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Risk assessment of potentially toxic elements in groundwater using Monte Carlo simulation and geoaccumulation index near mechanical workshops premises, Omu-Aran

Olugbenga Elemile[1,2], Praise Ejigboye[1,2*], Abu Gana[1], Enoch Ibitogbe[1], Adeyemi Adetoro[1,3], Emmanuel Oluwadamisi[4], Mayowa Elemile[5], Olarewarenju Ibitoye[1] and Opeyemi Olajide[1]

Abstract

Major activities in automobile workshops involve the release of toxic substances into the surrounding soil and water, which could pose adverse impact on human health. This study aimed at conducting a Monte Carlo simulation-based risk assessment for the concentrations of heavy metals (Lead (Pb), Iron (Fe), Chromium (Cr), Cadmium (Cd), and Arsenic (As)) and geoaccumulation index of these potentially toxic elements in the vicinity of mechanical workshops in Omu-Aran, Nigeria. Forty-eight samples were collected in hand-dug wells (HDWs) near automobile workshop premises and one control point in Omu-Aran. The water samples were subjected to acid digestion as a preparation step prior to evaluating their concentrations using an Atomic Absorption Spectrophotometer. The classification of contamination levels was determined using the geoaccumulation index (Igeo). Physicochemical and heavy metals parameters were determined in the groundwater samples using standard APHA methods. Data analyses were carried out by Monte Carlo Simulation and ANOVA at α0.05. All heavy metals (Pb, Fe, Cd, Cr, and As) were significantly different from control and above permissible limits. The detected heavy metal falls within categorized into three Igeo classifications, following Muller's interpretation: significantly to exceedingly contaminated (Cd), moderately to significantly contaminated (Pb, Cr, and As), and ranging from uncontaminated to moderately contaminated (Fe). Based on the result obtained from the Monte Carlo's simulation, the observed hazard index (HI) values suggest that children have a higher likelihood (84%) of exceeding an HI value of 1 compared to adults (20%) when exposed to Cr in hand-dug wells (HDWs). In the case of Pb exposure via oral pathways, the computed lifetime carcinogenic risk (LTCR) values are comfortably below the 10^{-4} threshold, indicating no expected carcinogenic risk from Pb exposure. However, for Cr exposure in children through hand-dug wells (HWs), the LTCR values range from 0 to $2.14*10^{-4}$, signifying a potential risk associated with current Cr levels. The groundwater within the vicinity of auto mechanic repair activities areas in Omu-Aran has been greatly impacted negatively.

Keywords Potentially toxic elements, Mechanical workshops, Geoaccumulation index, Monte Carlo simulation

*Correspondence:
Praise Ejigboye
ejigboye.praise@lmu.edu.ng
[1] Department of Civil Engineering, College of Engineering, Landmark University, Omu-Aran, Nigeria
[2] Landmark University SDG 6 (Clean Water and Sanitation Research Group), Omu-Aran, Nigeria
[3] Department of Civil Engineering, School of Engineering, Federal Polytechnic, Ado-Ekiti, Nigeria
[4] Department of Civil Engineering, College of Engineering, University of Abuja, Abuja, Nigeria
[5] Department of Community Health Nursing, University of Medical Sciences, Ondo, Nigeria

Introduction

Water resources have remained the most heavily utilized natural system, serving essential roles in domestic, industrial, and agricultural functions since the dawn of civilization [28, 46]. The existing disparity in the allocation of social amenities within many developing countries worldwide has presented numerous hurdles for the functionality and performance of infrastructure. Consequently, the distribution of piped water is significantly impacted, leading to a consideration of groundwater as an alternative water source for domestic, industrial, and agricultural needs [3, 4, 24]. The quality of water and soil affects the quality of life, because water is one of the necessities of life employed by man for consumption and is directly or indirectly influenced by the quality of soil via operations such as percolation [16, 44].

However, though water is of great importance to man, polluted water can also serve as a medium to transmit pathogens and parasites that are harmful to human health [43, 62]. Unintended urbanization, disregard for exploration protocols, and inappropriate disposal of solid and liquid wastes facilitate the entry of toxic materials into the under groundwater resources [36]. Contamination of the soil, water, and atmosphere is caused by industrial and anthropogenic activities, aggravating the severity of environmental problems [22, 65].

The rising demand for private vehicles, particularly pre-owned cars in Nigeria, leads to an uptick in mechanical workshop activities, thereby contributing to elevated levels of heavy metal pollution [32, 37, 57]. Due to inadequate waste management systems, these waste materials are indiscriminately discharged within the mechanical workshop premises. Over time, the soil begins to accumulate the metals deposited by vehicle workshops, turning it into a repository for these substances [18]. Certain heavy metals, such as Zn, Ca, Co, Cu, Fe, Mn, Mg, K, Cr, Mo, Ni, and Na, are vital nutrients necessary for the growth and advancement of living organisms. In contrast, elements such as Cd, Pb, and Hg lack any nutritional or biochemical functions [27]. Pb can accumulate within the bones, from where it can subsequently be released and lead to chronic neurotoxic effects. Moreover, engagement in practices such as pica and other hand-to-mouth behaviors renders children more vulnerable to the adverse effects of lead when compared to adults [56]. During rainfall, these potentially hazardous metals within the soil may be carried through infiltration into the groundwater or released into surface water [49].

Several automobile mechanical operations have become a hub for the release of heavy metals into the soil and groundwater, including battery charging, engine and lubricating oil, welding and soldering, engine and gearbox overhaul, panel beating, electrical work, polishing, automobile bodywork, combustion process, and painting [42]. They require the use of oil, electrodes and other substances that can contaminate soil and water [37]. Oil includes oxidants, sediments, liquids and metallic fragments produced from wear of equipment, used batteries, organic and inorganic chemicals used in oil additives and metals. These substances contain heavy metals and hydrocarbons in high concentrations which pose serious risk to the environment. In general, they contain an extensive cocktail of toxic compounds which can build up and persist in the environment for years [19].

The evaluation of groundwater quality, which establishes its usefulness, is a key component of groundwater analysis [51]. Assessment of groundwater quality and its degradation have been studied extensively by various researchers [5, 9, 23, 30, 50, 54]. However, they do not account for the uncertainties inherent in a wide variety of risk-related problems.

Monte Carlo simulation (MCS) is a statistical technique that produce probability distributions which highlights the likelihood towards exposure and health risks [10]. MCS is used by recent studies to assess the risk levels, which involves account for the uncertainties and interpretation [8, 13, 17].

Numerous approaches have been employed to monitor and analyze the levels of heavy metals in groundwater [31, 52]. The geoaccumulation index (Igeo) is regarded as one of the most efficient methods for evaluating heavy metal concentrations. When both Monte Carlo Simulation (MCS) and Igeo are employed together, they can effectively gauge the pollution risk levels of different elements in water, rendering them especially valuable for the assessment of groundwater contamination.

This study was aimed at evaluating the risk associated with potential toxic elements using the Igeo and MCS in the vicinity of mechanical workshops within the Omu-Aran community. In addition, the study sought to investigate whether there is a lack of a significant correlation between anthropogenic activities in the chosen mechanical workshops and the accumulation of potentially toxic elements.

Consequently, given the growing proliferation of mechanic workshops and their uncontrolled discharge of used oil into the environment, it is imperative to assess the water's suitability based on the prescribed standards set by different regulatory bodies for water quality classification.

Materials and methods

Study area and sampling points

The research was conducted in Omu-Aran, which serves as the administrative center of the Irepodun Local Government Area in Kwara State, Nigeria, as shown in

Fig. 1. Omu-Aran is situated in the north-central region of Nigeria and spans an area of 73.7 square kilometers. According to the 2006 census data from the National Population Commission [34], the human population in this area was recorded as 148,610.

In this study, five sampling points were strategically chosen within automobile workshop premises, and data collection was carried out over 5 months. The precise geographic coordinates, including GPS location and altitude, for each of these sampling points in the field study are detailed in Fig. 1.

The city's population exhibits an uneven distribution, leading to the dispersal of municipal, commercial, and agricultural zones, as well as recreational and administrative areas, automobile repair workshops, and residential neighborhoods throughout the city. You can find a detailed account of the sampling locations within the study area in Fig. 1.

A total of 48 water samples were gathered from 5 hand-dug wells in the proximity of the automobile workshop and a control point. Each water sample from its respective location was meticulously stored in a PET bottle under 4 °C before analysis. Eight (8) samples from each the 5 sampling points and the control were collected and assessed. The hand-dug wells in each location have minimum depth of 8 m and at a close proximity of less than 10 m to the mechanical workshops.

Five mechanic workshop locations were purposefully selected in Omu-Aran. The locations selected are Secretariat, Bovas, Water works, Oroago Garage and G.R.A. The five mechanic workshops were selected using the following criteria:

i. Absence of other industries within the area,
ii. The hand-dug wells are located near mechanical workshops that have been operational for more than 10 years
iii. Presence of dug wells

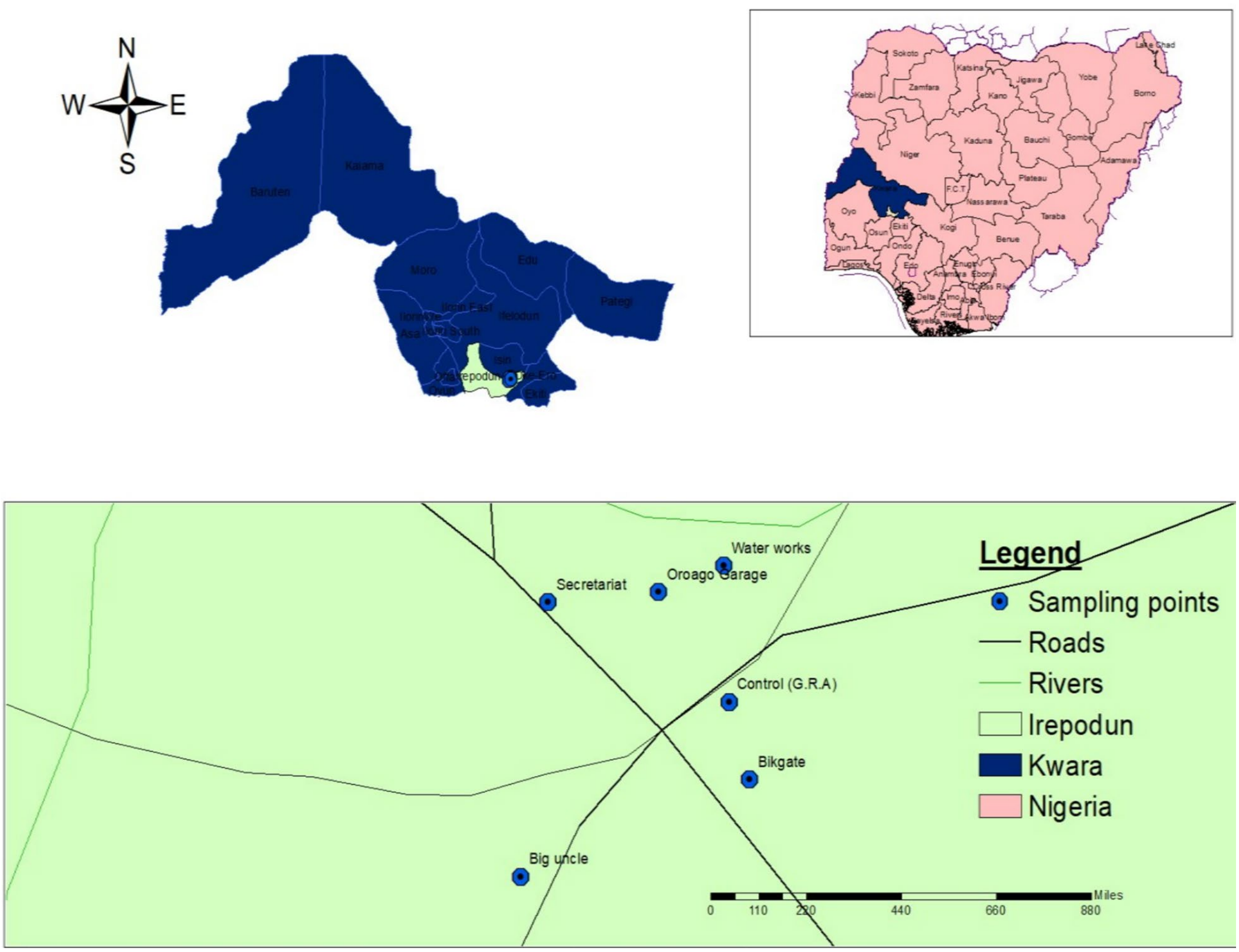

Fig. 1 Study map of Omu-Aran, Kwara State, Nigeria

A residential area where industries and mechanic activities are absent will serve as control.

Sample preparation and analysis

Digestion of water sample for heavy metal determination

Water samples were gathered over a span of 4 months (October to January) from five distinct locations, where hand-dug wells are located. Subsequently, the water samples were prepared for analysis using the acid digestion procedure outlined in the USEPA Method 3005A. Each water sample, comprising 100 mL, was subjected to digestion in 10 mL of concentrated HCl, followed by thorough mixing. The beaker was heated gently to 95 °C, the temperature was maintained until the volume reduces to about 15–20 mL. Afterwards, the mixture was filtered, and analytical procedures, including the examination of heavy metal parameters, were conducted on each sample. The concentration of heavy metals was assessed using an Atomic Absorption Spectrophotometer (AAS BULK SCIENTIFIC MODEL 211 VGP). Strict preservation protocols were adhered to prevent any subsequent reactions after the collection process.

Determination of physio-chemical parameters

The physio-chemical parameters analyzed are selected based on the need for water quality assessment. This was done according to the American Public Health Association (APHA) Standard Method. The physio-chemical parameters includes pH using pH meter model PHS-3C, Dissolved oxygen using Smart D.O meter model mw600, Electrical Conductivity (EC) using a multi parameter tester model DZS-706, Total Dissolved Solids (TDS) using a multi parameter tester model DZS-706, Oil and Grease using partition-gravimetric method, Temperature using a standard thermometer. Phosphate, chlorine and sulphate were determined using the multi parameter photometer. Sodium, calcium and magnesium using Jen Way flame photometer.

Monte Carlo simulation

The Monte Carlo method was employed Oracle Crystal Ball™, was utilized to simulate health risk values for both non-carcinogenic (HI) and carcinogenic (LTCR) risks in adults and children exposed to drinking water in the context of HDWs scenarios. It has proven effective in depicting uncertain quantitative events and yielding numerical results with equivalent precision. In practical terms, a method capable of managing a multitude of uncertainties for various data points within a risk assessment model is essential.

Development of pollution index of groundwater

The pollution index of groundwater (PIG) is a numerical scale that quantifies the level of contamination, providing a widely used tool for assessing variations in groundwater quality resulting from diverse geochemical factors [1, 2, 59, 60]. Calculating the pollution index of groundwater (PIG) involves assigning a relative weight (RW) to each chemical parameter, with RW values ranging from 1 to 5 based on their potential impact on human health. Maximum weight (5) was given to Cl^{-}, SO_4^{2-}, pO_4^{-} and Mg, and minimum weight (1) was assigned to K^{+} and Ca^{+}. In addition, weight parameter (WP) is calculated for each chemical parameter to assess its relative contribution to the overall groundwater quality [1, 2, 59, 60]. The WP is determined using the following equation:

$$\mathrm{WP} = \mathrm{RW} \Big/ \sum \mathrm{RW} \tag{1}$$

$$\mathrm{SC} = \frac{C_i{}^n}{DQS_i{}^n} \tag{2}$$

$$\mathrm{OW} = \mathrm{WP} \times \mathrm{SC} \tag{3}$$

where C concentration of chemical parameter “n”, and DQS is the drinking water quality standard “nth” parameter.

The overall groundwater quality (OW) is then determined by multiplying the weight parameter (WP) with the sub-index score (SC), as shown in Eq. 3. Finally, the pollution index of groundwater (PIG) is calculated using the following equation:

$$\mathrm{PIG} = \sum\nolimits_i^n OW \tag{4}$$

Furthermore, Subba Rao [55] categorized the pollution index of groundwater for five classes based on PIG values which are presented in Table 1.

Geoaccumulation index

The geoaccumulation index (Igeo) was employed to assess the degree of heavy metal contamination in the water within the confines of the five automobile repair

Table 1 PIG range and classification for drinking purposes

Serial No	Range	PIG Classes
1	< 1.0	Insignificant pollution
2	1.5	Low pollution
3	1.5–2.0	Moderate pollution
4	2.0–2.5	High pollution
5	> 2.5	Very high pollution

workshops and control points. The Igeo values were derived using the formula devised by Muller:

$$\text{Igeo} = \log_2 \frac{c_\text{n}}{1.5B_\text{n}} \quad (5)$$

where Cn = the measured overall metal content in the sample ($\mu g \cdot g^{-1}$)

Bn = geochemical background values of metals ($\mu g \cdot g^{-1}$)

1.5 = the background matrix correction factor due to lithogenic effects. The Igeo scale consists of seven grades (0–6), as shown in Table 2.

Statistical analysis

To identify a correlation between water quality at sampling points and pollution parameters, descriptive analysis was employed to interpret the data and calculate the mean and standard deviation for each parameter. The correlation between the physicochemical parameters of groundwater across various locations and the concentrations of heavy metals in groundwater will be established through the application of analysis of variance (ANOVA).

Table 2 Classification of geoaccumulation index (Igeo) after [33]

Class	Igeo value	Designation of water quality
0 Class	Igeo > 0	practically uncontaminated
1 Class	0 < Igeo < 1	uncontaminated to moderately contaminated
2 Class	1 < Igeo < 2	moderately contaminated
3 Class	2 < Igeo < 3	moderately to heavily contaminated
4 Class	3 < Igeo < 4	heavily contaminated
5 Class	4 < Igeo < 5	heavily to extremely contaminated
6 Class	5 < Igeo	extremely contaminated

Correlation analysis, analysis of variance (ANOVA) ($P < 0.05$) as applicable were carried out using IBM Spss V.22 software.

Key assumptions; Normal distribution of data within each group, homogeneity of variances and Independence of observations [20, 63].

Limitations; Violations of assumptions reduce reliability and outliers can skew results [58, 64].

Results

Physio-chemical parameters

Water samples collected from ground water sources in dug wells were analyzed for various physiochemical parameters, such as pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), oil and grease, sulphite, chlorine, sodium, magnesium, calcium and potassium, as shown in Table 3.

Numerous studies have pointed out that samples tend to accumulate contaminants due to the intense pace of human activities within urban areas [26, 47]. These heavy metal parameters encompass Pb, Cd, Fe, Cr, and As. An overview of the heavy metal concentrations at various locations is detailed in Table 3.

pH

The values of the pH ranged between 6.17 ± 0.75 and 5.39 ± 0.33 which falls below acceptable range of WHO [61]. The pH value of control (6.92 ± 0.34) is significantly different from values obtained in other locations. This shows that water samples at all sampling points are acidic. The recorded pH values across the sampling sites were slightly higher than that reported by previous studies [10]. The pH of water is a significant factor which influences geochemical reactions that takes place within

Table 3 Descriptive statistics for groundwater physicochemical properties

Parameters	Units	Bikgate	Water works	Oroago garage	Secretariat	Big uncle	Control	WHO
pH		6.17 ± 0.750b	5.87 ± 0.130bc	5.39 ± 0.330c	5.56 ± 0.450bc	5.92 ± 0.470bc	6.92 ± 0.340a	6.5–8.5
TDS	mg/L	26.84 ± 3.050a	24.81 ± 9.650a	27.4 ± 2.060a	73.2 ± 7.750b	32.48 ± 1.230a	25 ± 4.310a	500
EC	μs/cm	50.33 ± 6.380ab	47.83 ± 15.406ab	50.91 ± 4.960ab	135.3 ± 16.090c	60.6 ± 3.610b	38.4 ± 6.240a	1000
DO	mg/L	2.58 ± 0.350	2.98 ± 0.170	4.15 ± 0.129	3.53 ± 0.080	4.66 ± 0.170	6.85 ± 0.560	5
Oil and Grease	mg/L	0.41 ± 0.030	0.41 ± 0.050	0.04 ± 0.010	4.58 ± 0.430	0.57 ± 0.070	__	0.05
PO_4^{3-}	mg/L	0.14 ± 0.080	0.71 ± 0.050	0.89 ± 0.140	0.35 ± 0.260	0.14 ± 0.020	0.12 ± 0.010	5
SO_4^{2-}	mg/L	13.89 ± 2.340	13.36 ± 1.790	11.01 ± 0.870	9.43 ± 1.360	12.18 ± 1.870	10.21 ± 3.210	100
Cl	mg/L	48 ± 26.720	46.5 ± 8.350	34.5 ± 3.870	56.75 ± 27.760	36.25 ± 13.920	24.38 ± 4.570	250
Mg	mg/L	1.11 ± 0.117	0.99 ± 0.160	2.92 ± 0.130	12.15 ± 1.160	1.58 ± 0.018	0.31 ± 0.230	150
Na	mg/L	0.03 ± 0.010	0.01 ± 0.000	0.06 ± 0.010	0.11 ± 0.030	0.04 ± 0.010	0.26 ± 0.130	250
Ca	mg/L	5.73 ± 0.630	8.95 ± 2.870	6.68 ± 0.710	5.4 ± 0.520	6.08 ± 1.230	16.46 ± 3.850	75
K	mg/L	0.10 ± 0.070	0.12 ± 0.020	0.21 ± 0.030	0.29 ± 0.080	0.27 ± 0.030	0.32 ± 0.130	20

Results are expressed as the mean of duplicates ± SD and as compared on the same row followed by different superscripts (a–d) showing a significant difference ($P < 0.05$) using Duncan's test (ANOVA) groundwater. Water becomes corrosive at low pH values which is of particular importance as past literature has shown that apart from organoleptic concerns, it could lead to water pollution, since it can intensify leaching of metal from pipes, such as copper and lead [21, 66].

Total dissolved solids

The TDS values obtained for at all sampling points varied from 24.81 ± 9.65 to 73.2 ± 7.75 mg/L. The control has TDS value slightly lower than other sampling points; however, only secretariat is significantly different from control. These may be caused by non-plastered walls that allow entry of runoff during precipitation, The result all fall within the WHO guideline values of 500 mg/L According to [53], the groundwater in the study area can be characterized as freshwater (TDS < 1000 mg/L). Water becomes undrinkable at a high level of TDS which may even corrode storage containers used.

Electrical conductivity

The values of the electrical conductivity ranged between 47.83 ± 15.46 and 135.3 ± 16.09 µs/cm for all sampling points, while control has a value of 25 ± 4.31 µs/cm. All values were found to be relatively low and within the WHO maximum permissible limits (1000 µs/cm) for conductivity, although well at secretariat have significantly higher value than other sampling points including control. This is a measure of ability of a medium (water) to transmit electric current [40]. The findings suggested that the water samples lack salinity, as the concentration of dissolved salts in the water is minimized. Consistent intake of water with values surpassing permissible limits over time can adversely impact human health by disrupting endocrine functions and potentially leading to severe brain damage.

Dissolved oxygen

The value for DO ranged between 2.58 ± 0.35 and 4.66 ± 0.17 mg/L with the highest value recorded at big uncle station. The DO values are significantly different across sampling sites and this dissimilarity could be a result of the presence and action of micro-organisms and strong oxidizing substances. Result obtained failed to meet both minimum WHO requirements (5 mg/L) and SON standard (7.5 mg/L) indicating slight degree of pollution by organic matter [11].

Oil and grease

The concentration of Oil and Grease in the groundwater samples measured ranged from 0.04 ± 0.01 to 4.58 ± 0.43 with an average value of 1.2 ± 1.75 mg/L. The measured values of oil and grease in the five sampling points falls above the permissible limit (0.05 mg/L) except at oroago garage. The occurrence of oil and grease in the area can be linked to the operations of oil-related activities, household usage, and automotive shops within the study area. Consequently, an unavoidable release of a certain quantity of hydrocarbons into the groundwater has occurred [38].

Phosphate

The value for Phosphate ranged between 0.14 ± 0.02 and 0.89 ± 0.14 mg/L with mean value of 0.45 ± 0.34 mg/L. All phosphate values fall within the W.H.O permissible limits (5 mg/L). The phosphate value of control (0.12 ± 0.01 mg/L) is lower than values of sample points. Groundwater samples from oroago garage have the highest value of phosphate concentration, this may be caused by the presence of car wash facility in the automobile mechanic workshop. The presence of phosphate in water could result to eutrophication.

Sulphate

The sulphate levels ranged from 9.43 ± 1.36 to 13.89 ± 2.34 mg/L, with the water samples from Bik Gate showing the highest value at 13.89 ± 2.34 mg/L. There is no specific guideline value for sulphate with respect to human health, the World Health Organization (WHO) suggests that any concentration exceeding the acceptable limit of 100 mg/L is considered unhygienic.

Chloride

The chloride concentration varied from 34.5 ± 3.87 to 56.75 ± 27.76 mg/L. The average value for the control group was 24.38 ± 4.57 mg/L. While all these values fall within the World Health Organization's (WHO) permissible limits of 250 mg/L, notable distinctions were observed in the chloride levels between the study and control wells. Although chloride ions are generally benign at lower concentrations, excessive chloride content in well water may have detrimental effects on plants if used for gardening or irrigation. Furthermore, it could impart an unpleasant taste to drinking water if consumed [6].

Sodium

The sodium content varied from 0.01 ± 0 to 0.06 ± 0.01 mg/L, and all of these measurements fell within the World Health Organization's (WHO) acceptable threshold of 50 mg/L. It is worth noting that elevated levels of sodium, typically above 200 mg/liter, have been reported to potentially influence the taste of drinking water [15].

Calcium

The value for the calcium ranged between 9.43 ± 1.36 and 13.89 ± 2.34 mg/L. Although the values were within the WHO permissible limits of 75 mg/L, they were significantly lower than the value from the control (16.46 ± 3.85 mg/L).

Potassium

The potassium ranged between 0.10 ± 0.07 and 0.27 ± 0.03 mg/L. The measured values of potassium fall within the permissible limits of 20 mg/L. The implication of a high value of potassium is that the water becomes undrinkable and it can also lead to eutrophication [29, 41].

Determination of heavy metals in water samples

The Heavy metal parameters include Pb, Fe, Cd, Cr, and Ar. The summary of heavy metal levels across the locations are presented in Table 4.

Lead (Pb)

The observed lead values ranged from 0.048 ± 0.012 to 0.105 ± 0.009 mg/L. The values are beyond the acceptable WHO standard limits of 0.05 mg/L. The Pb levels in the control wells is significantly different from other sampling locations. Pb accumulates and increases over a period of time in the blood vessels and bones. It may reach man's body system through water consumption, food and air intake [35]. As well as being carcinogenic, Pb also affects the exposed person's core neurological system. It could also distort physical and mental growth in children and could disrupt childrens' care and learning skills [39].

Iron (Fe)

The concentration of Fe ranged from 0.130 ± 0.008 to 0.269 ± 0.005 mg/L. The values are beyond the acceptable WHO standard limits of 0.05 mg/L. Fe reaches the ground water from the surrounding rocks that penetrate the groundwater. The Fe levels differed significantly between the control wells and other sampling points. It is regarded as an essential trace metal but in high quantities it is toxic which harms human health. It has also been reported as a possible carcinogen of cancer in man [45, 48].

Cadmium (Cd)

The cadmium concentration in all groundwater samples exhibited a range of 0.011 ± 0.004 to 0.115 ± 0.002 mg/L. Variations in the metal's distribution can be attributed to either human activities occurring in distinct locations or differences in sediment composition. Cadmium infiltrates groundwater through processes such as soil and bedrock weathering, erosion, or direct discharge from industrial sources. Once within the body, cadmium accumulates primarily in the kidneys, where it can impair the filtration mechanism, leading to various health issues, including diarrhea, bone fractures, reproductive problems, infertility, central nervous system damage, compromised immune function, psychological disorders, and an increased risk of cancer development [7, 12].

Chromium (Cr)

The Cr value for all groundwater samples ranged from 0.068 ± 0.014 to 0.12 ± 0.004 mg/L. The concentration falls beyond the acceptable WHO standard limits of 0.05 mg/L. The concentration of the chromium in the sampling locations is significant different from control well. Groundwater contamination from chromium may be caused by exposure to chromate waste disposal products. Chromium's detrimental impacts on humans are mostly related to its oxidized state. Cr intake can damage includes liver necrosis and membrane ulcers and causes dermatitis if it contacts the skin [14].

Arsenic (As)

The concentration of As ranged from 0.015 ± 0.004 to 0.08 ± 0.002 mg/L. Although the arsenic values for all samples were within the WHO allowable limits of 0.01 mg/L, they are significantly different from the control well. Arsenic is one of the metals known to be highly injurious to human health particularly if they exist in high proportion.

Table 4 Descriptive statistics for heavy metals properties in groundwater

Parameters	Units	Bikgate	Water works	Oroago garage	Secretariat	Big uncle	Control
Pb	mg/L	0.048 ± 0.012	0.078 ± 0.017	0.056 ± 0.009	0.105 ± 0.009	0.085 ± 0.006	0.00 ± 0.00
Fe	mg/L	0.207 ± 0.015	0.130 ± 0.008	0.144 ± 0.013	0.188 ± 0.021	0.269 ± 0.005	0.050 ± 0.004
Cd	mg/L	0.011 ± 0.004	0.018 ± 0.002	0.037 ± 0.007	0.022 ± 0.007	0.017 ± 0.004	0.003 ± 0.001
Cr	mg/L	0.068 ± 0.014	0.095 ± 0.008	0.112 ± 0.006	0.069 ± 0.08	0.115 ± 0.002	0.00 ± 0.00
As	mg/L	0.014 ± 0.003	0.027 ± 0.004	0.016 ± 0.004	0.082 ± 0.015	0.064 ± 0.005	0.004 ± 0.003

Results are expressed as mean of duplicates ± SD and as compared on same row followed by different superscripts (a–d) show significant difference ($P < 0.05$) using Duncan's test by (ANOVA)

Arsenic was also found in all the water samples analyzed in abnormal proportions. Long-term human exposure to Arsenic in drinking water is caused by higher risk of skin, lungs, bladder and kidney cancer, as well as other skin change such as changes in hyperkeratosis and pigmentation (Abernathy et al., 2001).

Pollution index of groundwater (PIG)

The pollution index of groundwater (PIG) values for groundwater samples in the study area ranged from 0.318 to 2.091. 20% of samples falls within the 'High pollution' category that shows the water is not fit for drinking purposes, as shown in Table 5.

Table 5 Pollution index of groundwater for each sampling location

Range	PIG	PIG Classes
Bigate	0.387	Insignificant pollution
Water Works	1.681	Moderate pollution
Garage	2.091	High pollution
Secretariat	0.952	Insignificant pollution
Big Uncle	0.379	Insignificant pollution
Control	0.318	Insignificant pollution

As indicated by the PIG, 20% of water samples were fall in the 'moderate pollution' water category and 60% of samples in the study area falls in the 'Insignificant pollution' water category. Most samples from within the vicinity of mechanical workshop fall in the 'high pollution and moderate pollution' water category, while all samples from control fall in the insignificant pollution categories. Therefore, the area can be considered as a vulnerable area for water quality-related issues.

Monte Carlo simulation

Oracle Crystal Ball™, was employed to simulate both non-carcinogenic (HI) and carcinogenic (LTCR) health risk assessments for both children and adults exposed to portable drinking water in scenarios related to HDWs using Monte Carlo technique (Elemile et al., 2020). Probabilistic evaluations of hazard index (HI) for HDWs, with a 95% confidence level, are illustrated in Figs. 2, and 3, respectively.

The study examined four heavy metals, with particular emphasis on lead (Pb) due to its toxicity and chromium (Cr), because it is categorized as carcinogenic. Upon simulating non-carcinogenic risk values, the outcomes at both mean and 95th percentile levels revealed that the risk consistently stayed below the threshold value (HI < 1). However, when it comes to exposure to chromium in the context of HDWs, the respective

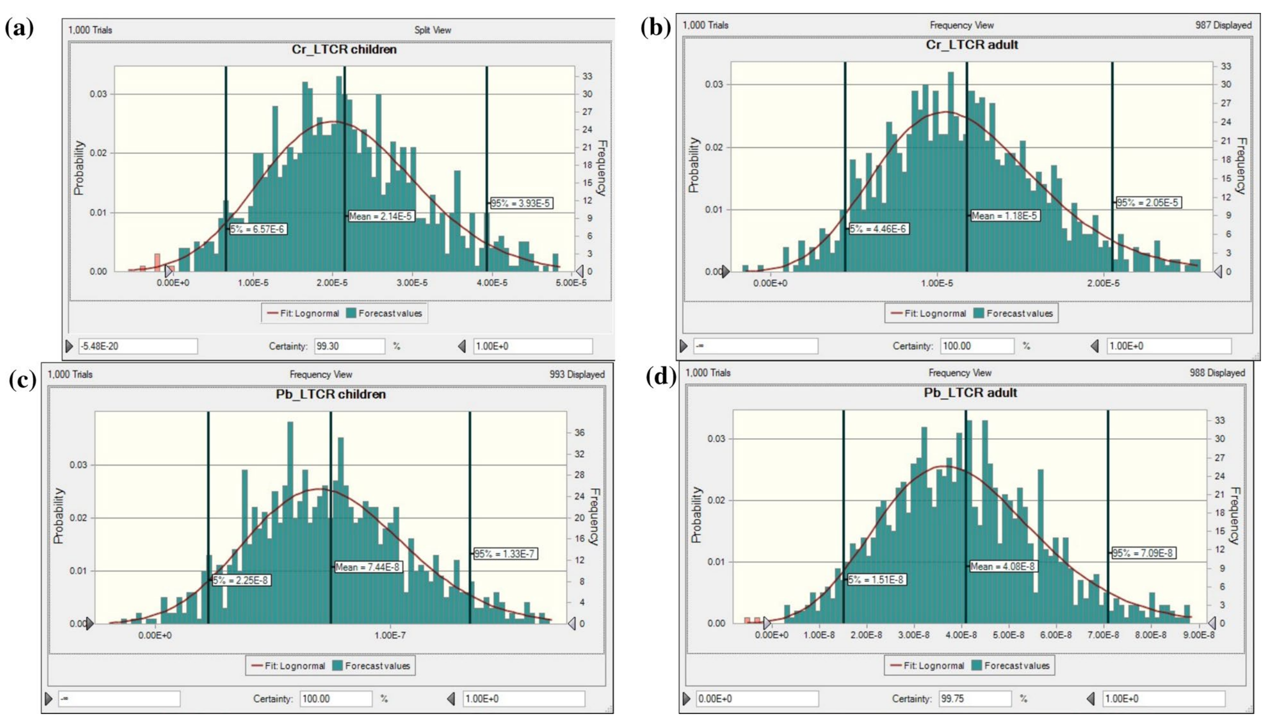

Fig. 2 Monte Carlo simulation for carcinogenic risk in Hdws (**a**), exposure to Cr in case of children (b) and adults (**c**), exposure to Pb in case of children (**d**) and adults

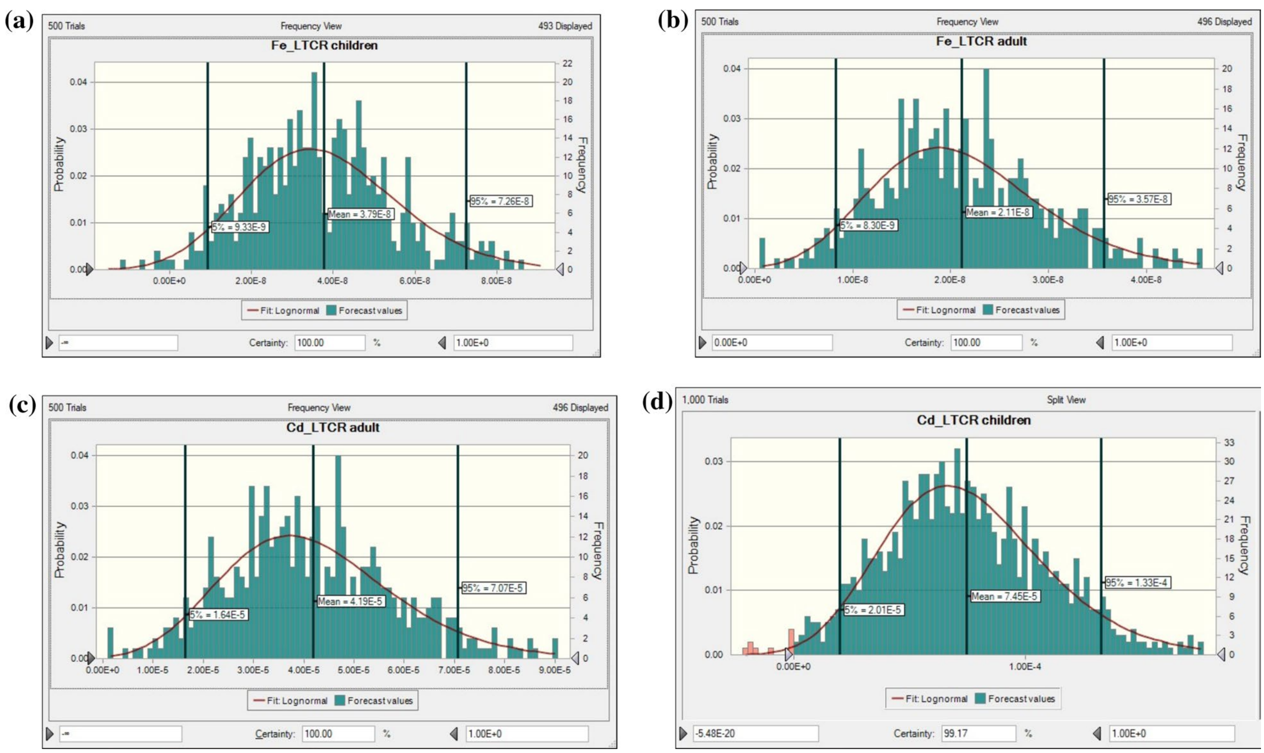

Fig. 3 Monte Carlo simulation for carcinogenic risk in Hdws (**a**), exposure to Fe in case of children (**b**), and adults (**c**), exposure to Cd in case of children (**d**) and adults

mean and 95th percentile levels were 1.77 and 2.86 for children and 0.79 and 1.27 for adults, signifying a non-carcinogenic health risk. The probability of surpassing this threshold is notably higher in children (approximately 84%) compared to adults (about 20%).

Furthermore, the study conducted simulations to estimate the LTCR associated with lead (Pb) and chromium (Cr) for both types of water sources. For HDWs, the mean and 95th percentile values for Lifetime Cancer Risk (LTCR) associated with lead were determined to be 4.16×10^{-8} and 7.41×10^{-8}, respectively. Similarly, for Cr, the mean and 95th percentile LTCR values for children were 2.1×10^{-5} and 4.57×10^{-5}, and for adults, they were 1.2×10^{-5} and 2.46×10^{-5}. When considering BHs, the mean and 95th percentile LTCR values for Pb in children were 4.33×10^{-9} and 8.9×10^{-9}, and for adults, they were 2.43×10^{-9} and 4.55×10^{-9}. Similarly, the mean and 95th percentile LTCR values for Cr in children were 6.34×10^{-6} and 1.22×10^{-5}, and for adults, they were 3.57×10^{-5} and 3.41×10^{-5}. It is noteworthy that the LTCR values determined in this study are below the maximum acceptable carcinogenic risk recommended by the USEPA (1×10^{-4}). Moreover, the likelihood of exceeding this threshold is nearly non-existent.

Sensitivity analysis

Sensitivity analysis plays a crucial role in risk management and informed decision-making processes. Sensitivity analysis was employed to assess the alterations in parameter values, including metal concentration, IR and EF, impact the hazard index (HI) [1, 2]. In this study, sensitivity analysis was employed to identify the key factors influencing the overall risk assessment. The analysis revealed that the IR exhibited the most substantial positive influence on the estimation of carcinogenic risk associated with exposure to Pb and Cr in HDWs (as illustrated in Fig. 2). In addition, both the exposure frequency (EF) and the concentration of metals had a notable impact on the overall risk assessment in both scenarios [59, 60].

Fe is most sensitive to ingestion rate and exposure duration for children. Exposure factors (EF) and body weight (BW) could also influence variance. Cadmium is highly skewed distribution with a long right tail, indicating a possibility of high-risk values in some scenarios. Mean LTCR is higher than Fe. Children show a higher peak probability density and slightly higher LTCR values. Fe typically poses low carcinogenic risk, so even wide spreads may still remain within safe thresholds. Chromium has symmetrical lognormal distribution. Children again show higher peak probability, and risk range is wider compared to adults. Sensitive to exposure duration and oral slope factor. Chromium's carcinogenic nature (especially hexavalent Cr) means that even slight exposure differences impact risk significantly.

Geoaccumulation index

The data presented in Fig. 4 illustrates the Igeo values for the concentration of heavy metals in the HDWs water samples. These Igeo values exhibit variations depending on the location and class of sampling. Across all sample types, the five metals can be categorized into two Igeo levels according to Muller's interpretation: heavily to extremely contaminated (Pb), moderately to heavily contaminated (Cd and As), and uncontaminated to moderately contaminated (Fe). The source of this pollution is likely linked to human activities, primarily associated with mechanical operations.

Igeo values for elements such as arsenic, cadmium, and chromium indicate a significant level of contamination in the HDWs 5 and HDWs 4 regions. Meanwhile, all sampled locations exhibit elevated concentrations of Lead in the sample. Specifically, HDWs 5 and HDWs 4 area are categorized as having extreme and moderate contamination with respect to lead compounds, as shown in Table 6.

The observed Igeo values at the sampling sites reveal the presence of heavy metal concentrations, potentially stemming from various sources of contamination in the research area. The HDWs 5 area, as indicated in Table 6, falls into the category of heavy contamination for all the assessed heavy metals. This contamination could be attributed to activities such as battery charging, welding, and painting operations conducted in the vicinity. In the Oroago garage area (HDWs 3), the Igeo classification for Chromium is moderately contaminated, likely due to its use in chrome plating of certain motor vehicle parts, mechanical components, polymers, miscellaneous elements, and various electronic and electrical devices.

The HDWs 4 area has been categorized as experiencing moderate contamination with respect to Arsenic. The presence of Arsenic in this area is primarily associated with emissions resulting from the combustion of diesel and gasoline.

Conclusion

The levels of the five heavy metals within the confines of the mechanic workshop premises were significantly higher than the background values, indicating a substantial impact of mechanical activities on water quality in the polluted area. Of particular concern was the contamination of water by Cd, with Igeo values ranging from 4 to 5. The average concentrations of Pb, Cr, and As in the polluted water exceeded reference values, whereas Fe concentrations remained within the lower range typical of unpolluted conditions.

Based on the Monte Carlo simulation results, it is evident that children are at a significantly higher risk (84%) of surpassing a hazard index (HI) value of 1 in comparison with adults (20%) when exposed to Cr through Hangdug wells (HDWs). In the case of Pb exposure through oral routes, the calculated lifetime carcinogenic risk (LTCR) values comfortably remain below the threshold of 10^{-4}, indicating an absence of

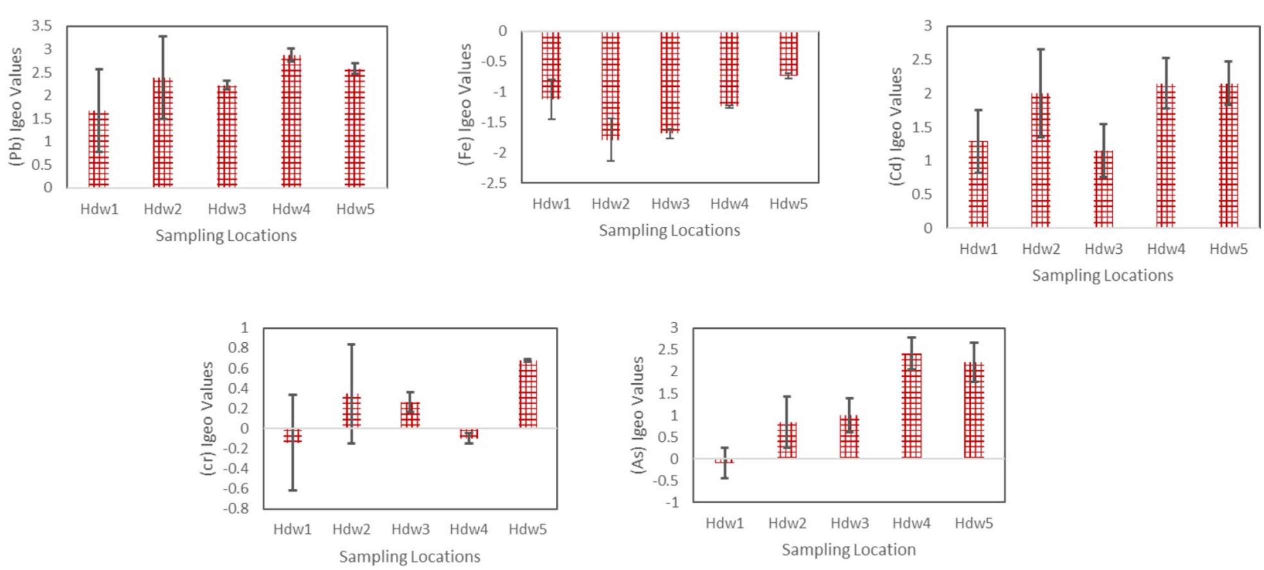

Fig. 4 Average concentration Pb, Fe, Cd, Cr, As Igeo values of the measured heavy metals were studied with respect to the natural background

Table 6 Possible contamination sources responsible for Igeo classification in sampling locations

Heavy metals	Igeo Classification according to locations	The possible source of contamination
Pb	Heavily contaminated—waterworks Moderately to heavily contaminated—Secretariat, Big uncle, Oroago garage Moderately contaminated—Bikgate Uncontaminated to moderately contaminated—Null Practically uncontaminated—Null	Experts specialized in batteries, known as 'battery chargers,' are sought after throughout Nigeria and play a significant role in lead (Pb) emissions. In addition, welding and painting operations can contribute to the presence of lead [25]
Fe	Heavily contaminated—Null Moderately to heavily contaminated—Null Moderately contaminated—Null Uncontaminated to moderately contaminated—Null Practically uncontaminated—waterworks, Oroago garage, Secretariat, Big uncle, BikGate	Iron (Fe), lead (Pb), and arsenic (As), which are a combination of metalloids and metallic elements, are found in the gasoline used as vehicle fuel. Prior studies by different researchers have identified heavy metals such as iron (Fe), chromium (Cr), and lead (Pb) as components of tire wear dust
Cd	Heavily contaminated—Null Moderately to heavily contaminated—Null Moderately contaminated—BikGate, waterworks, Oroago garage, Secretariat, Big uncle Uncontaminated to moderately contaminated—Null Practically uncontaminated—Null	Cadmium is detected in the Pigments used in automotive bodywork paints, glass, welding electrodes employed by professionals known as 'panel beaters' (bodywork specialists), as well as in the combustion of petroleum products. It can also be found in certain brands of motor vehicle tires and some lubricating oils
Cr	Heavily contaminated—Null Moderately to heavily contaminated—Null Moderately contaminated—Null Uncontaminated to moderately contaminated—BikGate, waterworks, Big uncle Practically uncontaminated—Oroago garage, Secretariat	Chromium (Cr) is frequently Linked to its application in the chrome plating of various motor vehicle components, mechanical parts, polymers, and a range of components, including electronic and electrical devices
As	Heavily contaminated—Null Moderately to heavily contaminated—waterworks Moderately contaminated—Oroago garage, Secretariat, Big uncle Uncontaminated to moderately contaminated—Null Practically uncontaminated—BikGate	The combustion of diesel and Gasoline fuels produces heavy metals, such as arsenic, cadmium, and chromium

expected carcinogenic risks from Pb exposure. However, in the context of Chromium exposure among children via Hangdug wells (HDWs), the LTCR values span from 0 to $2.14*10^{-4}$, suggesting a potential risk associated with current levels of Cr. Individuals residing in the control area seem to be out of harm's way. On the contrary, those living in the contaminated region are confronted with significant health hazards arising from Cd and other heavy metals.

Abbreviations

As	Arsenic
Cd	Cadmium
Cr	Chromium
Igeo	Geoaccumulation index
HI	Hazard index
LTCR	The calculated lifetime carcinogenic risk
HDWs	Hangdug wells
Pb	Lead
IR	Ingestion rate
CF	Conversion factor
EF	Exposure frequency
ED	Exposure duration
BW	Body weight
AT	Average time
SA	Surface area
Kp	Permeability coefficient
MCS	Monte Carlo simulation

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Author contributions
All authors contributed to this study design. Material preparation and data collection analysis were performed by Ejigboye praise oladapo. Analysis was carried out by Mr PE, Mr EI and Dr. OE, Dr. AG worked on the review. The first draft of the manuscript was written by Ejigboye, praise oladapo and all authors commented on previous versions of the manuscript. Mr OO and OI review the manuscript and made corrections. All authors read and approved the final manuscript.

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Data availability
The data set is available via Databris repository of Landmark University.

Declarations

Ethics approval
All the authors mentioned in the manuscript have agreed for authorship, read and approved the manuscript, and given consent for submission and subsequent publication of the manuscript.

Consent to participate
Not applicable.

Consent for publications
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Competing interests
The authors declare that there is no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed, consent, misconduct, data fabrication and, or falsification, double publication and no submission, and redundancy have been completely witnessed by the authors.

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