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# Assessment of health risks associated with contaminants in groundwater in the catchment area of selected dumpsites in Abuja north central Nigeria

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# Assessment of health risks associated with contaminants in groundwater in the catchment area of selected dumpsites in Abuja north central Nigeria

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**Abstract**
The human health risk assessment associated with heavy metals contained in sources of drinking water within the catchment area of some dumpsites in FCT Abuja were carried out. Surface and groundwater samples collected within the catchment area of the selected dumpsites were subjected to inductively coupled plasma mass spectrometry (ICP-MS) in order to obtain the required analytes for the assessment. Parameters like Hazard Quotient (HQ), Hazard Index (HI) and Carcinogenic Risk Index (CR) that are needed for the assessment were computed. HQ and HI were computed for non-carcinogenic risk assessment while (CR) was computed for carcinogenic risk assessment. The estimated HI for adults via ingestion across all the investigated dumpsites, ranges from 2.38 to 11.6 which is considered unacceptable. The estimated HI value for adults via dermal absorption across all the investigated dumpsites, ranges from 0.026 to 0.07, which is interpreted to be acceptable. The estimated HI for children via ingestion across all the investigated dumpsites, ranges from 8.051 to 29.868, which is interpreted to be unacceptable. The estimated HI value for Children via dermal absorption across all the investigated dumpsites, ranges from 0.3820 to 1.237 in which about 80% are considered acceptable. The CR ranges from 0.0021 to 0.0109 and 0.004940 to 0.026 for adults and children respectively. This results according to USEPA indicate that both children and adults taking the investigated water via ingestion, are at high risk of contracting cancer.

**Keywords** Carcinogenic risk index · Non-carcinogenic risk assessment · Health risk index · Hazard quotient · Dumpsites · Solid wastes

## 1 Introduction

One of the disadvantages associated with industrialization and urbanization in developing countries like Nigeria is the uncontrolled discharge of hazardous substances into the environment [1, 2]. These hazardous substances are contained in industrial effluents, municipal wastes and chemicals from agricultural activities such as herbicides and insecticides. Exposure to these hazardous contaminants can have negative impact on human health and persistence in surface water can affect health of aquatic organisms [3, 4].

The relocation of the Federal Capital Territory (FCT) of Nigeria from Lagos to Abuja in 1991 brought about a geometric increase in the population of the people living in the area. People from different parts of the country moved to the new FCT in search of job opportunities and improved standards of living. However, the rapid expansion of the FCT Abuja has

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exceeded what was anticipated in the Master Plan, as the population now exceeds the original design capacity. In 1991 the population of the FCT was 378,671, and this had increased to 5,724,205 by 2001 [5]. Projected population figure for this area is about ten (10) million people by 2026 [6, 7].

One problem associated with increased population in the study area is a poorly developed waste management system. Open and uncontrolled dumping which is capable of subjecting ambient air and groundwater resources to contamination, are the waste disposal strategies adopted in this area [8]. These waste disposal sites were not designed due to their low capital investment, thus allowing for environmental pollution in this area. Wastes generated in this area contain hazardous trace elements and heavy metals which can pose serious health risks to the residents [9].

International Agency for Research on Cancer (IARC) carried out evaluation of carcinogenicity of substances and classifies them into different categories based on the strength of evidence. They classified several inorganic substances including asbestos, arsenic, cadmium, chromium, and nickel as carcinogenic to humans, [10]. The U.S. Environmental Protection Agency (USEPA) assessed the risks involved in the exposure of human to environmental pollutants and provides guidelines for safe exposure levels. They established maximum contaminant levels for several inorganic substances, including arsenic, cadmium, chromium, and lead [11]. Also, the National Toxicology Program (NTP) evaluates the carcinogenicity of substances and came up with hazard identification and risk assessment reports. They classified several inorganic substances as known or suspected human carcinogens, including asbestos, arsenic, cadmium, chromium, and nickel [12].

Studies have shown that chronic exposure to these hazardous trace element and metals can result in health effects such as cancer [1, 13–15]. The continued exposure to hazardous elements like Cadmium (Cd), Arsenic (As), Chromium (Cr) and Nickel (Ni) can also cause agonistic and antagonistic effects on hormones and enzymes [16]. According to (IARC) and (USEPA), human exposure to carcinogens such as Arsenic and other inorganic carcinogens can occur through ingestion and dermal absorption of contaminated water [17]. In view of the aforementioned, the aim of this research is to measure the concentration of the contaminants in the drinking water sources and assess the potential health risks associated with the ingestion and dermal absorption within the catchment area of several dumpsites in FCT, Abuja.

## 2 Methods

### 2.1 Site description

The study area is located near Abuja at the geographic centre of Nigeria as shown in Fig. 1 [18]. The study area covers part of FCT Abuja and falls within Latitudes N8°10′ and N9°45′ and Longitudes E6°30′ and E7°45′E, with an approximate area of 120km$^2$. The Federal Capital Territory of Nigeria has six (6) local councils, which are: Abuja Municipal, Abaji, Bwari, Gwagwalada, Kuje and Kwali [19]. The seven dumpsites under investigation include Gosa, Karshi, Gwagwalada, Kubwa, Bwari, Azhata and Kuje.

### 2.2 Geology of the study area

The study area is underlain by Basement Complex consisting of Precambrian to Lower Paleozoic bedrock, including Precambrian igneous granite and high grade metamorphic schist, gneiss and migmatite [20–23] (Fig. 2). Groundwater occurrence in this area is controlled by geologic features such as depth of weathering (thickness and continuity of the regolith) and the intensity of fracturing.

### 2.3 Water sampling and analytical method

A total of twenty seven (27) of both surface and groundwater samples were collected directly using 100 ml polythene bottles (Fig. 3). Bottles were soaked in 10% $HNO_3$ for 24 h and rinsed several times with deionised water, prior to sample collection for trace elements and cations [24, 25]. Bottles were also rinsed with aliquots of the sampled water at the time of collection to avoid carryover of contaminants that may compromise the quality of the results [26]. The groundwater samples were collected from hand-dug wells and water boreholes in the vicinity of the study area. Upon arrival at the laboratory, samples were stored in the refrigerator until the day of the analysis. This was done to preserve the integrity of the samples.

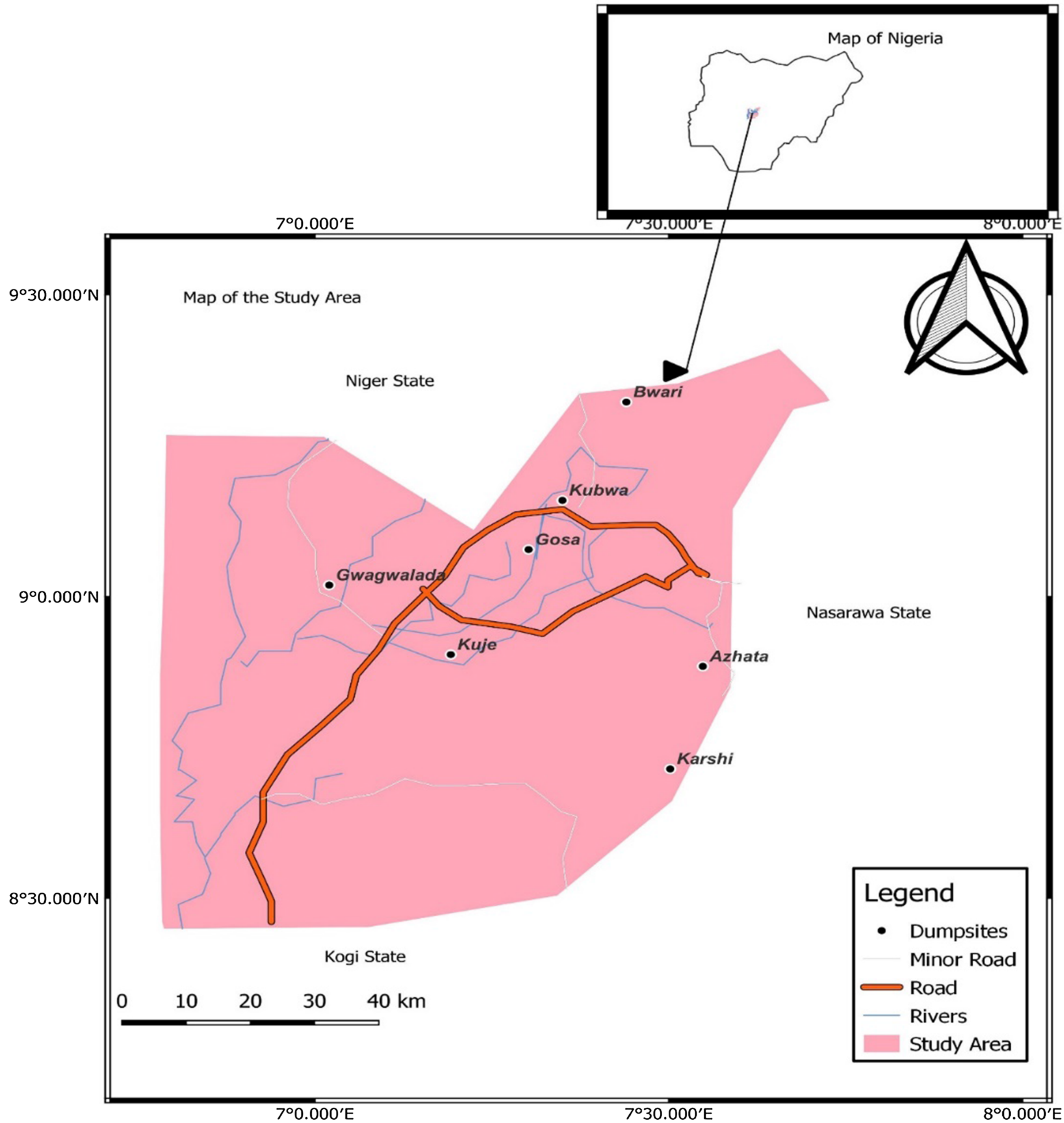


**Fig. 1** Map of FCT, Abuja showing the dumpsites

All samples were filtered (using 0.45 µm pore size membrane) and analysed for dissolved trace elements, including cadmium, arsenic, lead, copper, zinc, and nickel, on a Thermo ICAP-RQ inductivity coupled plasma mass spectrometer at the University of Nebraska Water Sciences Laboratory (Lincoln, Nebraska USA). Reagent blanks, laboratory duplicates, and fortified blanks were prepared and used to monitor quality of laboratory measurements. Instrument detection limits are listed with analytical results.

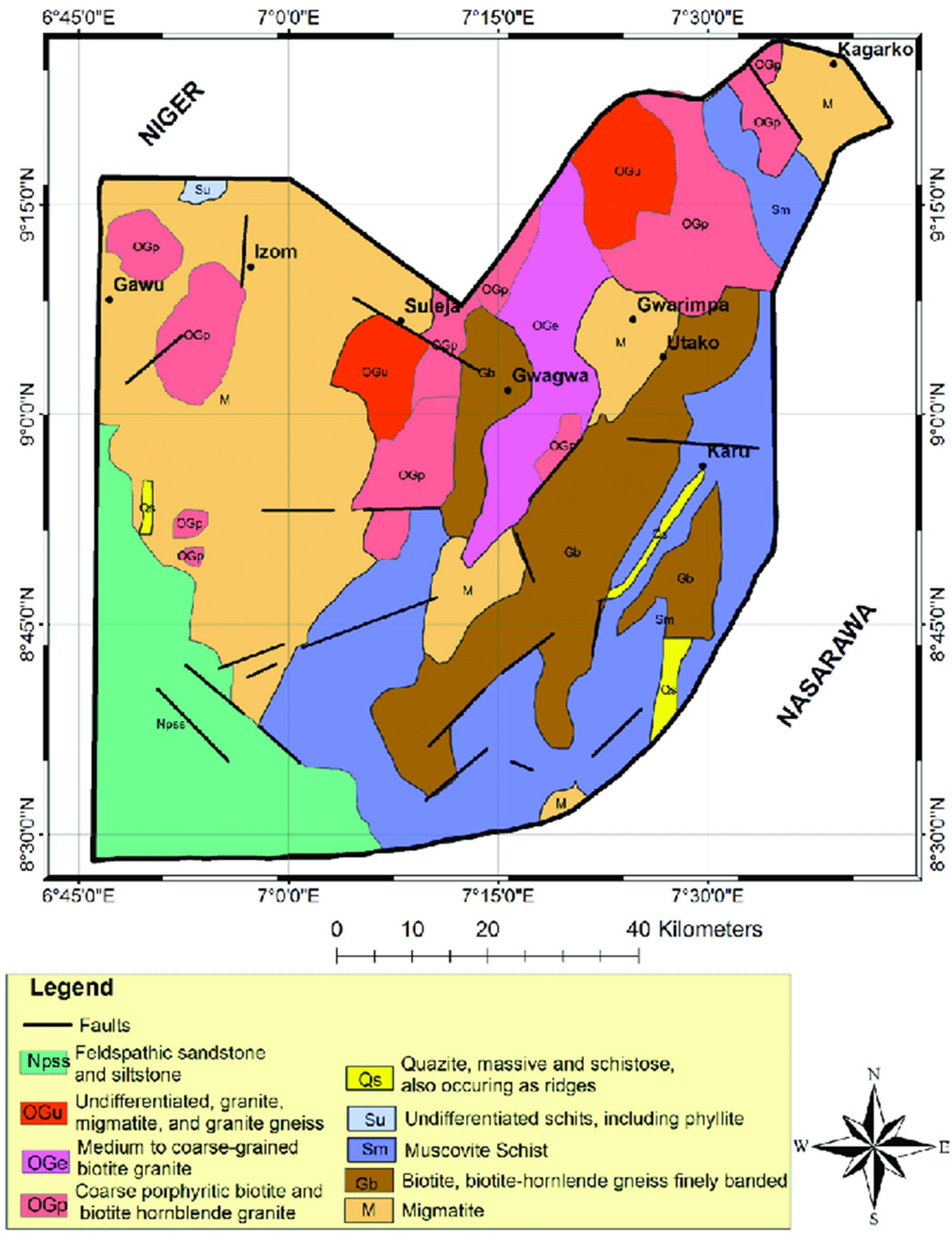


**Fig. 2** Geological Map of the study area

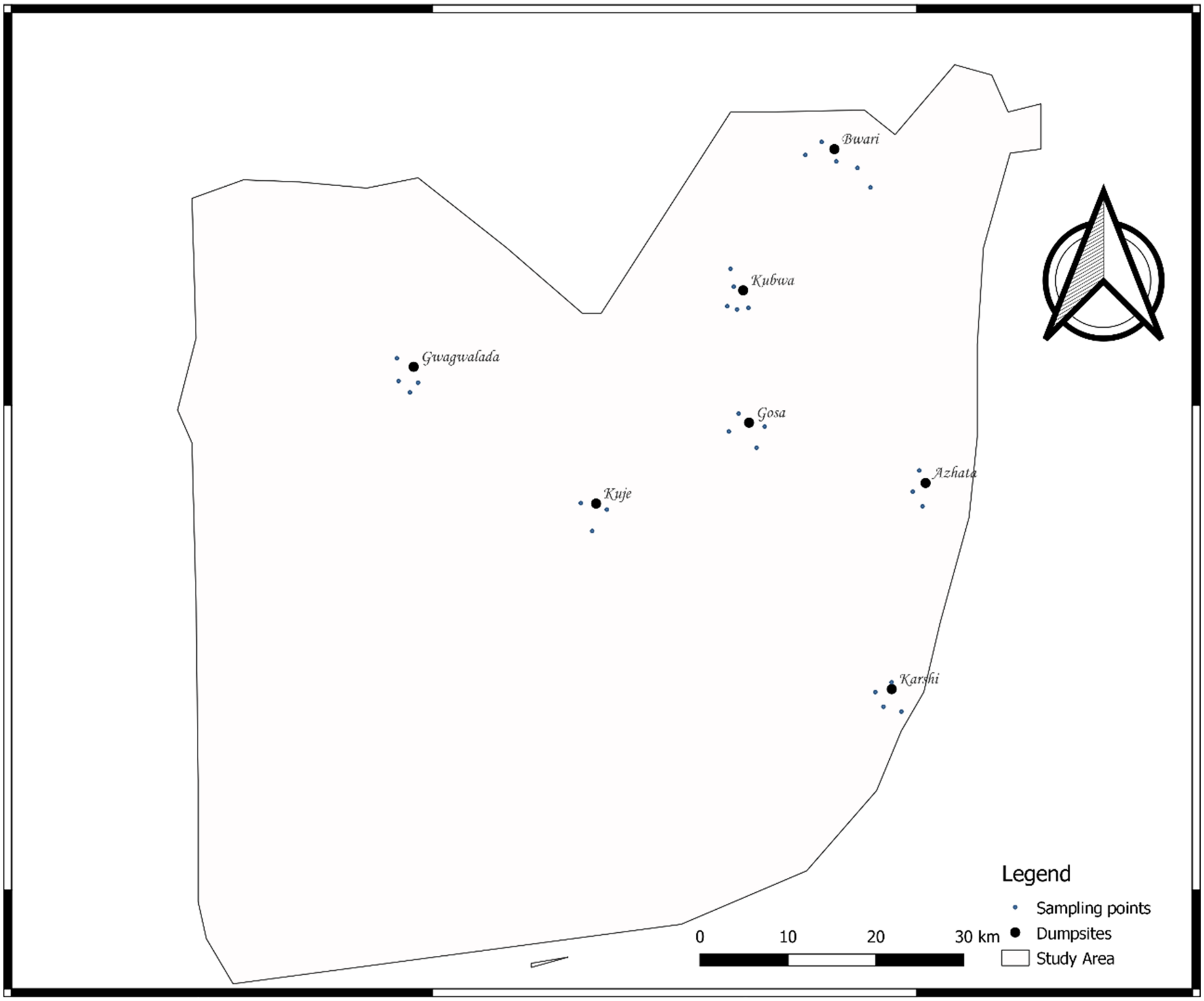


**Fig. 3** Map of the study area showing the sampling points

Samples were subjected to microwave assisted acid digestion before they were analysed using ICP-MS. Microwave extraction is designed to mimic extraction using convectional heating with nitric acid ($HNO_3$) or alternatively nitric acid and hydrochloric acid (HCL).

## 2.4 Reagents and standards

Thermo, THERMO-4AREV.

Thermo, THERMO-4AREV.

Nitric Acid, trace metal grade (Fisher, A509-P212).

Hydrochloric acid, trace metal grade (Fisher, A509-P212).

Distilled deionized water (DDW).

Copper Standard Solution 1000µgmL, 125 mL (SPEX Certiprep™ CLCU2-2Y).

Manganese Standard Solution 1000µgmL, 125 mL (SPEX Certiprep™ PLMN2-2Y).

Arsenic Standard Solution 1000µgmL, 125 mL (SPEX Certiprep™ CLAS2-2Y).

Iron Standard Solution 1000µgmL, 125 mL (SPEX Certiprep™ PLFE2-2Y).

Nickel Standard Solution 1000µgmL, 125 mL (SPEX Certiprep™ PLNI2-2Y).

Zinc Standard Solution 1000µgmL, 125 mL (SPEX Certiprep™ CLZN2-2Y).

**Table 1** Some of the Parameters used for health risk assessment [31–34]

| Metals | RfD_ingestion (mg /kg/ day) | RfD_dermal(mg /kg/ day) | CSF_ ingestion(mg / kg/ day) |
|---|---|---|---|
| Cr | 3 | 0.075 | 0.5 |
| Mn | 24 | 0.96 | |
| Fe | 700 | 140 | |
| Ni | 20 | 0.8 | 1.7 |
| Cu | 40 | 8 | |
| Zn | 300 | 60 | |
| As | 0.3 | 0.285 | 1.5 |
| Cd | 0.5 | 0.025 | 6.1 |
| Pb | 1.4 | 0.42 | |

**Table 2** Standard for health risk Assessment [23, 31]

| Parameter | Adult | Children | Units |
|---|---|---|---|
| Ingestion Rate (IR) | 1.5 | 0.7 | L/d |
| Exposure Frequency (EF) | 365 | 365 | d |
| Exposure Duration (ED) | 30 | 12 | an |
| Average Body Weight (BW) | 70 | 15 | Kg |
| Average Exposure Time (AET) | 10,950 | 4380 | d |
| Constant Duration (t) | 0.4 | 0.4 | h/d |
| Skin Permeability coefficient (Kp) | 0.001 | 0.001 | cm/h |
| Conversion factor (CF) | 0.001 | 0.001 | |
| Average Height (H) | 165 | 153 | cm |

Cadmium Standard Solution 1000µgmL, 125 mL (SPEX Certiprep™ CLCD2-2Y).
Chromium Standard Solution 1000µgmL, 125 mL (SPEX Certiprep™ PLCR2-2Y).
Lead Standard Solution 1000µgmL, 125 mL (SPEX Certiprep™ CLPB2-2Y).

## 2.5 Quality assurance

To verify the accuracy of the measurement in this study, standard reference solutions (spiked solutions) with known concentrations of the heavy metals were used as control samples. For the measurements of heavy metals by ICP-MS, certified reference materials (CRMs) and standard reference solutions with known concentrations of elements were recognized as an essential tool for ensuring the quality and establishing the accuracy of the results [27].

Two types of Blanks that were used for the analysis include calibration Blank and rinse Blank. The calibration Blank was used to establish the calibration curve while the rinse Blank was used to flush the system between samples and standards. The sample preparation procedures that were used for samples was also used for the Blanks. All reagents used were of analytical grade. The reliability and reproducibility of the measurements were ensured by calibrating the instruments used and procedural blanks determined.

## 2.6 Health risk assessment

The carcinogenic and non-carcinogenic health risks associated with the ingestion/dermal absorption of water that is contaminated with toxic heavy metals were assessed using hazard quotient (HQ), Hazard index (HI) and carcinogenic health risk (CR) [28].

**Table 3** Levels and values of assessment standards for carcinogenic health risk [35]

| Risk grades | Ranges of risk value | Acceptability |
|---|---|---|
| Grade I (Extremely low risk) | $<10^{-4}$ | Completely acceptable |
| Grade II (Low risk) | $10^{-6}$ to $10^{-5}$ | Not willing to care about risk |
| Grade III (Low-medium risk) | $10^{-5}$ to $5\times10^{-5}$ | Do not mind about the risk |
| Grade IV (Medium risk) | $5\times10^{-5}$ to $10^{-4}$ | Care about the risk |
| Grade V (Medium–high) | $10^{-4}$ to $5\times10^{-4}$ | Care about the risk and willing to invest |
| Grade VI (High risk) | $5\times10^{-4}$ to $10^{-3}$ | Pay attention to the risk and take action to solve it |
| Grade VII (Extremely high risk) | $>10^{-3}$ | Reject the risk and must solve it |

**Table 4** Concentration of dissolved trace elements measured in the water samples

| Sample | Label | Cu (ug/g) | Cd (ug/g) | As (ug/g) | Zn (ug/g) | Pb (ug/g) | Mn (ug/g) | Ni (ug/g) | Fe (ug/g) | Cr (ug/g) |
|---|---|---|---|---|---|---|---|---|---|---|
| BWw1 | Bwari | 4.310 | 0.005 | 0.015 | 9.850 | 0.026 | 0.521 | 0.071 | 0.525 | 0.062 |
| BWw2 | Bwari | 2.080 | 0.001 | 0.052 | 4.660 | 0.015 | 0.640 | 0.043 | 1.104 | 0.077 |
| BWw3 | Bwari | 2.080 | 0.008 | 0.017 | 8.370 | 0.013 | 0.930 | 0.150 | 0.433 | 0.109 |
| BWw4 | Bwari | 1.560 | 0.001 | 0.018 | 12.300 | 0.019 | 0.739 | 0.055 | 0.106 | 0.014 |
| GWv1 | Gwagwalada | 2.540 | 0.010 | 0.051 | 6.860 | 0.130 | 1.037 | 0.045 | 0.941 | 0.096 |
| GWv2 | Gwagwalada | 1.150 | 0.000 | 0.007 | 4.750 | 0.011 | 0.899 | 0.075 | 0.289 | 0.010 |
| GWv3 | Gwagwalada | 2.820 | 0.001 | 0.034 | 8.240 | 0.018 | 0.410 | 0.037 | 0.268 | 0.089 |
| GWv4 | Gwagwalada | 1.080 | 0.002 | 0.011 | 1.650 | 0.019 | 0.744 | 0.086 | 0.139 | 0.019 |
| KWw1 | Kubwa | 0.240 | 0.002 | 0.067 | 4.720 | 0.011 | 1.106 | 0.000 | 1.086 | 0.079 |
| KWw2 | Kubwa | 0.640 | 0.001 | 0.019 | 9.530 | 0.014 | 1.020 | 0.022 | 1.015 | 0.098 |
| KWw3 | Kubwa | 4.460 | 0.000 | 0.025 | 3.620 | 0.017 | 0.238 | 0.047 | 0.522 | 0.034 |
| KWw4 | Kubwa | 0.700 | 0.002 | 0.019 | 7.060 | 0.024 | 0.680 | 0.075 | 0.604 | 0.017 |
| KWw5 | Kubwa | 1.600 | 0.002 | 0.016 | 5.930 | 0.042 | 0.190 | 0.017 | 0.278 | 0.030 |
| KRSw1 | Karshi | 1.280 | 0.001 | 0.018 | 9.560 | 0.024 | 0.250 | 0.024 | 0.136 | 0.095 |
| KRSw2 | Karshi | 5.620 | 0.002 | 0.022 | 2.080 | 0.019 | 0.712 | 0.089 | 0.587 | 0.011 |
| KRSw3 | Karshi | 2.080 | 0.001 | 0.015 | 4.660 | 0.025 | 0.640 | 0.043 | 0.146 | 0.057 |
| KRSw4 | Karshi | 1.980 | 0.005 | 0.017 | 8.370 | 0.030 | 0.930 | 0.015 | 0.433 | 0.011 |
| GOw1 | Gosa | 1.560 | 0.001 | 0.078 | 12.300 | 0.022 | 0.739 | 0.051 | 0.106 | 0.038 |
| GOw2 | Gosa | 2.540 | 0.001 | 0.011 | 6.860 | 0.013 | 0.770 | 0.042 | 0.941 | 0.096 |
| GOw3 | Gosa | 1.150 | 0.013 | 0.007 | 4.750 | 0.011 | 0.899 | 0.075 | 0.289 | 0.015 |
| GOw4 | Gosa | 2.820 | 0.001 | 0.013 | 8.240 | 0.018 | 0.459 | 0.030 | 0.255 | 0.089 |
| AZHw1 | Azhata | 1.080 | 0.003 | 0.011 | 16.500 | 0.013 | 0.744 | 0.086 | 1.090 | 0.011 |
| AZHw2 | Azhata | 0.240 | 0.001 | 0.015 | 4.720 | 0.021 | 0.646 | 0.000 | 1.000 | 0.091 |
| AZHw3 | Azhata | 1.560 | 0.001 | 0.011 | 12.300 | 0.090 | 0.739 | 0.051 | 0.106 | 0.010 |
| KUJw1 | Kuje | 2.540 | 0.002 | 0.019 | 6.860 | 0.013 | 0.437 | 0.045 | 0.941 | 0.096 |
| KUJw2 | Kuje | 1.150 | 0.001 | 0.007 | 4.750 | 0.018 | 0.850 | 0.075 | 0.289 | 0.012 |
| KUJw3 | Kuje | 2.820 | 0.002 | 0.034 | 8.240 | 0.018 | 1.010 | 0.034 | 0.210 | 0.089 |

**Table 5** Statistical analysis of the measured concentration for the analytes

| | Cu (ug/g) | Cd (ug/g) | As (ug/g) | Zn (ug/g) | Pb (ug/g) | Mn (ug/g) | Ni (ug/g) | Fe (ug/g) | Cr (ug/g) |
|---|---|---|---|---|---|---|---|---|---|
| Mean | 1.98815 | 0.00259 | 0.0233 | 7.32333 | 0.0257 | 0.70293 | 0.05122 | 0.51256 | 0.05389 |
| Max | 5.62 | 0.013 | 0.078 | 16.5 | 0.13 | 1.106 | 0.15 | 1.104 | 0.109 |
| Min | 0.24 | 0 | 0.007 | 1.65 | 0.011 | 0.19 | 0 | 0.106 | 0.01 |

**Table 6** Hazard quotient and health risk index for adult through ingestion of the contaminated water

| Sample | Label | HQ_Pb | HQ_Zn | HQ_Mn | HQ_Cd | HQ_Cr | HQ_Fe | HQ_Ni | HQ_As | HQ_Cu | HI_I_Adult | Interpretation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BWw1 | Bwari | 0.531 | 0.938 | 0.006 | 0.286 | 0.590 | 0.021 | 0.102 | 1.429 | 3.079 | 6.981 | Unacceptable |
| BWw2 | Bwari | 0.306 | 0.444 | 0.001 | 0.057 | 0.733 | 0.045 | 0.061 | 4.952 | 1.486 | 8.086 | Unacceptable |
| BWw3 | Bwari | 0.265 | 0.797 | 0.010 | 0.457 | 1.038 | 0.018 | 0.214 | 1.619 | 1.486 | 5.904 | Unacceptable |
| BWw4 | Bwari | 0.388 | 1.171 | 0.001 | 0.063 | 0.131 | 0.004 | 0.079 | 1.695 | 1.114 | 4.647 | Unacceptable |
| GWv1 | Gwagwalada | 2.653 | 0.653 | 0.012 | 0.571 | 0.914 | 0.038 | 0.064 | 4.857 | 1.814 | 11.578 | Unacceptable |
| GWv2 | Gwagwalada | 0.224 | 0.452 | 0.000 | 0.000 | 0.096 | 0.012 | 0.107 | 0.667 | 0.821 | 2.380 | Unacceptable |
| GWv3 | Gwagwalada | 0.367 | 0.785 | 0.002 | 0.074 | 0.848 | 0.011 | 0.053 | 3.238 | 2.014 | 7.392 | Unacceptable |
| GWv4 | Gwagwalada | 0.380 | 0.157 | 0.002 | 0.086 | 0.181 | 0.006 | 0.123 | 1.048 | 0.771 | 2.753 | Unacceptable |
| KWw1 | Kubwa | 0.224 | 0.450 | 0.002 | 0.091 | 0.752 | 0.044 | 0.000 | 6.381 | 0.171 | 8.116 | Unacceptable |
| KWw2 | Kubwa | 0.286 | 0.908 | 0.002 | 0.080 | 0.933 | 0.041 | 0.031 | 1.810 | 0.457 | 4.548 | Unacceptable |
| KWw3 | Kubwa | 0.347 | 0.345 | 0.000 | 0.000 | 0.324 | 0.021 | 0.067 | 2.381 | 3.186 | 6.670 | Unacceptable |
| KWw4 | Kubwa | 0.490 | 0.672 | 0.002 | 0.086 | 0.162 | 0.025 | 0.106 | 1.810 | 0.500 | 3.852 | Unacceptable |
| KWw5 | Kubwa | 0.857 | 0.565 | 0.002 | 0.091 | 0.286 | 0.011 | 0.024 | 1.524 | 1.143 | 4.503 | Unacceptable |
| KRSw1 | Karshi | 0.480 | 0.910 | 0.001 | 0.057 | 0.905 | 0.006 | 0.034 | 1.714 | 0.914 | 5.022 | Unacceptable |
| KRSw2 | Karshi | 0.388 | 0.198 | 0.002 | 0.086 | 0.107 | 0.024 | 0.127 | 2.095 | 4.014 | 7.041 | Unacceptable |
| KRSw3 | Karshi | 0.510 | 0.444 | 0.001 | 0.057 | 0.543 | 0.006 | 0.061 | 1.448 | 1.486 | 4.556 | Unacceptable |
| KRSw4 | Karshi | 0.061 | 0.797 | 0.006 | 0.286 | 0.104 | 0.018 | 0.021 | 1.619 | 1.414 | 4.326 | Unacceptable |
| GOw1 | Gosa | 0.449 | 1.171 | 0.001 | 0.057 | 0.362 | 0.004 | 0.072 | 7.429 | 1.114 | 10.660 | Unacceptable |
| GOw2 | Gosa | 0.265 | 0.653 | 0.001 | 0.063 | 0.914 | 0.038 | 0.059 | 1.048 | 1.814 | 4.857 | Unacceptable |
| GOw3 | Gosa | 0.224 | 0.452 | 0.015 | 0.743 | 0.143 | 0.012 | 0.107 | 0.667 | 0.821 | 3.185 | Unacceptable |
| GOw4 | Gosa | 0.367 | 0.785 | 0.001 | 0.057 | 0.848 | 0.010 | 0.043 | 1.276 | 2.014 | 5.402 | Unacceptable |
| AZHw1 | Azhata | 0.257 | 1.571 | 0.004 | 0.171 | 0.104 | 0.044 | 0.123 | 1.048 | 0.771 | 4.094 | Unacceptable |
| AZHw2 | Azhata | 0.429 | 0.450 | 0.001 | 0.057 | 0.867 | 0.041 | 0.000 | 1.429 | 0.171 | 3.444 | Unacceptable |
| AZHw3 | Azhata | 0.184 | 1.171 | 0.001 | 0.063 | 0.095 | 0.004 | 0.073 | 1.029 | 1.114 | 3.735 | Unacceptable |
| KUJw1 | Kuje | 0.265 | 0.653 | 0.002 | 0.091 | 0.914 | 0.038 | 0.064 | 1.819 | 1.814 | 5.662 | Unacceptable |
| KUJw2 | Kuje | 0.367 | 0.452 | 0.002 | 0.074 | 0.113 | 0.012 | 0.107 | 0.667 | 0.821 | 2.616 | Unacceptable |
| KUJw3 | Kuje | 0.367 | 0.785 | 0.003 | 0.120 | 0.848 | 0.009 | 0.049 | 3.238 | 2.014 | 7.432 | Unacceptable |

#### 2.6.1 The non-carcinogenic health risk index

The non-carcinogenic hazard index was determined using the formula in Eq. 1 [29]

$$\mathrm{HI} = \sum_{i=1}^{n} HQ \tag{1}$$

The hazard quotient (HQ) was used to assess the potential for non-carcinogenic health risk for all the heavy metals that were encountered in the water samples. The health quotient of each metal was determined using the formula in Eq. 2 [29]

$$\mathrm{HQ} = \frac{ADD}{RfD} \tag{2}$$

#### 2.6.2 ADD is the average daily dose

*$R_fD$ is the oral reference dose for each of the metals in mg/Kg/day* [29].

The average daily dose (ADD) through ingestion and dermal absorption were calculated using the formula in Eqs. 3 and 4 below.

$$\mathrm{ADDingestion} = \frac{CxIRxEDxEF}{BWxAT} \tag{3}$$

**Table 7** Hazard quotient and health risk index for adult through dermal absorption of the contaminated water

| Sample | Label | HQ_Pb | HQ_Zn | HQ_Ni | HQ_Mn | HQ_Fe | HQ_Cu | HQ_Cr | HQ_Cd | HQ_As | HI_d_adult | interpretation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BWw1 | Bwari | 0.00096 | 0.01520 | 0.00274 | 0.00837 | 0.00006 | 0.00831 | 0.01275 | 0.00309 | 0.00081 | 0.05229 | Acceptable |
| BWw2 | Bwari | 0.00055 | 0.00719 | 0.00166 | 0.01029 | 0.00012 | 0.00401 | 0.01584 | 0.00062 | 0.00282 | 0.04309 | Acceptable |
| BWw3 | Bwari | 0.00048 | 0.01291 | 0.00579 | 0.01495 | 0.00005 | 0.00401 | 0.02242 | 0.00494 | 0.00092 | 0.06646 | Acceptable |
| BWw4 | Bwari | 0.00070 | 0.01898 | 0.00212 | 0.01188 | 0.00001 | 0.00301 | 0.00284 | 0.00068 | 0.00096 | 0.04117 | Acceptable |
| GWv1 | Gwagwalada | 0.00478 | 0.01058 | 0.00174 | 0.01667 | 0.00010 | 0.00490 | 0.01975 | 0.00617 | 0.00276 | 0.06744 | Acceptable |
| GWv2 | Gwagwalada | 0.00040 | 0.00733 | 0.00289 | 0.01445 | 0.00003 | 0.00222 | 0.00208 | 0.00000 | 0.00038 | 0.02978 | Acceptable |
| GWv3 | Gwagwalada | 0.00066 | 0.01271 | 0.00144 | 0.00659 | 0.00003 | 0.00544 | 0.01831 | 0.00080 | 0.00184 | 0.04783 | Acceptable |
| GWv4 | Gwagwalada | 0.00068 | 0.00255 | 0.00332 | 0.01196 | 0.00002 | 0.00208 | 0.00391 | 0.00093 | 0.00060 | 0.02603 | Acceptable |
| KWw1 | Kubwa | 0.00040 | 0.00728 | 0.00000 | 0.01778 | 0.00012 | 0.00046 | 0.01625 | 0.00099 | 0.00363 | 0.04691 | Acceptable |
| KWw2 | Kubwa | 0.00051 | 0.01470 | 0.00085 | 0.01639 | 0.00011 | 0.00123 | 0.02016 | 0.00086 | 0.00103 | 0.05586 | Acceptable |
| KWw3 | Kubwa | 0.00062 | 0.00559 | 0.00180 | 0.00383 | 0.00006 | 0.00860 | 0.00699 | 0.00000 | 0.00135 | 0.02884 | Acceptable |
| KWw4 | Kubwa | 0.00088 | 0.01089 | 0.00287 | 0.01093 | 0.00007 | 0.00135 | 0.00350 | 0.00093 | 0.00103 | 0.03244 | Acceptable |
| KWw5 | Kubwa | 0.00154 | 0.00915 | 0.00066 | 0.00305 | 0.00003 | 0.00309 | 0.00617 | 0.00099 | 0.00087 | 0.02554 | Acceptable |
| KRSw1 | Karshi | 0.00086 | 0.01475 | 0.00093 | 0.00402 | 0.00001 | 0.00247 | 0.01954 | 0.00062 | 0.00097 | 0.04417 | Acceptable |
| KRSw2 | Karshi | 0.00070 | 0.00321 | 0.00343 | 0.01144 | 0.00006 | 0.01084 | 0.00230 | 0.00093 | 0.00119 | 0.03411 | Acceptable |
| KRSw3 | Karshi | 0.00092 | 0.00719 | 0.00166 | 0.01029 | 0.00002 | 0.00401 | 0.01173 | 0.00062 | 0.00082 | 0.03725 | Acceptable |
| KRSw4 | Karshi | 0.00011 | 0.01291 | 0.00058 | 0.01495 | 0.00005 | 0.00382 | 0.00224 | 0.00309 | 0.00092 | 0.03866 | Acceptable |
| GOw1 | Gosa | 0.00081 | 0.01898 | 0.00195 | 0.01188 | 0.00001 | 0.00301 | 0.00782 | 0.00062 | 0.00422 | 0.04929 | Acceptable |
| GOw2 | Gosa | 0.00048 | 0.01058 | 0.00160 | 0.01238 | 0.00010 | 0.00490 | 0.01975 | 0.00068 | 0.00060 | 0.05106 | Acceptable |
| GOw3 | Gosa | 0.00040 | 0.00733 | 0.00289 | 0.01445 | 0.00003 | 0.00222 | 0.00309 | 0.00802 | 0.00038 | 0.03881 | Acceptable |
| GOw4 | Gosa | 0.00066 | 0.01271 | 0.00117 | 0.00738 | 0.00003 | 0.00544 | 0.01831 | 0.00062 | 0.00073 | 0.04704 | Acceptable |
| AZHw1 | Azhata | 0.00046 | 0.02546 | 0.00332 | 0.01196 | 0.00012 | 0.00208 | 0.00224 | 0.00185 | 0.00060 | 0.04809 | Acceptable |
| AZHw2 | Azhata | 0.00077 | 0.00728 | 0.00000 | 0.01038 | 0.00011 | 0.00046 | 0.01872 | 0.00062 | 0.00081 | 0.03916 | Acceptable |
| AZHw3 | Azhata | 0.00033 | 0.01898 | 0.00197 | 0.01188 | 0.00001 | 0.00301 | 0.00206 | 0.00068 | 0.00058 | 0.03949 | Acceptable |
| KUJw1 | Kuje | 0.00048 | 0.01058 | 0.00174 | 0.00702 | 0.00010 | 0.00490 | 0.01975 | 0.00099 | 0.00103 | 0.04659 | Acceptable |
| KUJw2 | Kuje | 0.00066 | 0.00733 | 0.00289 | 0.01366 | 0.00003 | 0.00222 | 0.00245 | 0.00080 | 0.00038 | 0.03042 | Acceptable |
| KUJw3 | Kuje | 0.00066 | 0.01271 | 0.00132 | 0.01623 | 0.00002 | 0.00544 | 0.01831 | 0.00130 | 0.00184 | 0.05783 | Acceptable |

$$ADDdermal = \frac{CxSAxKpxETxEDxEFxCF}{BWxAT} \quad (4)$$

*C is the concentration of heavy metals in* drinking *water*

*IR is the daily exposure rate (1/day)*

*ED is the exposure* duration *(years)*

*EF is the exposure* frequency *(365 days/year)*

*SA is the exposure area of the skin [(6600cm$^2$, children), (18,000 cm.$^2$, Adult)]*

*Kp is the dermal* permeability *coefficient in water (cm/h);*

*BW is the average body weight (kg)*

*AT is the average lifetime of human exposure*

*For non-carcinogenic* health *risk estimation, AT = EDx365*

*For carcinogenic health* risk *estimation, AT = 55 × 365(Life expectancy in Nigeria is 55 years)*

There would be an adverse effects on adults or children consuming water contaminated with the identified heavy metals through ingestion and dermal contact if HI, HQ > 1 but there would be no cause for concern if the computed HI < 1 [30].

## 2.7 The carcinogenic health risk Index (CR)

The carcinogenic health risk index is a measure or risk involved by being exposed to a carcinogens (As, Cd, Cr etc.) for lifetime. CR of the water samples were determined using the formula in Eq. 5 [36]

**Table 8** Hazard quotient and health risk index for children through ingestion in the study area

| Sample | Label | HQ_Cu | HQ_Ni | HQ_Mn | HQ_Cd | HQ_Fe | HQ_Cr | HQ_Pb | HQ_Zn | HQ_As | Hi_i_child | Interpretation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BWw1 | Bwari | 7.183 | 0.237 | 1.447 | 0.667 | 0.050 | 1.378 | 1.238 | 2.189 | 3.333 | 17.722 | Unacceptable |
| BWw2 | Bwari | 3.467 | 0.143 | 1.778 | 0.133 | 0.105 | 1.711 | 0.714 | 1.036 | 11.556 | 20.643 | Unacceptable |
| BWw3 | Bwari | 3.467 | 0.500 | 2.583 | 1.067 | 0.041 | 2.422 | 0.619 | 1.860 | 3.778 | 16.337 | Unacceptable |
| BWw4 | Bwari | 2.600 | 0.183 | 2.053 | 0.147 | 0.010 | 0.307 | 0.905 | 2.733 | 3.956 | 12.893 | Unacceptable |
| GWv1 | Gwagwalada | 4.233 | 0.150 | 2.881 | 1.333 | 0.090 | 2.133 | 6.190 | 1.524 | 11.333 | 29.868 | Unacceptable |
| GWv2 | Gwagwalada | 1.917 | 0.250 | 2.497 | 0.000 | 0.028 | 0.224 | 0.524 | 1.056 | 1.556 | 8.051 | Unacceptable |
| GWv3 | Gwagwalada | 4.700 | 0.125 | 1.139 | 0.173 | 0.026 | 1.978 | 0.857 | 1.831 | 7.556 | 18.384 | Unacceptable |
| GWv4 | Gwagwalada | 1.800 | 0.287 | 2.067 | 0.200 | 0.013 | 0.422 | 0.886 | 0.367 | 2.444 | 8.486 | Unacceptable |
| KWw1 | Kubwa | 0.400 | 0.000 | 3.072 | 0.213 | 0.103 | 1.756 | 0.524 | 1.049 | 14.889 | 22.006 | Unacceptable |
| KWw2 | Kubwa | 1.067 | 0.073 | 2.833 | 0.187 | 0.097 | 2.178 | 0.667 | 2.118 | 4.222 | 13.441 | Unacceptable |
| KWw3 | Kubwa | 7.433 | 0.155 | 0.661 | 0.000 | 0.050 | 0.756 | 0.810 | 0.804 | 5.556 | 16.225 | Unacceptable |
| KWw4 | Kubwa | 1.167 | 0.248 | 1.889 | 0.200 | 0.058 | 0.378 | 1.143 | 1.569 | 4.222 | 10.873 | Unacceptable |
| KWw5 | Kubwa | 2.667 | 0.057 | 0.528 | 0.213 | 0.026 | 0.667 | 2.000 | 1.318 | 3.556 | 11.031 | Unacceptable |
| KRSw1 | Karshi | 2.133 | 0.080 | 0.694 | 0.133 | 0.013 | 2.111 | 1.119 | 2.124 | 4.000 | 12.409 | Unacceptable |
| KRSw2 | Karshi | 9.367 | 0.297 | 1.978 | 0.200 | 0.056 | 0.249 | 0.905 | 0.462 | 4.889 | 18.402 | Unacceptable |
| KRSw3 | Karshi | 3.467 | 0.143 | 1.778 | 0.133 | 0.014 | 1.267 | 1.190 | 1.036 | 3.378 | 12.405 | Unacceptable |
| KRSw4 | Karshi | 3.300 | 0.050 | 2.583 | 0.667 | 0.041 | 0.242 | 0.143 | 1.860 | 3.778 | 12.664 | Unacceptable |
| GOw1 | Gosa | 2.600 | 0.168 | 2.053 | 0.133 | 0.010 | 0.844 | 1.048 | 2.733 | 17.333 | 26.923 | Unacceptable |
| GOw2 | Gosa | 4.233 | 0.138 | 2.139 | 0.147 | 0.090 | 2.133 | 0.619 | 1.524 | 2.444 | 13.468 | Unacceptable |
| GOw3 | Gosa | 1.917 | 0.250 | 2.497 | 1.733 | 0.028 | 0.333 | 0.524 | 1.056 | 1.556 | 9.893 | Unacceptable |
| GOw4 | Gosa | 4.700 | 0.101 | 1.275 | 0.133 | 0.024 | 1.978 | 0.857 | 1.831 | 2.978 | 13.878 | Unacceptable |
| AZHw1 | Azhata | 1.800 | 0.287 | 2.067 | 0.400 | 0.104 | 0.242 | 0.600 | 3.667 | 2.444 | 11.610 | Unacceptable |
| AZHw2 | Azhata | 0.400 | 0.000 | 1.794 | 0.133 | 0.095 | 2.022 | 1.000 | 1.049 | 3.333 | 9.827 | Unacceptable |
| AZHw3 | Azhata | 2.600 | 0.170 | 2.053 | 0.147 | 0.010 | 0.222 | 0.429 | 2.733 | 2.400 | 10.764 | Unacceptable |
| KUJw1 | Kuje | 4.233 | 0.150 | 1.214 | 0.213 | 0.090 | 2.133 | 0.619 | 1.524 | 4.244 | 14.421 | Unacceptable |
| KUJw2 | Kuje | 1.917 | 0.250 | 2.361 | 0.173 | 0.028 | 0.264 | 0.857 | 1.056 | 1.556 | 8.461 | Unacceptable |
| KUJw3 | Kuje | 4.700 | 0.114 | 2.806 | 0.280 | 0.020 | 1.978 | 0.857 | 1.831 | 7.556 | 20.141 | Unacceptable |

$$CR = ADD \times CSF \tag{5}$$

*ADD = Average daily dose*
*CSF = Cancer slope factor*

## 3 Results and discussion

The parameters in Tables 1, 2, 3 and 4 above were used for the computation of results shown in Tables 5, 6, 7, 8, 9, 10 and 11

Table 6 contains the data, results and interpretations for the non-carcinogenic HQ and HI. The assessment is for the risk involved for adults in the use of the water within the catchment area of the investigated dumpsites through ingestion. The results revealed that the risk involved for an adult using all the investigated water bodies is unacceptable [30]. This result suggests that the daily intake of the examined heavy metal is higher that the level of concern (i.e. HQ, HI > 1); therefore the non-carcinogenic health risk from heavy metals through ingestion of the investigated water is not in safe range for adult population of the study area. This result agrees with [37–40].

Table 7 contains the data, results and interpretations for the non-carcinogenic HQ and HI for adult population through dermal absorption. The results revealed that the risk involved for an adult using all the investigated water bodies through

**Table 9** Hazard quotient and health risk index for children through dermal absorption in the study area

| Sample | Label | HQ_As | HQ_Cd | HQ_Cu | HQ_Fe | HQ_Mn | HQ_Cr | HQ_Ni | HQ_Pb | HQ_Zn | HI_d_child | Interpretation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BWw1 | Bwari | 0.0132 | 0.0440 | 0.1896 | 0.0010 | 0.1433 | 0.4365 | 0.0047 | 0.0016 | 0.0260 | 0.8599 | Acceptable |
| BWw2 | Bwari | 0.0458 | 0.0088 | 0.0915 | 0.0021 | 0.1760 | 0.5421 | 0.0028 | 0.0009 | 0.0123 | 0.8823 | Acceptable |
| BWw3 | Bwari | 0.0150 | 0.0704 | 0.0915 | 0.0008 | 0.2558 | 0.7674 | 0.0099 | 0.0008 | 0.0221 | 1.2336 | Unacceptable |
| BWw4 | Bwari | 0.0157 | 0.0097 | 0.0686 | 0.0002 | 0.2032 | 0.0972 | 0.0036 | 0.0012 | 0.0325 | 0.4319 | Acceptable |
| GWv1 | Gwagwalada | 0.0449 | 0.0880 | 0.1118 | 0.0018 | 0.2852 | 0.6758 | 0.0030 | 0.0082 | 0.0181 | 1.2367 | Unacceptable |
| GWv2 | Gwagwalada | 0.0062 | 0.0000 | 0.0506 | 0.0005 | 0.2472 | 0.0711 | 0.0050 | 0.0007 | 0.0125 | 0.3938 | Acceptable |
| GWv3 | Gwagwalada | 0.0299 | 0.0114 | 0.1241 | 0.0005 | 0.1128 | 0.6266 | 0.0025 | 0.0011 | 0.0218 | 0.9306 | Acceptable |
| GWv4 | Gwagwalada | 0.0097 | 0.0132 | 0.0475 | 0.0003 | 0.2046 | 0.1338 | 0.0057 | 0.0012 | 0.0044 | 0.4202 | Acceptable |
| KWw1 | Kubwa | 0.0590 | 0.0141 | 0.0106 | 0.0020 | 0.3042 | 0.5562 | 0.0000 | 0.0007 | 0.0125 | 0.9591 | Acceptable |
| KWw2 | Kubwa | 0.0167 | 0.0123 | 0.0282 | 0.0019 | 0.2805 | 0.6899 | 0.0015 | 0.0009 | 0.0252 | 1.0570 | Unacceptable |
| KWw3 | Kubwa | 0.0220 | 0.0000 | 0.1962 | 0.0010 | 0.0655 | 0.2394 | 0.0031 | 0.0011 | 0.0096 | 0.5377 | Acceptable |
| KWw4 | Kubwa | 0.0167 | 0.0132 | 0.0308 | 0.0011 | 0.1870 | 0.1197 | 0.0049 | 0.0015 | 0.0186 | 0.3936 | Acceptable |
| KWw5 | Kubwa | 0.0141 | 0.0141 | 0.0704 | 0.0005 | 0.0523 | 0.2112 | 0.0011 | 0.0026 | 0.0157 | 0.3820 | Acceptable |
| KRSw1 | Karshi | 0.0158 | 0.0088 | 0.0563 | 0.0003 | 0.0688 | 0.6688 | 0.0016 | 0.0015 | 0.0252 | 0.8471 | Acceptable |
| KRSw2 | Karshi | 0.0194 | 0.0132 | 0.2473 | 0.0011 | 0.1958 | 0.0788 | 0.0059 | 0.0012 | 0.0055 | 0.5682 | Acceptable |
| KRSw3 | Karshi | 0.0134 | 0.0088 | 0.0915 | 0.0003 | 0.1760 | 0.4013 | 0.0028 | 0.0016 | 0.0123 | 0.7080 | Acceptable |
| KRSw4 | Karshi | 0.0150 | 0.0440 | 0.0871 | 0.0008 | 0.2558 | 0.0767 | 0.0010 | 0.0002 | 0.0221 | 0.5027 | Acceptable |
| GOw1 | Gosa | 0.0686 | 0.0088 | 0.0686 | 0.0002 | 0.2032 | 0.2675 | 0.0033 | 0.0014 | 0.0325 | 0.6542 | Acceptable |
| GOw2 | Gosa | 0.0097 | 0.0097 | 0.1118 | 0.0018 | 0.2118 | 0.6758 | 0.0027 | 0.0008 | 0.0181 | 1.0422 | Unacceptable |
| GOw3 | Gosa | 0.0062 | 0.1144 | 0.0506 | 0.0005 | 0.2472 | 0.1056 | 0.0050 | 0.0007 | 0.0125 | 0.5427 | Acceptable |
| GOw4 | Gosa | 0.0118 | 0.0088 | 0.1241 | 0.0005 | 0.1262 | 0.6266 | 0.0020 | 0.0011 | 0.0218 | 0.9228 | Acceptable |
| AZHw1 | Azhata | 0.0097 | 0.0264 | 0.0475 | 0.0021 | 0.2046 | 0.0767 | 0.0057 | 0.0008 | 0.0436 | 0.4170 | Acceptable |
| AZHw2 | Azhata | 0.0132 | 0.0088 | 0.0106 | 0.0019 | 0.1777 | 0.6406 | 0.0000 | 0.0013 | 0.0125 | 0.8665 | Acceptable |
| AZHw3 | Azhata | 0.0095 | 0.0097 | 0.0686 | 0.0002 | 0.2032 | 0.0704 | 0.0034 | 0.0006 | 0.0325 | 0.3981 | Acceptable |
| KUJw1 | Kuje | 0.0168 | 0.0141 | 0.1118 | 0.0018 | 0.1202 | 0.6758 | 0.0030 | 0.0008 | 0.0181 | 0.9623 | Acceptable |
| KUJw2 | Kuje | 0.0062 | 0.0114 | 0.0506 | 0.0005 | 0.2338 | 0.0838 | 0.0050 | 0.0011 | 0.0125 | 0.4049 | Acceptable |
| KUJw3 | Kuje | 0.0299 | 0.0185 | 0.1241 | 0.0004 | 0.2778 | 0.6266 | 0.0023 | 0.0011 | 0.0218 | 1.1023 | Unacceptable |

dermal absorption is acceptable [30]. In the case of dermal absorption, the computed HQ and HI computed for adult population in the area are below level of concern (HQ, HI < 1). This result is in concordance with [32, 37].

Table 8 contains the data, results and interpretations for the non-carcinogenic HQ and HI for the non-adult population in the study area. The assessment is for the risk involved for children in the use of the investigated water through ingestion. The computed HQ and HI across the investigated dumpsites for the children population shows that the non-carcinogenic risk via ingestion of the examined heavy metals is higher than the level of concern (i.e. HQ, HI > 1) [30]. The result agrees with [36]. According to World Health Organization report, children are a vulnerable population to health risks via ingestion because they drink more water, consume more food, and breathe more air in proportion to their weight. Children's immune, digestive, reproductive, and nervous systems are still growing. At the early part of development, exposure to toxic elements causes irreversible damage [37].

Table 9 contains the data, results and interpretations for the non-carcinogenic HQ and HI for non-adult population in the study area through dermal absorption of the investigated water. The result suggests that the dermal absorption of the examined heavy metal is lower that the level of concern (i.e. HQ, HI < 1) for about 80% of the samples; therefore the non-carcinogenic health risk from heavy metals through dermal absorption of the investigated water is in safe range for children population of the study area except for few samples representing about 20% of the total samples from Kuje, Gosa, Gwagwalada and Bwari dumpsites that are unacceptable [30]. This result agrees with [36–39].

Table 10 contains the data, results and interpretations for carcinogenic risk index. The assessment is about the risk involved for an adult to contract cancer using the investigated water via ingestion. The estimated $CR_{ingestion}$ for all the toxic elements (inorganic carcinogens that were discovered in the samples) are in the range of 0.0021 to 0.0109 for adult population in the area [39, 40]. The results when compared with USEPA and other regulatory guidelines, suggest that the probability of carcinogenic risk via ingestion is 1in 1000 [42–46]. Also, when the results are compared with the

**Table 10** Carcinogenic risk (CR) for adult through ingestion in the study area

| Sample | Label | CR_As | CR_Cd | CR_Cr | CR_Ni | ∑_CR | Risk grade |
|---|---|---|---|---|---|---|---|
| BWw1 | Bwari | 0.000351 | 0.000475 | 0.000483 | 0.0018837 | 0.0031928 | GradeVI |
| BWw2 | Bwari | 0.001216 | 9.51E-05 | 0.0006 | 0.0011392 | 0.0030499 | GradeVI |
| BWw3 | Bwari | 0.000397 | 0.000761 | 0.000849 | 0.003974 | 0.0059813 | GradeVI |
| BWw4 | Bwari | 0.000416 | 0.000105 | 0.000108 | 0.0014571 | 0.0020854 | GradeVI |
| GWv1 | Gwagwalada | 0.001192 | 0.000951 | 0.000748 | 0.0011922 | 0.0040831 | GradeVI |
| GWv2 | Gwagwalada | 0.000164 | 0 | 7.87E-05 | 0.001987 | 0.0022294 | GradeVI |
| GWv3 | Gwagwalada | 0.000795 | 0.000124 | 0.000694 | 0.0009909 | 0.0026028 | GradeVI |
| GWv4 | Gwagwalada | 0.000257 | 0.000143 | 0.000148 | 0.0022784 | 0.0028262 | GradeVI |
| KWw1 | Kubwa | 0.001566 | 0.000152 | 0.000616 | 0 | 0.0023339 | GradeVI |
| KWw2 | Kubwa | 0.000444 | 0.000133 | 0.000764 | 0.0005829 | 0.0019237 | GradeVI |
| KWw3 | Kubwa | 0.000584 | 0 | 0.000265 | 0.0012346 | 0.0020839 | GradeVI |
| KWw4 | Kubwa | 0.000444 | 0.000143 | 0.000132 | 0.0019738 | 0.002693 | GradeVI |
| KWw5 | Kubwa | 0.000374 | 0.000152 | 0.000234 | 0.0004504 | 0.0012103 | GradeVI |
| KRSw1 | Karshi | 0.000421 | 9.51E-05 | 0.00074 | 0.0006358 | 0.0018919 | GradeVI |
| KRSw2 | Karshi | 0.000514 | 0.000143 | 8.73E-05 | 0.0023579 | 0.0031021 | GradeVI |
| KRSw3 | Karshi | 0.000355 | 9.51E-05 | 0.000444 | 0.0011392 | 0.0020338 | GradeVI |
| KRSw4 | Karshi | 0.000397 | 0.000475 | 8.49E-05 | 0.0003974 | 0.0013551 | GradeVI |
| GOw1 | Gosa | 0.001823 | 9.51E-05 | 0.000296 | 0.0013379 | 0.0035525 | GradeVI |
| GOw2 | Gosa | 0.000257 | 0.000105 | 0.000748 | 0.0010995 | 0.0022092 | GradeVI |
| GOw3 | Gosa | 0.000164 | 0.001236 | 0.000117 | 0.001987 | 0.0035034 | GradeVI |
| GOw4 | Gosa | 0.000313 | 9.51E-05 | 0.000694 | 0.0008054 | 0.0019072 | GradeVI |
| AZHw1 | Azhata | 0.000257 | 0.000285 | 8.49E-05 | 0.0022784 | 0.0029057 | GradeVI |
| AZHw2 | Azhata | 0.000351 | 9.51E-05 | 0.000709 | 0 | 0.0011548 | GradeVI |
| AZHw3 | Azhata | 0.000252 | 0.000105 | 7.79E-05 | 0.0013512 | 0.0017861 | GradeVI |
| KUJw1 | Kuje | 0.000446 | 0.000152 | 0.000748 | 0.0011922 | 0.0025389 | GradeVI |
| KUJw2 | Kuje | 0.000164 | 0.000124 | 9.27E-05 | 0.001987 | 0.002367 | GradeVI |
| KUJw3 | Kuje | 0.000795 | 0.0002 | 0.000694 | 0.0009034 | 0.0025914 | GradeVI |

standards in Table 4, it can be seen that they belong to Grade VI which means one out of every one thousand adults that take from any of the sampled water via ingestion is at a very high risk of contracting cancer [34]. The results obtained is in tandem with the findings of [41, 42].

Table 11 contains the data, results and interpretations for carcinogenic risk index. The assessment is about the risk involved for children population of the study area to contract cancer using the investigated water via ingestion. When the results were compared with the USEPA and other regulatory guidelines, it revealed that the risk involved for children in the study area to contract cancer, calls for serious concern [42–47]. When compared with the standard in Table 4, the results fall under Grade V which means one out of every ten thousand Children that take from any of the sampled waters is at risk of contracting cancer [35]. The results obtained are also in tandem with the findings of [40, 41].

## 4 Conclusion

The hazard quotient via ingestion (HQ ingestion), hazard quotient via dermal absorption (HQ dermal), and health risk index (HI) were used for non-carcinogenic risk involved in the in-take of analysed heavy metals for both children and adult population of the study area. The carcinogenic risk (CR) for both children and adults were estimated using the concentration of heavy metals that were analysed in the water samples. Results indicated that there is low to high metal contamination in the water bodies within the catchment area of the investigated dumpsites and that the intake of the water poses high risk for both Children adult population of the study area. These indices were used because it has been observed that evaluations that involve just benchmarking the metal concentrations against regulatory standards, does not give a clear idea about serious health danger, the toxic heavy metals poses to man.

**Table 11** Carcinogenic risk (CR) for children through ingestion in the study area

| Sample | Label | CR_NI | CR_Cr | CR_Cd | CR_As | Ʃ_CR | Risk grade |
|---|---|---|---|---|---|---|---|
| BWw1 | Bwari | 0.0008791 | 0.0002255 | 0.0002218 | 0.0001636 | 0.00149 | Grade VI |
| BWw2 | Bwari | 0.0005316 | 0.00028 | 4.436E-05 | 0.0005673 | 0.0014233 | Grade VI |
| BWw3 | Bwari | 0.0018545 | 0.0003964 | 0.0003549 | 0.0001855 | 0.0027913 | Grade VI |
| BWw4 | Bwari | 0.00068 | 5.018E-05 | 0.0000488 | 0.0001942 | 0.0009732 | Grade VI |
| GWv1 | Gwagwalada | 0.0005564 | 0.0003491 | 0.0004436 | 0.0005564 | 0.0019055 | Grade VI |
| GWv2 | Gwagwalada | 0.0009273 | 3.673E-05 | 0 | 7.636E-05 | 0.0010404 | Grade VI |
| GWv3 | Gwagwalada | 0.0004624 | 0.0003236 | 5.767E-05 | 0.0003709 | 0.0012146 | Grade VI |
| GWv4 | Gwagwalada | 0.0010633 | 6.909E-05 | 6.655E-05 | 0.00012 | 0.0013189 | Grade VI |
| KWw1 | Kubwa | 0 | 0.0002873 | 7.098E-05 | 0.0007309 | 0.0010892 | Grade VI |
| KWw2 | Kubwa | 0.000272 | 0.0003564 | 6.211E-05 | 0.0002073 | 0.0008977 | Grade V |
| KWw3 | Kubwa | 0.0005761 | 0.0001236 | 0 | 0.0002727 | 0.0009725 | Grade V |
| KWw4 | Kubwa | 0.0009211 | 6.182E-05 | 6.655E-05 | 0.0002073 | 0.0012567 | Grade VI |
| KWw5 | Kubwa | 0.0002102 | 0.0001091 | 7.098E-05 | 0.0001745 | 0.0005648 | Grade V |
| KRSw1 | Karshi | 0.0002967 | 0.0003455 | 4.436E-05 | 0.0001964 | 0.0008829 | Grade V |
| KRSw2 | Karshi | 0.0011004 | 4.073E-05 | 6.655E-05 | 0.00024 | 0.0014476 | Grade VI |
| KRSw3 | Karshi | 0.0005316 | 0.0002073 | 4.436E-05 | 0.0001658 | 0.0009491 | Grade V |
| KRSw4 | Karshi | 0.0001855 | 3.964E-05 | 0.0002218 | 0.0001855 | 0.0006324 | Grade VI |
| GOw1 | Gosa | 0.0006244 | 0.0001382 | 4.436E-05 | 0.0008509 | 0.0016578 | Grade VI |
| GOw2 | Gosa | 0.0005131 | 0.0003491 | 0.0000488 | 0.00012 | 0.001031 | Grade VI |
| GOw3 | Gosa | 0.0009273 | 5.455E-05 | 0.0005767 | 7.636E-05 | 0.0016349 | Grade VI |
| GOw4 | Gosa | 0.0003759 | 0.0003236 | 4.436E-05 | 0.0001462 | 0.00089 | Grade V |
| AZHw1 | Azhata | 0.0010633 | 3.964E-05 | 0.0001331 | 0.00012 | 0.001356 | Grade VI |
| AZHw2 | Azhata | 0 | 0.0003309 | 4.436E-05 | 0.0001636 | 0.0005389 | Grade V |
| AZHw3 | Azhata | 0.0006305 | 3.636E-05 | 0.0000488 | 0.0001178 | 0.0008335 | Grade V |
| KUJw1 | Kuje | 0.0005564 | 0.0003491 | 7.098E-05 | 0.0002084 | 0.0011848 | Grade VI |
| KUJw2 | Kuje | 0.0009273 | 4.327E-05 | 5.767E-05 | 7.636E-05 | 0.0011046 | Grade VI |
| KUJw3 | Kuje | 0.0004216 | 0.0003236 | 9.316E-05 | 0.0003709 | 0.0012093 | Grade VI |

## 5 Recommendation

Engineered landfilling that will protect the surrounding soil and water against contamination is highly recommended. Integrated solid waste management as against what is currently adopted, is also highly recommended to reduce the impacts of solid waste on human health.

**Author contributions** Omali Aurelius and Arogundade Johnson wrote the main manuscript textOmali Aurelius and Arogundade Johnson prepared tables and figures.Daniel Snow carried out the Laboratory analysis.All authors reviewed the Manuscript.

**Data availability** The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Competing interests** The authors declare no competing interests.

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