Article

Human health implications of heavy metal contaminants in well water used for domestic purposes in Ojoo, Ibadan

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Abstract
An adequate supply of safe drinking water is fundamental to the protection of public health; however, lack of sources of portable water has exposed most rural and urban dwellers to alternative water sources such as hand dug well. These sources can become severely contaminated and represent a significant health risk to the user population. This research examines the human health implications of heavy metal contaminants in hand-dug wells in Ojoo and environs, Ibadan, Nigeria. Ten samples were taken from selected wells used for domestic purposes in residential areas. These sample were analysed for heavy metals including (cadmium, chromium, lead, nickel and manganese) using Atomic Absorption Spectrophotometer (AAS). The results show that there are high concentration of most of the heavy metals in the well water samples with Pb, Ni, Cr, and Cd having mean concentrations above the maximum limit as stipulated by World Health Organisation. The risk assessment results indicates that the Hazard Quotient (HQ) and the Total Hazard Index (THI) were greater than 1 in most of the samples analysed and therefore constitutes a health risk. It is obvious from our findings that ground water gets easily contaminated and exposes users to severe health risks. Government should provide good portable water to her citizens to curb diseases arising from heavy metal contamination.

Keywords heavy metals; Hazard Quotient (HQ); Total Hazard Index (THI); risk assessment; toxicity; oral daily intake.

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1 Introduction

Safe drinking-water is very important to health. The importance of water, sanitation and hygiene for health and development has been reflected in the outcome of a series of international policy forums. These include health-oriented conferences such as the Millennium Development Goals adopted by the General Assembly of the United Nations (UN) in 2000 and the outcome of the Johannesburg World Summit for Sustainable Development in 2002. The UN General Assembly declared the period from 2005 to 2015 as the International Decade for Action, "Water for Life". Most recently, the UN General Assembly declared safe and clean drinking-water and sanitation a human right essential to the full enjoyment of life and all other human rights (WHO, 2008).

Unfortunately, access to safe drinking water remains a mirage in Nigeria and other developing countries. People on the outskirts of cities, in small communities, and in rural areas depend on wells and other unhygienic sources for their drinking water. Most residents of Ojoo in Akinyele Local Government Area of Ibadan are not any different. If a well is located and constructed correctly, it can be a source of good drinking water for decades. However, unlike water supplies in large municipal and urban centres, there are often no regulations regarding the quality of private water supplies like a well. Often, the only requirement for testing is in the event of a real estate transaction, for insurance purposes, or for other administrative reasons. Beyond this, and unless there is unexplained illness, the majority of well owners never even think to test their well for contaminants that could be present in every glass of water. Clear water does not always mean safe water.

Ground water can become contaminated from natural sources or numerous types of human activities (Table 1). Residential, municipal, commercial, industrial, and agricultural activities can all affect ground water quality. Contaminants may reach ground water from activities on the land surface, such as releases or spills from stored industrial wastes; from sources below the land surface but above the water table, such as septic systems or leaking underground petroleum storage systems; from structures beneath the water table, such as wells; or from contaminated recharge water (EPA/625/R-93/002).

Table 1 Typical sources of potential ground water contamination by land use category.

Category	**Contaminant Source**	
Agriculture	Animal burial areas	Irrigation sites
	Animal feedlots	Manure spreading areas/pits
	Fertilizer storage/use	Pesticide storage/use
Commercial	Airport	Jewellery/metal plating
	Auto repair shops	Laundromats
	Boat yards	Medical institutions
	Construction areas	Paint shops
	Car washes	Photography establishments
	Cemeteries	Railroad tracks and yards research laboratories
	Dry cleaners	Scrap and junkyards
	Gas stations	Storage tanks
	Golf courses	
Industrial	Asphalt plants	Petroleum production/storage pipelines
	Chemical manufacture/storage	Septage lagoons and sludge sites
	Electronics manufacture	Storage tanks
	Electroplaters	Toxic and hazardous spills
	Foundries/metal fabricators	Well (operating/abandoned)
	Machine/metalworking shops	Wood preserving facilities
	Mining and mine drainage	
Residential	Fuel oil	Septic systems, cesspools
	Furniture stripping/refinishing	Sewer lines
	Household hazardous products	Swimming pools (chemical storage)
	Household lawns	
Other	Hazardous waste landfills	Recycling/reduction facilities
	Municipal incinerators	Road deciding operations
	Municipal landfills	Road maintenance depots
	Municipal sewer lines	Storm water drains/basins
	Open burning sites	Transfer stations

Source: U.S. EPA (1991).

Thousands of synthetic chemicals have the potential to contaminate ground water. Methemoglobinemia or "blue baby syndrome," an illness affecting infants, can be caused by drinking water that is high in nitrates. Benzene, a component of gasoline, is a known human carcinogen. The serious health effects of lead are well known - learning disabilities in children; nerve, kidney, and liver problems; and pregnancy risks (EPA/625/R-93/002). Concentrations in drinking water of these and other substances are regulated by federal and state laws. Hundreds of other chemicals, however, are not yet regulated, and many of their health effects are unknown or not well understood. Preventing contaminants from reaching the ground water is the best way to reduce the health risks associated with poor drinking water quality.

2 Study Area and Methodology

2.1 Study area

This study was carried out in Ojoo, Akinyele Local Government Area of Oyo State, Ibadan, Nigeria. The common source of water in this area is hand-dug well. Residence use this water for domestic purposes including drinking. This is because government has failed to provide these community with pipe-borne water. In this study, Samples were taken from ten different wells; these samples were properly preserved and taken to the laboratory for preparation and analysis.

2.2 Water sampling and analysis

All chemicals and reagents used were of analytical grade. The laboratory glasswares and sampling bottles were soaked overnight in 10% nitric acid followed by vigorous rinsing with soap and distilled water prior to using it for sample collection. The sampling bottles were also rinsed with the well water sample immediately before collection. To prevent Losses of metals from dilute aqueous solution on storage, the samples were acidified with drops of 10% nitric acid on collection. To ensure the removal of organic impurities from the samples and thus prevent interference in analysis, the samples were digested with concentrated nitric acid. 10ml of nitric acid was added to 50ml of water in 250ml conical flask. The mixture was digested in a hot plate after which it was allowed to cool and then filtered. Blank was prepared following the same procedure as described above. Digested samples were transferred into plastic bottles and stored at 4^0C prior to analysis by AAS. Samples were analysed in duplicates.

2.3 Recovery studies

A recovery study was performed to validate the method of analysis. This was done by spiking selected samples with standards of known concentrations. The percentage recovery was determined according to the equation:

$$\text{Percentage Recovery} = \frac{\text{Conc. of Spiked Sample - Conc. of Unspiked Sample}}{\text{Conc. of Known Spike added}} \times 100$$

The calculated percentage recoveries ranges from 85 to 97% for all the metals analysed. This is within the acceptable limit of 100±10% (Pip, 1991).

2.4 Health risk assessment

The exposure of rural dwellers to toxic metal contamination in the water samples were quantified using the USEPA (1989) as proposed in the Risk Assessment Guideline for Superfund (RAGS) methodology, the numeric expressions for risk assessment due to ingestion is presented below (Collins et al., 2019):

$$D_{ing} = \frac{C_{water} \times IR \times EF \times ED}{BW \times AT}$$

where, D_{ing} is defined as the average daily dose (exposure dose) via ingestion of water (mg/L-day); C_{water} is defined as the estimated concentration of metals in surface water (mg/L). The other input parameters are presented in Table 2, while Table 3 presents the Oral reference dose of the various heavy metals used for the determination of toxicity responses.

Table 2 Input parameters to characterize the Average Daily Dose.

Exposure parameters	Symbols	Units	Value	
			Adult	Children
Ingestion rate	IR	L/day	2.2	1.8
Exposure frequency	EF	Days/year	350	350
Exposure duration	ED	Years	70	6
Body weight	BW	Kg	70	15
Average time	AT	Years	25550	2190
Exposed skin area	SA	cm^2	18000	6600
Exposure time	ET	hrs/day	0.58	1.0
Unit conversion factor	CF	L/cm^3	0.001	0.001

Source: (Wongsasuluk et al., 2014).

Table 3 Oral reference dose of the various heavy metals used for the determination of toxicity responses.

Heavy Metal	Oral RfD (mg/kg/day)
Cd	5.0×10^{-4}
Cu	4.0×10^{-3}
Pb	3.5×10^{-3}
Zn	3.0×10^{-1}
Fe	7.0×10^{-1}
Mn	1.4×10^{-2}
As	3.0×10^{-4}
Hg	3.0×10^{-4}

Source: Tay et al. (2016).

The Hazard Quotient (HQ) was estimated from the equation (Collins et al., 2019):

$$HQ_{ing} = \frac{D_{ing}}{RfD_{ing}}$$

where RfD_{ing} is the Oral Reference Dose or tolerable daily intake which was obtained from United States Environmental Protection Agency tables (USEPA–IRIS, 2010) and refers to the maximum amount of toxicant which does not translate to adverse effect on the one ingesting the toxicants. A summation of the hazard quotients for all chemicals to which an individual is exposed was used to calculate the total hazard index (USEPA, 2011):

THI = HQA + HQB + ………….. + HQn

Health risk assessment of toxicant was interpreted based on the values of HQ and THI. Values less than one (HQ or THI <1) means no risk and the greater the values above one, the greater is the level of risk of the toxicants manifesting long term health hazards effects (Wang et al., 2012).

Carcinogenic risks can be estimated however, by calculating the increase possibility of an individual to develop cancer as a result of exposure to the potential carcinogen over a lifetime. The estimated daily intake of toxin is converted by slope factor which is averaged by direct exposure over a lifetime to the increased chances of an individual to develop cancer (USEPA, 1989):

Carcinogenic Risk = ADI × CSF

Carcinogenic Risk is therefore a unit less of chances of an individual developing cancer when exposed over a lifetime; CSF is the cancer slope factor (per mg/kg/day) and ADI is the acceptable daily intake. Risks values exceeding 1×10^{-4} are regarded as intolerable, risks less than 1×10^{-6} are not regarded to cause significant health effects, and risks lying between 1×10^{-4} and 1×10^{-6} are regarded generally as satisfactory range, but circumstances and condition of exposure determine the range of the values (Hu et al., 2012).

3 Results and Discussion

3.1 Results

The results of the analysis are shown in Tables 4 and 5.

Table 4 Concentration of toxic metals in the studied hand-dug well.

Hand dug well	Average concentration of metals in mg/l				
Sampling points	**Pb**	**Cd**	**Cr**	**Ni**	**Mn**
W_1	1.20	0.23	0.02	0.50	0.25
W_2	BDL	0.18	0.05	1.25	0.75
W_3	0.40	0.05	0.01	0.53	0.50
W_4	2.64	0.05	0.01	0.75	0.62
W_5	0.21	0.07	0.06	0.80	0.34
W_6	BDL	0.02	0.21	0.55	0.63
W_7	1.25	0.09	0.03	1.26	0.23
W_8	0.50	0.01	0.06	0.84	0.64
W_9	1.23	0.01	0.02	1.30	0.15
W_{10}	BDL	0.05	0.02	0.25	0.20
WHO (2011) Standards	0.40	0.03	0.05	0.02	0.40
NIS (2011) Standards	0.010	0.030	0.050	0.020	0.200

Table 5 Summary of the non-carcinogenic heath risk assessment for selected heavy metals in well water including Average Daily Dose, ADD (exposure dose) via ingestion of water, Hazard Quotient (HQ) for Adult and Children and Total Hazard Index (THI).

Sampling Points/Analytes	Variable	Pb	Cd	Cr	Ni	Mn	THI
W_1	ADD_{Child}	5.98×10^{-1}	2.65×10^{-2}	2.3×10^{-3}	5.75×10^{-2}	2.88×10^{-2}	**181.019**
	ADD_{adult}	1.56×10^{-1}	6.9×10^{-2}	6.0×10^{-4}	1.5×10^{-2}	7.5×10^{-3}	**40.867**
	HQchild	1.50×10^{2}	2.65×10^{1}	7.67×10^{-1}	2.88×10^{0}	8.72×10^{-1}	
	HQadult	3.90×10^{1}	6.90×10^{1}	2.0×10^{-1}	7.5×10^{-1}	2.27×10^{-1}	
W_2	ADD_{Child}	-	2.07×10^{-2}	5.75×10^{-3}	1.44×10^{-1}	8.63×10^{-2}	**32.44**
	ADD_{adult}	-	5.4×10^{-3}	1.5×10^{-3}	3.75×10^{-2}	2.25×10^{-2}	**8.462**
	HQchild		2.07×10^{1}	1.92×10^{0}	7.2×10^{0}	2.62×10^{0}	
	HQadult		5.4×10^{0}	5.0×10^{-1}	1.88×10^{0}	6.82×10^{-1}	
W_3	ADD_{Child}	4.6×10^{-2}	5.75×10^{-3}	1.15×10^{-3}	6.1×10^{-2}	5.75×10^{-2}	**22.423**
	ADD_{adult}	1.2×10^{-2}	1.5×10^{-3}	3.0×10^{-4}	1.59×10^{-2}	1.5×10^{-2}	**5.85**
	HQchild	1.15×10^{1}	5.75×10^{0}	3.83×10^{-1}	3.05×10^{0}	1.74×10^{0}	
	HQadult	3.0×10^{0}	1.5×10^{0}	1.0×10^{-1}	7.95×10^{-1}	4.55×10^{-1}	
W_4	ADD_{Child}	3.04×10^{-1}	5.75×10^{-3}	1.15×10^{-3}	8.63×10^{-2}	7.13×10^{-2}	**88.613**
	ADD_{adult}	7.92×10^{-2}	1.5×10^{-3}	3.0×10^{-4}	2.25×10^{-2}	1.86×10^{-2}	**23.094**
	HQchild	7.60×10^{1}	5.75×10^{0}	3.83×10^{-1}	4.32×10^{0}	2.16×10^{0}	
	HQadult	1.98×10^{1}	1.5×10^{0}	1.0×10^{-1}	1.13×10^{0}	5.64×10^{-1}	
W_5	ADD_{Child}	2.42×10^{-2}	8.05×10^{-3}	6.9×10^{-3}	9.2×10^{-2}	3.91×10^{-2}	**22.18**
	ADD_{adult}	6.3×10^{-3}	2.1×10^{-3}	1.8×10^{-3}	2.4×10^{-2}	1.02×10^{-2}	**5.789**
	HQchild	6.05×10^{0}	8.05×10^{0}	2.3×10^{0}	4.6×10^{0}	1.18×10^{0}	
	HQadult	1.58×10^{0}	2.1×10^{0}	6.0×10^{-1}	1.2×10^{0}	3.09×10^{-1}	
W_6	ADD_{Child}	-	2.3×10^{-3}	2.42×10^{-2}	6.33×10^{-2}	7.25×10^{-2}	**15.74**
	ADD_{adult}	-	6.0×10^{-4}	6.3×10^{-3}	1.65×10^{-2}	1.89×10^{-2}	**63.498**
	HQchild		2.3×10^{0}	8.07×10^{0}	3.17×10^{0}	2.20×10^{0}	
	HQadult		6.0×10^{1}	2.1×10^{0}	8.25×10^{-1}	5.73×10^{-1}	
W_7	ADD_{Child}	1.44×10^{-1}	1.04×10^{2}	3.45×10^{-3}	1.45×10^{-2}	2.65×10^{-2}	**142.678**
	ADD_{adult}	3.75×10^{-2}	2.7×10^{-3}	9.0×10^{-4}	3.78×10^{-2}	6.9×10^{-3}	**14.479**
	HQchild	3.60×10^{1}	1.04×10^{2}	1.15×10^{0}	7.25×10^{-1}	8.03×10^{-1}	
	HQadult	9.38×10^{0}	2.7×10^{0}	3.0×10^{-1}	1.89×10^{0}	2.09×10^{-1}	
W_8	ADD_{Child}	5.75×10^{-2}	1.15×10^{-3}	6.9×10^{-3}	9.66×10^{-2}	7.36×10^{-2}	**24.91**
	ADD_{adult}	1.5×10^{-2}	3.0×10^{-4}	1.8×10^{-3}	2.52×10^{-2}	1.92×10^{-2}	**36.192**
	HQchild	1.44×10^{1}	1.15×10^{0}	2.3×10^{0}	4.83×10^{0}	2.23×10^{0}	
	HQadult	3.75×10^{0}	3.0×10^{1}	6.0×10^{-1}	1.26×10^{0}	5.82×10^{-1}	
W_9	ADD_{Child}	1.41×10^{-1}	1.15×10^{-3}	2.3×10^{-3}	1.45×10^{-1}	1.73×10^{-2}	**44.991**
	ADD_{adult}	3.69×10^{-2}	3.0×10^{-4}	6.0×10^{-4}	3.9×10^{-2}	4.5×10^{-3}	**41.516**
	HQchild	3.53×10^{1}	1.15×10^{0}	7.67×10^{-1}	7.25×10^{0}	5.24×10^{-1}	
	HQadult	9.23×10^{0}	3.0×10^{1}	2.0×10^{-1}	1.95×10^{0}	1.36×10^{-1}	
W_{10}	ADD_{Child}	-	5.75×10^{-3}	2.3×10^{-3}	2.88×10^{-2}	2.3×10^{-2}	**8.654**
	ADD_{adult}	-	1.5×10^{-3}	6.0×10^{-4}	7.5×10^{-3}	6.0×10^{-3}	**2.257**
	HQchild		5.75×10^{0}	7.67×10^{-1}	1.44×10^{0}	6.97×10^{-1}	
	HQadult		1.50×10^{0}	2.0×10^{-1}	3.75×10^{-1}	1.82×10^{-1}	

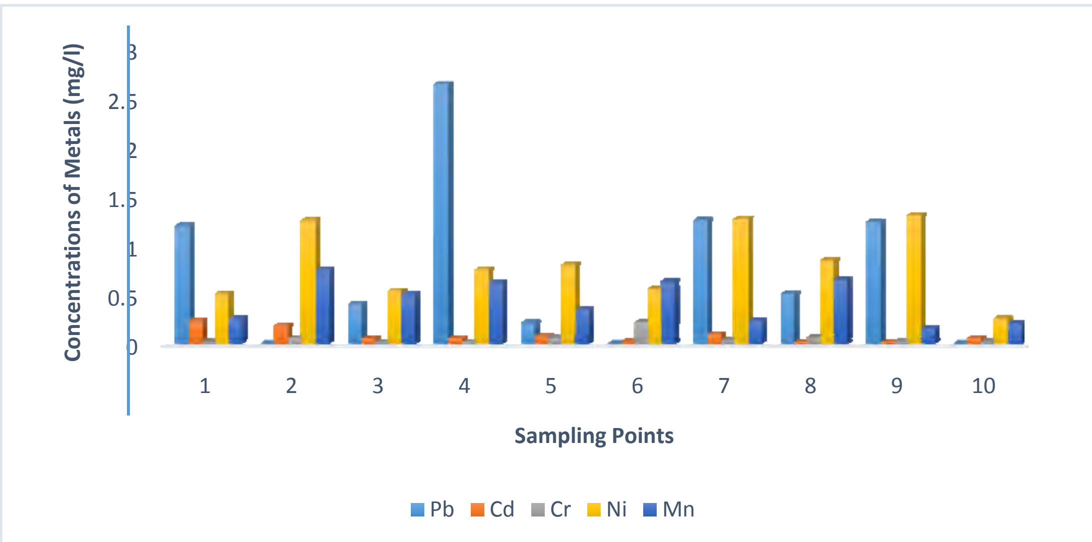

Fig. 1 Graph showing the concentrations of metals at different sampling points.

3.2 Discussion

3.2.1 Concentration of toxic metals in the studied hand-dug well

Table 4 presents the summary of the average concentrations of toxic metals in the studied hand dug wells. From the results, it is obvious that traces of toxic metals are present in these wells to varying concentrations. The concentration range of the metals as can be deduced from the table are from BDL to 2.64, 0.01 to 0.23, 0.01 to 0.21, 0.25 to 1.30, and 0.15 to 0.75 for Pb, Cd, Cr, Ni and Mn respectively. Comparing these results to WHO standards (WHO, 2011), it can be seen that these metals were present in concentration well above the acceptable limits in all the water samples analysed. The heavy metal abundance in well water sampled is in the order: Pb > Ni > Mn > Cd > Cr. Figure 1 is a graph showing the concentrations of metals at different sampling points.

World Health Organization has reported heavy metals like Arsenic (As), Cadmium (Cd), Lead (Pb) and Mercury (Hg) as the major contaminants of public health concern (WHO, 2013). Heavy Metals are components of Earth’s crust and are essential nutrients for plants and animals but at trace levels. However, all metals can be harmful in high concentrations and prolonged exposure. Prolonged exposure to heavy metals could cause lung, kidney, liver, digestive tract, and pancreas cancers; it could also cause oxidative cellular stress, respiratory problems, cardiovascular diseases, nervous system toxicity, and kidney damage via inhalation (Krzyzanowsky, 2012). Similar studies show elevated levels of toxic metals in ground and surface water sources (Adekunle et al., 2007; Ogunlaja and Ogunlaja, 2007; Nwagozie and Ogelle, 2007; Ekere et al., 2014).

The major exposure pathway of inorganic lead (Pb) is via ingestion and adsorption through the gastrointestinal tract, respiratory tract and inhalation (Vaishaly et al., 2015). Kidney and liver are considered potential targets of lead toxicity before storage in bones. Depending on the level of exposure, lead has potential to cause a variety of biological effects such as decreased hemoglobin synthesis, impairment of neurobehavioral and psychological functions, peripheral neuropathy, indirect effect on heart, renal tubular damage and reproductive problems (Jarup, 2003; Brown and Kodama, 1987). Children are particularly susceptible to Pb exposure due to high gastrointestinal uptake, and the permeable blood brain barrier leading to neurotoxin effects even at low level of exposure (Athar and Vohora, 1995).

Similarly, Cadmium (Cd) is an extremely toxic industrial and environmental pollutant classified as a human carcinogen (Group 1 – according to International Agency for Research on Cancer (IARC, 1993); Group 2a – according to Environmental Protection Agency (EPA); and 1B carcinogen classified by European Chemical Agency (IPCS, 1992; ATSDR, 2012)). Ingestion of any significant amount of cadmium causes immediate poisoning and damage to the liver and the kidneys. Compounds containing cadmium are also carcinogenic (Osha.gov., 2021). The bones become soft (osteomalacia), lose bone mineral density (osteoporosis) and become weaker. This causes the pain in the joints and the back, and also increases the risk of fractures. In extreme cases of cadmium poisoning, mere body weight causes a fracture. The kidneys lose their function to remove acids from the blood in *proximal renal tubular dysfunction*. The kidney damage inflicted by cadmium poisoning is irreversible. The *proximal renal tubular dysfunction* creates low phosphate levels in the blood (hypophosphatemia), causing muscle weakness and sometimes coma. Food and cigarette smoking are the most important exposure root of Cadmium apart from water (Vaishaly et al., 2015). It could accumulates within the kidney and liver over a long period of time.

Nickel is one of the many carcinogenic metals known to be an environmental and occupational pollutant. The New York University School of Medicine warns that chronic exposure has been connected with increased risk of lung cancer, cardiovascular disease, neurological deficits, developmental deficits in childhood, and high blood pressure (Chervona et al., 2012). Researchers at Dominican University of California have linked nickel exposure to breast cancer (Aquino et al., 2012). Also, nickel has been identified as a toxin that severely damages reproductive health and can lead to infertility, miscarriage, birth defects, and nervous system defects (Forgacs et al., 2012; Apostoli and Catalani, 2011). Upon exposure to Nickel, an individual may show increased levels of nickel in their tissues and urine.

Chromium (Cr) is a naturally occurring element present in the earth's crust, with oxidation states (or valence states) ranging from chromium (II) to chromium (VI) (Jacobs and Testa, 2005). Elemental chromium (Cr(0)) does not occur naturally. Chromium enters into various environmental matrices (air, water, and soil) from a wide variety of natural and anthropogenic sources with the largest release coming from industrial establishments. The increase in the environmental concentrations of chromium has been linked to air and wastewater release of chromium, mainly from metallurgical, refractory, and chemical industries. Chromium released into the environment from anthropogenic activity occurs mainly in the hexavalent form (Cr(VI)) (ATSDR, 2012). Hexavalent chromium (Cr(VI)) is a toxic industrial pollutant that is classified as human carcinogen by several regulatory and non-regulatory agencies (IARC, 1990; U.S. EPA, 1992). The health hazard associated with exposure to chromium depends on its oxidation state, ranging from the low toxicity of the metal form to the high toxicity of the hexavalent form.

Furthermore, Manganese is needed by the body tissues at low concentration; however, deficiency of manganese could lead to osteoporosis, epilepsy, and diabetes mellitus; and concentration above threshold values causes manganese toxicity in the body (Iwegbue et al., 2013). Neurological toxicity associated with excess manganese could lead to behavioural changes, which are characterized by slow movement, tremors, facial muscle spasms, irritability, aggressiveness, and hallucinations (Iweala et al., 2014). Health authorities and governments at local government levels should put a measure in place to providing potable water to rural dwellers in order to avert serious health emergencies arising from these contaminants.

It is important to note that this study focuses strictly on heavy metal contamination of water media and exposure through ingestion. In conducting an environmental health risk assessment, other media/exposure routes may be considered as shown in Fig. 2.

3.2.2 Health risk assessment of heavy metals from calculated exposure dose via ingestion of water

The calculated exposure dose via ingestion of water (ADD) for both child and adult; hazard quotient (HQ) and total hazard index (THI) are presented in Table 5. The result of the potential risk assessment calculations shows that the hazard quotient (HQ) of the metals ranges from $1.58 \times 10^0 - 3.53 \times 10^1$, $1.15 \times 10^0 - 6.90 \times 10^1$, $1.0 \times 10^{-1} - 8.07 \times 10^0$, 3.75×10^{-1} -7.25×10^0, and 1.82×10^{-1} - 2.62×10^0 for lead, cadmium, chromium, nickel and manganese respectively; all showing values of HQ greater than 1 (HQ > 1). These values pose a health risk to those who depend on them for drinking and cooking. The Total Hazard Index (THI) of the metals in all the wells sampled show high risk with the highest risks in sampling points W_1 and W_7 with the values 181.019 and 142.678 respectively. This result is a source of concern because of possible heavy metal bioaccumulation among the consumers of these water sources.

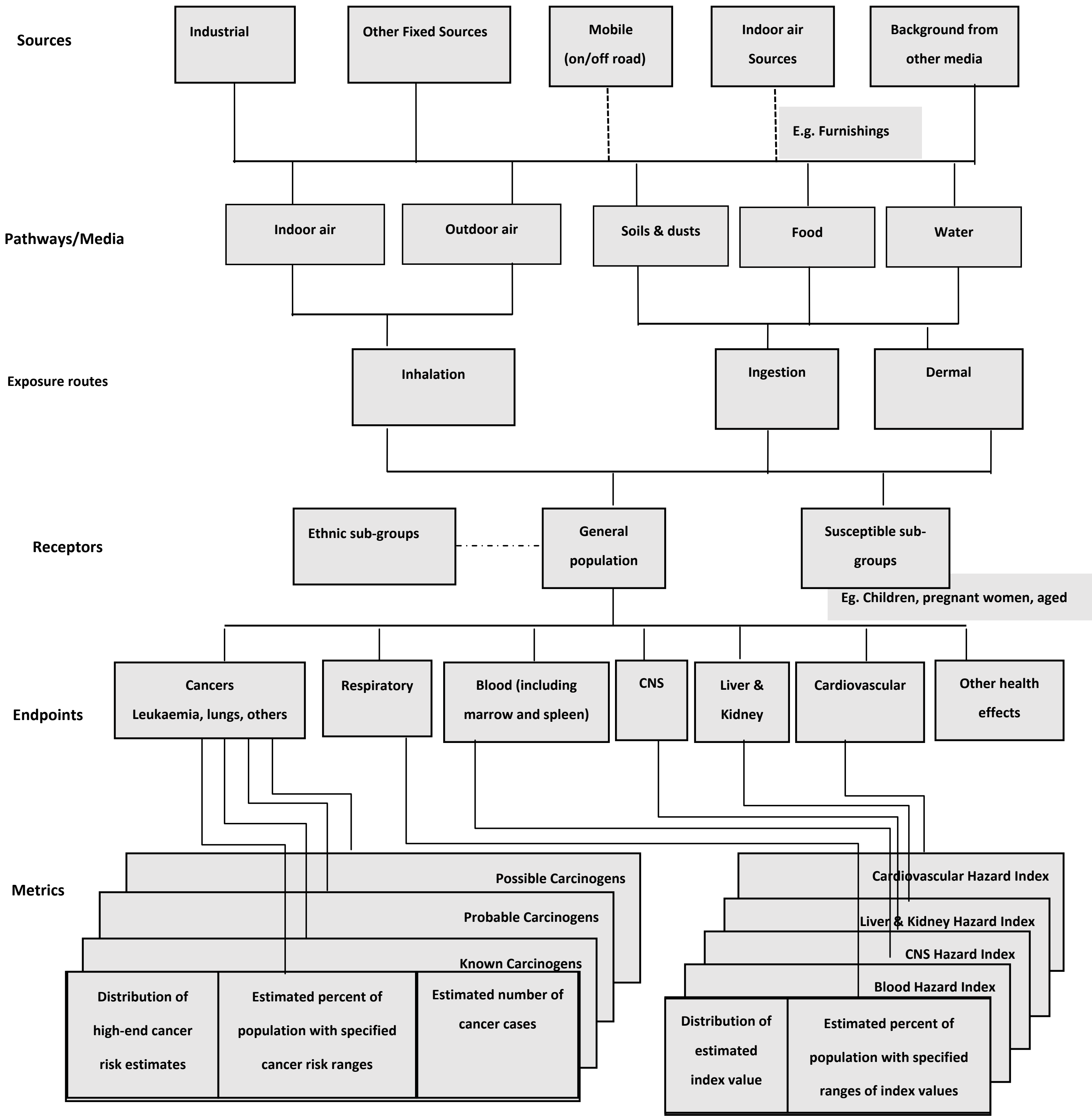

Fig. 2 Expanded illustration of the major exposure pathways, potentially exposed groups leading to potential health outcomes. Solid lines indicate pathways usually considered. Other pathways may not be considered in conventional EHRAs. Adapted from NRC (2008).

4 Conclusion

Five toxic metals were assessed in water samples examined in this research. The results show that these metals were present at varying concentrations. Continuous consumption and use of these water sources poses a serious health concern to those who depend on these water sources for domestic purposes. The state government should do everything possible to provide portable water to both rural and urban dwellers in the state as this would reduce the cases of major and minor health risks arising from heavy metal contaminations.

List of Abbreviations

WHO	-	World Health Organisation
US-EPA	-	United State Environmental Protection Agency
ADI	-	Acceptable Daily Intake
CSF	-	Cancer Slope Factor
AAS	-	Atomic Absorption Spectroscopy
BDL	-	Below Detection Limit
ADD	-	Average Daily Dose
HQ	-	Hazard Quotient
THI	-	Total Hazard Index
UN	-	United Nations
RAGS	-	Risk Assessment Guideline for Superfund
NRC	-	National Research Council
NIS	-	Nigerian Standard for Drinking Water Quality
EHRA	-	Environmental Health Risk Assessment

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