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Evaluating the human health risks of heavy metal contamination in copper and steel factory effluents in Nnewi, Anambra State, Nigeria

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ABSTRACT

Heavy metal (HM) contamination above permissible limits poses a risk to human health. The study evaluated the health risk (cancer and non-cancer) of exposure to copper (Cu) and steel factory wastes on water samples near the factory based on the hazard quotient (HQ) derived from the HM concentrations. Triplicate water samples were collected by purposive sampling and their concentrations of selected HMs [Pb, Zn, Cu, Mn, Mg, Fe, Cd] were analyzed by Atomic Absorption Spectrometry. The health risks were determined from the concentrations of HMs in water samples ingested orally. The range concentrations were [Fe, 0.074–0.178], [Pb, 0.011–0.013], [Cd, 0.005–0.02], and [Mn, 0.023–0.045] which were above the reference values set by World Health Organization. The contribution of the individual metal to the chronic daily intake (CDI) in the three samples are Mg>Fe>Mn>Zn>Cd>Pb>Cu. In the three different samples, the CDI for Mg was highest in the factory borehole [0.15523]. Comparing the CDI values from the three different collection points, Cu, Pb, Zn and Fe were highest from the factory effluent. Mg contributed the highest HQ [5.46307] in all the water samples, followed by Pb [3.87618] and then Cd[2.64009], which reflect their significantly high hazard indices observed. The incremental life cancer risk [ILCR] via ingestion showed that the cancer risk resulting from Cd in the different sources demands attention. The factory effluent recorded the highest mean levels of the metals analyzed, which were higher than the permissible limits. Magnesium contributed the highest non-cancer risk, while Cd had the highest cancer risk.

1. Introduction

The contamination of ground water by heavy metals is one of the most important environmental problems in recent time [1]. Anthropogenic and industrial activities have increased human exposure to heavy metals with attendant adverse health effects [2]. Globally, millions of people are exposed to these heavy metals daily through the air, water, and soil [3], and outbreak of water-borne diseases originating from ground water contamination have been reported [4,5]. The main sources of ground water contamination are natural/ geogenic, poor landfill waste and sanitary practice, and the use of agrochemicals [4]. Borehole water has continuously been a primary source of water for drinking and domestic purposes for the residents of Nnewi in Anambra State Nigeria [6,7].

The study area, Nnewi, is an urban center in Southeast Nigeria with significant industrial, agricultural, and residential activities [8]. The town is home to many medium scale industrial clusters in Southeastern Nigeria [9] that produces automobile, petrochemicals, metals, paints, electric wires, cables, car battery, vegetable oil, soap, plastic tanks, and animal feeds [10,11]. These industrial activities have been reported to be responsible for polluting the surrounding land surface in Nnewi [9,12,13]. Also, these unbridled human activities, including borehole water pumping, industrial emission of heavy metals, and poor waste handling, have led to significant water pollution in the region [14]. Due to poor regulations, industrial run off with little or no treatment is either entirely or in part discharged into nearby areas, agricultural fields or waste dumps, leading to the pollution of ground water with HM in the area [15]. Wastewater from industries may possibly contain heavy metals, which accumulate with time in soil deposit along waste waterways and in organisms that dwell in such waterways. In densely populated urban areas or places where wastewater is recycled for domestic and agricultural purposes human exposure to contaminated wastewater

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is common [16].

There are studies conducted in and around Nnewi to examine surface and groundwater quality for drinking and agricultural purpose using different water quality indices [5,9,10,13,17,18]. Also there are studies on heavy metals content of borehole water within landfill/waste dumpsites in Nnewi [7,19] and on soil samples [11,20]. There is a remarkable lack of study on metal poisoning resulting from copper and steel factory wastes and its consequences for human health in the study region.

The copper (Cu) manufacturing industries play a significant part in the production of copper wires, burners, pesticides, and cupric dyes for tanning industries. Wastes from metal finishing industries contain contaminants like heavy metals and organic substances at levels that are harmful to humans. Steel and Cu factory wastes contain acidic discharge, heavy metals, and organic pollutants that meaningfully contribute to the pollution of the environment. As a result of disparities in the type of raw materials used, by-products, and state-of-the-art operation system, contaminated water discharged from steel and copper manufacturing industries varied greatly in the concentration of heavy metals [21,22].

- The popular technique for assessing health risk impact is to directly compare the determined values with the allowable limits. This system, though acceptable, does not adequately represent hazard levels and also cannot differentiate risk agents of the most concern [23]. By assessing the potential hazard risk involved, the probable health implications due to numerous pollutants in an environment can be estimated [24]. This strategy has been used in many studies to determine the likely harmful health risks of human exposure to polluted water sources, especially heavy metals [25,26].The health risk assessment is a good instrument for evaluating the relationship between the environment and human health, which can be quantitatively expressed in terms of hazard degree [27].

Although there has not been an outbreak of any disease condition in Nnewi which was attributed to heavy metal poisoning, it is known that rising heavy metal concentration levels in drinking water can cause immediate and chronic health problems for the residents [28]. The study

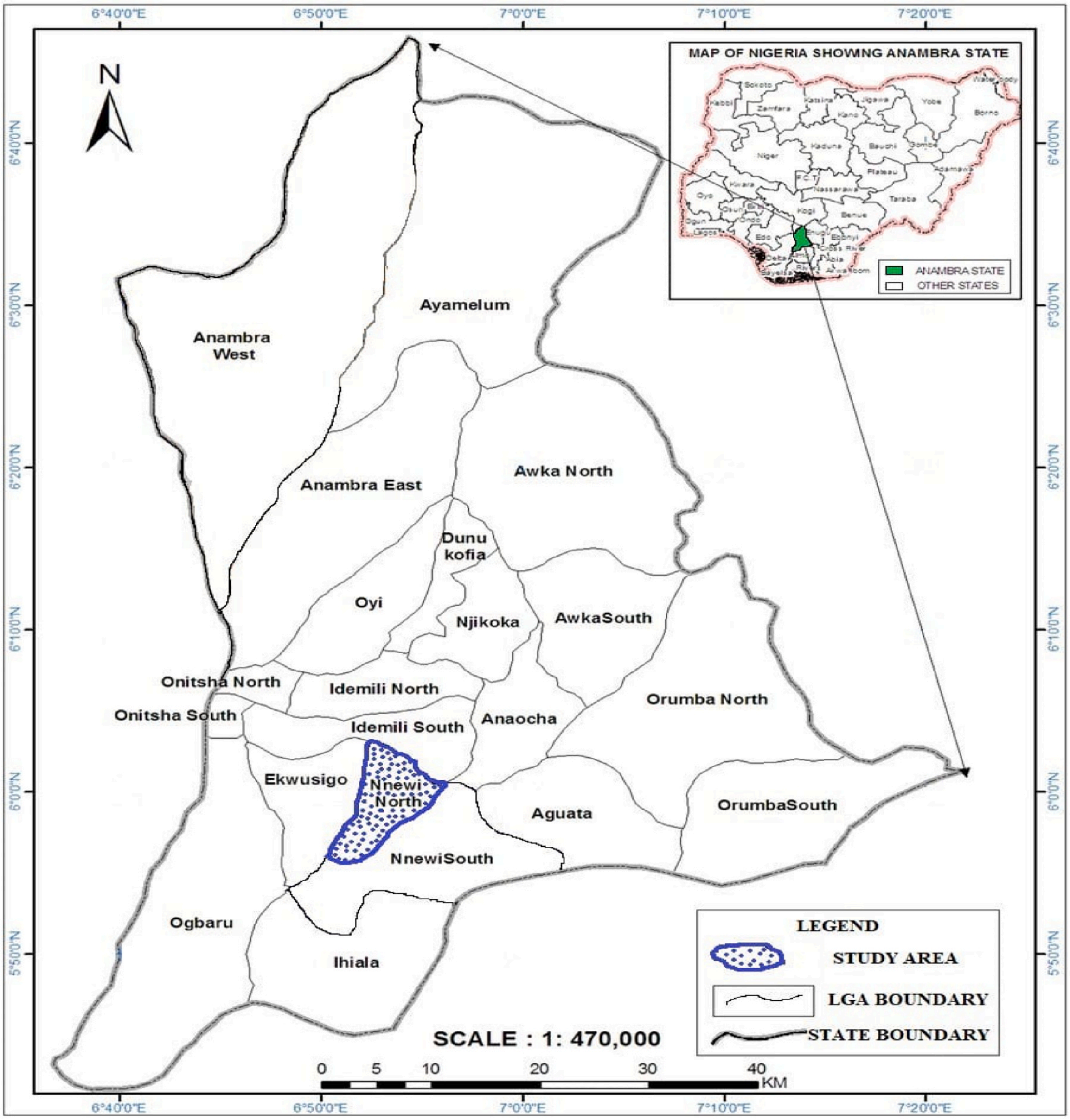

Fig. 1. Sampling location. (Source Google map).

site is located in a residential area and its wastes may affect the ground water dispersion patterns with probable health worries regarding oral exposure to heavy metals through borehole drinking channels [5]. Thus, this study evaluated the heavy metal pollution status and the negative health risks of exposure to copper and steel factory wastes on water samples in and around the factory in Nnewi, Anambra State, Nigeria.

2. Materials and methods

2.1. Study site

This study was carried out at a copper and steel factory site that produces electric wires and cables. The factory is located in the industrial town of Nnewi in the Nnewi North Local Government Area of Anambra State, Nigeria. The study site is located close to residential areas. Nnewi lies between longitudes $6^o\ 91^1$ E and $6^o\ 55^1$ E and latitudes $6^o\ 16^1$ N and $6^o\ 10^1$ N (Fig. 1). Its altitude ranges from 105 m to 300 m above sea level. There is rapid urbanization in the city due to its commercial activities. The climate is hot and humid. The year is divided into two major seasons, namely, the rainy season (April to October) averaging between 2000 and 3000 mm per year and the dry season (November to March) with average yearly temperatures of 22–33∘C [15]. Nnewi is a metropolitan area renowned for its large automobile markets and spare parts fabrication with expanding industrialization and economic activities. It is home to Nigeria's first automobile producing company [5,18].The increasing population and economic activities among the residence have contributed to the volume of both industrial and residential wastes in the study area. The wastewater from these industries and residential areas are channeled through a drainage system that empties into streams.

2.2. Sample collection

The samples were collected in the month of November 2021. Samples were collected by purposive sampling from 3 different sources in triplicates and grouped into 3 (samples from the effluent discharge of the factory, samples from boreholes in the factory, and samples from boreholes around the factory; about 100 m away from the factory).

Preliminary measures were taken following the standard guidelines [29] to avoid any possible contamination. Liquid samples were collected by submerging a sterile, clearly labeled (5 mL) plastic universal container beneath the surface of the factory's effluent. Factory and neighborhood borehole water samples were collected directly from the plastic tap after running the tap for about 2 min. Each sample was mixed with 1 mL of concentrated nitric acid as a preservative and capped tightly. The samples in batches were taken to the laboratory immediately after collection and were analyzed within seven days.

2.3. Hydrogeology of study area

Nnewi region is geologically underlain by Nanka Sand and Ogwashi-Asaba formation. The lithostratigraphic composition of Nanka sand are poorly sorted to friable sand, medium to coarse grain sand, and silt stone with intercalation of calcareous shale, while that of Ogwashi-Asaba formation is composed of lignite, unconsolidated sandstone and mudstone with clay intercalations. What account for the groundwater in the region are those fine, medium to coarse sand units which either could be poorly sorted that form the aquifer within the Nnewi region. Due to these sand units, the ground water potential within this region could be high within those aquifer zone [13,19,20].

2.4. Sample preparation and analysis

The samples were each digested with concentrated HNO_3 before analysis using AAS (Model WFX 210). The different sample was well shaken and 100 mL of each sample was transferred into a 250 mL Pyrex beaker. Ten (10) mL of concentrated HNO_3 was added. The solution was gently heated and then evaporated to 20 mL volume. Another 5 mL of concentrated HNO_3 was added followed by the addition of 5 mL H_2O_2. The beaker was covered with a watch glass immediately. The mixture was continuously heated to produce white fumes and a clear solution which was cooled at room temperature. This was to destroy organic matter, removes interfering ions and brings metallic compounds in suspension to the solution [30]. After digestion, the resulting solution was then filtered through Whatman paper No 42. The filtrates were transferred into a 100 mL volumetric flask and made up to the mark with distilled water and then mixed well. The solution was then transferred into a polypropylene bottle, ready for AAS analysis [18].

For the individual metal concentration analysis using atomic absorption spectrophotometer (AAS), the corresponding hollow cathode lamp was appropriately used. An incision width of 0.4 nm was used with corresponding wavelengths of elements of 324.8, 283.3, 248.3, 213.8, 279.5, 228.8 and 285.2 nm for Cu, Pb, Fe, Zn, Mn, Cd and Mg, while the corresponding limit of detection (LOD) for Cd and Pb is 0.0003 ppm and 0.0001 ppm for Cu, Mn, Zn, Fe, and Mg, respectively. The reagent and chemicals used were of analytical grade and manufactured by Sigma-Aldrich.

A 1000 ppm stock solution of 2 % HNO_3 was used to prepare a standard solution and calibration standards for the experiment. For each heavy metal, two standard solutions were prepared from the stock solution. The blank samples and certified reference materials were analyzed to ensure the accuracy, consistency and reproducibility of the results [31]. The results were found within 5 % of the certified values and a recovery rate between 93.4 % and 101.2 %. After every 10 samples, a certified standard and a blank solution were run to check for contamination and drift. The analyses were performed in triplicate with the mean concentration of the metal present extrapolated from the standard curve recorded [7].The heavy metals determination and their instrumentation procedures were applied following standard guidelines [32]. Every batch of samples was prepared similarly to the reagent blanks. Analysis of a mixture of metal standards (Cu, Pb, Fe, Zn, Mn, Cd and Mg) prepared from their stock solutions was also carried out as part of the analytical data quality assurance. Evaluation of the precision and accuracy of the analytical instrument was performed by triplicate standard analysis.

2.5. Human health risk assessment

2.5.1. Exposure assessment

To assess both non-cancer and cancer risks for adults, the chronic daily intake (CDI) of HMs, which represents the lifetime average daily dose (LADD) of exposure to a contaminant, was used [33]. The CDI of the HMs via oral ingestion was calculated using Eq. 1:

$$CDI = (C \text{ x } IR \text{ x } EF \text{ x } ED)/(BW \text{ x } AT) \ldots\ldots\ldots\ldots \quad (1)$$

Where: CDI is the chronic daily intake (mg/kg/day); C is the concentration of the contaminant in the factory effluent, factory borehole, and neighborhood borehole (mg/L); IR is the ingestion rate per unit time (2.2 L/day for an adult) [33]; ED is the exposure duration (30 years for an adult); EF is the exposure frequency (365 days/year); BW is body weight (70 kg for an adult); AT is the average exposure time (for carcinogens, AT= 70 ×365 = 2550 days for adults; for non-carcinogens, AT = ED x 365 = 10950 days for adults, respectively), [33]. The other variables for estimating human risk assessment through different pathways are listed in Table 1.

2.6. Non-cancer risks

Non-cancer risks due to the non-carcinogenic effects of HMs in the factory effluent, factory borehole, and neighborhood borehole were determined by the non-cancer hazard quotient using Eq. 2:

Table 1
Parameters used for estimating exposure assessment of heavy metals in drinking water.

Parameters	Unit	Value
Concentration of heavy metal	Ppm	-
Water ingestion rate(IR)	L/day	2.2
Exposure frequency (EF)	day/year	365
Average exposure time (adults)(AT)	days	10,950
Exposure duration (adults)(ED)	years	30.0
Average body weight (adult) (Bw)	Kg	70.0
Oral reference dose (copper)	mg/kg/day	0.04
Oral reference dose (zinc)	mg/kg/day	0.3
Oral reference dose (manganese)	mg/kg/day	0.14
Oral reference dose (magnesium)	mg/kg/day	0.08
Oral reference dose (iron)	mg/kg/day	0.3
Oral reference dose (Cadmium)	mg/kg/day	0.0005
Oral reference dose (lead)	mg/kg/day	0.0003
Cancer slop factor (lead)	mg/kg/day	0.0085
Cancer slop factor (cadmium)	mg/kg/day	6.3

Ref:[35]

$$HQ = CDI/RfD\ldots\ldots\ldots\ldots \tag{2}$$

Where: HQ is the non-cancer hazard quotient; CDI is the chronic daily intake (mg metal/kg/day); and RfD represents the chronic oral reference dose, which approximates the human population daily oral exposure level, plus a delicate subpopulation that is probably to be without a significant risk of harmful effects through lifetime [34]. Possible risk to human health as a result of contact with multiple HMs was determined by the chronic hazard index (HI), which is the sum of all HQ calculated for the individual heavy metal [35,36]. A value of HQ or HI < 1 implies no significant non-cancer risks; a value ≥ 1 implies significant non-cancer risks, which increase with the increasing value of HQ or HI [37].

2.7. *Cancer risk*

Cancer risk is the hazard from a lifetime average dose exposure to 1 mg/kg body weight/day of a pollutant. Cancer risk was expressed in terms of incremental lifetime cancer risk (ILCR), which is the probability that one may develop cancer over a 70-year lifetime due to a 24-hour exposure to a potential carcinogen [38]. Cancer risk was calculated as the product of CDI (mg/kg/day) and cancer slope factor (CSF) measured in (mg/kg/day) [38]:

$$ILCR = CDI \times CSF\ldots\ldots\ldots \tag{3}$$

Where: ILCR = incremental life cancer risk; CDI = chronic intake (mg/kg/BW/day); CSF = cancer slope factor. The total cancer risk due to exposure to multiple pollutants as a result of the contact or consumption of a particular type of water (factory effluent, factory boreholes, and neighborhood boreholes) was assumed to be the sum of each metal incremental risk (ΣILCR). The minimum or acceptable cancer risk for regulatory purposes is considered by the United States Environmental Protection Agency (USEPA) to be within the range of 1×10^{-6} to 1×10^{-4} [36].

2.8. *Statistical analysis*

The statistical analysis was done using SPSS 20 software (SPSS Inc., Chicago). An analysis of variance (ANOVA) was used to test whether or not significant differences existed between groups. Statistical significance was considered at $p < 0.05$.

3. Results and discussion

The results of the concentrations of the heavy metals in the different water samples are presented in Table 2. The results show the concentrations of the studied heavy metals in the factory effluent, borehole, and neighborhood borehole. The result showed that the mean values of the iron(Fe), lead (Pb), cadmium (Cd), and manganese (Mn) were above the reference limit while cupper(Cu) and zinc (Zn) were within the reference values set by World Health Organization (WHO) and United State Environmental Protection Agency (USEPA) [29,39]. Copper was found to be significantly higher in the factory effluent relative to the factory borehole and neighborhood borehole (P<0.05). There was no trace of copper in the factory borehole, while negligible quantities were recorded from the neighborhood borehole. For all the metals analyzed, the factory effluent recorded the highest levels of each metal when compared to the borehole water inside the factory and the water from the neighborhood boreholes, respectively. This may be attributed to the industrial activities going on inside the copper and steel factory. Copper, like the other metals, was found highest in the factory effluent because copper and other metals are used in the manufacture of various items in the factory, including electrical wires, steel equipment, and alloys that could find their way into the environment. Copper is important for good health, but higher concentrations can be dangerous [40]. In high concentrations, Cu can elicit harmful effects on the intestine, liver and the stomach [41,42]. Also, when ingested in excess amounts, it can cause skin cancer, peripheral neuropathy, and vascular disease [43,44].

The level of iron in the factory waste was significantly higher than in the neighborhood borehole. These values were significantly higher than the reference value for iron in drinking water, which is 0.007 ppm [39]. The values of iron exceeded the reference limit in the factory waste, which can be attributed to it being one of the primary metals used and anthropogenic activity in the factory under study. Iron deficiency can result in anaemia and fatigue, while higher concentrations could result in neurological defects [45].

The concentrations of lead in the factory effluent and the factory borehole were 0.013 and 0.011 ppm, respectively, which were not significant compared to the neighborhood borehole. These values were higher than the reference value of lead (0.0035 ppm) [39]. Lead contamination is known to cause central nervous system injury, lung dysfunction, and hematological alterations (anaemia) [3]. Workers can be occupationally exposed in different ways, especially in mines and smelters, welding of lead-painted metals, and glass industries [40]. Inhalation of lead-contaminated dust particles and aerosols or consumption of contaminated food and water are the exposure pathways for lead. Long-term exposure to lead intoxication can lead to acute psychosis, reduced consciousness, kidney dysfunction and respiratory damage as a result of inflammatory, oxidative, and immune modulatory mechanisms [46,47]. Headache, dullness, memory loss, and irritability are the initial symptoms of lead-associated exposure poisoning [48]. Lead poisoning can induce disruption of hemoglobin synthesis and anemia and may decrease intelligence capacity in children with chronic exposure to low concentrations [49].

The mean cadmium concentrations in the factory effluent, borehole and neighborhood borehole were 0.017, 0.020, and 0.005 ppm, respectively. The mean cadmium concentrations in the factory effluent and borehole were significantly higher than the reference range of cadmium, which is 0.0005 ppm [39]. Cadmium (Cd) exposure in water may disrupt vital mechanisms in the body. Cadmium has been classified as carcinogenic among other health hazards linked to its dietary intake that are associated with injuries to neurons, skeletons, kidneys, and cardiovascular disorders by the International Agency for Research on Cancer (IARC) [35,50]. It occurs naturally and from processes like fossil fuel burning, industrial waste, fertilizer application, and significantly in humans through cigarette smoking, working in primary metal industry, and cadmium-contaminated work places [40,51]. Cadmium is also reported to cause degenerate bone disease, gastrointestinal discomfort, kidney dysfunction, and liver and lung disorders [52–54]. Chronic exposure to Cd in children includes injuries to the respiratory, renal, skeletal, and cardiovascular systems and the development of cancers of

Table 2
Mean concentration of heavy metals in the liquid effluent, factory borehole and neighborhood boreholes.

Heavy Metals	Copper (ppm)	Lead (ppm)	Zinc (ppm)	Manganese (ppm)	Cadmium (ppm)	Magnesium (ppm)	Iron (ppm)
Factory effluent N=6	0.006±0.01^{a}	0.013±0.01^{a}	0.094±0.09^{a}	0.036±0.04^{a}	0.017±0.01^{a}	4.823±2.36^{a}	0.178±0.40^{a}
Factory borehole N=6	0.000±0.00^{b}	0.011±0.00^{a}	0.003±0.00^{b}	0.023±0.02^{a}	0.020±0.00^{a}	4.939±0.04^{b}	0.000±0.00^{b}
Neighborhood borehole N=6	0.001±0.00^{c}	0.013±0.00^{a}	0.005±0.01^{c}	0.045±0.02^{a}	0.005±0.01^{b}	4.144±0.72^{b}	0.074±0.07^{b}

Results are mean ±SD of triplicate readings. Values with different alphabetical superscript in a column are significant to each other (P≤0.05).

the lungs, kidneys, prostate, and stomach [49].

The concentration of manganese in this study was 0.036, 0.023, and 0.045 ppm, respectively, in the factory effluent, borehole, and neighborhood borehole, respectively. These values were higher than the reference values of Mn (0.014 ppm) [39]. The highest Mn value was recorded in the neighborhood borehole, though not significantly higher than the factory effluent and borehole. Manganese (Mn) is vital in the carbohydrates, cholesterol, and amino acid metabolism. Exposure to higher concentrations of Mn can result in neurotoxicity, male infertility, birth defects, and bone defects [40,43,55]. The introduction of methyl cyclopentadienyl manganese tricarbonyl (MMT) as a gasoline additive has become of global concern as it is linked with the development of tremor and cognitive damage [40].

The results showed that the mean zinc concentration ranged between 0.003 and 0.094 ppm which was significantly lower than the reference limit of 0.3 ppm [39]. Also, the factory effluent recorded the highest value of 0.094 ppm which was significantly to the factory borehole and neighborhood borehole. Zinc toxicity is symbolized by irritability, loss of appetite and nausea and may provide protection against cadmium and lead toxicities [56]. Zinc toxicity is also determined by conditions like temperature, pH and hardness of the water [29].

A study that evaluated some toxic elements in groundwater in the industrial area of Nnewi reported a range of 0.00–0.01 ppm for cadmium and 0.1–0.38 ppm for Fe respectively [9]. The study reported high Cd values above the guideline value of 0.003 due to poor wastes disposal from battery and fertilizer producing industries to the environment. They also reported the Fe concentration in their study to be above the recommended guideline of 0.3 and traced it to the geology of the study area that is rich in sedimentary rocks [9]. Another study on the heavy metals contamination of groundwater around Nnewi industrial area showed that the concentrations of Cu, Fe, Zn and Pb were within their WHO permissible limits except Pb [18] but a similar study results showed high distribution of Cu, Cd, and Zn while Pb was not detected [10]. A study on the assessment of water quality in parts of Nnewi reported the levels of Pb and Cd to be higher than WHO permissible limits but did not detect Fe [13]. Aralu et al. [7] reported the Fe and Cd levels to be above the WHO permissible limits while Zn and Cu levels were below their permissible limits respectively. Their study also showed Pb and Mn to be near/equal their permissible limits. A study on urban water pollution by heavy metal in a nearby city (Onitsha) reported that Cd, Pb and Fe were above the WHO permissible limits while Cu and Zn levels were below the WHO limit [17]. A recent study also reported Fe, Pb and Cd levels to be above the maximum allowable values while Cu was below established WHO limit [5].

The results for the chronic daily intake (CDI) or (the average daily intake dose, ADI) for exposure pathway in the liquid factory effluent and borehole and in the neighborhood boreholes are shown in Table 3 for the metals. The CDI indices for the heavy metals in the factory effluent were found to be in the order Mg >Fe >Zn >Mn >Cd >Pb >Cu and Mg >Mn >Cd >Pb >Cu=Fe for the factory borehole. The CDI for the neighborhood borehole ranged from 0.00016 to 0.13024 and in the order Mg >Fe >Mn >Cd >Pb >Zn=Cd >Cu. The CDI for the neighborhood borehole ranged from 0.00016 – 0.13024 and in the order Mg >Fe >Mn >Pb >Zn =Cd >Cu. In the three different samples, the CDI for Mg was highest with the factory borehole also highest. Comparing the CDI values from the three different collection points, Cu, Pb, Zn and Fe were highest from the factory effluent. For Pb the CDI trend was (factory effluent = neighborhood borehole) > factory borehole while for Pb it was factory borehole >factory borehole > neighborhood borehole. The contribution of the individual metal to the CDI in the three samples are Mg>Fe>Mn>Zn>Cd>Pb>Cu. It is clear from the results that magnesium contributed the highest CDI followed by Fe while Cu and Pb contributed the least CDI. Magnesium, therefore, could pose a health risk to the workers working at the factory site studied. Reports from animal and human studies indicate that Cd could predispose humans to cancer [35,57,58]. We observed a lower contribution of Cd to CDI in this study.

The hazard quotient (HQ) and hazard index (HI) for the heavy metals in the three different samples collected in and around the factory site are shown in Table 4. The HQ trend was Mg>Pb>Cd>Fe>Mn>Zn>Cu, with Mg, Cd, and Pb having HQ slightly greater than 1, while Cu, Zn, Mn, and

Table 4
Hazard Quotient (HQ) and Hazard Index (HI) in the liquid effluent, factory borehole and neighborhood boreholes.

Heavy metals	Factory effluent	Factory borehole	Neighborhood borehole	Hazard index (HI)
	Hazard quotient	Hazard quotient	Hazard quotient	
Copper	0.00471	0.00000	0.00079	0.0055
Lead	1.36190	1.15238	1.36190	3.87618
Zinc	0.00985	0.00031	0.00052	0.01068
Manganese	0.00818	0.00516	0.01010	0.02344
Cadmium	1.06866	1.25714	0.31429	2.64009
Magnesium	1.89475	1.94032	1.62800	5.46307
Iron	0.01865	0.00000	0.00775	0.0264
				∑(HI) 12.04536

Table 3
Chronic Daily Intake (CDI) or Average Daily Intake (ADI) doses in the liquid effluent, factory borehole and neighborhood boreholes.

Heavy Metals	Copper	Lead	Zinc	Manganese	Cadmium	Magnesium	iron
Factory effluent N=6	0.00019	0.00041	0.00295	0.00113	0.00053	0.15158	0.00559
Factory borehole N=6	0.00000	0.00035	0.00009	0.00072	0.00063	0.15523	0.00000
Neighborhood borehole N=6	0.00003	0.00041	0.00016	0.00141	0.00016	0.13024	0.00233

Fe had HQ less than 1. The HQ results from the factory borehole were $Mg>Cd>Pb>Mn>Zn>Fe{=}Cu$. Also, Mg, Cu, and Pb presented HQ values greater than 1 while those of Zn, Mg, Cu and Fe were less than 1 and negligible. From the results obtained in the neighborhood bore hole, the HQ was highest with Mg, followed by Pb but least with Zn and Cu, respectively. A HQ value less than one ($HQ<1$) is safe, while a HQ greater than one ($HQ>1$) is unsafe [35,59]. From the results obtained (Table 4), Mg, Cd, and Pb had a HQ that was above 1 and may indicate a carcinogenic/non-carcinogenic risk to the factory workers and the neighborhood residents. In our previous study, Cd was the highest contributor to the HQ, and closely followed by Pb with a $HQ>1$ [35]. The HQ for the heavy metals, which were greater than one, implies that the factory workers or the surrounding population would also experience non-cancer risks as a result of exposure to these heavy metals in the drinking water sources.

The values for the HQ indices for Mg were in the order factory borehole > factory effluent > neighborhood borehole, while for Pb the HQ trend was (factory effluent = neighborhood borehole) > factory borehole. For Cd, the HQ trend was factory borehole > factory effluent > neighborhood borehole, respectively. From the results obtained, it is apparent that Mg contributed the highest HQ values in all the water samples, followed by Pb and then Cd, which reflect their significantly high hazard indices observed. Copper and Fe, which are some of the primary raw materials used in the Cu and steel factories did not show unsafe HQ values from the results obtained.

The HQ was greater than 1 for the factory borehole and neighborhood borehole as calculated, which presents an unacceptable risk for non-carcinogenic adverse effects, especially as it concerns Mg, Pb, and Cd. Magnesium contributed most to the exposure to non-cancer risks, followed by Pb in the exposed population and then Cd. In a study, Cd contributed the highest to a non-cancer risk [35]. In another study, Pb was reported to be a major contributor to non-cancer risk [34]. A HQ value of $1<HQ<5$ depicts the level of unease, while a value of $10<HQ<100$ demands additional data collection [36]. From the results, there may be no need for further data collection on the heavy metals. This means that at long-term exposure, the health risk is not high, while the non-cancer adverse is low but not to be neglected.

The results of the carcinogenic risk due to heavy metal exposure in the liquid effluent, factory borehole, and neighborhood boreholes are presented in Table 5. The incremental life cancer risk (ILCR) via ingestion of Pb showed the highest risks in the neighborhood borehole and factory effluent (3.485×10^{-6}), while for Cd, the cancer risk was highest in the factory borehole (3.969×10^{-3}) followed by the neighborhood borehole at (1.008×10^{-3}), respectively. The United States Environmental Protection Agency (USEPA) recommended a suitable ILCR range of 1.00×10^{-4} [60]. Based on the recommendations of USEPA, the carcinogenic risk range for Pb is $2.975\times10^{-6} – 3.485 \times 10^{6}$ and for Cd, it ranges between 3.33×10^{-4}-3.969×10^{3}, respectively for the three exposure sources (Table 5). Hence, the cancer risk resulting from Cd in the different sources demands urgent attention.

A risk of 1.0×10^{-3} requires protective approaches [61]. Related to this risk range, the values from this study exhibited no pronounced cancer risks from heavy metals in the different water sources. Cumulatively, the carcinogenic risk of the heavy metals (Pb and Cd) showed a higher risk as the $\sum$TICR was above the acceptable range of (10^{-6} to 10^{-4}) that regulatory bodies regard as intolerable. The ILCR approximates the incremental increase in the hazard for the exposed populations over a lifetime but does not state when the risk will manifest [62]. Also, the constant parameters imputed in calculating the risks suggest that the concentrations of heavy metals in the water samples are directly proportional to the carcinogenic and non-carcinogenic risk concentrations. To prevent the incidence of cancer in the future, preventive measures should be put in place to mitigate early and insidious exposure to cancer-causing agents in the environment, especially in drinking water [63]. The enforcement of regulations to prevent high levels of heavy metals in the environment should be vigorously implemented.

Table 5
Incremental Life Cancer Risk (ILCR) and Total Cancer Risk (TCR) in the liquid effluent, factory borehole and neighborhood boreholes.

Heavy metals	Factory effluent	Factory borehole	Neighborhood borehole	Total cancer risk (TCR)
Copper	-	-	-	-
Lead	3.485E-06	2.975E-06	3.485E-06	9.945E-06
Cadmium	3.33E-04	3.969E-03	1.008E-03	5.3109E-03
				TCR=$\sum$ (ILCR) 5.32E-03

E= 10 to the power of X

Conclusion: Generally, the factory effluent recorded the highest mean levels of the metals analyzed, which were higher than the permissible limits. Magnesium contributed the highest non-cancer risk, while Cd had the highest cancer risk.

4. Conclusion

The study assessed the health risks related to heavy metal contamination from copper and steel industrial effluents in Nnewi, Anambra State, Nigeria. The amounts of Fe, Pb, Cd, and Mn in water samples from industrial effluent, factory boreholes, and neighborhood boreholes exceeded WHO permissible limits, posing a significant cancer and non-cancer risks. According to the health risk assessment, magnesium had the highest non-cancer hazard quotient (HQ), followed by Cd and Pb, which was reflected in their high hazard indices. More so, oral ingestion of Cd posed a significant cancer risk. These findings highlight the critical need for improved waste management practices and regulatory measures in order to mitigate heavy metal contamination and safeguard human health in industrial locations.

CRediT authorship contribution statement

Dike Chijioke Charles: Validation, Methodology. **Mbachu Amara Nancy:** Supervision. **Maduka Hugh Cliford Chima:** Supervision, Project administration, Conceptualization. **chidiebere Emmanuel ugwu:** Writing – review & editing, Writing – original draft. **Igbokwe Adaolisa Milicent:** Investigation, Formal analysis, Data curation. **Suru Stephen Monday:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interest or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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