

Methodology Article

Assessment of Water Contamination by Heavy Metals and Radionuclides Near Industrial, Automobile, and Residential Areas in Gboko, Nigeria

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Abstract

Water contamination by heavy metals and radionuclides poses a major environmental and public health concern due to their toxicity, persistence, and bioaccumulation potential. This study aimed to assess the contamination levels of water sources near industrial, automobile, and residential areas in Gboko, Nigeria. Specifically, the concentrations of heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), iron (Fe), and zinc (Zn), as well as naturally occurring radionuclides including ^{226}Ra , ^{232}Th , and ^{40}K , were analysed in borehole, well, and stream water samples. Results showed that residential areas generally had metal concentrations below WHO permissible limits, while automotive and industrial areas recorded higher levels, especially for Pb, Cd, Cr, and Fe. Lead levels in industrial streams reached 0.04 mg/L, exceeding WHO standards, with potential long-term health risks such as neurological damage and kidney dysfunction. Radionuclide activity was highest at the industrial sites, with Total Annual Effective Dose (TAED) values ranging from 0.00146 to 0.00221 mSv/year, which, although within WHO safety limits, approached the Excess Lifetime Cancer Risk (ELCR) thresholds. The elevated contamination levels in industrial and automotive areas were attributed to emissions from vehicular activities, industrial discharges, and surface runoff carrying pollutants into water bodies. Overall, while zinc concentrations remained within safe limits across all sites, the presence of other heavy metals and increasing radionuclide activities in industrial areas indicate a growing pollution burden. The study concludes that periodic monitoring and implementation of pollution control measures are essential to mitigate the potential health hazards associated with contaminated water sources in Gboko, thereby ensuring the safety of residents who rely on these water supplies for domestic and drinking purposes.

Keywords

Health Risk, Water Contamination, Environmental Pollution, Internal Hazard Index, Radiological Hazard, Phytotoxic Effects

1. Introduction

Water resources and water quality are crucial for urban development and the ecological environment, especially in areas of severe water shortage [30]. Access to safe water is

effective in promoting health and reducing poverty. WHO leads global efforts to prevent waterborne disease transmission by promoting health-based regulations to governments

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and promoting risk management practices to water suppliers, communities, and households [18]. Water plays a vital role in physiological functions, such as temperature control, and is a solvent for dissolved gases, minerals, organic nutrients, and metabolic wastes. It helps distribute vegetation over the Earth's surface and shapes the Earth's surface through processes like dissolution, erosion, and deposition [16]. Water is also essential for human domestic purposes such as food preparation, washing clothes, sanitation, and drinking [8].

Water containing heavy metals and radionuclides can be hazardous to human health and the environment because of their toxicity, persistence, and tendency to bioaccumulate [11]. Heavy metals are metals with a density greater than 5 g/cm³ [33]. They are non-biodegradable substances that cannot be easily detoxified and removed by metabolic processes, leading to their bioaccumulation in the ecosystem. This pollution poses serious environmental concerns due to its long-term implications on human health and the environment [3]. Sources of heavy metal contamination in water can either be natural or through anthropogenic processes such as irrigation, agricultural activities, animal feed, packing materials etc. [1]. When humans are exposed to heavy metals like cadmium (Cd), arsenic (As), lead (Pb), and mercury (Hg), there are several detrimental short- and long-term impacts. Diabetes, high blood pressure, kidney and renal failure, and osteoporosis are the main manifestations of these consequences. Additionally, heavy metals can build up in human neurological tissues, influencing nerve growth and resulting in severe, irreparable harm [6]. Radionuclides on the other hand are unstable chemicals with unstable nuclei. They stabilize through radioactive decay or transformation, which involves spontaneous fission, alpha particle emission, or neutron conversion. This process often results in the release of ionizing radiation like beta particles, neutrons, or gamma rays [22]. Radionuclides can be released in soil, water bodies, and wastewater collection systems through disposal from oil and gas plants or automobile mechanic sites, patient urine, excreta, or hospital liquid waste discharge [4]. Non-point sources of radionuclides can also be released into the soil through leakage in collection systems or into the atmosphere or potable water sources [11]. Natural or artificial radionuclide exposure can have a range of negative health impacts, from short-term risks like skin burns and acute radiation sickness to long-term hazards like cardiovascular disease and cancer [3].

Nigeria's growing industrialization, which is fueled by industries including manufacturing, mining, oil and gas, and agriculture, has greatly boosted the country's economy but also puts the quality of its water at serious risk [35]. The oil sector is well known for spills and pipeline breaches, which contaminate groundwater and waterways with heavy metals and hydrocarbons [12]. Mining operations send cyanide and mercury into the water, while manufacturing facilities dump untreated chemicals, such as dyes and hazardous metals, straight into water bodies, exacerbating water pollution [9]. Runoff from fertilizer and pesticides is one way that industrial

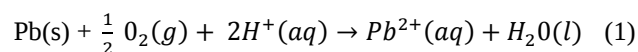
farming leads to pollution. These contaminants cause radionuclides and heavy metals to bioaccumulate in the food chain, cause waterborne illnesses, and reduce aquatic biodiversity. Human health and agriculture are also impacted by contaminated water [25].

[2], evaluated the concentrations of seven heavy metals Arsenic (As), Nickel (Ni), Cadmium (Cd), Chromium (Cr), Lead (Pb), Manganese (Mn), and Zinc (Zn) in borehole and hand-dug well water samples from various locations in Gboko, Benue State. The results were compared to World Health Organization (WHO) drinking water standards, revealing that all sampled water sources contained metal concentrations significantly above permissible limits, indicating extensive groundwater contamination. With these negative impacts, it is very important to assess the level of heavy metals and radionuclides in water around industrial, automobile, and residential areas in Gboko.

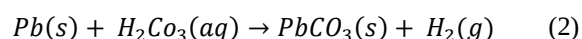
Theoretical Framework and Relevant Theories

The study of water contamination by heavy metals and radionuclides near industrial, automotive, and residential areas involves several key principles from chemistry, environmental science, and physics. These include principles of atomic theory, nuclear physics, radioactive decay, and the behaviour of heavy metals in aquatic environments. Heavy metal solubility is influenced by pH, redox potential, temperature, and the presence of complexing agents. In acidic environments, heavy metals remain in dissolved ionic forms, making them more bioavailable and toxic. In alkaline conditions, they precipitate as hydroxides or carbonates, reducing solubility [31]. Redox reactions affect metal solubility, with varying oxidation states affecting their solubility. Heavy metals can form complexes with ligands, increasing mobility in water. Higher temperatures and ionic strength also affect solubility. Understanding these factors is crucial for developing remediation strategies, such as pH adjustment, chemical precipitation, and adsorbents to remove heavy metals from contaminated water [29].

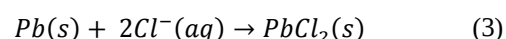
The dissolution of lead (Pb) in water depends on the conditions such as the preserve of oxygen PH, and other dissolved substances in pure water lead has very low solubility, but in the presence of oxygen and acidic conditions, it can dissolve as follows in the presence of oxygen and acidic water.



If the water contains chloride (Cl^-), Lead may form soluble complexes. In carbonate-containing water



In chloride-containing water



Lead solubility increases in acidic conditions, and lead (u

ions (Pb^{2+}) can become toxic in water supplies.

Diffusion and Transport Mechanism

Fick's Law of Diffusion describes this movement of heavy metals and radionuclides through water. This law explains how substances move from regions of high concentration to regions of lower concentration. Fick's first law states that the diffusive flux is proportional to the negative of the concentration gradient, with the proportionality constant being the diffusivity or diffusion coefficient [27].

$$J = -D \frac{dc}{dx} \quad (4)$$

where J is the diffusive flux, D is the diffusivity, and dC/dx is the concentration gradient

Toxicology and Dose-Response Theory

The harmful effects of heavy metals and radionuclides on living organisms are studied using toxicological principles. A dose-response relationship refers to the relation between the likelihood and severity of resulting adverse health effects from a given dose of agent and the condition of exposure. The dose response relationship is a crucial concept in toxicology, as it is essential for health, economic assessments, and regulatory decisions [10].

The dosage of a toxicant is the amount of heavy metals or radionuclide per unit of animal mass or weight, which can be expressed as the amount of toxicant per unit of mass or weight per unit of time. The route of exposure is an important component of assessing the toxicity of heavy metals or radionuclides. Common routes include inhalation, oral, and dermal, with variations for each. Oral exposure involves offering a known amount of the chemical in drinking water, via gavage, or gastrostomy [26].

$$E(C) = E_{max} \frac{C^n}{C^n + EC_{50}^n} \quad (5)$$

Where E(C) is the severity of the toxic effect at concentration C, E_{max} is the maximum possible effect. EC_{50} is the contaminant concentration at which 50% of the maximum effects occur, n is the Hill coefficient, determining the steepness of the response curve.

Toxicology and dose-response relationship for heavy metals

The dose-response relationship, which establishes the effects of heavy metals according to concentration and exposure length, governs their toxicity. Even at low concentrations, metals like lead, mercury, cadmium, and arsenic are poisonous, build up in biological systems, and have detrimental impacts on health [34].

$$LCR = CDI \times SF \quad (6)$$

Where LCR is Lifetime Cancer Risk (dimensionless, probability of cancer over a lifetime, CDI is the chronic Daily intake of the contaminant (mg/kg-day), SF is the slope factor (mg/kg-day), which quantifies the risk per unit dose of

the contaminant.

Biological effect of ionizing radiation (BEIR) VII model

A well-known framework for risk assessment, the Biological Effects of Ionizing Radiation (BEIR) VII model is used to calculate the risks of cancer and other illnesses from low-dose ionizing radiation exposure. The linear no-threshold (LNT) model, which claims that even the lowest radiation doses can raise cancer risk without a safe threshold, is the subject of BEIR VII, which was created by the National Research Council. The model is based on epidemiological data, namely from medical radiation exposures and survivors of the atomic bomb. It takes into consideration genetic susceptibility, age, sex, and dosage rate when estimating risk. To establish radiation safety guidelines, direct regulatory actions, and enhance radiation protection tactics for exposures in the workplace, healthcare, and environment, BEIR VII is essential. With new epidemiological and biological data, risk projections may be improved in subsequent updates [19]. The Cancer Risk from Radiation is given as,

$$R = D \times RF \quad (7)$$

Where R = Risk of cancer (often expressed as the probability of excess cancer cases per exposed individual), D = Radiation dose received (measured in Sieverts, Sv), RF = Risk factor (cancer risk per unit dose, typically in cases per Sv).

2. Materials and Methods

This study was carried out in Gboko, Benue State, Nigeria. The areas considered were the mechanic site, residential, and industrial (Dangote cement factory). Gboko is a local Government area in Benue State, North Central Nigeria, having a land mass of 2264 sq km, with a population of 361325 according to the 2006 census. It is one of the largest of the 23 local Governments by population in Benue State [13], which has a latitude that lies between 7°19'30.00" N and longitude 9°00'18.00" E. The vegetation type in Gboko is Guinea savannah with annual rainfall between 150 - 180 mm and temperatures of 26 °C - 40 °C [32].

Table 1. Coordinate of Sampled locations.

Sample Location	Latitude	Longitude
Tyeku	7 023'25.84 N	904'52.07 E
Yandev	7020'38'N	8059'59'E
Mbayion	70199.81 N	90123.34 E

Table 2. Materials.

Parameter	Instrument/Method Used
pH Level	pH Meter or pH Test Strips
Temperature	Digital Thermometer
Turbidity (Cloudiness)	Turbidity Meter (Nephelometer)
Total Dissolved Solids (TDS)	TDS Meter
Total Suspended Solids (TSS)	Filtration & Gravimetric Method
Dissolved Oxygen (DO)	DO Meter
Biochemical Oxygen Demand (BOD)	Winkler's Titration Method
Chemical Oxygen Demand (COD)	COD Reactor & Spectrophotometer
Heavy Metals (Pb, Cd, Hg, Cr, Fe, Zn, Cu,)	Atomic Absorption Spectrophotometer (AAS) and HANNA® Multiparameter water tester model HI 98129
Oil & Grease Content	Soxhlet Extraction
Chlorine (Cl ⁻) Content	Titration Method (Mohr's Method)
Gross Beta Radiation	Beta Counter (Proportional Counter, Liquid Scintillation Counter)
Radium-226 (²²⁶ Ra)	Gamma Spectrometry (HPGe Detector)
Uranium (²³⁸ U, ²³⁵ U, ²³² Th)	Inductively Coupled Plasma Mass Spectrometry (ICP-MS)
Cesium-137 (¹³⁷ Cs), Strontium-90 (⁹⁰ Sr)	Gamma Spectroscopy & Liquid Scintillation Counting

Procedure for Water Analysis

Sterilized 75 cl capacity plastic bottles were used to collect the samples of water from boreholes, well water, and streams in Residential, Automotive, and Industrial Areas in Gboko, Benue State. In each of the sample locations, two samples were taken to determine the presence of Radionuclides and heavy metals. The water samples were poured in 75 cl plastic bottles, tagged, and submitted to a laboratory at Centre for Energy Research Training, Ahmadu Bello University, Zaria. 2 mL of nitric acid (HNO₃) was added to preserve the radionuclide. The pH was measured using a pH meter with buffer solutions (pH 4, 7, 10), the electrode was inserted into the sample, and the reading was recorded. The digital thermometer was dipped into the water sample for 2 minutes, and the temperature was recorded. The sample was poured into the turbidity meter's cuvette, inserted, and turbidity recorded in NTU (Nephelometric Turbidity Units). and TDS meter was dipped into the sample, and Total Dissolved Solids (TDS) was measured and recorded in mg/L, respectively. Dissolved

Oxygen (DO) was measured using a DO meter by adding MnSO₄ + KI + NaOH, then titrating with Na₂S₂O₃., measurement was done on day 0, the sample was incubated in the dark at 20 °C for 5 days, and Biochemical Oxygen Demand (BOD) was calculated. Soxhlet extraction was used to extract the oil, and the weight difference was measured.

The water sample was filtered through a 0.45 µm filter, pre-concentrated by evaporating to 1/10th volume, and measured using a High-Purity Germanium (HPGe) Detector. Radium-226 (²²⁶Ra), Uranium (²³⁸U, ²³⁵U) & Thorium (²³²Th) were co-precipitated with barium sulphate and analysed using gamma spectrometry.

Procedure for Heavy Metal Analysis

In each of the sample locations, two samples were taken at residential, Automotive, and Industrial areas to determine the presence of heavy metals. The water samples were poured into 75 cl plastic bottles, tagged, and submitted to a laboratory at the Department of Fisheries and Aquaculture, Joseph Sarwuan Tarkaa University, Makurdi. The equipment used to evaluate heavy metals is Atomic Absorption Spectrometer (AAS). The sample was poured and inserted into the well of the equipment after being cleaned and zeroed using the meter zero key. The desired parameter to be determined was selected using the mode key. A 10 ml of the stock was measured into a vial. Nitric Acid (HNO₃) was added in two drops in the stock in 10 ml vial, the sample was removed and then the Hydrochloric Acid (HCl) was added to the sample and shaken for one minute after which it was placed in the hollow space in the equipment, the sample containing the reagent was inserted and allowed to be steady before readings/result were taken.

Measurement of soil physicochemical parameters

The method as described by [27] was adopted. A sample was randomly selected from the three points of collection, 20 g of water was dissolved in 100 ml of distilled water, it was stirred with a glass rod, and allowed to stand for 30 minutes. The filter using a sieve to get the stock Hannah Multiparameter water tester model HI 98129, was dipped into the stock and allowed to read the desired parameter. This preparation serves as a stock solution for all the physicochemical parameters. pH, Electrical Conductivity, Total dissolved solids, and Temperature were determined by using HANNA® Multiparameter water tester model HI 98129. The probe was immersed in a water sample, and the mode was set to read the desired parameter using the MODE keypad. The reading was taken after it was left to stabilize for about five (5) minutes.

Pollution Load Index

The Pollution Load Index (PLI): The Pollution Load Index (PLI) is obtained as a degree of overall contamination using the concentration factors (CF). CF is the quotient obtained by dividing the concentration of each metal by the background value. The PLI of the place is calculated by obtaining the n root from the n-CFs that were obtained for all the metals. Generally, pollution load index (PLI) as developed by [22], which is as

$$CF = \frac{C_{metal}}{C_{background\ value}} \quad (8)$$

$$PLI = n \sqrt{(CF1 \times CF2 \times CF3 \times \dots \times CFn)} \quad (9)$$

$$PLI = n\sqrt{(CF1 \times CF2 \times CF3 \times \dots \times CFn)} \quad (10)$$

Where, CF = Contamination factor where, 0=none, 1=none-medium, 2= moderate, 3 = moderately-strong, 4 = strongly polluted, 5 = strong-very polluted, 6=very polluted. n= number of metals, C_{metal} = Metal Concentration in polluted soil sediments, $C_{background\ value}$ = Background value of the metal. The PLI value of > 1 is polluted, whereas < 1 is no pollution [20]. Microsoft Excel and ANOVA were used for statistical calculations.

Geo-accumulated index (I_{geo})

Geo-accumulated index (I_{geo}) is a quantitative measure used to assess the level of heavy metal contamination in the soils or segment. It provides an indication of the degree of pollution in the environment due to human activities or natural processes.

$$I_{geo} = \log_2(Cn/Bn1.5) \quad (11)$$

Where Cn = measured concentration of the element in the soil(mg/kg), Bn = geochemical background value of the element in the soil.

Biochemical Oxygen Demand (BOD)

$$BOD_5 = DO_{initial} - DO_{final} \quad (12)$$

PH Measurement

The pH of water is measured using:

$$pH = -\log[H^+] \quad (13)$$

Where $[H^+]$ = hydrogen ion concentration in moles per litre (mol/L)

Total Dissolved Solids (TDS)

$$TDS = \times EC \quad (14)$$

Where K= Conversion factor typically (0.5 - 0.7), EC= Electrical conductivity ($\mu S/cm$)

Alternatively,

$$TDS\ (mg/L) = \frac{W_1 - W_0}{V} \times 1000 \quad (15)$$

Where W_1 = weight of filter + residue (mg), W_0 = Weight of filter paper (mg), V = Sample of volume (mL)

Dissolved Oxygen (DO) (Winkler's method)

$$DO = \frac{(V_1 - V_2) \times N \times 8000}{V} \quad (16)$$

Where V_1 = volume of sodium thiosulfate used for blank (mL), V_2 = Volume of sodium thiosulfate used for sample (mL), N = Normality of sodium thiosulfate, V = volume of sample (mL)

Biochemical Oxygen Demand (BOD_5)

$$BOD_5 = DO_{initial} - DO_{final} \quad (17)$$

Where $DO_{initial}$ = Initial dissolved oxygen (mg/L), DO_{final} = Dissolved oxygen after 5 days of incubation (mg/L)

Chemical Oxygen Demand (COD)

$$COD = \frac{V_{blank} - V_{sample} \times N \times 8000}{V} \quad (18)$$

Where V_{blank} = volume of FAS (Ferrous Ammonium Sulphate) used in blank (mL), V_{sample} = volume of FAS used in sample (mL), N = Normality of FAS, V = sample volume (mL), Heavy Metal Concentration

$$C = \frac{A \times V}{W} \quad (19)$$

Radionuclide Analysis Equation

Activity concentration of radionuclide (Bq/L)

$$A = \frac{C \times 1000}{V} \quad (20)$$

Where A = Activity concentration (Bq/L), C = Count rate from detector (count per second, cps)

V = Sample volume (mL)

Gross Alpha and Beta Radiation Activity

$$A = \frac{Ns - Nb}{E \times V} \quad (21)$$

Where, A = Activity in Bq/L, Ns = Sample count rate (cps), Nb = Background count rate (cps),

E = Detector efficiency, V = Volume of samples (L).

Radiation dose from water consumption

$$D = \sum(A_i \times DCF_i) \quad (22)$$

Where D = Dose received (mSv/year)

A_i = Activity concentration of radionuclide i (Bq/L), DCF_i = Dose conversion factor for radionuclide i (mSv/Bq).

Table 3. Comparison with WHO and NESREA Standards.

Parameter	WHO limit	Equation used
pH	6.5-8.5	$pH = -\log[H^+]$

Parameter	WHO limit	Equation used
TDS (mg/L)	<500	$TDS = K \times EC$
DO (mg/L)	>5	$DO = \frac{V_1 - V_2 \times N \times 8000}{V}$
BOD (mg/L)	<10	$BOD_5 = DO_{initial} - DO_{final}$
COD (mg/L)	<40	$COD = \frac{V_1 - V_2 \times N \times 8000}{V}$
Heavy Metals	Varies	$C = \frac{A \times V}{W}$
Gross Alpha (Bq/L)	<0.1	$A = \frac{(N_a - N_b)}{E \times V}$
Gross Beta (Bq/L)	<0.1	$A = \frac{(N_a - N_b)}{E \times V}$
^{226}Ra (Bq/L)	<0.05	$A = \frac{C - 1000}{V}$
^{226}U (Bq/L)	<0.03	$A_t = A_{oe}^{-\lambda t}$

3. Results

Physicochemical properties

The results of the physicochemical properties of the water

collected from residential, automotive, and industrial areas are presented in Table 4. At all the sampling points, water was collected from a borehole, well, and stream.

Table 4. The physicochemical properties of water samples.

Sample Location	pH	Temp (°C)	Turbidity (NTU)	TDS (mg/L)	DO (mg/L)	BOD (mg/L)	COD (mg/L)
Residential	7.2	27.5	2.1	250	6.8	2.5	8.0
Automobile	6.3	29.0	8.7	500	5.5	10.2	45.0
Industrial	5.9	30.4	15.2	850	3.2	35.0	210.0

Heavy metals

The results of the concentration of heavy metals in the water collected from residential, automotive, and industrial

areas are presented in Table 5. At all the sampling points, water was collected from a borehole, well and stream.

Table 5. Concentration of heavy metals in water samples.

Sample Location	Water source	Lead (Pb) (mg/L)	Cadmium (Cd) (mg/L)	Chromium (Cr) (mg/L)	Iron (Fe) (mg/L)	Zinc (Zn) (mg/L)
Residential	Borehole	0.005	0.002	0.01	0.2	0.6
	Well water	0.007	0.0025	0.015	0.3	0.7
	Stream	0.009	0.003	0.02	0.4	0.8
Automotive	Borehole	0.015	0.004	0.03	0.5	1.2
	Well water	0.02	0.005	0.04	0.6	1.5

Sample Location	Water source	Lead (Pb) (mg/L)	Cadmium (Cd) (mg/L)	Chromium (Cr) (mg/L)	Iron (Fe) (mg/L)	Zinc (Zn) (mg/L)
Industrial	Stream	0.03	0.007	0.06	0.8	1.8
	Borehole	0.025	0.006	0.05	0.9	2.0
	Well water	0.03	0.007	0.06	1.2	2.3
	Stream	0.04	0.009	0.08	1.5	2.7
WHO limits (mg/L)		0.01	0.003	0.05	0.3	3.0

Radionuclides in the water samples

The results of the radionuclides present in the water collected from residential, automotive, and industrial areas are

presented in Table 6: At all the sampling points, water was collected from a borehole, well, and stream.

Table 6. Radionuclide present in the water samples.

Sample Location	Water source	²²⁶ Ra (Bq/L)	²³² Th (Bq/L)	⁴⁰ K (Bq/L)	Total Activity (Bq/L)	TAED (mSv/year)	ELCR	WHO
Residential	Borehole	0.02	0.008	0.05	0.078	0.00058	2.9 x 10 ⁻⁵	0.1
	Well water	0.03	0.01	0.07	0.11	0.00079	3.95 x 10 ⁻⁵	0.1
	Stream	0.04	0.012	0.09	0.142	0.00098	4.9 x 10 ⁻⁵	0.1
Automotive	Borehole	0.04	0.015	0.09	0.145	0.00102	5.1 x 10 ⁻⁵	
	Well water	0.05	0.02	0.10	0.17	0.00123	6.15 x 10 ⁻⁵	
	Stream	0.06	0.025	0.12	0.205	0.00148	7.4 x 10 ⁻⁵	
Industrial	Borehole	0.06	0.022	0.12	0.202	0.00146	7.3 x 10 ⁻⁵	
	Well water	0.07	0.025	0.15	0.245	0.00186	9.3 x 10 ⁻⁵	
	Stream	0.08	0.03	0.18	0.29	0.00221	9.3 x 10 ⁻⁵	

4. Discussion

Heavy metal concentration in residential, automotive, and industrial areas

The results of the concentration of heavy metals in the water collected from residential, automotive, and industrial areas, as presented in Table 4, for borehole, well and stream water show the following:

Lead (Pb)

The level of lead in the borehole, well water, and stream at the residential area studied was 0.005, 0.007, and 0.009 mg/L respectively. These values are less than the WHO permissible limits for drinking water. This result is lower than the 0.85-1.91 mg/L as reported by [2, 23] for surface water, and

less than the range of values (0.001-0.019 mg/L) as reported by [15] for well water. Pb is mostly found in batteries and pigments. There may have been no traces of batteries and pigment disposal around the study area. Pb poisoning in the human system may cause dysfunction of the kidney, liver, brain, and the central nervous system, which may lead to sicknesses [27]. The level lead at the automotive area recorded a higher concentration of Pb for borehole, well water and stream water (0.015, 0.02, 0.03 mg/L), which is slightly above the WHO permissible limit. The same thing applies to the location at the industrial area (borehole, well water and stream, which had 0.025, 0.03 and 0.04 mg/L, respectively). The presence of Pb at these sites can be attributed to the emission from car exhausts, vehicle batteries, cables, etc. People drinking this water may be prone to some diseases

over a long time.

Cadmium (Cd)

The concentration of Cd in the residential area was 0.002, 0.0025 and 0.003 mg/L for borehole, well water and stream water, respectively. The concentration in the borehole and well water were below the WHO, while the stream water is exactly as the WHO permissible limit. This implies that this water is safe for domestic activities. The automotive site recorded a concentration of Cd for borehole, well water and stream water to be 0.004, 0.005 and 0.007 mg/L, respectively. Similarly, the concentration at the industrial area was 0.006, 0.007, and 0.009 mg/L, respectively. Even though these results are more than the WHO permissible limit, they are less than a report (0.35-0.36 mg/L) by [28] on well water. Cd has no known beneficial role in the human body. It accumulates more in the kidneys and liver. It distorts the excretory, skeletal, and respiratory systems and is classified as a human carcinogen. Therefore, continuous consumption of this water may result in some acute effects on the human system [20].

Chromium (Cr)

The borehole, well and stream water at the residential area have a concentration of Cr to be 0.01, 0.015 and 0.02 mg/L, respectively. These concentrations are less than the WHO permissible limit, implying that the water is safe from Cr poison. The values are not too different from the range of values (0.010-0.018 mg/L) reported by [14] on groundwater. The water from the borehole and well at the automotive area also has a concentration less than the WHO limit. However, the stream water at this point contains a concentration of Cr slightly above the WHO permissible limit. The concentration of Cr in the borehole water in the industrial area was within the WHO permissible limit (0.05 mg/L), while the well water and stream water at this place contained a high (0.06 and 0.08 mg/L respectively), which is above the WHO permissible limit. Chromium is a hazardous element with recognized potential health risks such as nasal septum perforations, skin ulcerations, and respiratory cancer [17]. The high concentration at the automotive and industrial area may lead to toxic effects to consumers over time.

Iron (Fe)

The water from the borehole and well at the residential area contains Fe in low concentration (0.2 and 0.3 mg/L), which is below the permissible limit, while the stream at this place contains 0.4 mg/L, which is slightly above the WHO standard. The result is lower than 0.004-0.0226 mg/L reported by [24] on groundwater. The concentration of Fe in the automotive area is 0.5, 0.6 and 0.8 mg/L for borehole, well and stream water, which are above the WHO permissible limits. On the same hand, the concentration of the borehole, well and stream water at the industrial area were 0.9, 1.2 and 1.5 mg/L, which are far above the WHO permissible limit. The shortage of iron causes a disease called "anemia", and prolonged consumption of drinking water with a high concentration of iron may lead to liver disease called hemosiderosis [15].

Zinc (Zn)

The concentration of Zn in the residential area for borehole, well, and stream water was 0.6, 0.7, and 0.8 mg/L, respectively. The concentration at automotive for both collections was 1.2, 1.5, and 1.8 mg/L, respectively, while the concentrations at the industrial area were 2.0, 2.3, and 2.7 mg/L for borehole, well, and stream water, respectively. These values are below the range (0.2-0.48 mg/L) reported by [7]. Toxic manifestations of zinc in humans include stomach pain, loss of appetite, and vomiting [21]. Though all the values were below WHO permissible limits, it can be concluded that the sources of water are free from the toxic effects of Zn

Radionuclides present in water samples

Table 4 presents radiological assessment results of different water sources (borehole, well, and stream) across three different sample sites (residential, automotive, and industrial). The parameters measured include the activity concentrations of radionuclides ^{226}Ra , ^{232}Th , and ^{40}K in Becquerels per liter (Bq/L), the Total Activity (sum of radionuclide concentrations), the Total Annual Effective Dose (TAED) in millisieverts per year (mSv/year), and the Excess Lifetime Cancer Risk (ELCR).

Residential site

At the residential site, borehole water had the lowest total activity content (0.078 Bq/L), followed by well water (0.11 Bq/L) and stream water (0.142 Bq/L). Although boreholes are better shielded from environmental contaminants, this pattern illustrates how water sources are becoming more exposed to surface pollution. In all types of water, ^{40}K was the most prevalent radionuclide, whereas ^{232}Th had the least activity. The Total Annual Effective Dose (TAED) values, which varied from 0.00058 mSv/year in borehole water to 0.00098 mSv/year in stream water, were below the WHO recommended limit of 0.1 mSv/year [5]. Likewise, the Excess Lifetime Cancer Risk (ELCR) was below the USEPA established tolerable limit. Even though there seems to be little radioactive risk in residential water sources, ongoing monitoring is advised to guarantee long-term safety.

Automotive site

Radionuclide concentrations were somewhat higher in the automobile area than in the residential area. In stream water, the total activity was 0.205 Bq/L, whereas in borehole water, it was 0.145 Bq/L. Moderate industrial and vehicular activity may be to blame for this rise, as these activities can contaminate surface and groundwater through infiltration and runoff. The predominant radionuclide at the home location was ^{40}K . The TAED levels were remained much below the WHO criterion [5], ranging from 0.00102 to 0.00148 mSv/year. While staying within the USEPA safety limit, ELCR readings varied from 5.1×10^{-5} in borehole water to 7.4×10^{-5} in stream water. Despite being within permissible limits, the higher values relative to the residential site suggest that automotive activities may pose a slightly increased radiological exposure risk, particularly in surface water sources.

Industrial area

Among the three locations, the industrial site had the

greatest radioactive concentrations, with total activity ranging from 0.29 Bq/L in stream water to 0.202 Bq/L in borehole water. This notable rise suggests a greater contribution of surface runoff, waste discharge, and industrial operations to the increase in radioactive content. Once more, ^{40}K was the most common radionuclide, whereas ^{232}Th was still the least concentrated. TAED was consistently greater than those found in the residential and automobile locations, ranging from 0.00146 to 0.00221 mSv/year, although still being within the safe limit. The acceptable risk range's upper limit was approached by the ELCR values, which varied from 7.3×10^{-5} to 9.3×10^{-5} . These findings highlight the necessity of more stringent regulation, treatment, and routine monitoring of water supplies in such settings, as well as the possible long-term health effects of industrial activities on water quality.

5. Conclusion

This study evaluated the concentrations of naturally occurring radionuclides and heavy metals in stream, well, and borehole water in residential, industrial, and automobile settings. The findings showed there was regional variation in the quality of the water, with the industrial site consistently showing the greatest quantities of radionuclides and heavy metals, followed by the residential and automobile regions. Lead (Pb), cadmium (Cd), chromium (Cr), and iron (Fe) were among the heavy metals that were found to be above the WHO permitted limits in certain water samples, especially those from the industrial and automotive sites. On the other hand, all samples' zinc (Zn) values were below recommended limits, suggesting that there currently exists no toxicological risk. Along with the Total Annual Effective Dose (TAED) and Excess Lifetime Cancer Risk (ELCR), the observed activity concentrations of ^{226}Ra , ^{232}Th , and ^{40}K for radionuclides were below the world's safety limits established by the USEPA and WHO. A steady rise in TAED and ELCR values from residential to industrial locations, however, suggests a rising radioactive load that might provide long-term health hazards with repeated exposure.

Author Contributions

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Conflict of Interest

The authors declare no conflicts of interest.

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