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Groundwater Quality And Risk Assessment Of Heavy Metal Pollution Using Water Quality Index As A Communication Tool: Evidence from Ejigbo, Lagos-Nigeria

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ABSTRACT
Pollution poses serious threat to groundwater sustainability with significant health, socio-economic, and environmental challenges on human. The study examined groundwater pollution in Ejigbo, Lagos-Nigeria using water quality indicators as a communication tool. Groundwater parameters were measured for pH, total dissolved solids, and electrical conductivity using portable meters and were analysed for eight major ions and ten heavy metals from 30 randomly selected wells using standard procedure. Water quality index, ecological risk index, pollution index of groundwater, environmental water quality index, heavy metal evaluation index and contamination index were employed for data analysis. The result shows that the pH of groundwater is acidic. The measured EC, TDS, and the major ions are all within the WHO limit for drinking water standard. Heavy metal concentration in groundwater indicates that 93%, 86.7%, 70%,46.7%, 36.7% and 23.3% of the sampled wells had lead, zinc, mercury, nickel, arsenic, and cadmium concentrations above WHO standard limit for drinking, respectively. All the wells had chromium levels above WHO limit for drinking water except at two locations. The concentration of cobalt in all the wells exceeded the WHO standard for drinking water. The computed water quality index, ecological risk index, pollution index of groundwater, environmental water quality index, contamination index, and heavy metal evaluation index shows that water from the wells are unsuitable for consumption. The study provides a novel methodology for easy communication of water quality status in the study area. Protection of aquifer from oil pipeline leakage, regulation and enforcement of appropriate laws relating to groundwater pollution were proferred.
Keywords: Ejigbo, groundwater, heavy metal, pollution, risk assessment, water quality index,

INTRODUCTION
Groundwater is a vital resource for safe water supply for human consumption worldwide. It is also essential for the livelihood and food security of about 1.2 to 1.5 billion households in Africa and Asia

(Siebert et al., 2010). Globally, the pressure on groundwater resources is on the increase due to natural, e.g. geochemical processes and anthropogenic impacts such as; unplanned urbanization, industrial development, oil leakages from pipeline and tank farms, untreated/partially treated wastewater, excessive use of fertilizers, and pesticides, over-abstraction, and improper management of aquifers, etc. (Kawo and Karuppannan, 2018). This transformation has threatened groundwater resources in developing countries with significant socio-economic, environmental and health challenges (Egburi, 2020).

One of the significant threats to groundwater quality across the world is heavy metal contamination. The problem of heavy metal contamination in groundwater has continued to raise serious concern worldwide due to their carcinogenic and toxicity effects on living organisms, including human health. Contaminated water due to heavy metal poses a dangerous threat to groundwater sustainability and can influence human health through the direct intake, inhalation, and dermal absorption through the skin (Olasoji et al., 2019 and Rezaei et al. 2019). In Nigeria, the government has introduced regulatory guidelines or standards as part of an environmental pollution abatement policy strategy geared toward achieving sustainable environmental development in the country. Similarly, the Lagos State Regulatory Commission (LSWRC), is saddled with the responsibility of regulating all water and wastewater sector activities in the public sector impacting the quality of groundwater sources and potable drinking water in the state (LWSL, 2004).

Assessment of groundwater quality is essential to ascertain its suitability for various uses such as drinking, irrigation, and industrial (Boyacioglu, 2007). Various techniques such as the traditional method based on comparing experimentally determined parameter values with existing guidelines have been employed in water quality assessment. This method allows proper identification of contamination sources essential for checking legal compliance (Boyacioglu, 2007). Other techniques include the application of the water quality index (WQI). The WQI serves as a tool for summarizing large amounts of water quality data into simple terms for easy communication to the public. It is also helpful in examining trends and specific environmental conditions of water quality status for effective planning and monitoring by relevant agencies and decision-makers about the level of compliance to regulatory standards at specific locations (Christiane et al., 2010; Bharti and Katyal, 2011). This study, therefore, seeks to examine the groundwater quality of Ejigbo in Lagos-Nigeria using evaluation of water quality indices to ascertain the health implication for a policy decision on human activities impacting on groundwater resources in the state.

MATERIAL AND METHODS

The study area

The study area is located at Ejigbo community in Alimosho Local Government area of Lagos State. It lies on Long 3^0 17’ 0’’E to 3^0 18’ 30’’ E and Lat 6^0 33’ 0’’ N to 6^0 34’ 0’’ N (Fig.1).

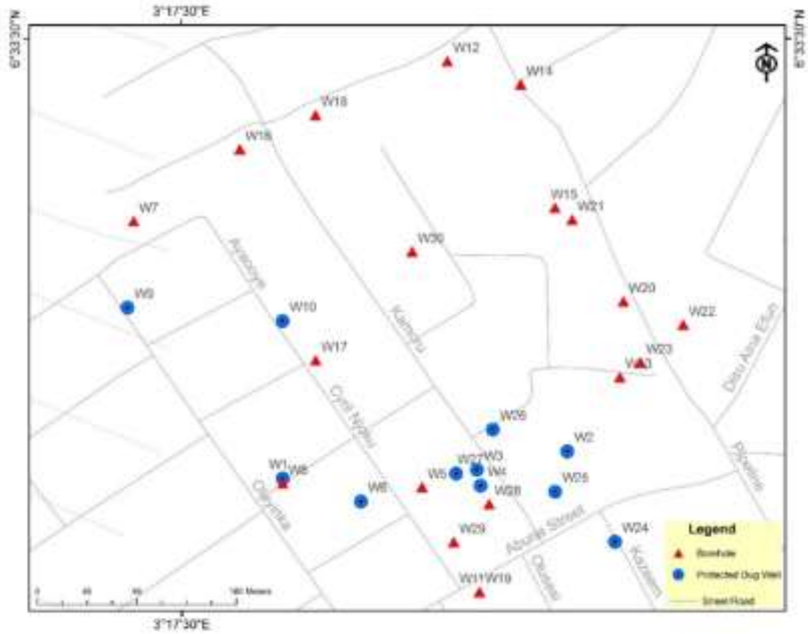

Figure 1: Study area

The climate is typical of Lagos state, and the geology of the area is consistent with regional geology of the Lagos metropolis. The study area is underlain by Coastal Plain Sand (CPS) aquifer. Longe (2011) reported that the CPS is the principal aquifer in the Lagos metropolis, accounting for more than 30% of groundwater supply to meet domestic, municipal, and industrial water needs. The study area is confronted with the problem of groundwater pollution as far back as 1982. By 2013, the residents started noticing contamination of their wells. The situation worsened by 2018 when more than 28 streets were already affected due to oil pipeline leakage, which was left unattended, thereby constituting significant socioeconomic and health challenges in the community (Ugwoha and Omenogor, 2017).

Groundwater analysis

A total of 30 wells were randomly selected and measured for 3 in situ parameters, namely, total dissolved solids (TDS), pH, and electrical conductivity (EC). Orion pH Meter SA720 model was used to measure pH of the water sample, while TDS and EC were measured using JENWAY meter. The major cations, namely sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) were determined using a JENWAY flame photometer, while chloride (Cl^-) was determined using Argentometric method, bicarbonate (HCO_3^-), carbonate (CO_3^-) were evaluated using titration method and sulfate (SO_4^{2-}), turbidimetric method.Ten heavy metals, namely; Arsenic (As), Copper (Cu), Lead (Pb), Manganese (Mn), Zinc (Zn), Mercury (Hg), Cobalt (Co), Nickel (Ni), Cadmium (Cd), and Chromium (Cr) were determined using Atomic Absorption Spectrophotometry (AAS) method. Each parameter was read directly at its specific wavelength based on the standard methods by APHA (2012). The sample was analyzed at Emzor Pharmaceutical Laboratory.

Data analysis and techniques

Descriptive statistics and evaluation of water quality indices such aswater quality index (WQI),ecological risk index (ERI),pollution index of groundwater (PIG),environmental water quality index (EWQI),contamination index (Cd), and heavy metal evaluation index (HEI) were employed for water quality analysis.

Evaluation of water quality indices

Five water evaluation quality indices were adopted for the groundwater quality assessment. The indices are;

Water quality index (WQI)

Twenty parameters were used to compute the WQI using Sahu and Sikdar (2008) method. The computation involved four stages: Allocation of weight to each parameter according to their relative importance in line with WHO (2017) guideline for drinking purposes. The second stage is the computation of relative weight (Wi) based on Eq. 1. Thirdly, allocation of the quality rating scale (qi) for each parameter as indicated in Eq.2. The final stage is the calculation of WQI is using equations 3 and 4.

$$\mathbf{Wi} = wi/\sum_{i=1}^{n} wi \quad \text{Eq.1} \qquad qi = \frac{Ci}{Si} x100 \quad \text{Eq.2}$$

$$SIi = Wixqi \quad \text{Eq.3} \qquad WQI = \sum SIi \quad \text{Eq.4}$$

Where: qi = quality rating according to the concentration of ith parameter, n = is number of parameters. Ci = concentration of each parameter, Si = WHO drinking water guideline for each parameter.

The final WQI values are classified into five categories: < 50 Excellent water, 50–100 Good water, 100–200 Poor water, 200–300 Very poor water, and > 300 Water unfit for drinking Avijit and Kamalakannan 2023

Ecological risk index (ERI)

The ERI for each of the groundwater samples was calculated using equations 5 and 6.

$$ERI = ERI - \sum Ti\ x\ PI \quad \text{Eq.5} \qquad PI = Cs/Cb \quad \text{Eq.6}$$

where, ERI is the potential ecological risk factor of each heavy metal; Ti is the toxic-response factor of heavy metal; PI is the pollution index; Cs is the concentration of heavy metals in the sample; and Cb is the corresponding WHO standard values. The toxic-response factor of heavy metals is given as: Hg=40; As = 10; Cd = 30; Pb = 7; Cu = 5; Ni=5; Co=5; Cr = 2; and Zn and Mn = 1(Hananson, 1980 and Wang et al. 2018). The final index was classified into four groups, low (ERI < 150), moderate (150 ≤ ERI < 300), considerable (300 ≤ ERI < 600), and very high (ERI > 600) risk, respectively (Sharifi et al., 2016; Wen et al., 2019).

Pollution index of groundwater (PIG)

The computation of PIG involves five steps. The first step involved the estimation of relative weight (Rw). 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 (Eq.7). In the third step, the status of concentration (Sc) was estimated by dividing each of the analyzed water quality variables' content (C) in each of the water samples by their respective water quality standard limits using the WHO permissible limits of 2017 (Ds; Eq. (8). In the fourth step, the overall quality of the groundwater (Ow) was computed as shown in Eq. (9). The final step involved the summation of all the Ow values per sample (Eq. (10).

$$Wp = Rw/\sum Rw \quad \text{Eq.7} \qquad Sc = C/Ds \quad \text{Eq.8}$$

$$Ow = WpxSc \quad \text{Eq.9} \qquad PIG = \sum Ow \quad \text{Eq.10}$$

The PIG is classified into five groups: PIG < 1.0 indicates insignificant pollution; 1.0–1.5 indicates low pollution; 1.5–2.0 signifies moderate pollution; 2.0–2.5 signifies high pollution; and PIG > 2.5 indicates very high pollution (Subba Rao et al., 2018; Subba Rao and Chaudhary, 2019).

Environmental water quality index (EWQI)

The stages of computing the EWQI includes; multiplying the concentration of each measured metal in the water samples with their corresponding hazard intensity to determine the water quality impact. The hazard intensity of each parameter was determined based on the total score assigned according to ATSDR (2015). After that, the total score of each trace element was multiplied by its analyzed concentration, and products were added to determine the trace element toxicity index (TETI). The final EWQI was determined by dividing the WQI by TETI using equation 11.

$$EWQI = \frac{wQI}{\sum_{i=0}^{n} Ci * TSi} \quad \text{Eq. 11}$$

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.
The classification values for EWQI are grouped into low (poor) = EWQI <0.5), medium (fair) EWQI = 0.5±0.9) and high (good) EWQI >0.9) water quality respectively (Ali et al., 2017).

Contamination index (Cd)

The contamination index (Cd) is calculated individually for each water sample as a sum of the contaminant factors of a single component that exceed the maximum contaminant levels according to Barkat et al. (2023) and Ramos et al. (2004) based on equations 12 and 13.

$$Cd = \sum_{i=1}^{n} Cfi \quad \text{Eq. 12} \qquad Cfi = CAi/CN - 1 \quad \text{Eq.13}$$

Where, Cd= contamination index; Cfi=contamination factor of the i-th component, CAi = analytical value of the i-th component and CNi=upper permissible concentration of the i-th component according to (WHO, 2017). The value scale for contamination index consists of 3 ranges; Cd< 20 (low contamination), 20-40 (medium contamination) and Cd > 40 (high contamination) (Edet and Offiong (2002).

Heavy metal evaluation index (HEI)

The HEI was calculated based on Edet and Offiong (2002) formula given in equation 14.

$$HEI = \sum_{i=1}^{n} \frac{Hc}{Hmac} \quad \text{Eq. 14}$$

Where, Hc is the monitored value and Hmac is the maximum admissible concentration of the ith parameter. The HEI values are classified into three main groups namely, low (HEI< 400), medium (HEI = 400-800), and high (HEI > 800) contamination, respectively Ighalo, and Adeniyi 2020.

RESULTS AND DISCUSSION

In situ parameters of groundwater quality

The descriptive statistics of the in situ parameters show that pH ranged from 4.1 to 6.5 with a mean value of 5.1. The measured value of EC varied from 54.4 to 702µs/cm with an average value of 278.5µs/cm, while TDS ranged from 32.6 to 421 with a mean value of 167mg/L. The pH indicates that almost all the sampled wells are acidic. High pH in drinking water impacts the operational water quality parameters with adverse effects on its taste and appearance (WHO, 2017). The measured EC/TDS shows that all the sampled wells are within the WHO standard for potable water.

Major cations and anions in groundwater

The descriptive statistics of the major cations and anions show that Ca and Mg ranged from 14.1 to 52.0 and 4.2 to 12.7mg/L with a mean value of 30.4 and 6.7mg/L, respectively. The concentration of K and Na ranged from 1.4 to 19.4 and 16.0 to 54mg/L with a mean value of 8.2 and 30.4, respectively. Low intake of Ca^{2+} in drinking water can cause osteoporosis, rickets, and hypertension in humans, while low magnesium intake can result in osteoporosis, insulin resistance and increased risk of cardiovascular disease (Kurtz and Morris, 1993). Chloride, bicarbonate, and sulfate varied from 55-371.2, 9.9 to 17.8, and 7.1 to 27.5mg/L with the respective mean values obtained as; 156.7, 15.0, and 14.5mg/L in the study area.

Heavy metal concentration in groundwater

The descriptive statistics of heavy metal concentration in groundwater shows that Hg ranged from ND to 2.04mg/L with an average value of 0.92mg/L. About 70% of the sampled wells were above the standard limit for drinking water. A high concentration of Hg in drinking water has been linked to acute oral poisoning resulting in haemorrhagic gastritis and colitis; and kidney damage (WHO, 2017). The concentration of Pb ranged from 0.002 to 2.95mg/L with an average value of 0.98mg/L. Approximately 93% of the sampled locations had Pb concentrations above the WHO standard limit for drinking water. High Pb in drinking water may result in mental retardation, nervous systems disorder, and cancer development (WHO, 2017). Chromium ranged from ND to 12.18 mg/L with a mean value of 5.57mg/L. Chromium in all the locations were above the WHO standard limit for drinking water in the study area except for locations W_{19} to W_{21} where it was not detected. A high concentration of Cr in drinking water has been linked to lung cancer (WHO, 2017). The concentration of Co varied from 0.84 to 2.12mg/L with an average value of 1.35mg/L. The concentration of Co in all the wells exceeded the WHO prescribed limit for drinking water. A high concentration of Co in drinking water is responsible for sterility, hair loss, bleeding etc. (WHO, 2017). Cadmium varied from ND to 1.39mg/L with a mean value of 0.9mg/L. About 23.3% of the sampled wells had a concentration above the WHO allowable limit for drinking water. A high concentration of Cd in drinking water can cause an increased risk for tubular dysfunction and kidney problem (WHO, 2017). The concentration of Zn ranged from 2.02 to 17.65mg/L with a mean value of 6.55mg/L. Approximately 86.7% of the sample wells had Zn concentrations above the regulatory standard for drinking water.

The high concentration of Zn in drinking water is responsible for undesirable astringent taste in water. It can also cause an opalescent appearance, developing a greasy film on boiling (WHO, 2017). Arsenic varied from ND to 2.43mg/L with an average value of 0.71mg/L. Approximately 36.7% of the sampled wells had a concentration above the WHO limit for drinking water standards in the study area. Nickel ranged from ND to 1.01mg/L with an average of 0.38mg/L. About 46.7% of the sampled locations had a concentration above the WHO standard for drinking water. High Ni concentration can cause kidney diseases, lung toxicity, fibrosis, lung, nasal cancer etc (Sutunkova et al., 2018). The concentration of Cu varied from ND to 0.05mg/L with an average value of 0.02mg/L. Manganese ranged from ND to 0.04mg/L with a mean value of 0.02mg/L.

Evaluation of water quality indices

Water Quality Index (WQI) and Ecological Risk Index (ERI)

The computed WQI shows that it ranges from 313.15 to 8778.85 with a mean value of 2467.48, indicating that all the samples are unsuitable for drinking water quality. The ERI varied from 219.03 to 300005.69, with an average value of 7661.91, indicating that all the samples are classified as very heavy ecological risk.

Pollution index of Groundwater (PIG) and Environmental water Quality Index (EWQI)

The PIG index varied from 3.13 to 87.79, with a mean value of 24.67. All the samples were classified as very high pollution in the study area. The computed EWQI ranged from 0.04 to 0.35, with a mean value of 0.16 indicating that all the sampled wells were classified as having low water quality.

Contamination degree (Cd)* and *Heavy Metal Index (HEI)

The computed Cd revealed that it ranged from 51.5 to 1522.81 with a mean value of 429.27. The result shows that all the sampled wells have high contamination. The computed HEI varied from 50.5 to 1520.81, with an average value of 428.23. The computed HEI of the study area shows that 6.7, 36.7, and 56.7% of the sampled wells indicate heavy pollution, medium pollution, and low pollution, respectively, in the study area (Fig. 2).

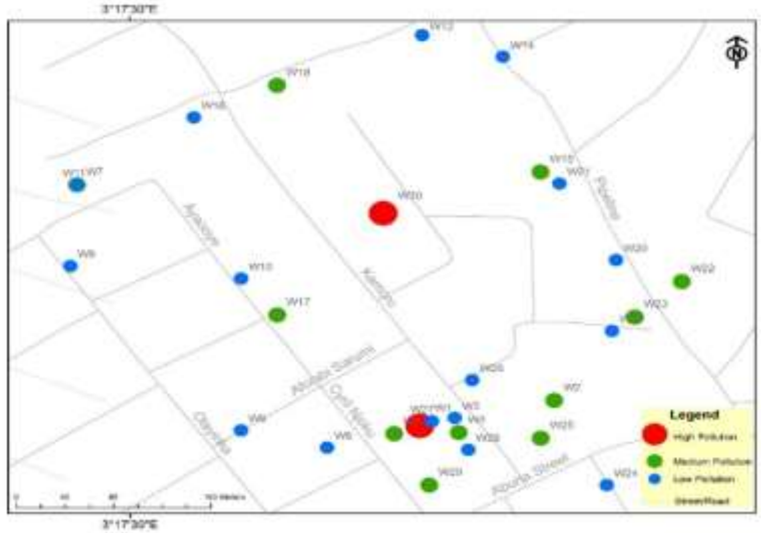

Fig. 2: Patterns of the heavy metal index in the study area

CONCLUSION

The present study revealed that pH of almost all the wells are acidic. The concentration Cr and Co in groundwater exceeded WHO standard limit for drinking water in all the locations while 93, 86.7, 70, 46.7, 36.7 and 23% of the sampled wells had Pb, Zn, Hg, Ni, As and Cd concentrations above the WHO standard limit respectively in the study area. The computed water quality index shows that the WQI and ERI are unsuitable for drinking water quality with severe ecological risks. The PIG index revealed very high pollution while the EWQI as characterized by low water quality. The computed Cd shows that all the sampled wells have high contamination. In contrast, HEI shows that 6.7, 36.7, and 56.7% of the sampled wells indicate heavy pollution, medium pollution, and low pollution, respectively in the study area. Protection of aquifer from oil pipeline leakage, regulation and enforcement of appropriate laws relating to groundwater pollution were preferred.

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