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Original Research

Human Health Risk Assessment of Cadmium in the Groundwater Resources of Some Nigerian Communities

Oyindamola Araoye[1], David Omole[2]*, Oluranti Agboola[3]

[1]Department of Civil Engineering, Covenant University, PMB 1023, Ota 112233, Ogun State, Nigeria
[2]School of Civil & Environmental Engineering, University of the Witwatersrand, Johannesburg, Private Bag 3, Johannesburg, WITS 2050, South Africa
[3]Department of Chemical Engineering, Covenant University, PMB 1023, Ota 112233, Ogun State, Nigeria

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Abstract

Water from machine and hand-dug wells in six communities in Ogun State, Nigeria, was examined for cadmium. Sixty samples (ten from each community) were collected and analyzed in triplicate using standard methods. Results showed that cadmium concentrations in the six communities ranged from 0.001 mg/L to 0.530 mg/L. The mean cadmium concentrations from the Olujobi, Wasinmi, Itori, Papalanto, Ifo, and Onihale communities were 0.002 mg/L, 0.054 mg/L, 0.053 mg/L, 0.001 mg/L, 0.017 mg/L, and 0.032 mg/L, respectively. In contrast, the permissible maximum contaminant limit (MCL) is 0.003 mg/L, which shows that four of the six sampled communities had mean values exceeding the MCL. Also, 180 residents of the sampled communities consented to participate in the study by providing information for a human health risk assessment (HHRA). The participants were grouped into nine age ranges for the HHRA. The computed hazard index (HI) showed HI (ingested) >1 in 16 of the 60 samples and HI (dermal) <1 in all the samples. Computed values for incremental lifetime cancer risk (ILCR) were significant in four of the six sampled communities, with the highest risk associated with children between ages 1 and 6.

Keywords: groundwater, hazard index, human health risk assessment, cadmium, water quality

Introduction

A significant proportion of the world's population lives in urban areas, thus putting pressure on available freshwater sources and infrastructure [1, 2]. In developing countries, people obtain water for domestic use from rainfall, dams, wells, boreholes, unprotected springs, streams, rivers, and other surface water bodies [3, 4]. Nkatha [5] and Ritchie et al. [6] estimate that 71% of the global population is water-insecure, and a quarter of that percentage (nearly 2 billion people) comes from Africa. In Nigeria, over

*e-mail: david.omole@wits.ac.za;
Tel: +27-632-650-185

66% of the population lacks access to clean drinking water and relies solely on untreated surface and groundwater sources to meet their domestic needs [7, 8]. However, the available freshwater sources are increasingly being rendered unfit for drinking through uncontrolled pollution activities such as industrial, agricultural, and domestic effluent discharges into water bodies [2, 8, 9]. Therefore, public health is constantly jeopardized by exposure to unsafe water [10].

Nigeria has abundant water resources to cater to its population of 218 million people [11]. However, the dearth of clean drinking water for its people is linked to insufficient infrastructure, poorly trained water personnel, ineffective standards enforcement, and poor financing [12]. According to Ogunbodede et al. [13] and Abioye & Perera [14], approximately 60-76% of the Nigerian population relies exclusively on groundwater (whether from hand-dug wells, machine-dug wells, or boreholes). The implication is that as many as 168 million people in the country rely on daily water withdrawal from groundwater resources. Without adequate guidelines on groundwater resource exploitation and management, the nation's groundwater resources are under constant stress and possible pollution by different users [12]. A major threat to groundwater quality is the proximity of septic tanks to water wells. Nearly every home in Nigeria is responsible for its water and sanitation management, which leads to indiscriminate and unscientifically advised siting of groundwater and sanitary facilities [12]. Odey et al. [15] said that 91% of urban and semi-urban dwellers use septic only. With failed leakages or improper construction, neighboring groundwater sources are at risk. Other possible sources of pollution in groundwater include discharges from industrial activities such as manufacturing, sewage treatment, and mineral exploration (which requires industrial processes that disturb natural geologic deposits and leach contaminants into the environment and the water table) [16]. One pollutant that has posed serious risks to public health and the environment in general is cadmium.

Cadmium

Cadmium (Cd) has been identified as one of the most toxic contaminants in groundwater and classified as a group 'A' carcinogenic agent [17-19]. It is a heavy metal with similar characteristics to mercury. Cadmium can combine with minerals such as carbonates, sulfides, and oxides under natural processes like fertilization, seasonal variation, combustion, and landfill leachates [17]. Production of cement, steel, and iron; incineration of solid waste; phosphate fertilizers; and mining activities are ways cadmium can seep into the environment. Wastewater containing cadmium and other heavy metals is frequently released into the atmosphere from industries that produce batteries, electroplating, and plastics [20]. A secondary source of cadmium pollution has also been found in discarded and recycled electronic and electrical wastes [21]. The toxicity of cadmium has been related to diseases such as hypertension, bone weakness, kidney and liver damage, renal diseases, and, in extreme cases, death [22]. Cadmium bio-accumulates in plants and aquatic animal tissues and can eventually cause serious health issues when humans ingest them [23].

Therefore, this study assessed cadmium contaminant levels in domestic water sources in selected communities in Ogun State, Nigeria. Further, it assessed the risks to human health from exposure to cadmium-polluted water among different age groups by calculating the hazard index (HI), hazard quotient (HQ), and incremental lifetime cancer risk (ILCR), which are standard methods for benchmarking the impact of toxic metals on human health [10, 18, 19]. By focusing on the drinking water sources of the average household in Ogun State, Nigeria, this research offers a unique insight into potential risks posed to unsuspecting consumers of water that is contaminated by heavy metals such as cadmium.

Experimental

Description of Study Area

Field reconnaissance and water sampling exercises were conducted in six communities surrounding industrial areas within three Ogun State local governments in July 2021. The communities are Ewekoro LGA (Wasinmi, Olujobi, Itori, and Papalanto communities), Ifo LGA (Ifo community), and Ado-Odo/Ota (Onihale community) (Fig. 1). These six semi-urban to rural communities were selected based on their proximity to Ewekoro, an industrial community with the largest limestone deposit and the largest cement manufacturing enterprise in Nigeria, with a production capacity of 13 million metric tons of cement per annum [24].

Water Sample Collection

Sixty water samples were collected from the six communities identified in the study area (Fig. 1). The collection points of the water samples were 36 hand-dug wells, four mechanized wells, and 20 boreholes. Most of the wells from which samples were obtained were poorly covered (Fig. 2).

The Global Positioning System (GPS) of the sampled points was recorded. The sampling locations targeted areas with concentrated habitations. The water samples were collected in clean 65 ml light-density polyethylene (LDPE) bottles. Each collected water sample was fixed with two drops of nitric acid (HNO_3) to prevent rapid parameter degradation or changes. The samples were immediately labeled, preserved at 4ºC, and transported to the laboratory within 24 hours of collection.

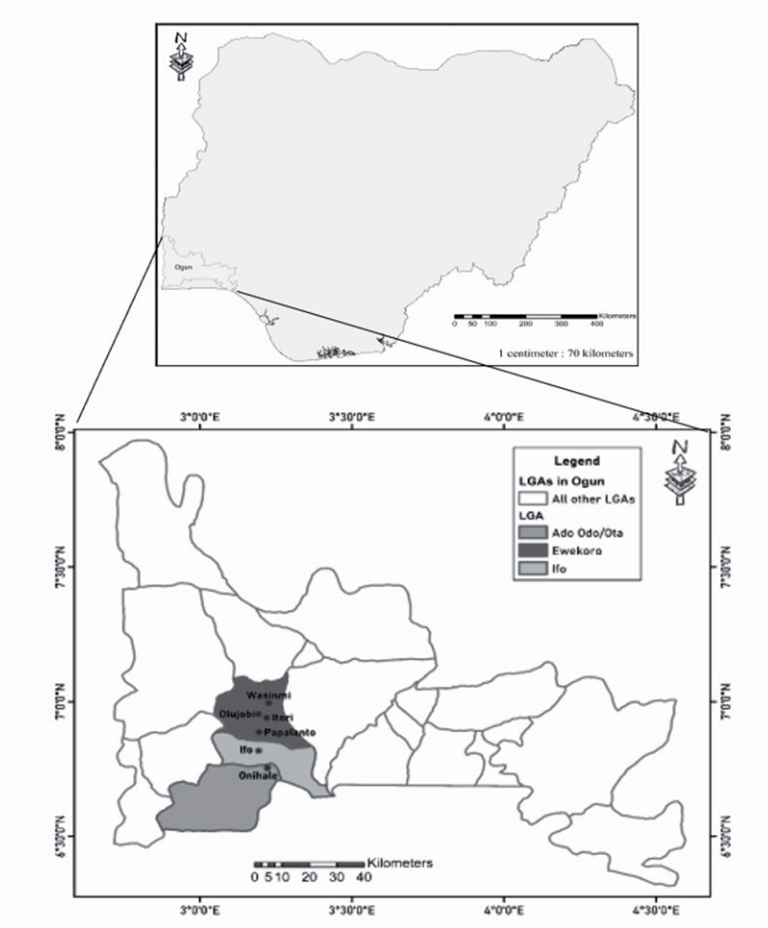

Fig. 1. The sampled locations within Ogun State, Nigeria.

The groundwater sampling protocol [25] for collecting water samples from both hand-dug wells and boreholes was strictly followed.

Sample Analysis for Cadmium

To determine the concentration of cadmium, each of the sixty water samples was analyzed in triplicate using the Agilent 710-axial inductively coupled plasma-optical emission spectrometry (ICP-OES). The mean values of the analyses were adopted for this report. The Agilent 710-axial ICP-OES, which has a limit of detection (LoD) and a limit of quantitation (LoQ) of 0.096 mg/l and 0.292 mg/l, respectively, for cadmium, is a USEPA-approved trace-level elemental analysis technique that uses the emission spectra of a sample to identify

Fig. 2a). Poorly maintained hand-dug wells within the communities.

Fig. 2b). Borehole water storage and point of supply within the communities.

and quantify elements present in the sample through a process that desolvates, ionizes, and stimulates them. Standard calibration solutions of cadmium were prepared for the ICP-OES calibration curves. The solutions were prepared from stock standard reference solutions of the individual metals and metalloids by appropriate dilution with deionized water in a volumetric flask. Cadmium was determined in the prepared sample solutions using ICP-OES. An Agilent SPS-3 Autosampler delivered the sample solutions to the ICP. A 3-second rinse was used to assist with the washout of high concentrations of the elements. The reagent blank was determined against a 5-point calibration curve plotted for the standard metal solutions. Quantitation of the analytes was obtained with Agilent Expert II software, and the test results were validated with calibration curves obtained with certified metal standards.

Data Analysis

Statistical data analysis was performed using the Statistical Package for Social Sciences (SPSS) version 21 and Microsoft Excel. The concentration of heavy metals obtained from the laboratory was analyzed based on standardized applications. The non-carcinogenic and carcinogenic health risks were calculated using Microsoft Excel 2016 and following the equations used for calculating average daily dose (ADD) via ingestion and dermal routes, hazard quotient (HQ), hazard index (HI), and incremental lifetime cancer risk (ILCR). Results obtained for the daily dose via ingestion and dermal routes were presented in tables using scientific values for easy readability.

Geospatial Analysis

The spatial distribution of contaminants in the study area was analyzed using ArcGIS version 10.8.1. The concentration of cadmium from the water sources was grouped into different ranges and used to determine possible locations where the contaminant might be present. A variability map was created, and spatial autocorrelation (Moran's I) on the spatial statistics tool of ArcToolBox was used to determine the cadmium trend using the selected points where contaminant concentrations were detected in the selected communities. Moran's autocorrelation and correlation coefficients' significance were evaluated based on random permutation and a comparison with the pseudo-value.

Health Risk Assessment

Human Health Risk Assessment (HHRA) is a method used to evaluate possible hazards to human health after exposure to microbial agents or certain toxic chemicals. It assesses the probable impact of a biological, chemical, social, or physical agent on a specified human population system under a specific set of conditions and for a certain timeframe [26-28]. According to the US Environmental Protection Agency, continuous intake of cadmium and other toxic heavy metals through drinking water may increase carcinogenic and non-carcinogenic risks to human health [29, 30]. The human health risk assessment model measures the potential health risk of the contaminants investigated using toxicity and exposure determination [23, 26]. HHRA was used in this study to determine the health risk of cadmium concentration in the population in the selected communities. The most common exposure pathways to water are dermal and ingestion routes. The calculations were carried out using Microsoft Excel Version 2016. The four steps involved in risk assessment are:

(i) Hazard identification: a study of the contaminants found in the stated site, determination of their concentration levels through standard procedures, and spatial distribution.
(ii) Assessment/evaluation of exposure: evaluation of the intensity, frequency, and period or duration of human exposure to the contaminants, which is carried out by calculating the Average Daily Dose (ADD) through dermal and ingestion routes by the inhabitants.

(iii) Toxicity/dose-response assessment: evaluation of the toxicity of the contaminant due to exposure intensities. The two major toxicity indices used in this work are the non-carcinogenic threshold, called Reference Dose (RfD), and the carcinogenic potency factor, called the Slope Factor (SF). For cadmium, the reference dose (RfD) for ingestion and dermal routes are 5.00×10^{-4} and 5.00×10^{-6} mg/kg/day, respectively [26, 31].

(iv) Risk characterization: This helps predict the probability of cancer and non-cancerous health risks in the study population by conducting quantitative assessments of cancer risks and hazard indices.

Carcinogenic and non-carcinogenic health risks were evaluated according to USEPA guidelines for the study area population exposed to polluted water through ingestion and dermal routes. The parameters and input assumptions for assessing cadmium exposure through ingestion and dermal routes for the different selected age groups are presented in Table 1 [32, 33].

Both children (as a sensitive group) and adults (as the general population) were taken into consideration due to their physiological and behavioral differences, as well as their access to domestic water supply [18, 34-36]. The age groups selected for this study ranged from 1 - <2 years, 2 - <3 years, 3 - <6 years, 6 - <11 years, 11 - <16 years, 16 - <18 years, 18 - <21 years, 21 - <65 years, and >65 years according to USEPA guidelines [32]. Cadmium concentrations were used to calculate the health risk due to daily consumption of the contaminants. The Average Daily Dose (ADD) via ingestion and dermal absorption routes was calculated using equations 1 and 2 [34, 35].

$$\text{ADD (Ingestion)} = \frac{CW \times IngR \times EF \times ED}{BW \times AT} \quad (1)$$

$$\text{ADD (dermal)} \ \frac{CW \times SA \times KP \times ABS \times ET \times EF \times ED \times CF}{BW \times AT} \quad (2)$$

where ADD (Ingestion & Dermal) = Average Daily Dose for both ingestion and dermal routes (mg/kg/day)
CW = concentration of cadmium in water (in mg/L)
IngR = Ingestion Rate (L/day)
EF = Exposure Frequency (350 days/year)
ED = Exposure Duration (years)
BW = Average Body Weight (Kg)
AT = Average Time (ED x 365 in days)
SA = Skin Area available for contact (in cm^2)
KP = Permeability Coefficient (As & Cd = 0.001 cm/hour)
ABS = skin absorption factor (carcinogenic = 0.01; non-carcinogenic = 0.001)
ET = exposure time (hour/day)
CF = conversion factor (10^{-6} kg/mg)

Non-Carcinogenic Health Risk Assessment

The hazard quotient (HQ), as shown in (Eq. 3), is the ratio of the estimated Average Daily Dose (ADD) to the Reference Dose (RfD). If the HQ is greater than 1, there is a high possibility of adverse non-carcinogenic health effects on the exposed population. However, if HQ is less than 1, there is no probability of adverse health effects. The HQ for ingestion and dermal routes for cadmium was calculated for this study using the formula given by [32]:

$$HQ(ingestion / dermal) = \frac{ADD(ingestion / dermal)}{RfD(ingestion / dermal)} \quad (3)$$

The average daily dose (ADD) and reference dose (RfD) are expressed in mg/kg/day. The sum of all HQs estimates the total potential health risks, or Hazard Index (HI). The HI was established to evaluate human health risks through exposure to more than a single heavy metal. The calculation of the HI is presented in Eq. (4):

$$\text{Hazard Index (HI)} = \sum_{i=1}^{n} HQ(ingestion / dermal) \quad (4)$$

Table 1. Parameters and input assumptions for exposure assessment of cadmium.

Age Groups	Ingestion Rate (L/day)	Body Weight (Kg)	Skin Area (cm^2)	Exposure Duration (years)	Average Time (days)	Exposure Time (hour/day)
1 to <2 years	0.837	11.4	6.10E+3	1	365	0.533
2 to <3 years	0.877	13.8	7.00E+3	1	365	0.750
3 to <6 years	0.959	18.6	9.50E+3	3	1095	1.000
6 to <11 years	1.316	31.8	1.48E+4	5	1825	0.767
11 to <16 years	1.821	56.8	2.06E+4	5	1825	0.717
16 to <18 years	1.783	71.6	2.33E+4	2	730	1.000
18 to <21 years	2.368	71.6	2.33E+4	3	1095	1.000
21 to <65 years	2.958	80.0	2.43E+4	45	16425	0.283
>65 years	2.730	80.0	2.26E+4	65	23725	0.283

Carcinogenic Health Risk Assessment

The carcinogenic health risk is calculated using the Incremental Lifetime Cancer Risk (ILCR), which is the incremental probability of an individual developing any cancer over a lifetime because of twenty-four hours per day exposure to a given daily amount of a carcinogenic element for seventy years [34, 35]. The probable carcinogenic health risk from exposure to a specified dose of cadmium in the water sources was computed using the incremental lifetime cancer risk (ILCR). Equation Eq. 5 was used for the calculation of the lifetime cancer risk following the USEPA guidelines:

$$ILCR = ADD \times SF \tag{5}$$

The Slope Factor (SF) is the cancer slope factor, defined as the risk generated by an average lifetime amount of one mg/kg/day of carcinogenic chemicals. The slope factor for cadmium is 15 mg/kg/day [37]. The permissible limits for a single carcinogenic element and multi-element carcinogen are 10^{-6} and $<10^{-4}$, respectively [38]. Cancer risk greater than 1×10^{-4} is considered high as it poses a higher cancer risk, while values below 1×10^{-6} are considered cancer risk-free to humans [35, 38]. Table 2 shows the classification of the ILCR ranges and the acceptability levels.

Results and Discussion

The concentrations of cadmium from the 60 sampling points are presented in Table 3, along with the description of the source where the respective samples were collected. The results showed that water samples collected from some points had high cadmium concentrations above the Nigerian Industrial Standard's [39] National Standard for Drinking Water Quality (NSDWQ). From Table 3, the concentration of cadmium varied from 0.001 mg/L to 0.530 mg/L. The highest cadmium concentration (0.530 mg/L) was obtained from a hand-dug well in the Wasinmi community. In contrast, the lowest detectable value was obtained from a hand-dug well in the Papalanto community. Cadmium concentrations ranging from 0.001 mg/L to 0.205 mg/L were found in hand-dug wells in the Onihale community. Ifo community boreholes and hand-dug wells had cadmium concentrations ranging from 0.001 mg/L to 0.080 mg/L. The Papalanto community had hand-dug wells and boreholes with a 0.001 mg/L cadmium concentration. The Itori community had two wells and five boreholes with cadmium concentrations between 0.008 mg/L and 0.160 mg/L. Only one borehole in the Olujobi community had a cadmium concentration as high as 0.009 mg/L. Elevated concentrations of cadmium in water samples have been reported in some neighboring Ogun communities [40]. Aladejana and Talabi [41] reported a mean cadmium concentration of 0.005 mg/L in groundwater sources in Abeokuta, Ogun State, but could not detect the source of pollution. Emenike et al. [23] reported the cadmium concentration in River Atuwara, located in Ado-Odo Ota, Ogun State, to be between 0.004 mg/L and 1.01 mg/L, which is high compared to the Nigeria Industrial Standards [39]. They attributed the sources of pollution to agricultural and industrial activities. Adeyemi and Ojekunle [42] also reported high cadmium concentrations in two industrial communities within Ogun State (Ota and Sagamu). The cadmium concentration ranged from 0.007 mg/L in Ota to 0.015 mg/L in Sagamu (another industrial community in Ogun State). These previous studies all indicate that the problem of cadmium in Ogun State is widespread.

A summary of the statistical analysis of the cadmium concentrations is shown in Table 4. The mean cadmium concentration for all the samples ranged between 0.001 and 0.530 mg/L, significantly higher than the Nigeria Industrial Standard's NSDWQ [39] prescribed maximum contaminant limit (MCL) of 0.003 mg/L (Table 4). The Wasinmi community had the highest cadmium concentration of 0.530 mg/L (17,677% higher than the MCL). This concentration was found in a hand-dug well. These extremely high cadmium levels pose a significant public health risk to the users of the well. Onihale community had a maximum concentration of 0.205 mg/L (6,833%). The Itori community had a maximum concentration of 0.160 mg/L (5,333%), while the Ifo community had a maximum concentration

Table 2. Levels of assessment standard [35, 37, 38].

Risk Levels	Intensity	Range of risk value	Acceptability
Level I	Extremely low risk	$< 10^{-6}$	Acceptable
Level II	Low risk	10^{-6} to 10^{-5}	Not eager to care about the probable risk
Level III	Low to medium risk	10^{-5} to 5×10^{-5}	Not be mindful about the risk
Level IV	Medium risk	5×10^{-5} to 10^{-4}	Worry about the probable risk
Level V	Medium to high risk	10^{-4} to 5×10^{-4}	Care about the risk and willing to invest
Level VI	High risk	5×10^{-4} to 10^{-3}	Pay attention and take action to solve it
Level VII	Extremely high risk	$>10^{-3}$	Must solve it

Table 3. Cadmium (Cd) concentrations of analyzed water samples from sources in selected communities.

S/N	Community	Longitude	Latitude	Water Source	Cd (mg/L)
Onihale					
1		3°12’55”E	6°45’56”N	Hand-dug well	0.018
2		3°12’55”E	6°45’55”N	Hand-dug well	0.205
3		3°12’56”E	6°45’60”N	Hand-dug well	0.085
4		3°12’52”E	6°46’1”N	Hand-dug well	<0.001
5		3°12’52”E	6°45’5”N	Hand-dug well	<0.001
6		3°12’53”E	6°45’5”N	Hand-dug well	0.008
7		3°12’3”E	6°45’58”N	Hand-dug well	<0.001
8		3°13’3”E	6°46’2”N	Mechanized well	<0.001
9		3°13’5”E	6°46’2”N	Mechanized well	<0.001
10		3°13’52”E	6°45’49”N	Mechanized well	<0.001
Ifo					
11		3°12’3”E	6°48’16”N	Borehole	0.077
12		3°12’6”E	6°48’14”N	Hand-dug well	<0.001
13		3°12’6”E	6°48’12”N	Hand-dug well	<0.001
14		3°11’59”E	6°48’7”N	Hand-dug well	<0.001
15		3°12’0”E	6°48’15”N	Borehole	<0.001
16		3°11’57”E	6°48’17”N	Borehole	<0.001
17		3°11’59”E	6°48’18”N	Borehole	<0.001
18		3°11’59”E	6°49’18”N	Hand-dug well	0.080
19		3°11’44”E	6°49’23”N	Hand-dug well	<0.001
20		3°11’44”E	6°49’22”N	Hand-dug well	<0.001
Papalanto					
21		3°11’30”E	6°52’59”N	Hand-dug well	<0.001
22		3°11’28”E	6°51’18”N	Hand-dug well	<0.001
23		3°11’27”E	6°52’59”N	Hand-dug well	<0.001
24		3°11’26”E	6°52’59”N	Pipe-borne water	<0.001
25		3°11’25”E	6°52’57”N	Hand-dug well	0.001
26		3°11’26”E	6°52’56”N	Hand-dug well	<0.001
27		3°12’11”E	6°51’50”N	Hand-dug well	<0.001
28		3°11’22”E	6°52’54”N	Hand-dug well	<0.001
29		3°11’19”E	6°52’58”N	Hand-dug well	<0.001
30		3°11’17”E	6°52’57”N	Hand-dug well	<0.001
Itori					
31		3°12’54”E	6°55’44”N	Mechanized well	0.070
32		3°12’51”E	6°55’45”N	Borehole	0.099
33		3°12’49”E	6°55’44”N	Borehole	0.086
34		3°12’48”E	6°55’46”N	Borehole	0.008
35		3°12’47”E	6°55’50”N	Hand-dug well	<0.001
36		3°12’45”E	6°55’51”N	Hand-dug well	0.068

37		3°12’45”E	6°55’50”N	Borehole	<0.001
38		3°12’42”E	6°55’56”N	Hand-dug well	<0.001
39		3°12’4”E	6°55’53”N	Borehole	0.040
40		3°12’40”E	6°55’50”N	Borehole	0.160
Wasinmi					
41		3°13’34”E	6°59’20”N	Hand-dug well	<0.001
42		3°13’39”E	6°59’19”N	Hand-dug well	<0.001
43		3°13’35”E	6°59’17”N	Hand-dug well	<0.001
44		3°13’38”E	6°59’15”N	Hand-dug well	<0.001
45		3°13’38”E	6°59’16”N	Hand-dug well	0.530
46		3°13’55”E	6°59’15”N	Hand-dug well	<0.001
47		3°13’50”E	6°59’12”N	Borehole	<0.001
48		3°13’49”E	6°59’6”N	Borehole	<0.001
49		3°13’42”E	6°59’13”N	Borehole	<0.001
50		3°13’42”E	6°59’10”N	Borehole	<0.001
Olujobi					
51		3°11’32”E	6°57’5”N	Borehole	<0.001
52		3°11’31”E	6°57’4”N	Borehole	<0.001
53		3°11’29”E	6°57’5”N	Hand-dug well	<0.001
54		3°11’25”E	6°57’8”N	Hand-dug well	<0.001
55		3°11’25”E	6°57’7”N	Borehole	<0.001
56		3°11’24”E	6°57’6”N	Borehole	0.009
57		3°11’24”E	6°57’5”N	Hand-dug well	<0.001
58		3°11’21”E	6°57’5”N	Hand-dug well	<0.001
59		3°11’29”E	6°57’10”N	Hand-dug well	<0.001
60		3°11’31”E	6°57’10”N	Borehole	<0.001
Maximum Contaminant Limit by Nigeria Industrial Standard (2015)					0.003

of 0.080 mg/L (2,667%). The Olujobi community had a maximum concentration of 0.009 mg/L, three times higher than the MCL. The Papalanto community had a maximum cadmium concentration of 0.001 mg/L, below the standard, and was the only community with low cadmium concentrations below the MCL at all sampling points. All six communities also had safe wells (concerning cadmium) with concentrations of less than 0.003 mg/L.

Geospatial Distribution of Cadmium

The interpolated spatial distribution of cadmium concentration in the study area was determined using ArcGIS (Fig. 3). The spatial distribution showed that the cadmium concentration in the six communities exceeded the Nigeria Industrial Standard [39], even at the lowest range. The Ifo community showed high cadmium concentration in the northern part of the community. The south and parts of the east showed a safe cadmium concentration range. Onihale community had high cadmium distribution from the north-central down to the southern part of the community. The west and northeast of the Onihale community showed safe cadmium distribution compared to other parts. The Papalanto community showed low cadmium distribution towards the western part of the community and parts of the north. The central, southern, and eastern parts of Papalanto showed high cadmium distribution. The southern and central parts of the Itori community showed high cadmium distribution compared to other parts of the map. The cadmium distribution in the Itori community was relatively high in all areas compared to the Nigeria Industrial Standard [39]. The southwestern part of the Olujobi community had high cadmium distribution compared to other parts of the community.

Table 4. Summary of cadmium concentrations in water samples from the study areas.

Communities	N Total	STD	Min (mg/l)	Max (mg/l)	Mean (mg/l)	Lower 95% CI of the mean	Upper 95% CI of the mean	Skewness	Kurtosis	Coeff of variation	Geo SD
Onihale	10	0.0661	0.001	0.205	0.0322	-0.0152	0.0794	2.4589	6.0284	2.0606	8.9100
Ifo	10	0.0328	0.001	0.080	0.0165	-0.0073	0.0397	1.7808	1.4205	2.0240	7.6227
Papalanto	10	0.0002	0.001	0.001	0.001	-0.0007	0.0009	-0.4444	-1.1871	0.1998	1.2367
Itori	10	0.0533	0.001	0.160	0.0534	0.0152	0.0914	0.7534	0.0554	0.9991	9.4438
Wasinmi	10	0.1673	0.001	0.530	0.0539	-0.066	0.1735	3.1623	9.9999	3.1128	7.7569
Olujobi	10	0.0026	0.001	0.009	0.0018	-0.0003	0.0035	3.1497	9.9416	1.6468	2.231

In the Wasinmi community, the northwestern region of the map had a higher cadmium distribution ranging from 0.04 mg/L to 0.53 mg/L. The southern and eastern parts of Wasinmi had low cadmium distributions compared to the rest of the community. There are no safe zones in the Wasinmi, Itori, and Onihale communities.

Sources of cadmium pollution can be geogenic through dredging and mining activities or anthropogenic from industrial effluents and agricultural activities like herbicides and pesticide applications [43]. Some of the anthropogenic activities that directly involve cadmium and carry a higher risk of exposure include battery manufacture, welding or soldering, smelting, mining, textile work, cadmium alloy manufacture, manufacture of materials that contain cadmium, such as certain paints and plastics, jewelry making, glassware decorated

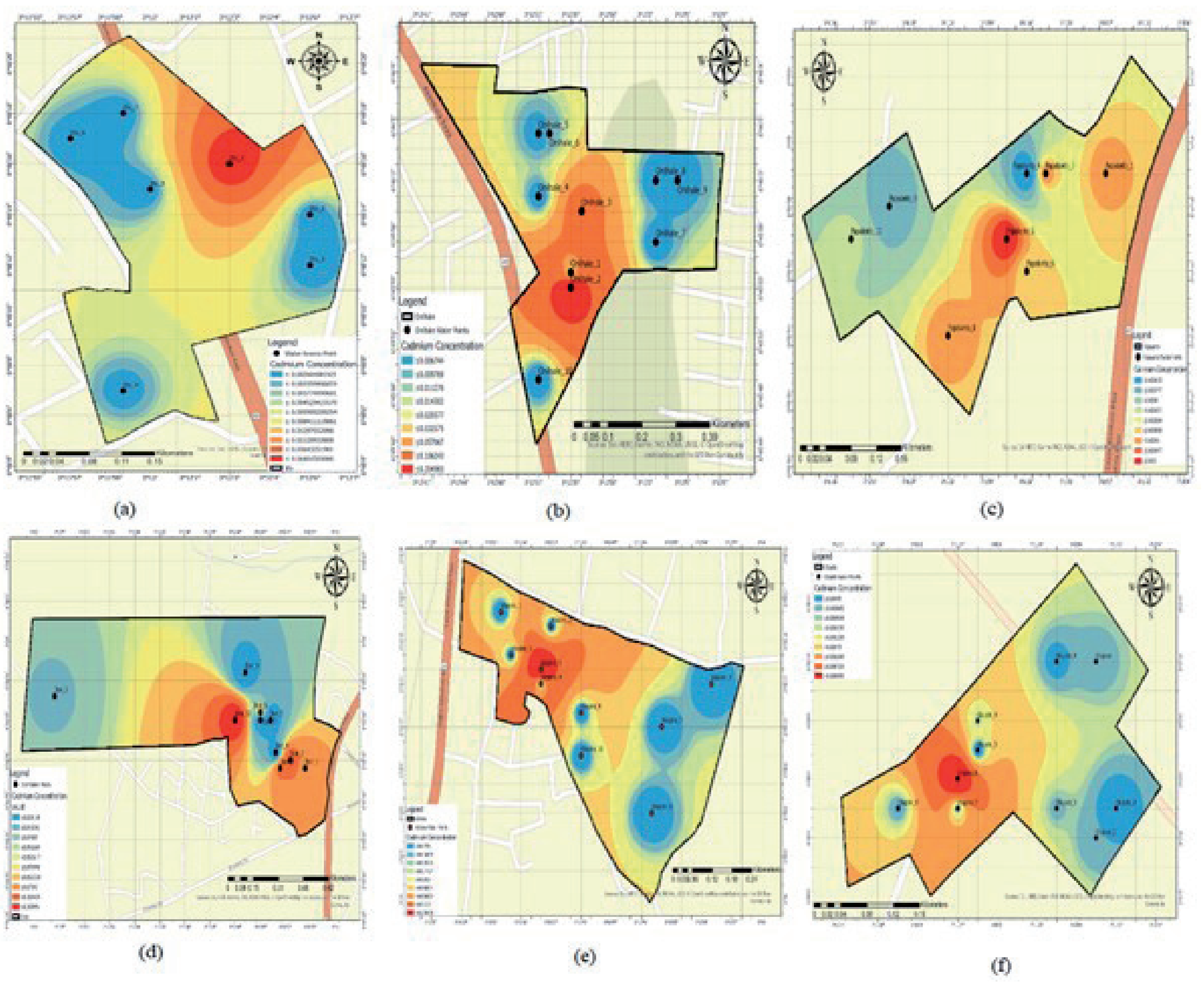

Fig. 3. Distribution of Cadmium in the study areas a) Ifo community, b) Onihale community, c) Papalanto, d) Itori, e) Wasimi, f) Olujobi.

with cadmium, and municipal solid waste disposal [44]. Several studies have been carried out detailing the effects of continuous exposure to cadmium-polluted water. Health complications such as cardiovascular diseases, cancer, osteoporosis, and kidney diseases can be a result of human exposure to cadmium pollution. In turn, laboratory studies demonstrated that cadmium adversely affects adipose tissue physiopathology through several mechanisms, thus contributing to increased insulin resistance and enhancing diabetes [44].

Human Health Risk Assessment

The health risks of cadmium exposure via ingestion and dermal pathways were assessed by calculating the Average Daily Dose (ADD) of water via ingestion and dermal routes using standard parameters and age groups of the population. The non-carcinogenic health risk was assessed by calculating the hazard quotient (HQ) and hazard index (HI). The carcinogenic health risk was assessed by calculating the incremental lifetime cancer risk (ILCR) for the selected age groups in the six communities.

Average Daily Dose (ADD) via Ingestion Route in mg/kg/day

The average daily dose through the ingestion route for cadmium in the different communities and age categories is shown in Table 5. In the Onihale community, the average daily dose values were exceptionally high at points 2 and 3 for all nine age groups compared to the other eight points. The calculated ADD for children within the age groups of 1 to <2 years, 2 to <3 years, and 3 to <6 years is relatively high compared to other age groups. The highest ADD value at Onihale was obtained from point 2 for children aged 1 to <2 years. The ADD values at points 1 and 8 in the Ifo community were high when compared to other points in the community for all nine age groups, especially for children within the age groups of 1 to <2 years and 2 to <3 years. In the Papalanto community, the values for all nine age groups were low, ranging from 1.62E-05 to 3.17E-05 in adults and 1.66E-05 to 7.04E-05 in children. The highest ADD value in the Itori community was found in children within the age group of 1 to <2 years, which was 1.13E-02. The ADD values

Table 5. Average daily dose (ADD) via ingestion of cadmium in different communities and age categories.

S/N	Community	Age Groups								
		1 to <2 years	2 to <3 years	3 to <6 years	6 to <11 years	11 to <16 years	16 to <18 years	18 to <21 years	21 to <65 years	>65 years
1	Onihale	1.27E-03	1.10E-03	8.90E-04	7.58E-04	5.53E-04	4.30E-04	5.71E-04	6.38E-04	5.89E-04
2	Onihale	1.44E-02	1.25E-02	1.01E-02	8.63E-03	6.30E-03	4.90E-03	6.50E-03	7.27E-03	6.71E-03
3	Onihale	5.98E-03	5.18E-03	4.20E-03	3.58E-03	2.61E-03	2.03E-03	2.69E-03	3.01E-03	2.78E-03
4	Onihale	6.55E-05	5.67E-05	4.60E-05	3.91E-05	2.86E-05	2.22E-05	2.95E-05	3.30E-05	3.04E-05
5	Onihale	5.63E-05	4.88E-05	3.96E-05	3.37E-05	2.46E-05	1.91E-05	2.54E-05	2.84E-05	2.62E-05
6	Onihale	5.63E-04	4.88E-04	3.96E-04	3.37E-04	2.46E-04	1.91E-04	2.54E-04	2.84E-04	2.62E-04
7	Onihale	4.58E-05	3.96E-05	3.21E-05	2.74E-05	2.00E-05	1.55E-05	2.06E-05	2.30E-05	2.13E-05
8	Onihale	4.93E-05	4.27E-05	3.46E-05	2.95E-05	2.15E-05	1.67E-05	2.22E-05	2.48E-05	2.29E-05
9	Onihale	6.20E-05	5.36E-05	4.35E-05	3.70E-05	2.71E-05	2.10E-05	2.79E-05	3.12E-05	2.88E-05
10	Onihale	6.48E-05	5.61E-05	4.55E-05	3.87E-05	2.83E-05	2.20E-05	2.92E-05	3.26E-05	3.01E-05
1	Ifo	5.42E-03	4.69E-03	3.81E-03	3.24E-03	2.37E-03	1.84E-03	2.44E-03	2.73E-03	2.52E-03
2	Ifo	4.37E-05	3.78E-05	3.07E-05	2.61E-05	1.91E-05	1.48E-05	1.97E-05	2.20E-05	2.03E-05
3	Ifo	3.87E-05	3.35E-05	2.72E-05	2.32E-05	1.69E-05	1.31E-05	1.74E-05	1.95E-05	1.80E-05
4	Ifo	5.70E-05	4.94E-05	4.00E-05	3.41E-05	2.49E-05	1.93E-05	2.57E-05	2.87E-05	2.65E-05
5	Ifo	4.58E-05	3.96E-05	3.21E-05	2.74E-05	2.00E-05	1.55E-05	2.06E-05	2.30E-05	2.13E-05
6	Ifo	5.56E-05	4.81E-05	3.91E-05	3.33E-05	2.43E-05	1.89E-05	2.50E-05	2.80E-05	2.59E-05
7	Ifo	3.52E-05	3.05E-05	2.47E-05	2.10E-05	1.54E-05	1.19E-05	1.59E-05	1.77E-05	1.64E-05
8	Ifo	5.63E-03	4.88E-03	3.96E-03	3.37E-03	2.46E-03	1.91E-03	2.54E-03	2.84E-03	2.62E-03
9	Ifo	4.15E-05	3.60E-05	2.92E-05	2.48E-05	1.81E-05	1.41E-05	1.87E-05	2.09E-05	1.93E-05

10	Ifo	4.93E-05	4.27E-05	3.46E-05	2.95E-05	2.15E-05	1.67E-05	2.22E-05	2.48E-05	2.29E-05
1	Papalanto	6.34E-05	5.48E-05	4.45E-05	3.79E-05	2.77E-05	2.15E-05	2.85E-05	3.19E-05	2.95E-05
2	Papalanto	4.79E-05	4.14E-05	3.36E-05	2.86E-05	2.09E-05	1.62E-05	2.16E-05	2.41E-05	2.23E-05
3	Papalanto	6.41E-05	5.55E-05	4.50E-05	3.83E-05	2.80E-05	2.17E-05	2.89E-05	3.23E-05	2.98E-05
4	Papalanto	4.01E-05	3.47E-05	2.82E-05	2.40E-05	1.75E-05	1.36E-05	1.81E-05	2.02E-05	1.87E-05
5	Papalanto	7.04E-05	6.09E-05	4.94E-05	4.21E-05	3.07E-05	2.39E-05	3.17E-05	3.55E-05	3.27E-05
6	Papalanto	6.13E-05	5.30E-05	4.30E-05	3.66E-05	2.67E-05	2.08E-05	2.76E-05	3.08E-05	2.85E-05
7	Papalanto	3.80E-05	3.29E-05	2.67E-05	2.27E-05	1.66E-05	1.29E-05	1.71E-05	1.91E-05	1.77E-05
8	Papalanto	6.34E-05	5.48E-05	4.45E-05	3.79E-05	2.77E-05	2.15E-05	2.85E-05	3.19E-05	2.95E-05
9	Papalanto	4.86E-05	4.20E-05	3.41E-05	2.90E-05	2.12E-05	1.65E-05	2.19E-05	2.45E-05	2.26E-05
10	Papalanto	5.70E-05	4.94E-05	4.00E-05	3.41E-05	2.49E-05	1.93E-05	2.57E-05	2.87E-05	2.65E-05
1	Itori	4.93E-03	4.27E-03	3.46E-03	2.95E-03	2.15E-03	1.67E-03	2.22E-03	2.48E-03	2.29E-03
2	Itori	6.97E-03	6.03E-03	4.89E-03	4.17E-03	3.04E-03	2.36E-03	3.14E-03	3.51E-03	3.24E-03
3	Itori	6.05E-03	5.24E-03	4.25E-03	3.62E-03	2.64E-03	2.05E-03	2.73E-03	3.05E-03	2.81E-03
4	Itori	5.63E-04	4.88E-04	3.96E-04	3.37E-04	2.46E-04	1.91E-04	2.54E-04	2.84E-04	2.62E-04
5	Itori	4.08E-05	3.53E-05	2.87E-05	2.44E-05	1.78E-05	1.38E-05	1.84E-05	2.06E-05	1.90E-05
6	Itori	4.79E-03	4.14E-03	3.36E-03	2.86E-03	2.09E-03	1.62E-03	2.16E-03	2.41E-03	2.23E-03
7	Itori	5.56E-05	4.81E-05	3.91E-05	3.33E-05	2.43E-05	1.89E-05	2.50E-05	2.80E-05	2.59E-05
8	Itori	6.34E-05	5.48E-05	4.45E-05	3.79E-05	2.77E-05	2.15E-05	2.85E-05	3.19E-05	2.95E-05
9	Itori	2.82E-03	2.44E-03	1.98E-03	1.68E-03	1.23E-03	9.55E-04	1.27E-03	1.42E-03	1.31E-03
10	Itori	1.13E-02	9.75E-03	7.91E-03	6.74E-03	4.92E-03	3.82E-03	5.07E-03	5.67E-03	5.24E-03
1	Wasinmi	5.63E-05	4.88E-05	3.96E-05	3.37E-05	2.46E-05	1.91E-05	2.54E-05	2.84E-05	2.62E-05
2	Wasinmi	4.01E-05	3.47E-05	2.82E-05	2.40E-05	1.75E-05	1.36E-05	1.81E-05	2.02E-05	1.87E-05
3	Wasinmi	6.90E-05	5.97E-05	4.85E-05	4.13E-05	3.01E-05	2.34E-05	3.11E-05	3.47E-05	3.21E-05
4	Wasinmi	5.42E-05	4.69E-05	3.81E-05	3.24E-05	2.37E-05	1.84E-05	2.44E-05	2.73E-05	2.52E-05
5	Wasinmi	3.73E-02	3.23E-02	2.62E-02	2.23E-02	1.63E-02	1.27E-02	1.68E-02	1.88E-02	1.73E-02
6	Wasinmi	6.97E-05	6.03E-05	4.89E-05	4.17E-05	3.04E-05	2.36E-05	3.14E-05	3.51E-05	3.24E-05
7	Wasinmi	5.77E-05	5.00E-05	4.05E-05	3.45E-05	2.52E-05	1.96E-05	2.60E-05	2.91E-05	2.68E-05
8	Wasinmi	6.41E-05	5.55E-05	4.50E-05	3.83E-05	2.80E-05	2.17E-05	2.89E-05	3.23E-05	2.98E-05
9	Wasinmi	5.56E-05	4.81E-05	3.91E-05	3.33E-05	2.43E-05	1.89E-05	2.50E-05	2.80E-05	2.59E-05
10	Wasinmi	6.62E-05	5.73E-05	4.65E-05	3.96E-05	2.89E-05	2.24E-05	2.98E-05	3.33E-05	3.08E-05
1	Olujobi	4.22E-05	3.66E-05	2.97E-05	2.53E-05	1.84E-05	1.43E-05	1.90E-05	2.13E-05	1.96E-05
2	Olujobi	5.49E-05	4.75E-05	3.86E-05	3.28E-05	2.40E-05	1.86E-05	2.47E-05	2.77E-05	2.55E-05
3	Olujobi	5.98E-05	5.18E-05	4.20E-05	3.58E-05	2.61E-05	2.03E-05	2.69E-05	3.01E-05	2.78E-05
4	Olujobi	6.90E-05	5.97E-05	4.85E-05	4.13E-05	3.01E-05	2.34E-05	3.11E-05	3.47E-05	3.21E-05
5	Olujobi	3.94E-05	3.41E-05	2.77E-05	2.36E-05	1.72E-05	1.34E-05	1.78E-05	1.99E-05	1.83E-05
6	Olujobi	6.34E-04	5.48E-04	4.45E-04	3.79E-04	2.77E-04	2.15E-04	2.85E-04	3.19E-04	2.95E-04
7	Olujobi	5.70E-05	4.94E-05	4.00E-05	3.41E-05	2.49E-05	1.93E-05	2.57E-05	2.87E-05	2.65E-05
8	Olujobi	5.35E-05	4.63E-05	3.76E-05	3.20E-05	2.34E-05	1.81E-05	2.41E-05	2.69E-05	2.49E-05
9	Olujobi	4.93E-05	4.27E-05	3.46E-05	2.95E-05	2.15E-05	1.67E-05	2.22E-05	2.48E-05	2.29E-05
10	Olujobi	5.63E-05	4.88E-05	3.96E-05	3.37E-05	2.46E-05	1.91E-05	2.54E-05	2.84E-05	2.62E-05

were high for all nine age groups in the Itori community in six of the ten points. Children within the age groups of 1 to <2 years, 2 to <3 years, and 3 to <6 years had higher ADD values compared to other age groups.

In the Wasinmi community, nine out of ten points showed low ADD values for all age groups, ranging from 1.36E-05 to 6.97E-05. Only point 5 in the Wasinmi community had high ADD values for all the nine age groups. Children within the age groups of 1 to <2 years and 2 to <3 years had the highest ADD values at point five. In the Olujobi community, the ADD values were low for all age groups except for point six, which had values ranging from 2.15E-04 for those within the age group of 16 to <18 years to 6.34E-04 for children within the age group 1 to <2 years. Generally, the average daily dose values via ingestion were higher for younger than older age groups.

Average Daily Dose (ADD) via Dermal Route in mg/kg/day

Table 6 shows cadmium's average daily dose via the dermal route in the different communities. The ADD (dermal) values obtained for all six communities were significantly lower than the ADD (ingestion) values. The Onihale community had ADD values ranging from 1.00E-10 for children between the ages of 3 to <6 years to 7.58E-14 for adults between the ages of 21 to <65 years. In the Ifo community, points one and eight had higher ADD values than other points in the community, especially for children under 3 to <6 years. Papalanto community had ADD values as low as 7.67E-14 for adults in the age group of >65 years and 1.42E-13 for children between the ages of 11 and <16 years. The ADD values for the Itori community were generally higher than those of the other five communities. The values obtained for the average daily dosevia the dermal route for all six communities were low for all nine selected age groups, which meansthat the impact of using water from contaminated sources for domestic activities like bathing,washing hands, swimming, and washing is relatively low compared to when the water is ingested.

Hazard Quotient (HQ) and Hazard Index (HI) via Ingestion Route

The non-carcinogenic health risk assessment of respondents for cadmium via ingestion is shown

Table 6. Average daily dose (ADD) via dermal for cadmium in the different communities.

S/N	Community	Age Groups								
		1 to <2 years	2 to <3 years	3 to <6 years	6 to <11 years	11 to <16 years	16 to <18 years	18 to <21 years	21 to <65 years	>65 years
1	Onihale	4.92E-12	6.57E-12	8.82E-12	6.16E-12	4.49E-12	5.62E-12	5.62E-12	1.48E-12	1.38E-12
2	Onihale	5.61E-11	7.48E-11	1.00E-10	7.02E-11	5.11E-11	6.40E-11	6.40E-11	1.69E-11	1.57E-11
3	Onihale	2.32E-11	3.10E-11	4.16E-11	2.91E-11	2.12E-11	2.65E-11	2.65E-11	7.01E-12	6.52E-12
4	Onihale	2.54E-13	3.39E-13	4.55E-13	3.18E-13	2.32E-13	2.90E-13	2.90E-13	7.67E-14	7.13E-14
5	Onihale	2.19E-13	2.92E-13	3.92E-13	2.74E-13	1.99E-13	2.50E-13	2.50E-13	6.59E-14	6.13E-14
6	Onihale	2.19E-12	2.92E-12	3.92E-12	2.74E-12	1.99E-12	2.50E-12	2.50E-12	6.59E-13	6.13E-13
7	Onihale	1.78E-13	2.37E-13	3.18E-13	2.22E-13	1.62E-13	2.03E-13	2.03E-13	5.36E-14	4.98E-14
8	Onihale	1.91E-13	2.55E-13	3.43E-13	2.40E-13	1.75E-13	2.18E-13	2.18E-13	5.77E-14	5.37E-14
9	Onihale	2.41E-13	3.21E-13	4.31E-13	3.01E-13	2.19E-13	2.75E-13	2.75E-13	7.25E-14	6.75E-14
10	Onihale	2.52E-13	3.36E-13	4.51E-13	3.15E-13	2.29E-13	2.87E-13	2.87E-13	7.58E-14	7.05E-14
1	Ifo	2.11E-11	2.81E-11	3.77E-11	2.64E-11	1.92E-11	2.40E-11	2.40E-11	6.35E-12	5.90E-12
2	Ifo	1.70E-13	2.26E-13	3.04E-13	2.12E-13	1.55E-13	1.93E-13	1.93E-13	5.11E-14	4.75E-14
3	Ifo	1.50E-13	2.01E-13	2.69E-13	1.88E-13	1.37E-13	1.72E-13	1.72E-13	4.53E-14	4.22E-14
4	Ifo	2.22E-13	2.95E-13	3.97E-13	2.77E-13	2.02E-13	2.53E-13	2.53E-13	6.68E-14	6.21E-14
5	Ifo	1.78E-13	2.37E-13	3.18E-13	2.22E-13	1.62E-13	2.03E-13	2.03E-13	5.36E-14	4.98E-14
6	Ifo	2.16E-13	2.88E-13	3.87E-13	2.70E-13	1.97E-13	2.47E-13	2.46E-13	6.51E-14	6.06E-14
7	Ifo	1.37E-13	1.82E-13	2.45E-13	1.71E-13	1.25E-13	1.56E-13	1.56E-13	4.12E-14	3.83E-14
8	Ifo	2.19E-11	2.92E-11	3.92E-11	2.74E-11	1.99E-11	2.50E-11	2.50E-11	6.59E-12	6.13E-12
9	Ifo	1.61E-13	2.15E-13	2.89E-13	2.02E-13	1.47E-13	1.84E-13	1.84E-13	4.86E-14	4.52E-14

10	Ifo	1.91E-13	2.55E-13	3.43E-13	2.40E-13	1.75E-13	2.18E-13	2.18E-13	5.77E-14	5.37E-14
1	Papalanto	2.46E-13	3.28E-13	4.41E-13	3.08E-13	2.24E-13	2.81E-13	2.81E-13	7.42E-14	6.90E-14
2	Papalanto	1.86E-13	2.48E-13	3.33E-13	2.33E-13	1.70E-13	2.12E-13	2.12E-13	5.61E-14	5.21E-14
3	Papalanto	2.49E-13	3.32E-13	4.46E-13	3.11E-13	2.27E-13	2.84E-13	2.84E-13	7.50E-14	6.98E-14
4	Papalanto	1.56E-13	2.08E-13	2.79E-13	1.95E-13	1.42E-13	1.78E-13	1.78E-13	4.70E-14	4.37E-14
5	Papalanto	2.73E-13	3.65E-13	4.90E-13	3.42E-13	2.49E-13	3.12E-13	3.12E-13	8.24E-14	7.67E-14
6	Papalanto	2.38E-13	3.17E-13	4.26E-13	2.98E-13	2.17E-13	2.71E-13	2.71E-13	7.17E-14	6.67E-14
7	Papalanto	1.48E-13	1.97E-13	2.64E-13	1.85E-13	1.35E-13	1.69E-13	1.68E-13	4.45E-14	4.14E-14
8	Papalanto	2.46E-13	3.28E-13	4.41E-13	3.08E-13	2.24E-13	2.81E-13	2.81E-13	7.42E-14	6.90E-14
9	Papalanto	1.89E-13	2.52E-13	3.38E-13	2.36E-13	1.72E-13	2.15E-13	2.15E-13	5.69E-14	5.29E-14
10	Papalanto	2.22E-13	2.95E-13	3.97E-13	2.77E-13	2.02E-13	2.53E-13	2.53E-13	6.68E-14	6.21E-14
1	Itori	1.91E-11	2.55E-11	3.43E-11	2.40E-11	1.75E-11	2.18E-11	2.18E-11	5.77E-12	5.37E-12
2	Itori	2.71E-11	3.61E-11	4.85E-11	3.39E-11	2.47E-11	3.09E-11	3.09E-11	8.16E-12	7.59E-12
3	Itori	2.35E-11	3.14E-11	4.21E-11	2.94E-11	2.14E-11	2.68E-11	2.68E-11	7.09E-12	6.59E-12
4	Itori	2.19E-12	2.92E-12	3.92E-12	2.74E-12	1.99E-12	2.50E-12	2.50E-12	6.59E-13	6.13E-13
5	Itori	1.59E-13	2.12E-13	2.84E-13	1.99E-13	1.45E-13	1.81E-13	1.81E-13	4.78E-14	4.45E-14
6	Itori	1.86E-11	2.48E-11	3.33E-11	2.33E-11	1.70E-11	2.12E-11	2.12E-11	5.61E-12	5.21E-12
7	Itori	2.16E-13	2.88E-13	3.87E-13	2.70E-13	1.97E-13	2.47E-13	2.46E-13	6.51E-14	6.06E-14
8	Itori	2.46E-13	3.28E-13	4.41E-13	3.08E-13	2.24E-13	2.81E-13	2.81E-13	7.42E-14	6.90E-14
9	Itori	1.09E-11	1.46E-11	1.96E-11	1.37E-11	9.97E-12	1.25E-11	1.25E-11	3.30E-12	3.07E-12
10	Itori	4.38E-11	5.84E-11	7.84E-11	5.48E-11	3.99E-11	4.99E-11	4.99E-11	1.32E-11	1.23E-11
1	Wasinmi	2.19E-13	2.92E-13	3.92E-13	2.74E-13	1.99E-13	2.50E-13	2.50E-13	6.59E-14	6.13E-14
2	Wasinmi	1.56E-13	2.08E-13	2.79E-13	1.95E-13	1.42E-13	1.78E-13	1.78E-13	4.70E-14	4.37E-14
3	Wasinmi	2.68E-13	3.58E-13	4.80E-13	3.35E-13	2.44E-13	3.06E-13	3.06E-13	8.08E-14	7.51E-14
4	Wasinmi	2.11E-13	2.81E-13	3.77E-13	2.64E-13	1.92E-13	2.40E-13	2.40E-13	6.35E-14	5.90E-14
5	Wasinmi	1.45E-10	1.93E-10	2.60E-10	1.81E-10	1.32E-10	1.65E-10	1.65E-10	4.37E-11	4.06E-11
6	Wasinmi	2.71E-13	3.61E-13	4.85E-13	3.39E-13	2.47E-13	3.09E-13	3.09E-13	8.16E-14	7.59E-14
7	Wasinmi	2.24E-13	2.99E-13	4.02E-13	2.81E-13	2.04E-13	2.56E-13	2.56E-13	6.76E-14	6.29E-14
8	Wasinmi	2.49E-13	3.32E-13	4.46E-13	3.11E-13	2.27E-13	2.84E-13	2.84E-13	7.50E-14	6.98E-14
9	Wasinmi	2.16E-13	2.88E-13	3.87E-13	2.70E-13	1.97E-13	2.47E-13	2.46E-13	6.51E-14	6.06E-14
10	Wasinmi	2.57E-13	3.43E-13	4.60E-13	3.22E-13	2.34E-13	2.93E-13	2.93E-13	7.75E-14	7.21E-14
1	Olujobi	1.64E-13	2.19E-13	2.94E-13	2.05E-13	1.50E-13	1.87E-13	1.87E-13	4.95E-14	4.60E-14
2	Olujobi	2.13E-13	2.85E-13	3.82E-13	2.67E-13	1.94E-13	2.43E-13	2.43E-13	6.43E-14	5.98E-14
3	Olujobi	2.32E-13	3.10E-13	4.16E-13	2.91E-13	2.12E-13	2.65E-13	2.65E-13	7.01E-14	6.52E-14
4	Olujobi	2.68E-13	3.58E-13	4.80E-13	3.35E-13	2.44E-13	3.06E-13	3.06E-13	8.08E-14	7.51E-14
5	Olujobi	1.53E-13	2.04E-13	2.74E-13	1.92E-13	1.40E-13	1.75E-13	1.75E-13	4.62E-14	4.29E-14
6	Olujobi	2.46E-12	3.28E-12	4.41E-12	3.08E-12	2.24E-12	2.81E-12	2.81E-12	7.42E-13	6.90E-13
7	Olujobi	2.22E-13	2.95E-13	3.97E-13	2.77E-13	2.02E-13	2.53E-13	2.53E-13	6.68E-14	6.21E-14
8	Olujobi	2.08E-13	2.77E-13	3.72E-13	2.60E-13	1.90E-13	2.37E-13	2.37E-13	6.26E-14	5.83E-14
9	Olujobi	1.91E-13	2.55E-13	3.43E-13	2.40E-13	1.75E-13	2.18E-13	2.18E-13	5.77E-14	5.37E-14
10	Olujobi	2.19E-13	2.92E-13	3.92E-13	2.74E-13	1.99E-13	2.50E-13	2.50E-13	6.59E-14	6.13E-14

in Table 7. Most of the communities assessed were exposed to adverse health risks as the calculated health quotient was greater than 1. Children between the ages of 1 to <2 years, 2 to <3 years, and 3 to <6 years were more exposed, followed by the older age groups, especially at Onihale. The HQ values at Onihale ranged between 0.0915 and 28.9 for children between 1 and <2 years old. Points 1, 2, 3, and 6 had HQs greater than one for all nine age groups compared to other points. The highest HQ values in the Onihale community were recorded at Point 2. The HQs calculated for all the nine age groups in the Ifo community were greater than one at points 1 and 8. The highest HQ value in the Ifo community was calculated as 11.3 at point 8 for children between the ages of 1 to <2 years, followed by 10.8 at point 1 for the same age group, which means children are at higher risks of non-carcinogenic health effects of cadmium poisoning.

The calculated HQ values at the Papalanto community were less than 1 for all nine age groups. Therefore, there is no associated adverse health risk for residents in the community. Only point 6 in the Olujobi community had HQ values greater than one for all nine age groups; the rest of the age groups showed HQ via ingestion to be less than one, which is safe. All age groups assessed in the Wasinmi community showed HQ greater than one for point 5, while the other values were less than one for all age groups at other points. The highest HQ value calculated at Wasinmi was 74.6 for children between the ages of 1 to <2 years, followed by 64.6 for children aged 2 to <3 years. The Hazard Index (HI), which is the sum of the HQs across all age groups, was calculated. Only sixteen out of the sixty points had HI values greater than one. Generally, children are at higher risk of adverse non-carcinogenic health effects compared to adults. Non-carcinogenic health effects such as shortness of breath, asthma, respiratory disorders, tubular dysfunction, lung inefficiency, and glucose metabolism disorder can occur in children, especially those between 6 months and less than 11 years of age. Cadmium exposure in adults can result in a gradual loss of taste and smell, kidney dysfunction, tubular proteinuria, glomeruli, Itai-Itai disease, bone degeneration, renal dysfunction, lung inefficiency, hypertension, liver damage, cardiac failure, osteoporosis, fibrosis, skeletal symptoms, tubular proteinuria, and cardiovascular diseases [45].

Table 7. Non-carcinogenic health risk assessment of respondents (ingestion route).

S/N	Community	Age Groups									
		1 to <2 years	2 to <3 years	3 to <6 years	6 to <11 years	11 to <16 years	16 to <18 years	18 to <21 years	21 to <65 years	>65 years	HI
1	Onihale	2.53E+00	2.19E+00	1.78E+00	1.52E+00	1.11E+00	8.60E-01	1.14E+00	1.28E+00	1.18E+00	1.36E+01
2	Onihale	2.89E+01	2.50E+01	2.03E+01	1.73E+01	1.26E+01	9.79E+00	1.30E+01	1.45E+01	1.34E+01	1.55E+02
3	Onihale	1.20E+01	1.04E+01	8.40E+00	7.16E+00	5.23E+00	4.06E+00	5.39E+00	6.03E+00	5.56E+00	6.42E+01
4	Onihale	1.31E-01	1.13E-01	9.20E-02	7.83E-02	5.72E-02	4.44E-02	5.90E-02	6.59E-02	6.09E-02	7.02E-01
5	Onihale	1.13E-01	9.75E-02	7.91E-02	6.74E-02	4.92E-02	3.82E-02	5.07E-02	5.67E-02	5.24E-02	6.04E-01
6	Onihale	1.13E+00	9.75E-01	7.91E-01	6.74E-01	4.92E-01	3.82E-01	5.07E-01	5.67E-01	5.24E-01	6.04E+00
7	Onihale	9.15E-02	7.92E-02	6.43E-02	5.47E-02	4.00E-02	3.10E-02	4.12E-02	4.61E-02	4.25E-02	4.91E-01
8	Onihale	9.86E-02	8.53E-02	6.92E-02	5.89E-02	4.30E-02	3.34E-02	4.44E-02	4.96E-02	4.58E-02	5.28E-01
9	Onihale	1.24E-01	1.07E-01	8.70E-02	7.41E-02	5.41E-02	4.20E-02	5.58E-02	6.24E-02	5.76E-02	6.64E-01
10	Onihale	1.30E-01	1.12E-01	9.10E-02	7.75E-02	5.66E-02	4.39E-02	5.83E-02	6.52E-02	6.02E-02	6.94E-01
1	Ifo	1.08E+01	9.38E+00	7.61E+00	6.48E+00	4.73E+00	3.68E+00	4.88E+00	5.46E+00	5.04E+00	5.81E+01
2	Ifo	8.73E-02	7.56E-02	6.13E-02	5.22E-02	3.81E-02	2.96E-02	3.93E-02	4.40E-02	4.06E-02	4.68E-01
3	Ifo	7.74E-02	6.70E-02	5.44E-02	4.63E-02	3.38E-02	2.63E-02	3.49E-02	3.90E-02	3.60E-02	4.15E-01
4	Ifo	1.14E-01	9.87E-02	8.01E-02	6.82E-02	4.98E-02	3.87E-02	5.14E-02	5.74E-02	5.30E-02	6.11E-01
5	Ifo	9.15E-02	7.92E-02	6.43E-02	5.47E-02	4.00E-02	3.10E-02	4.12E-02	4.61E-02	4.25E-02	4.91E-01
6	Ifo	1.11E-01	9.63E-02	7.81E-02	6.65E-02	4.86E-02	3.77E-02	5.01E-02	5.60E-02	5.17E-02	5.96E-01
7	Ifo	7.04E-02	6.09E-02	4.94E-02	4.21E-02	3.07E-02	2.39E-02	3.17E-02	3.55E-02	3.27E-02	3.77E-01
8	Ifo	1.13E+01	9.75E+00	7.91E+00	6.74E+00	4.92E+00	3.82E+00	5.07E+00	5.67E+00	5.24E+00	6.04E+01
9	Ifo	8.31E-02	7.19E-02	5.83E-02	4.97E-02	3.63E-02	2.82E-02	3.74E-02	4.18E-02	3.86E-02	4.45E-01
10	Ifo	9.86E-02	8.53E-02	6.92E-02	5.89E-02	4.30E-02	3.34E-02	4.44E-02	4.96E-02	4.58E-02	5.28E-01

1	Papalanto	1.27E-01	1.10E-01	8.90E-02	7.58E-02	5.53E-02	4.30E-02	5.71E-02	6.38E-02	5.89E-02	6.79E-01
2	Papalanto	9.57E-02	8.29E-02	6.72E-02	5.72E-02	4.18E-02	3.25E-02	4.31E-02	4.82E-02	4.45E-02	5.13E-01
3	Papalanto	1.28E-01	1.11E-01	9.00E-02	7.66E-02	5.60E-02	4.35E-02	5.77E-02	6.45E-02	5.96E-02	6.87E-01
4	Papalanto	8.03E-02	6.95E-02	5.64E-02	4.80E-02	3.50E-02	2.72E-02	3.61E-02	4.04E-02	3.73E-02	4.30E-01
5	Papalanto	1.41E-01	1.22E-01	9.89E-02	8.42E-02	6.15E-02	4.78E-02	6.34E-02	7.09E-02	6.54E-02	7.55E-01
6	Papalanto	1.23E-01	1.06E-01	8.60E-02	7.32E-02	5.35E-02	4.15E-02	5.52E-02	6.17E-02	5.69E-02	6.57E-01
7	Papalanto	7.60E-02	6.58E-02	5.34E-02	4.55E-02	3.32E-02	2.58E-02	3.42E-02	3.83E-02	3.53E-02	4.08E-01
8	Papalanto	1.27E-01	1.10E-01	8.90E-02	7.58E-02	5.53E-02	4.30E-02	5.71E-02	6.38E-02	5.89E-02	6.79E-01
9	Papalanto	9.72E-02	8.41E-02	6.82E-02	5.81E-02	4.24E-02	3.30E-02	4.38E-02	4.89E-02	4.52E-02	5.21E-01
10	Papalanto	1.14E-01	9.87E-02	8.01E-02	6.82E-02	4.98E-02	3.87E-02	5.14E-02	5.74E-02	5.30E-02	6.11E-01
1	Itori	9.86E+00	8.53E+00	6.92E+00	5.89E+00	4.30E+00	3.34E+00	4.44E+00	4.96E+00	4.58E+00	5.28E+01
2	Itori	1.39E+01	1.21E+01	9.79E+00	8.33E+00	6.09E+00	4.73E+00	6.28E+00	7.02E+00	6.48E+00	7.47E+01
3	Itori	1.21E+01	1.05E+01	8.50E+00	7.24E+00	5.29E+00	4.11E+00	5.45E+00	6.10E+00	5.63E+00	6.49E+01
4	Itori	1.13E+00	9.75E-01	7.91E-01	6.74E-01	4.92E-01	3.82E-01	5.07E-01	5.67E-01	5.24E-01	6.04E+00
5	Itori	8.17E-02	7.07E-02	5.74E-02	4.88E-02	3.57E-02	2.77E-02	3.68E-02	4.11E-02	3.80E-02	4.38E-01
6	Itori	9.57E+00	8.29E+00	6.72E+00	5.72E+00	4.18E+00	3.25E+00	4.31E+00	4.82E+00	4.45E+00	5.13E+01
7	Itori	1.11E-01	9.63E-02	7.81E-02	6.65E-02	4.86E-02	3.77E-02	5.01E-02	5.60E-02	5.17E-02	5.96E-01
8	Itori	1.27E-01	1.10E-01	8.90E-02	7.58E-02	5.53E-02	4.30E-02	5.71E-02	6.38E-02	5.89E-02	6.79E-01
9	Itori	5.63E+00	4.88E+00	3.96E+00	3.37E+00	2.46E+00	1.91E+00	2.54E+00	2.84E+00	2.62E+00	3.02E+01
10	Itori	2.25E+01	1.95E+01	1.58E+01	1.35E+01	9.84E+00	7.64E+00	1.01E+01	1.13E+01	1.05E+01	1.21E+02
1	Wasinmi	1.13E-01	9.75E-02	7.91E-02	6.74E-02	4.92E-02	3.82E-02	5.07E-02	5.67E-02	5.24E-02	6.04E-01
2	Wasinmi	8.03E-02	6.95E-02	5.64E-02	4.80E-02	3.50E-02	2.72E-02	3.61E-02	4.04E-02	3.73E-02	4.30E-01
3	Wasinmi	1.38E-01	1.19E-01	9.69E-02	8.25E-02	6.03E-02	4.68E-02	6.21E-02	6.95E-02	6.41E-02	7.40E-01
4	Wasinmi	1.08E-01	9.38E-02	7.61E-02	6.48E-02	4.73E-02	3.68E-02	4.88E-02	5.46E-02	5.04E-02	5.81E-01
5	Wasinmi	7.46E+01	6.46E+01	5.24E+01	4.46E+01	3.26E+01	2.53E+01	3.36E+01	3.76E+01	3.47E+01	4.00E+02
6	Wasinmi	1.39E-01	1.21E-01	9.79E-02	8.33E-02	6.09E-02	4.73E-02	6.28E-02	7.02E-02	6.48E-02	7.47E-01
7	Wasinmi	1.15E-01	9.99E-02	8.11E-02	6.90E-02	5.04E-02	3.92E-02	5.20E-02	5.81E-02	5.37E-02	6.19E-01
8	Wasinmi	1.28E-01	1.11E-01	9.00E-02	7.66E-02	5.60E-02	4.35E-02	5.77E-02	6.45E-02	5.96E-02	6.87E-01
9	Wasinmi	1.11E-01	9.63E-02	7.81E-02	6.65E-02	4.86E-02	3.77E-02	5.01E-02	5.60E-02	5.17E-02	5.96E-01
10	Wasinmi	1.32E-01	1.15E-01	9.29E-02	7.91E-02	5.78E-02	4.49E-02	5.96E-02	6.67E-02	6.15E-02	7.09E-01
1	Olujobi	8.45E-02	7.31E-02	5.93E-02	5.05E-02	3.69E-02	2.87E-02	3.80E-02	4.25E-02	3.93E-02	4.53E-01
2	Olujobi	1.10E-01	9.51E-02	7.71E-02	6.57E-02	4.80E-02	3.73E-02	4.95E-02	5.53E-02	5.10E-02	5.89E-01
3	Olujobi	1.20E-01	1.04E-01	8.40E-02	7.16E-02	5.23E-02	4.06E-02	5.39E-02	6.03E-02	5.56E-02	6.42E-01
4	Olujobi	1.38E-01	1.19E-01	9.69E-02	8.25E-02	6.03E-02	4.68E-02	6.21E-02	6.95E-02	6.41E-02	7.40E-01
5	Olujobi	7.89E-02	6.83E-02	5.54E-02	4.71E-02	3.44E-02	2.67E-02	3.55E-02	3.97E-02	3.66E-02	4.23E-01
6	Olujobi	1.27E+00	1.10E+00	8.90E-01	7.58E-01	5.53E-01	4.30E-01	5.71E-01	6.38E-01	5.89E-01	6.79E+00
7	Olujobi	1.14E-01	9.87E-02	8.01E-02	6.82E-02	4.98E-02	3.87E-02	5.14E-02	5.74E-02	5.30E-02	6.11E-01
8	Olujobi	1.07E-01	9.26E-02	7.51E-02	6.40E-02	4.67E-02	3.63E-02	4.82E-02	5.39E-02	4.97E-02	5.74E-01
9	Olujobi	9.86E-02	8.53E-02	6.92E-02	5.89E-02	4.30E-02	3.34E-02	4.44E-02	4.96E-02	4.58E-02	5.28E-01
10	Olujobi	1.13E-01	9.75E-02	7.91E-02	6.74E-02	4.92E-02	3.82E-02	5.07E-02	5.67E-02	5.24E-02	6.04E-01

<1- No Adverse Health Risk, >1 – Adverse Health Risk

Hazard Quotient (HQ) and Hazard Index (HI) via Dermal Route

Table 8 shows respondents' non-carcinogenic health risk assessment for cadmium via the dermal route. All the values calculated for the hazard quotient through dermal routes were less than one for all the points at the six communities across all selected age groups. The hazard index (HI), a sum of all hazard quotient values across the age groups, was calculated to be less than one for all sixty points. The values showed no potential health risk through dermal exposure for the nine age groups selected. Non-carcinogenic health effects such as shortness of breath, asthma, respiratory disorders, tubular dysfunction, lung inefficiency, and glucose metabolism disorder can occur in children, especially those between 1 and less than 16 years of age. Cadmium exposure in adults can result in a gradual loss of taste and smell, kidney dysfunction, tubular proteinuria, glomeruli, Itai-Itai disease, bone degeneration, renal dysfunction, lung inefficiency, hypertension, liver damage, cardiac failure, osteoporosis, fibrosis, skeletal symptoms, tubular proteinuria, and cardiovascular diseases [19, 45].

Incremental Lifetime Cancer Risk (ILCR) via Ingestion and Dermal Routes

Cadmium's carcinogenic health risk assessment was calculated using the incremental lifetime cancer risk standard, and results were computed as shown in Tables 9 and 10. The obtained values were graded according to the Delphi method of classification [35]. Residents had a higher risk of developing cancer from ingesting cadmium than from dermal contact. Points 2 and 3 (Onihale) had ILCR values within Level VII for all age groups (extremely high risk of cancer) among the population. The ILCR values for other points at Onihale were between Levels V and VI (medium to high cancer risk in the population). Points 1 and 8 in the Ifo community showed values within Level VI (high risk) across all nine age groups. Other points in the community showed values within the level IV (medium risk) for cancer occurrence.

In the Papalanto community, the ILCR values across all nine age groups were between low and medium risk (level III). In the Itori community, seven out of the ten points had ILCR values between Level VI and Level VII (high risk to extremely high risk). The Wasinmi

Table 8. Non-carcinogenic health risk assessment of respondents (Dermal Route).

S/N	Community	Age Groups									
		1 to <2 years	2 to <3 years	3 to <6 years	6 to <11 years	11 to <16 years	16 to <18 years	18 to <21 years	21 to <65 years	>65 years	HI
1	Onihale	9.85E-07	1.31E-06	1.76E-06	1.23E-06	8.98E-07	1.12E-06	1.12E-06	2.97E-07	2.76E-07	9.01E-06
2	Onihale	1.12E-05	1.50E-05	2.01E-05	1.40E-05	1.02E-05	1.28E-05	1.28E-05	3.38E-06	3.14E-06	1.03E-04
3	Onihale	4.65E-06	6.20E-06	8.33E-06	5.82E-06	4.24E-06	5.30E-06	5.30E-06	1.40E-06	1.30E-06	4.25E-05
4	Onihale	5.09E-08	6.79E-08	9.11E-08	6.37E-08	4.64E-08	5.80E-08	5.80E-08	1.53E-08	1.43E-08	4.66E-07
5	Onihale	4.38E-08	5.84E-08	7.84E-08	5.48E-08	3.99E-08	4.99E-08	4.99E-08	1.32E-08	1.23E-08	4.00E-07
6	Onihale	4.38E-07	5.84E-07	7.84E-07	5.48E-07	3.99E-07	4.99E-07	4.99E-07	1.32E-07	1.23E-07	4.00E-06
7	Onihale	3.56E-08	4.74E-08	6.37E-08	4.45E-08	3.24E-08	4.06E-08	4.06E-08	1.07E-08	9.97E-09	3.25E-07
8	Onihale	3.83E-08	5.11E-08	6.86E-08	4.79E-08	3.49E-08	4.37E-08	4.37E-08	1.15E-08	1.07E-08	3.50E-07
9	Onihale	4.81E-08	6.42E-08	8.62E-08	6.02E-08	4.39E-08	5.49E-08	5.49E-08	1.45E-08	1.35E-08	4.40E-07
10	Onihale	5.03E-08	6.71E-08	9.01E-08	6.30E-08	4.59E-08	5.74E-08	5.74E-08	1.52E-08	1.41E-08	4.61E-07
1	Ifo	4.21E-06	5.62E-06	7.54E-06	5.27E-06	3.84E-06	4.81E-06	4.80E-06	1.27E-06	1.18E-06	3.85E-05
2	Ifo	3.39E-08	4.52E-08	6.07E-08	4.24E-08	3.09E-08	3.87E-08	3.87E-08	1.02E-08	9.51E-09	3.10E-07
3	Ifo	3.01E-08	4.01E-08	5.39E-08	3.77E-08	2.74E-08	3.43E-08	3.43E-08	9.07E-09	8.43E-09	2.75E-07
4	Ifo	4.43E-08	5.91E-08	7.93E-08	5.55E-08	4.04E-08	5.06E-08	5.05E-08	1.34E-08	1.24E-08	4.05E-07
5	Ifo	3.56E-08	4.74E-08	6.37E-08	4.45E-08	3.24E-08	4.06E-08	4.06E-08	1.07E-08	9.97E-09	3.25E-07
6	Ifo	4.32E-08	5.76E-08	7.74E-08	5.41E-08	3.94E-08	4.93E-08	4.93E-08	1.30E-08	1.21E-08	3.95E-07
7	Ifo	2.73E-08	3.65E-08	4.90E-08	3.42E-08	2.49E-08	3.12E-08	3.12E-08	8.24E-09	7.67E-09	2.50E-07
8	Ifo	4.38E-06	5.84E-06	7.84E-06	5.48E-06	3.99E-06	4.99E-06	4.99E-06	1.32E-06	1.23E-06	4.00E-05
9	Ifo	3.23E-08	4.30E-08	5.78E-08	4.04E-08	2.94E-08	3.68E-08	3.68E-08	9.73E-09	9.05E-09	2.95E-07
10	Ifo	3.83E-08	5.11E-08	6.86E-08	4.79E-08	3.49E-08	4.37E-08	4.37E-08	1.15E-08	1.07E-08	3.50E-07

1	Papalanto	4.92E-08	6.57E-08	8.82E-08	6.16E-08	4.49E-08	5.62E-08	5.62E-08	1.48E-08	1.38E-08	4.51E-07
2	Papalanto	3.72E-08	4.96E-08	6.66E-08	4.66E-08	3.39E-08	4.24E-08	4.24E-08	1.12E-08	1.04E-08	3.40E-07
3	Papalanto	4.98E-08	6.64E-08	8.91E-08	6.23E-08	4.54E-08	5.68E-08	5.68E-08	1.50E-08	1.40E-08	4.56E-07
4	Papalanto	3.12E-08	4.16E-08	5.58E-08	3.90E-08	2.84E-08	3.56E-08	3.56E-08	9.40E-09	8.74E-09	2.85E-07
5	Papalanto	5.47E-08	7.30E-08	9.80E-08	6.85E-08	4.99E-08	6.24E-08	6.24E-08	1.65E-08	1.53E-08	5.01E-07
6	Papalanto	4.76E-08	6.35E-08	8.52E-08	5.96E-08	4.34E-08	5.43E-08	5.43E-08	1.43E-08	1.33E-08	4.35E-07
7	Papalanto	2.95E-08	3.94E-08	5.29E-08	3.70E-08	2.69E-08	3.37E-08	3.37E-08	8.90E-09	8.28E-09	2.70E-07
8	Papalanto	4.92E-08	6.57E-08	8.82E-08	6.16E-08	4.49E-08	5.62E-08	5.62E-08	1.48E-08	1.38E-08	4.51E-07
9	Papalanto	3.77E-08	5.03E-08	6.76E-08	4.72E-08	3.44E-08	4.31E-08	4.31E-08	1.14E-08	1.06E-08	3.45E-07
10	Papalanto	4.43E-08	5.91E-08	7.93E-08	5.55E-08	4.04E-08	5.06E-08	5.05E-08	1.34E-08	1.24E-08	4.05E-07
1	Itori	3.83E-06	5.11E-06	6.86E-06	4.79E-06	3.49E-06	4.37E-06	4.37E-06	1.15E-06	1.07E-06	3.50E-05
2	Itori	5.41E-06	7.22E-06	9.70E-06	6.78E-06	4.94E-06	6.18E-06	6.18E-06	1.63E-06	1.52E-06	4.96E-05
3	Itori	4.70E-06	6.27E-06	8.42E-06	5.89E-06	4.29E-06	5.37E-06	5.37E-06	1.42E-06	1.32E-06	4.30E-05
4	Itori	4.38E-07	5.84E-07	7.84E-07	5.48E-07	3.99E-07	4.99E-07	4.99E-07	1.32E-07	1.23E-07	4.00E-06
5	Itori	3.17E-08	4.23E-08	5.68E-08	3.97E-08	2.89E-08	3.62E-08	3.62E-08	9.56E-09	8.89E-09	2.90E-07
6	Itori	3.72E-06	4.96E-06	6.66E-06	4.66E-06	3.39E-06	4.24E-06	4.24E-06	1.12E-06	1.04E-06	3.40E-05
7	Itori	4.32E-08	5.76E-08	7.74E-08	5.41E-08	3.94E-08	4.93E-08	4.93E-08	1.30E-08	1.21E-08	3.95E-07
8	Itori	4.92E-08	6.57E-08	8.82E-08	6.16E-08	4.49E-08	5.62E-08	5.62E-08	1.48E-08	1.38E-08	4.51E-07
9	Itori	2.19E-06	2.92E-06	3.92E-06	2.74E-06	1.99E-06	2.50E-06	2.50E-06	6.59E-07	6.13E-07	2.00E-05
10	Itori	8.75E-06	1.17E-05	1.57E-05	1.10E-05	7.98E-06	9.99E-06	9.98E-06	2.64E-06	2.45E-06	8.01E-05
1	Wasinmi	4.38E-08	5.84E-08	7.84E-08	5.48E-08	3.99E-08	4.99E-08	4.99E-08	1.32E-08	1.23E-08	4.00E-07
2	Wasinmi	3.12E-08	4.16E-08	5.58E-08	3.90E-08	2.84E-08	3.56E-08	3.56E-08	9.40E-09	8.74E-09	2.85E-07
3	Wasinmi	5.36E-08	7.15E-08	9.60E-08	6.71E-08	4.89E-08	6.12E-08	6.11E-08	1.62E-08	1.50E-08	4.91E-07
4	Wasinmi	4.21E-08	5.62E-08	7.54E-08	5.27E-08	3.84E-08	4.81E-08	4.80E-08	1.27E-08	1.18E-08	3.85E-07
5	Wasinmi	2.90E-05	3.87E-05	5.19E-05	3.63E-05	2.64E-05	3.31E-05	3.31E-05	8.74E-06	8.13E-06	2.65E-04
6	Wasinmi	5.41E-08	7.22E-08	9.70E-08	6.78E-08	4.94E-08	6.18E-08	6.18E-08	1.63E-08	1.52E-08	4.96E-07
7	Wasinmi	4.49E-08	5.98E-08	8.03E-08	5.61E-08	4.09E-08	5.12E-08	5.12E-08	1.35E-08	1.26E-08	4.10E-07
8	Wasinmi	4.98E-08	6.64E-08	8.91E-08	6.23E-08	4.54E-08	5.68E-08	5.68E-08	1.50E-08	1.40E-08	4.56E-07
9	Wasinmi	4.32E-08	5.76E-08	7.74E-08	5.41E-08	3.94E-08	4.93E-08	4.93E-08	1.30E-08	1.21E-08	3.95E-07
10	Wasinmi	5.14E-08	6.86E-08	9.21E-08	6.44E-08	4.69E-08	5.87E-08	5.86E-08	1.55E-08	1.44E-08	4.71E-07
1	Olujobi	3.28E-08	4.38E-08	5.88E-08	4.11E-08	2.99E-08	3.74E-08	3.74E-08	9.89E-09	9.20E-09	3.00E-07
2	Olujobi	4.27E-08	5.69E-08	7.64E-08	5.34E-08	3.89E-08	4.87E-08	4.87E-08	1.29E-08	1.20E-08	3.90E-07
3	Olujobi	4.65E-08	6.20E-08	8.33E-08	5.82E-08	4.24E-08	5.30E-08	5.30E-08	1.40E-08	1.30E-08	4.25E-07
4	Olujobi	5.36E-08	7.15E-08	9.60E-08	6.71E-08	4.89E-08	6.12E-08	6.11E-08	1.62E-08	1.50E-08	4.91E-07
5	Olujobi	3.06E-08	4.09E-08	5.49E-08	3.83E-08	2.79E-08	3.49E-08	3.49E-08	9.23E-09	8.59E-09	2.80E-07
6	Olujobi	4.92E-07	6.57E-07	8.82E-07	6.16E-07	4.49E-07	5.62E-07	5.62E-07	1.48E-07	1.38E-07	4.51E-06
7	Olujobi	4.43E-08	5.91E-08	7.93E-08	5.55E-08	4.04E-08	5.06E-08	5.05E-08	1.34E-08	1.24E-08	4.05E-07
8	Olujobi	4.16E-08	5.54E-08	7.44E-08	5.20E-08	3.79E-08	4.74E-08	4.74E-08	1.25E-08	1.17E-08	3.80E-07
9	Olujobi	3.83E-08	5.11E-08	6.86E-08	4.79E-08	3.49E-08	4.37E-08	4.37E-08	1.15E-08	1.07E-08	3.50E-07
10	Olujobi	4.38E-08	5.84E-08	7.84E-08	5.48E-08	3.99E-08	4.99E-08	4.99E-08	1.32E-08	1.23E-08	4.00E-07

<1- No Adverse Health Risk, >1 – Adverse Health Risk

Table 9. Incremental Lifetime Cancer Risk (ILCR) of residents exposed to cadmium pollution via the ingestion route.

S/N	Community	Age Groups								
		1 to <2 years	2 to <3 years	3 to <6 years	6 to <11 years	11 to <16 years	16 to <18 years	18 to <21 years	21 to <65 years	>65 years
1	Onihale	1.90E-03	1.65E-03	1.33E-03	1.14E-03	8.30E-04	6.45E-04	8.56E-04	9.57E-04	8.84E-04
2	Onihale	2.16E-02	1.87E-02	1.52E-02	1.29E-02	9.45E-03	7.34E-03	9.75E-03	1.09E-02	1.01E-02
3	Onihale	8.98E-03	7.77E-03	6.30E-03	5.37E-03	3.92E-03	3.04E-03	4.04E-03	4.52E-03	4.17E-03
4	Onihale	9.82E-05	8.50E-05	6.90E-05	5.87E-05	4.29E-05	3.33E-05	4.42E-05	4.95E-05	4.56E-05
5	Onihale	8.45E-05	7.31E-05	5.93E-05	5.05E-05	3.69E-05	2.87E-05	3.80E-05	4.25E-05	3.93E-05
6	Onihale	8.45E-04	7.31E-04	5.93E-04	5.05E-04	3.69E-04	2.87E-04	3.80E-04	4.25E-04	3.93E-04
7	Onihale	6.86E-05	5.94E-05	4.82E-05	4.10E-05	3.00E-05	2.33E-05	3.09E-05	3.46E-05	3.19E-05
8	Onihale	7.39E-05	6.40E-05	5.19E-05	4.42E-05	3.23E-05	2.51E-05	3.33E-05	3.72E-05	3.44E-05
9	Onihale	9.29E-05	8.04E-05	6.53E-05	5.56E-05	4.06E-05	3.15E-05	4.19E-05	4.68E-05	4.32E-05
10	Onihale	9.72E-05	8.41E-05	6.82E-05	5.81E-05	4.24E-05	3.30E-05	4.38E-05	4.89E-05	4.52E-05
1	Ifo	8.13E-03	7.04E-03	5.71E-03	4.86E-03	3.55E-03	2.76E-03	3.66E-03	4.10E-03	3.78E-03
2	Ifo	6.55E-05	5.67E-05	4.60E-05	3.91E-05	2.86E-05	2.22E-05	2.95E-05	3.30E-05	3.04E-05
3	Ifo	5.81E-05	5.03E-05	4.08E-05	3.47E-05	2.54E-05	1.97E-05	2.62E-05	2.93E-05	2.70E-05
4	Ifo	8.55E-05	7.40E-05	6.01E-05	5.11E-05	3.74E-05	2.90E-05	3.85E-05	4.31E-05	3.98E-05
5	Ifo	6.86E-05	5.94E-05	4.82E-05	4.10E-05	3.00E-05	2.33E-05	3.09E-05	3.46E-05	3.19E-05
6	Ifo	8.34E-05	7.22E-05	5.86E-05	4.99E-05	3.64E-05	2.83E-05	3.76E-05	4.20E-05	3.88E-05
7	Ifo	5.28E-05	4.57E-05	3.71E-05	3.16E-05	2.31E-05	1.79E-05	2.38E-05	2.66E-05	2.45E-05
8	Ifo	8.45E-03	7.31E-03	5.93E-03	5.05E-03	3.69E-03	2.87E-03	3.80E-03	4.25E-03	3.93E-03
9	Ifo	6.23E-05	5.39E-05	4.38E-05	3.73E-05	2.72E-05	2.11E-05	2.81E-05	3.14E-05	2.90E-05
10	Ifo	7.39E-05	6.40E-05	5.19E-05	4.42E-05	3.23E-05	2.51E-05	3.33E-05	3.72E-05	3.44E-05
1	Papalanto	9.50E-05	8.23E-05	6.67E-05	5.68E-05	4.15E-05	3.22E-05	4.28E-05	4.79E-05	4.42E-05
2	Papalanto	7.18E-05	6.22E-05	5.04E-05	4.29E-05	3.14E-05	2.44E-05	3.23E-05	3.62E-05	3.34E-05
3	Papalanto	9.61E-05	8.32E-05	6.75E-05	5.75E-05	4.20E-05	3.26E-05	4.33E-05	4.84E-05	4.47E-05
4	Papalanto	6.02E-05	5.21E-05	4.23E-05	3.60E-05	2.63E-05	2.04E-05	2.71E-05	3.03E-05	2.80E-05
5	Papalanto	1.06E-04	9.14E-05	7.42E-05	6.31E-05	4.61E-05	3.58E-05	4.76E-05	5.32E-05	4.91E-05
6	Papalanto	9.19E-05	7.95E-05	6.45E-05	5.49E-05	4.01E-05	3.12E-05	4.14E-05	4.63E-05	4.27E-05
7	Papalanto	5.70E-05	4.94E-05	4.00E-05	3.41E-05	2.49E-05	1.93E-05	2.57E-05	2.87E-05	2.65E-05
8	Papalanto	9.50E-05	8.23E-05	6.67E-05	5.68E-05	4.15E-05	3.22E-05	4.28E-05	4.79E-05	4.42E-05
9	Papalanto	7.29E-05	6.31E-05	5.12E-05	4.36E-05	3.18E-05	2.47E-05	3.28E-05	3.67E-05	3.39E-05
10	Papalanto	8.55E-05	7.40E-05	6.01E-05	5.11E-05	3.74E-05	2.90E-05	3.85E-05	4.31E-05	3.98E-05
1	Itori	7.39E-03	6.40E-03	5.19E-03	4.42E-03	3.23E-03	2.51E-03	3.33E-03	3.72E-03	3.44E-03
2	Itori	1.05E-02	9.05E-03	7.34E-03	6.25E-03	4.57E-03	3.55E-03	4.71E-03	5.27E-03	4.86E-03
3	Itori	9.08E-03	7.86E-03	6.38E-03	5.43E-03	3.97E-03	3.08E-03	4.09E-03	4.57E-03	4.22E-03
4	Itori	8.45E-04	7.31E-04	5.93E-04	5.05E-04	3.69E-04	2.87E-04	3.80E-04	4.25E-04	3.93E-04
5	Itori	6.13E-05	5.30E-05	4.30E-05	3.66E-05	2.67E-05	2.08E-05	2.76E-05	3.08E-05	2.85E-05
6	Itori	7.18E-03	6.22E-03	5.04E-03	4.29E-03	3.14E-03	2.44E-03	3.23E-03	3.62E-03	3.34E-03
7	Itori	8.34E-05	7.22E-05	5.86E-05	4.99E-05	3.64E-05	2.83E-05	3.76E-05	4.20E-05	3.88E-05
8	Itori	9.50E-05	8.23E-05	6.67E-05	5.68E-05	4.15E-05	3.22E-05	4.28E-05	4.79E-05	4.42E-05

9	Itori	4.22E-03	3.66E-03	2.97E-03	2.53E-03	1.84E-03	1.43E-03	1.90E-03	2.13E-03	1.96E-03
10	Itori	1.69E-02	1.46E-02	1.19E-02	1.01E-02	7.38E-03	5.73E-03	7.61E-03	8.51E-03	7.85E-03
1	Wasinmi	8.45E-05	7.31E-05	5.93E-05	5.05E-05	3.69E-05	2.87E-05	3.80E-05	4.25E-05	3.93E-05
2	Wasinmi	6.02E-05	5.21E-05	4.23E-05	3.60E-05	2.63E-05	2.04E-05	2.71E-05	3.03E-05	2.80E-05
3	Wasinmi	1.03E-04	8.96E-05	7.27E-05	6.19E-05	4.52E-05	3.51E-05	4.66E-05	5.21E-05	4.81E-05
4	Wasinmi	8.13E-05	7.04E-05	5.71E-05	4.86E-05	3.55E-05	2.76E-05	3.66E-05	4.10E-05	3.78E-05
5	Wasinmi	5.60E-02	4.84E-02	3.93E-02	3.35E-02	2.44E-02	1.90E-02	2.52E-02	2.82E-02	2.60E-02
6	Wasinmi	1.05E-04	9.05E-05	7.34E-05	6.25E-05	4.57E-05	3.55E-05	4.71E-05	5.27E-05	4.86E-05
7	Wasinmi	8.66E-05	7.50E-05	6.08E-05	5.18E-05	3.78E-05	2.94E-05	3.90E-05	4.36E-05	4.02E-05
8	Wasinmi	9.61E-05	8.32E-05	6.75E-05	5.75E-05	4.20E-05	3.26E-05	4.33E-05	4.84E-05	4.47E-05
9	Wasinmi	8.34E-05	7.22E-05	5.86E-05	4.99E-05	3.64E-05	2.83E-05	3.76E-05	4.20E-05	3.88E-05
10	Wasinmi	9.93E-05	8.59E-05	6.97E-05	5.94E-05	4.33E-05	3.37E-05	4.47E-05	5.00E-05	4.61E-05
1	Olujobi	6.34E-05	5.48E-05	4.45E-05	3.79E-05	2.77E-05	2.15E-05	2.85E-05	3.19E-05	2.95E-05
2	Olujobi	8.24E-05	7.13E-05	5.78E-05	4.93E-05	3.60E-05	2.79E-05	3.71E-05	4.15E-05	3.83E-05
3	Olujobi	8.98E-05	7.77E-05	6.30E-05	5.37E-05	3.92E-05	3.04E-05	4.04E-05	4.52E-05	4.17E-05
4	Olujobi	1.03E-04	8.96E-05	7.27E-05	6.19E-05	4.52E-05	3.51E-05	4.66E-05	5.21E-05	4.81E-05
5	Olujobi	5.91E-05	5.12E-05	4.15E-05	3.54E-05	2.58E-05	2.01E-05	2.66E-05	2.98E-05	2.75E-05
6	Olujobi	9.50E-04	8.23E-04	6.67E-04	5.68E-04	4.15E-04	3.22E-04	4.28E-04	4.79E-04	4.42E-04
7	Olujobi	8.55E-05	7.40E-05	6.01E-05	5.11E-05	3.74E-05	2.90E-05	3.85E-05	4.31E-05	3.98E-05
8	Olujobi	8.03E-05	6.95E-05	5.64E-05	4.80E-05	3.50E-05	2.72E-05	3.61E-05	4.04E-05	3.73E-05
9	Olujobi	7.39E-05	6.40E-05	5.19E-05	4.42E-05	3.23E-05	2.51E-05	3.33E-05	3.72E-05	3.44E-05
10	Olujobi	8.45E-05	7.31E-05	5.93E-05	5.05E-05	3.69E-05	2.87E-05	3.80E-05	4.25E-05	3.93E-05

Table 10. Incremental Lifetime Cancer Risk (ILCR) of residents exposed to cadmium pollution via the dermal route.

S/N	Community	Age Groups								
		1 to <2 years	2 to <3 years	3 to <6 years	6 to <11 years	11 to <16 years	16 to <18 years	18 to <21 years	21 to <65 years	>65 years
1	Onihale	7.38E-11	9.85E-11	1.32E-10	9.24E-11	6.73E-11	8.43E-11	8.42E-11	2.23E-11	2.07E-11
2	Onihale	8.41E-10	1.12E-09	1.51E-09	1.05E-09	7.67E-10	9.60E-10	9.59E-10	2.53E-10	2.36E-10
3	Onihale	3.49E-10	4.65E-10	6.24E-10	4.36E-10	3.18E-10	3.98E-10	3.98E-10	1.05E-10	9.77E-11
4	Onihale	3.82E-12	5.09E-12	6.83E-12	4.78E-12	3.48E-12	4.35E-12	4.35E-12	1.15E-12	1.07E-12
5	Onihale	3.28E-12	4.38E-12	5.88E-12	4.11E-12	2.99E-12	3.74E-12	3.74E-12	9.89E-13	9.20E-13
6	Onihale	3.28E-11	4.38E-11	5.88E-11	4.11E-11	2.99E-11	3.74E-11	3.74E-11	9.89E-12	9.20E-12
7	Onihale	2.67E-12	3.56E-12	4.78E-12	3.34E-12	2.43E-12	3.04E-12	3.04E-12	8.04E-13	7.47E-13
8	Onihale	2.87E-12	3.83E-12	5.14E-12	3.59E-12	2.62E-12	3.28E-12	3.28E-12	8.66E-13	8.05E-13
9	Onihale	3.61E-12	4.82E-12	6.46E-12	4.52E-12	3.29E-12	4.12E-12	4.12E-12	1.09E-12	1.01E-12
10	Onihale	3.77E-12	5.03E-12	6.76E-12	4.72E-12	3.44E-12	4.31E-12	4.31E-12	1.14E-12	1.06E-12
1	Ifo	3.16E-10	4.21E-10	5.66E-10	3.95E-10	2.88E-10	3.60E-10	3.60E-10	9.52E-11	8.85E-11
2	Ifo	2.54E-12	3.39E-12	4.55E-12	3.18E-12	2.32E-12	2.90E-12	2.90E-12	7.67E-13	7.13E-13
3	Ifo	2.26E-12	3.01E-12	4.04E-12	2.82E-12	2.06E-12	2.57E-12	2.57E-12	6.80E-13	6.32E-13
4	Ifo	3.32E-12	4.43E-12	5.95E-12	4.16E-12	3.03E-12	3.79E-12	3.79E-12	1.00E-12	9.31E-13

5	Ifo	2.67E-12	3.56E-12	4.78E-12	3.34E-12	2.43E-12	3.04E-12	3.04E-12	8.04E-13	7.47E-13
6	Ifo	3.24E-12	4.32E-12	5.80E-12	4.06E-12	2.95E-12	3.70E-12	3.70E-12	9.77E-13	9.08E-13
7	Ifo	2.05E-12	2.74E-12	3.67E-12	2.57E-12	1.87E-12	2.34E-12	2.34E-12	6.18E-13	5.75E-13
8	Ifo	3.28E-10	4.38E-10	5.88E-10	4.11E-10	2.99E-10	3.74E-10	3.74E-10	9.89E-11	9.20E-11
9	Ifo	2.42E-12	3.23E-12	4.33E-12	3.03E-12	2.21E-12	2.76E-12	2.76E-12	7.29E-13	6.78E-13
10	Ifo	2.87E-12	3.83E-12	5.14E-12	3.59E-12	2.62E-12	3.28E-12	3.28E-12	8.66E-13	8.05E-13
1	Papalanto	3.69E-12	4.92E-12	6.61E-12	4.62E-12	3.37E-12	4.21E-12	4.21E-12	1.11E-12	1.03E-12
2	Papalanto	2.79E-12	3.72E-12	5.00E-12	3.49E-12	2.54E-12	3.18E-12	3.18E-12	8.41E-13	7.82E-13
3	Papalanto	3.73E-12	4.98E-12	6.69E-12	4.67E-12	3.40E-12	4.26E-12	4.26E-12	1.13E-12	1.05E-12
4	Papalanto	2.34E-12	3.12E-12	4.19E-12	2.93E-12	2.13E-12	2.67E-12	2.67E-12	7.05E-13	6.55E-13
5	Papalanto	4.10E-12	5.47E-12	7.35E-12	5.13E-12	3.74E-12	4.68E-12	4.68E-12	1.24E-12	1.15E-12
6	Papalanto	3.57E-12	4.76E-12	6.39E-12	4.47E-12	3.25E-12	4.07E-12	4.07E-12	1.08E-12	1.00E-12
7	Papalanto	2.22E-12	2.95E-12	3.97E-12	2.77E-12	2.02E-12	2.53E-12	2.53E-12	6.68E-13	6.21E-13
8	Papalanto	3.69E-12	4.92E-12	6.61E-12	4.62E-12	3.37E-12	4.21E-12	4.21E-12	1.11E-12	1.03E-12
9	Papalanto	2.83E-12	3.78E-12	5.07E-12	3.54E-12	2.58E-12	3.23E-12	3.23E-12	8.53E-13	7.93E-13
10	Papalanto	3.32E-12	4.43E-12	5.95E-12	4.16E-12	3.03E-12	3.79E-12	3.79E-12	1.00E-12	9.31E-13
1	Itori	2.87E-10	3.83E-10	5.14E-10	3.59E-10	2.62E-10	3.28E-10	3.28E-10	8.66E-11	8.05E-11
2	Itori	4.06E-10	5.42E-10	7.27E-10	5.08E-10	3.70E-10	4.63E-10	4.63E-10	1.22E-10	1.14E-10
3	Itori	3.53E-10	4.71E-10	6.32E-10	4.42E-10	3.22E-10	4.03E-10	4.02E-10	1.06E-10	9.89E-11
4	Itori	3.28E-11	4.38E-11	5.88E-11	4.11E-11	2.99E-11	3.74E-11	3.74E-11	9.89E-12	9.20E-12
5	Itori	2.38E-12	3.17E-12	4.26E-12	2.98E-12	2.17E-12	2.71E-12	2.71E-12	7.17E-13	6.67E-13
6	Itori	2.79E-10	3.72E-10	5.00E-10	3.49E-10	2.54E-10	3.18E-10	3.18E-10	8.41E-11	7.82E-11
7	Itori	3.24E-12	4.32E-12	5.80E-12	4.06E-12	2.95E-12	3.70E-12	3.70E-12	9.77E-13	9.08E-13
8	Itori	3.69E-12	4.92E-12	6.61E-12	4.62E-12	3.37E-12	4.21E-12	4.21E-12	1.11E-12	1.03E-12
9	Itori	1.64E-10	2.19E-10	2.94E-10	2.05E-10	1.50E-10	1.87E-10	1.87E-10	4.95E-11	4.60E-11
10	Itori	6.56E-10	8.76E-10	1.18E-09	8.22E-10	5.98E-10	7.49E-10	7.49E-10	1.98E-10	1.84E-10
1	Wasinmi	3.28E-12	4.38E-12	5.88E-12	4.11E-12	2.99E-12	3.74E-12	3.74E-12	9.89E-13	9.20E-13
2	Wasinmi	2.34E-12	3.12E-12	4.19E-12	2.93E-12	2.13E-12	2.67E-12	2.67E-12	7.05E-13	6.55E-13
3	Wasinmi	4.02E-12	5.36E-12	7.20E-12	5.03E-12	3.67E-12	4.59E-12	4.59E-12	1.21E-12	1.13E-12
4	Wasinmi	3.16E-12	4.21E-12	5.66E-12	3.95E-12	2.88E-12	3.60E-12	3.60E-12	9.52E-13	8.85E-13
5	Wasinmi	2.17E-09	2.90E-09	3.89E-09	2.72E-09	1.98E-09	2.48E-09	2.48E-09	6.55E-10	6.09E-10
6	Wasinmi	4.06E-12	5.42E-12	7.27E-12	5.08E-12	3.70E-12	4.63E-12	4.63E-12	1.22E-12	1.14E-12
7	Wasinmi	3.36E-12	4.49E-12	6.02E-12	4.21E-12	3.07E-12	3.84E-12	3.84E-12	1.01E-12	9.43E-13
8	Wasinmi	3.73E-12	4.98E-12	6.69E-12	4.67E-12	3.40E-12	4.26E-12	4.26E-12	1.13E-12	1.05E-12
9	Wasinmi	3.24E-12	4.32E-12	5.80E-12	4.06E-12	2.95E-12	3.70E-12	3.70E-12	9.77E-13	9.08E-13
10	Wasinmi	3.86E-12	5.14E-12	6.91E-12	4.83E-12	3.52E-12	4.40E-12	4.40E-12	1.16E-12	1.08E-12
1	Olujobi	2.46E-12	3.28E-12	4.41E-12	3.08E-12	2.24E-12	2.81E-12	2.81E-12	7.42E-13	6.90E-13
2	Olujobi	3.20E-12	4.27E-12	5.73E-12	4.00E-12	2.92E-12	3.65E-12	3.65E-12	9.64E-13	8.97E-13
3	Olujobi	3.49E-12	4.65E-12	6.24E-12	4.36E-12	3.18E-12	3.98E-12	3.98E-12	1.05E-12	9.77E-13
4	Olujobi	4.02E-12	5.36E-12	7.20E-12	5.03E-12	3.67E-12	4.59E-12	4.59E-12	1.21E-12	1.13E-12
5	Olujobi	2.30E-12	3.06E-12	4.11E-12	2.88E-12	2.09E-12	2.62E-12	2.62E-12	6.92E-13	6.44E-13
6	Olujobi	3.69E-11	4.92E-11	6.61E-11	4.62E-11	3.37E-11	4.21E-11	4.21E-11	1.11E-11	1.03E-11

7	Olujobi	3.32E-12	4.43E-12	5.95E-12	4.16E-12	3.03E-12	3.79E-12	3.79E-12	1.00E-12	9.31E-13
8	Olujobi	3.12E-12	4.16E-12	5.58E-12	3.90E-12	2.84E-12	3.56E-12	3.56E-12	9.40E-13	8.74E-13
9	Olujobi	2.87E-12	3.83E-12	5.14E-12	3.59E-12	2.62E-12	3.28E-12	3.28E-12	8.66E-13	8.05E-13
10	Olujobi	3.28E-12	4.38E-12	5.88E-12	4.11E-12	2.99E-12	3.74E-12	3.74E-12	9.89E-13	9.20E-13

community had ILCR values between Level III and Level IV across all age groups (low to medium cancer risk) except for the fifth point, which had values greater than 10^{-3}, which is Level VII (extremely high). Olujobi community showed ILCR values between Levels III and IV across all age groups (low to medium cancer risk). All ILCR values obtained via dermal routes all showed Level I (very low cancer risk via the dermal route). Cancer risk is exceptionally high if children continue drinking water from the same sources over an extended period. The carcinogenic health effects of continuous exposure to high levels of cadmium include breast cancer, especially in the female population, and lung cancer. Associations between cadmium exposure and cancerous tumors (such as kidney, breast, and prostate) have been well-researched and established in the literature.

Conclusions

In conclusion, this research provided a snapshot of the condition of drinking water and the risk to which the average family in the identified communities is exposed. In particular, the research showed that children below the age of six are most at risk from prolonged exposure to cadmium contaminants in drinking water. The situation in the six studied communities in Ogun State, Nigeria, was objectively highlighted using HHRA, which encompasses the calculation of the ADD, HQ, HI, and ILCR. The assessment revealed that the carcinogenic health risk in the studied area is exceptionally high, especially in children, if they continue to drink water from the identified sources over extended periods.

The key takeaways from this research are fourfold. First, the study highlights the risks of ingesting water from domestic water sources without prior testing and /or pretreatment. Heavy metal pollution cannot be detected by physical inspection. Yet, its impact on public health can be devastating. The release of cadmium into the environment and drinking water sources has a profound impact with long-term repercussions on both people and the environment. Second, this research spotlights the need for interventions to protect the public from the impact of industrial polluters as well as other natural sources of pollution. Regulatory bodies need to intervene by enforcing the available standards and sanctioning polluters. This action is necessary to protect the unsuspecting public. Thirdly, it is important to conduct a more detailed epidemiological study in the identified geographical area and beyond. Several other communities (which were not captured in this study) may be affected by the identified problems. Fourth, this study underscored the use of HHRA tools in assessing the public's long-term exposure to environmental contaminants such as cadmium.

While this study focused on just six communities in Ogun State, Nigeria, the insights show that several other communities across the country and beyond may require urgent inspections of drinking water sources to protect consumers, especially children. This research demonstrated practical approaches to HHRA in under-represented rural and semi-rural communities.

The study was limited because the water samples used for the research were collected in one day. For a clearer insight into the extent of the identified problems, repeated sampling visits spanning all the climatic seasons of the year should be carried out. Such a detailed study will help identify the possible diluting effects of drought and precipitation on heavy metal concentrations. Furthermore, environmental protection institutions may need to prioritize an epidemiological study to establish the possible link between prevalent illness among the population in the affected areas and cadmium contamination. These actions will inform the necessary remedial actions. A detailed epidemiological study will require a multidisciplinary approach involving academic scientists, health professionals, regulatory authorities, members of the community, and other stakeholders. To safeguard public health, the continuous monitoring of drinking water resources should be an integral responsibility of water and sanitation institutions in the country. Additionally, public advocacy on affordable treatment methods for cadmium should be made available to the affected communities. Intuitive and economically friendly water testing kits should be made available to responsible, skilled, and field personnel responsible for routine testing and monitoring of drinking water resources.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. EMENIKE C.P., TENEBE I.T., OMOLE D.O., NGENE B.U., ONIEMAYIN B.I., MAXWELL O., ONOKA B.I. Accessing safe drinking water in sub-Saharan Africa:

Issues and challenges in South–West Nigeria. Sustainable Cities and Society, **30**, 263, **2017**.
2. OMOLE D., NDAMBUKI J. Sustainable living in Africa: Case of water, sanitation, air pollution and energy. Sustainability, **6** (8), 5187, **2014**.
3. IDDRISU U.F., ARMAH E.K., TETTEH E.K., AMEDORME B.S. Assessing groundwater quality: a case study in Ghana Talensi district. Water Practice and Technology, **18** (9), 2096, **2023**.
4. KHAN Z., SHAH S.T.H., MURODOV D. Poor Industrial and Domestic Wastewater Management in Developing Countries, Resulting in Depleting Drinkable Water Resources: a Geophysical and Hydrochemical Application. Water, Air, and Soil Pollution, **234** (12), 758, **2023**.
5. NKATHA K. Water Woes: 13 Undeniable Facts about Africa's Water Scarcity. Available online: https://www.greenpeace.org/africa/en/blog/55086/water-woes-13-undeniable-facts-about-africas-water-scarcity/#:~:text=According%20to%20statistics%2C%205.52%20billion,90%25%20of%20the%20continent's%20population (accessed on 17 August 2024).
6. RITCHIE H., SPOONER F., ROSER M. Clean Water. Available online: https://ourworldindata.org/clean-water (accessed on 16 August 2024)
7. AIKOWE J.O., MAZANCOVÁ J. Barriers to water access in rural communities: Examining the factors influencing water source choice. Water, **13** (19), 2755, **2021**.
8. IGHALO J.O., ADENIYI A.G. A comprehensive review of water quality monitoring and Assessment in Nigeria. Chemosphere, **260**, 127569, **2020**.
9. OMOLE D.O., LONGE E.O., MUSA A.G. An Approach to Reaeration Coefficient Modeling in Local Surface Water Quality Monitoring. Environmental Modeling and Assessment, **18** (1), 85, **2013**.
10. EMENIKE P.C., TENEBE I., OGAREKPE N., OMOLE D. Probabilistic risk assessment and spatial distribution of potentially toxic elements in groundwater sources in SouthwesternNigeria. Scientific Reports, **1**, **2019**.
11. AKPAN V.E., OMOLE D.O., BASSEY D.E. Assessing the public perceptions of treated wastewater reuse: opportunities and implications for urban communities in developing countries. Heliyon, **6** (10), e05246, **2020.**
12. OMOLE D.O., NDAMBUKI J.M. Nigeria's Legal Instruments for Land and Water Use: Implications for National Development. In: In-Country Determinants and Implications of Foreign Land Acquisitions. Evans Osabuohien (Ed): IGI GLOBAL, Hershey, PA, USA: Business Science Reference, pp. 354, **2015**.
13. OGUNBODE T.O., ESAN V.I., AKANDE J.A. Water resources endowment and the challenge of underutilization in a tropical community in Nigeria. Sustainable Water Resources Management, **10**, 72, **2024**.
14. ABIOYE S.O., PERERA, E.D.P. Public health effects due to insufficient groundwater quality monitoring in Igando and Agbowo regions in Nigeria: A review. Sustainable Water Resources Management, **5** (4), 1711, **2019**.
15. ODEY E.A., LI Z., GIWA A.S., ETOKIDEM E.U. Sanitation approach toward resource recovery in rural and semi-urban centers: Insight from South South Nigeria. Environmental Quality Management, **28** (1), 13, **2018.**
16. OYEYEMI K.D., AIZEBEOKHIA A.P., ANAKE W.U., SANUADE O.A., AKINSIKU A.A., OLOFINNADE O.M., JONATHAN H.O., AYARA W.A. Geospatial distribution of heavy metal contamination in Ewekoro Limestone, SW Nigeria. Journal of Physics: Conference Series, **1299** (1), 012080, **2019**.
17. KUBIER A., PICHLER T. Cadmium in groundwater - A synopsis based on a large hydrogeochemical data set. Science of the Total Environment, **689**, 831, **2019**.
18. ISINKARALAR O., ISINKARALAR K., NGUYEN T.N.T. Toxic metal accumulation, health risk, and distribution in road dust from the urban traffic-intensive environment. Environmental Science and Pollution Research, **31** (51), 60792, **2024**.
19. ISINKARALAR O., ISINKARALAR K., AMBADE B. Assessment of Societal Health Risks: Spatial Distribution and Potential Hazards of Toxic Metals in Street Dust Across Diverse Communities. Water Air and Soil Pollution, **235** (5), 302, **2024**.
20. IDREES N., TABASSUM B., ABD ALLAH E.F., HASHEM A., SARAH R., HASHIM M. Groundwater contamination with cadmium concentrations in some west U.P. Regions, India. Saudi Journal of Biological Sciences, **25** (7), 1365, **2018**.
21. ANGAYE T. The environmental impacts of electronic wastes in Bayelsa state, Nigeria. Moj Toxicology, **4** (5), **2018**.
22. SHAIKH R., KAZI T.G., AFRIDI H.I., AKHTAR A., BAIG J.A. An environmentally friendly enrichment method for microextraction of cadmium and lead in groundwater samples: Impact on biological sample of children. Chemosphere, **237**, **2019**.
23. EMENIKE P.C., TENEBE I., NERIS J.B., OMOLE D.O., AFOLAYAN O., OKEKE C.U., EMENIKE I.K. An integrated assessment of land-use change impact, seasonal variation of pollution indices and human health risk of selected toxic elements in sediments of River Atuwara, Nigeria. Environmental Pollution, **265**, 114795, **2020**.
24. ETIM M., BABAREMU K., LAZARUS J., OMOLE D. Health risk and environmental assessment of cement production in Nigeria. Atmosphere, **1**, **2021**.
25. SUNDARAM B., FEITZ A.J., DE CARITAT P., PLAZINSKA A., BRODIE R.S., CORAM J., RANSLEY T. Groundwater sampling and analysis-A field guide. Geoscience Australia, **2009.**
26. ISINKARALAR O., ISINKARALAR K., NGUYEN T.N.T. Spatial distribution, pollution level and human health risk assessment of heavy metals in urban street dust at neighbourhood scale. International Journal of Biometeorology, **68** (10), 2055, **2024**.
27. ISINKARALAR K., ISINKARALAR O., BAYRAKTAR E.P. Ecological and Health Risk Assessment in Road Dust Samples from Various Land Use of Düzce City Center: Towards the Sustainable Urban Development. Water Air and Soil Pollution, **235** (1), 84, **2024**.
28. ISINKARALAR O., ISINKARALAR K., BAYRAKTAR E.P. Monitoring the spatial distribution pattern according to urban land use and health risk assessment on potential toxic metal contamination via street dust in Ankara, Türkiye. Environmental Monitoring and Assessment, **195** (9), 1085, **2023**.
29. USEPA. Human health risk assessment. Available online: https://www.epa.gov/risk/human-health-risk-assessment (accessed on 17 August 2024).
30. USEPA. Risk assessment: Guidance for superfund Volume I: Human health evaluation manual (Part E, Supplemental Guidance for Dermal Risk Assessment). Available online: https://www.epa.gov/risk/risk-assessment-guidance-superfund-rags-part-e (accessed on 17 August 2024)
31. RAIS. Chemical Risk Calculator User's Guide. The Risk Assessment Information System. Available online:

https://rais.ornl.gov/tools/rais_chemical_risk_guide.html (accessed on 17 August 2024).

32. USEPA. Exposure factors handbook chapter 3 (Update): Ingestion of water and other select liquids. United States Environmental Protection Agency. Available online: https://cfpub.epa.gov/ncea/efp/recordisplay.cfm?deid=343661 (accessed on 17 August 2024).
33. OGBIYE A.S., TENEBE I.T., EMENIKE P.C., ANAKE U.W. Computation of Human Health Risk in Surface Water in Ado-Odo Ota, Ogun State, Nigeria. Data in Brief, **19**, 1574, **2018.**
34. MOHAMMADI A.A., ZAREI A., MAJIDI S., GHADERPOURY A., HASHEMPOUR Y., SAGHI M.H., ALINEJAD A., YOUSEFI M., HOSSEINGHOLIZADEH N., GHADERPOORI M. Carcinogenic and non-carcinogenic health risk assessment of heavy metals in drinking water of Khorramabad, Iran. Methodsx*,* **6**, 1642, **2019**.
35. OROSUN M.M. Assessment of arsenic and its associated health risks due to mining activities in parts of North-Central Nigeria: Probabilistic approach using Monte Carlo. Journal of Hazardous Materials, **412**, 125262, **2021**.
36. BELLO S., NASIRU R., GARBA N.N., ADEYEMO D.J. Carcinogenic and non-carcinogenic health risk assessment of heavy metals exposure from Shanono and Bagwai Artisanal gold mines, Kano State, Nigeria. Scientific African, **6**, 4, **2019**.
37. TEPANOSYAN G., MAGHAKYAN N., SAHAKYAN L., SAGHATELYAN A. Heavy metals pollution levels and children health risk assessment of Yerevan Kindergartens soils. Ecotoxicology and Environmental Safety*,* **142**, 257, **2017**.
38. LI F., QIU Z., ZHANG J., LIU C., CAI Y. Spatial Distribution And Fuzzy Health Risk Assessment of Trace Elements in Surface Water from Honghu Lake. International Journal of Environmental Research and Public Health, **1**, **2017**.
39. Nigeria Industrial Standard. Nigerian Standard For Drinking Water Quality (NSDWQ). Available online: https://africacheck.org/sites/default/files/Nigerian-Standard-for-Drinking-Water-Quality-NIS-554-2015.pdf (accessed on 17 August 2024).
40. ADEBOLA A., ADEDAYO O.B., ABIOLA O. Pollution studies on ground water contamination: Water quality of Abeokuta, Ogun State, Southwest Nigeria. Journal of Environmental Earth Sciences, **3** (5), 161, **2020**.
41. ALADEJANA J., TALABI A.O. Assessment of groundwater quality in Abeokuta Southwestern, Nigeria. International Journal of Engineering Sciences, **2** (6), 21, **2015.**
42. ADEYEMI A.A., OJEKUNLE Z.O. Concentrations and health risk assessment of industrial heavy metals pollution in groundwater in Ogun State, Nigeria. Scientific African*,* **11**, E00666, **2021**.
43. CAO J., GUO Z., LV Y., XU M., HUANG C., LIANG H. Pollution risk prediction for cadmium in soil from an abandoned mine based on random forest model. International Journal of Environmental Research and Public Health, **20** (6), 5097, **2023**.
44. FATIMA G., RAZA A.M., HADI N., NIGAM N., MAHDI A.A. Cadmium in human diseases: It's more than just a mere metal. Indian Journal of Clinical Biochemistry, **34** (4),371, **2019**.
45. RATHI B.S., KUMAR P.S., VO D.V.N. Critical review on hazardous pollutants in water environment: Occurrence, monitoring, fate, removal technologies and risk assessment. Science of the Total Environment, **797**, 149134, **2021**.