Contamination Indices and Heavy Metal Assessment in Groundwater: Evidence from Lagos-Nigeria

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Abstract
Groundwater protection is vital for its sustainability. The study assessed heavy metal contamination in groundwater using indices in Lagos-Nigeria. Thirty wells were randomly selected and analyzed for Pb, Cr, Zn, As, Cu and Zn using standard procedure. Descriptive, correlation and contamination indices were applied to analyse the data. The result shows that heavy metal concentration is in the order of Pb> Cr > Zn >Mn> Cu >As. Lead, Cr and As have their mean value above WHO limits while 13% of the stations recorded the highest concentration for Pb, As, Cr, Cu, Zn and Mn. The result of HEI, ERI, and NeI show low contamination, low risk and insignificant contamination respectively with the worst value from Ig1. The EQWI value revealed that 60, 33.3 and 6.7% of the sites represent medium, high, and low water quality respectively while the PIG result indicates that 43.3, 33.3 and 23.3% of the stations represent insignificant, very high and low pollution, respectively. The correlation result of the heavy metals revealed that Cu has a high positive correlation at ($P <.05$) with Cr and Pb suggesting similar origin of pollution sources. Similarly, the association of HEI with PIG, ERI, and EWQI indicate significant high positive correlation. The study provides an appropriate methodology tool for policymakers in planning and monitoring water resources around tank farms. The study concluded that Pb and Mn pose a major threat to groundwater quality in the area. Remediation, monitoring and regulation of tank farm operations by the concerned agencies were proffered.

Keywords: Contamination indices; groundwater quality; heavy metal; Lagos-Nigeria; tank farm

INTRODUCTION

Groundwater plays a pivotal role in ensuring the sustenance of terrestrial, aquatic, and marine ecosystems (Morris et al. 2003). Across the world, groundwater serves as a vital resource for safe water supply and food security in urban and rural areas to about 2 billion households (Morris et al. 2003; Cobbing and Davies, 2008; Siebert et al. 2010; Kawo and Karuppannan 2018). The steady rise in human population growth, urbanization, and industrialization coupled with the pressure on the demand for groundwater resources for various purposes has led to a series of transformation that threatens groundwater reservoir and consequently human health and the environment particularly in developing countries (MacDonald et al. 2014; Subba Rao et al. 2018; Egbueri 2018; Subba Rao and Chaudhary 2019; Hossain et al. 2020; Egburi 2020). This transformation is triggered by both natural, e.g. geochemical processes and anthropogenic impacts such as oil leakages from tank farms, untreated/partially treated wastewater, excessive use of fertilizers, and pesticides, over-abstraction, and improper management of aquifers, etc.

One of the main threats to groundwater quality across the world is heavy metal contamination. The problems of heavy metal contamination in groundwater have continued to raise serious concern worldwide (Bai et al. 2016; Raessler, 2018; Quintana and Mirlean 2018; Olasoji et al. 2019). Rezaei et al. (2019a), noted that heavy metal contamination in water supply sources poses a major threat to groundwater sustainability and human health due to their carcinogenic and toxicity effects. The residents of the study area are experiencing serious groundwater contamination challenges from tank farms and leakages from oil pipelines. The situation has worsened residents' access to clean potable water for their daily water needs. This unpleasant situation requires an urgent need for efficient water resources management, regulation of the activities of tank farm operators and adequate maintenance of oil pipeline leakages to forestall aquifer deterioration and consequently contamination of water sources (Tadros 2020).

Regular water quality assessment and monitoring of heavy metals in groundwater are necessary for sustainable water resource management (Hynds et al. 2014; Olasoji et al. 2019; Rezaei et al. 2019b). Water quality assessment is one of the vital tools necessary for sustainable water resources management (Egbueri 2018; Mgbenu and Egbueri 2019; Li and Wu 2019; Subba Rao and Chaudhary 2019). One of the widely used approaches in groundwater contamination studies is the water quality index (WQI). The index serves as a veritable tool for water quality assessment which can easily be understood by policymakers for an informed decision in sustainable water quality management (Singaraja 2014; Reza and Singh, 2010; Olasoji et al. 2019; Rezaei et al. 2019a; Rezaei et al. 2019b).

Previous studies on groundwater contamination abound in the literature. For example, Edet and Offiong (2002), Jahan and Strezov (2017), Sobhanardakani et al. (2017), Ghaderpoori et al. (2018), Wright et al. (2019), DoležalováWeissmannová et al. (2019), Rahaman et al. (2019), and Maskooni et al. (2020). The majority of these studies employed multivariate statistical methods in assessing groundwater quality. Other scholars used the geochemical evaluation technique (Hynds et al. 2014), heavy metal pollution index, environmental water quality index (EWQI), contamination factor, and ecological risk index among others for evaluating groundwater contamination (Aggarwal et al. 2000; Dowling et al. 2002; Stollenwerk et al. 2007; Reza et al. 2010; Zarei et al. 2014; Bodrud-Doza et al. 2016; Islam et al. 2017; Zhang et al. 2018; Rezaei et al. 2019c; Chen et al. 2019 and Maskooni et al. 2020).

Despite these numerous works, studies around settlements with dense tank farms and oil pipeline networks geared towards assessing heavy metal contamination using varied contamination indices in the study area are scanty. Therefore, the study seeks to apply contamination indices to assess heavy metals in groundwater the study area using varied techniques such as the heavy metal evaluation index (HEI), Nemerow index (NeI), ecological risk index (ERI), environmental water quality index (EWQI) and pollution index of groundwater. The study is novel because it will provide an appropriate methodology tool for evaluating heavy metal contamination as baseline information that will assist policymakers in planning and monitoring water resources around tank farms and oil pipeline leakages in developing nations in a sustainable manner.

METHODS

Study area

The study sites cover three settlements namely, Ijegun-Egba in Amuwo-Odofin Local Government Area (LGA), Aboru and Ijegun within Alimosho LGA. It is located approximately on Latitudes 6029’N and 6027’N; Longitudes 3014’W and 3012’W. The study area is flanked by Ajeromi/Ifelodun and Oshodi/Isolo in the East, Agege/Ifako-Ijaye and Ikeja LGAs in the North while, in the South it is bordered by the Atlantic Ocean and in the west by Ojo LGA (Fig.1).

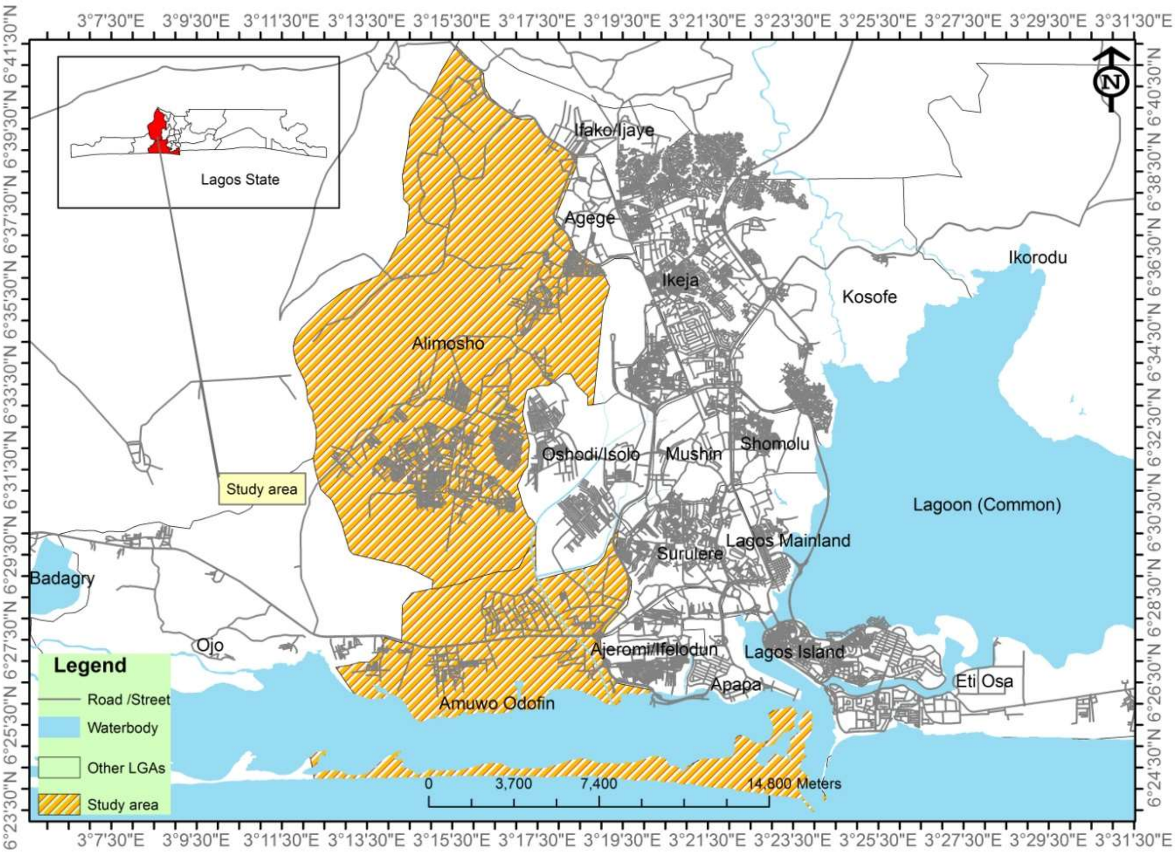

Figure 1: Study area

Location, physical attributes and environmental challenges

The climate of the area is characterized by dry and wet seasons. The dry season spans between November and March while the wet season covers April to October (Akoteyon 2014). The average temperature is about 270C with an average rainfall of about 1.532 mm (Adetoyinbo and Babatunde 2010). The drainage system consists of Lagoons and waterways, barrier islands, and sandy beaches. The major source of groundwater supply in Lagos state is the Coastal Plain Sands (CPS). The CPS aquifer accounts for more than 30% of the groundwater supply to meet Lagos residents' domestic, municipal, and industrial water needs (Longe, 2011). The CPS is characterized by several lateral variations in lithology and water quality (Coode et al., 1997). Coode et al. (1977), classified the CPS into four namely, the recent sediments, the upper and lower CPS and the Abeokuta formation. The major underlying formation in the area is the recent sedimentary rock made of alluvial materials (Longe 2011; Akoteyon 2014). Groundwater occurrence in the CPS is essentially semi-confined to unconfined, consisting of sand and clay (Adelana et al., 2008). The variation in the thickness between the first and third CPS aquifers ranged between 200m and 250m, respectively (Adelana et al., 2008). The study area is confronted with some environmental challenges resulting from human activities such as seepages and infiltration of petroleum products from tank farms and underground oil pipeline leakages into the production wells. Tank farms hold toxic materials such as gasoline and oil that contain dangerous substances, such as heavy metals, benzene, and toluene among others and can cause cancer and harm developing children. It can also threaten communities as their walls corrode by silently leaking toxins into their drinking water supplies, homes and businesses (ED, 2005). The problem has become more worrisome due to ageing, poor regulatory control and lack of maintenance of petroleum storage facilities coupled with the incessant vandalization of oil pipelines by saboteurs. The protection of aquifers against contamination from leaking storage tanks and oil pipeline leakage is very important to safeguard the health of millions of people. The role of the relevant agencies with appropriate measures put in place by the regulatory agencies to avoid oil leakage reaching the production wells should be avoided or prevented because it may be difficult if not impossible to remedy or clean up such aquifer. Should this situation continue unabated, it will pose significant environmental and health challenges to the residents in the area.

Sample collection and procedure

Thirty water samples were randomly selected from wells used for domestic purposes in the study area (Fig. 2a-c). The groundwater samples were collected inside 1.5L polyethene bottles after being thoroughly rinsed with the water being sampled and coded Ig1 to 10, Ab1 to 10 and Ij1 to 10 representing Ijegun-Egba, Aboru and Ijegun in Lagos, Nigeria respectively. The groundwater samples were acidified with nitric acid to a pH of < 2 and stored with ice cubes prior to the laboratory analysis. The groundwater samples were analyzed for; Arsenic (As), Copper (Cu), Lead (Pb), Manganese (Mn), Zinc (Zn), and Chromium (Cr) using Atomic Absorption Spectrophotometry (AAS) method. Each of the parameters was read directly at their specific wavelength according to APHA (2005). The study area and well stations map were generated using Arc map software by exporting the coordinates from the Global Positioning System (GPS) Garmin, 76CSX model.

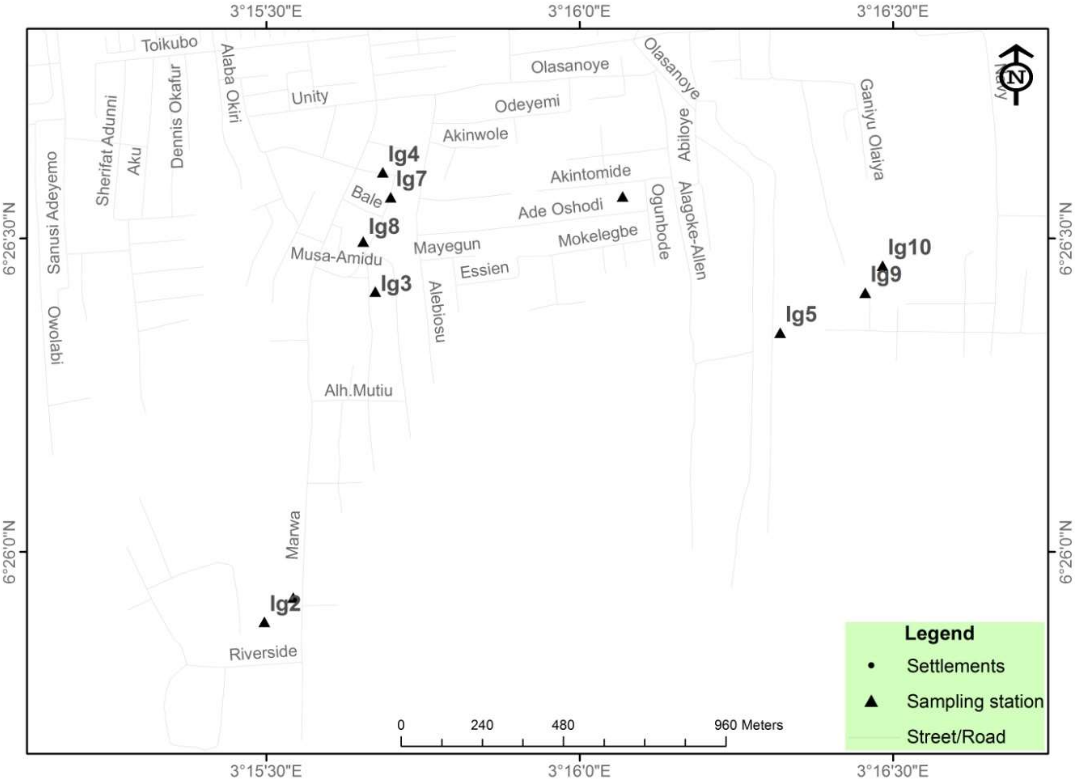

Figure 2a: Ijegun-Egba sampling stations

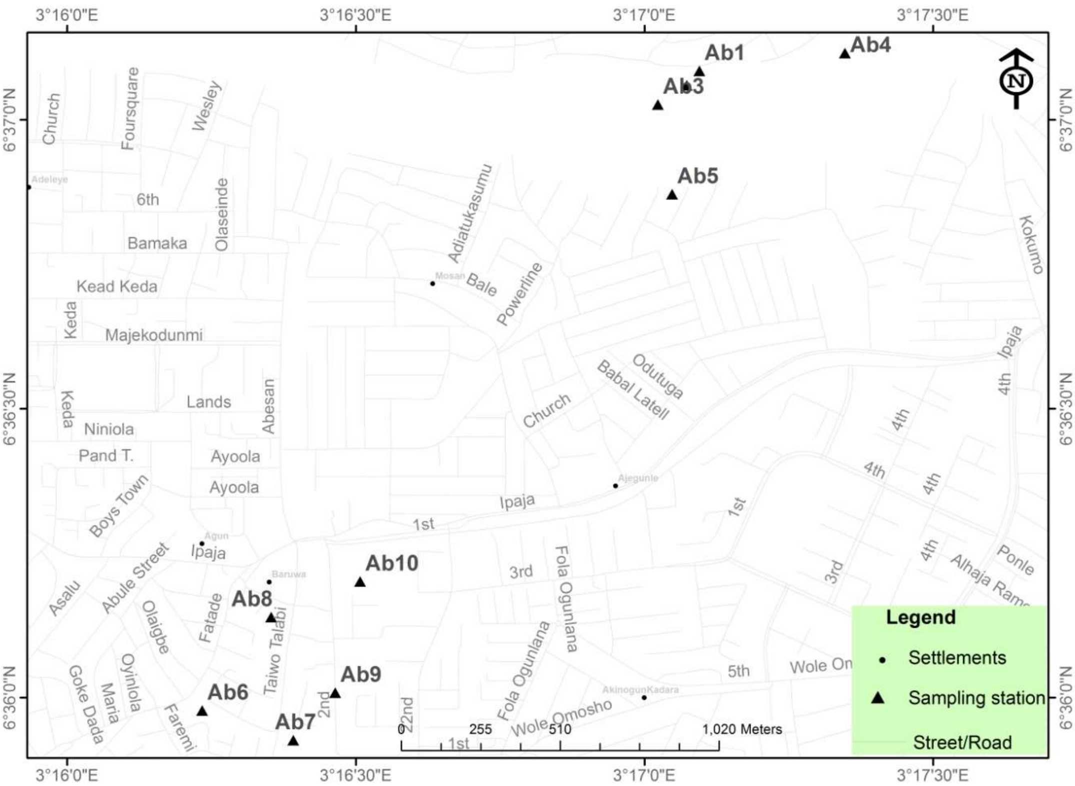

Figure 2b: Aboru sampling stations

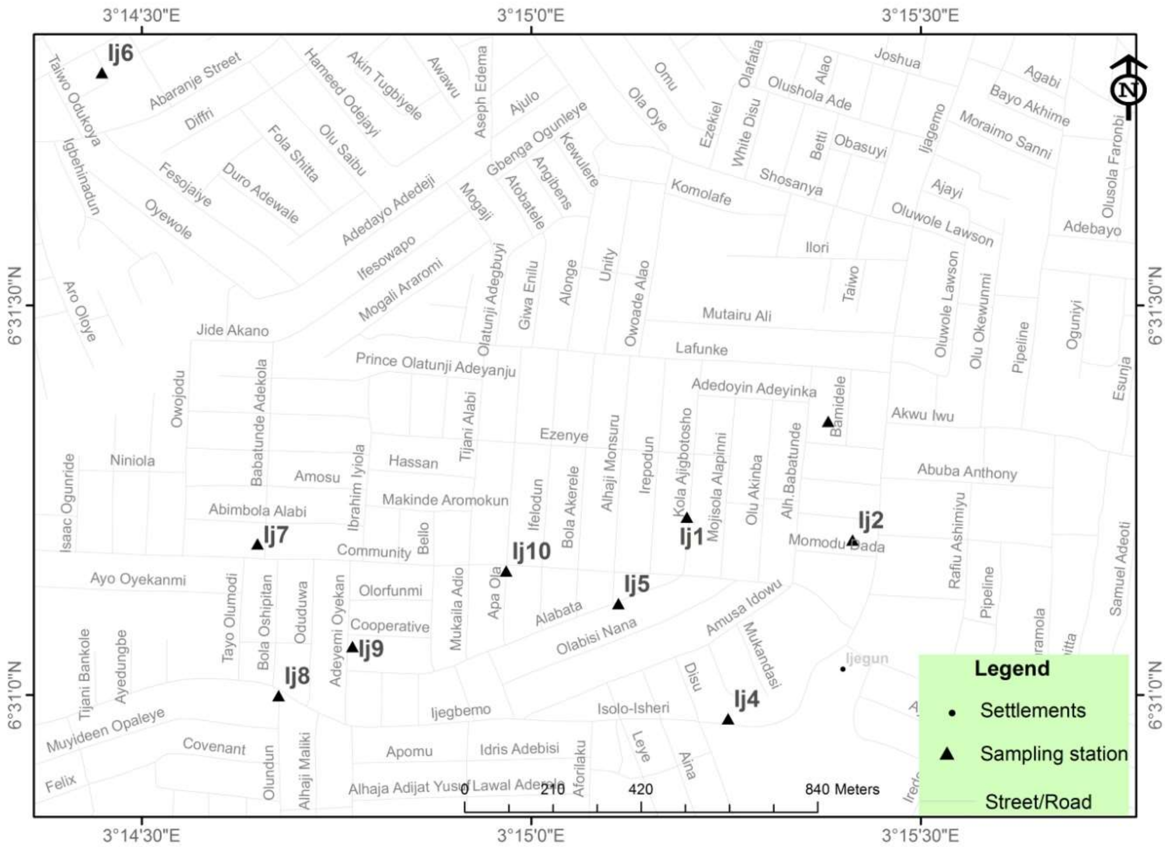

Figure 2c: Ijegun sampling stations

Data analysis

Descriptive and correlation statistical techniques were used to examine the measure of spread, and the relationship of the data set respectively. Five water evaluation quality indices were employed for the assessment of heavy metals in groundwater. The indices are;

i. ***Heavy metal evaluation index (HEI)***

The HEI is used to describe water quality conditions in response to anthropogenic heavy metals (Jahan and Strezov, 2017). The HEI was calculated based on Edet and Offiong (2002) formula given in Equation 1.

$$HEI = \sum_{i=1}^{n} \frac{Hc}{Hmac}$$

Eq. 1

Where Hc is the monitored value and Hmac is the maximum admissible concentration of the ith parameter. The HEI values are classified according to Edet and Offiong (2002) as; low (HEI< 400), medium (HEI = 400±800), and high (HEI > 800) contamination respectively.

ii. **Nemerow Index (NeI)**

This is a multi-factorial and integrated assessment approach to water quality assessment. The index is determined using the formula stated in Equation 2, according to Liu et al. (2015) and Vu et al. (2017).

$$NeI = \frac{\left\{\left(\frac{Mi}{Ii}\right)2\ mean + \left(\frac{Mi}{Ii}\right)2\max\right\}^{1/2}}{n}$$

Eq.2

Where (Mi/Ii) mean is the average value of (Mi/Ii) max of all the examined heavy metals of a water sample and (Mi/Ii) max is the maximum value of (Mi/Ii) among all analysed heavy metals detected in the water sample (Maskooni et al. 2020). Based on Maskooni et al. (2020), the NeI values were classified as; insignificant (NeI< 1), slightly (1 ≤ NeI< 2.5), moderately (2.5 ≤ NeI< 7), and heavily (NeI ≥7) contaminated water respectively (Liu et al. 2015; Maskooni et al. 2020).

iii. Ecological Risk Index (ERI)

The ERI was employed to evaluate the potential ecological hazards associated with heavy metals in groundwater. The computation was determined based on the formula given by Wen et al. (2019) presented in Equation 3.

$$ERI = \sum_{i=1}^{n} \left[Ti\ x\left(\frac{Mi}{Ii}\right)\right]$$

Eq. 3

Where Ti is the biological toxicity factor of the ith analysed heavy metal (Maskooni et al. 2020). The toxic-response factors of the examined heavy metals are: As = 10; Pb = 7; Cu = 5; Cr = 2; and Zn and Mn = 1 (Hananson, 1980; Wang et al. 2018 and Maskooni et al. 2020). Using Maskooni et al. (2020) classification scheme, the ERI values were classified as; low (ERI < 110), moderate (110 ≤ ERI < 200), considerable (200 ≤ ERI < 400), and very high risk (ERI ≥ 400) risk respectively (Wen et al. 2019; Maskooni et al. 2020).

iv. Environmental water quality index (EWQI)

The method proposed by Ali et al. (2017) and Jahan and Strezov (2017) was employed to compute EWQI. The computation involved several stages. Firstly, multiplication of the concentration of each measured metal in the water samples with their corresponding hazard intensity to obtain the water quality impact. The determination of hazard intensity of the respective parameter was based on the total score assigned by ATSDR (2015), Jahan and Strezov (2017) by the Toxicological Profiles of the Priority List of Hazardous Substances, the Division of Toxicology and Environmental Medicine, Atlanta, USA (Jahan and Strezov, 2017). This was followed by the multiplication of the total score of each trace element by its analyzed concentration. The final sub-index was added to determine the trace element toxicity index (TETI). The overall EWQI was calculated by dividing the WQI by TETI using Equation 4.

$$EWQI = \frac{wQI}{\sum_{i=0}^{n} Ci * TSi}$$

Eq. 4

Where WQI = water quality index; Ci = Concentration of individual trace element; TSi =
Total Score (Agency for Toxic Substances and Disease Registry) of individual trace elements (Jahan and Strezov, 2017). The EWQI values were classified as; low= EWQI <0.5), medium EWQI = 0.5±0.9) and high EWQI >0.9) water quality,

respectively (Ali et al. 2017; Jahan and Strezov, 2017).

v. Pollution index of groundwater (PIG)

The PIG proposed by (Subba Rao et al., 2018; Subba Rao and Chaudhary, 2019) was employed. The evaluation of PIG involved five steps. The first step involved the estimation of relative weight (Rw) on a scale of 1 to 5 of analyzed parameters based on their importance in the water quality assessment and their relative impact on human health (Subba Rao et al., 2018), see Table 1. The second step involved the evaluation of the weight parameter (Wp) for each of the water quality variables, to assess their relative contributions to the overall quality of the groundwater samples using equation Eq.5. The third step deals with the estimation of the status of the concentration (Sc) by dividing each of the analyzed water quality variables' content (C) in each of the water samples by their respective water quality standard limits (Ds; using Eq. 6. The WHO (2017) permissible limits were used for the PIG assessment. In the fourth step, the overall groundwater quality (Ow) was computed by multiplying the Wp with the Sc, as shown in Eq. (7), while the final step of the PIG assessment involved the summation of all the Ow values per sample indicated in Eq. 8.

$$\boldsymbol{Wp = Rw/\sum Rw} \quad \text{Eq.5}$$

$$\boldsymbol{Sc = C/Ds} \quad \text{Eq.6}$$

$$\boldsymbol{Ow = Wp\ x\ Sc} \quad \text{Eq.7}$$

$$\boldsymbol{PIG = \sum Ow} \quad \text{Eq.8}$$

The degree of pollution of drinking water based on PIG is classified into five groups namely; PIG < 1.0 (insignificant pollution); 1.0–1.5 (low pollution); 1.5–2.0 (moderate pollution); 2.0–2.5 (high pollution); and PIG > 2.5 (very high pollution), (Subba Rao et al., 2018; Subba Rao and Chaudhary, 2019).

Table 1: Water quality parameters, drinking water standard and their ratings

S/N	Parameters	WHO standard	Wi/Rw	Wi/Wp
1	Arsenic	0.01	4	0.06
2	Copper	2.0	2	0.03
3	Lead	0.01	5	0.08
4	Manganese	0.4	3	0.05
5	Zinc	3.0	2	0.03
6	Chromium	0.05	3	0.05

RESULTS AND DISCUSSION

Descriptive statistics of heavy metal in groundwater

The descriptive statistics of heavy metal concentrations in groundwater samples is presented in Table 2. The result shows that the metals ranged from BDL to 0.0, 0.006 to 0.24, 0.034 to 2.7, 0.002 to 0.124, 0.014 to 0.304 and 0.008 to 0.93mg/L with average concentration value of 0.019, 0.073, 0.56, 0.08, 0.12 and 0.235mg/L representing As, Cu, Pb, Mn, Zn, and Cr respectively. The concentration of the examined heavy metals is in the order of Pb> Cr > Zn >Mn> Cu >As with Pb, Cr, and As having their mean value above WHO recommended limits for drinking water. The sampling stations from Ig1, 3, 7 and 9 recorded the highest concentration of Pb, As, Cr and Cu while Zn and Mn recorded the highest concentration from locations Ab_7 and Ij_1 respectively. Regarding the compliance with WHO standard, the concentration of As exceeded two locations i.e. Ig_2 and Ig_3 while the concentration of Pb was found to be above the WHO regulatory limit in all the stations. Similarly, about 46.7% of the locations have concentration of Cr above the prescribed standard limit set by WHO. The observed elevated concentration of Pb, As, Cr and Cu at these locations can be attributed to the presence of high density of tank farms around the settlements. Similarly, high concentration of Zn and Mn from locations Ab_7 and Ij_1could result from the impacts of effluent from storage tanks farm or leakages from vandalized pipelines used for transporting petroleum products. The result is consistent with previous findings of (Ipingbemi, 2009; Jahan and Strezov, 2017 and Kwaya et al. 2019). Previous studies have shown that the presence of Cr, Pb and As in high concentration in drinking water poses health threats to humans, including aquatic lives in such environment. In addition, the impact petroleum leakage on crop could be alarming when it gets into the human system (Ipingbemi, 2009). Similarly, the health challenges of elevated concentration of Pb could result into mental retardation, nervous systems disorder, acute psychosis, anemia, impaired hearing, and blood cell formation, and cancer development (WHO, 2017). High concentration of Cr in drinking water can also cause lung cancer while concentration of Zn in high quantity in drinking water has been linked to undesirable astringent taste in water which can be responsible for an opalescent appearance that forms a greasy film on boiling (WHO, 2017).Acute gastric irritation may also be observed in some individuals with concentrations of Cu in drinking water above 3 mg/L (WHO, 2017).

Table 3 presents the statistics of the water evaluation quality indices. The result shows that, HEI, ERI, EWQI, NeI and PIG range from 5.3 to 285.9, 0.7 to 46.1, 0.3 to 1.5, 0.06 to 0.09 and 0.37 to 22.39 with mean concentration value of 62.3, 9.71, 0.85, 0.07 and 4.8 mg/L respectively. Across the study area, location Ig1 recorded the highest index value for HEI, ERI, NeI and PIG while location Ig4 has the highest value for EWQI. The breakdown of the analysis indicates that HEI, ERI, and NeI have low contamination, low risk and insignificant contamination respectively in the study area. Similar results were reported by Jahan and Strezov (2017) and Grema et al. (2022). Also, study by Sobhanardakani et al (2017), Ghaderpoori et al. (2018), Kwaya et al. (2019) noted that HEI of heavy metal in groundwater is low. This is consistent with the present study. However, study by Belkhiri et al. (2017), was at variance with the present study. They reported high contamination of HEI due to Cd and Pb while Maskooniet al. (2020) reported medium pollution based on HEI, NeI, and ERI in their study.

Table 2: Descriptive statistics of heavy metals in groundwater

Sn	Code	As	Cu	Pb	Mn	Zn	Cr
1	Ig1	BDL	0.13	2.7	0.092	0.0382	0.78
2	Ig2	0.07	0.19	1.6	0.052	0.064	0.63
3	Ig3	0.5	0.08	1.4	0.048	0.024	0.42
4	Ig4	BDL	0.18	2.3	0.048	0.014	0.29
5	Ig5	BDL	0.13	0.4	0.002	0.014	0.36
6	Ig6	BDL	0.11	0.62	0.021	0.018	0.63
7	Ig7	BDL	0.12	2.1	0.064	0.022	0.93
8	Ig8	BDL	0.19	0.83	0.032	0.026	0.92
9	Ig9	BDL	0.24	0.86	0.032	0.041	0.31
10	Ig10	BDL	0.18	1.8	0.042	0.017	0.81
11	Ab1	BDL	0.027	0.117	0.094	0.072	0.031
12	Ab2	BDL	0.014	0.094	0.088	0.141	0.024
13	Ab3	0.001	0.014	0.127	0.062	0.187	0.083
14	Ab4	BDL	0.039	0.085	0.091	0.091	0.04
15	Ab5	BDL	0.041	0.138	0.101	0.189	0.032
16	Ab6	BDL	0.014	0.091	0.076	0.014	0.127
17	Ab7	BDL	0.009	0.117	0.113	0.304	0.044
18	Ab8	BDL	0.024	0.072	0.082	0.219	0.039
19	Ab9	0.001	0.032	0.034	0.091	0.034	0.076
20	Ab10	BDL	0.006	0.051	0.068	0.256	0.097
21	Ij1	0.001	0.048	0.099	0.124	0.192	0.021
22	Ij2	0.001	0.032	0.091	0.094	0.145	0.009
23	Ij3	0.002	0.044	0.131	0.089	0.167	0.009
24	Ij4	0.001	0.028	0.124	0.12	0.189	0.023
25	Ij5	0.002	0.036	0.132	0.099	0.158	0.017
26	Ij6	BDL	0.062	0.114	0.098	0.164	0.012
27	Ij7	BDL	0.041	0.088	0.108	0.172	0.016
28	Ij8	0.001	0.045	0.097	0.118	0.148	0.008
29	Ij9	0.002	0.038	0.118	0.104	0.162	0.017
30	Ij10	BDL	0.032	0.127	0.118	0.179	0.019
	Mean	0.019	0.073	0.555	0.079	0.115	0.227
	Max	0.500	0.240	2.700	0.124	0.304	0.930
	Min	0.000	0.006	0.034	0.002	0.014	0.008
	WHO Std	0.01	2.0	0.01	0.4	3.0	0.05

WHO-World Health Organization, Std- standard, BDL- below detection limit

The computed EQWI revealed that 60, 33.3 and 6.7% of the stations indicate medium, high and low water quality respectively. A previous study by Oboh and Osuala (2017) attributed poor water quality in Ifie community, Nigeria to the activities of petroleum tank farms and other anthropogenic factors. The observed VHP of the computed PIG value is an indication of the infiltration or leakages of petroleum product into the subsurface from tank farms used for the storage of petroleum product around Ijegun-Egba community. Leaking tank farms and oil pipeline poses grave threat to communities and vulnerable people, such as children who rely on groundwater for their daily water supply needs. Higher rates of respiratory and skin disorders, increases in cancer incidence and mortality has been linked with elevated concentration of oil contamination in drinking water supplies (San Sebastián et al. 2001; Ana et al., 2009; Kponee et al., 2015). This finding is consistent with previous studies by Uzma et al. (2008; Smith, 2010; Wickliffe et al. 2014; Kanno and McCray, 2021), where cases of throat and skin irritation, rashes and anemia were reported due to oil contamination in drinking water supplies. Approximately 43.3, 33.3 and 23.3% of the locations represents insignificant, very high and low pollution respectively in the study area. The higher the EWQI value the better the quality.

Table 3: Descriptive statistics of water evaluation quality indices

Sn	Code	HEI	Class	ERI	Class	EWQI	Class	NeI	Class	PIG	Class
1	Ig1	285.9	LC	46.1	LR	1.4	H	0.09	In	22.39	VHP
2	Ig2	179.8	LC	29.9	LR	1.3	H	0.08	In	13.86	VHP
3	Ig3	198.6	LC	25.6	LR	1.4	H	0.07	In	14.63	VHP
4	Ig4	236	LC	38.7	LR	1.5	H	0.09	In	18.7	VHP
5	Ig5	47.3	LC	7.2	LR	1	H	0.07	In	3.56	VHP
6	Ig6	74.7	LC	11.2	LR	1	H	0.07	In	5.59	VHP
7	Ig7	228.8	LC	36.3	LR	1.3	H	0.08	In	17.74	VHP
8	Ig8	101.6	LC	15.1	LR	1	H	0.07	In	7.57	VHP
9	Ig9	92.4	LC	14.8	LR	1.2	H	0.07	In	7.2	VHP
10	Ig10	196.4	LC	31.1	LR	1.3	H	0.08	In	15.22	VHP
11	Ab1	12.6	LC	2	LR	0.9	M	0.06	In	0.98	In
12	Ab2	10.2	LC	1.6	LR	0.7	M	0.06	In	0.79	In
13	Ab3	14.7	LC	2.2	LR	0.7	M	0.06	In	1.11	Low
14	Ab4	9.6	LC	1.5	LR	0.7	M	0.06	In	0.73	In
15	Ab5	14.8	LC	2.4	LR	0.7	M	0.07	In	1.15	L
16	Ab6	11.8	LC	1.7	LR	0.8	M	0.06	In	0.86	In
17	Ab7	13	LC	2	LR	0.5	M	0.06	In	1	L
18	Ab8	8.3	LC	1.3	LR	0.5	M	0.06	In	0.63	In
19	Ab9	5.3	LC	0.7	LR	0.4	L	0.07	In	0.37	In
20	Ab10	7.3	LC	1	LR	0.3	L	0.07	In	0.52	In
21	Ij1	10.8	LC	1.7	LR	0.6	M	0.07	In	0.84	In

22	Ij2	9.7	LC	1.5	LR	0.6	M	0.07	In	0.76	In
23	Ij3	13.8	LC	2.2	LR	0.8	M	0.07	In	1.08	L
24	Ij4	13.3	LC	2.1	LR	0.7	M	0.07	In	1.04	L
25	Ij5	14.1	LC	2.2	LR	0.8	M	0.08	In	1.1	L
26	Ij6	12	LC	1.9	LR	0.7	M	0.08	In	0.94	In
27	Ij7	9.5	LC	1.5	LR	0.6	M	0.07	In	0.74	In
28	Ij8	10.3	LC	1.6	LR	0.6	M	0.07	In	0.81	In
29	Ij9	12.7	LC	2	LR	0.7	M	0.08	In	0.99	In
30	Ij10	13.5	LC	2.2	LR	0.7	M	0.06	In	1.05	L
	Mean	62.29		9.71		0.85		0.07		4.80	
	Max	285.9		46.1		1.5		0.09		22.39	
	Min	5.3		0.7		0.3		0.06		0.37	

LC-low contamination; LR-low risk; L-low; M-medium; In- insignificant; H-high; VHP-very high pollution

Relationship of heavy metals and contamination indices in groundwater

The relationship of heavy metals in groundwater is presented in Table 4. The result revealed that Cu have high positive significant correlation at (P <.05) with Cr and Pb while the relationship with Mn and Zn indicates moderate significant negative correlation. The relationship of Pb with Cr shows high positive significant association whereas, it indicates moderate positive and low negative correlation between Zn and Mn respectively. The association of Mn with Zn and Cr indicate moderate positive and negative significant correlation respectively. Zinc shows moderate negative correlation with Cr and is significant at p< 0.01 level. The observed high positive correlation values between Cu and (Cr and Pb) suggest similar origin of pollution sources and consequently their role in groundwater contamination in the study area while low or negative correlation coefficient obtained indicate different sources which could be related to natural or geogenic processes (Ma et al. 2016; Doležalová et al. 2019; Grema et al. 2022).

Table 4: Relationship of heavy metals in groundwater

		Cu	Pb	Mn	Zn	Cr
Cu	r	1				
	p-value					
Pb	r	.733**	1			
	p-value	.000				
Mn	r	-.696**	-.450*	1		
	p-value	.000	.013			
Zn	r	-.673**	-.612**	.668**	1	
	p-value	.000	.000	.000		
Cr	r	.764**	.806**	-.657**	-.676**	1
	p-value	.000	.000	.000	.000	

***. Correlation is significant at the 0.01 level*

Similarly, the association of HEI with PIG, ERI and EWQI shows significant high positive correlation with PIG, ERI, and EWQI whereas it indicates significant moderate relationship with NeI. Also, ERI have high significant positive correlation with PIG, EWQI and NeI. Unlike the correlation of EWQI with PIG and NeI, the association indicates significant high positive and low correlation respectively (Table 5). The strong positive relationship that was obtained between HEI and (PIG, ERI and EWQI shows the appropriateness of the methodology as an effective tool for evaluating heavy metals contamination in groundwater quality of the study area (Grema et al. 2022).

Table 5: Relationship of water evaluation quality indices

		HEI	ERI	EWQI	NeI	PIG	Cd
HEI	r	1					
	p-value						
ERI	r	.996**	1				
	p-value	.000					
EWQI	r	.903**	.895**	1			
	p-value	.000	.000				
NeI	r	.681**	.701**	.580**	1		
	p-value	.000	.000	.001			
PIG	r	1.000**	.998**	.901**	.689**	1	
	p-value	.000	.000	.000	.000		

CONCLUSIONS

The present study applied contamination indices to assess heavy metals in groundwater in Lagos-Nigeria using a heavy metal index, Nemerow index, ecological risk index, environmental water quality index and pollution index of groundwater techniques. The findings show that the concentration of heavy metals in groundwater is in the order of Pb> Cr > Zn >Mn> Cu >As. Three heavy metals namely, Pb, Cr, and As have their mean value above WHO recommended limits for drinking water. Four locations recorded the highest concentration for Pb, As, Cr, Cu, Zn and Mn. The observed elevated concentration of heavy metals in the study area can be attributed to the presence of a high density of tank farms and the impacts of oil pipeline leakages used for transporting petroleum products around the settlements. The presence of Cr, Pb and As in high concentration in drinking water poses health threats such as mental retardation, acute psychosis, impaired hearing, and cancer development. The computed indices show that HEI, ERI, and NeI have low contamination, low risk and insignificant contamination respectively. Location Ig1 recorded the highest index value for HEI, ERI, NeI and PIG while the EQWI value indicates that 60, 33.3 and 6.7% of the points indicate medium, high and low water quality respectively. Approximately 43.3, 33.3 and 23.3% of the locations represent insignificant, very high and low pollution respectively based on the PIG value. The observed VHP value of PIG is a reflection of the infiltration or leakages of petroleum products into the subsurface from tank farms used for the storage of petroleum products around the study locations.

The relationship of the heavy metals in groundwater revealed that Cu has a high positive significant correlation at ($P < .05$) with Cr and Pb whereas it is moderate between Mn and Zn with a significant negative correlation. The observed high positive correlation values between Cu and (Cr and Pb) suggest similar origins of pollution sources and consequently their role in groundwater contamination in the study area while the low or negative correlation coefficient obtained indicates different sources which could be related to natural or geogenic processes. The correlation of HEI with PIG, ERI, and EWQI shows that it has a significant high positive correlation whereas it indicates significant moderate relationship with NeI. The strong positive relationship obtained between HEI and (PIG, ERI and EWQI) shows the appropriateness of the methodology employed as an effective tool for evaluating heavy metal contamination in groundwater in the study area.

The study provides an appropriate methodology tool for evaluating heavy metals contamination as baseline information that will assist policymakers in the planning, protection, and monitoring of groundwater resources around tank farms in a sustainable manner. The study revealed that all the sample stations had Pb concentrations above the regulatory threshold with almost 50% and 20% having Cr and As concentrations exceeding the limit for drinking water respectively. The study concluded that Pb and Mn constitute the major parameters impacting groundwater quality in the area. Remediation, monitoring and regulation of tank farm operations by the concerned agencies to forestall aquifer contamination in the area were proffered.

Declaration Section

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