

# Assessment of Seasonal Variation of Groundwater Quality Due to Heavy Metal Pollution in an Industrial Suburb



B. H. Anitha, C. Nanjundaswamy, S. N. Maya Naik, and M. S. Divyanand

**Abstract** Heavy metals concentration in groundwater, even at low concentrations affects human health severely. The objective of this study is to assess the seasonal variations of groundwater quality and to determine the concentration of heavy metal pollution in the Peenya industrial area, Bengaluru. The heavy metal concentrations in pre-monsoon were found in the order:  $\text{Cr} > \text{Cr}^{+6} > \text{Pb} > \text{Ni} > \text{Fe} > \text{Cu} > \text{Cd}$ , whereas for post-monsoon the order was  $\text{Cr} > \text{Cr}^{+6} > \text{Fe} > \text{Cu} > \text{Ni} > \text{Pb} > \text{Cd}$ . Powerful tools like MI (metal index) and HPI (heavy metal pollution index), which emphasize quality were used for the system of ranking. As per HPI and MI analysis, about 83% and 73% of groundwater samples, respectively, in pre-monsoon, about 57% and 50% in post-monsoon were not suitable for domestic usage. The mean HPI concentration for pre- and post-monsoon are 846 and 336.7, respectively, which is considered to be very high (critical value  $>100$ ). The mean concentration of MI for pre and post-monsoon are 27.2 and 12.62, respectively, is also high (critical value  $>6$ ) and is categorized as seriously affected. The overall status of water in the Peenya Industrial Area is highly polluted and not suitable for any domestic and industrial usage.

**Keywords** Groundwater quality · Pollution indices · Heavy metal pollution · Peenya industrial area

## 1 Introduction

Water is an elixir of life and earth's most distinctive feature, which is essential for every living organism on the planet. It is a crucial environmental resource and has

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played a significant role in the social and economic growth of human civilization [1]. It is estimated that the largest user of groundwater in the world is India, with 248 cubic kilometers of groundwater usage per year [2]. Due to the rapid growth of the human population, industrialization, urbanization, and improvement in the standard of living, the water demand is extended. Over the past few decades, there has been a massive increase in the demand for freshwater [3], leading to the shortage of surface water and greater dependency on groundwater. The demand for groundwater resources has gone up [4].

Groundwater is a natural source of potable water. It is less vulnerable to pollution than the earth's surface water, but cleaning up groundwater, once contaminated is difficult [2]. Due to the increase in per capita demand for water, the dependency on groundwater has increased rapidly [4]. The various anthropogenic activities affected the quality of groundwater and are more susceptible to contamination from various sources such as improper and untreated wastewater disposal [3] leakage from landfills, municipal sewers, septic tanks, infiltration of fertilizers, and chemicals from industrial activity, saltwater intrusion, etc. [4]. Groundwater pollution and its over-exploitation has been observed as localized contamination in major industrial zones [2].

The quality of groundwater in a particular region not only depends on factors like the nature of rocks present, the composition of the soil, and residence time but also on the recharge water. It also depends on the geology of the region, topography, climate, soil, etc. [5]. When groundwater contamination occurs in aquifers, it perseveres for a long time as a result of the slow movement [6], and also some major ions induced by geological features disperse over a large area [4]. So, regular monitoring of the quality of groundwater ensures water is safe, usable, and in an acceptable form. Monitoring groundwater is not only time taking and costly process but also difficult [5]. The groundwater quality varies seasonally and identifying the cause for quality deterioration leads to possible remediation [7].

The current work proposes the status of groundwater quality in Peenya industrial area, Bengaluru district of Karnataka state. Bengaluru has got the name 'silicon city' due to boom in the information technology. For the past many decades, it has overgrown in its size and the district administration is struggling to provide the necessary infrastructure and required demand for water supply [2].

Heavy metals are toxic and cause carcinogenic effects on living organisms [4]. Non-biodegradable, stable, and toxic heavy metals penetrate the food chain and increase the toxic levels, causing health problems [5]. If heavy metal exposure is for the long term, it causes health problems like damage to organs such as the brain, heart, kidney, liver, lungs. In extreme cases, the possibility and risk of cancer increases.

Heavy metals usage in the field of industrial, domestic, medical, and technology has resulted in large distribution and occurrence of metal ions in the environment [8]. The pollution of heavy metals is the most prominent cause of threatening water quality.

Several factors influence the toxicity of heavy metals such as the age of the person, gender, level of exposure, dosage, etc. [8]. The existence of toxic heavy metals in groundwater is a clear indication of anthropogenic activities. The industries which

use metals as raw materials for metal plating, chemical processing, finishing, and decorative purposes add a significant amount of trace metals into the environment. Groundwater contamination with chromium (Cr) has severe and toxic impacts on the environment and humans. The presence of Cr in groundwater is mainly derived from industrial wastewater discharge, which causes elevated concentrations of Cr in water bodies. Chromium in trivalent form is less soluble in water and less toxic but when it is oxidized to Cr (VI), it becomes highly toxic and more mobile in both groundwater and surface water [9]. Metals with high toxicity have led to chronic diseases like brain tumors, nerve damage, high blood pressure, lung cancer, and skeletal and kidney disorders [10].

The investigations made by many researchers found that the origin of trace metals and their transport, the rise of epidemiological issues, biomagnification of these toxic elements in the food chain, which has altered the life process severely.

Investigations are done concerning the concentration of heavy metals in the Bazman basin [11], southeastern Iran revealed a high concentration of Arsenic and selenium. Few researchers, [8, 12, 13] have investigated the groundwater quality and heavy metal contamination in Peenya industrial area using WQI, GIS interpolation techniques, bacteriological investigations like gram staining, heavy metal pollution index, and found heavy metals like chromium, lead, cadmium, mercury, copper, nickel, iron, etc. From the literature review, it has revealed that the Peenya is highly polluted since the past decades due to industrialization. The criteria for selection of wells for groundwater analysis is the excessive concentration of heavy metals due to increased industrial activity and its pollution in and around Peenya.

In recent times, an extensively used method for the qualitative detection of heavy metals in groundwater is pollution indices i.e., heavy metal index (HPI) and metal index (MI). These indices are useful tools for environmentalists, civil executives, and concerned authorities. The overall level of pollution of groundwater resources can be studied through these recent advanced methods. In pollution indices, considering overall parameters and the results can be converted into a single number. In MI, the total evaluation of the present state of quality and comparing the high concentration of heavy metals to its standard permissible limit for each element. HPI is an effective tool and also rating technique for assessing the quality of groundwater with special reference to heavy metals [14, 15].

An attempt has been made to analyze the seasonal variations of heavy metals in the groundwater of the study area for pre and post-monsoon seasons. The assessment of groundwater quality was not carried out during the monsoon season due to changes in rainfall patterns, which may lead to alterations in the level of groundwater. In a city like Bangalore, it is difficult to predict the rainfall pattern which varies seasonally [16]. The focus of research using the metal index (MI) and heavy metal pollution index (HPI) is to determine groundwater quality based on the concentration level of heavy metal presence in groundwater of PIA, Bengaluru.

## 2 Materials and Methodology

### 2.1 Description of the Study Area

Bengaluru city of Karnataka covers an area of 400 km<sup>2</sup>, which lies between 12° 58' N latitude and 77° 35' E longitude. The PIA (Peenya Industrial Area) has a latitude of 13° 01' N and a longitude of 77° 30' E which is located in the northwest suburbs. The main aim of the current work is to evaluate seasonal variations of groundwater samples for heavy metal detection from PIA. Peenya is considered the largest industrial region in Asia and is approximately 40 km<sup>2</sup> covering 1800 active industries [17].

Dominating industries are electroplating, textile, leather, pharmaceutical, power coating, locomotives, etc. With less scientific knowledge and carelessness of the concerned authorities, PIA is polluted for many decades. Effluents are discharged into nearby rivers or lakes, and also due to heavy rainfall leaching and runoff of chemicals enter into the subsurface. Unorganized factories dump wastewater without any treatment into nearby vicinity. The detailed literature survey revealed that Peenya is highly affected by heavy metal contamination due to the largest manufacturing industries present in that area. The main objective of the present study is to assess the seasonal variations of heavy metal pollution of selected groundwater samples in the PIA, Bengaluru, using HPI and MI. It provides an overview of current groundwater quality for domestic and industrial usage.

Figures 1 and 2 map showing the location of the study area [15, 18].

### 2.2 Geology and Climate

The area is a part of the peninsular gneissic complex consists of reddish sandy soil. It is non-clayey, non-sticky, but porous which is common in the Peenya suburb region. It usually consists of granite, gneiss, and rock dykes. The study area has a highly undulating topography with sub-dendritic nature with varying hydrological characteristics [19]. The rainfall in Bengaluru for the past 20 years was 900 to 1056 mm and the temperature lies between 15 °C min and a maximum of 35 °C. The geology of the study area is depicted in Table 1.

### 2.3 Collection of Sample and Analysis

The sampling sites were identified in the study area and the 30 groundwater samples were collected according to the 'grab sampling' method in the pre-monsoon (January–February 2020) and post-monsoon (November 2020) seasons which is depicted in Fig. 3. The criteria for selection of wells are based on the existence of

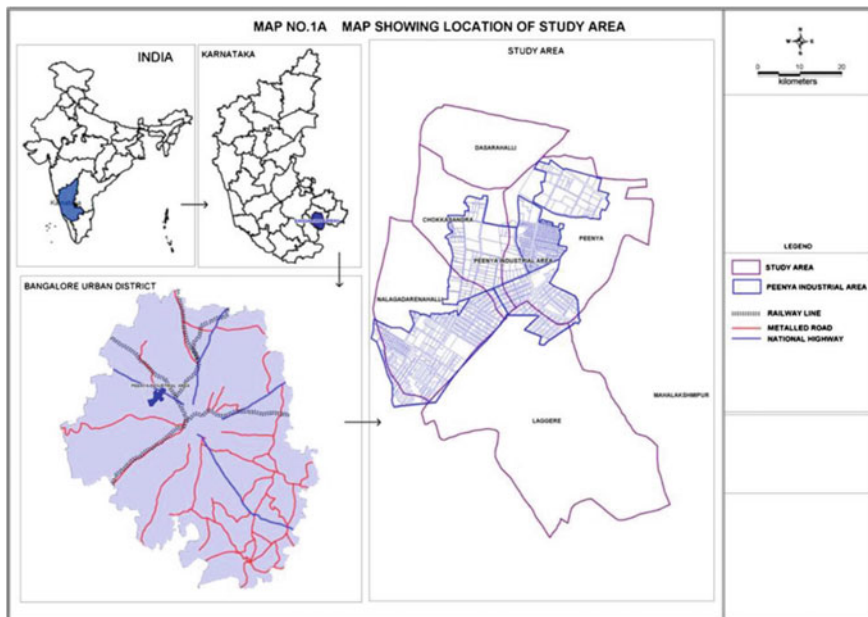


Fig. 1 Location of PIA

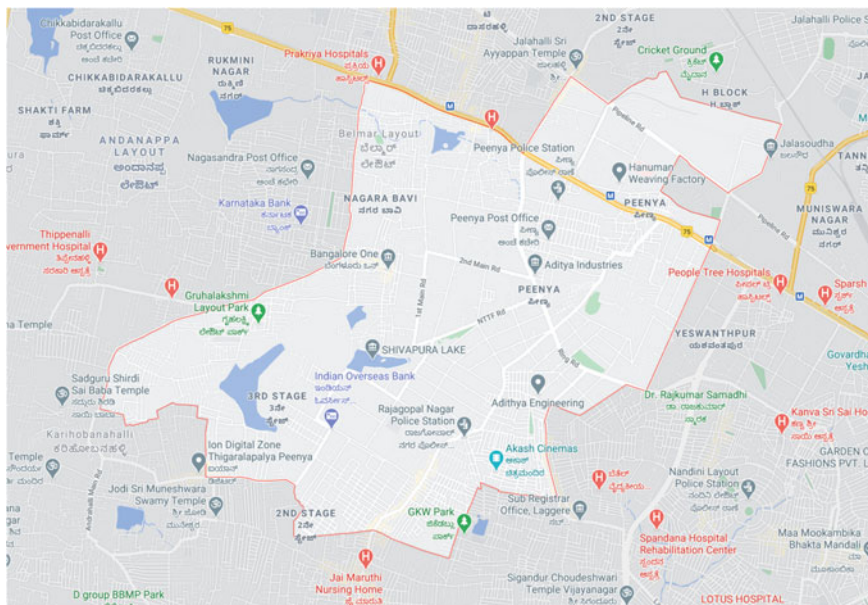


Fig. 2 Map showing PIA. Source From Google Maps

**Table 1** Geological characteristics [15]

Type of characteristics	Details
Topography	Highly undulating topography with sub-dendritic nature and varying hydrological characteristics
Watershed	South Pinakini toward the eastern portion and Arkavathi toward the western portion
Water bodies	Nelagedranalli, Shivapura, Dasarahalli, and Karihobanahalli



**Fig. 3** Locations of sampling points. *Source* From Google Maps

wells near the major industries, which have been established a long time ago to know the contamination level. The samples were collected in cleaned high-density polyethylene (HDPE) cans that had been washed with distilled water and acidic solution such as 1 N nitric acid, which follows the sampling protocols. The local impurities were washed out before collecting the samples. The samples collected in cans were taken to the laboratory carefully and analysis was done using standard APHA [20] methods. All the reagents were of analytical grade and instruments were calibrated before taking readings. Based on the availability of sources, the selected seven toxic heavy metals in the study area are hexavalent chromium, total chromium, nickel, copper, lead, cadmium, and iron. The selection of these heavy metals is based on the type of major industries present, raw materials used, processing, and type of wastewater generated in the study area. The clear indication of the presence of a high concentration of heavy metals in PIA is referred from the literature survey [8, 12, 13]. Analysis of the samples was carried out using an effective graphite furnace Perkin Elmer PinAAcle 900z atomic absorption spectrometer (AAS). The fuel used here is acetylene and the processing of samples includes digestion with concentrated

nitric acid and dilution directly injected into graphite furnace AAS [21]. To ensure accurate and precise readings, measurements were repeated twice. The results of the analysis followed the standard specifications under the Bureau of Indian Standards [22].

## 2.4 Estimation of Heavy Metal Pollution Index (HPI)

The term heavy metal pollution index (HPI) refers to the overall quality of water for assessing the level of concentration of heavy metal pollution. It is an effective tool that is considered for the overall influence of particular heavy metals on the total quality of groundwater. This useful tool is used by the public sector and regulatory agencies for pollution reduction and decision-making, related to resource management [6].

HPI was first proposed by Mohan et al. [23] as

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

where

$n$  = total number of parameters,

$W_i$  = unit weightage, and

$Q_i$  = sub-index of  $i$ th parameter, respectively, is as shown in Eq. (1).

The calculation of the sub-index,  $Q_i$ , is given by

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

where

$M_i$  = monitored value,

$I_i$  = ideal values, and

$S_i$  = the standard value indicating the  $i$ th parameter is as shown in Eq. (2).

## 2.5 Estimation of Metal Index (MI)

MI is defined as the presence of a heavy metal concentration of each element in the solution to the maximum permissible limit of each element.

It has been proposed by Tamasi and Cini [24].

$$\text{MI} = \sum_{i=1}^n \frac{C_i}{(\text{MAC})_i} \quad (3)$$



where  $C_i$  is the concentration of each element in the given sample,  $i$  represents the  $i$ th sample, whereas MAC is the maximum allowable concentration for each element as shown in Eq. (3).

### 3 Results and Discussions

#### 3.1 Result of Analysis of Heavy Metals

The results of concentrations of heavy metals such as hexavalent chromium, total chromium, copper, nickel, lead, cadmium, and iron for pre-monsoon and post-monsoon in 30 groundwater samples are as shown in Figs. 4 and 5. The hexavalent chromium and total chromium concentrations range from 0.01 to 16.5 mg/l and 0.1 to 25.6 mg/l for pre-monsoon season, whereas it varies from 0.03 to 7.5 mg/l and 0.02 to

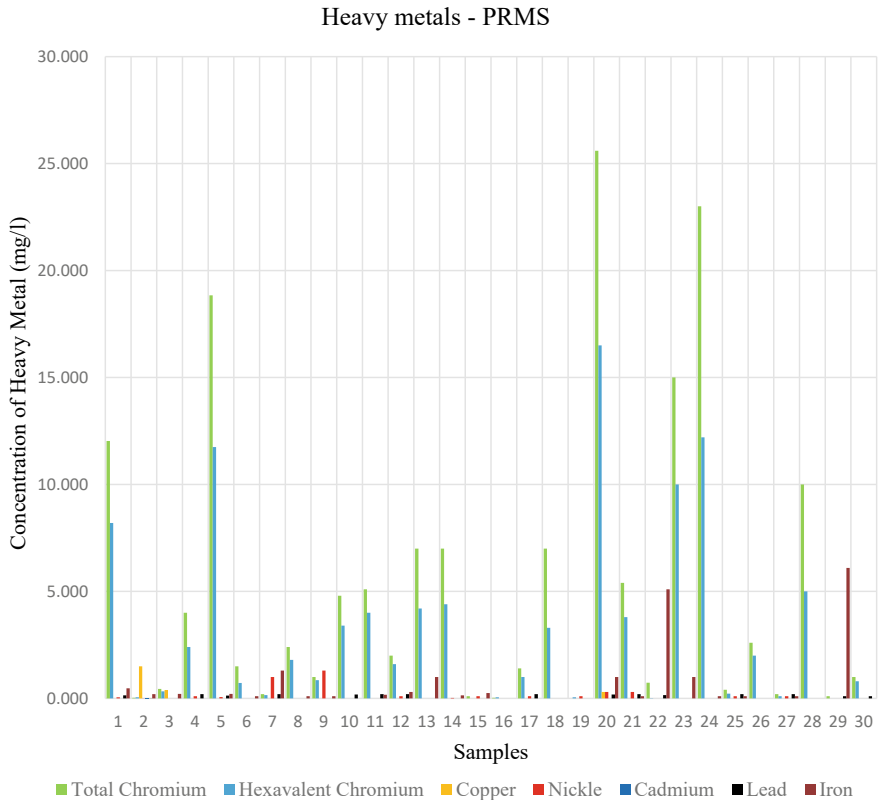
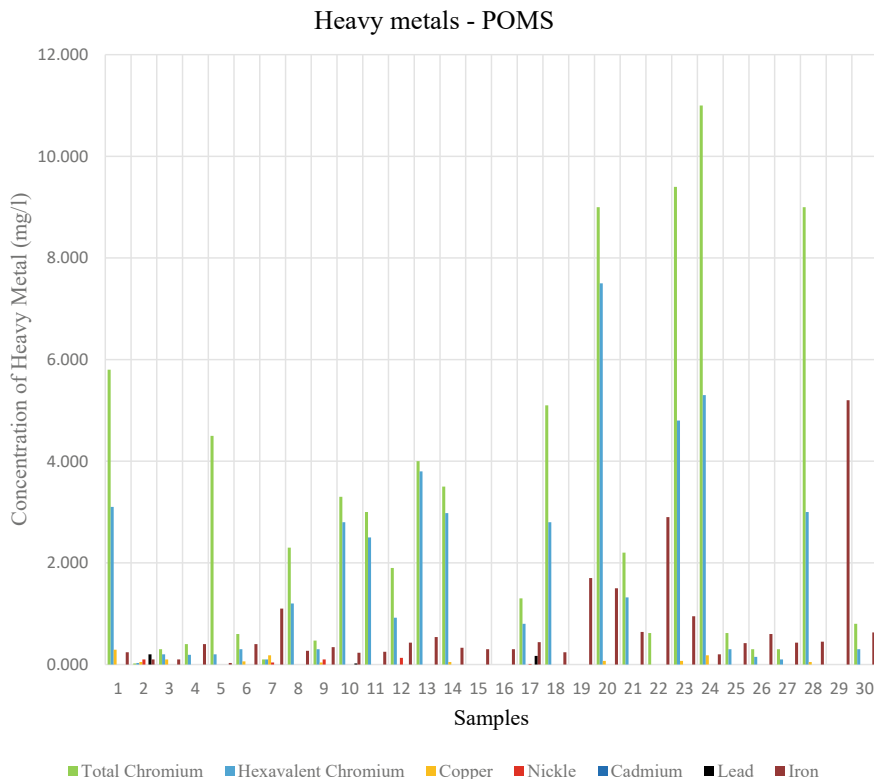


Fig. 4 Variation of heavy metal concentration for pre-monsoon season (PRMS)





**Fig. 5** Variation of heavy metal concentration for post-monsoon season (POMS)

11 mg/l for post-monsoon season, respectively. The concentration of total chromium was detected in 29 out of 30 sampling stations and 26 out of 30 sampling points in pre and post-monsoon seasons, respectively. The concentration of hexavalent chromium was detected in 28 out of 30 sampling stations and 25 out of 30 sampling stations in pre and post-monsoon season, respectively. The results revealed that the concentration of hexavalent and total chromium exceeded the permissible limit of 0.05 mg/l of BIS Standard. The detection of copper, in the case of pre-monsoon, is seen only in three sampling points and in 11 sampling points for the post-monsoon season, but within the permissible limit of 1.5 mg/l. The concentration of nickel in 14 stations exceeds the permissible limit of 0.02 mg/l, but it is seen below the detection level in sixteen sampling points in case of pre-monsoon. During post-monsoon season, the nickel concentration is detected only in 5 sampling points, and in 4 sampling points, it is exceeding the permissible limit. The lead concentration in the case of pre-monsoon exceeds the permissible limit of 0.01 mg/l in 15 sampling points. During post-monsoon, the lead concentration was detected in only three sampling points. In pre-monsoon, the cadmium concentration was detected at only one sampling point (sampling station 2), and during post-monsoon, it is detected in none of the sampling

points. Out of 30, in 21 sampling points, iron concentration was detected and in 14 stations it is within the permissible limit of 0.3 mg/l during pre-monsoon. But in post-monsoon, it was detected in all the sampling points and exceeded the maximum permissible limit in 19 sampling points.

Figures 4 and 5 show the graphical representation of variations in concentration of heavy metals in the study area for pre-monsoon and post-monsoon seasons. The co-occurrence of multi-elements in groundwater is due to the solubility of minerals, geology of the area, precipitation, semi-arid and arid conditions, presence of type of industries like chromium plating industries, textile industries, leather industries and its waste products, overexploitation of groundwater, contribution of anthropogenic activities, etc. [25]. From the above results, it is clear that high concentrations of heavy metals depict higher pollution due to the anthropogenic activities [17] that may include the leather industry and its waste products, electroplating industry and its applications, tanneries, textiles, etc. The toxicity of these metals may have entered groundwater through leaching, drainage leakage, corrosion of pipes that carry wastewater, etc.

From the analysis, it is clear that groundwater samples are highly contaminated with total chromium, hexavalent chromium, lead, nickel, and iron exceeding the BIS standards, which are at high risk of cancer in children and adults. Long-term exposure to these heavy metals may lead to potential health effects like kidney damage, high blood pressure, speech impairment, nerve damage, weak immune system, cancer, etc. Hexavalent chromium toxicity is severe compared to total chromium which mainly targets the respiratory tract and causes shortness of breath, nose irritation, wheezing, cough, and in severe cases lung cancer. It affects mainly body cells and damages DNA [26].

### **3.2 Evaluation of HPI and MI**

The present study is to determine the seasonal variations in the given study area and to apply the pollution indices such as HPI and MI for the detection of the level of concentration of heavy metals. In Table 2, the specimen calculation of sample 1 for metal index and heavy metal pollution index in the case of post-monsoon is depicted. In Table 3, the results of HPI and MI of pre and post-monsoon seasons along with its latitude and longitude coordinates are shown, while Figs. 6 and 7 show the graphical representation of seasonal variations of HPI and MI in PIA. From the revealed results, the mean HPI was 846 for pre-monsoon and 336.7 for the post-monsoon season, which indicates an excessive level of contamination and a higher critical value of 100. The high amount of pollution content in groundwater shows a higher value of HPI. The percentage of the higher critical value of the heavy metal is 83% and 57 for pre- and post-monsoon in PIA. The mean MI concentration was found to be 27.2 in pre-monsoon and 12.62 in case of post-monsoon, and it was observed that 73 and 50% of samples were “Seriously Affected”, which is above the range of 6.

**Table 2** The specimen calculation for heavy metal pollution index and metal index (first sample of post-monsoon)

Heavy metals	Monitored value (Mi)/concentration (Ci) in mg/l	Standard value (Si)/MAC in mg/l	Ideal value (Ii) in mg/l	Unit weightage (Wi)	Sub-index (Qi)	Wi * Qi	HPI = $\frac{\sum_{i=1}^n QiWi}{\sum_{i=1}^n Wi}$	MI = $\frac{CI}{\sum_{i=1}^n (MAC)_i}$
Cr	5.8	0.05		20.0	11,600	232,000		
Cr+6	3.1	0.05		20.0	6200	124,000		
Cu	0.29	0.05	1.5	20.0	83.5	1669		
Ni	-	0.02		50.0	0	0		
Cd	-	0.003		333.3	0	0		
Pb	-	0.01		100.0	0	0		
Fe	0.24	0.3		3.3	80	266.7	654.8	26.4

**Table 3** Results of HPI, MI analysis

Sample station	Latitude	Longitude	HPI (PRMS)	HPI (POMS)	MI (PRMS)	MI (POMS)
1	13.0222	77.5229	1760.16	654.76	60.38	26.37
2	13.0162	77.5007	29.33	419.11	4.69	3.90
3	13.0286	77.5195	59.57	40.32	3.41	1.76
4	13.0188	77.5133	879.88	43.98	21.86	1.88
5	13.0189	77.5131	2503.96	343.96	89.79	13.44
6	13.0103	77.5007	162.64	70.30	6.39	2.93
7	13.0198	77.5135	851.42	38.49	11.62	1.90
8	13.0155	77.5027	307.52	256.65	12.05	10.13
9	13.0146	77.5031	730.08	106.45	14.62	3.19
10	13.0286	77.5197	929.27	483.39	26.00	17.82
11	13.0242	77.5099	1032.05	402.95	28.94	15.83
12	13.0147	77.5029	675.61	266.67	14.00	9.19
13	13.0392	77.5271	821.54	571.83	32.48	22.54
14	13.0227	77.5111	843.58	478.48	32.78	18.81
15	13.0163	77.5013	53.56	0.61	1.12	0.14
16	13.0345	77.5085	5.85	0.61	0.23	0.14
17	13.0161	77.5033	587.20	470.10	10.43	8.71
18	13.0313	77.5179	753.66	578.54	29.43	22.69
19	13.0235	77.5269	49.39	3.46	0.86	0.81
20	13.0215	77.5109	3552.01	1213.97	126.33	48.06
21	13.0313	77.5196	1176.42	258.86	31.33	10.36
22	13.0317	77.5192	338.90	51.26	6.69	3.15
23	13.0304	77.5193	1831.30	1044.56	71.90	41.22
24	13.0207	77.5143	2575.81	1196.42	100.62	47.18
25	13.0164	77.4971	457.15	68.17	5.39	2.83
26	13.0203	77.5105	336.59	34.15	13.14	1.57
27	13.0085	77.4996	433.74	30.14	4.48	1.35
28	13.0151	77.5094	1097.56	882.62	42.86	34.64
29	13.0306	77.5202	202.64	10.57	4.62	2.48
30	13.0212	77.5137	314.63	81.77	6.57	3.44

PRMS—Pre-monsoon season

POMS—post-monsoon season

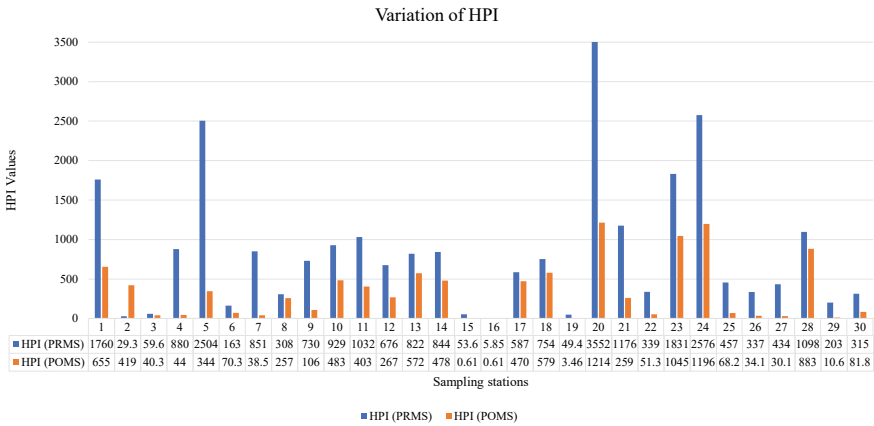


Fig. 6 Variation of HPI in the groundwater of PIA

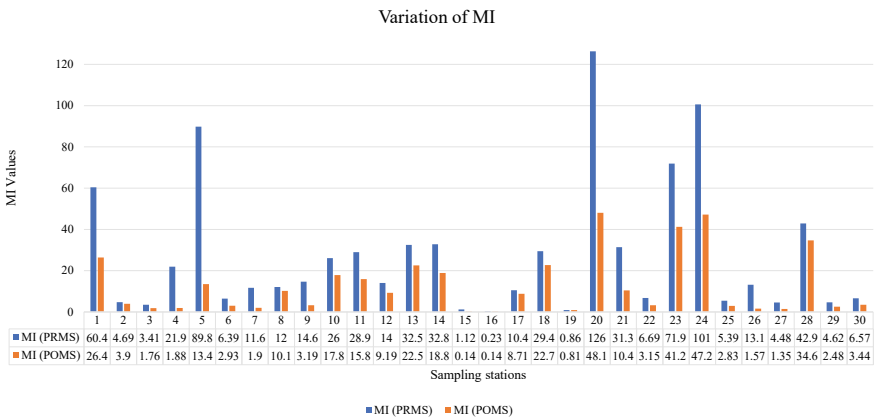


Fig. 7 Variation of MI in the groundwater of PIA

The higher value of HPI is due to the presence of a high concentration of heavy metals in groundwater samples.

In the selected seven toxic heavy metals, the highest concentration level was total chromium and then it was followed by the order hexavalent chromium, lead, nickel, iron, copper, and cadmium in pre-monsoon. In post-monsoon, total chromium remains to be highest like in the case of pre-monsoon and later followed by hexavalent chromium, iron, copper, nickel, lead, and cadmium. The depth of water in wells varies from 45 to 49 m during pre-monsoon and 55–60 m during post-monsoon [17].

Results have exhibited significantly a high concentration of heavy metals in pre-monsoon compared to a moderate concentration in post-monsoon. It is because of the effect of high precipitation that dissolves the minerals and influence of groundwater recharge, which leads to the improvement of the quality and quantity of groundwater.

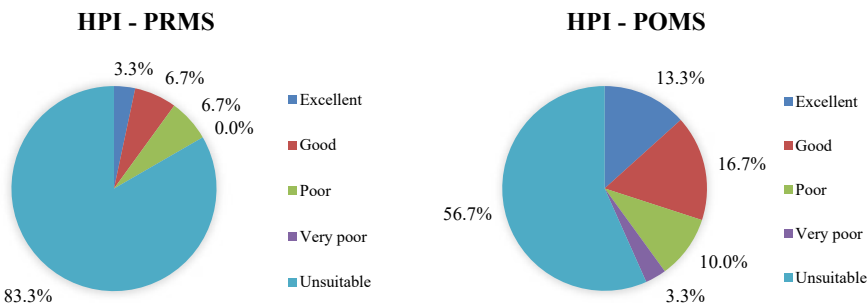
The quality of groundwater depends on the quantity of groundwater recharge that occurs from rainfall and climate variations [27]. The dilute effect of monsoon season results in the consequent reduction of toxic metals. Sometimes, surface contaminants may take the path into the deep aquifer through leaching, and also due to runoff, the addition of contaminants during monsoon will increase concentration levels in post-monsoon.

Table 4 shows the range, characteristics, number of samples, and percentage of groundwater quality based on HPI and MI for pre- and post-monsoon is as shown in Table 4. Figures 8 and 9 show the pie chart of seasonal variation of groundwater quality distribution and its percentage based on HPI and MI results for pre and post-monsoon.

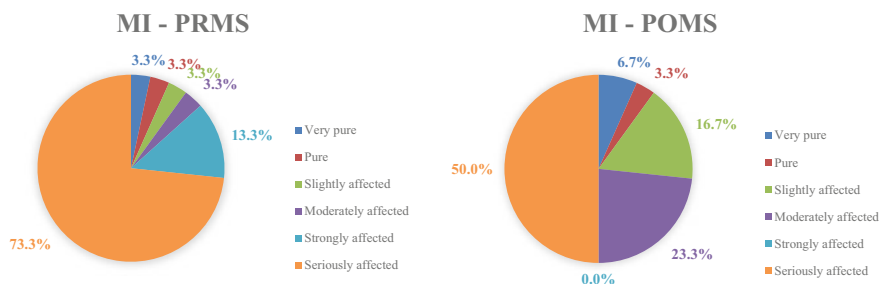
According to this classification, for pre and post-monsoon season the percentage of samples falls into the different categories as follows: 3.33 and 13.33 percentage of samples lie in the “Excellent category”, the samples with the percentage of 6.70 and

**Table 4** Groundwater quality classification

Index method	Range	Characteristics	PRMS number of samples (%)	POMS samples count (%)
HPI	>100	Unsuitable	25 (83.30%)	17 (56.67%)
	76–100	Very poor	0 (0.00%)	1 (3.30%)
	51–75	Poor	2 (6.70%)	3 (10.00%)
	26–50	Good	2 (6.70%)	5 (16.67%)
	<25	Excellent	1 (3.30%)	4 (13.30%)
MI	>6.0	Seriously affected	22 (73.30%)	15 (50.00%)
	4.0–6.0	Strongly affected	4 (13.30%)	0 (0.00%)
	2.0–4.0	Moderately affected	1 (3.30%)	7 (23.30%)
	1.0–2.0	Slightly affected	1 (3.30%)	5 (16.67%)
	0.3–1.0	Pure	1 (3.30%)	1 (3.30%)
	<0.3	Very pure	1 (3.30%)	2 (6.67%)



**Fig. 8** Seasonal variation of HPI-based groundwater quality



**Fig. 9** Seasonal variation of MI-based groundwater quality

16.6 lie in the “Good category”, whereas 6.70 and 10% of samples lies under “Poor category”. None of the samples fall under the category “very poor” in pre-monsoon and 3.33% of samples fall into “Very Poor” in post-monsoon. Out of 30 sampling stations, 83% during pre-monsoon and 56.6% during post-monsoon are deemed completely “Unsuitable”. Excessive HPI values are mainly due to the presence of industries in the study area like textile industries, nickel plating, decorative items, pharmaceutical industries, garment washing, electroplating manufacturers, etc.

The concentration mean value of MI in pre and post-monsoon was found to be 27.166 and 12.62, respectively. Just 3.33 and 6.3% of samples in pre- and post-monsoon are categorized as “Very pure”, which are considered for portable usage and domestic activities. The samples with 93.3% in pre-monsoon and 90.0% in post-monsoon season fall above the threshold alert (1.0). It means that the range above 0.3–1.0 falls under threshold alert and the total percentage of samples above 1.0 (slightly affected) gives the alert note of contamination of groundwater. So, the samples that fall above threshold alert 1.0 are not suitable for domestic or industrial usage. Only 3.3% of the samples are classified under the “pure” category in both pre and post-monsoon. Around 3.30% of samples were found to be classified under the category “slightly” and “moderately” affected in pre-monsoon. Whereas, it is observed that 16.66% and 23.33% of samples are “Slightly” and “Moderately affected” in post-monsoon. In pre-monsoon, the samples of 13.30% are classified as “Strongly affected” but none of the samples falls under the category “Strongly affected” in post-monsoon. About 73.3% and 50% of samples in pre and post-monsoon are “Seriously affected”.

## 4 Conclusion

The observations drawn from the obtained results indicate the high pollution contamination in groundwater in PIA. The concentration of heavy metals was high in the pre-monsoon study. The post-monsoon study revealed a decrease in concentration compared to the pre-monsoon. The high level of Cr, Cr<sup>+6</sup>, Pb, Ni, and Fe are exceeding



the permissible limits of BIS in both seasons. The effective tool for heavy metal detection is HPI and metal index. From the above investigations, the work carried out for heavy metals is as follows: 83.3% of samples are unsuitable and have a mean HPI value of 846 for pre-monsoon whereas 56.7% of samples are unsuitable and have a mean HPI value of 336.7 for post-monsoon. In both seasons, it is exceeding the critical index value of 100 significantly. For MI analysis, 73% of samples lie under the category “seriously affected” with a mean MI concentration of 27.2 in pre-monsoon season. But in post-monsoon 50% of samples lies under “seriously affected” with a mean concentration of 12.62. Comparatively the high concentration of heavy metals in pre-monsoon has reduced significantly in post-monsoon due to the dilution effect of precipitation. The study emphasizes PIA is highly polluted and the reason may be due to excess toxic contents from many years. So, from the above results, it is highly recommended not to use contaminated water for any further domestic or industrial usage which may lead to severe health effects. The remedial measures such as bioremediation of heavy metals through microorganisms, biosorption, phytochemical remediation, adsorption process, which are inexpensive and eco-friendly methods should be implemented. Toxicity reduction like immobilization, integrated approach like the soil washing process should be adopted to avoid further contamination. So, periodic monitoring of groundwater pollution from concerned authorities, and regular monitoring from the pollution control board is necessary to mitigate the level of intensity of pollution. Further contamination of heavy metal pollution in groundwater should be prevented for sustainable development.

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