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# Water quality index, heavy metal pollution index and seasonal variation correlation of groundwater of Bailadila iron ore mine area and its peripherals: Dantewada district, Chhattisgarh, India

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**ABSTRACT**

Groundwater quality of Bailadila iron ore mine area has been studied. Groundwater samples were collected from hand pumps, and analysed in order to find out water quality index (WQI) and heavy metal pollution index (HPI). A comprehensive study has been carried out with respect to aluminium ($Al^{3+}$), chromium ($Cr^{6+}$), lead ($Pb^{2+}$), iron ($Fe^{2+}$) and zinc ($Zn^{2+}$). Seasonal variation in the metal concentration has been assessed in pre-monsoon and post-monsoon seasons. The physio-chemical parameters have been analyzed with standard procedure and instrumental techniques. It is found that a sizeable number of groundwater samples contain iron at toxic level. At few locations, $Pb^{2+}$ concentrations are also found higher than permissible limit. $Al^{3+}$, $Cr^{6+}$ and $Zn^{2+}$ content of groundwater were found to be within the guideline value of World Health Organisation (WHO). The metal concentration of groundwater in Bailadila iron ore mine area follows the trend $Fe^{2+} > Zn^{2+} > Al^{3+} > Cr^{6+} > Pb^{2+}$ in both pre and post monsoon seasons. The correlation ability of five heavy metals has been selected for the study area and these metals cause eco-toxicology and health hazards to the human being as well as to aquatic biota. The estimation of the concentration of these heavy metals associated element may establish the trend of heavy metals distribution. Monitoring and correlation data show that the quality of groundwater is vulnerable to anthropogenic contamination. The overall results indicate that groundwater quality of Bailadila iron ore mine area and its peripherals is very poor and not safe for human consumption without treatment.

*Keywords:* Bailadila; Groundwater; Water quality index; Heavy metal pollution index; Pearson correlation; Seasonal variation

## 1. Introduction

Water has unique chemical properties due to its polarity and hydrogen bonds which means that it is able to dissolve, absorb or suspend various compounds. Thus in nature water is not pure as it acquires contaminants from its surrounding and those arising from activities of human beings and animals. One of the most important environmental issues today is groundwater contamination. Amongst the diverse contaminants affecting water resources, [1] heavy metals require particular concern considering their strong toxicity even at low concentration. The accumulation of metals in groundwater has direct consequences to man and to the ecosystem. The metals such as zinc and copper, which are required for metabolic activity of organisms lie in the narrow "window" between their essentiality and toxicity. Others such as aluminium ($Al^{3+}$), cadmium ($Cd^{6+}$) and lead ($Pb^{2+}$) exhibit extreme toxicity even at trace levels [2].

Opencast as well as under ground mining of metals disturbs the water quality. Iron ore mining activity in Bailadila range started five decades back, since then the water quality is undergoing a change [3] in the study area. Approximately, 90% population in the study area consume water without

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any treatment. Heavy metals are priority toxic pollutants that severely limit the beneficial use of water for domestic or industrial applications. Groundwater pollution over the years due to contaminants leaking from the disposal sites is a big problem in many countries. Leachates from the landfill sites are another source of heavy metal contamination in groundwater. Increase in human activities such as industrialisation coupled with over population and increase in ambient temperature amongst other factors has become major environmental issues in recent years. Exposure to very low levels of elements such as lead, cadmium and mercury is known to have cumulative effects on human, since there is no homeostatic mechanism that can operate to regulate the levels of these toxic substances. Some heavy metals considered as micronutrients become detrimental to human health when their concentration exceeds the permissible level of drinking water [4]. Rapid industrialisation and urbanisation has affected the groundwater quality due to over exploitation and improper waste disposal. The rocks bearing minerals is yet another one of major causes of heavy metal pollution; anthropogenic source includes mining effluent [5].

Adsorption technology hugely applied for removal of variety of organic, inorganic [6] and metal ions from water sample in aqueous condition [7–11]. Various types of adsorbents such as metal oxide, modified adsorbent [12], bio-adsorbent, some synthetic materials [13], especially based on functional group exchanger, have been reported to be effective as adsorbents. The adsorption efficiency of iron oxide-impregnated dextrin nanocomposite, synthesis and its applications for the biosorption of Cr(IV) ions from aqueous solution was investigated by Mittal et al. [14,15] by batch experiments and found that adsorption capacity depends upon on the material of adsorbent and contact time. They also used environment friendly adsorbent for toxic metal reported in "Science, Responsibility and Governance" [16].

In Bailadila iron ore mine area; groundwater is the main source of drinking water for the people. This resource is flagrantly consumed without recourse to its quality. We are not immediately aware of previous heavy metals study on the groundwater of this area. It is imperative to understand the groundwater resource to ensure that it is fit to drink, and protect the water supply from heavy metal contamination. Guidelines issued by Bureau of Indian standard (BIS), WHO [17] and United States Environmental Protection Agency have been adopted for the study with special emphasis on BIS and WHO guidelines [18].

Bailadila iron ore mine area is a remote, hilly and a mineral rich area in which people mainly depend upon tube wells, hand pumps, pond and river for drinking water. Also no detailed study of heavy metals in groundwater of Bailadila iron ore mine area has been reported yet. The objective of this study is to find out water quality index (WQI) and heavy metal pollution index (HPI) of groundwater sample of Bailadila iron ore mine area and its peripherals, Dantewada district, Chhattisgarh, India. Additionally, the heavy metal concentrations of groundwater samples have been found in pre-monsoon and post-monsoon seasons during which the possibility of heavy metal contamination is maximum. Also the factors responsible for their accumulation in groundwater were found out, and the correlation existing among the heavy metals such as $Al^{3+}$, $Cr^{6+}$, $Pb^{2+}$, $Fe^{2+}$ and $Zn^{2+}$ in groundwater samples has been determined. The obtained results will establish a baseline data for future reference.

## 2. Materials and methods

### *2.1. Study area*

The study area, that is, Bailadila iron ore mine area and its peripherals come under South Bastar Dantewada district, Chhattisgarh, India and is represented schematically in Fig. 1. The district has its borders with Maharashtra in west, Andhra Pradesh in south and Odisha in east. The study area lies between latitude north 18°07′ to 18°59′ and longitude east 81°07′ to 82°21′. Total area of the district is around 3,410.50 km$^2$. The district has Godavari basin and Bastar plateau which are the oldest geological formations. The rock mass in the district is mainly composed of crystalline metamorphic rocks having sedimentary and igneous origin. 70% of this district is covered with heavy forests. Shankhini and Dankini rivers flowing through the district have confluence with Indravati river. The district has about 430 villages and the maximum population is employed in agriculture, forest products and mining. 84% of the available land is used for agriculture purpose and paddy is the most common cultivation crop [19]. The maximum temperature in summer rises up to 43°C between May and June whereas minimum temperature in winter drops to 10°C from December to January. The area receives heavy rains during monsoon from June to September along with the best average rainfall 1,450 mm. Heavy rainfall causes depletion of minerals in water and geochemical formation of mineral rocks due to the existence of the red sandy soils and red loamy soils in wide range. Bailadila hills are known for having one of the richest deposition of iron ore. The hills are situated in the southern part of Chhattisgarh and central part of India. The quantity of the ore is estimated up to 7,000 lac MT. The hills have 14 proved reserves of iron ore. The principal ores of iron are hematite (ferric oxide, $Fe_2O_3$), magnetite (ferrous ferric oxide, $Fe_3O_4$), siderite (ferrous carbonate, $FeCO_3$) and limonite (ferric oxide trihydrate, $2Fe_2O_3{\cdot}3H_2O$), iron pyrite (iron disulfide, $FeS_2$), goethite (FeO(OH)), ankerite ($Ca(Fe,Mg,Mn)(CO_3)_2$), turgite ($Fe_2O_3\ nH_2O$) are also known to occur in the deposits.

### *2.2. Sampling and sample collection*

The studied area is geographically hilly, dense forest, remote, mine area and hand pumps/borings are not in equal distance, hence we followed the standard random

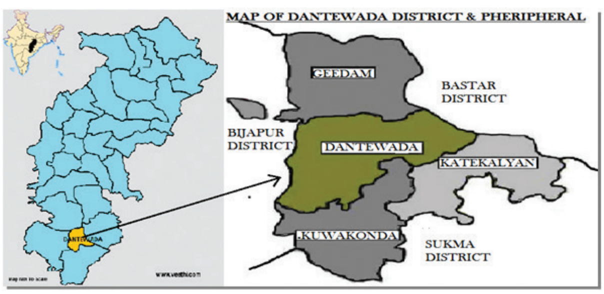


Fig. 1. Location of Bailadila iron ore mine area and its peripherals in South Baster, Dantewada, Chhattisgarh, India.

procedure of sampling in Bailadila iron ore mine area and peripherals. Groundwater samples (20 nos) were collected in pre-monsoon and post-monsoon seasons from tube wells and manually-operated hand pumps located at different sites of the study area. Samples were collected once in a week in both the seasons by random selection of sites but in a systematic manner in clean and sterile polyethylene bottles. The samples were hermetically sealed under pressure and transported in a vertical position to the laboratory and were frozen at –18°C [20].

### 2.3. Sample digestion

To ensure the removal of organic impurities from the samples and to prevent interference in analysis, the samples were digested immediately with concentrated nitric acid to bring the pH below 2 to avoid precipitation. 10 mL of nitric acid was added to 50 mL of water in a 250 mL conical flask [21]. The mixture was evaporated to half of its volume on a hot plate after which it was allowed to cool and then filtered.

### 2.4. Standard solutions preparation

The stock solutions of $Al^{3+}$, $Pb^{2+}$, $Fe^{2+}$, $Zn^{2+}$ and $Cr^{6+}$ were prepared in a 1.0 L volumetric flask by dissolving 24.62, 1.60, 2.96, 1 and 1 g of aluminium sulphate octadecahydrate, lead nitrate, ferric chloride, zinc and chromium pure standard, respectively, with 5% nitric acid. The mixture was shaken well and diluted to 1.0 L marks with distilled water. Similarly, calibration solutions of the target metal ions were prepared from the standard stock by serial dilution.

### 2.5. Sample analysis

The analysis of water quality parameters was done using BIS method. Physio-chemical parameters such as total hardness, $Ca^{2+}$ hardness and $Mg^{2+}$ hardness were calculated by using standard titrimetric (complexometric) method. Total dissolved solids analysis was done by gravimetric method. For the analysis of $Al^{3+}$, $Cr^{6+}$, $Pb^{2+}$, $Fe^{2+}$, $Zn^{2+}$, chloride, sulphate, nitrate and phosphate, Spectroquant Nova 60 photometer (Merck, Germany) was used. Electrical conductivity was measured by using digital conductivity meter 304 (Systronics, India) and turbidity was measured by using digital turbidity meter (Systronics, India).

The digested water samples were also analysed and the presence of $Al^{3+}$, $Cr^{6+}$, $Pb^{2+}$, $Fe^{2+}$ and $Zn^{2+}$ ions are found using inductively coupled plasma-optical emission spectrophotometer (ICP-OES), Teledyne Leeman Labs, USA. The ICP-OES has multielement capabilities, longer linear dynamic ranges and greater sensitivity which result in significantly lower detection limits for most of the element [22]. Method validation and quality control were done by using standard reference materials. Standard solutions and groundwater samples were analysed in batches including a procedural blank (double distilled water). Each element calibration curve was evaluated before sample analysis and the same was repeated for confirmation [23]. Repeat analysis of each sample was done by another photometer named Nova 60 Spectroquant® photometer, as per the standard procedure. All possible safety measures were taken at every stage, starting from sample collection, storage, transportation and final analysis of the sample to avoid or minimise contamination. In this study, the experimental tools were used for data analysis with aim to define possible relationships. The observed parameters are graphically co-related and the sample data are also subjected to statistical treatment using normal or Gaussian distribution statistic and correlation analysis.

### 2.6. Water quality index

WQI is a means by which water quality data are summarised for reporting to the public in a consistent manner. WQI expresses overall water quality based on several water quality parameters. It reduces the large amount of water quality data to a single numerical value and is calculated from the point of view of human consumption. Water quality and its suitability for drinking purpose have been considered for calculation of WQI [24] by equation:

$$\mathrm{WQI} = \sum W_n q_n / \sum W_n \tag{1}$$

where $n$ = 1 to $n$ number of parameters, $W_n$ is unit weight of each parameter and $q_n$ is the quality rating of each parameter. The unit weight $W_n$ is calculated as $(K/S_n)$, where $K$ is proportionality constant and calculated as:

$$K = 1/[(1/S_1) + (1/S_2) + (1/S_3) + \ldots\ldots(1/S_n)] \tag{2}$$

where $S_1$, $S_2$, $S_3$,…..$S_n$ are standard values of respective parameters.

Let there be $n$ number of water quality parameters and quality rating ($q_n$) corresponding to $n$th term parameter is a number reflecting relative value of respective parameter in the water sample with respect to its standard permissible limits value. The quality rating ($q_n$) value is calculated by the relationship:

$$q_n = 100\,(\mathrm{Va} - \mathrm{Vi})/(\mathrm{Vs} - \mathrm{Vi}) \tag{3}$$

where Va is observed value (average value), Vs is standard value, Vi is ideal value, in all cases Vi = 0 except in certain parameters such as pH, dissolved oxygen (Vi [pH] = 7.0 and Vi [DO] = 14.6).

The WQI values for drinking water are 0–25: excellent, 26–50: good, 51–75: poor, 76–100: very poor and more than 100: unfit for drinking [25].

### 2.7. Heavy metal pollution index

HPI represents the total quality of water with respect to heavy metals. HPI is based on weighted arithmetic quality mean method and has been developed in two steps. First step involves establishment of a rating scale for each selected parameters giving weightage followed by selection of parameters on which the index is to be based. The rating system has an arbitrary value between 0 and 1. Its selection depends upon the importance of individual quality consideration in a comparative way alternatively it can be assessed by making values inversely proportional to the recommended standard for corresponding parameters. In computing the HPI, Lilly Florence et al. [25] considered unit weightage ($W_i$) as a value inversely proportional to the recommended standard ($S_i$) of the corresponding parameter as shown in equation:

$$\text{HPI} = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \quad (4)$$

where $n$ = 1 to $n$th. The suitability of HPI values for human consumption are rated as follows. Let there be water quality parameters and quality rating or sub-index ($Q_i$) corresponding to $n$th term parameter is a number reflecting relative value of this parameter in the polluted water with respect to its standard permissible limits value as shown in equation:

$$Q_i = \sum_{i=1}^{n} \frac{\{M_i - I_i\}}{(S_i - I_i)} \times 100 \quad (5)$$

where $M_i$ is the actual value/observed value, $S_i$ is the standard value, $I_i$ is the ideal value, in most cases $I_i$ = 0. The sign (–) indicates the numeric difference of the two values, ignoring the algebraic sign. The critical pollution index value for drinking water as given by Prasad et al. is 100 [26]. However, a modified scale using three classes has been used in the present study. The classes have been demarcated as low, medium and high for HPI values <15, 15–30 and >30, respectively.

### 3. Results and discussion

For the potential of human health, guidelines for the presence of heavy metals in water have been set by different international organisation such as WHO, Indian Standards Specification for Drinking Water (IS 10500), BIS [27]. Thus heavy metals have permissible limits in water as specified by them. The experimental results of selected heavy metals $Al^{3+}$, $Zn^{2+}$, $Cr^{6+}$, $Fe^{2+}$ and $Pb^{2+}$ in groundwater of study area are presented in Tables 1 and 2 to assess the seasonal variations, distribution patterns [28,29] and the metal contents present. The results indicate that the concentration of $Al^{3+}$, $Cr^{6+}$ and $Zn^{2+}$ has not been found at any sampling point does not exceed the prescribed limit set by drinking water standards. While $Fe^{2+}$ concentration has been found higher than desirable limit in both the seasons especially at Bhansi, Bade Bacheli, Dugeli, Kameli, Shyamagiri, Gamawara, Goipad, Papachel and Chalnar sampling points. The concentration of $Fe^{2+}$ has exceeded the highest permissible values 1.0 mg/L at sampling points 2, 6, 7, 8, 11, 12, 13 and 16 in pre-monsoon and sampling points 1, 2, 4, 5, 7, 8, 11, 12, 14, 15, 16 and 20 in post-monsoon seasons. This phenomenon may be due to the presence of rich $Fe^{2+}$ in groundwater or due to rich iron deposits in peripherals of Bailadila hills area [30,31]. The higher value of $Pb^{2+}$ concentration has been found in ground water samples of Kameli, Camp Bhansi, Goipad which might be due to the lead coated iron pipes. It is also found that old hand pumps reported high $Pb^{2+}$ value due to corrosion of iron which promotes the dilution of $Pb^{2+}$ ion with water. The results have been compared with standard values and data were subjected to several statistical treatments. Descriptive statistics based on normal distribution has been summarised for both pre-monsoon and post-monsoon season in Table 3. In pre-monsoon season, $Fe^{2+}$ concentrations vary more, as compared with other heavy metals and its percentage of variance is found to be 92.4%. The mean value of $Fe^{2+}$ in pre-monsoon is found as 1.415 ppm which is much higher than permissible limit. In post-monsoon season, the maximum concentration for $Fe^{2+}$ is found to be 4.050 ppm, which is slightly lower value than pre-monsoon season. This may be due to heavy rainfall, hence dilution factor play an important role. This is also proved by reduction of variation percentage of iron, that is, 75.7%. The correlation analysis was performed by Pearson's correlation using GraphPad Prism Software and presented in

Table 1
Metal content (mg/L) in groundwater of Bailadila iron ore mine area and its peripherals in pre-monsoon season

| S. no. | Sampling point | $Al^{3+}$ | $Cr^{6+}$ | $Pb^{2+}$ | $Fe^{2+}$ | $Zn^{2+}$ |
|---|---|---|---|---|---|---|
| GW1 | Bus stop Bacheli | 0.110 | 0.010 | 0.002 | 0.670 | 2.500 |
| GW2 | Bhansi | 0.040 | 0.010 | 0.010 | 1.200 | 2.540 |
| GW3 | Nerli | 0.110 | 0.008 | 0.002 | 0.760 | 1.440 |
| GW4 | Pina Bacheli | 0.130 | 0.005 | 0.002 | 0.500 | 1.220 |
| GW5 | Camp Bhansi | 0.120 | 0.013 | 0.011 | 0.390 | 5.020 |
| GW6 | Bade Bacheli | 0.040 | 0.001 | 0.001 | 2.020 | 0.580 |
| GW7 | Dugeli | 0.220 | 0.012 | 0.003 | 1.870 | 2.980 |
| GW8 | Kameli | 0.110 | 0.011 | 0.006 | 2.260 | 0.560 |
| GW9 | Ganjenaar | 0.100 | 0.004 | 0.002 | 0.310 | 1.220 |
| GW10 | Main market Kirandul | 0.080 | 0.002 | 0.007 | 0.780 | 3.680 |
| GW11 | Shyamagiri | 0.090 | 0.005 | 0.008 | 4.330 | 3.110 |
| GW12 | Bus stop Kirandul | 0.001 | 0.001 | 0.009 | 1.280 | 1.340 |
| GW13 | Gamawara | 0.001 | 0.011 | 0.001 | 2.010 | 3.480 |
| GW14 | Goipad | 0.060 | 0.001 | 0.010 | 3.660 | 2.840 |
| GW15 | Papachel | 0.030 | 0.001 | 0.003 | 0.120 | 0.880 |
| GW16 | Cholnaar | 0.010 | 0.008 | 0.002 | 4.110 | 4.520 |
| GW17 | Kasipal | 0.040 | 0.005 | 0.003 | 0.070 | 3.620 |
| GW18 | B. camp Kirandul | 0.060 | 0.011 | 0.006 | 0.990 | 1.650 |
| GW19 | Dhurali | 0.020 | 0.001 | 0.002 | 0.260 | 5.020 |
| GW20 | Chalnar | 0.110 | 0.012 | 0.002 | 0.710 | 2.200 |

Table 2
Metal content (mg/L) in groundwater of Bailadila iron ore mine area and its peripherals in post-monsoon season

| S. no. | Sampling point | $Al^{3+}$ | $Cr^{6+}$ | $Pb^{2+}$ | $Fe^{2+}$ | $Zn^{2+}$ |
|---|---|---|---|---|---|---|
| GW1 | Bus stop Bacheli | 0.120 | 0.005 | 0.002 | 2.420 | 1.020 |
| GW2 | Bhansi | 0.130 | 0.001 | 0.011 | 1.890 | 1.640 |
| GW3 | Nerli | 0.100 | 0.009 | 0.002 | 0.450 | 1.520 |
| GW4 | Pinabacheli | 0.170 | 0.004 | 0.004 | 1.500 | 1.010 |
| GW5 | Camp Bhansi | 0.150 | 0.010 | 0.011 | 2.390 | 3.120 |
| GW6 | Bade Bacheli | 0.001 | 0.001 | 0.003 | 0.650 | 0.270 |
| GW7 | Dugeli | 0.130 | 0.011 | 0.005 | 1.300 | 1.990 |
| GW8 | Kameli | 0.080 | 0.010 | 0.012 | 3.260 | 1.010 |
| GW9 | Ganjenaar | 0.190 | 0.009 | 0.005 | 0.310 | 0.630 |
| GW10 | Main market Kirandul | 0.080 | 0.003 | 0.008 | 0.780 | 4.010 |
| GW11 | Shyamagiri | 0.090 | 0.010 | 0.010 | 2.260 | 1.340 |
| GW12 | Bus stop Kirandul | 0.070 | 0.001 | 0.007 | 1.010 | 2.650 |
| GW13 | Gamawara | 0.010 | 0.010 | 0.001 | 0.290 | 1.940 |
| GW14 | Goipad | 0.010 | 0.010 | 0.012 | 2.150 | 0.560 |
| GW15 | Papachel | 0.060 | 0.007 | 0.010 | 3.290 | 0.680 |
| GW16 | Cholnaar | 0.070 | 0.009 | 0.003 | 4.050 | 2.120 |
| GW17 | Kasipal | 0.001 | 0.003 | 0.012 | 0.260 | 1.050 |
| GW18 | B. camp Kirandul | 0.060 | 0.011 | 0.007 | 0.220 | 2.150 |
| GW19 | Dhurali | 0.090 | 0.001 | 0.002 | 0.300 | 4.120 |
| GW20 | Chalnar | 0.180 | 0.010 | 0.003 | 2.130 | 1.200 |

Table 3
Comparison of statistical data of different metals (mg/L) in groundwater of Bailadila iron ore mine area and its peripherals in pre- and post-monsoon season

| Statistical parameters | $Al^{3+}$ | | $Cr^{6+}$ | | $Pb^{2+}$ | | $Fe^{2+}$ | | $Zn^{2+}$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| Minimum | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.070 | 0.220 | 0.560 | 0.270 |
| Maximum | 0.300 | 0.190 | 0.013 | 0.011 | 0.011 | 0.012 | 4.330 | 4.050 | 5.020 | 4.120 |
| Mean | 0.078 | 0.089 | 0.006 | 0.007 | 0.004 | 0.007 | 1.415 | 1.546 | 2.525 | 1.702 |
| Standard error | 0.015 | 0.012 | 0.001 | 0.001 | 0.001 | 0.001 | 0.292 | 0.261 | 0.317 | 0.242 |
| Median | 0.070 | 0.085 | 0.006 | 0.009 | 0.003 | 0.007 | 0.885 | 1.400 | 2.520 | 1.430 |
| Standard deviation | 0.067 | 0.057 | 0.004 | 0.003 | 0.003 | 0.004 | 1.308 | 1.171 | 1.419 | 1.086 |
| Variance, % | 85.90 | 64.60 | 67.40 | 57.40 | 77.40 | 57.30 | 92.40 | 75.70 | 56.10 | 63.80 |

Table 4. There are no specific correlations between all the heavy metals and the seasons. This indicates that concentration of heavy metal in groundwater depends upon the types of rocks, geological formation and weathering conditions. In evolution of HPI of ground water, heavy metals such as $Pb^{2+}$, $Cr^{6+}$ have been given no relation in drinking water standard and they have been given high weightage ($W_i$) value in HPI calculation. Since the weightage ($W_i$) of $Al^{3+}$, $Zn^{2+}$ and $Fe^{2+}$ is very less, hence even their smaller concentration ($Pd^{2+}$, $Cr^{6+}$) present in water samples make the water of poor quality and gives high values in HPI calculation.

In the present study, WQI of Bailadila iron ore mines and its peripherals groundwater has been calculated in Table 5 for both pre- and post-monsoon seasons. The sampling points 2, 11, in pre-monsoon and sampling points 2, 8, 14 in post-monsoon have values above of critical index value of 100. Other sampling points such as 5, 7, 8, 10, 11, 12, 14, 16, 18 and 20 in pre-monsoon and sampling points 2, 5, 7, 8, 10, 11, 12, 14, 16 and 18 in post-monsoon seasons have WQI value above 30. WQI was found to be above the critical index (100) in Bhansi, Shyamagiri, Kameli sampling points in both seasons. As WQI value of the groundwater sample of Bailadila iron ore mine area is approaching 100, the suitability of water for drinking purpose or human consumption is rated as very poor as per water quality rating. In addition to above, in Table 6, HPI of groundwater samples of Bailadila iron ore mines and its peripherals have been given separately for all 20 nos. study area samples. The results show that sampling point 2, 11 and 14 in pre-monsoon and sampling point 2, 5, 8, 14 and 15 in post-monsoon are having HPI above of critical index value of 100. Other sampling point such as 5, 7, 8, 10, 12, 16 and 18 in pre-monsoon and sampling point 1, 4, 7, 9, 10, 12, 16, 17, 18 and 20 in post-monsoon season are having above the 30 (high) index value. Based on the experimental data it is concluded that in both the season, heavy

Table 4
Pearson's correlation matrix of groundwater samples of Bailadila iron ore mine area and its peripherals during pre- and post-monsoon season

| Correlation | $Al^{3+}$ | | $Cr^{6+}$ | | $Pb^{2+}$ | | $Fe^{2+}$ | | $Zn^{2+}$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| $Al^{3+}$ | 1 | 1 | | | | | | | | |
| $Cr^{6+}$ | –0.444 | 0.156 | 1 | 1 | | | | | | |
| $Pb^{2+}$ | –0.068 | –0.051 | 0.025 | 0.114 | 1 | 1 | | | | |
| $Fe^{2+}$ | –0.063 | 0.139 | 0.005 | 0.281 | 0.206 | 0.336 | 1 | 1 | | |
| $Zn^{2+}$ | –0.070 | 0.080 | 0.156 | –0.203 | 0.169 | –0.141 | 0.120 | –0.213 | 1 | 1 |

Table 5
Water quality Index (WQI) values of groundwater samples of Bailadila iron ore mine area and its peripherals

| Sample ID | Sampling point | Pre-monsoon | Post-monsoon |
|---|---|---|---|
| GW1 | Bus stop Bacheli | 20.79 | 28.50 |
| GW2 | Bhansi | 120.70 | 104.80 |
| GW3 | Nerli | 29.50 | 25.40 |
| GW4 | Pina Bacheli | 20.00 | 29.50 |
| GW5 | Camp Bhansi | 65.00 | 95.50 |
| GW6 | Bade Bacheli | 16.50 | 28.90 |
| GW7 | Dugeli | 40.50 | 50.20 |
| GW8 | Kameli | 72.80 | 111.20 |
| GW9 | Ganjenaar | 20.40 | 28.90 |
| GW10 | Main market Kirandul | 60.90 | 51.20 |
| GW11 | Shyamagiri | 128.40 | 87.00 |
| GW12 | Bus stop Kirandul | 61.45 | 54.40 |
| GW13 | Gamawara | 18.90 | 17.60 |
| GW14 | Goipad | 98.90 | 101.00 |
| GW15 | Papachel | 25.30 | 17.00 |
| GW16 | Cholnaar | 40.00 | 42.50 |
| GW17 | Kasipal | 30.90 | 24.50 |
| GW18 | B. Camp Kirandul | 50.70 | 51.20 |
| GW19 | Dhurali | 24.06 | 26.04 |
| GW20 | Chalnar | 37.00 | 30.00 |

metals contaminate groundwater quality due to mineral rocks, runoff, mining waste and other anthropogenic sources.

### *3.1. Aluminium ($Al^{3+}$)*

Aluminium is the most abundant element found in the earth's crust. The results obtained from analysis show that $Al^{3+}$ concentration in Bailadila iron ore mines groundwater was found to be within the range of 0.001–0.220 mg/L during pre-monsoon season and 0.001–0.190 mg/L during post-monsoon season and plotted as Fig. 2. It is observed that the all groundwater samples in study area have $Al^{3+}$ concentration within the permissible limit, that is, of <0.2 mg/L [17]. Normal data range and normal standard deviation in case of $Al^{3+}$ in both the seasons are likely to bias the normal distribution statistic. Significant differences among mean, median, values were observed for $Al^{3+}$ in both seasons. This indicates the departure of sample frequency distribution curve from normal.

### *3.2. Chromium ($Cr^{6+}$)*

In natural water, the concentration of chromium is low. There are four states of chromium $Cr^{2+}$, $Cr^{3+}$, $Cr^{+5}$ and $Cr^{6+}$. Chromium in water is in the form of trivalent or hexavalent state and is potentially toxic in dissolved form [32]. In the

Table 6
Heavy metal pollution index (HPI) values of groundwater samples of Bailadila iron ore mine area and its peripherals

| Sample ID | Sampling point | Pre-monsoon | Post-monsoon |
|---|---|---|---|
| GW1 | Bus stop Bacheli | 22.79 | 40.38 |
| GW2 | Bhansi | 107.70 | 104.80 |
| GW3 | Nerli | 26.80 | 24.24 |
| GW4 | Pina Bacheli | 24.00 | 48.66 |
| GW5 | Camp Bhansi | 95.49 | 112.35 |
| GW6 | Bade Bacheli | 26.33 | 29.29 |
| GW7 | Dugeli | 49.15 | 56.14 |
| GW8 | Kameli | 71.78 | 126.22 |
| GW9 | Ganjenaar | 21.47 | 48.09 |
| GW10 | Main market Kirandul | 63.49 | 51.59 |
| GW11 | Shyamagiri | 103.04 | 102.22 |
| GW12 | Bus stop Kirandul | 81.45 | 64.94 |
| GW13 | Gamawara | 28.69 | 13.65 |
| GW14 | Goipad | 110.98 | 115.26 |
| GW15 | Papachel | 25.30 | 30.58 |
| GW16 | Cholnaar | 53.88 | 62.55 |
| GW17 | Kasipal | 26.39 | 36.59 |
| GW18 | B. Camp Kirandul | 59.87 | 61.02 |
| GW19 | Dhurali | 18.66 | 20.34 |
| GW20 | Chalnar | 27.63 | 38.39 |

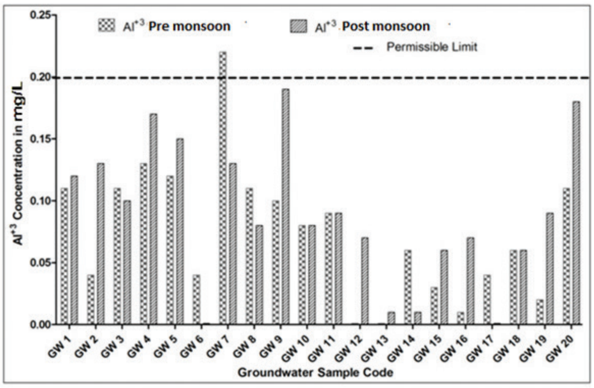


Fig. 2. Seasonal variations of $Al^{3+}$ in groundwater samples of Bailadila iron ore mine area and its peripherals.

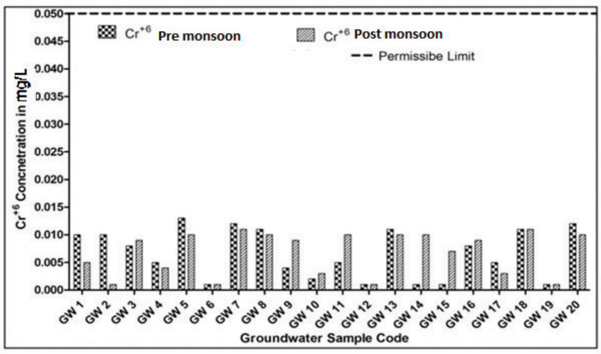


Fig. 3. Seasonal variations of $Cr^{6+}$ in groundwater samples of Bailadila iron ore mine area and its peripherals.

present study, chromium content in groundwater is found to be within permissible limit of WHO [17]. The concentration of chromium was observed at 0.001–0.013 mg/L in pre-monsoon and 0.001–0.011 mg/L in post-monsoon seasons and presented as Fig. 3. Chromium ($Cr^{6+}$) ion concentration in the study area was almost similar in pre- and post-monsoon seasons and is 0.013 mg/L. The statistic values for chromium in both seasons indicate that its distribution in the study area is uniform.

### 3.3. Lead ($Pb^{2+}$)

Lead ($Pb^{2+}$) in suspended matter and sediment comes from soil erosion in catchments with plumbo-ferrous subsoil. Lead occurs geologically in association with sulphides minerals and may be present in generally elevated concentration in area with ores. Lead occurs naturally in the environment. It is an undesirable trace metal less abundantly found in groundwater. The possible long-term effects of chronic exposure to $Pb^{2+}$ present in drinking water are of considerable public concern [33]. Analysis of $Pb^{2+}$ from the groundwater samples collected from Bailadila iron ore mine area and its peripherals is shown in Fig. 4. Present investigation shows that the $Pb^{2+}$ concentration is not in permissible limit as per the guideline of WHO. The concentration of $Pb^{2+}$ is observed to be 0.001–0.011 mg/L in pre-monsoon and 0.001–0.012 mg/L in post-monsoon seasons. The data indicate that the concentration of $Pb^{2+}$ is more in post-monsoon as compared with pre-monsoon. The statistic values for $Pb^{2+}$ in both the seasons indicate that the distribution in the study area is not uniform. The comparatively higher concentrations in a few localities are attributed to the chemistry of aquifer.

### 3.4. Iron ($Fe^{2+}$)

Iron is frequently found in solution in groundwater as ferrous ($Fe^{2+}$) ions with ferrous compounds which is believed to be toxic. The availability of iron for aqueous solution is affected by environment conditions, particularly changes in degree of oxidation or reduction, which depends upon pH range, redox potentials and temperature. Iron has critical importance to plants, human beings and animals. It has been observed that iron content of groundwater at 50% of sampling sites is very high (>1.0 ppm). Average $Fe^{2+}$ in groundwater in both the seasons fall outside the maximum permissible limit of 0.3 ppm as set by WHO [30] whereas in post-monsoon 0.22–4.05 mg/L as shown in Fig. 5. Iron distribution in the area is found to be flat during pre-monsoon season and sharp during post-monsoon season with asymmetric tail pointing towards right of the median [34]. This is mainly due to presence of iron ore in the study area and also may be due to mine drainage. The concentration of iron in various water samples collected near iron ore deposit contain higher level of concentration vis-à-vis the locations which are far apart [35]. Excess concentration of iron causes bad taste along with an increase in the corrosive property of water. Colour of the most of the water samples was found to be reddish due to high contamination by iron. Prolonged consumption of drinking water with high concentration of iron may lead to liver disease called as haemosiderosis.

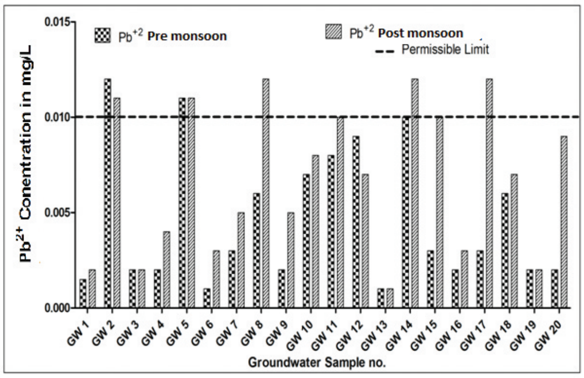


Fig. 4. Seasonal variations of $Pb^{2+}$ in groundwater samples of Bailadila iron ore mine area and its peripherals.

### 3.5. Zinc ($Zn^{2+}$)

The concentration of zinc ($Zn^{2+}$) in groundwater is usually below 10–40 mg/L. Zinc is a nutritionally essential trace element [36]. It is necessary for the growth and is involved in several physiological functions. In all the samples under investigation, the $Zn^{2+}$ content is much below the guideline value of 5.0 mg/L. The concentration of $Zn^{2+}$ in groundwater varies from 0.56 to 5.02 mg/L in pre-monsoon whereas it varies from 0.27 to 4.12 mg/L in post-monsoon, respectively, as given in Fig. 6. The results clearly indicate that $Zn^{2+}$ concentrations in pre- and post-monsoon season are within limits.

### 3.6. Seasonal variations in heavy metal concentrations

During the study, seasonal variations are also observed for five trace metals, that is, $Fe^{2+}$, $Al^{3+}$, $Zn^{2+}$, $Cr^{6+}$ and $Pb^{2+}$ under investigation. Except $Fe^{2+}$, all the trace metals show higher values in pre-monsoon season than in the post-monsoon season. By comparing the average values of all the trace metals, it is observed that the metal content of groundwater in the study area follows the trend $Fe^{2+} > Zn^{2+} > Al^{3+} > Cr^{6+} > Pb^{2+}$ in both the seasons. Pearson's correlation coefficient matrix, employed for measuring the linear association among $Cr^{6+}$, $Zn^{2+}$, $Al^{3+}$, $Fe^{2+}$ and $Pb^{2+}$, shows that some of the metals are significantly co-related at the 0.05 mg/L level.

## 4. Conclusions

Statistical observations on aluminium, chromium, lead, iron, zinc in groundwater of Bailadila iron ore mines

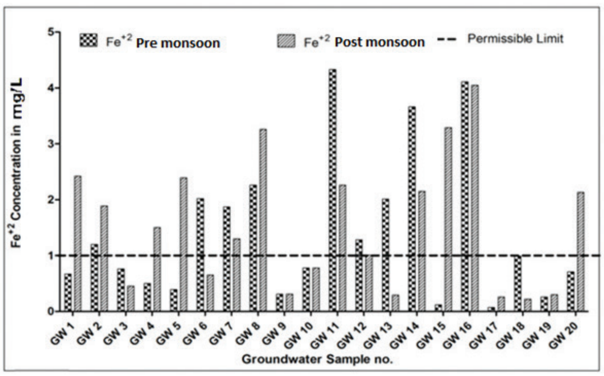


Fig. 5. Seasonal variations of $Fe^{2+}$ in groundwater samples of Bailadila iron ore mine area and its peripherals.

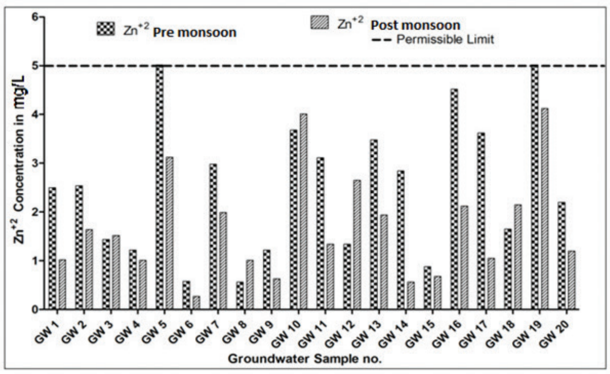


Fig. 6. Seasonal variations of $Zn^{2+}$ in groundwater samples of Bailadila iron ore mine area and its peripherals.

area and its peripherals show that all these metals exhibit a non-uniform distribution. It is found that half of groundwater samples in post-monsoon seasons exhibit an alarming level mostly in concentration of iron. This might be due to the dilution of taconite and natural weathering of rocks, bearing soils in groundwater or runoff of minerals waste as well as favourable condition for weathering of iron-bearing rocks. The concentration of lead in groundwater is due to plumbing factors and corrosion of iron pipes coated with lead. The presence of iron in groundwater samples in excess amount (>0.3 mg/L) is due to the weathering and dilution of iron rich minerals. A usually high concentration of the harmful metals at some of the sampling sites requires that regular monitoring of water sources should be ensured by the concerned authorities to prevent the outbreak of waterborne diseases in the area. The method has been found very useful to calculate overall pollution level of ground water with respect to heavy metals. WQI and HPI have been found separately for all samples; result shows that WQI average value was found to be 49.13 in pre-monsoon and 50.25 in post-monsoon season and HPI average value found to be 52.24 in pre-monsoon and 59.35 in post-monsoon season. WQI and HPI index values shift to higher side from pre-monsoon to post-monsoon. This may be due to weathering of rocks, minerals and improper disposal of waste. These values show that the groundwater of Bailadila iron ore mine area is rated as very poor as per water quality rating.

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