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# Groundwater quality index and human health risk assessment of heavy metals in and around Asansol industrial area, West Bengal, India

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# Groundwater quality index and human health risk assessment of heavy metals in and around Asansol industrial area, West Bengal, India

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**Abstract:** Both the quality and quantity are equally important during the administration of water assets. Unscientific practices at Asansol industrial zone that houses a diverse range of industries, releases a lot of untreated sewage along with the municipal waste that is adversely affecting the groundwater quality of this area. Poor quality water poses a risk of adverse effects on human health. Groundwater collected from 26 study locations has shown the prevalence of bicarbonate in the groundwater. Though some fluctuation in the parameters was observed both in pre and post monsoon season, the range is well within the permissible limit. Piper diagram shows the mixing of cations in the groundwater. Heavy metal analysis revealed that presence of copper (Cu) was higher due to the industrial discharges that reach to the groundwater. Human health risk assessment data, here clearly showed the non-carcinogenic risk associated from arsenic (As) and cadmium (Cd) in the region. Thus, this study will be proven helpful in reforming the municipal planning strategies for groundwater resources in this region accordingly.

**Keywords:** groundwater modelling; spatial distribution; piper diagram; human health risk; GIS; geographic information system; water fluctuation; water pollution; WQI; heavy metals; nanotechnology.

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## 1 Introduction

India, as a country of subtropical region heavily utilises the groundwater for domestic and drinking purposes [1]. Analysing the status quo of the groundwater is very sensitive for environmental and human health aspect [2,3]. Presence of any deleterious contaminants in the groundwater matrix may cause havoc for consuming community [4,5]. Groundwater quality deterioration in the vicinity of complex industrially active area is being reported in several studies [6–11]. However, local geologic formation may also add some levels in the pollutant concentration in groundwater sources [12–14]. Asansol industrial estate which is situated between rivers Ajoy and Damodar is composed of an assorted range of manufacturing and public sector giants like Indian Iron and Steel Company Limited (IISCO), Eastern Coalfields Limited (ECL) and Chittaranjan Locomotive Works (CLW). These industrial activities discharge a diverse range of contaminants including heavy metals in the peripheral water bodies that in turn reaches to the groundwater facet at different degrees [15,16]. Alarming socio-economic condition, lack of groundwater management and awareness in this region drives the residents to use the untreated water exposing them directly to the contamination [17,18]. In this present study, the selected heavy metal and dissolved ions have been analysed through sophisticated analysis technique like Inductively Coupled Plasma-Mass Spectrometry

(ICP-MS) along with its spatial distribution through high throughput geographic information system (GIS) software [19]. Heavy metal analysis can also be done nowadays, through application of nanotechnology [20]. A statistical tool is used to analyse the inherent correlation between the observed contaminants. Water quality indices study that conveys the information regarding the quality of water body is thoroughly studied to reveal the physicochemical status of the waterbodies in this area. Seasonal Water level fluctuations (SWLF) study is also undertaken to understand the amount of surface water that finally affects the level of water below the ground. Though most of the metals and ions are considerably low in the study area, their impact on human heal this analysed through Hazard Index evaluation [21,22].

Predominant source of the contaminants is the anthropogenic sources and disposal of industrial effluents that contaminate the surface water and in turn the groundwater. Absence of a suitable water management plan leads to such unscientific discharge. Such an extensive work on the assessment of groundwater quality and related health impact in this area was not studied previously in the Asansol Industrial Area of West Bengal. The data obtained from the study will be proved very useful for improving the water resources management practices along with a scientific utilisation of the groundwater in the area. Further, this study is anticipated to provide insight into the fate and behaviour of those pollutants thereby promoting greater health protection of the community of this area.

## 2 Materials and methods

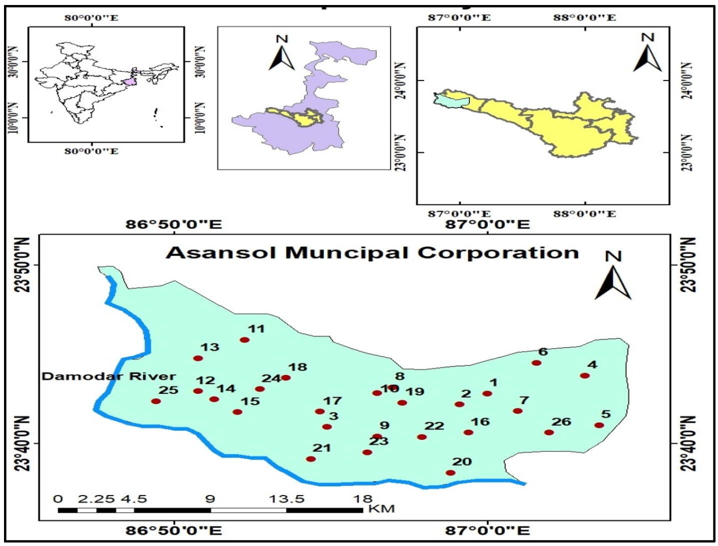
### *2.1 About the Study area and sampling*

Asansol is a metropolitan city in West Bengal, India, popularly known for its mining, industries, commerce, and wholesale trade. It is spread over 127.23 sq. km spanning from 23°68’N latitude to 86°97′E longitude with a total population of 48,86,304 (Census 2011). To fulfil the objective of the present study, the 26 groundwater samples were collected from various locations of Asansol Municipal Corporation area during the years 2018–2019 (Figure 1) for pre-monsoon (PRM) and post-monsoon (POM) season. pH and temperature of each water sample were determined on-site using a pocket pH meter (Model No – Multi-parameter PCTesterTM 35), and the samples were stored at 4°C till further analysis.

### *2.2 Analytical Method and Software used*

The physicochemical characterisation of collected water samples was performed using the standard methods of American Public Health Association [23]. The concentration of sulphate ($SO_4^{2-}$) and nitrate ($NO_3^-$) were analysed with the help of a UV-Vis spectrophotometer (Model No – Motras Scientific, India). Moreover, the Flame Photometer (Model No – ESICO 1385) was used for the determination of major cation ($Ca^{2+}$, $Mg^{2+}$, $K^+$, and $Na^+$) and anions ($Cl^-$, $HCO_3^-$, $SO_4^{2-}$, and $NO_3^-$). Heavy metals concentration in the water were measured using an Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) (Model No – Perkin Elmer model ELAN DRCe, 710, Bridgeport Avenue Shelton, Connecticut 06484-4794, USA). To determine the water level fluctuations (WLF), the depth level of groundwater was recorded by a sensor-based water level recorder (Model-K-11107). The spatial distribution of heavy metals and groundwater's ion-balance chemistry were investigated with the help of ArcGIS 10.2 and AQUA CHEM (version 1.1.5.1.) software respectively. The Pearson correlation analysis was performed by using the commercial statistics software package SPSS version 13.0.

**Figure 1** Location map of the study area (see online version for colours)




## 2.3 WQI modelling approach

WQI technique is the rating tool that reflects the composite influence of different water quality parameters [24]. The 13 physicochemical parameters (pH, EC, TDS, TH, $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$, $HCO_3^{-}$, $SO_4^{2-}$, $Cl^{-}$, $F^{-}$, $NO_3^{-}$) were analysed and the concentration values were compared with the Bureau of Indian Standard (BIS,2012), which is also considered for computing the WQI. The steps involved in WQI modelling are illustrated in Figure 2. In the very first step, the weight ($w_i$) was assigned to each variable on a scale of 1 (least effect on water quality) to 5 (highest effect on water quality) (Table 1). Afterwards, the relative weight ($W_i$) was calculated using equation (1).

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \tag{1}$$

Here, $W_i$, $w_i$, and $n$ represent the relative weight, the weight of individual parameters, and the number of variables, respectively. Then, a quality rating ($q_i$) and $SI_i$ index for each parameter is calculated by equations (2) and (3).

$$q_i = (C_i/S_i)*100 \tag{2}$$

$$SI_i = W_i * qi \tag{3}$$

Here, $q_i$ and $C_i$ are the quality rating and concentration of each water sample (mg/L), $S_i$ is taken from BIS (2012) guideline. Finally, the WQI was evaluated using equation (4)

$$\text{WQI} = \sum SI_i \tag{4}$$

**Figure 2** Steps for WQI modelling (see online version for colours)

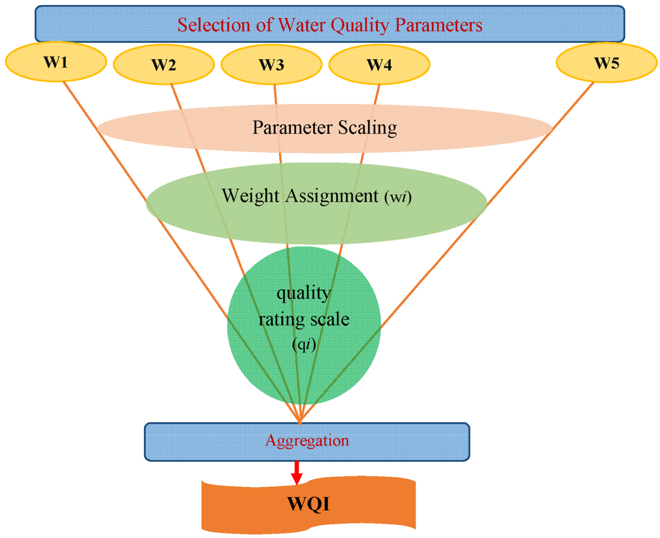



**Table 1** Variables relative weights

| *Variables* | *Weight* ($w_i$) | *Relative weight* ($W_i$) | *BIS standards* |
|---|---|---|---|
| pH | 4 | 0.11 | 8.5 |
| Total dissolved solids | 5 | 0.13 | 500 |
| Fluoride | 5 | 0.13 | 1 |
| Chloride | 5 | 0.13 | 250 |
| Nitrate | 5 | 0.13 | 45 |
| Sulphate | 5 | 0.13 | 200 |
| Bicarbonate | 1 | 0.03 | 200 |
| Calcium | 3 | 0.08 | 75 |
| Magnesium | 3 | 0.08 | 30 |
| Total hardness | 2 | 0.05 | 300 |
| | $\Sigma w_i = 38$ | $\Sigma W_i = 1.00$ | |

## 2.4 *Assessments of human health risk*

Risk assessment is the process of estimating the probability magnitude of the adverse health impact of any substances over a specified period of time. The non-carcinogenic human health risk associated with the heavy metals in the groundwater via oral ingestion can be evaluated by the computing hazard index (HI) method based on USEPA [25] (equation (5)).

$$\text{ADD} = (Cw \times IR \times EF \times ED)/(BW \times AT) \quad (5)$$

The hazard quotient (HQ) ratio of individual elements exposure to the reference dose (RfD) for metals can be calculated by (equation (6)) [26]. The RfD values of various heavy metals are based on USEPA [27]. The hazard index (HI) value, which is the ratio of multiple substance/single-exposure pathways, can be expressed as the sum of all HQ values (equation (7)) [28].

$$HQ = \text{exposure level (ADD)/RfD} \quad (6)$$

$$HI = \sum HQ \quad (7)$$

Here, ADD is the average daily dose of heavy metals (mg/kg/day), CW is the concentration of heavy metals (mg/l) in the water samples, IR is the ingestion rate (3 l/day for adults) [26], EF is the exposure frequency (days/year), ED is the exposure duration (years), BW is the body weight (57.5 kg adults) [29], and AT is the averaging time (days).

### *2.5 Quality assurance/quality control (QA/QC)*

Suitable quality affirmation methodology and safeguard were undertaken to establish reliability, and samples were properly handled to avert contamination. Glassware was appropriately cleansed and scientific grade reagents were used. Milli Q water was utilised throughout the analysis. Blank reagent was used to calibrate the instrument. The accuracy of the analysis was checked with reference standard of water (NIST 1640a and NIST 1643b). The precision obtained in most cases was better than 5% RSD with comparable accuracy.

## 3 Result and discussion

### *3.1 Physicochemical characterisation and correlation analysis of variables*

The physicochemical characterisation and ionic composition of groundwater samples collected in and around the Asansol Municipal Corporation for PRM and POM season are illustrated in Table 2(a) and (b). pH designates the acidic and alkaline nature of any water sample [30]. In this study, the value of pH ranged between 6.7 to 7.8 and 6.9 to 8.1 for PRM and POM season, respectively, complying with BIS guidelines. The electrical conductivity (EC) of samples varied from 390 to 2290 µS/cm (PRM) and 310 to 2625 µS/cm (POM). In addition, the monitored value Total dissolved solids (TDS) and Total hardness (TH) were also found within the prescribed limit of BIS for all the samples except the location no 23 for TH in both seasons. The range of DO (PRM – 1.7 to 7.3 mg/l and POM – 3.2 to 7.6) showed a good quality of water for drinking purposes. The ionic chemistry of groundwater showed the dominancy of bicarbonate ($HCO_3^-$) followed by chloride ($Cl^-$) > sulphate ($SO_4^{2-}$) > sodium ($Na^+$) > calcium ($Ca^{2+}$) > magnesium ($Mg^{2+}$) > nitrate ($NO_3^-$) > potassium ($K^+$) and fluoride ($F^-$) for PRM season. The same trends were also observed for the POM except for Potassium ($K^+$) and Nitrate ($NO_3^-$). The higher bicarbonate proportions to other ions indicate weathering of primary silicate minerals dominated by the alkaline rocks in this area [31]. Throughout the study, it was observed that the range value of all the variables was found to be slightly higher in location no 23 in both seasons. The variation is due to the mining and industrial activities in the vicinity, affecting the groundwater quality [31,32]. Both seasons showed the excellent quality of water for drinking purposes. However, the quality of water seems to be better in PRM than in POM. Good water quality leads to healthy environment and alleviates public health problems [33].

**Table 2** The statistical summary of water quality parameters: (a) PRM season and (b) POM

*(a) PRM season*

| *Sampling locations* | *Parameters* | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *pH* | *EC* (µS/cm) | *TDS* (mg/l) | *TH* (mg/l) | *DO* (mg/l) | $Na^+$ (mg/l) | $K^+$ (mg/l) | $Ca^{2+}$ (mg/l) | *Mg* (mg/l) | $HCO_3^-$ (mg/l) | $SO4^-$ (mg/l) | $NO3^-$ (mg/l) | $Cl^-$ (mg/l) | $F^-$ (mg/l) |
| 1 | 7.8 | 831 | 461 | 252 | 3.4 | 56.9 | 2.3 | 62.7 | 22.9 | 289.7 | 62.3 | 4.06 | 61.48 | 0.5 |
| 2 | 7.1 | 1015.0 | 582.0 | 296.0 | 5.1 | 83.7 | 1.0 | 91.1 | 17.2 | 281.7 | 76.5 | 0.8 | 123.5 | 0.4 |
| 3 | 7.4 | 652.0 | 339.0 | 315.0 | 4.3 | 124.0 | 1.7 | 66.9 | 35.0 | 489.0 | 100.5 | 34.2 | 87.5 | 0.9 |
| 4 | 7.3 | 733.0 | 423.0 | 275.0 | 3.8 | 36.4 | 2.9 | 61.8 | 29.5 | 334.6 | 55.8 | 1.7 | 27.0 | 0.2 |
| 5 | 7.4 | 685.0 | 439.0 | 223.0 | 3.5 | 65.0 | 2.3 | 67.8 | 13.2 | 302.4 | 64.8 | 5.6 | 26.5 | 0.8 |
| 6 | 7.2 | 706.0 | 467.0 | 223.0 | 3.8 | 67.5 | 7.5 | 71.6 | 11.2 | 265.8 | 78.6 | 6.0 | 41.7 | 1.1 |
| 7 | 7.1 | 1324.0 | 807.0 | 347.0 | 3.1 | 116.0 | 4.7 | 108.0 | 19.1 | 426.3 | 118.5 | 13.5 | 82.5 | 0.3 |
| 8 | 6.9 | 1116.0 | 638.0 | 377.0 | 3.6 | 75.2 | 2.8 | 96.0 | 31.0 | 349.0 | 110.2 | 2.9 | 68.6 | 0.7 |
| 9 | 7.5 | 1016.0 | 576.0 | 295.0 | 3.1 | 77.1 | 0.6 | 74.7 | 26.5 | 354.6 | 107.4 | 3.5 | 52.5 | 0.4 |
| 10 | 7.3 | 1690.0 | 998.0 | 372.0 | 2.3 | 172.0 | 70.4 | 121.0 | 17.2 | 510.3 | 182.3 | 38.5 | 86.5 | 0.3 |
| 11 | 6.7 | 390.0 | 258.0 | 139.0 | 3.7 | 25.5 | 9.7 | 41.8 | 7.9 | 127.0 | 65.1 | 11.7 | 21.5 | 0.4 |
| 12 | 7.7 | 582.0 | 387.0 | 225.0 | 4.8 | 39.5 | 1.8 | 43.7 | 28.9 | 214.0 | 68.6 | 8.3 | 51.7 | 0.3 |
| 13 | 7.1 | 865.0 | 526.0 | 243.0 | 4.1 | 58.5 | 5.5 | 73.5 | 17.1 | 311.4 | 91.6 | 2.9 | 35.7 | 0.5 |
| 14 | 7.2 | 951.0 | 562.0 | 290.0 | 4.6 | 65.6 | 10.1 | 92.0 | 15.0 | 306.7 | 72.5 | 12.3 | 67.5 | 0.4 |
| 15 | 7.5 | 1072.0 | 595.0 | 255.0 | 2.9 | 110.0 | 5.7 | 80.0 | 13.5 | 378.2 | 78.9 | 6.6 | 67.7 | 0.2 |

**Table 2** The statistical summary of water quality parameters: (a) PRM season and (b) POM (continued)

| *(a) PRM season* | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Parameters* | | | | | | | | | | | | | |
| *Sampling locations* | *pH* | *EC* (µS/cm) | *TDS* (mg/l) | *TH* (mg/l) | *DO* (mg/l) | $Na^+$ (mg/l) | $K^+$ (mg/l) | $Ca^{2+}$ (mg/l) | *Mg* (mg/l) | $HCO_3^-$ (mg/l) | $SO4^-$ (mg/l) | $NO3^-$ (mg/l) | $Cl^-$ (mg/l) | $F^-$ (mg/l) |
| 16 | 7.3 | 889.0 | 654.0 | 289.0 | 3.7 | 116.0 | 16.5 | 100.6 | 18.6 | 400.5 | 153.0 | 22.3 | 660.5 | 0.9 |
| 17 | 7.3 | 741.0 | 478.0 | 225.0 | 7.3 | 52.3 | 7.4 | 64.8 | 15.5 | 224.3 | 74.1 | 10.8 | 50.0 | 0.5 |
| 18 | 7.7 | 612.0 | 368.0 | 184.0 | 3.9 | 44.9 | 2.8 | 53.8 | 12.5 | 258.3 | 68.8 | 0.6 | 10.0 | 0.4 |
| 19 | 7.2 | 846.0 | 458.0 | 156.0 | 2.9 | 148.0 | 20.8 | 108.0 | 22.5 | 326.0 | 99.0 | 22.5 | 33.5 | 0.5 |
| 20 | 7.8 | 1095.0 | 687.0 | 177.0 | 3.7 | 192.0 | 1.1 | 51.1 | 12.5 | 472.0 | 94.3 | 2.5 | 38.5 | 0.3 |
| 21 | 6.9 | 1021.0 | 549.0 | 246.0 | 1.7 | 205.0 | 10.5 | 48.0 | 24.9 | 211.0 | 78.0 | 10.5 | 55.5 | 0.8 |
| 22 | 7.3 | 804.0 | 444.0 | 251.0 | 2.9 | 58.1 | 3.4 | 70.2 | 18.9 | 279.0 | 75.9 | 8.5 | 42.4 | 0.9 |
| 23 | 7.4 | 2290.0 | 1510.0 | 702.0 | 4.4 | 154.5 | 61.6 | 205.0 | 45.7 | 565.5 | 299.5 | 19.5 | 161.0 | 1.1 |
| 24 | 7.7 | 805.0 | 461.0 | 253.0 | 4.1 | 48.6 | 2.3 | 68.7 | 20.1 | 305.0 | 36.3 | 13.7 | 52.5 | 0.5 |
| 25 | 7.4 | 1064.0 | 585.0 | 245.0 | 2.8 | 113.0 | 6.1 | 81.6 | 14.6 | 401.0 | 80.6 | 7.1 | 60.5 | 0.3 |
| 26 | 7.2 | 864.0 | 666.0 | 297.0 | 3.9 | 120.0 | 18.6 | 121.0 | 20.5 | 389.0 | 156.0 | 25.1 | 667.0 | 0.9 |
| Min | 6.7 | 390.0 | 258.0 | 139.0 | 1.7 | 25.5 | 0.6 | 41.8 | 7.9 | 127.0 | 36.3 | 0.6 | 10.0 | 0.2 |
| Max | 7.8 | 2290.0 | 1510.0 | 702.0 | 7.3 | 205.0 | 70.4 | 205.0 | 45.7 | 565.5 | 299.5 | 38.5 | 667.0 | 1.1 |
| Average | 7.3 | 948.4 | 573.8 | 275.1 | 3.7 | 93.3 | 10.8 | 81.7 | 20.4 | 337.4 | 98.0 | 11.4 | 105.1 | 0.5 |

**Table 2** The statistical summary of water quality parameters: (a) PRM season and (b) POM (continued)

*(b) POM*

| *Sampling locations* | *Parameters* | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *pH* | *EC* (µS/cm) | *TDS* (mg/l) | *TH* (mg/l) | *DO* (mg/l) | $Na^+$ (mg/l) | $K^+$ (mg/l) | $Ca^{2+}$ (mg/l) | *Mg* (mg/l) | $HCO_3^-$ (mg/l) | $SO_4^-$ (mg/l) | $NO_3^-$ (mg/l) | $Cl^-$ (mg/l) | $F^-$ (mg/l) |
| 1 | 7.6 | 898 | 561 | 296 | 3.9 | 73.5 | 2.5 | 80.9 | 22.9 | 364.8 | 58.9 | 4.08 | 96.96 | 0.8 |
| 2 | 7.2 | 1174.0 | 713.0 | 269.0 | 5.5 | 106.5 | 1.7 | 74.3 | 20.3 | 275.0 | 59.9 | 0.7 | 162.4 | 0.8 |
| 3 | 7.4 | 597.0 | 379.0 | 98.0 | 6.9 | 33.7 | 3.3 | 37.0 | 25.0 | 117.0 | 61.0 | 11.0 | 80.0 | 0.7 |
| 4 | 7.2 | 728.0 | 454.0 | 198.0 | 5.0 | 58.2 | 1.8 | 53.7 | 25.6 | 308.6 | 49.8 | 7.9 | 52.5 | 0.5 |
| 5 | 7.6 | 653.0 | 408.0 | 229.0 | 4.5 | 60.4 | 1.9 | 48.5 | 26.1 | 298.4 | 54.6 | 1.9 | 30.0 | 0.8 |
| 6 | 7.8 | 632.0 | 387.0 | 220.0 | 5.8 | 56.0 | 6.9 | 51.0 | 25.1 | 268.8 | 52.1 | 31.6 | 50.9 | 0.9 |
| 7 | 7.4 | 1180.0 | 798.0 | 360.0 | 5.6 | 106.7 | 4.6 | 87.7 | 34.4 | 402.2 | 80.1 | 10.2 | 170.4 | 0.3 |
| 8 | 6.9 | 1024.0 | 589.0 | 273.0 | 4.2 | 84.8 | 5.2 | 72.7 | 38.4 | 312.5 | 67.4 | 12.7 | 134.0 | 0.8 |
| 9 | 7.6 | 968.0 | 615.0 | 286.0 | 3.2 | 104.0 | 0.6 | 71.0 | 26.4 | 365.0 | 104.8 | 2.7 | 76.1 | 0.4 |
| 10 | 7.3 | 1575.0 | 967.0 | 362.0 | 3.9 | 120.9 | 70.7 | 182.0 | 33.7 | 492.3 | 131.4 | 31.3 | 214.4 | 0.2 |
| 11 | 8.1 | 353.0 | 229.0 | 140.0 | 6.1 | 26.1 | 8.0 | 31.4 | 14.7 | 120.0 | 49.7 | 8.7 | 30.0 | 0.5 |
| 12 | 6.9 | 679.0 | 377.0 | 214.0 | 6.3 | 43.8 | 1.9 | 42.6 | 26.4 | 212.4 | 58.6 | 2.5 | 62.5 | 0.5 |
| 13 | 7.2 | 883.0 | 519.0 | 258.0 | 4.5 | 60.8 | 6.0 | 58.4 | 27.4 | 270.0 | 57.2 | 0.9 | 94.1 | 0.6 |
| 14 | 7.9 | 1002.0 | 570.0 | 293.0 | 3.9 | 61.8 | 15.6 | 63.9 | 32.4 | 279.0 | 70.6 | 1.7 | 112.5 | 0.5 |
| 15 | 7.5 | 898.0 | 566.0 | 271.0 | 5.9 | 79.1 | 7.5 | 60.3 | 29.5 | 374.0 | 79.8 | 4.3 | 76.5 | 0.5 |

**Table 2** The statistical summary of water quality parameters: (a) PRM season and (b) POM (continued)

*(b) POM*

| *Sampling locations* | *Parameters* | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *pH* | *EC* (µS/cm) | *TDS* (mg/l) | *TH* (mg/l) | *DO* (mg/l) | $Na^+$ (mg/l) | $K^+$ (mg/l) | $Ca^{2+}$ (mg/l) | *Mg* (mg/l) | $HCO_3^-$ (mg/l) | $SO_4^-$ (mg/l) | $NO_3^-$ (mg/l) | $Cl^-$ (mg/l) | $F^-$ (mg/l) |
| 16 | 7.8 | 310.0 | 146.0 | 442.0 | 5.5 | 80.6 | 14.6 | 50.6 | 10.4 | 204.6 | 28.8 | 5.8 | 115.0 | 0.9 |
| 17 | 7.1 | 830.0 | 490.0 | 234.0 | 7.4 | 58.4 | 11.3 | 62.1 | 19.4 | 202.0 | 48.9 | 4.3 | 120.7 | 0.8 |
| 18 | 7.4 | 433.0 | 271.0 | 120.0 | 4.1 | 27.4 | 11.5 | 29.3 | 11.2 | 113.0 | 56.2 | 1.5 | 32.5 | 1.0 |
| 19 | 7.3 | 1018.0 | 567.0 | 287.0 | 3.6 | 71.2 | 7.9 | 65.2 | 29.8 | 371.3 | 66.7 | 1.3 | 62.2 | 0.7 |
| 20 | 7.3 | 1104.0 | 660.0 | 197.0 | 3.8 | 144.0 | 0.5 | 51.4 | 16.6 | 466.0 | 71.5 | 0.5 | 24.5 | 0.5 |
| 21 | 6.9 | 1198.0 | 465.0 | 164.0 | 7.6 | 40.3 | 1.7 | 41.7 | 18.6 | 328.6 | 56.4 | 0.3 | 25.0 | 0.4 |
| 22 | 7.1 | 773.0 | 468.0 | 265.0 | 3.2 | 42.4 | 1.7 | 44.7 | 37.3 | 245.0 | 52.2 | 6.5 | 60.0 | 1.0 |
| 23 | 7.2 | 2625.0 | 1664.0 | 805.0 | 4.9 | 172.0 | 63.6 | 167.0 | 94.0 | 545.0 | 282.0 | 13.5 | 278.0 | 1.3 |
| 24 | 7.6 | 842.0 | 484.0 | 248.0 | 3.9 | 54.5 | 8.4 | 61.3 | 23.2 | 212.3 | 56.5 | 11.6 | 105.5 | 0.6 |
| 25 | 7.1 | 555.0 | 358.0 | 103.0 | 7.3 | 35.6 | 3.8 | 40.5 | 26.5 | 121.0 | 64.0 | 13.5 | 81.5 | 0.8 |
| 26 | 7.4 | 751.0 | 514.0 | 204.0 | 5.3 | 60.4 | 2.4 | 50.6 | 30.6 | 312.0 | 51.0 | 8.6 | 55.5 | 0.7 |
| Min | 6.9 | 310.0 | 146.0 | 98.0 | 3.2 | 26.1 | 0.5 | 29.3 | 10.4 | 113.0 | 28.8 | 0.3 | 24.5 | 0.2 |
| Max | 8.1 | 2625.0 | 1664.0 | 805.0 | 7.6 | 172.0 | 70.7 | 182.0 | 94.0 | 545.0 | 282.0 | 31.6 | 278.0 | 1.3 |
| Average | 7.37 | 910.88 | 546.88 | 266.88 | 5.06 | 71.65 | 10.21 | 64.60 | 27.91 | 291.56 | 71.92 | 7.67 | 92.44 | 0.67 |

**Table 3** Pearson correlation matrix: (a) PRM and (b) POM

| *(a) PRM* | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *pH* | *EC* | *TDS* | *TH* | *DO* | *$Na^+$* | *$K^+$* | *$Ca^{2+}$* | *$Mg^{2+}$* | *$HCO_3^-$* | *$SO_4^-$* | *$NO_3^-$* | *$Cl^-$* | *$F^-$* |
| pH | 1 | | | | | | | | | | | | | |
| EC | –0.01 | 1 | | | | | | | | | | | | |
| TDS | 0.00 | 0.97 | 1 | | | | | | | | | | | |
| TH | –0.04 | 0.85 | 0.87 | 1 | | | | | | | | | | |
| DO | 0.13 | –0.19 | –0.09 | 0.04 | 1 | | | | | | | | | |
| Na+ | –0.06 | 0.60 | 0.56 | 0.30 | –0.45 | 1 | | | | | | | | |
| K+ | –0.11 | 0.75 | 0.78 | 0.63 | –0.17 | 0.49 | 1 | | | | | | | |
| $Ca^{2+}$ | –0.12 | 0.83 | 0.88 | 0.84 | –0.02 | 0.40 | 0.75 | 1 | | | | | | |
| $Mg^{2+}$ | 0.08 | 0.46 | 0.44 | 0.72 | 0.04 | 0.21 | 0.29 | 0.48 | 1 | | | | | |
| $HCO_3^-$ | 0.25 | 0.73 | 0.73 | 0.66 | –0.19 | 0.61 | 0.54 | 0.68 | 0.43 | 1 | | | | |
| $SO_4^-$ | –0.09 | 0.83 | 0.90 | 0.84 | –0.06 | 0.53 | 0.82 | 0.89 | 0.53 | 0.71 | 1 | | | |
| $NO_3^-$ | –0.12 | 0.30 | 0.33 | 0.31 | –0.12 | 0.47 | 0.65 | 0.46 | 0.26 | 0.50 | 0.53 | 1 | | |
| $Cl^-$ | –0.09 | 0.09 | 0.25 | 0.21 | 0.04 | 0.22 | 0.21 | 0.39 | 0.08 | 0.27 | 0.44 | 0.42 | 1 | |
| $F^-$ | –0.19 | 0.10 | 0.19 | 0.34 | 0.03 | 0.16 | 0.19 | 0.33 | 0.28 | 0.11 | 0.39 | 0.27 | 0.40 | 1 |

**Table 3** Pearson correlation matrix: (a) PRM and (b) POM (continued)

| *(b) POM* | *pH* | *EC* | *TDS* | *TH* | *DO* | *$Na^+$* | *$K^+$* | *$Ca^{2+}$* | *$Mg^{2+}$* | *$HCO_3^-$* | *$SO_4^-$* | *$NO_3^-$* | *$Cl^-$* | *$F^-$* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 1 | | | | | | | | | | | | | |
| EC | –0.32 | 1 | | | | | | | | | | | | |
| TDS | –0.24 | 0.98 | 1 | | | | | | | | | | | |
| TH | –0.04 | 0.80 | 0.79 | 1 | | | | | | | | | | |
| DO | –0.20 | –0.18 | –0.23 | –0.22 | 1 | | | | | | | | | |
| $Na^+$ | –0.09 | 0.79 | 0.83 | 0.74 | –0.35 | 1 | | | | | | | | |
| $K^+$ | 0.00 | 0.69 | 0.70 | 0.68 | –0.15 | 0.54 | 1 | | | | | | | |
| $Ca^{2+}$ | –0.11 | 0.84 | 0.86 | 0.76 | –0.28 | 0.76 | 0.88 | 1 | | | | | | |
| $Mg^{2+}$ | –0.23 | 0.82 | 0.86 | 0.78 | –0.16 | 0.57 | 0.61 | 0.68 | 1 | | | | | |
| $HCO_3^-$ | –0.15 | 0.80 | 0.79 | 0.67 | –0.40 | 0.85 | 0.49 | 0.74 | 0.57 | 1 | | | | |
| $SO_4^-$ | –0.13 | 0.89 | 0.92 | 0.80 | –0.16 | 0.71 | 0.77 | 0.79 | 0.89 | 0.64 | 1 | | | |
| $NO_3^-$ | 0.13 | 0.18 | 0.23 | 0.15 | 0.06 | 0.14 | 0.54 | 0.48 | 0.26 | 0.14 | 0.27 | 1 | | |
| $Cl^-$ | –0.14 | 0.75 | 0.79 | 0.79 | –0.08 | 0.67 | 0.75 | 0.86 | 0.68 | 0.48 | 0.72 | 0.37 | 1 | |
| $F^-$ | –0.06 | 0.09 | 0.13 | 0.31 | –0.03 | 0.02 | 0.09 | –0.03 | 0.36 | –0.18 | 0.24 | 0.00 | 0.16 | 1 |

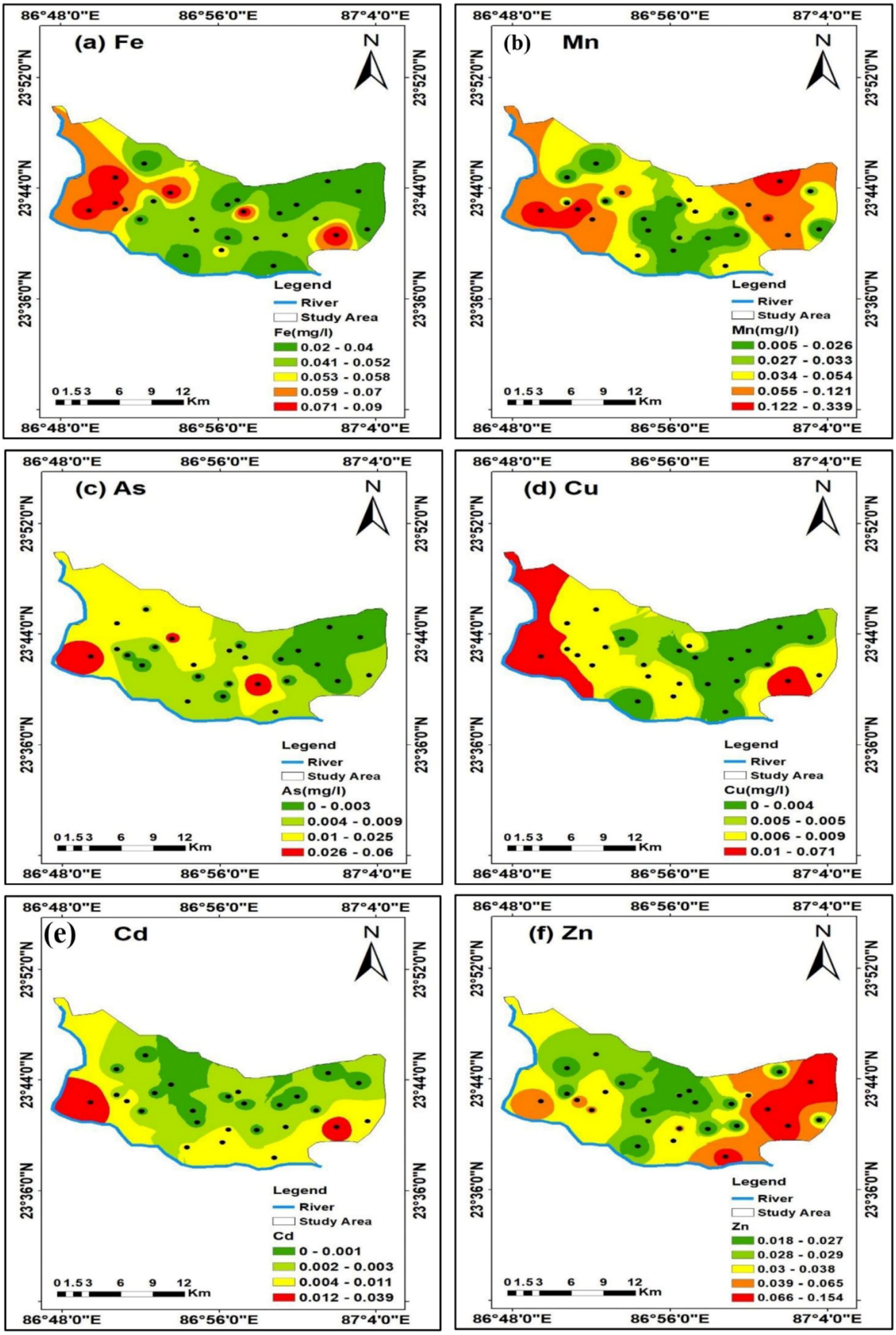
The correlation matrix of water quality parameters with major cation ($Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$) and anions ($HCO_3^{-}$, $SO_4^{2-}$, $Cl^{-}$, $F^{-}$, $NO_3^{-}$) were established using the Pearson correlation methods. It represents the strength of association between two variables that bears a linear relationship ranging between +1 (positive correlation) to –1 (negative correlation) [34]. The correlation of groundwater variables is shown in Table 3(a) and (b) for PRM and POM season. With respect to ions, organic, and inorganic compounds, TDS is the flagship, as it represents the sum of all cations and anions [35]. It showed a strong and significant correlation with ions indicating that the concentration level of TDS dramatically influences water quality. Besides, the positive correlation of TDS with total hardness also signifies that the bicarbonate, calcium, magnesium, fluoride, and sodium are highly dependent upon this key parameter [36,37]. The present study results are very much similar to the findings of Raghunath [38], Gopinath and Seralathan [39]. The correlation matrix of POM was found to exhibit similar to the PRM (Table 3(a) and (b)).

## *3.2 Spatial distribution of heavy metals*

There are significant differences in heavy metals concentration of groundwater in the Asansol metropolitan. The spatial distribution map of all six selected heavy metals is shown in Figure 3(a)–(f). Iron (Fe) and manganese (Mn), are the naturally occurring heavy metals in the Earth's surface, that may create severe aesthetic problems in groundwater [40]. The concentration level of Fe varied from 0.02 to 0.09 mg/L, complying with the BIS's guideline value (0.3 mg/l). However, the groundwater from the western part of the study was found to be dominated by Fe (Figure 3(a)). Mn is also an essential nutrient for human health, whose intake is usually substantially lower than food [41]. It contributed to several critical physiological processes in the human body. The value of Mn in the study area was ranged between 0.005 to 0.339 mg/l, exceeding the prescribed standards of BIS (0.1 to 0.3 mg/l). However, the two locations in the western and one location in the eastern region were found to have a slightly higher concentration range of Mn (Figure 3(b)). The concentration range of arsenic (As) in this area varied from 0.0 to 0.06 mg/l, which are well within the set guideline value (0.01 to 0.05 mg/l) of the BIS specification of drinking water quality (BISIS:105002012) (Figure 3(c)).

The distribution of copper (Cu) in the groundwater of this area may vary significantly due to the discharge of industrial effluents and many other activities [42]. The concentration range of Cu varied from 0.0 to 0.071 μg/L and indicated a good water quality for drinking purposes in terms of Cu (Figure 3(d)). Cadmium (Cd) is not an essential non-beneficial element known to have toxic potential. It replaces zinc biochemically and causes high blood pressure and damaged kidneys and other body organs. The range value of Cd varied from 0 to 0.039 mg/l which is safe for drinking (Figure 3(e)). Zinc (Zn) is essential for the physiological and metabolic process of the human body, nevertheless turning to toxic at a high range [43]. It plays an essential role in protein synthesis. The variation of Zn in groundwater mainly depends upon rock weathering and other natural sources [42,43]. In the present study concentration level of Zn (0.018 to 0.15 mg/l) is found within the guideline value of BIS [44] in the sampling location (Figure 3(f)). The concentration range of these heavy metals in the study area was found in the order of Mn > Zn > Fe > Cu >As> and Cd, within the safe limit of BIS guidelines for drinking purposes.

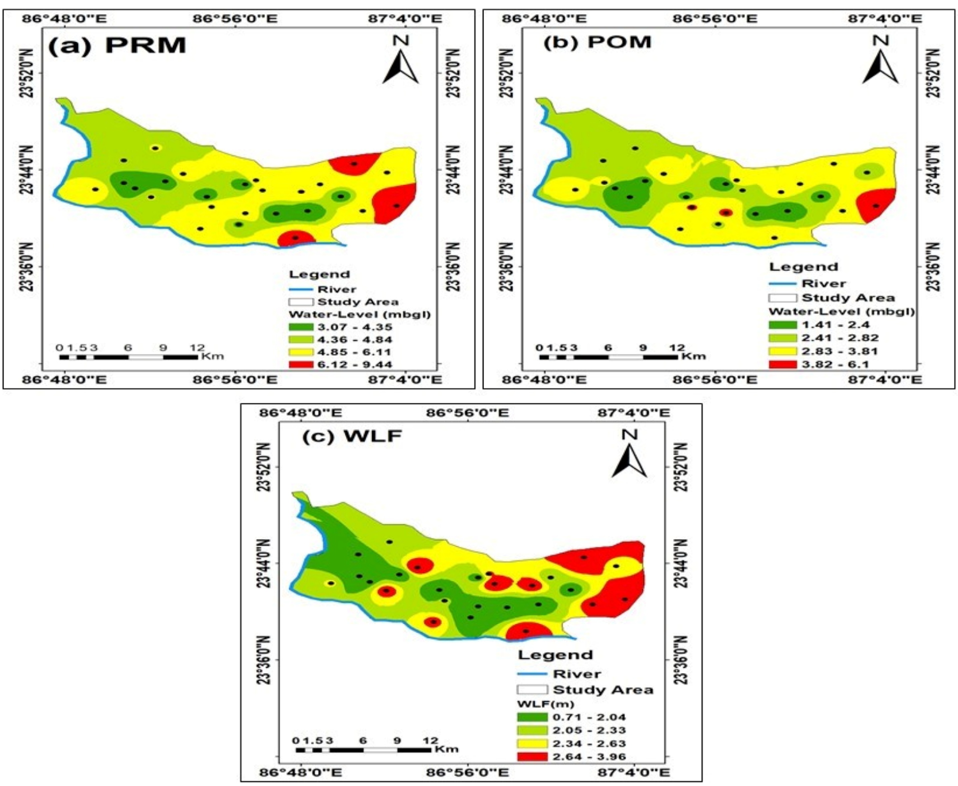
**Figure 3** Spatial distribution of heavy metals: (a) Fe, (b) Mn, (c) As, (d) Cu, (e) Cd and (f) Zn (see online version for colours)



## 3.3 Seasonal water level fluctuations (SWLF)

Being a mining and industrial hub, Asansol metropolitan experiences massive groundwater inflow, which ultimately affects the level of water below the ground [45]. The spatial distribution map for groundwater water level during PRM and POM were depicted in Figure 4(a) and (b), respectively. The groundwater of most of the areas in this region was found in the range of 3.47 to 4.34 mbgl (PRM), and 1.41 to 2.4 mbgl (POM) showed a good picture of these resources' occurrence in both seasons. However, the water level was observed at higher depth for locations 6 and 20 during PRM and location no 5 for both seasons. Moreover, the water level fluctuations in this region were ranging from 0.71 to 3.96 m. Out of all 26 sampling points, the groundwater of locations no 2, 5, 6, 15, 18, 19, 20, 21, and 26 were observed to have higher fluctuations (Figure 4(c)). This is mainly because of the diverse amount of rainfall, the difference in the infiltration rate, impermeability of rocks, geological formation, and the type of aquifers may vary from region to region, significantly affecting the WLF [42,46].

**Figure 4** The water level in (a) PRM, (b) POM and (c) WLF (see online version for colours)

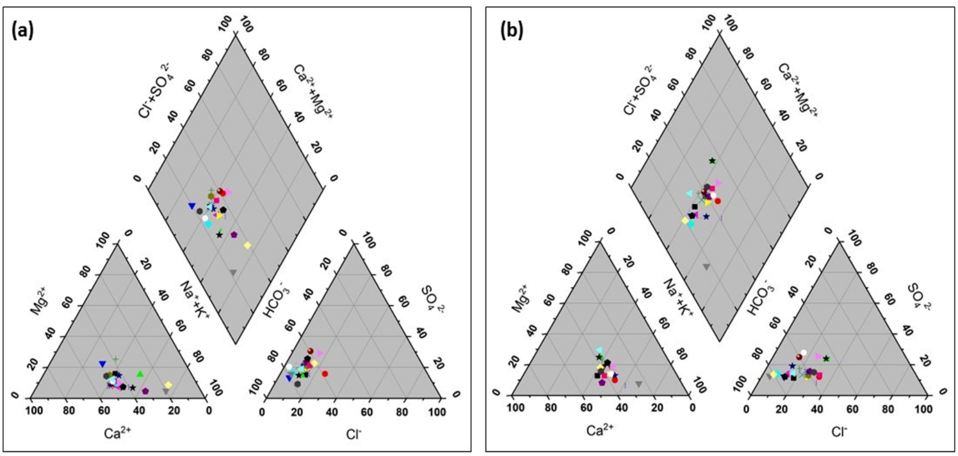



## 3.4 Hydrogeochemical Investigation of groundwater

The hydrogeochemical investigation of groundwater can be elucidated by plotting the trilinear Piper diagram. Figure 5(a) and (b) depict the main chemical facies of groundwater in terms of cations and anions, and the proportions are expressed in meq/L

[47,48]. Concerning the cations, mixed-type water was observed in the study area in both seasons. However, 3 locations during the PRM and 1 location during the POM showed the supremacy of $Na^+$ and $K^+$ (40 to 80 %). Moreover, in the case of anions, 60 to 80% and 40 to 80% of the samples were found to be dominated with $HCO_3^-$ over the $SO_4^{2-}$, and $Cl^-$ for PRM and POM season, respectively. The diamond shape diagram indicated that most groundwater samples were laid in mixed categories in the study area for both seasons. The groundwater chemistry in this region was controlled with the mix and cation exchange process [11]. The deviation in the level of cations and anions is mainly due to the facts of industrial effluents, geological conditions, and occurrence of natural rocks [39,49].

**Figure 5** Piper diagram plot of (a) PRM and (b) POM season (see online version for colours)




## 3.5 *Human health risk assessment of heavy metals*

The oral ingestion non-carcinogenic heavy metals risk from all 26 sampling locations was estimated for adults and children, methods based on USEPA. The calculated value of HQ and HI are illustrated in Table 4. The HQ value > 1 signifies adverse non-carcinogenic health effects on the human body, whereas the value <1 is considered safe for human consumption [46,50]. Research results indicated that the Zn, Mn, and Fe showed minimum hazard to the consumers as their HQ is <1 in all the 26 locations. However, its value in some of the locations for As (5, 10, 11, 12,17,18,19, 22, and 25) and Cd (25 and 26) exceeded the guideline (> 1) of USEPA and exhibited non-carcinogenic risk for both adult and children (Table 4). The risk associated with oral ingestion mainly depends on the human body weight and the volume of water consumed [26].

In addition, the calculated value of HI was varied from 9.93E-03 to 1.16E+01 and 1.18E-02 to 1.38E+01 for adults and children, respectively. According to the USEPA guideline, HI value ≥1 indicates the non-carcinogenic risk, and the value ≤1 is supposed to be safe [51]. The entire study area is assumed to be at risk of non-carcinogenic risk as to the value HI exceeding the unity for all the sampling locations in adults and children. Moreover, the children were observed to be more prone to non-carcinogenic health risks than adults.

**Table 4** Non-carcinogenic risk (HQ and HI) of heavy metals

| *S. No.* | *HQ* | | | | | | | | | | | | *HI* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Zn* | | *Mn* | | *Fe* | | *As* | | *Cd* | | *Cu* | | | |
| | *Adult* | *Child* | *Adult* | *Child* | *Adult* | *Child* | *Adult* | *Child* | *Adult* | *Child* | ***Adult*** | ***Child*** | *Adult* | *Child* |
| 1 | 6.88E-03 | 8.17E-03 | 4.40E-02 | 5.23E-02 | 2.29E-03 | 2.71E-03 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | **0.00E+00** | **0.00E+00** | 5.32E-02 | 6.31E-02 |
| 2 | 4.07E-03 | 4.83E-03 | 3.12E-03 | 3.70E-03 | 2.74E-03 | 3.25E-03 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | **6.54E-03** | **7.77E-03** | 9.93E-03 | 1.18E-02 |
| 3 | 5.33E-03 | 6.33E-03 | 2.49E-03 | 2.96E-03 | 4.03E-03 | 4.78E-03 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | **9.45E-03** | **1.12E-02** | 1.19E-02 | 1.41E-02 |
| 4 | 2.54E-02 | 3.01E-02 | 9.76E-03 | 1.16E-02 | 2.78E-03 | 3.30E-03 | 1.94E-01 | 2.30E-01 | 0.00E+00 | 0.00E+00 | **5.82E-03** | **6.90E-03** | 2.32E-01 | 2.75E-01 |
| 5 | 4.75E-03 | 5.64E-03 | 2.70E-03 | 3.21E-03 | 2.29E-03 | 2.71E-03 | 1.36E+00 | 1.61E+00 | 1.75E-01 | 2.07E-01 | **8.00E-03** | **9.49E-03** | 1.54E+00 | 1.83E+00 |
| 6 | 3.68E-03 | 4.37E-03 | 9.37E-02 | 1.11E-01 | 2.45E-03 | 2.91E-03 | 2.91E-01 | 3.45E-01 | 0.00E+00 | 0.00E+00 | **4.36E-03** | **5.18E-03** | 3.91E-01 | 4.64E-01 |
| 7 | 3.00E-02 | 3.56E-02 | 5.44E-02 | 6.46E-02 | 3.91E-03 | 4.64E-03 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | **5.82E-03** | **6.90E-03** | 8.83E-02 | 1.05E-01 |
| 8 | 4.65E-03 | 5.52E-03 | 2.35E-02 | 2.79E-02 | 2.53E-03 | 3.01E-03 | 0.00E+00 | 0.00E+00 | 1.75E-01 | 2.07E-01 | **9.45E-03** | **1.12E-02** | 2.05E-01 | 2.43E-01 |
| 9 | 7.66E-03 | 9.09E-03 | 1.33E-02 | 1.58E-02 | 2.16E-03 | 2.56E-03 | 2.13E-01 | 2.53E-01 | 1.75E-01 | 2.07E-01 | **7.27E-03** | **8.63E-03** | 4.11E-01 | 4.88E-01 |
| 10 | 5.24E-03 | 6.21E-03 | 2.49E-03 | 2.96E-03 | 2.24E-03 | 2.66E-03 | 1.94E+00 | 2.30E+00 | 0.00E+00 | 0.00E+00 | **3.64E-03** | **4.31E-03** | 1.95E+00 | 2.31E+00 |
| 11 | 5.62E-03 | 6.67E-03 | 2.08E-03 | 2.47E-03 | 2.24E-03 | 2.66E-03 | 1.75E+00 | 2.07E+00 | 0.00E+00 | 0.00E+00 | **8.73E-03** | **1.04E-02** | 1.75E+00 | 2.08E+00 |
| 12 | 3.49E-03 | 4.14E-03 | 2.49E-03 | 2.96E-03 | 6.56E-03 | 7.79E-03 | 1.36E+00 | 1.61E+00 | 0.00E+00 | 0.00E+00 | **5.82E-03** | **6.90E-03** | 1.37E+00 | 1.63E+00 |
| 13 | 4.56E-03 | 5.41E-03 | 5.40E-03 | 6.41E-03 | 6.98E-03 | 8.28E-03 | 3.88E+00 | 4.60E+00 | 0.00E+00 | 0.00E+00 | **6.54E-03** | **7.77E-03** | 3.89E+00 | 4.62E+00 |

**Table 4** Non-carcinogenic risk (HQ and HI) of heavy metals (continued)

| S. No. | HQ | | | | | | | | | | | | HI | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Zn* | | *Mn* | | *Fe* | | *As* | | *Cd* | | *Cu* | | | |
| | *Adult* | *Child* | *Adult* | *Child* | *Adult* | *Child* | *Adult* | *Child* | *Adult* | *Child* | ***Adult*** | ***Child*** | *Adult* | *Child* |
| 14 | 8.43E-03 | 1.00E-02 | 1.41E-01 | 1.67E-01 | 5.15E-03 | 6.11E-03 | 0.00E+00 | 0.00E+00 | 2.91E-01 | 3.45E-01 | **7.27E-03** | **8.63E-03** | 4.45E-01 | 5.29E-01 |
| 15 | 7.46E-03 | 8.86E-03 | 2.58E-02 | 3.06E-02 | 2.83E-03 | 3.35E-03 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | **9.45E-03** | **1.12E-02** | 3.60E-02 | 4.28E-02 |
| 16 | 3.97E-03 | 4.72E-03 | 2.49E-03 | 2.96E-03 | 4.15E-03 | 4.93E-03 | 0.00E+00 | 0.00E+00 | 1.45E-01 | 1.73E-01 | **5.82E-03** | **6.90E-03** | 1.56E-01 | 1.85E-01 |
| 17 | 4.36E-03 | 5.18E-03 | 5.61E-03 | 6.66E-03 | 3.37E-03 | 3.99E-03 | 3.49E+00 | 4.14E+00 | 0.00E+00 | 0.00E+00 | **6.54E-03** | **7.77E-03** | 3.50E+00 | 4.16E+00 |
| 18 | 4.65E-03 | 5.52E-03 | 2.45E-02 | 2.91E-02 | 6.81E-03 | 8.09E-03 | 5.82E+00 | 6.90E+00 | 0.00E+00 | 0.00E+00 | **5.82E-03** | **6.90E-03** | 5.85E+00 | 6.95E+00 |
| 19 | 3.59E-03 | 4.26E-03 | 1.91E-02 | 2.27E-02 | 6.98E-03 | 8.28E-03 | 1.36E+00 | 1.61E+00 | 0.00E+00 | 0.00E+00 | **5.82E-03** | **6.90E-03** | 1.39E+00 | 1.65E+00 |
| 20 | 1.52E-02 | 1.81E-02 | 1.58E-02 | 1.87E-02 | 1.66E-03 | 1.97E-03 | 6.79E-01 | 8.05E-01 | 2.33E-01 | 2.76E-01 | **4.36E-03** | **5.18E-03** | 9.44E-01 | 1.12E+00 |
| 21 | 4.46E-03 | 5.29E-03 | 1.66E-02 | 1.97E-02 | 2.74E-03 | 3.25E-03 | 7.76E-01 | 9.20E-01 | 1.75E-01 | 2.07E-01 | **2.91E-03** | **3.45E-03** | 9.74E-01 | 1.16E+00 |
| 22 | 3.97E-03 | 4.72E-03 | 7.48E-03 | 8.88E-03 | 3.82E-03 | 4.54E-03 | 1.16E+01 | 1.38E+01 | 0.00E+00 | 0.00E+00 | **4.36E-03** | **5.18E-03** | 1.16E+01 | 1.38E+01 |
| 23 | 6.50E-03 | 7.71E-03 | 5.40E-03 | 6.41E-03 | 4.86E-03 | 5.77E-03 | 0.00E+00 | 0.00E+00 | 4.65E-01 | 5.52E-01 | **1.31E-02** | **1.55E-02** | 4.82E-01 | 5.72E-01 |
| 24 | 6.98E-03 | 8.28E-03 | 6.23E-03 | 7.40E-03 | 3.61E-03 | 4.29E-03 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | **6.54E-03** | **7.77E-03** | 1.68E-02 | 2.00E-02 |
| 25 | 9.21E-03 | 1.09E-02 | 6.05E-02 | 7.17E-02 | 6.07E-03 | 7.20E-03 | 9.11E+00 | 1.08E+01 | 2.27E+00 | 2.69E+00 | **1.03E-01** | **1.23E-01** | 1.15E+01 | 1.36E+01 |
| 26 | 1.43E-02 | 1.70E-02 | 6.05E-02 | 7.17E-02 | 6.07E-03 | 7.20E-03 | 0.00E+00 | 0.00E+00 | 1.16E+00 | 1.38E+00 | **2.91E-02** | **3.45E-02** | 1.24E+00 | 1.48E+00 |

## 4 Conclusion

This elaborated study reveals the status of overall water quality in the Asansol industrial belt. According to the study the industrial activities have very low impact on the water quality. There is a considerable influx in the water during the rainy season that has been observed revealing the porous nature of the geology. The studied heavy metals are found in a very low concentration which is having a low non-carcinogenic risk as seen from the USEPA approved methods. The procedures adopted in this study were very efficient in discussing the underlying issues and shall stand useful for the authorities associated with the water resources management to enhance and amend the strategies pertaining to the betterment of groundwater resources considering risks associated to human health in the area. Subsequently, continuous monitoring and assessment is required to understand the behaviour of groundwater.

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