Qualitative Assessment of Mine Water of the Western Jharia Coalfield Area, Jharkhand, India

ANJANI KUMAR* and PRASOON KUMAR SINGH

Department of Environmental Science and Engineering,
Indian School of Mines, Dhanbad-826004, Jharkhand, India.
*Corresponding author E-mail: njnkumar32@gmail.com

ABSTRACT

A geochemical study of mine water in the Western Jharia coalfield area was undertaken to assess its quality and suitability for drinking and domestic purposes. To assess mine water quality of the study area, a systematic sampling was carried out during the monsoon season, 2013. Eighteen representatives mine water sample were collected from both underground (underground sump and surface water discharge) and opencast mines, and analyzed for pH, electrical conductivity (EC), total dissolved solids (TDS), major cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) and major anions (HCO_3^-, F^-, Cl^-, NO_3^-, SO_4^{2-}). The pH of the analyzed mine waters ranged from 6.8 o 8.3 and electrical conductivity (EC) values ranged from 608 uS cm^{-1} to 1350 uS cm^{-1}. TDS ranged from 432 to 1080 mg L^{-1} and the spatial differences in TDS reflect the geological formations, hydrological processes and prevailing mining conditions of the region. The anion and cation chemistry indicate the general ionic abundance as: $HCO_3^- > SO_4^{2-} > Cl^- > NO_3^- > F^-$ and $Mg^{2+} > Ca^{2+} > Na^+ > K^+$ in the mine water of the study area. The water quality assessment indicated that total dissolved solids (TDS), total hardness (TH), magnesium and sulphate are the major parameters of concern in the study area and make it unsuitable for drinking and domestic purposes.

Key words: Jharia coalfield, Mine water chemistry, Underground water, water quality.

INTRODUCTION

Rapid urbanization and industrial development during last decade have provoked some serious concerns for the environment[1]. In the last few decades, due to rapid industrialization and increase in human population, there has been a tremendous pressure on the demand of fresh water[2,3]. Water quality plays an important role in promoting agricultural production and standard of human health. Water quality is much depending on the desired use of water, hence different uses require different criteria of water quality assessment as well as standard method for reporting and comparing result of water analysis[4,5]. Water quality analysis and statistical methods are very useful and efficient for assessing the quality of water and for communicating the information on overall quality of water[14-28].

Mining threatens the quality and quantity of surface and ground water resources in many parts of India[6-13]. Water pollution in mining areas is mainly due to overburden (OB) dumps, surface impoundments, mine water, industrial effluents, acid mine drainage, tailing ponds etc[2]. Mining's impacts on the natural water environment may be observed throughout the life cycle of a mine and even long after mine closure[29]. The large volumes of water can be released from aquifers during opencast and underground coal mining operations. Even a few weight percent of sulphide minerals in coal or mine waste has the potential to generate acidic conditions and create

significant environmental degradation [30]. The coal mining activity in India started decades back, since then the groundwater is getting affected. Along with coal mining, leachates generated from large number of industrial waste and overburden dumps that are in abundance around the mining areas, may reach the groundwater and may adversely affect its quality[8]. Several studies have reported that anthropogenic activities can adversely affect the water quality by introducing contaminants[31,32]. Coal has relatively high importance for the economical growth of a country. The Mining industry in India is a major economic activity which contributes significantly to the economy of country. The GDP contribution of the mining industry varies from 2.2% to 2.5% only, but going by the GDP of the total industrial sector it contributes around 10% to 11%[33]. Bharat Coking Coal Limited (BCCL), A Mini Ratna company (a subsidiary of Coal India Ltd.), Government of India undertaking, is the major coal mining company and only producer of prime coking coal in India. It operates in Jharia

Coal Field (JCF), one of the oldest and important coalfields of India where mining is continuing since more than 125 years[33]. The quality of mine water depends on a series of geological, hydrological and mining conditions, which vary significantly from mine to mine[29, 37]. The discharged mine water varies greatly in the concentration of contaminants and in some cases it may even meet the drinking water specifications[12]. Many times, the discharged mine water as such is not usable and may contain unacceptable levels of heavy metals, toxic anions, organic and biological contaminants[8,7]. A long history of unscientific exploitation of the Jharia coalfield has caused environmental problems, including water resource depletion and contamination[6,13,21,34-36]. In recent times, many researchers in India have shown keen interest in the key environmental parameters in the mining regions of the country[9,20, 53-61].

The mine water resources available in the study area may be harnessed for utilization in
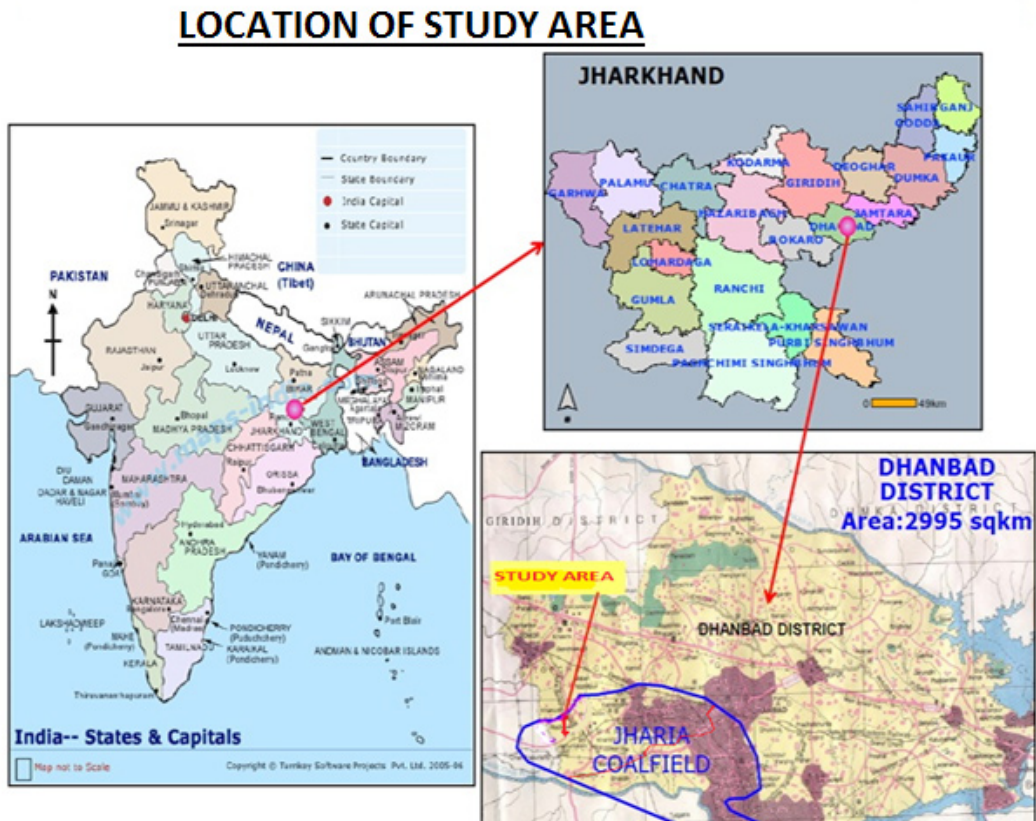

Fig. 1: Location map of study area

the irrigation, industrial and even in drinking water purposes after treatment. This will not only solve the problem of water scarcity of the area but also help in controlling the water pollution threat. In this background, it is observed that a proper study is required for the assessment/evaluation of this huge mine water, development of suitable techniques for ascertaining its suitability and utilization of the same for the society, thereby converting waste to wealth. Hence, the samples were collected from different mines of study area including Damoda underground, Phularitand 10 seam underground, Jogidih Adarsh colony, Kharkhari 16 seam, Shatabadi Open Cast Project (OCP), Muraidih OCP, Jamunia OCP etc. and the qualitative assessment was done to evaluate mine water quality relative to drinking and domestic uses.

Study Area

The study area lies in the Western part of the Jharia coalfield and is bounded within the latitude 23º42´ N and 23º49´ N and longitude 86º08´E and 86º19´E (Figure 1). The Jharia coalfield stretches from west to east in the shape of sickle. The Jharia coalfield (JCF) is India's largest and most extensively developed coalfield, and has been mined for more than a century. It is India's sole repository of much-needed coking coal. It is situated about 260 km northwest of Calcutta in the heart of the Damodar Valley, mainly along the north of this river. The coalfield lies within the district of Dhanbad and is in the northeastern margin. The coalfield is named after the chief mining centre Jharia that is situated in the eastern part of the field. The field is roughly sickle shaped its longer axis running northwest – southeast. The coal basin extends for about 8 km in an east west direction and a maximum of 18 km in north south direction. The climate of the place is typical monsoon type with maximum precipitation occurring in the month of June to September. During the summer months (April to June) the temperature goes as high as 48^0C. The minimum summer temperature is around 20^0C. The winters (November to February) are cold and temperature drops down to 6^0C. The highest percentage of wind blows in the West. The monsoon breaks in June and lasts till October. The average rainfall for the area is 1272 mm. The highest recorded rainfall is 1851 mm in 1997 and the lowest recorded rainfall is 744 mm in 2004[41].

Geology of Study Area

Geologically, the major feature is the great coal basin of this region with intervening areas of crystalline rocks. The ancient rock types of Dharwar and post Dharwars period form the basement rock over which the Lower-Gondwana group of sedimentary strata consisting of coal seams and patches of sandstone are formed[38]. The region is important for its large reserves of Lower-Gondwana coal distributed in these fields, the Jharia and Chandrapura coalfields and the Barakar series, which extends into the Raniganj coalfield in the West Bengal. The main axis of the Jharia coalfield basin runs West- North - West-East-South-East and is petering gently towards West and can be seen by the dips of the Raniganj strata along the Jamunia River. This line of axis is neither straight nor curved in simple manner, but it is corrugated due to the forces probably coming from east to west. The Jharia coalfield is formed of sedimentary deposit in Damodar River valley. The geological sequences consist of metamorphic rocks in the base and overlain by Talchir formation followed by Barakar Formation[39,40]. This Barakar Formation is the main coal bearing measure. In the places where there are high populations density mining is still done by underground methods. This occupies in the South-Central part of the coalfield where most of the mines are underground because of the thick layer of the Barren Measures and is the uppermost coal bearing sequence of the Jharia coalfield. This measure is located at the south west part of the coalfield. The detailed geology of the Jharia coalfield is shown in Figure 2.

MATERIALS AND METHODS

To assess mine water quality of the Western Jharia coalfield area, a systematic sampling was carried out during the monsoon season, 2013 for analysis. Eighteen representatives mine water samples were collected from different mines of the study area. Out of these, thirteen were from Underground coal mines and five were from OCP (Open Cast Project) coal mines (Table 1 and Figure. 3). The mine water samples were collected in 1 L narrow-mouthed pre-washed high-density polyethylene bottles. Water quality parameters such as pH, temperature, and electrical conductivity were measured immediately after the collection

of the samples by using Portable Multi Parameter Tester 35 Series. For other parameters such as major cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) and major anions (F^-, Cl^-, HCO_3^-, SO_4^{2-} and NO_3^-), samples were suitably preserved and sent to the laboratory, where detailed analysis was carried out as per the Standard Methods for the Examination of Water and Wastewater[42]. The details of sampling locations along with their latitude and longitude are illustrated in the Table 1 and Figure 3.

RESULTS AND DISCUSSION

Mine Water Chemistry

Hydro-chemical characteristic of mine water samples of study area and statistical summary of the analytical results of mine water were compared with the standard guideline values recommended by the World Health Organisation (WHO1997) and Bureau of Indian Standards (BIS 1991) for drinking and public health (Table 2 and Table 3). The pH ranged from 6.8 to 8.3 in the study area. The minimum pH values 6.8 were observed at Phularitand 10 seam underground and maximum values 8.3 observed at. Jogidih 5,6,7 Underground and Bhuringia colliery. The measured EC of the mine water in the study area varied from 608 to 1350 µS cm-1 with an average value of 1080 µS cm-1. The maximum values of electrical conductivity were observed high at Jamunia OCP of the Western Jharia coalfield. Concentration of

total dissolved solids (TDS) in the mine water of the study area ranged from 432 to 1080 mg l-1 with an average value of 838 mg l-1. The differences in TDS values may be attributed to the variation in geological formations, hydrological processes and prevailing mining conditions in the region (25). The differences in the TDS and EC values in the water samples collected from the underground mine sumps and pump water discharges in the case of underground mine were not very significant except at few sites. Bicarbonate (HCO_3^-) and sulphate (SO_4^{2-}) are the dominant anions in these mine waters, with minor contributions from chloride (Cl^-), nitrate (NO_3^-), and fluoride (F^-). The order of anions abundance in the mine water was found as $HCO_3^- > SO_4^{2-} > Cl^- > NO_3^- > F^-$. Concentration of HCO_3^- ranges from 187 mg L-1 to 571 mg L-1, the average HCO_3^- concentration was 336 mg L-1. HCO3 - is the most dominant anion at the locations of Hantudih, Bhurungia colliery and Lohapatti Colierry. Concentration of sulphate ranged from 21 to 498 mg L-1 with an average value of 253 mg L-1. The variation of sulphate concentration showed higher values for the mine water of Block-II OCP, Hantudih, Phularitand 10 seam UG, Jogidih 5,6,7 seam UG, Kharkhari UG, Mahesh pur 9 top, Titulia colliery, Lohapatti Colliery, Bhurungia Colliery locations. Sulphates in the water are usually derived from the oxidative weathering of sulphide-bearing minerals such as pyrite (FeS_2), gypsum ($CaSO_4 \cdot 2H_2O$) and anhydrite ($CaSO_4$). Jharia coals are

Barakar Formation
Talcher Formation
Barren Measure
Raniganj Formation
Metamorphics
Faults
Dykes

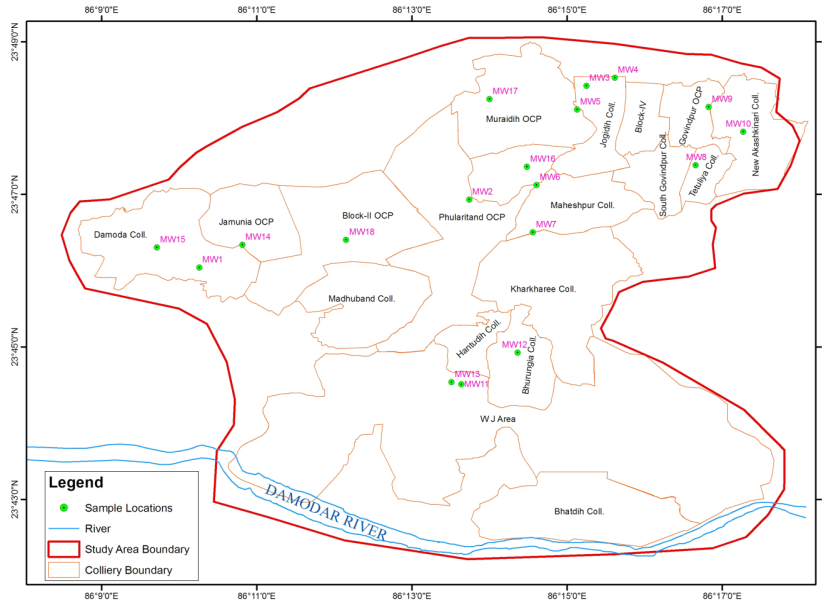**Fig. 2: Geology of the Jharia coalfield**

Fig. 3: Sampling locations map of the study area

Table 1: Details of sampling locations of the study area

Sampling Code	Locations	Latitude (Degree decimal)	Longitude (Degree decimal)
MW1	Damoda Underground	23.77	86.17
MW2	Phularitand 10 seam Underground	23.78	86.23
MW3	Block IV, 3 Seam Undergound	23.81	86.25
MW4	Jogidih (Adarsh Colony)	23.81	86.26
MW5	Jogidih 5,6,7 Undergorund	23.80	86.25
MW6	Maheshpur 9 top (VIII B)	23.79	86.24
MW7	Kharkhari 16 seam	23.78	86.24
MW8	Tituliya colliery (9 Bottom seam)	23.79	86.28
MW9	Aakash Kinari 1 Seam Underground	23.80	86.28
MW10	Chatabad 4 seam akash kinari	23.80	86.29
MW11	Lohapatti colliery, Pathargaria B seam	23.74	86.23
MW12	Bhurungia colliery	23.75	86.24
MW13	Hantudih	23.74	86.23
MW14	Jamunia OCP	23.77	86.18
MW15	Damoda OCP	23.77	86.16
MW16	Shatabdi OCP	23.79	86.24
MW17	Muraidih OCP	23.80	86.23
MW18	Block II OCP	23.77	86.20

Table 2: Hydro-chemical characteristic of mine water samples of study area

Sample code	Location name	pH	EC	TDS	F-	Cl-	HCO$_3$-	SO$_4$$^{2-}$	NO$_3$-	Ca^{2+}	Mg^{2+}	Na$^+$	K$^+$	TH
MW1	Damoda Underground	7.2	1201	926	0.74	41.5	363	234	31	93	123	29	5.6	738
MW2	Phularitand 10 seam underground	6.8	705	560	0.91	26.4	283	130	0.8	33.7	46.6	26.5	6.5	276
MW3	Block IV,3rd seam underground	8.2	990	775	1.17	23.5	195	364	2.4	92	46.5	40.1	4.5	421
MW4	Jogidih Adarsh Colony	8.0	920	711	0.75	51.7	241	242	5.2	63	65.2	31.3	6.3	384
MW5	Jogidih 5,6,7 Underground	8.3	918	725	0.78	46.1	256	254	2.1	66	52.3	38.4	6.1	380
MW6	Mahesh pur 9 Top	8.1	1230	975	0.8	25.2	355	342	1.6	87.9	115.6	35.2	6.4	695
MW7	Kharkari 16 seam	8.0	1133	861	0.41	35.4	371	252	2.3	60.4	90.3	41.3	6.2	522
MW8	Tituliya Colliery	8.2	1031	784	0.46	43.0	344	198	6.9	52.1	87.7	46.9	3.6	491
MW9	Akash Kinari 1 seam underground	7.8	1190	927	0.84	23.5	316	345	4.6	92	104.5	29.8	5.1	659
MW10	Chatabad 4 seam akash kinari	7.6	1250	937	0.65	33.8	187	498	2.78	133	62.3	15.2	3.5	589
MW11	Lohapatti Colliery	8.1	952	752	0.64	47.4	464	29	4.6	24.1	19.6	157.1	3.3	141
MW12	Bhuringia colliery	8.3	1167	898	0.78	31.1	571	38	8.3	26.3	16.9	196.9	4.1	135
MW13	Hantudih	8.2	1034	796	0.84	64.8	488	21	18.6	24.5	28.8	140.6	7.9	180
MW 14	Jamunia OCP	7.5	1350	1080	1.60	16.7	336	455	40.5	87.3	108.6	20.5	8.5	665
MW15	Damoda OCP	7.7	1320	1056	0.92	10.3	353	432	34.5	79.7	110.7	25.8	6.5	654
MW16	Shatabadi OCP	7.6	1163	872	2.21	35.8	348	245	24.8	91.8	95.8	21.2	5.6	623
MW17	Muraidih OCP	7.5	608	432	0.62	34.6	238	67	3.6	37.8	21.2	21.9	1.7	182
MW18	Bloc II OCP	7.6	1276	1021	0.91	15.2	335	416	30.6	82.4	117.3	15.3	4.3	688
	Minimum	6.8	608	432	0.41	10.3	187	21	0.8	24.1	16.9	15.2	1.7	135
	Maximum	8.3	1350	1080	2.21	64.8	571	498	40.5	133	123	196.9	8.5	738
	Average	7.8	1080	838	0.9	33.7	336	253	12.5	68.2	73	52	5.3	468

poor in sulphur; usually contain less than 1% sulphur. However, mineral pyrite (FeS_2) is reported to occur as a secondary mineral in these coals and associated sediments[40]. Sulphate causes odour and corrosion of sewers because it gets converted to hydrogen sulphide. It may also cause corrosion of metals in the distribution system, particularly in water with low alkalinity. Chloride concentration in the analysed samples ranged from 10.3 to 64.8 mg L^{-1} with an average value of 33.7 mg L^{-1}. Chloride is present in lower concentrations in common rock types than any other major constituents of natural water. It is assumed that bulk of the chloride in water is derived primarily from halite, sea spray, brines and hot springs. Abnormal concentration of chloride may result from anthropogenic sources including agricultural runoff, domestic and industrial wastes and leaching of saline residues in the soil. The large lateral variation in the Cl^- concentration and observed high values in some mine water samples indicate local recharge and may be attributed to the contamination by untreated industrial and mining waste effluents. Concentration of NO_3^- ranged from 0.8 to 40.5mg L^{-1} and average concentration value was 12.5 mg L^{-1}. The chief sources of the nitrate are biological fixation, atmospheric precipitation and the application of fertilizers and industrial sewage[44].

The use of explosive in the mining areas may also be one possible source of nitrate in the mine water. Concentration of fluoride in the samples ranged from 0.41 to 2.21 mg L^{-1} with an avg. 0.9 mg L^{-1}. In general, concentrations of F^- were found to be low as compared with the other anions. Higher F^- values in these samples may be due to the weathering of fluoride bearing minerals such as biotite, muscovite, fluorite and apatite, which occur as accessory minerals in the granites, granite-gneisses and intrusive rocks of the area. Higher concentration of fluoride causes dental and skeletal fluorosis such as mottling of teeth, deformation of ligaments and bending of spinal chord[15]. Except for a few samples, concentrations of F^- did not exceed the prescribed limit.

Among major cations, magnesium was the dominant ions representing on average 37% of total cations. Calcium and sodium ions were of secondary importance, representing on average 34% and 26% of total cations, respectively. Potassium was least dominant cation and representing 3% of the total cations (Fig. 3b). The order of cation abundance in the mine water was $Mg^{2+}>Ca^{2+}>Na^+>K^+$. Concentration of Ca^{2+} in the samples varied from minimum value of 24.1 mg L^{-1} to maximum value of 133 mg L^{-1}

Table 3: Statistical summary of measured parameters in the mine water, compared to prescribed limits of WHO 1997 and Indian standards BIS 1991 for drinking water

| Parameters | Minimum | Maximum | Average | WHO (1997) | | BIS(1991) | |
				Maximum desirable	Highest permissible	Maximum desirable	Highest permissible
pH	6.8	8.3	7.8	7.0-8.5	6.5-9.2	6.5-8.5	8.5-9.2
EC	608	1350	1080	750	1,500	_	_
TDS	432	1080	838	500	1,500	500	2,000
F^-	0.41	2.21	0.9	0.6-0.9	1.5	1	1.5
Cl^-	10.3	64.8	33.7	250	600	250	1,000
HCO_3^-	187	571	336	200	600	200	600
SO_4^{2-}	21	498	253	200	600	200	400
NO_3^-	0.8	40.5	12.5	_	50	45	100
Ca^{2+}	24.1	133	68.2	75	200	75	200
Mg^{2+}	16.9	123	73	30	150	30	100
Na^+	15.2	196.9	52	50	200	_	_
K^+	1.7	8.5	5.3	100	200	_	_
TH	135	738	468	100	500	300	600

All concentration in mg L^{-1}, except pH and EC (μS cm^{-1})

with an average of 68.2 mg L^{-1}. The higher values were found in the Block IV 3rd seam underground, Phularitand 10 seam underground, Maheshpur 9 top, and Chatabad 4 seam. Concentration of Mg^{2+} in the samples varied from16.9 to 123 mg L^{-1} with an average value of 73 mg L^{-1}. Concentration of Ca^{2+} and Mg^{2+} are exceeding the desirable limits of 75 mg L^{-1} and 30 mg L^{-1} in 50 % and 78 % of the mine water samples respectively. The presence of calcium and magnesium make the water hard (4). Na $^{+}$and K^{+} in the aquatic system are mainly derived from the atmospheric deposition; evaporate dissolution and silicate weathering[45]. Weathering silicates such as albite, anorthite and orthoclase are the possible source minerals for the Na $^{+}$ and K $^{+}$ in the present study area (46,47). The evaporate encrustations of Na^{+}/K^{+} salts developed due to cyclic wetting and drying periods of Damodar River cause the formation of alkaline/saline soils, which may also serve as a source of Na^{+} and K^{+} (48). Total hardness (TH) is the property attributed to the presence of alkaline earths in solution. On the basis of hardness, water can be classified as soft (<75 mg L^{-1}), moderately hard (75–150 mg L^{-1}), hard (150–300 mg L^{-1}) and very hard (>300 mg L^{-1}) water (Sawyer and McCarty 1967[49]. The hardness of the analysed samples varied from 135 to 738 mg L^{-1} (avg. 468 mg L^{-1}), indicating moderately hard to very hard types of water in the study area. The data indicate that 33 % of the mine water samples have TH values higher than desirable limit of 300 mg L^{-1}, and 40% samples exceed the maximum permissible limit of 600 mg L^{-1}[43]. Hardness has no known adverse effect on health, but it can prevent the formation of lather with soap and increases the boiling point of the water. The high TH may cause precipitation of calcium carbonate and encrustation on water supply distribution systems. Long-term consumption of extremely hard water might lead to an increased incidence of urolithiasis, anencephaly, parental mortality, some types of cancer and cardio-vascular disorders[50,51].

CONCLUSION

The mine water of the study area is mildly acidic to alkaline in nature. The chemistry of mine water is dominated by Mg^{2+} and Ca^{2+} and HCO$_3^-$ and SO$_4^{2-}$. In majority of the samples, the analyzed parameters are well within the desirable limits. However, higher concentration of EC, TDS, SO$_4^{2-}$ and TH in a number of mine water samples as such make it unsafe for drinking uses. Our results suggest that the chemical composition of the mine water of the study area is largely controlled by rock weathering with minor contributions from mining sources. The presence of water at mining sites creates a range of operational and stability problems and requires an effective water management strategy for drinking purpose after treatment and disinfection.

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