Environ Monit Assess (2019) 191: 289
https://doi.org/10.1007/s10661-019-7453-9

A critical assay of heavy metal pollution index for the groundwaters of Peenya Industrial Area, Bangalore, India

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Received: 6 June 2018 / Accepted: 4 April 2019 / Published online: 18 April 2019

Abstract Heavy metals, due to their non-biodegradability and tendency to cause detrimental effects in human beings, are considered as the most hazardous and toxic pollutants. The present investigation was taken up to evaluate the heavy metal concentrations in the groundwaters of Peenya Industrial Area in Bangalore. The concentration of six eco-toxic metals such as chromium, copper, cadmium, iron, nickel, and lead were analyzed for 30 groundwater sampling stations in the study area using atomic absorption spectrometer. The concentration of heavy metals followed the order Cr> Fe >Pb>Cu> Ni> Cd. The analysis results have been used to compute two pollution indices in the groundwater, namely heavy metal pollution index and metal index. Heavy metal pollution index is an effective method of rating and ascertaining the water quality with respect to heavy metals. An index value of 100 is considered to be critical, and on the basis of mean concentration, this value in the study area was observed to be 146.32, which is considerably higher than the stipulated critical index value. 63.33% of the groundwater samples are seen to be having an index far above the critical figure of 100. The mean concentration of metal index was 10.36 and it was seen that 46.67% of the groundwater samples fell under the seriously affected category (metal index values above 6). The results not only show that groundwater of the present study is unacceptable for drinking but also clearly indicate the influence of urban, industrial, and agricultural activities on the groundwaters of the said area. This study has massive relevance in designing control measures and action plans for reducing the pollutant influx into the groundwaters. Prompt enforcement of environmental protection laws is needed to prevent continuous pollution of the area. Further, an immediate and sustainable collective action by all stakeholders to control the pollution level is highly recommended, as this issue poses a severe public health threat.

Keywords Groundwater · Heavy metal pollution index · Metal index · Peenya Industrial Area · Rating

Highlights

- Heavy metals are probably the most harmful and insidious pollutants because of their non-biodegradable nature and their potential to cause adverse effects in human beings at certain levels of exposure and absorption.
- Heavy metal pollution index (HPI) is a rating method and an effective tool to assess the water quality with respect to heavy metals.
- There is an increase in epidemiological and other evidences, indicating an association between water quality and mortality from cardiovascular and other chronic disease.
- There have been few studies on heavy metals in groundwater in many parts of the world, but very little research has been done in the study area with respect to heavy metal pollution indexing.
- 63.33% of the groundwater samples have an HPI higher than the critical value, which clearly indicates the alarming heavy metal contamination in the study area.
- Further pollution needs to be prevented by adopting proper management measures that include precise treatment of wastes from industries and complying with wastewater disposal standards.

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Abbreviations

AAS	Atomic absorption spectrometer
APHA	American Public Health Association
BIS	Bureau of Indian Standards
HPI	Heavy metal pollution index
IARC	International Agency for Research on Cancer
MAC	Maximum admissible concentration
MI	Metal index
PIA	Peenya Industrial Area

Introduction

The massive usage of heavy metals in several fields such as domestic, industrial, medical, agricultural, and technology have resulted in large-scale distribution in the environment and hence raised concerns about their toxic potential on the environment. Several factors such as the dose, exposure route, age, and gender of the exposed persons influence their toxicity (Tchounwou et al. 2012).

Heavy metals are among the most common environmental pollutants, and their occurrence in water and biota indicate the presence of natural or anthropogenic sources (Akoto et al. 2008; Adaikpoh et al. 2005).

Heavy metals are added to aquifer systems, both from natural and manmade sources. Trace metals, which are selectively concentrated by vegetation, reach the surface and groundwaters. Wastewaters from industries such as metal plating, alloying, mining, and cleaning also add significant amount of trace metals to aquatic systems. Considerable quantities of trace metals are also added to both surface as well as groundwaters by municipal sewage. Despite being absolutely essential for living beings, if excess quantities of these metals are consumed, they may result in physiological disorders. Soils with excessive heavy metal concentrations may induce phytotoxicity and severe health threats in human beings (Sirajudeen et al. 2015). Contamination of groundwaters and food chain transmission may lead to some indirect effects (Pulford et al. 2002).

A rise in epidemiological evidences seems to point out to a direct relationship between the quality of water and deaths resulting from cardiovascular as well as some chronic diseases (Shivashankaran 1997).

The heavy metals have made researchers take note, for a variety of reasons ranging from need for identification of the origin of trace metals, metal transport as related to public health, to the problem of biomagnification of these toxic elements in the food chain. It is thus imperative to understand the basic routes and distribution pattern of elements that are critical for life process.

High concentrations of heavy metals are extremely toxic to human beings as well as aquatic life (Ouyang et al. 2002). Very small amount of chromium is required for normal functioning, whereas excessive concentrations may be toxic causing issues in the kidneys and liver (Loubières et al. 1999; Knight et al. 1997). Another metal with high toxicity is lead that is carcinogenic to humans, causing serious chronic health disorders such as including headaches, blood pressure, abdominal pain, irritability, kidney and nerve damage, brain tumors, and cancer of the lungs (Keshav Krishna and Mohan 2016). Children and neonatals are very sensitive and more vulnerable to lead. Complicated health issues, such as dementia and behavioral disorders, may be caused as a result of exposure to excessive concentrations of lead. Anemia may be caused as a result of extended exposure to lead (Jarup 2003; Mortada et al. 2001; Steenland and Boffetta 2000). Exposure to cadmium causes acute and chronic effects on living beings. These chronic issues include skeletal and kidney disorders. Experimental studies conducted on humans and animals show that cadmium may cause cancer in humans (Jarup et al. 2000; IARC 1993; Nordberg et al. 2002). In this regard, recognizing heavy metal contaminations and their possible sources is an issue that needs to be investigated (Mirzabeygi et al. 2017).

Investigations by Sajadi et al. (2015) as well as Bazrafshan et al. (2016) with respect to the concentration of heavy metals in Sistan along with Baluchistan's groundwater revealed high concentrations of Cd and Pb in the studied area. Further, Muhammad et al. (2011) based on their studies revealed much lower concentrations in the water in the Kohistan region, north Pakistan.

The heavy metal concentrations are generally assessed to evaluate the water quality of a system which hints about the extent of pollution caused with respect to these parameters. From the analysis results, two pollution indices in the groundwater, namely heavy metal pollution index (HPI) and metal index (MI) have been computed. Heavy metal pollution index is an effective method of rating and ascertaining the water quality with respect to heavy metals. The indices aid, not only in arriving at an integrated influence of the parameters of pollution but also enables the same into a clear reproducible form and assist in the compilation of the pollution parameters to a relatively easier approach (Balakrishnan and Ramu 2016).

Quite a few studies have been carried out to assess the concentration of heavy metals content in the groundwaters of many parts of the world which includes a few isolated areas in Bangalore, India, too. But there has been very little research done in and around the study area (Peenya Industrial Area (PIA)), related to heavy metal pollution indexing. Hence, this investigation was taken up to determine the groundwater quality in the Peenya Industrial Area of Bangalore, mainly aimed at evaluating the concentration of selected heavy metals and to appraise the critical impact of anthropogenic activities on the groundwater, by evaluating the HPI and MI, to ascertain the overall influence of pollution in the groundwaters of PIA.

Materials and methods

Details of Peenya Industrial Area (study area)

Bangalore City lies between north latitude 12° 52′ 21″ to 13° 6′ 0″ and east longitude 77° 0′ 45″ to 77° 32′ 25″, approximately covering 400 km^2 of the area. The Peenya Industrial Area is located on the 57 H/9 Toposheet, Survey of India. It covers about 9 km^2 lying in the heart of Bangalore City to the northern part and comprises of almost 2000 industries, out of which, industries such as pharmaceutical, chemical, metal plating, and leather dominate. But people in this area have been using polluted water for washing of clothes and utensils, cleaning, as well as several other domestic chores. The author on holding discussions with the public of PIA and also with the authorities of primary health center received crucial information about a number of people in this area suffering from extreme skin problems such as boils, rashes, itching sensation on their hands and legs along with experiencing severe joint pain in their hips and knees after using the water (Shankar et al. 2008).

Analysis methodology

Thirty sampling sites comprising both open as well as borewells were identified in the study area, from which groundwater was collected in 2-l polyethylene sampling containers, cleansed with acidic water, and swilled with distilled water, strictly adhering to the sampling protocols. The location of sampling stations and source details is presented in Table 1. The analysis was conducted to estimate the concentration levels of six metals, namely Fe, Pb, Cu, Cr, Ni, and Cd using an AAS, i.e., atomic absorption spectrometer as per the American Public Health Association (APHA 2002). The analysis results were processed following the protocols prescribed under the specifications of Bureau of Indian Standards (BIS 10500: 2003). Figure 1 depicts the study area (PIA), showing the sampling locations.

Indexing approach

Pollution indices HPI and MI were developed and determined as explained in this indexing approach.

Heavy metal pollution index

Monitoring of heavy metal contamination is important because heavy metals pose threat to aquatic life, to human health, and to the environment due to biomagnifications and their toxicity (Ahmed et al. 2015; Ali et al. 2016). As the extent of these heavy metals may differ in different water containing sites, the scientists have arrived at a formula to quantitatively measure the combined effect of these heavy metals in this form (HPI). With the alarming increasing trends observed with respect to groundwater pollution by heavy metals and to protect water bodies from pollution, continuous monitoring is necessary to reduce further pollution. In this direction, it is necessary to identify some pollution monitoring tools for water bodies (Chougule et al. 2009; Yankey et al. 2013). Heavy metal pollution indices are a useful and a relatively easy way to assess the composite of overall heavy metal pollution (Al-Hejuje 2014).

HPI is a powerful technique for the assessment of water quality with respect to heavy metal concentration (Ali Rezaei et al. 2017). HPI is a rating technique that depicts the composite influence on the overall quality of water with respect to individual heavy metals (Reza and Singh 2010). The quality of water and its suitability for drinking can be examined by evaluating its quality index (Mohan et al. 1996; Prasad and Kumari 2008; Prasad and Mondal 2008).

The interpretation of spatial and seasonal concentration of heavy metals through HPI can be useful in

Table 1 Details of sampling stations with the latitude and longitude

Sample no. and code	Sampling locations	Source	Latitude	Longitude
P1	Aditya Apparels, Peenya Istg, Peenya Industrial Area	BW	77.5153	13.0175
P2	Vinayaka Mosquito Coil Mfg. Co, Peenya Industrial Area	MWS	77.5167	13.0177
P3	Opp Hitco Tools Ltd, III Ph, Peenya Industrial Area	BW	77.5187	13.0249
P4	Rexroth Bosch India Ltd, III Ph, Peenya Industrial Area	BW	77.519	13.025
P5	Zuman Exports, III Ph, Peenya Industrial Area	BW	77.5188	13.0249
P6	Opp Shakthi Mosaics, Sanjay Gandhi Nagar slum, PIA	HP	77.4617	13.0367
P7	Peenya Industrial Estate, Bangalore North	HP	77.523	13.0288
P8	Near Super Tax Labels, II stage, PIA	BW	77.5061	13.0164
P9	Auma Industries Limited, II stage, Peenya Dasarahalli	BW	77.5078	13.0169
P10	Opp Industrial Electrocontrols, III stage, II Ph, Peenya	MWS	77.4572	13.0256
P11	Malnad Furnitures, T-Dasarahalli, Peenya	BW	77.4872	13.0236
P12	Near Unique Instruments, III main, IV Ph, PIA	HP	77.513	13.0279
P13	Power Plastics, III main, IV Ph, PIA	HP	77.5161	13.028
P14	M/S Paragon Footwear Pvt Ltd, Iiph, PIA	BW	77.5283	13.0268
P15	Honeyhills Energy System, PIA	BW	77.5244	13.0397
P16	Fine Tools India Ltd, IV Ph, PIA	BW	77.5144	13.03
P17	Byraveshwara Stores, Nandini Layout, I stage, II block	BW	77.538	13.0136
P18	Petrol Bunk, Nandini Layout	BW	77.5367	13.0103
P19	Hi-Power Equipments Pvt Ltd, II Ph, PIA	OW	77.5161	13.0244
P20	M/S Biopharma Drugs and Pharmaceuticists, PIA	BW	77.525	13.025
P21	Simco Insulator Manufacturing Company, II Ph, PIA	BW	77.527	13.0261
P22	Hitachi Koki India Ltd, I Ph, PIA	BW	77.5189	13.0265
P23	Venus Engineering Industries, III Ph, PIA	BW	77.5172	13.0249
P24	Near Shruthi Innovations, Peenya	BW	77.5356	13.033
P25	CMC-Water, Peenya	BW	77.5383	13.032
P26	Hanuman Weaving Factory, I Ph, PIA	MWS	77.4928	13.0391
P27	Hind Hivac Pvt Ltd, I Ph, PIA	BW	77.5289	13.0405
P28	John Crane Sealing Systems, I Ph, PIA	BW	77.5258	13.0389
P29	Trident Fabricants, KIADB, I Ph, PIA	BW	77.4967	13.0367
P30	CMTI, Peenya	BW	77.535	13.0325

BW borewell, *OW* open well, *MWS* mini water supply scheme, *HP* hand pump

assessment of degree of pollution load and water quality trend of a river (Reza and Singh 2010; Prasanna et al. 2012). HPI of a river can be a useful tool for regulatory agencies to make necessary policies and decisions regarding pollution abatement and resource management (Rama Pal et al. 2017). The metal quality indices may be computed to assess the suitability level of water resources for drinking with respect to metals (Ojekunle et al. 2016).

The HPI has been arrived at, by assigning a rating or weightage (W_i) for each selected parameter (Prasad and Sangita 2008). The rating system is an arbitrary value between zero and one, reflecting the relative importance of individual quality considerations, and thus, W_i can be defined as inversely proportional to the recommended standard (S_i) for each parameter (Horton 1965; Mohan et al. 1996; Reddy 1995). The highest tolerant value for drinking water (S_i) refers to the maximum allowable concentration in drinking water in absence of any alternate water source. The desirable maximum value (I_i) indicates the standard limits for the same parameters in drinking water (Richa Bhardwaj et al. 2017).

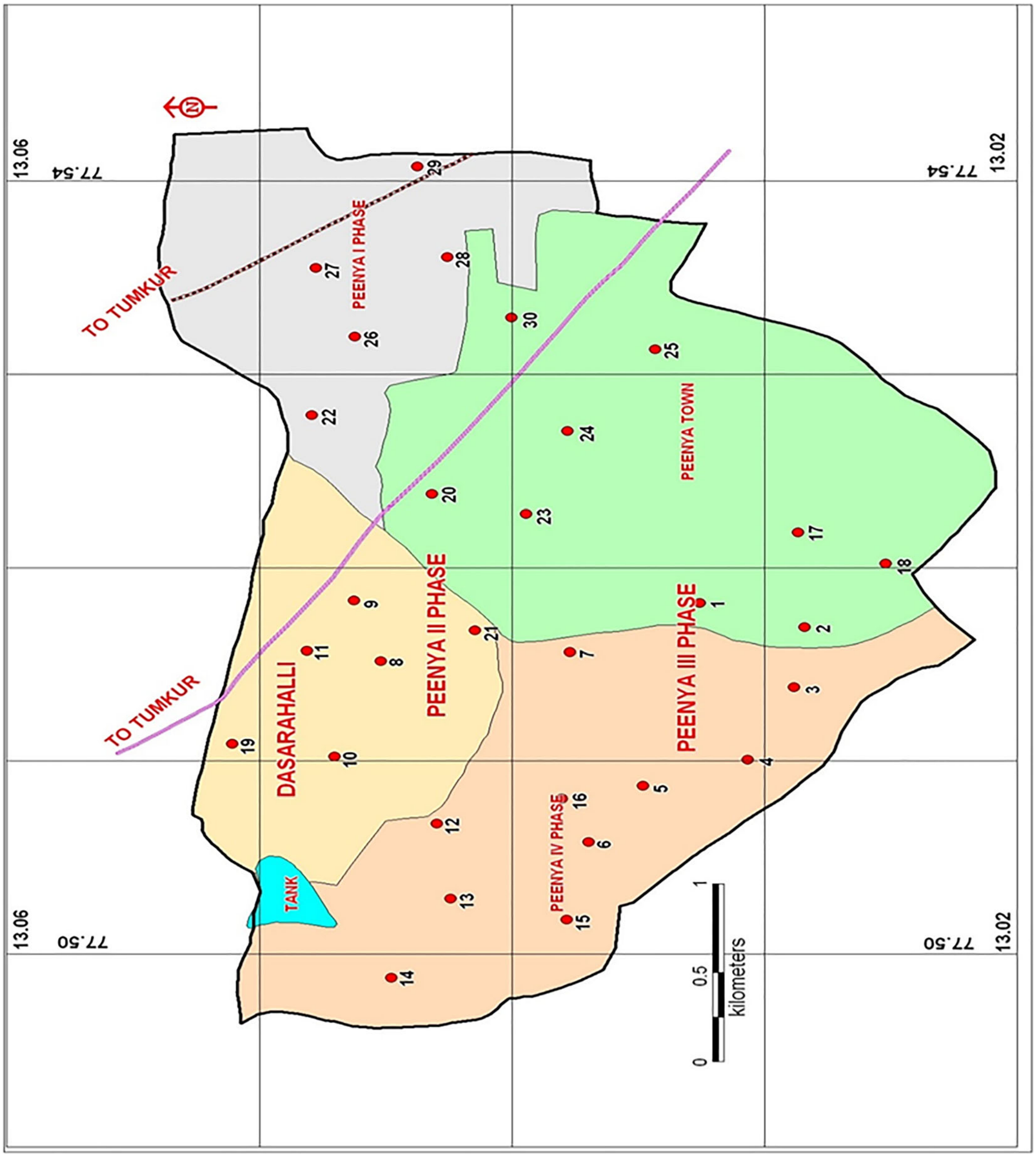

Fig. 1 Map of the Peenya Industrial Area with sampling stations

HPI has been developed and formulated (Mohan et al. 1996) as

$$\mathrm{HPI} = \frac{\sum_{i=1}^{n} Q_i W_i}{\sum_{i=1}^{n} W_i}$$

Q_i and W_i represent the sub-index and unit weightage of the ith parameter respectively and n represents the total number of parameters that has been considered for the study. The sub-index (Q_i) is calculated by

$$Q_i = \sum_{i=1}^{n} \left[\frac{M_i - \mathrm{I}_i}{S_i - \mathrm{I}_i} \right] \times 100$$

where M_i and I_i denote the monitored value and ideal value of the ith parameter, while S_i represents the standard value pertaining to the *i*th parameter in ppm (Prasad 1999). Among the six parameters studied, BIS has placed the upper limit (maximum permissible limit) only for Cu. Since it is not desirable to have these metals or ions in drinking water, the ideal value is taken to be 0 (Elumalai et al. 2017). The quantity $[M_i - I_i]$ indicates numerical difference of the two values, ignoring the algebraic sign; which is the absolute value (Richa Bhardwaj et all. Bhardwaj et al. 2017). The critical pollution index of HPI value for drinking water is taken as 100 (Anju kumari et al. 2016). According to Prasad and Bose (2001), W_i, the unit weightage value is stated to be inversely proportional to MAC, i.e., maximum admissible concentration pertaining to the corresponding parameter as proposed by Siegel (2002). The same approach has been adopted in this current work. The specimen calculation for HPI in the study area is presented in Table 2.

The HPI model appears to be promising and is proved to be a very useful tool in evaluating the overall pollution level of groundwater in terms of heavy metal in the water samples. Thus, HPI serves as a bridge between professionals and laymen or the decision makers (Al-Hejuje et al. 2017a, 2017b).

Metal index

The metal index (MI) was preliminarily defined by Tamasi and Cini (2004). This index can be expressed by the following equation:

$$MI = \sum_{i=1}^{n} \frac{C_i}{(MAC)_i}$$

where MI is the metal index, C is the concentration of each element in solution, MAC is the maximum admissible/allowable concentration for each element, and the subscript i is the *i*th sample (Hadi Hajizadeh et al. 2010).

The specimen calculation for calculating MI for groundwater sample is presented in the Table 3.

Results and discussion

Heavy metal analysis

The estimation of the concentration of these heavy metals associated element may establish the trend of heavy metal distribution (Jareda et al. 2018).

A comprehensive analysis for the selected heavy metals was taken up by considering 30 groundwater samples from PIA. The results of the entire physico-chemical groundwater analysis has been presented in Table 4, while the analysis results of the six heavy metals considered for the study has been separately presented in Table 5. Based on the analysis, it was seen that 43.33%, 36.67%, 40%, 63.33%, and 83.33% of the samples had excessive concentrations (as per BIS, 10,500) with respect to Fe, Pb, Cr, Ni, and Cd respectively. With respect to the maximum permissible limits, none of the samples showed Cu concentrations in excess of this (1.5 mg/l), but it was seen that 33.33% of the samples indicated Cu concentrations in excess of the BIS desirable limits (0.05 mg/l). A graphical representation of the trace metal levels in comparison with BIS permissible values is presented in Fig. 2. The higher levels recorded for groundwater samples indicate serious contamination which may be as a result of anthropogenic activities within the area or geologic migration of the metals.

Table 2 Specimen calculation for HPI in Peenya Industrial Area (study area)

Heavy metal	Monitored value in mg/l M_i	Standard value in mg/l S_i	Ideal value in mg/l I_i	Unit weightage W_i	Sub-index Q_i	W_iQ_i	HPI $\Sigma W_iQ_i/\Sigma W_i$
Fe	3.14	0.3		3.333333	1046.667	3488.889	
Pb	0.08	0.01		100	800	80,000	
Cr	5.4	0.05		20	10,800	216,000	
CU	0.28	0.05	1.5	20	84.13793	1682.759	
Ni	0.04	0.02		50	200	10,000	
Cd	0.06	0.003		333.3333	2000	666,666.7	
				$\Sigma W_i = 526.6667$		$\Sigma W_iQ_i = 977{,}838.3$	65.49

Table 3 Specimen calculation for MI in Peenya Industrial Area (study area)

Heavy metal	Concentration in mg/l C_i	Maximum allowable concentration in mg/l MAC	$MI = \sum \frac{C_i}{(MAC)}$
Fe	3.14	0.3	10.46667
Pb	0.08	0.01	8
Cr	5.4	0.05	108
CU	0.28	0.05	5.6
Ni	0.04	0.02	2
Cd	0.06	0.003	20
			154.0667
			Mean = 25.68

Heavy metal indices

The main objective of the study has been to evaluate two key heavy metal pollution indices HPI and MI in the groundwaters of Peenya.

One of the most effective and practical methods to evaluate the pollution status of groundwater is by estimating the heavy metal pollution index, HPI (Abou Zakhem and Hafez 2015). This methodology has been used in the assessment of heavy metals to study the water quality of River Diyala, Iraq (Abdullah 2013), river Subarnarekha, India (Manoj et al. 2012), and river Kor, Iran (Sheykhi and Moore 2012). Similar studies were carried out to evaluate the HPI in the groundwaters of Tarka mining area in Ghana (Yankey et al. 2013). An assessment of heavy metals using the same model was carried out by Kumar et al. (2012) for the groundwaters of Chennai, India (Abou Zakhem and Hafez 2015).

Metals Fe, Pb, Cd, Cu, Cr, and Ni were considered for analysis in the present study by selecting 30 sampling stations and the HPI values for these samples were determined. From the analysis, the mean HPI of Peenya Industrial Area was 146.32, a figure, much higher than the critical value of 100, beyond which the degree of pollution for drinking water is deemed unacceptable (Prasad and Kumari 2008; Prasad and Mondal 2008). A high percentage of the water samples (63.33%) has an HPI higher than this critical value, which clearly indicates the alarming heavy metal contamination in PIA.

The last 3 years have seen a spurt in the studies related to heavy metals owing to the huge importance and environmental threat they pose. Some key studies have been discussed here.

El-Hamid and Hegazy carried out water quality pollution indices studies for the groundwater resources of New Damietta, Egypt (El- Hamid and Hegazy 2017) and based on their analysis, the heavy metal concentrations (Cd, Pb, Cr, As, Cu, Hg, Se, Zn, and Ni) were detected in water samples and the mean concentrations of heavy metals were 0.0016–0.0016, 0.003–0.00, 0.006–0.00, 0.00–0.004, and 0.002 mg/L respectively. Results also showed that the concentrations of heavy metals were within the permissible WHO limits in drinking water. The HPI of water samples in three sites were 20.57, which was lower than 100 the critical value for drinking water.

Similar studies (Rama Pal et al. 2017) were carried out to assess heavy metal pollution index for Yamuna Water in Agra Region, India. As per their study, overall HPI of Yamuna was 176.75 which was above the critical limit. The high HPI values were mainly due to industrial and domestic wastewater discharge into river. HPI of different sampling sites were compared to assess pollution load and assess the water quality for the selected sites and the HPI values were above the critical index limit at all sites.

Water quality of the Kazretula, Poladauri, and Mashavera rivers and three irrigation canals were examined in a research study (Sisira Withanachchi et al. 2018). The sediment and water analyses showed alarming levels of heavy metal contamination that exceeded national and international thresholds in several observed sites of the Mashavera River Basin. High concentrations of Cd and Pb were observed.

Studies carried out to determine the heavy metal contamination in the groundwaters of Asadabad Plain (Sobhanardakani et al. 2016) revealed that the values of

Table 4 Results of groundwater physico-chemical analysis in Peenya Industrial (study) Area

T.H	Ca	Mg	Na	K	HCO_3	CO_3	Cl	NO_3	SO_4	PO_4	TDS	EC	F	pH	Turbidity
1074	216	130	76	2	320	0	356	22	640	1	1600	2560	2.96	7.72	1.9
620	140	66	64	2.5	220	0	242	80	322	0.6	1030	1700	1.42	6.07	Nil
458	98	52	100	1.6	320	0	230	40	190	0.5	870	1410	0.8	7.42	0.6
172	44	15	55	0.6	54	0	50	12	170	0.3	370	580	2.2	8.1	0.2
716	152	82	200	2.8	360	5	410	86	442	1.5	1560	2500	1.27	7.92	2
840	142	118	196	4	418	2	600	114	228	1	1610	2700	0.66	7.97	0.4
1242	234	160	342	4	546	18	710	344	216	2.1	2300	3800	0.8	7.96	4
738	128	102	60	6	376	0	304	104	80	0.5	970	1550	0.4	7.79	3.2
590	128	66	74	1.6	230	0	440	58	32	1.2	920	1470	0.61	5.12	0.1
406	100	38	80	3.2	200	1	240	54	120	0.5	740	1180	2.1	6.16	0.2
322	88	25	55	3.2	178	0	172	16	66	0.4	510	820	1.38	6.4	2.8
2996	522	412	104	0.6	270	0	2120	164	542	8	4010	6600	5.92	6.11	16
3040	596	378	90	5	386	4	1860	122	380	4.4	3630	5800	6.12	7.14	5
538	74	86	112	6	200	0	470	40	50	1	940	1700	0.66	7.07	2.2
1262	236	164	182	4	382	14	640	40	604	4	2080	3300	0.48	7.02	Nil
1084	230	124	160	2.5	280	0	508	22	540	2.1	1730	2740	0.44	7.2	0.7
372	110	24	74	2	234	0	244	20	98	1	700	1160	1.5	7.82	Nil
322	80	30	94	4	212	12	124	38	68	2.1	560	900	0.22	7.24	0.8
432	140	20	52	8	80	8	98	56	242	1.8	670	1070	1.44	7.72	2.1
388	80	46	72	4	334	0	168	22	138	3.1	700	1120	0.45	7.5	Nil
542	112	64	102	3.8	214	4	396	18	114	1.1	920	1470	1.4	8.21	1.7
670	160	66	64	1.2	380	5	360	24	68	0.1	940	1560	1.9	7.9	1.1
318	88	24	114	6	210	0	270	98	62	0.3	770	1280	0.8	6.88	1
1502	352	152	212	5	360	0	412	40	934	2	2290	3800	0.48	7.02	8
1418	288	170	302	8	332	0	904	58	880	2.1	2780	4420	0.98	7.57	0.7
356	100	26	96	1.1	380	0	164	68	80	0	730	1100	1.32	8.22	0.8
128	25	16	55	0.5	130	2	110	16	27	0.4	320	520	2.4	7.02	0.6
536	136	48	72	0.6	332	3	182	26	110	0	740	1180	1.42	6.54	2.6
542	110	65	90	1.38	412	0	264	36	90	0.3	860	1380	1.44	6.92	0.7
136	38	10	66	0.8	136	0	74	14	24	1	300	490	1.32	7.12	Nil

All parameters except pH and EC in mg/l

HPI in groundwater were below the critical values but severe precaution considerations such as managing the use of agricultural inputs, prevention of use of wastewater and sewage sludge in agriculture, control of over use of organic fertilizers, and establishment of pollutant industries were recommended. Further, a comparison between the indices and heavy metal concentration showed a very strong correlation with Pb and Cd for spring and summer samples indicating that Pb and Cd were the main contributory parameters.

HPI values are an important indicator of water pollution by heavy metals. Studies carried out to assess the heavy metal contamination and calculation of its pollution index for the Uglješnica River, Serbia, revealed that the mean values for the HPI were 67.487 and 80.676 during the spring and autumn seasons, respectively. During the spring, increasing rainfall leads to a rise in river water level and the subsequent dilution effect of rainfall results in a decrease of the heavy metal concentrations in the water. The maximum obtained HPI value (112.722) was found during the autumn season at sampling site under the landfill and close to the highway. The existing landfill has a negative effect on groundwater and the quality of the river water (Milivojevic et al. 2016).

Table 5 Results of heavy metal analysis in Peenya Industrial (study) Area

Sampling station	Fe	Pb	Cr	Cu	Ni	Cd	Sampling station	Fe	Pb	Cr	Cu	Ni	Cd
P1	3.14	0.08	5.4	0.28	0.04	0.06	P16	0.32	0.14	0.01	nil	0	0
P2	2.88	1.26	2.42	1.18	0.03	0.33	P17	0.08	Nil	Nil	0.07	0.03	0.004
P3	0	Nil	Nil	Nil	–	–	P18	0.31	Nil	1.4	Nil	0.02	0.11
P4	0.21	0.11	1.98	0.44	0.21	0.02	P19	1.76	0.91	1.93	0.22	0.09	0.03
P5	0.64	Nil	Nil	Nil	0.06	0.008	P20	0.06	Nil	Nil	Nil	0.08	0.005
P6	0.28	0.13	2.77	Nil	–	0.01	P21	1.1	Nil	3.6	Nil	0.03	0.004
P7	0.22	0.08	Nil	0.11	0.018	0.016	P22	0	Nil	Nil	Nil	–	0.004
P8	0.23	Nil	0.16	Nil	0.04	0.09	P23	0.66	0.24	Nil	0.48	0.26	0.21
P9	0	Nil	Nil	Nil	0.002	0.01	P24	1.04	Nil	1.1	Nil	–	0.05
P10	0	Nil	0.02	Nil	–	–	P25	0.38	0.06	0.02	0.1	0.11	0.02
P11	0	Nil	0.11	Nil	0.04	0.23	P26	0	Nil	Nil	Nil	0	0.1
P12	0.08	1.1	1.7	0.22	0.98	0.08	P27	0.76	Nil	Nil	0.27	0.03	0.04
P13	0.04	Nil	Nil	Nil	–	–	P28	0.21	Nil	Nil	Nil	0.16	–
P14	0	Nil	Nil	Nil	0.03	0.16	P29	0	Nil	0.28	Nil	0.14	0.011
P15	0.88	Nil	1.43	Nil	0.05	0.18	P30	1.14	0.25	0.04	0.11	0.18	0.04

All parameters in mg/l

Five stations were selected at the middle part of Shatt Al-Arab river to determine the monthly variation of seven eco-toxic elements (Cd^{+2}, Cu^{+2}, Fe^{+2}, Mn^{+2}, Ni^{+2}, Pb^{+2}, and Zn^{+2}) concentrations and their distribution as dissolved and particulate (exchangeable and residual) phases during the low tide period from December, 2012 to November, 2013 (Al-Hejuje et al. 2017a, 2017b). The HPI results indicated that mean HPI values were found to be above the critical pollution index value of 100, ranging from 130.41 to 196.97 referred to polluted water caused by the world impermissible values of dissolved Pb, Fe, and Cd. The authors noted that the concentrations of heavy metals in particulate matter mostly depend on many factors such as wastewater discharge, seasonal loads, and the nature of basin.

In another study involving contamination of water along Damietta Nile branch, the overall HPI was seen to be 350.14, greater than the critical pollution index value of 100, indicating the contamination of water with heavy metals as a result of discharge of drainage waters of different anthropogenic activities along the branch. From the studied metal indices, it was concluded that the water quality of Damietta branch was seriously affected due to anthropogenic activities in the Nile delta as sewage, industrial, and agricultural wastewaters (Yasser El-Ameir 2017).

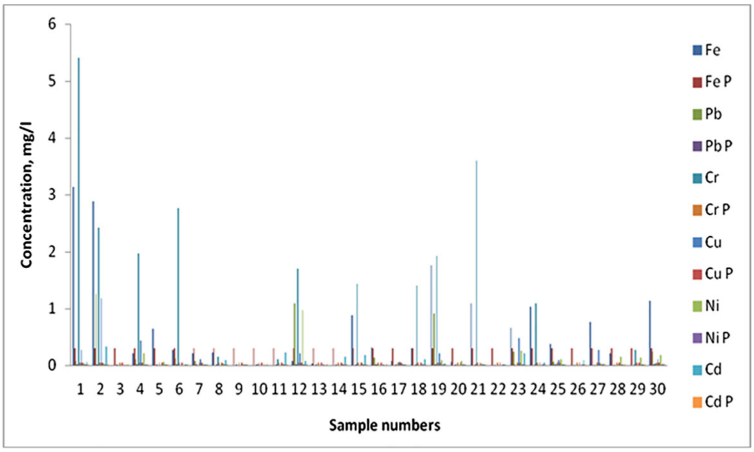

Fig. 2 Graphical representation of trace metal levels in comparison with BIS permissible values. Fe P, Pb P, Cr P, Cu P, and Ni P indicate the permissible values of the respective trace metals

Further, the groundwater has also been classified based on HPI (Elumalai et al. 2017), as presented in Table 6.

Based on this classification, it has been seen that 10% of samples each fall in the categories of excellent, good, and very poor category, while a whopping 63.33% of the samples fall in the totally unsuitable category. The excessive heavy metal pollution may be due to leaching of heavy metals from electroplating, pesticides, power coating, fertilizers, garment washing and textiles, and drug industries. Alloys, pigments, and batteries are also present in sufficient numbers in the study area. Barring Cu, all the other metals studied have been found to be contributing to heavy metal pollution. The results of HPI for the study area are presented in Table 7.

Metal index

Another index that has been evaluated for drinking water is the metal index (MI) which considers the likely additive effects on human health, of certain key heavy metals which aid in the rapid evaluation of the overall status of drinking water quality. The higher the concentration of a metal compared to its respective maximum allowable concentration (MAC value), the worse will be the quality of water (Goher et al. 2017). A MI value greater than 1 is considered as threshold of warning (Bakan et al. 2010), even in cases where C_i is less than MAC for all elements.

In a similar study on HPI and MI, two quantitative methods were used in assessing the risk level of heavy metal concentrations contamination in the samples: HPI and MI. The heavy metal pollution index for the study area was calculated using the mean concentration values of the selected metals (Pb, Zn, Fe, Cd, and Co) The metal index for the study area revealed very poor water quality with a MI value of 150.5 which is above the threshold limit of a MI value > 1 (Charles Izuma Addey et al. Charles et al. 2018).

Table 6 Groundwater classification based on HPI values

HPI range	Quality
< 25	Excellent
26 to 50	Good
51 to 75	Poor
76 to 100	Very poor
> 100	Totally unsuitable

Table 7 Analysis results of MI and HPI for the study area

Sampling station	HPI	MI
P1	65.49	25.68
P2	158.40	63.18
P3	20.00	0.00
P4	67.29	12.88
P5	120.74	1.30
P6	48.07	12.11
P7	166.05	2.86
P8	275.32	5.98
P9	254.44	0.57
P10	20.00	0.07
P11	314.04	13.48
P12	104.33	37.39
P13	18.10	0.02
P14	319.92	9.14
P15	218.03	15.67
P16	87.62	2.54
P17	132.17	0.75
P18	189.81	11.12
P19	89.28	25.73
P20	112.58	0.98
P21	25.05	13.08
P22	196.44	0.22
P23	240.25	19.80
P24	139.64	7.02
P25	150.43	3.64
P26	323.90	5.56
P27	249.51	3.79
P28	43.46	1.45
P29	98.54	2.71
P30	140.71	9.02

The analysis results of MI and HPI for the study area are presented in Table 7, while the variation of HPI as well as MI in the PIA are pictorially represented in Fig. 3.

The mean MI concentration was found to be 10.36. Twenty-three samples, i.e., 76.67% of samples fall above the threshold of warning (1.0), which infers that only 23.37% of the samples could be classified as pure and hence suitable for domestic and agricultural purposes.

Further individual sampling sites were classified according to the literature (Lyulko et al. 2001; Caerio et al. 2005) as shown in Table 8 and it was observed that

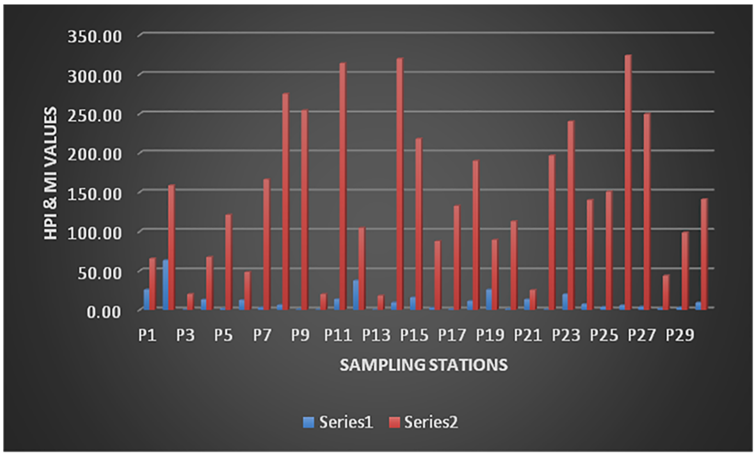

Fig. 3 Variation of HPI and MI in the groundwaters of the study area

46.67% of the samples were found to fall under the seriously affected class (MI values above 6), while 6.67% of groundwater samples were found to belong to the strongly affected class and 16.67% of the groundwater samples under moderately affected class. These alarming numbers could be attributed to the huge number of industries in the study area, such as electroplating, fertilizers, thermal power plant pesticides, and textiles.

Conclusions

The present heavy metal investigation was undertaken to appraise the heavy metal concentration of in the groundwaters of Peenya Industrial Area as well as to assess the impact of human activities/industrialization on the groundwater. This was achieved by evaluating two useful tools serving as pollution indices in the form of HPI and MI. Based on the investigation, the mean value of HPI was seen to be 146.32, a figure well above the critical value of 100. 63.33% of the samples reveal excessive HPI's. On the basis of average or mean concentration, the value of MI was seen to be 10.36 and it was observed that 46.67% of the groundwater samples fell under the seriously affected category (MI values above 6). The results clearly point out to the influence of industries, agricultural activities, and anthropogenicity in PIA, indicating massive groundwater contamination due to heavy metals, making the quality of water extremely poor and unsuitable for drinking purposes. But the people in the study area have been utilizing the same and being exposed to several health hazards.

It is becoming imperative now that further pollution needs to be prevented by employing precise management measures such as treating the industrial wastes and complying with statutory standards for disposing the wastewater. Strict pollution check measures need to be initiated via thorough enforcement of legislation to ensure proper operation and maintenance of their wastewater treatment plants. Consumption of the said water by the people may result in aggravating their health issues and hence it is absolutely essential to treat the groundwater too, to ensure its potability. Government interventions for provision of safe/potable water are also suggested.

Table 8 MI classification based on class

MI	Characteristics	Class	Sampling stations
< 0.3	Very pure	I	P3, P10, P13, P22
0.3–1.0	Pure	II	P9, P17, P20
1.0–2.0	Slightly affected	III	P5, P28
2.0–4.0	Moderately affected	IV	P7, P16, P25, P27, P29
4.0–6.0	Strongly affected	V	P8, P26
> 6.0	Seriously affected	VI	P1, P2, P4, P6, P11, P12, P14, P15, P18, P19, P21, P23, P24, P30

Such studies may provide the scientific basis for the risk management of drinking water quality in the area and also suggest a new mode and technical platform for water quality protection.

This study has massive relevance in designing control measures and action plans for reducing the pollutant influx into the groundwaters. Prompt enforcement of environmental protection laws is needed to prevent continuous pollution of the area. This knowledge of risks assessment shall be deemed as utmost priority considering continuous increase in heavy metal and general environmental pollution globally in water, air, and soil. Further, an immediate and sustainable collective action by all stake holders to control the pollution level is highly recommended, as this issue poses a severe public health threat. This plan will go a long way in ensuring the safety of the citizens especially children who are more vulnerable to toxicity of heavy metals.

The results of the study should be taken earnestly by the concerned water resource management authorities and policy makers for the pollution abatement of the groundwaters.

Acknowledgments The author is deeply indebted to the Director Dr. Prabhakar, principal and management of Gopalan College of Engineering and Management, Bangalore, for the support and encouragement, in addition to providing excellent library and laboratory facilities provided to the author during the course of this research work.

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