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Physico-chemical characterization of water quality in the Bastacola coalmine regions of Jharia coalfield, Dhanbad, India

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Abstract

Assessment of water quality is needed for its sustainable management in drinking, irrigation and industrial use. Coal mining activities are known to contaminate both the surface and ground area in their adjoining areas. In the present study fourteen physico-chemical parameters (pH, EC, TDS, HCO_3^-, F^-, Cl^-, Br^-, NO_3^-, SO_4^{2-}, PO_4^{3-}, Na^+, K^+, Ca^{+2}, Mg^{+2}) were estimated from 25 water samples, collected from seven coalmine sites in Jharia coalfield. The chemical analysis results were used to calculate the water quality index (WQI), percentage sodium (%Na) and sodium absorption ratio (SAR) to assess the suitability of water for drinking and agricultural purposes. While most of the samples are within permissible limit, five and seven samples were found to be high in nitrate and sulfate respectively. One sample each was also found to be above permissible limit for fluoride and total dissolved solid (TDS). WQI study categories the water sample into6 good, 14 medium and 5 bad categories. All the SAR values within permissible range, whereas few samples are slightly outside the range in case of % Na and TDS. Majority of the water samples belong to Na +Mg + Cl + SO_4 and Na + Cl + SO_4 type which indicate the rock water interaction. *It can be concluded that mining activity has been responsible for deterioration of water quality in the area, especially the increase in the SO_4^{2-} content. Agricultural activities may have increased the NO_3^- content in some water samples.*

Keywords: Water quality index (WQI), Percentage sodium (%Na), Sodium absorption ratio (SAR), Water pollution, Coal-mines.

Introduction

Ground water is generally used for drinking purpose as it is considered to be less prone to pollution than surface water. Several factors such as industrial discharge, agriculture and domestic discharge, land use practice, geological formation, rainfall pattern and its infiltration rate can affect the quality of ground water. Once contamination of ground water occurs, it persists for long time due to slow movement in them[1]. Local topographical change and drainage system directly affect quality and quantity of ground water. Rapid increase in industrialization and population leads to degradation of water quality. Coal mining activities, coal washeries, waste dump, coking coal plants, and thermal power plant causes significant water pollution. Ground water quality depends on factors such as quality of recharged water, amount and quality of precipitation, nature of inland surface water and subsurface geochemical processes.

Water pollution affects human health as well as the socio-economic developments. Contamination of water resources through various pollutants required great attention to know the status of water quality with reference to controlling measures and its importance. The protection of ground water from surface activity is very difficult to remediate but risk can be minimized by monitoring of impacted area and highly pollution prone area. So monitoring program should be reliable for estimation of water quality. Water quality index (WQI) is one of the useful techniques that interpret the quality of water with several important variables. WQI can express the large data in single unit, which will be easy to represent data in an informative way for local and general people[2]. WQI integrates the water quality variables and expresses the quality of water in good, medium, bad and very bad. Its purpose is to express the water quality for different usage and have ability to evaluate information in single unit from complex dat[3], which is easily understandable and useable by the general public and decision makers. The present study evaluates the water quality characteristic around the Bastacola coalmine area, Jharia coal-field to assess its suitability for drinking and agriculture purposes.

Materials and methods

Study area: The study area belongs to Jharia coalfield in Dhanbad district, which is located in the eastern part of the Jharkhand and one of the largest coal producing area in India (with approximately 200 opencast and underground coalmines). The area of investigation covered seven coal mines which is encompassed within latitudes (23.7282N-23.7739N) and longitudes (86.4194E-86.4634E). The seven coal mines currently active in the area are Bera, Dobari, Kuya, Kujama, Ghanudih, Golokdih and Bastacola. The twenty five sampling location around these seven mining area is given in Table-1 and shown in Figure-1.

Sampling and analysis: The samples were collected during the May 2013 (pre-monsoon) and preserved in refrigerator for further analysis. Fourteen physio-chemical parameters were estimated to determine the overall quality as per standard procedure[4]. The pH, electrical conductivity (EC), and total dissolved solid (TDS) were analyzed through thermo-scientific ion selective electrode while alkalinity (HCO_3^- + CO_3^{-2}) was examined by titrimetric method. Sodium (Na^+), calcium(Ca^{+2}), magnesium (Mg^{+2}), potassium (K^+), fluoride (F^-), chloride(Cl^-), nitrate (NO_3^-), bromide (Br^-), phosphate (PO_4^{3-}) and sulfate (SO_4^{2-}) were estimated through ion chromate-graph (Basic IC-plus 783). The mean, maximum, minimum and standard deviation of the parameters were calculated by MS Excel-2007.

Table-1: Sampling sites along with co-ordinates.

Site	Site names	Latitude	Longitude
S1	Dobari- 1	23.7567 N	86.4343 E
S2	Dobari-2	23.7562 N	86.4333 E
S3	Dobari -3	23.7545 N	86.4329 E
S4	Ghunudih-1(well)	23.7481 N	86.4398 E
S5	Ghunudih-2(pond)	23.7485 N	86.4330 E
S6	Ghunudih-3(well1)	23.7487 N	86.4377 E
S7	Ghunudih-4(well2)	23.7482 N	86.4386 E
S8	Kuiya-1	23.7408 N	86.4505 E
S9	Kuiya-2	23.7468 N	86.4452 E
S10	Kuiya-3	23.7497 N	86.4428 E
S11	kuiya-4(supply)	23.7398 N	86.4494 E
S12	Kuiya-5(Boaring)	23.7341 N	86.4526 E
S13	Golkdih-1	23.735 N	86.4634 E
S14	Kujama-1	23.7282 N	86.4339 E
S15	Ghunudih-5(well3)	23.7640 N	86.4194 E
S16	Bastacola-1	23.7727 N	86.4194 E
S17	Bastacola-2	23.7725 N	86.4202 E
S18	Bastacola-3	23.7739 N	86.4240 E
S19	Bastacola-4	23.7706 N	86.4415 E
S20	Bera-1(P1)	23.7682 N	86.4407 E
S21	Bera-2(P2)	23.7655 N	86.4391 E
S22	Bera-3(pond)	23.7558 N	86.4356 E
S23	Bera-4(well)	23.7567 N	86.4343 E
S24	Dobari-4(F)	23.7545 N	86.4354 E
S25	Dobari-5(WF)	23.7543 N	86.4352 E

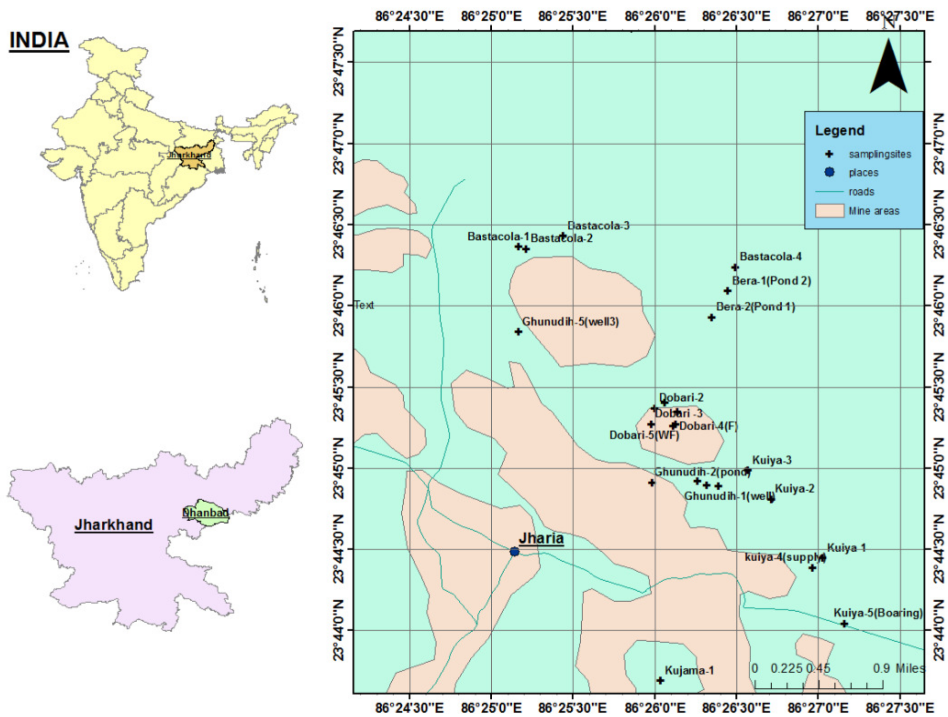

Figure-1: Study area showing sampling sites.

Indices calculation: For calculating various water quality indices, the ionic concentration of the water was first converted into milliequivalent/litre (meq/l) from milligram/litre (mg/l) using Equation (1). The concentration of Na^+, Ca^{2+} and Mg^{2+} ions in meq/l was applied as equation (2) to determine the values of sodium absorption ratio (SAR)[5], which provides an idea about the soil salinity. The combination of Na^+, K^+, Ca^{2+} and Mg^{2+} ions were calculated to identify the status of soil fertility by using percentage sodium (% Na) as in Equation (3)[5,6]. Permeability index (PI) was obtained from Na^+, HCO_3^-, Ca^{2+} and Mg^{2+} ions concentration using Equation (4) to identify the status of permeability of soil and how soil is influenced by the water quality[7].

$$\text{Milliequivalent per litre(meq/l)} = \frac{\text{Milligram per litre(mg/l)of selected ion}}{\text{Equivalent mass of respective ion}} \quad (1)$$

$$\text{Sodium Absorption Ratio (SAR)} = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \quad (2)$$

$$\text{Percentage Sodium (\%Na)} = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100 \quad (3)$$

$$\text{Permeability Index (PI)} = \frac{(Na^+ + \sqrt{HCO_3^-})}{Ca^{2+} + Mg^{2+} + Na^+} \times 100 \quad (4)$$

$$WQI = K \frac{\sum_i CiPi}{\sum_i Pi} \quad (5)$$

Equation-5 was used to calculate the Water Quality Index (WQI), where K= subjective constant. WQI is a mathematical technique used to transform large quantities of water characterization data into a single number by normalization factor (*C*i) and relative weight (Pi) which represents the water quality level into a 0 to 100 scale. The obtain value of WQI classified into five different scale viz. 0 – 25 = Very bad; 26 – 50 = Bad; 51 – 70 = Medium; 71 – 90 = Good and 91 – 100 = Excellent respectively[7,8] (1.0 for water without apparent contamination, 0.75 for light contaminated water, 0.5 for contaminated water and 0.25 for highly contaminated water). The water samples were plotted in Piper trilinear diagram using Aquachem scientific software to determine the hydro-chemical facies.

Results and discussion

Water quality characteristic: Descriptive statistics of all variables with minimum, maximum, mean and standard deviation are shown in Table-2. The pH values of the samples range from 6.1 to 7.3, with mean value of 6.9±0.3. With respect to pH, most of the water samples are within safe limit according to Indian standard[9] except S10 and S8 which have pH values below 6.5. The value of EC and TDS ranges from 87 to 1668 µs/cm and 56 to 1044 mg/l with mean values are 776.1 ± 477.5 µs/cm and 502.2±306.6 mg/l respectively. TDS value of only one water samples is above the permissible level. The range of F^- content is 0.2 to 2.4 mg/l and the mean value of 0.6±0.4 mg/l. Except one sample (S3), all samples have F^- content within permissible limit (1.5mg/l). Other ions such as HCO_3^-, Cl^-, Br^-, PO_4^{3-}, Na^+, K^+, Ca^{2+}, Mg^{2+} have concentration ranges from 12 to 40 mg/l, 2.1 to 153.9 mg/l, 0.3 to 1.4 mg/l, below 0.4 mg/l, 7.0 to 144.7 mg/l, 1.9 to 28.3 mg/l, 17 to 177 mg/l and 4.7 to 44.8 mg/l respectively. These values lie within permissible limit.

However, it was observed that out of total 25 samples, five and seven samples have NO_3^- and SO_4^{-2} content above the permissible limit. The mean value of NO_3^- is 19.0±36.2 mg/l. Water samples from S3, S10, S13, S16 and S24 have NO_3^- content higher than the permissible limit (45 mg/l). The range of SO_4^{2-} content from 6.5 to 682 mg/l and the mean value is 304.4±230.8 mg/l. Among them S3, S6, S9, S14, S15, S19 and S25 have SO_4^{2-} concentration higher the permissible limit with respect to drinking water quality. The NO_3^- rich samples are close to agricultural fields whereas SO_4^{2-}rich samples are nearer to the mine sites. Use of nitrogen fertilizers in the nearby agricultural fields may be responsible for the high in NO_3^- concentration in the locality. The SO_4^{2-} enrichment is associated with the coal mining activities. Pyrite (FeS_2) is commonly occur within coal bearing rock strata and by weathering and oxidation process they release SO_4^{2-} and contaminate both surface and ground water[10].

Suitability of water for irrigation purposes: Calculated value of sodium absorption ratio (SAR), percentage sodium (% Na) and permeability index (PI) are shown in Table-3. The estimated value of SAR mainly applied to express the sodium hazard in more reliable manner. The SAR value less than 10 is considered as excellent for irrigation purpose. SAR values of samples varies from 0.31 to 3.14 which indicates that water of study area is suitable for irrigation in terms of SAR value. %Na indicates to soil fertility as well as plant growth. It has capacity to reduce soil permeability[5]. The value of %Na higher than 15% considered well for plant growth[5]. In this study %Na varies from 13.32 to 48.87%. Majority of collected water samples have higher value of %Na, while site S9, S24 and S25 have %Na <15%. Similarly, the obtained value of PI varies from 20 to 55.78%. PI value should be greater than 25% according to classification of Doneen et al.[11]. Results indicates that the value of PI is higher than 25% in maximum samples while few sites like S2, S3, S5, S6, S9, S14, S15 and S22 have lower value (<25%). In this study, we also found that the higher level of TDS in site S18 which indicates that the water quality of this area is not under fresh water type (TDS<1000mg/l)[9,12]. The value of EC below 200 µs/cm is considered as good for irrigation purpose[13]. The study indicates that majority of the samples have high EC value except site S11, S17, S19, S21 and S22.

Table-2: Descriptive statistics of physico-chemical parameters.

Parameters	Minimum	Maximum	Mean± Std	Permissible limit
pH	6.1	7.3	6.9±0.3	6.5-8.5
EC	87.0	1668.0	776.1±477.5	-
TDS	56.0	1044.0	502.2±306.6	500-1000
HCO_3^-	12.0	40.0	25.9±7.3	200-600
F^-	0.2	2.4	0.6±0.4	1-1.5
Cl^-	2.1	153.9	52.5±48.4	250-1000
Br^-	0.3	1.4	0.7±0.2	-
NO_3^-	0.0	148.6	19.0±36.2	45
PO_4^{3-}	0.0	0.4	0.017±0.1	-
SO_4^{2-}	6.5	682.0	304.4±230.8	200-400
Na^+	7.0	144.7	47.8±33.5	-
K^+	1.9	28.3	8.5±8.1	-
Ca^{2+}	17.0	177.0	92.1±46.1	75-200
Mg^{2+}	4.7	44.8	24.7±12.5	30-100

*All the values are given in mg/l except pH (unit less) and EC (µs/cm).

Table-3: Site wise value of salinity indices.

Site	EC	TDS	SAR	%Na	PI
S1	699	454	1.01	26.19	32.72
S2	1345	862	0.88	17.69	22.43
S3	1386	900	0.88	17.55	21.86
S4	1280	832	2.19	40.22	40.98
S5	855	555	0.78	16.87	21.76
S6	646	420	0.56	17.21	23.21
S7	764	497	1.37	30.55	32.53
S8	528	343	0.88	23.28	33.00
S9	217	141	0.48	14.40	24.73
S10	378	246	2.35	48.87	58.30
S11	160	104	1.02	36.28	55.87
S12	683	444	2.33	42.44	49.63
S13	1428	928	3.14	46.45	46.97
S14	1059	688	0.88	18.07	22.84
S15	1031	670	0.83	17.35	21.42
S16	1034	672	1.40	25.61	30.36
S17	146	95	0.64	26.04	43.84
S18	1668	1044	1.57	27.34	28.56
S19	129	84	0.43	25.50	55.78
S20	577	375	0.91	22.09	29.58
S21	137	89	0.52	17.98	31.65
S22	87	56	0.31	16.92	42.40
S23	1389	903	1.80	28.62	32.56
S24	899	584	0.62	13.82	20.00
S25	877	570	0.58	13.32	20.72

Hydro chemical facies: Piper trilinear diagram shows relative concentrations of ions in the individual water samples and is helpful in identifying the hydro chemical facies. Piper plot of the water samples from the study area indicates that 24 ground water samples fall under type 1 and type 2 (Na +Mg + Cl + SO_4 and Na + Cl + SO_4) hydro chemical facies and S22 falls under type iii (Figure-2) hydro chemical facies. The dominance of type 1 and type 2 facies indicates that the water chemistry is mostly affected by the chemical interactions between the minerals of lithologic framework and ground water[14].

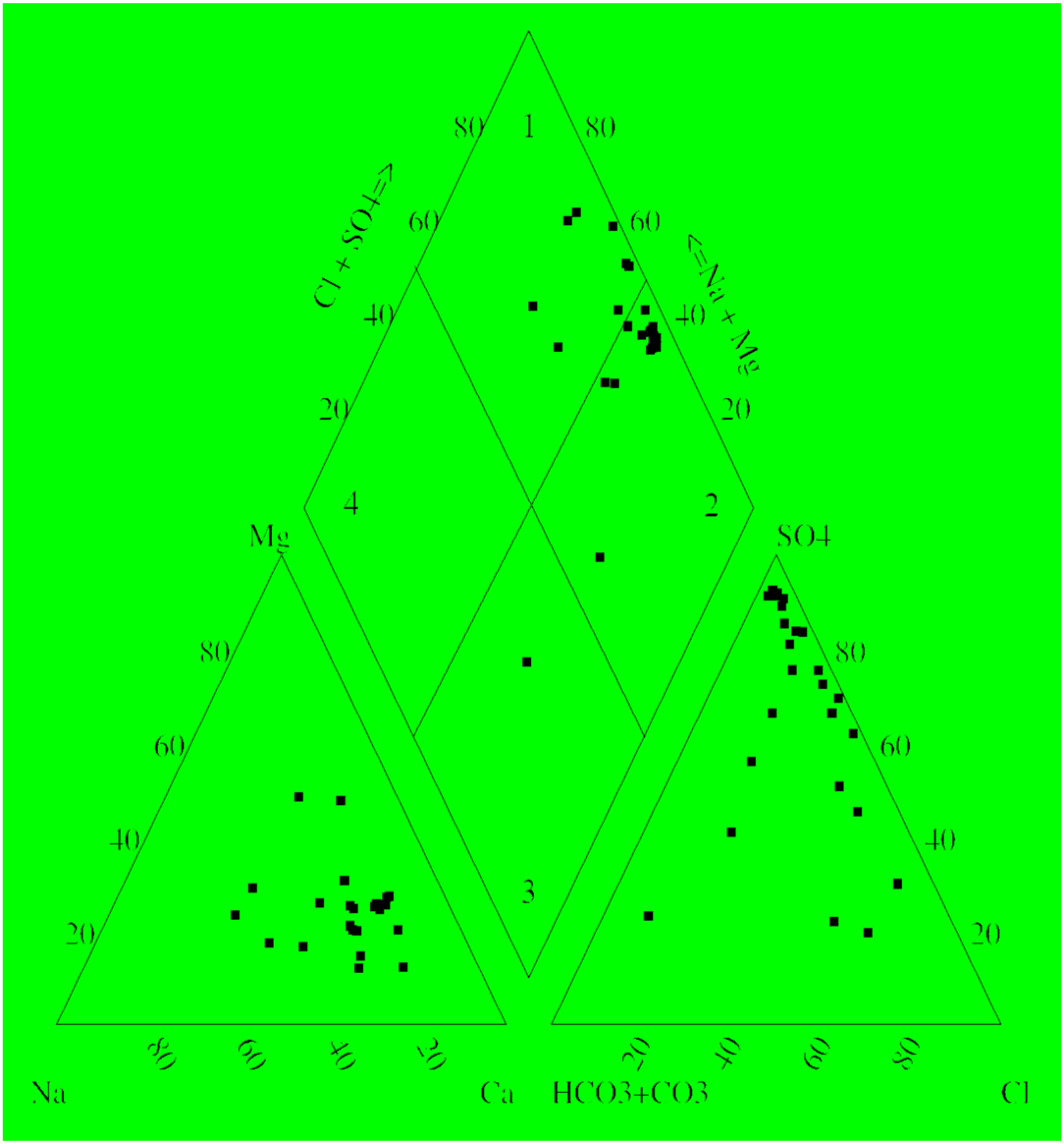

Figure-2: Piper trilinear diagram showing hydrochemical facies.

1-Na+Mg+Cl+SO_4Type; 2-Na+Cl+SO_4 Type; 3-Ca+Mg+Cl Type; 4-Na+Mg+HCO_3 Type.

Water quality index: To evaluate the water quality index data has been normalized according to WQI calculation. The obtain value of WQI of 25 sites categorized into three group like good, medium and bad category (Table-4). The value of WQI indicates that the about 56% of the samples fall under medium category whereas 24% of the sample (S9, S11, S17, S19, S21 and S22) fall under good category and 20% of the samples (S3, S4, S5, S13 and S18) belongs to bad category. No sample was found to be in the excellent category (±90%). The overall WQI result suggests that water of the study area is not suitable for drinking purpose without conventional treatment.

Table-4: Water quality status of Bastacola coalmine area.

site	WQI obtained value	Remarks	site	WQI obtained value	Remarks
S1	52.11	Medium	S14	52.94	Medium
S2	57.64	Medium	S15	55.29	Medium
S3	46.47	Bad	S16	56.47	Medium
S4	43.52	Bad	S17	71.17	Good
S5	54.7	Bad	S18	37.64	Bad
S6	61.76	Medium	S19	74.11	Good
S7	54.11	Medium	S20	55.29	Medium
S8	63.52	Medium	S21	71.17	Good
S9	70.58	Good	S22	71.17	Good
S10	59.41	Medium	S23	53.52	Medium
S11	71.17	Good	S24	57.64	Medium
S12	54.7	Medium	S25	59.41	Medium
S13	43.52	Bad			

Conclusion

The present study shows that water quality in the area is not good for drinking purpose without conventional treatment. While most of the samples are within permissible limit, five and seven samples were found to be high in nitrate and sulfate respectively. It can show adverse effect in human health. Fluoride and total dissolved solid (TDS) content were also found to be high in few samples. Though all the SAR values are within permissible range, few samples are outside the range in case of % Na and TDS making them unfit for irrigational use. WQI study categories the water sample into 6 good, 14 medium and 5 bad categories. Majority of the water samples belong to Na + Mg+ Cl + SO_4 and Na + Cl + SO_4 type which indicate the dominance of rock water interactions. It can be concluded that mining activity is primarily responsible for deterioration of water quality in the area, especially the increase in the SO_4^{2-} content. Agricultural activities may have increased the NO_3^- content in some locality. To mitigate the water pollution, mining activity should be properly managed and better drainage should be provided to overcome salinity problems.

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