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Heavy Metal Analysis and Health Risk Assessment of Groundwater and Soil in and Around Peenya Industrial Area, Bengaluru

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ABSTRACT

The present study in the Peenya Industrial Area in Bengaluru, India, carried out to assess the level of heavy metal contamination in the industrial area's soil and groundwater. The study also discusses the potential health risks that inhabitants would suffer from consuming contaminated groundwater. In 116 bore well water samples collected before and throughout the monsoon season, heavy metals including cadmium, chromium, copper, zinc, arsenic, mercury, lead, nickel, and aluminium were examined. Heavy metals concentration (mg/kg) was analysed for 36 soil samples collected in the research area and for heavy metals like chromium, nickel, copper, zinc, arsenic and cadmium. In the current study, the heavy metal pollution index (HPI), hazard index ($HQ_{(ing)}$) and cancer risk factor (CR) were calculated to assess the potential health risk. The HPI value inside the Peenya industrial area exceeded the critical pollution index value of 100. The hazard index ($HQ_{(ing)}$) via oral ingestion was found to be > 1.00 in Cr, Hg and As during both seasons, indicating maximum health impacts in the inhabitants of the study area. Cancer index values were > 10^{-4} in Cr, Ni, Cd, and Pb in the research area, posing cancer risk in people of all ages, from children to adults. Environmental and human health are both put at risk in a polluted region. To assess soil contamination, the following indices were utilized: geoaccumulation (I_{geo}), single contamination index (PI), and pollution load index (PLI).

Keywords: heavy metals (HM), hazard index ($HQ_{(ing)}$), cancer risk (CR), heavy metal pollution index (HPI), geoaccumulation (I_{geo}) index, single pollution index (PI), pollution load index (PLI).

INTRODUCTION

One of the most important natural resources that may meet rural and urban needs without sacrificing quality is groundwater. The expanding urbanization, industrialization, and population of the globe are all contributing factors that are driving up the demand for groundwater around the world. The loose surface layer that covers most of the ground nowadays is called soil. Soil is the word that refers to this substance. In addition to organic components, it also contains inorganic components in its makeup. In addition to being an essential supply of water and nutrients, soil is also a structural support system for plants that are used in agriculture. Groundwater and soils may become heavily polluted by heavy metals and metalloids. Emissions from fast industrial expansion, inappropriate storage of heavy metal, paint, sewage sludge, pesticides, and coal combustion residues, petrochemical spills, human or geogenic activity, and atmospheric deposition may cause this (Altaf Hussain Lahori et al., 2023, Shekhar et al., 2021). Soil pollution alters surface and groundwater regimes in polluted areas. Metallic elements exist naturally as heavy metals. Generally, trace metals are found to be highly toxic at low concentrations. HMs are measured in ppm or ppb. Normal levels of heavy metals in nature pose no threat to the environment. However, when these metal concentrations rise, they increase the risks and hazards to human health (Arif et al., 2017). Soil and groundwater pollution, increased concentrations of heavy metals, and metal leaching are all results of the study area's unscientific waste management procedures.

Migration of HM varies depending on the soil type, texture, mineralogy, classification of the soil, and compositions of the leachate. Additionally, it is affected by the time, the quantity of rainfall, the temperature, acid rain, airborne dust, and other anthropogenic activities (Ermakov et al., 2007). Trace metals in the atmosphere that are related with PM10 and PM2 have been shown to accumulate over time. A total of five particles will eventually be deposited by a combination of wet and dry deposition processes, which will finally result in the accumulation of pollutants on the terrestrial surface. In addition, the metals that have been deposited on the ground may be swept away by the flow of stormwater, which contributes to the pollution of the water sources that are receiving the water (Vithanage et al., 2022). The toxic HMs entering the food chain may lead to bioaccumulation and bio-magnification. A contaminated area might pose threats to both human health and the environment. Therefore, research on contamination levels serves as a warning bell to the locals and policy makers to monitor necessary treatment before it is used for humanoid consumption.

The weighted arithmetic mean Heavy Metal Pollution Index may be helpful for evaluating water quality, particularly HMs (Majhi et al., 2015, Balakrishnan et al., 2016, Mohan et al., 2008). Over the last few years, there has been a growing concern about groundwater quality and its influence on people of all ages, from children to adults. Therefore, to estimate and understand the impact of water on human health via ingestion, the US-EPA has established rules, recommendations, and HRA models (USEPA., 2011) (Shekhar et al., 2021). Concern about the possible role of potentially harmful substances in human toxicity has grown in recent years. By breathing, eating, and absorbing potentially hazardous compounds from soils and water, it is possible for these toxins to directly collect in the physique of the human being. Several studies have shown that these harmful metals may lead to a variety of health problems, including damage to the liver, kidneys, muscles, respiratory system, abnormalities in the fetus, skin, lungs, heart, and nervous system (Arif et al., 2021). Risk assessment for human health estimates the risk of a negative health effect on humans exposed to chemicals or stressors in polluted environmental media (soil, water, air, food) today or in the future. Hence, it is being widely adopted worldwide by researchers to delineate the adverse effects of HMs contamination on human health (Mehdi et al., 2018). According to recent studies, industrial effluents include larger quantities of heavy metals. There is growing worry about the quality of groundwater and soil, as well as how it affects various age groups, including children and older adults, due to the increased concentrations of toxins in these environments. (Yerima et al., 2023, Geronimo et al., 2021, Oketayo et al., 2022, Yerima et al., 2022, Arowojolu et al., 2021, Adimalla et al., 2019).

Using GIS, a modern tool for determining the spatial distribution of heavy metals, the soil profiles of the study region are investigated. Soil samples were taken at different depths. By performing heavy metal assays on the soils that were collected, we were able to determine the level of pollution that existed in the soil horizon both inside the Peenya industrial zone and five kilometres beyond it. The levels of pollution in the soil were determined by using a wide range of indicators and characteristics. This included the PLI, Index of I_{geo}, and PI. The degree of pollution levels due to various industrial activities is discussed in the current article. The current study's objective is to investigate the distribution and migration of heavy metals in groundwater and soil in and around (5 km) the Peenya Industrial Area, as well as to assess the detrimental impact of heavy metal concentrations on human health.

STUDY AREA

Location

Peenya industrial area is a major industrial sector in Bangalore, Karnataka, India. A major Southeast Asian industrial park is here. The Peenya Industrial Area lies in Bengaluru's northwestern sector, between 13 degrees 1 minute 42 seconds north and 77 degrees 30 minutes 45 seconds east. The industrial sector is crossed by National Highway 4, which runs between Bengaluru and Mumbai. Karnataka Industrial Development Board has subdivided the 40 km^2 Peenya Industrial Region into four phases: phases 1, 2, 3, and 4. Karnataka Small Industrial Development Corporation has devised three steps to build Peenya Industrial Region: Stages 1, 2, and 3 (NGRI., 2018). Bruhat Bangalore Mahanagara

Palike (BBMP) will soon have authority over the whole Peenya industrial sector. The Peenya Industrial region is home to about 2,101 different types of businesses (CEPI., 2020). Peenya Industrial Area has employed around 5.0 lakh people. These polluting enterprises include pharmaceutical formulations, electroplating, lead processing, textile dying, garment washing, powder coating, galvanizing, degreasing, spray painting, phosphating, pickling, and anodization. The Peenya Industrial Area is recognised by both Central and State Governments as the main pivot of industrial activity in Karnataka State and a significant supplier of manufactured goods with a reputation for quality in both domestic and export markets. On a map, Figure 1 depicts the locations of the groundwater sample sites, while Figure 2 depicts the 36 soil sampling points on a location in and around the Peenya industrial district, which is about 5 kilometres distant. Both figures are presented in the same format. We collected soil samples at various depths from the Peenya industrial region and its surroundings (5 km) as well as bore well water (groundwater) to determine the HPI levels and examine the movement and distribution of HMs in the soil profiles within the study area.

Hydrogeology

A representation of the geological features of the Peenya industrial zone may be seen in Figure 3. Granites, gneisses, and magmatites are all examples of peninsular gneissic rocks that are responsible for the formation of significant aquifers in the metropolitan areas of Bengaluru. The rock that is often referred to as magmatite is a combination of igneous and metamorphic rocks. The composite Migmatite rock is composed of a metamorphic host material that is veined or streaked with granite. Soils ranging from red fine loamy to clayey and red laterite are the components that make up the soil composition of the metropolitan region around Bengaluru. Figure 4 depicts the characteristics of the soil in the area under investigation. It is not uncommon to come across red sandy soil in the Peenya industrial region (Gupta et al., 2019). The sandy soils are light-textured, having decent water-holding capacity with greater infiltration rates. The research area has various types of soils, viz., loamy sand, sand loamy and sandy clay loamy. The extent to which these HMs are absorbed by the environment is highly dependent on the characteristics of the soil type. There are phreatic conditions in the north groundwater of Bengaluru. The research area has received an average of 923 mm of rainfall annually over the past 50 years. The weathered zone and the fresh gneisses and granite rock that lie underneath it are the components that make up the whole aquifer system in this region. Depending on the location, the weathering thickness in the Peenya Industrial Area might range anywhere from 20 to

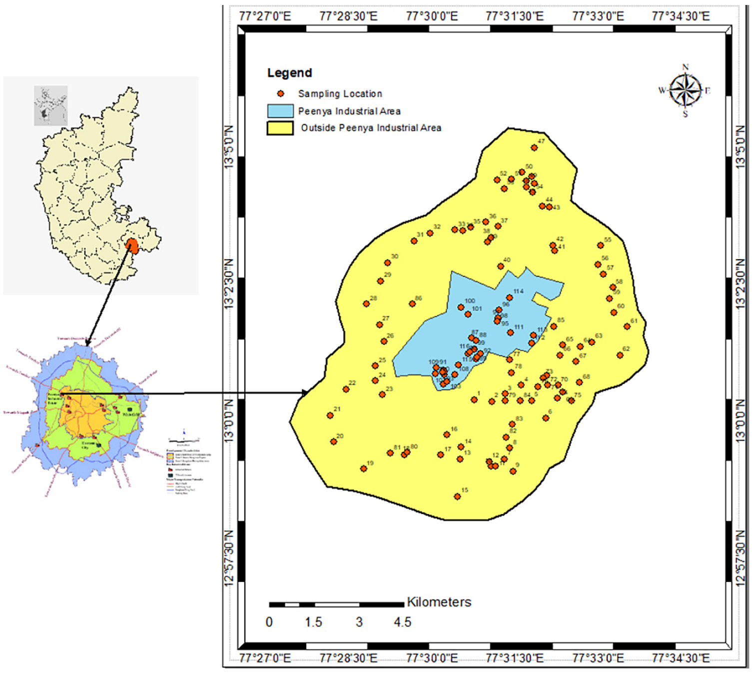

Figure 1. Location map of research area with groundwater sampling points

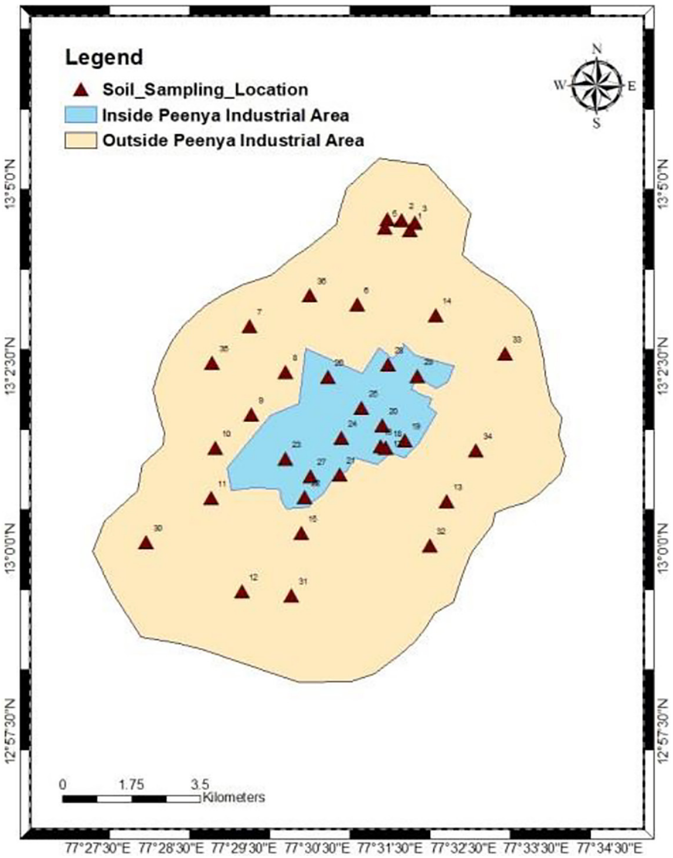

Figure 2. Location map of soil sampling points

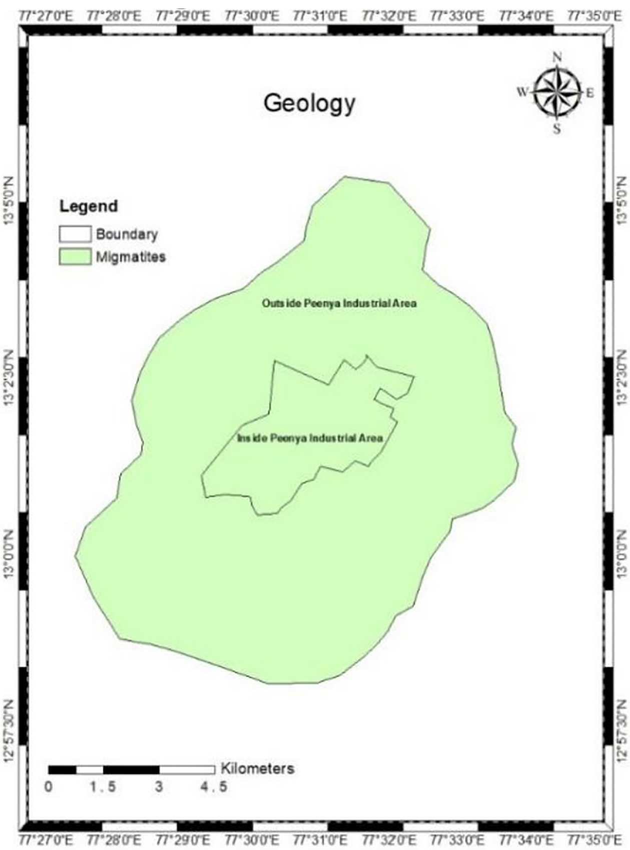

Figure 3. Geological features of research area

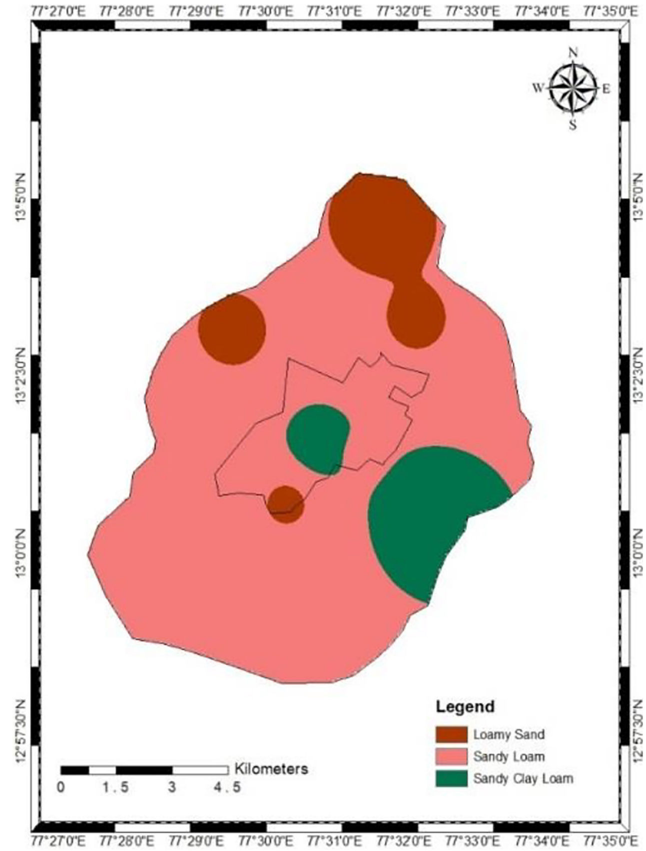

Figure 4. Soil details of research area

24 meters. The depths of groundwater before the monsoon season vary from 0 meters to 49.95 meters, whereas the depths of groundwater after the monsoon season range from 0.20 meters to 58.97 meters (NGRI, 2018). The Air Quality Index factor ranges from satisfactory to moderately polluted near the Peenya industrial area (AQI, 2015). The atmospheric temperature ranges from 14 to 34 degrees Celsius. The lowest recorded temperature was 7.8 degrees Celsius, while the highest was 38.9 degrees Celsius (NGRI, 2018).

METHODOLOGY

Groundwater sampling

Grab sampling was the method that was used to collect groundwater samples from several different locations. 116 bore well samples of groundwater were collected both before and after the monsoon season of 2021. These samples were gathered within a radius of five kilometres along the boundary of the Peenya Industrial Area. Thirty samples were collected inside the industrial area, and 86 samples were collected outside the industrial area (Figure 1). Clean polythene containers with a capacity of one litre were used to collect the groundwater samples. When collecting water samples, nitric acid (HNO_3) is added for heavy metal analysis. HNO_3 lowers the pH of the water below 2, which reduces bacterial activity as well as precipitation and adsorption to container walls. Using an atomic absorption spectrophotometer (PerkinElmer PinAAcle 900Z), the containers were brought to the laboratory for further examination of heavy metals (HMs) such as chromium, zinc, copper, cadmium, arsenic, mercury, lead, nickel, and aluminium. For preservation, the containers were tagged and put in ice cases. The Environmental Laboratory at BMS College of Engineering in Bengaluru filtered water samples using Grade 41 Whatman Ashless Filter Paper. This was done before the water samples were tested by AAS. Parts per billion were used for the measurement of each one of the metals.

Soil sampling

To study the movement and distribution of various HMs in the soil profiles inside and around the Peenya industrial region, which is about 5 km away, 36 soil samples were taken in 2022 (Figure 2). Transported the soil samples to the lab for additional analysis in clean, airtight polythene bags that had been appropriately labelled. The depths of the samples were 0, 30, and 60 cm. The Mehlich-I extraction technique evaluated soil samples for heavy metals. Mehlich-I extraction solution is made in the lab from 0.05 N hydrochloric acid and 0.025 N sulfuric acid. This solution is then used to conduct an analysis on the soil. Following the collection of the soil samples, we dried them in an oven for a period of twenty-four hours, at a temperature that ranged between 101 and 105 degrees Celsius. After the soil samples have been air-dried in an oven, they are next pulverized into a fine powder using a pestle and mortar. The next step is to put them through a mesh that is one millimetre in size. A conical flask with a capacity of fifty millilitres was filled with twenty millilitres of the Mehlich-I extraction solution and five grams of the specimen of soil that had been sieved is added. Mehlich-I extraction solutions and 5 grams of soil agitated for ten minutes using a mechanical rotary shaker. The speed of the shaker was indicated to be 250 revolutions per minute. Following the passage of the contents through Whatman filter paper, they were transferred to a volumetric flask with a capacity of fifty millilitres and left aside until the Mehlich-I extraction solution was diluted to fifty millilitres. AAS was employed to measure heavy metals in diluted soil samples (Ramakrishnaiah et al., 2016, Martis et al., 2018). A flowchart of the research technique is shown in Figure 5.

Heavy metal pollution index

One modern mathematical tool that may measure heavy metal contamination and groundwater quality is the heavy metal pollution index, or HPI. HMs worsen groundwater quality, as determined by (Tiwari et al., 2015 and Mohan et al., 2008) using the HPI mathematical rating technique (Matta et al., 2020) (Panigrahy et al., 2015, Bably et al., 2013). Water for human consumption must have an HPI value of 100 or above (Bably et al., 2013).

$$HPI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \quad (1)$$

where: Q_i represents the sub-index of the i^{th} parameter, W_i represents the unit weightage of the ith parameter, and n is the total number of parameters that are taken into consideration. The formula that follows is used to determine the sub-index, which is denoted by Q_i:

$$Q_i = \sum_{i=1}^{n} \frac{\{M_i(-)l_i\}}{S_i - l_i} \times 100 \quad (2)$$

where: M_i is the monitored heavy metal value, l_i and S_i are ideal and standard values of the i^{th} parameter, respectively. A numerical difference between the two values is indicated by the sign (−), which disregards the algebraic sign used in the calculation.

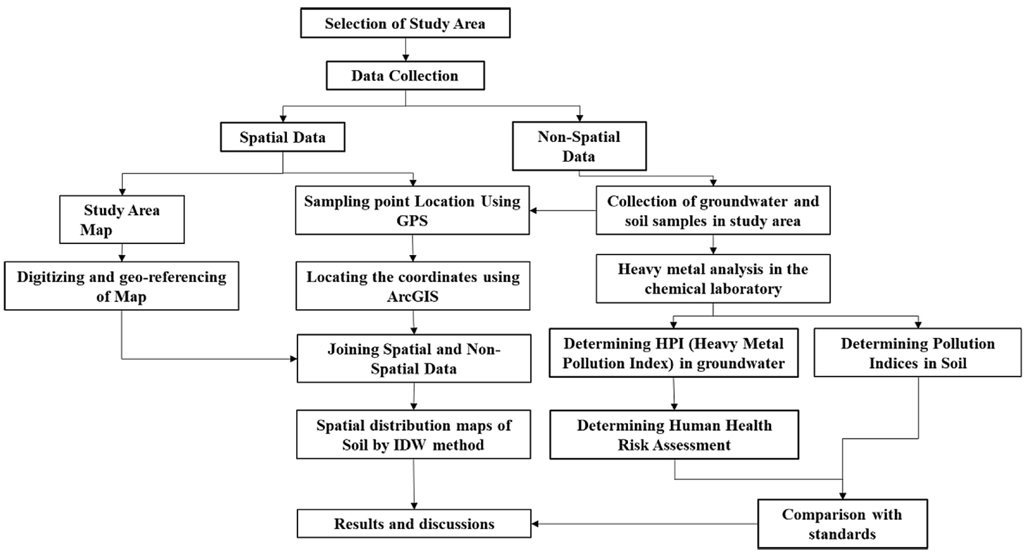

Figure 5. Methodology flowchart

Human health risk assessment

It is possible to estimate the potential risks to human health that are associated with prolonged interaction with chemical agents by using a technique that is known as human health risk assessment. Both children and adults are the subjects of this study, which investigates the possible non-carcinogenic health consequences of HMs in water. $CDI_{(ing)}$ can be estimated using contaminant concentrations in several environmental elements like water, soil, sediments and food and human behaviour information via exposure parameters, exposure surfaces etc.

Exposure assessment

The oral HM $CDI_{(ing)}$ was estimated using the following Equation (Ugwu et al., 2022, Bamuwuwamye et al., 2017).

$$CDI_{(ing)} = (C_W \times I_R \times E_F \times E_D)/(B_W \times A_T) \quad (3)$$

In this context, $CDI_{(ing)}$ refers to chronic daily intake via ingestion in milligrams per kilogramme per day; C_w is the concentration of the chemical present in the groundwater in milligrams per litre; I_R is the ingestion rate of water in millilitres per day, with a child's rate being 1 litre per day and an adult's rate being 2.3 litres per day (NGRI., 2018, Onyenmechi et al., 2022), A child's exposure length is six years and an adult's is thirty years; E_F is the exposure frequency in millilitres per year. The average kid weighs 15 kg. A_T = average exposure time (days)

- for carcinogenic = A_T = 70 year × 365 days/year = 25550 days (4), for all age group includes children;
- for non-carcinogenic = $A_T = E_D$ (year) × 365 days/year = 2190 days (5) for kids, 10950 for adults, respectively. Table 1 displays the additional factors that may be used to estimate risk assessment of human health via different pathways.

Non-cancer risks

The non-cancer hazard quotient proved that HMs in drinking water do not cause cancer and pose no health risks. ($HQ_{(ing)}$). Divide the value of $CDI_{(ing)}$ by the reference dose (RfD) to get the non-carcinogenic risk hazard quotient ($HQ_{(ing)}$). You can figure out $HQ_{(ing)}$ using this formula:

$$HQ_{(ing)} = CDI_{(ing)}/RfD \quad (6)$$

where: $HQ_{(ing)}$ = non-cancer hazard quotient, $CDI_{(ing)}$ = chronic daily intake (mg metal/kg/day); and RfD represents the oral reference dose (chronic), RfD an estimated daily chronic oral exposure dose for the general population and a sensitive subgroup without a substantial lifetime risk of deleterious consequences (Ugwu et al., 2022). The hazard index ($HQ_{(ing)}$) was used to assess the potential risk to human health provided by exposure to a variety of trace metals (Onyinyechi et al., 2018). A value of $HQ_{(ing)}$ < 1 suggests low non-cancer hazards, a value ≥ 1 implies significant non-cancer risks, and greater $HQ_{(ing)}$ value means a severe adverse effect on human health due to probable non-carcinogenic toxic effect (Shekhar et al., 2021, Felix et al., 2017).

Cancer risk

Person's CR is their chance of getting cancer throughout the course of their lifetime because of their actions in relation to a carcinogenic pollutant. In the communication of cancer risk, the incremental life-time cancer risk ($\Sigma ILCR$) was used to convey the probability of acquiring cancer during a 70 – year lifespan due to a 24 – hour exposure to a potentially carcinogenic pollutant (Ugwu et al., 2022). The daily cancer risk was determined by multiplying the $CDI_{(ing)}$ (mg/kg) with the CSF (mg/kg). To count ILCR, one may use the formula given by Michael Bamuwamye (Michael et al., 2017)

$$\Sigma ILCR = CDI_{(ing)} \times CSF \quad (7)$$

This definition uses CSF, CDI (mg/kg/day), and ILCR. At one time, the cumulative cancer risk from several pollutants in a particular water could be determined by adding up the metal component hazards. ($\Sigma ILCR$). The US Environmental Protection Agency (EPA) accepts a cancer risk of 1 × 10–6 to 1 × 10–4 for regulation purposes (USEPA, 2016). As to the US Environmental Protection Agency's recommendations for various age groups, including children, Under the condition when the risk value is less than 10−6, there is no chance whatsoever of developing cancer. If risk estimates fall between 10−6 to 10−4, carcinogenic risk is deemed tolerable. Conversely, cancer risk levels over 10−4 are deemed unacceptable (Péhégninon et al., 2021).

Table 1. Parameters used to calculate exposure doses of HMs in drinking water Ref: (Farah et al., 2019, NGRI., 2018, Ratnakar et al., 2020, Shekhar et al., 2021, Michael et al., 2017)

Parameters	Unit	Value
Concentration of heavy metal	mg/l	–
Water Ingestion rate (I_R)	L/day	2.3
Exposure Frequency (E_F)	day/year	365
Average exposure time (adults) (A_T)	days	10,950
Average exposure time (children) (A_T)days		2190
Exposure duration (adults)(E_D)	years	30
Exposure duration (children)(E_D)	years	6
Average body weight (adults) (B_W)	Kg	70
Average body weight (children) (B_W)	Kg	15
Oral reference dose (Chromium)	mg/kg/day	0.003
Oral reference dose (Nickel)	mg/kg/day	0.84
Oral reference dose (Lead)	mg/kg/day	0.0004
Oral reference dose (Copper)	mg/kg/day	0.04
Oral reference dose (Mercury)	mg/kg/day	0.0003
Oral reference dose (Zinc)	mg/kg/day	0.3
Oral reference dose (Aluminium)	mg/kg/day	1
Oral reference dose (Arsenic)	mg/kg/day	0.0003
Oral reference dose (Cadmium)	mg/kg/day	0.0005
Cancer slop factor (Lead)	mg/kg/day	8.5
Cancer slop factor(chromium)	mg/kg/day	0.5
Cancer slop factor (Nickel)	mg/kg/day	0.84
Cancer slop factor (Cadmium)	mg/kg/day	6.1

Pollution indices

Index of geo-accumulation

In 1969, Müller developed the first geo-accumulation indicator, which is represented as I_{geo}. In the present study use I_{geo} to assess metal pollution in soil (Yerima et al., 2023, Ratnakar et al., 2020, Gong et al., 2008). Compare present concentrations to pre-industrialization levels. I_{geo} values are calculated using this formula:

$$I_{geo}=log_2\,(C_n/(1.5\,B_n)) \tag{8}$$

where: C_n = monitored concentration of heavy metal, and B_n = geochemical background concentration or reference value of each metal. Because natural lithogenic and modest anthropogenic impacts may create fluctuations in background levels for a specific metal in the environment, constant factor 1.5 is utilized. There are seven distinct risk categories based on the geo-accumulation index (I_{geo}), which falls between $5 < I_{geo} \leq 0$ (Table 2) (Gong et al., 2008, Muller., 1969).

Single pollution index (PI)

According to research by Hakanson L et al. (1980) and Afonne et al. (2022), the soil pollution index (*PI*) is used to determine which trace metal poses the most damage to the ecosystem. Here is the Equation that enumerates the *PI*:

$$PI = C_n/B_n \tag{9}$$

where: C_n = concentration of heavy metals that has been measured and B_n = geochemical background value of each heavy metal in soil (Helena et al., 2017).

Pollution load index (PLI)

Following Tomlinson's proposal, the pollutant load index (*PLI*) is a crucial complicated metric for evaluating the soil's HM buildup (Onyenmechi et al., 2022, Tomlinson et al., 1980). The *PLI* offers a straightforward method for showing how HM buildup has altered soil conditions. It is calculated by taking the geometric mean of *PI* and estimating:

$$PLI = \sqrt[n]{PI_1 \times PI_2 \times PI_3 \times .....PI_n} \tag{10}$$

Here, n denotes the total number of heavy metals analysed, and *PI* stands for the single pollution index derived values. Table. 2 displays the PLI evaluation criteria.

RESULTS AND DISCUSSIONS

Groundwater quality analysis

Analyses of groundwater by the Bureau of Indian requirements (BIS:10500, 2012) revealed concentrations of chromium, mercury, and cadmium that were greater than the requirements. During pre-monsoon season, HM concentrations range from 0–17.54 mg/l for chromium, mercury, cadmium, copper, nickel, zinc, lead, arsenic, and aluminium. However, Table 3 shows post-monsoon concentrations of chromium (0–15.68 mg/l), mercury (0.001–0.182 mg/l), cadmium (0–0.019 mg/l), copper (0.005–0.076 mg/l), nickel (0–0.52 mg/l), zinc (0–3.125 mg/l), lead (0–0.003 mg/l), arsenic (0.0005–0.013 mg/l), and aluminium (0.004–0.586 mg/l).

Heavy metal contamination in groundwater

The present research computed HPI using 9 HMs. Both monsoon seasons' HPI calculations inside the Peenya Industrial Area were determined to be more than the critical index limit of 100. However, outside the Peenya industrial area, HPI Values showed 1% of groundwater samples found in excellent,1% in poor class, and 98% in unsuitable for drinking purposes in pre-monsoon season (Table 4), and 5% of groundwater samples found in excellent, 58% in poor class, 37% in very poor class in post-monsoon season (Table 4). Higher percentage values of HPI could be due to unscientific waste management, deposition of atmospheric trace metals on the ground, acid atmospheric precipitation, airborne dust particles, runoff through industrial areas, and other anthropogenic activities. The post-monsoon period HPI results show that the critical index value obtained outside the Peenya Industrial Area is decreased compared to the pre-monsoon period (Table 4). It is due to the dilution effect of rainwater. In contrast, the critical index value is increased inside the industrial area due to the illegal disposal of industrial metal-laden waste in groundwater aquifers. This clearly demonstrates that the contamination in the industrial region is caused not only by natural soil infiltration but also by the direct discharge of waste from industries into the aquifers.

Heavy metal contamination on health

The present investigation assessed the potential dangers of sneaking nine HMs into the body via the mouth.; Cr, Zn, Al, Cu, Hg, As, Ni, Cd, Pb. Table 5 displays the data for chronic daily intake ($CDI_{(ing)}$) among individuals of all ages in the vicinity of Peenya Industrial (5 km) via the ingestive route. In the research area, $CDI_{(ing)}$

Table 2. Pollution index classification

Parameter	Value	Environmental risk class	References
Single indices			
Igeo	Igeo ≤ 0	Absolutely free of any contamination	
	0 < Igeo ≤ 1	Uncontaminated to slightly contaminated with contaminants	Muller (1969)
	1 < Igeo ≤ 2	Moderately contaminated	
	2 < Igeo ≤ 3	Moderately to heavily contaminated	
	3 < Igeo ≤ 4	High levels of contamination	
	4 < Igeo ≤ 5	Extremely polluted to heavy contamination	
	Igeo > 5	Extremely contaminated	
PI	PI < 1	Minimal pollution	
	1 ≤ PI < 3	Moderate contamination	
	3 ≤ PI < 6	Considerable contamination	Hakanson (1980)
	PI > 6	High contamination	
Complex indices			
PLI	PLI < 1	Not polluted	
	PLI = 1	Baseline level of pollutants	Tomlinson et al. (1980)
	PLI > 1	Polluted	

Table 3. Heavy metal concentrations (ppm) in analysed groundwater samples in the research area

Season	Value	Cu	Ni	Cd	Zn	Cr	As	Hg	Al	Pb
Pre-monsoon	Min	0.000	0.000	0.001	0.000	0.000	0.010	0.001	0.000	0.000
	Max	0.136	0.064	0.057	0.298	17.154	0.034	0.185	0.288	0.038
	Median	0.010	0.008	0.009	0.127	0.001	0.012	0.002	0.000	0.010
	SD	0.022	0.016	0.007	0.060	1.856	0.002	0.027	0.047	0.005
	Avg	0.017	0.014	0.011	0.126	0.415	0.012	0.014	0.021	0.009
Pre-monsoon	Min	0.005	0.000	0.000	0.000	0.000	0.001	0.001	0.004	0.000
	Mx	0.076	0.052	0.019	3.125	15.680	0.013	0.182	0.586	0.004
	Median	0.007	0.000	0.000	0.011	0.004	0.003	0.001	0.018	0.000
	SD	0.007	0.009	0.005	0.293	1.587	0.004	0.073	0.068	0.001
	Avg	0.009	0.004	0.003	0.059	0.312	0.005	0.043	0.037	0.000
BIS limits	Acceptable limit	0.05	0.02	0.003	5	0.05	0.01	0.001	0.03	0.01
	Permissible limit	1.5	0	–	15	–	0.05	–	0.2	–
Concentration in mg/l										

Table 4. Groundwater quality classification based on HPI value for inside and outside (5 km) Peenya Industrial Area

Number of groundwater samples inside peenya industrial area					
Classification	Characteristics	Pre-monsoon	Post monsoon	% Pre-monsoon	% Post monsoon
< 25	Excellent	0	0	0%	0%
25–50	Good	0	0	0%	0%
51–75	Poor	0	0	0%	0%
76–100	Very poor	0	0	0%	0%
> 100	Unsuitable	30	30	100%	100%
Number of groundwater samples outside peenya industrial area					
Classification	Characteristics	Pre-monsoon	Post monsoon	% Pre-monsoon	% Post monsoon
< 25	Excellent	1	4	1%	5%
25–50	Good	0	0	0%	0%
51–75	Poor	0	50	0%	58%
76–100	Very poor	1	32	1%	37%
> 100	Unsuitable	84	0	98%	0%
Number of groundwater samples inside and outside peenya industrial area					
Classification	Characteristics	Pre-monsoon	Post monsoon	% Pre-monsoon	% Post monsoon
< 25	Excellent	1	4	1%	3%
25–50	Good	0	0	0%	0%
51–75	Poor	0	50	0%	43%
76–100	Very poor	1	32	1%	28%
> 100	Unsuitable	114	30	98%	26%

levels were marginally higher than the reference dosage suggested by the US Environmental Protection Agency and other international organizations. Residents of the Peenya industrial zone drank bad groundwater with HM levels over the acceptable limit, putting their health at risk. HM $CDI_{(ing)}$ indices in study regions were Cr > Zn > Al > Hg > Cu > Ni > As > Cd > Pb for adults and children in pre-monsoon season. Similarly, $CDI_{(ing)}$ indices for the HMs in study areas were in the order Cr > Al > Zn > Cu > Hg = Ni > As > Cd > Pb for adults and Al > Zn > Cr > Cu > Hg > Ni > As > Cd > Pb for the children in post-monsoon season. The results indicated $CDI_{(ing)}$ values were found to be comparatively high in people of all ages, from children to adults during both the monsoon seasons. The unregulated disposal of industrial metal waste into underground aquifers without proper scientific treatment is the main reason for contamination. Results show that HMs contributed significantly to the increased $CDI_{(ing)}$ levels reported in the research area and may pose a serious health risk. The $HQ_{(ing)}$ for the HMs is calculated for the different groundwater sources in and around (5 km) Peenya Industrial Area is shown in Table 5. The $HQ_{(ing)}$ for heavy metals like Cr, Hg and as shows higher values in people of all ages, from children to adults. The $HQ_{(ing)}$ was > 1 in the groundwater taken for the study during the pre-monsoon season for Cr, Cd, Pb, Hg & As (in adults) and Cr, Hg and As (in Children). The $HQ_{(ing)}$ was > 1 for Cr, Hg and As for people of all ages, from children to adults, in the groundwater taken for the study during post-monsoon season. The $HQ_{(ing)}$ indices > 1 the risk of non-carcinogenic harmful effects, particularly about HMs such as Cr, Hg, and As, is unacceptable when computed for all groundwater samples. According to the findings, there is a considerable danger to human health from ingesting the water over an extended period, and the non-cancer harmful consequences are just as concerning and need careful attention. In their 2016 report, the US Environmental Protection Agency (EPA) (USEPA, 2016) suggested an ILCR range that is considered acceptable, which falls between 1.00×10^{-6} and 1.00×10^{-4}. The pre-monsoon carcinogenic risk range for Cr was determined to be: Adult is 0–5.04×10^{-2} and for child is 0–2.04×10^{-2}, Cr (Post-Monsoon): Adult is 0–4.00×10^{-2} and for child is 0–1.62×10^{-2} respectively. However, the carcinogenic risk range obtained for Ni (Pre-Monsoon): Adult is 0–1.61×10^{-3} and for child is 0–6.53×10^{-4}, Ni (Post-monsoon): Adult is 0–0.06×10^{-3} and for Child is 0–2.05×10^{-3}. The carcinogenic risk range obtained for Cd (pre-monsoon): Adults is 6.32×10^{-5}–4.91×10^{-3} and for child is $2.57 \times 10^{-}$–1.99×10^{-3}, Cd (post-monsoon): Adult is 0–0.63×10^{-3} and for child is 0–6.63×10^{-4}. Similarly, the carcinogenic risk range obtained for Pb (pre-monsoon): Adult is 0–4.52×10^{-3} and for child is 0–1.83×10^{-3}, Pb (post-monsoon): Adult is 0–4.41×10^{-4} and for child is 0–1.79×10^{-4} respectively. A risk of 1.0 × 10–3 requires urgent precautions (Ugwu et al., 2022). According to the risk range determined by the study findings, drinking water throughout the lifespan significantly increases the apparent risk of developing cancer in all age groups. It is urgently necessary to cease consuming water from these bore wells if the risk exceeds 1.0 × 10^{-2}, since it suggests a greater likelihood of cancer. To protect the local population from the potential cancer dangers, government officials

Table 5. Chronic daily intake ($CDI_{(ing)}$) and hazard index ($HQ_{(ing)}$) in different groundwater samples in and around (5 km) Peenya Industrial Area

Season	Element	Adult				Child			
		$CDI_{[ing]}$		$HQ_{[ing]}$		$CDI_{[ing]}$		$HQ_{[ing]}$	
		Min	Max	Min	Max	Min	Max	Min	Max
Pre-monsoon	Cr	0.0000	0.1007	0.0000	33.5800	0.0000	0.0409	0.0000	13.6267
	Ni	0.0000	0.0019	0.0000	0.0958	0.0000	0.0008	0.0000	0.0389
	Cd	0.0000	0.0008	0.0207	1.6109	0.0000	0.0003	0.0084	0.6537
	Pb	0.0000	0.0005	0.0000	1.5196	0.0000	0.0002	0.0000	0.6167
	Cu	0.0000	0.0045	0.0000	0.1118	0.0000	0.0091	0.0000	0.2268
	Hg	0.0000	0.0061	0.0755	20.3057	0.0000	0.0124	0.1533	41.2000
	Zn	0.0000	0.0098	0.0000	0.0326	0.0000	0.0198	0.0000	0.0662
	Al	0.0000	0.0095	0.0000	0.0095	0.0000	0.0192	0.0000	0.0192
	As	0.0003	0.0011	1.1336	3.7348	0.0000	0.0023	2.3000	7.5778
Post-monsoon	Cr	0.0000	0.0800	0.0000	26.6612	0.0000	0.0325	0.0000	10.8190
	Ni	0.0000	0.0060	0.0000	0.3013	0.0000	0.0024	0.0000	0.1223
	Cd	0.0000	0.0003	0.0000	0.5354	0.0000	0.0001	0.0000	0.2173
	Pb	0.0000	0.0001	0.0000	0.1481	0.0000	0.0000	0.0000	0.0601
	Cu	0.0002	0.0156	0.0041	0.3909	0.0003	0.0317	0.0083	0.7932
	Hg	0.0000	0.0060	0.0924	19.9618	0.0000	0.0122	0.1874	40.5022
	Zn	0.0000	0.0342	0.0000	0.1139	0.0000	0.0693	0.0000	0.2311
	Al	0.0001	0.0347	0.0001	0.0347	0.0003	0.0705	0.0003	0.0705
	As	0.0000	0.0004	0.0572	1.4468	0.0000	0.0009	0.1160	2.9356

should move swiftly to prohibit such bore wells. Similarly, protective measures should be implemented to treat the contaminated groundwater with scientific remediation technology. Results from Table 6 showed a cancer risk from all four analysed heavy metals. The cancer risks via oral ingestion of Cr showed the highest risk in people of all ages, from children to adults (Table 6). Cancer risk from Table 6 shows that Cr significantly contributes more to cancer-causing risk in the groundwater samples taken in different bore wells. This could be attributed to Cr metal entering groundwater via direct discharge of wastewater from industries such as tanning, powder coating, electroplating, and allied industries, as well as poor waste disposal (Ratnakar et al., 2020). Cr is carcinogenic and linked to numerous health problems because of its consumption in food. Mutations, gastrointestinal problems, ulcers, respiratory issues, kidney and liver problems, lower immune system problems, lung cancer, and central nervous system abnormalities are all possible outcomes (Sylvester et al., 2016).

Distribution and migration of heavy metals in soil

The HMs concentration (mg/kg) analysis is done for collected 36 soil samples from the research area. Table 7 shows the statistical analysis results. The Cr concentration value ranges from 0–315.8 mg/kg, 0–181.80 mg/kg, and 0–132.46 mg/kg at 0 cm, 30 cm, and 60 cm soil depth respectively. Likewise, Ni ranges from 0–173.245 mg/kg, 0–100.7 mg/kg, 0–98.90; Zn ranges from 0.033–358 mg/kg, 0–177.97 mg/kg, 0.061–213.50 mg/kg; As ranges from 0–0.600 mg/kg, 0–0.030 mg/kg; Cd ranges from 0–6.621 mg/kg, 0–6.309 mg/kg, 0–4.667 mg/kg and copper ranges from 0–524.260 mg/kg, 0–221.360 mg/kg, 0–208.9 mg/kg at a depth of 0 cm, 30 cm, and 60 cm respectively.

Heavy metal contamination in soil

The results show that few HMs exceeded the normal threshold values of soil standards, raising the concern about soil contamination. There is a possibility that HMs might spread and migrate from areas

Table 6. Incremental life cancer risk (ICLR) in different groundwater samples in and around (5 km) Peenya Industrial Area

Season	Element	Adult				Child			
		Min	Max	Avg	SD	Min	Max	Avg	SD
Pre-monsoon	Cr	0	5.04×10^{-2}	2.17×10^{-3}	7.71×10^{-3}	0	2.04×10^{-2}	9.45×10^{-4}	3.37×10^{-3}
	Ni	0	1.61×10^{-3}	2.05×10^{-4}	2.58×10^{-4}	0	6.53×10^{-4}	8.31×10^{-5}	1.05×10^{-4}
	Cd	6.32×10^{-5}	4.91×10^{-3}	9.09×10^{-4}	6.32×10^{-4}	2.57×10^{-5}	1.99×10^{-3}	3.69×10^{-4}	2.56×10^{-4}
	Pb	0	4.52×10^{-3}	1.03×10^{-3}	6.36×10^{-4}	0	1.83×10^{-3}	4.20×10^{-4}	2.58×10^{-4}
	ΣILCR	4.02×10^{-4}	5.28×10^{-2}	4.31×10^{-3}	7.71×10^{-3}	1.63×10^{-4}	2.14×10^{-2}	2.14×10^{-2}	3.38×10^{-3}
Post-monsoon	Cr	0	4.00×10^{-2}	1.59×10^{-3}	5.92×10^{-3}	0	1.62×10^{-2}	6.45×10^{-4}	2.40×10^{-3}
	Ni	0	5.06×10^{-3}	9.88×10^{-5}	5.27×10^{-4}	0	2.05×10^{-3}	4.01×10^{-5}	2.14×10^{-4}
	Cd	0	1.63×10^{-3}	2.45×10^{-4}	4.27×10^{-4}	0	6.63×10^{-4}	9.93×10^{-5}	1.73×10^{-4}
	Pb	0	4.41×10^{-4}	1.76×10^{-5}	7.17×10^{-5}	0	1.79×10^{-4}	7.14×10^{-6}	2.91×10^{-5}
	ΣILCR	0	4.11×10^{-2}	1.95×10^{-3}	6.31×10^{-3}	0	1.67×10^{-2}	7.91×10^{-4}	2.56×10^{-3}

Table 7. Statistical summary of analysed heavy metals in soil at different depths

	0 cm depth			30 cm depth			60 cm depth		
Elements	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Cr	0.000	315.800	68.599	0.000	181.800	34.124	0.000	132.460	21.622
Ni	0.000	173.245	41.236	0.000	100.700	27.702	0.000	98.900	14.084
Zn	0.033	358.000	74.599	0.000	177.970	43.559	0.061	213.500	42.530
As	0.000	0.600	0.018	0.000	0.030	0.001	0.000	0.000	0.000
Cd	0.000	6.621	0.347	0.000	6.309	0.171	0.000	4.667	0.181
Cu	0.000	524.260	54.903	0.000	221.360	32.388	0.000	208.900	26.881
Values in mg/kg, min: minimum, max: maximum, avg: average									

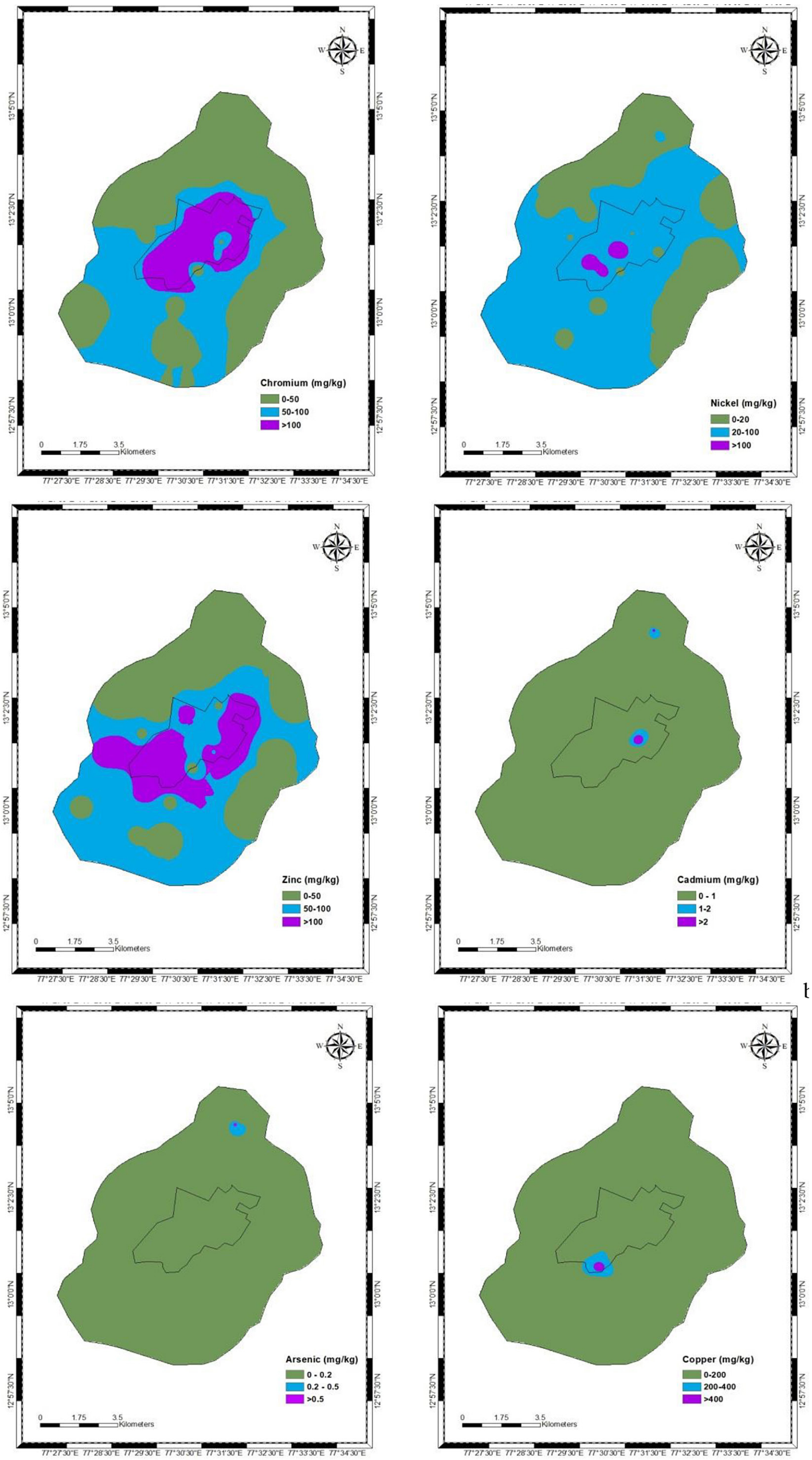

Figure 6. Spatial distribution maps of chromium, nickel, and zinc. cadmium, arsenic and copper (mg/kg) in soil samples

of pollution to areas around the Peenya industrial region that are not polluted. Soil HM content distribution is shown in Figure 6. Soil spatial distribution maps showing purple patches indicate regions with greater levels of HM contamination. A greater HM contamination level shows that precipitation-borne HMs enter soil profiles. The soil map's geographical distribution reveals polluted zones and pollutant transport pathways in the studied region. At the same time, the quantum of work can be reduced to policymakers by identifying contaminated zones of the study area and providing necessary treatments only to those zones.The geochemical index (Table 8) showed that study soils were uncontaminated to severely contaminated. Cr (-11.150–2.074) and Cu (-6.714–2.472); moderately contaminated by Ni (-11.722–1.208); uncontaminated to moderately contaminated by Zn (-13.164–0.255); however, the contamination by Cd and As were classified as practically uncontaminated by geochemical Indices. PI results (Table 9) indicated low to high contamination by Cr and Cu, substantial contamination by Ni, and moderate contamination by Zn, but low contamination risk class for Cd and As. The results from PI

Table 8. Geo accumulation index (I_{geo})

Elements	Min	Max	Avg	SD	Median
Cr	-11.150	2.074	-2.293	3.528	-0.950
Ni	-11.722	1.208	-2.401	3.626	-0.668
Zn	-13.164	0.255	-4.143	3.671	-3.011
As	-19.517	0.000	-1.802	4.993	0.000
Cd	-16.680	0.000	-1.278	3.406	0.000
Cu	-6.714	2.472	-2.044	2.183	-1.761
Min: minimum, max: maximum, avg: average, sd: standard deviation					

Table 9. Single pollution index (PI)

Elements	Min	Max	Avg	SD	Median
Cr	0	6.316	1.235	1.566	0.420
Ni	0	3.465	0.751	0.927	0.307
Zn	0	1.790	0.374	0.466	0.186
As	0	0.030	0.001	0.005	0
Cd	0	0.118	0.006	0.022	0
Cu	0	8.322	0.858	1.475	0.427
Min: minimum, max: miximum, avg: average, sd: standard deviation					

Table 10. Pollution load index (PLI)

Sample no.	Pollution load index (PLI)	Environmental risk class	Sample no.	Pollution load index (PLI)	Environmental risk class
1	0.201	Not polluted	19	0.690	Not polluted
2	0.200	Not polluted	20	0.452	Not polluted
3	0.004	Not polluted	21	0.023	Not polluted
4	0.001	Not polluted	22	0.705	Not polluted
5	0.004	Not polluted	23	2.212	Polluted
6	0.004	Not polluted	24	1.781	Polluted
7	0.002	Not polluted	25	0.514	Not polluted
8	0.023	Not polluted	26	1.221	Polluted
9	0.285	Not polluted	27	2.092	Polluted
10	1.064	Polluted	28	0.965	Not polluted
11	0.667	Not Polluted	29	1.413	Polluted
12	0.321	Not Polluted	30	0.160	Not Polluted
13	0.015	Not Polluted	31	0.104	Not Polluted
14	0.297	Not Polluted	32	0.062	Not Polluted
15	0.098	Not Polluted	33	0.476	Not Polluted
16	0.589	Not Polluted	34	0.206	Not Polluted
17	0.963	Not Polluted	35	0.027	Not Polluted
18	0.421	Not Polluted	36	0.013	Not Polluted

showed Cr, Cu, Ni and Zn contamination in soil poses a potential ecological risk in study area. Results of complex indices, PLI values showed that for six soil samples no. 10, 23, 24, 26, 27, and 29 were found > 1 indicating a polluted risk class, and remaining 30 soil samples were found < 1 indicating unpolluted risk class (Table 10).

CONCLUSIONS

Heavy metal contamination of the subject area's groundwater and soil profiles is detailed in the present investigation. Groundwater and soils in industrial areas are more polluted with heavy metals than the allowable limits, according to the investigation. HPI readings over 100 indicate a severe degree of metal contamination in groundwater samples collected inside the Peenya industrial zone. This indicates that the study area will eventually experience heavy metal pollution of the groundwater. Precautions that have been recommended, such as building a CETP to manage the solid and liquid waste from different businesses and directing stormwater runoff away from the wells in the industrial area, can help reduce the pollution that is leaking into the groundwater supply. GIS mapping procedure integrates the traditional sampling analysis methods. This study presents the diverse industrial and anthropogenic activities inside Peenya Industrial Area which contribute to the increasing levels of pollutants in the groundwater and soils. Current study also identifies contamination zones outside the industrial area due to distribution and migration of pollutants due to runoff from the industrial area. From the spatial distribution mapping, the quantum of work can be reduced to policymakers for identifying contamination zones of the study area and to take necessary actions to prevent further deterioration of soil quality towards uncontaminated regions of the study area. The human health risk assessment found that drinking water heavy metals produced Cr, Hg, and As high hazard quotients and Cr, Ni, Cd, and Pb's excess cancer risks over 70 years. These heavy metals represent a health risk that is both non-carcinogenic and carcinogenic to people of all ages. To manage the contamination of water sources caused by the introduction of heavy metals, it is necessary to revise the current national environmental policy. The findings of the pollution indexing modelling showed that the research area's soil is significantly contaminated with Cr, Ni, Zn, and Cu. Soil pollution load index (PLI) values greater than 1 indicate that soil quality in the research region is declining. Soil testing showed significant pollution indices, which indicated heavy metal contamination from the area's inadequate waste management. As a result, the study warns that government agencies should act quickly to prevent soil pollution in industrial areas. For example, industries should take measures to avoid dumping solid waste in open areas. Bio-remediation and phytoremediation may reduce soil pollution and its detrimental effects on human health, groundwater, terrestrial ecosystems, and the ecological system.

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