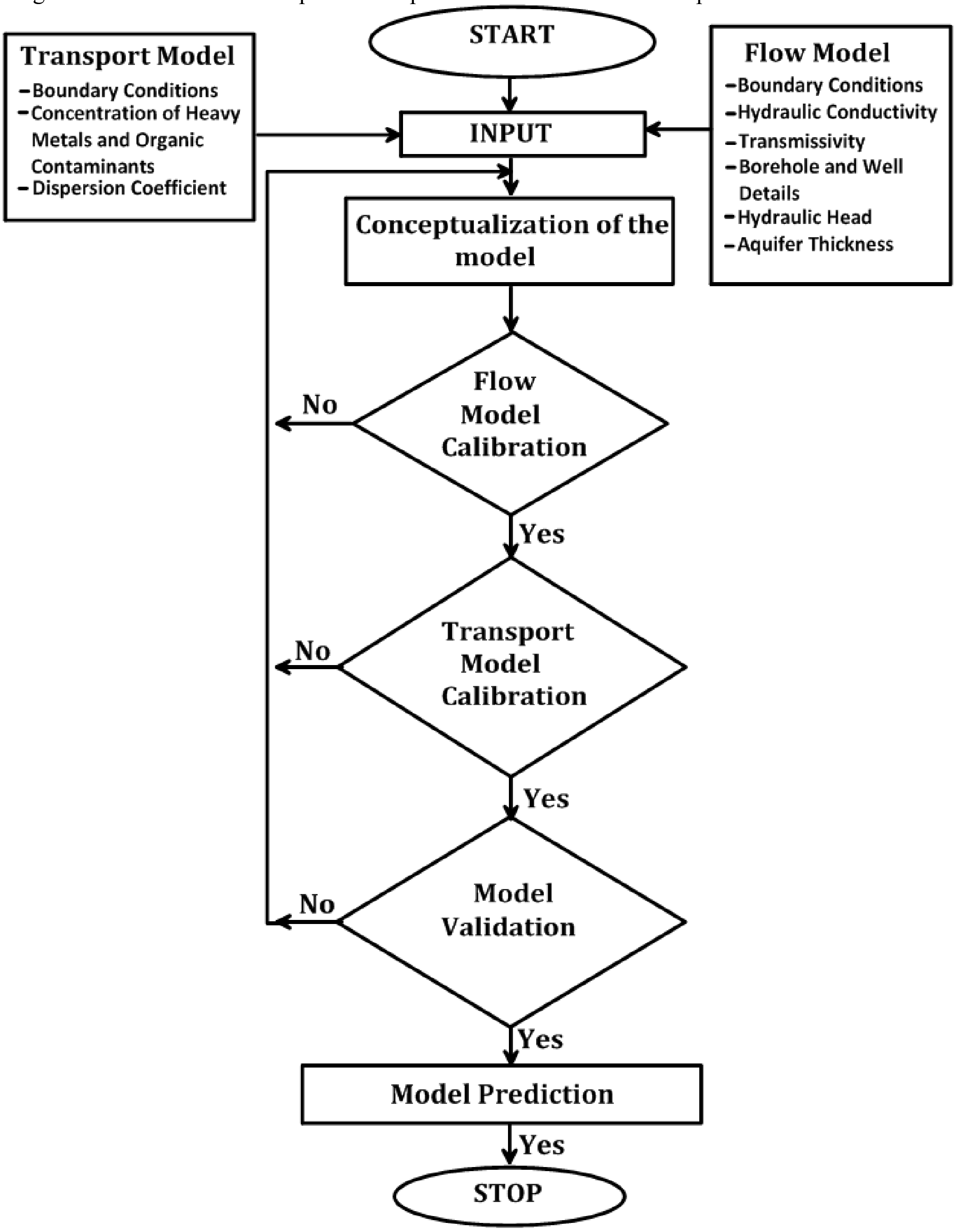

Fig. 7 Flow chart of contaminant and groundwater flow model

The study area was conceptualized as a one-layer aquifer system with a size of 7,890 m × 8,110 m. The information on the layer was used to interpolate from point value to spatial value for the single layer aquifer system. The digitized map of the area was used as input for numerical groundwater flow modeling. The numerical model was discretitized into 24 rows × 40 columns with a 60 m × 60 m grid. The aquifer condition as at the time of field work was taken as the initial condition of the simulation. The area was hypothesized as a single layer aquifer system consisting of fractured shales. Different transport and flow model parameters were assigned to spatially to the aquifer system within the study area. Hydraulic conductivity, transmissivity and aquifer thickness values were obtained from the work of Nwachukwu et al. (2022).

Fig. 8 shows the scatter plot of the model calibration for measured and estimated concentrations of the analyzed parameters. A root mean square were 119.52 was obtained with error values that were < 11% (Fig. 9). The good match indicated by the measured and estimated values suggests that the model closely represents the true subsurface condition in the study area. The groundwater contaminant transport model was then applied to understand and conceptualize the hydrogeological system and predict the results of the system changes. The model was run to simulate plume's movement. The analysis was carried out by assuming thesame concentration rates and hydraulic heads for the remaining period of the model prediction. The concentration values of the plume were predicted for the next 5, 10 and 15 years.

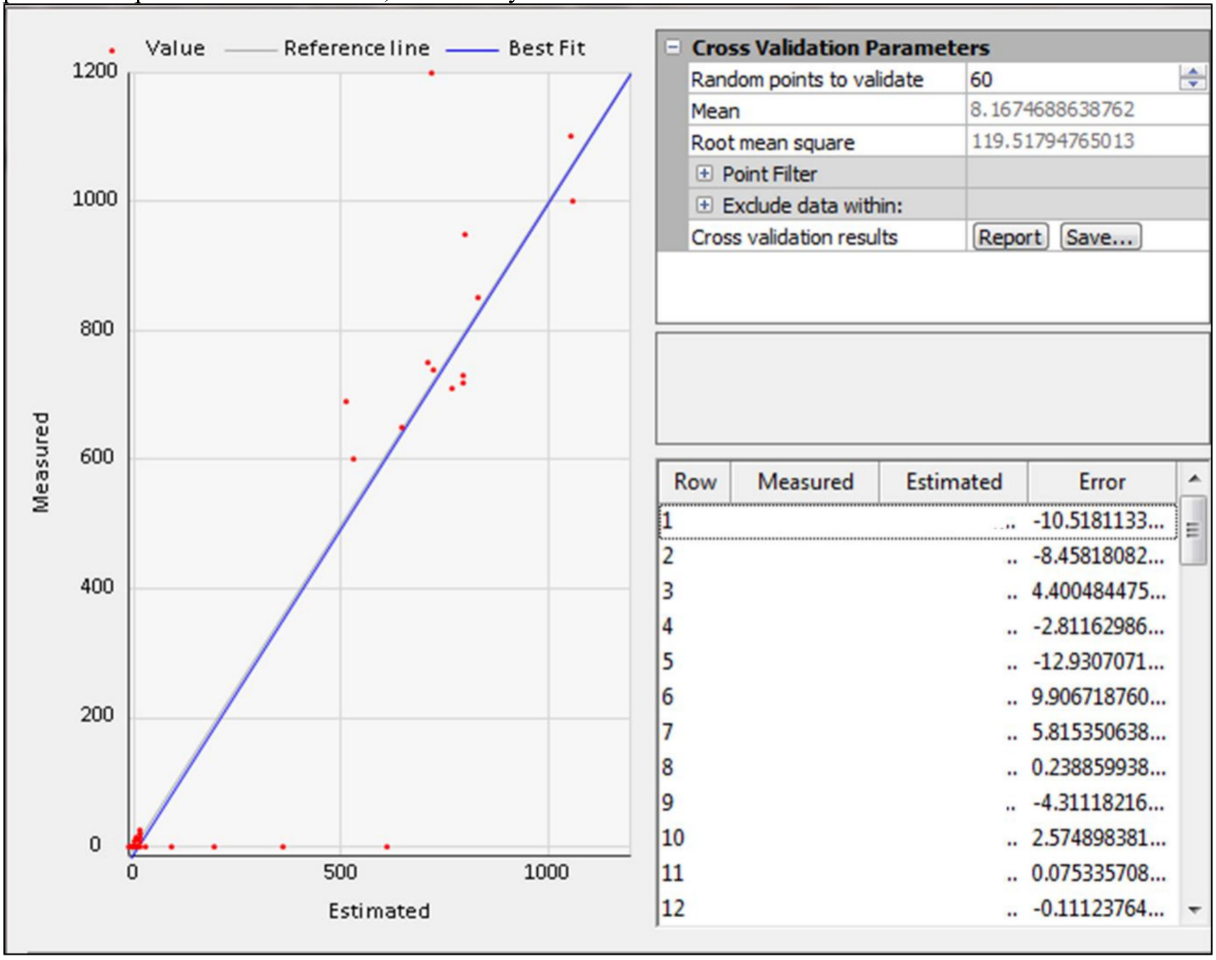

Fig. 8 Calibration curve between measured and estimated concentration valuesThe results of various water quality tests indicates that the groundwater in the study area is contaminated with some of the heavy metals and organic contaminants. After five years, the plume (Zone I) appears to move in an southeasterly direction with a concentration that exceeds 1300 mg/l and reached 2.5 km in thesame direction (Fig. 10a). It mainly covers the Emene settlement area to the east and partly occupies the Abakpa settlement area to the north-west. Other areas outside this zone indicates lesser concentration values that are generally below 325.1 mg/l especially Independence Layout and the northern, western and southern parts of Abakpa. In the tenth year, the plume concentration of over 1300 mg/l reached an additional 0.5 km along thesame southeasterly direction as shown within Zone I (Fig. 10b). However, the end of the fifteenth year showed a slight tilt in plume movement towards the northeastern parts of the study, although it also extends slightly in the eastern direction (Fig. 10c). The plume concentration as well as its area coverage increases progressively towards the Emene settlement area. This corroborates the results of the spatial distribution of heavy metals and organic contaminants within the area where the spatial maps of most heavy metals (As, Cr, Cu, Pb and Pb) and organic contaminants (TOH, boracol, MTBE, PAHs, phthalate and total kjeldhal) showed the highest concentration values occurring in groundwater samples that were taken within the Emene settlement area

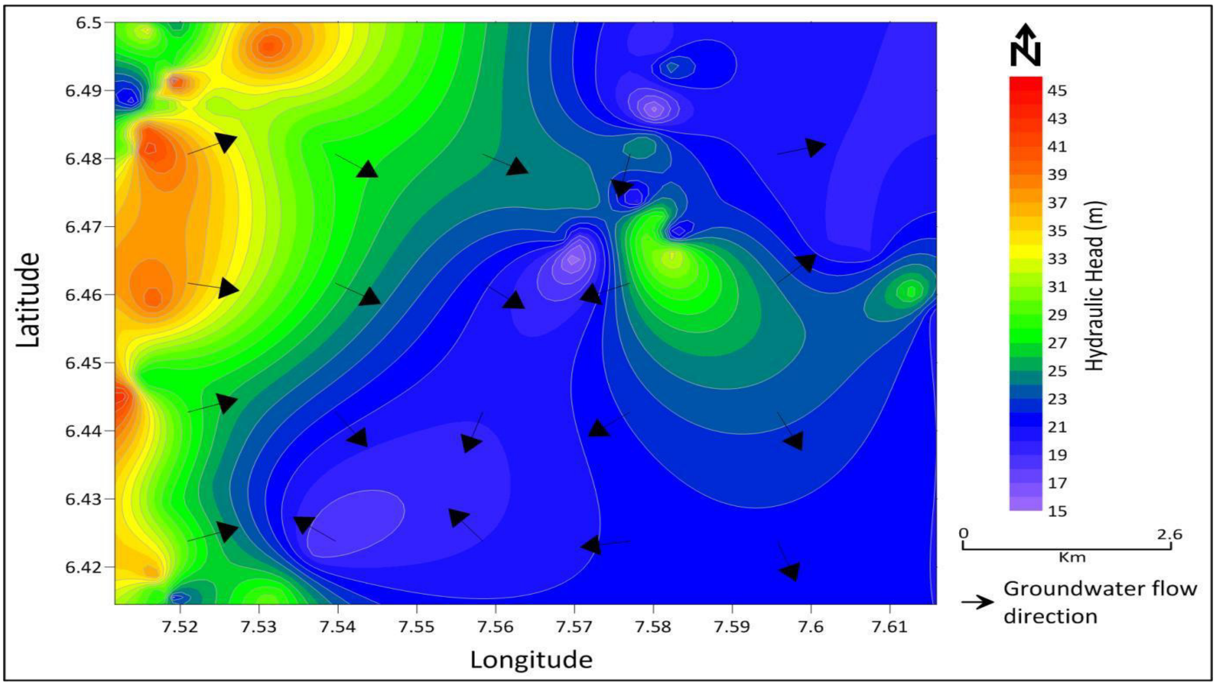

Fig. 9 Groundwater flow map generated from hydraulic head values

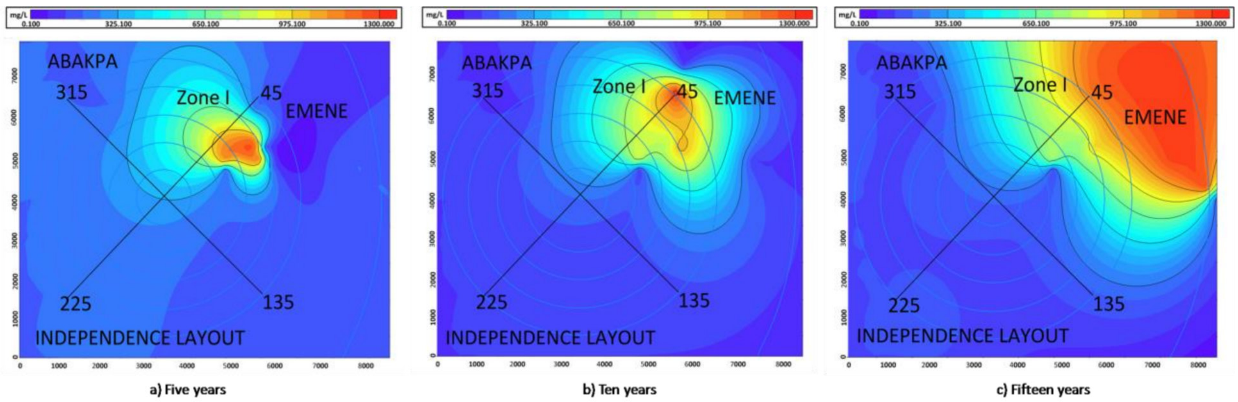

Fig. 10 Predicted plume movement for a) Five years b) Ten years c) Fifteen years

4.0 CONCLUSION

This study has shown that the groundwater quality within the study area is under serious pollution threats from dumpsite leachates, heavy metals and organic contaminants, which is the result of increase in the rate of urbanization within in the study. This portends severe health risk for the water users, most of whom consume groundwater without any form of treatment, which calls for appropriate measures to protect and remedy polluted groundwater for safety purposes.

HQdermal values calculated for all the analyzed water samples in the three settlement areas were within acceptable limits. However, HQoral values obtained for some of the samples exceeded the approved threshold values indicating that water consumers are more likely to contract non-cancer related ailment through drinking of contaminated water than through skin contact. Moreover, more samples had HIoral values that exceeded the allowable limit when compared to HIdermal values. ILCR values obtained for more than 75% of all the analyzed samples in the three settlement area exceeded the allowable limit of 0.000001-0.0001 indicating a high risk of contracting cancer from groundwater consumption in the areas. As and Mn poses the greatest threat of cancer related diseases in the settlement areas

The simulation results showed that plume movement was from northwest to east/northeast. It was also inferred that the overall groundwater flow gradient is easterly, which is approximately same with the contaminant particle movement.

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