Chapter 13
Performance of WQI and HPI for Groundwater Quality Assessment: Study from Sangramgarh Colliery of West Burdwan District, West Bengal, India

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Abstract This chapter attempts to study the groundwater quality of abandoned Sangramgarh colliery area using the weighted arithmetic water quality index method and heavy metal pollution index method. The present study also draws attention toward the seasonal changes of some water parameters and groundwater level of the study area. Scarcity of clean and potable drinking water is one of the most serious issues in this study area. The result of hydrochemical analysis shows the water quality rating as per weighted arithmetic water quality index method is 59.58, which indicates poor water quality of the groundwater, and it also shows near-neutral to alkaline conditions of the groundwater in abandoned Sangramgarh colliery area. Land filling materials, huge overburden dumps, mine waste and heavy metal leaching during the rainy season contaminate the groundwater and deteriorate drinking water quality, which is a serious human health issue. Therefore, a periodic assessment of groundwater quality is necessary in order to ascertain the quality for human consumption purpose and to take better planning for sustainable management of groundwater.

Keywords Abandoned colliery · AMD · HPI · WQI

13.1 Introduction

Water is an essential commodity to living things and nonliving things, and it is important in all aspects of human life (Tiwary and Dhar 1994; WHO 1984, 1997). Chemically, the combination of oxygen and hydrogen forms water. As water penetrates through the ground surface to the subsurface as groundwater, impurities get into it. Access to safe drinking water remains an urgent necessity, as 30% of urban and 90% of the rural Indian population still depend completely on untreated

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surface or groundwater resources. Scarcity of clean and potable drinking water has emerged in recent years as one of the most serious developmental issues in many parts of West Bengal, Jharkhand, Orissa, Western Uttar Pradesh, Andhra Pradesh, Rajasthan and Punjab (Tiwari and Singh 2014). The rate of depletion of groundwater level and deterioration of groundwater quality is of immediate concern in major cities and towns of country (Tiwary and Abhishek 2004, 2005; Ramakrishnaiah et al. 2009; Singh et al. 2011, 2013, 2014a; Tiwari and Singh 2014).

Mining is a major anthropogenic activity causing water pollution and environmental degradation (Abhishek and Sinha 2006). In abandoned coal mines, acid mine drainage (AMD) results from the oxidation of iron sulphide minerals which are associated with coal deposits. Huge overburden dumps or mine waste, resulting from the excavation process in open cast and underground mining operations, could also contain sulphide minerals (Bernd 2007). These materials are normally dumped on the surface, and water infiltrating through these materials can enhance the generation of AMD. But, AMD creation did not happen in all abandoned mines. The effect of this depends on the nature of the rocks. If coal seams have iron pyrites, sulphate and soluble metal ions are exposed to air and due to oxidation of the sulphide minerals form sulphuric acid which is called AMD. If they contain calcite or other carbonate minerals, the acidic mine water can be neutralized, and metals may stay immobile. In many abandoned mines, groundwater in hard-rock aquifers becomes vulnerable that may have a serious impact on human health. Besides, mining activities also released both major and trace elements into the environment. Trace elements or the heavy metals are classified among the most dangerous groups of pollutants due to their toxicity and persistence in the environment. Metals in the contaminated soils and water may reach the human body through agricultural products (Sponza and Karaoğlu 2002). Leaching of these heavy metals from the mine spoils during the rainy season contaminates the groundwater and deteriorates drinking water quality, which are serious human health issues. Groundwater contamination is one of the most important environmental problems in the present world where metal contamination is a major concern due to its high toxicity even at low concentration (Marcovecchio et al. 2007; Momudu and Anyakora 2010). According to the WHO, about 80% of all diseases in human beings are caused by water (Ramakrishnaiah et al. 2009).Therefore a periodic assessment of groundwater quality is necessary in order to ascertain the quality for human consumption purpose and to take better planning for sustainable management of groundwater.

The major objectives of the current study are (1) to measure the water quality of study area, (2) to assess the heavy metal contamination and (3) to reveal the seasonal fluctuation of some important water parameter and groundwater level.

13.2 Study Area

Sangramgarh colliery is located in the north-central part of Raniganj Coalfield and falls under Salanpur Area of Eastern Coalfields and West Burdwan district of West Bengal (Fig. 13.1). The colliery is to the north of GT Road and around 15 km from Asansol City. The latitudinal and longitudinal extensions of the mine are 23°47′N–23°48′N and 86°54′E–86°57′E. A total of 261 ha area is under leasehold of ECL. The leasehold area of the property being worked by underground is about 150 ha.

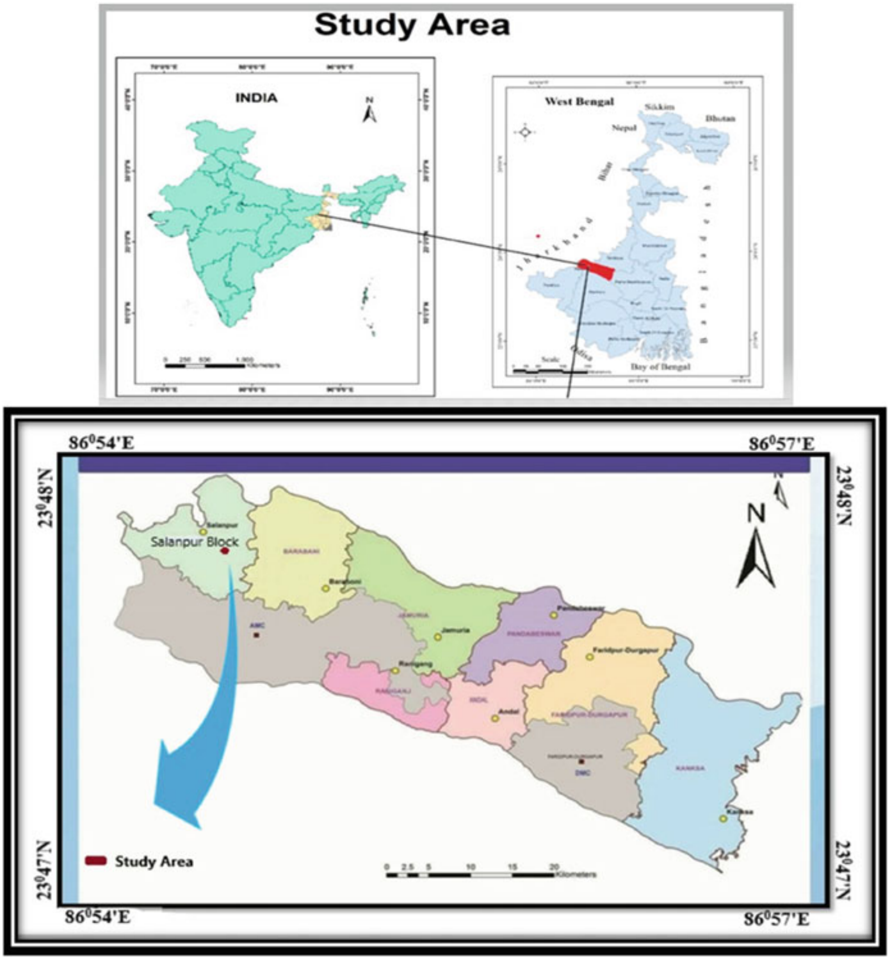

Fig. 13.1 Location map of the study area

13.3 Materials and Methods

13.3.1 Selection of Parameters

Firstly, study the Indian standard (BIS 2003) for drinking water specification. Here, the physicochemical parameters along with the desirable limits and related health effects are given. A parameter has to be selected based on its impact in the overall quality of water and health effects. 24 parameters like pH, BOD, COD, total dissolved solids (TDS), arsenic, lead (Pb), turbidity, iron, chlorides, Res free chlorine, calcium, copper, manganese, sulphate, nitrate, fluoride, selenium, zinc, chromium, boron, phenolics, alkalinity and total hardness have been selected.

13.3.2 Sample Collection and Analysis

Water samples are collected from CMPDI (Central Mine Planning and Design Institute) report, 2015–2016. Water quality of study area was evaluated by water quality index (WQI) technique. WQI indicates the quality of water in terms of index number which represents the overall quality of water for any intended use. A water quality index provides a single number that expresses overall water quality at a certain location and time based on several water quality parameters. In order to calculate WQI, 24 parameters have been selected. Water quality index was calculated for assessing the suitability of water for biotic communities and also drinking purposes.

13.3.3 Calculation of Water Quality Index (WQI)

The WQI has been applied for evaluating the water quality of study area. The WQI result represents the level of water quality in a given water basin such as lake, river or stream. WQI indicates the quality of water in terms of index number which represents the overall quality of water for any intended use. The indices are among the most effective ways to communicate the information on water quality trends to the general public or to the policy makers and in water quality management. Mostly it is done from the point of view of its suitability for human consumption.

Weighted Arithmetic Water Quality Index Method

In this paper the WQI was calculated using the weighted arithmetic water quality index (WAWQI) method which was proposed by Horton (1965), developed by Brown et al. (1970) and then by Cude (2001) in which water parameters are multiplied by a weighting factor and are then aggregated using a simple arithmetic mean by the following three equations.

Table 13.1 Water quality rating as per different water quality index methods

National Sanitation Foundation Water Quality Index (NSFWQI)	
91–100	Excellent water quality
71–91	Good water quality
51–71	Medium water quality
26–50	Bad water quality
0–25	Very bad water quality
Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI)	
95–100	Excellent water quality
80–94	Good water quality
60–79	Medium water quality
45–59	Bad water quality
0–44	Very bad water quality
Oregon Water Quality Index (OWQI)	
90–100	Excellent water quality
85–89	Good water quality
80–84	Fair water quality
60–79	Marginal water quality
0–59	Poor water quality

1. Relative Weight

For water quality index calculation, assigning a weight for each groundwater parameter (*wi*) for computing the relative weight (*Wi*) is needed. The assigned *wi* values for each parameter are shown in Table 13.1. Weighted values are assigned according to relative importance in the overall quality of water for drinking purposes (weight may be from 1 to 5). The highest weight of 5 was assigned to parameters which have the major effects on water quality. TDS and nitrate are assigned the highest weight because of their importance in the water quality assessment (Ramakrishnaiah et al. 2009). Chloride is given the minimum weight of 1 as it plays an insignificant role in the water quality assessment. The relative weight (*Wi*) of the chemical parameter is computed using the following equation:

$$\boldsymbol{Wi} = \boldsymbol{wi} / \sum \boldsymbol{wi} \ (\boldsymbol{i} = 1 \text{ to } \boldsymbol{n}) \tag{1}$$

where *Wi* is the relative weight, *wi* is the weight of each parameter and ‘n’ is the number of parameters.

Relative weight (*Wi*) of each parameter is calculated as a value inversely proportional to the Bureau of Indian Standards’ drinking water specifications. Factors which have higher permissible limits are less harmful because they can harm the quality of water when they are present in very high quantity.

2. Rating Scale

Rating scale (Table 13.1) was prepared for a range of values of each parameter. The quality rating scale (*Qi*) for each parameter is calculated by using this expression:

Table 13.2 Water quality rating as per weight arithmetic water

WQI value	Rating of water quality	Grading
0–25	Excellent water quality	A
26–50	Good water quality	B
51–75	Poor water quality	C
76–100	Very poor water quality	D
Above 100	Unsuitable for drinking purpose	E

Table 13.3 HPI value classes

HPI value	Class of pollution intensity
<15	Low
15–30	Medium
>30	High

$$\boldsymbol{Qi} = 100 \times [(\boldsymbol{Vi} - \boldsymbol{Vo})/(\boldsymbol{Si} - \boldsymbol{Vo})] \tag{2}$$

where

Qi is the quality rating scale.
Vi is the estimated concentration of ith parameter in the analysed water or observed value.
Vo is the ideal value of this parameter in pure water, *Vo* = 0 (the ideal value for pH = 7, dissolved oxygen = 14.6 mg/l, and for other parameters, it is equal to zero.
Si is the recommended standard value of ith parameter or the guideline value/desirable limit as given in Indian drinking water standard (BIS 2003).

3. Water Quality Index (WQI)

WQI is a compilation of a number of parameters that can be used to determine the overall quality of water. The numerical value is multiplied by a weighting factor that is relative to the significance of the test to water quality. The values of *Qi*, *Wi* and *QiWi* are given in Tables 13.2 and 13.3. Hence by multiplying *Wi* and *QiWi*, we can get the value of WQI. It is basically a mathematical means of calculating a single value from multiple test results:

$$\text{WQI} = \sum \boldsymbol{QiWi} / \sum \boldsymbol{Wi} \tag{3}$$

Based on the calculated WQI, the category of water quality types is shown in Table 13.2 according to Tyagi et al. (2013).

13.3.4 Calculation of Heavy Metal Pollution Index (HPI)

A heavy metal is any metallic element that has a relatively high density and is toxic or poisonous even at low concentrations. Heavy metals exist as natural constituents of the earth crust and are persistent environmental contaminants, because these cannot be degraded or destroyed. Human exposure to harmful heavy metals can occur in many ways. Consumption of contaminated water is one of them. Water quality and its suitability for drinking purpose can be examined by determining its quality index (Mohan et al. 1996; Prasad and Sangita 2008; Prasad and Mondal 2008; Tiwari et al. 2013) by heavy metal pollution index methods. The HPI represents the total quality of water with respect to heavy metals. The HPI is also based on weighted arithmetic quality mean method. The HPI model proposed is given by Mohan et al. (1996):

$$\mathbf{HPI} = \sum\nolimits^{n}_{i=1} WiQi / \sum\nolimits^{n}_{i=1} Wi \quad (1)$$

$$Qi = 100 \times [\{M_i(-)I_i\}/\{S_i(-)I_i\}] \quad (2)$$

where M_i is the monitored or observed value of heavy metal of the ith parameter

I_i is the ideal value (maximum desirable value for drinking water)
$S_{i\ is}$ the standard value (maximum permissive value for drinking water)

The (−) indicates the numerical difference of the two values, ignoring the algebraic sign. A modified scale is used in the present study after Edet and Offiong (2002). The scale is in the following table (Table 13.3).

13.4 Results and Discussion

13.4.1 Water Quality Index (WQI)

Finally, overall WQI was calculated according to the following expression:

$$\text{WQI} = \sum QiWi / \sum Wi$$

Water quality rating as per weighted arithmetic water quality index method is 59.58 which indicates a poor water quality in the study area.

The important water quality parameters and the water quality index are given in Table 13.4. pH is an important parameter which determines the suitability of water for various purposes having a desirable limit of 6.5–8.5 as specified by IS 10500. The pH of water is a measure of the acid-base equilibrium, and mostly natural water is controlled by the CO_2-bicarbonate-carbonate equilibrium system. An increased CO_2 concentration will therefore lower pH, whereas a decrease will cause it to rise. Acid deposition has many harmful ecological effects. But in the abandoned Sangramgarh colliery area, the result of hydrochemical analysis shows the annual mean pH value is 7.65 which indicates neutralization of the groundwater.

Table 13.4 Calculation of water quality index as per weighted arithmetic water quality index method

No.	Parameter	Unit	Standard value (Si)	Ideal value (*Vo*)	Observed values (*Vi*)	Weight (w_i)	Relative Weight (W_i)	Quality Rating (Qi)	Sub Index (SI) *Wi* x *Qi*
1	BOD	mg/L	5	0	3	4	0.054	60	3.24
2	COD	mg/L	10	0	24.3	4	0.054	243	13.12
4	TDS	mg/L	500	0	689	5	0.068	137.8	9.37
5	pH	pH units	7.5	7	7.53	4	0.054	106	5.72
6	Arsenic	mg/L	0.05	0	0.005	5	0.068	10	0.68
7	Lead (Pb)	mg/L	0.05	0	0.005	5	0.068	10	0.68
8	Turbidity	NTU	5	0	4.0	4	0.054	80	4.32
9	Iron	mg/L	0.30	0	0.06	4	0.054	20	1.08
10	Chlorides	mg/L	250	0	91	1	0.014	36.4	0.510
11	Res free chlorine	mg/L	0.20	0	0.02	2	0.027	10	0.27
12	Calcium	mg/L	75	0	49.6	2	0.027	66.1	1.78
13	Copper	mg/L	0.05	0	0.03	3	0.041	60	2.46
14	Manganese	mg/L	0.1	0	0.02	3	0.041	20	0.82
15	Sulphate	mg/L	200	0	62	4	0.054	31	1.67
16	Nitrate	mg/L	45	0	3.99	5	0.068	8.87	0.603
17	Fluoride	mg/L	1.0	0	0.62	3	0.041	62	2.54
18	Selenium	mg/L	0.01	0	0.005	2	0.027	50	1.35
19	Zinc	mg/L	5.0	0	0.02	3	0.041	0.4	0.016
20	Chromium	mg/L	0.05	0	0.01	3	0.041	20	0.82
21	Boron	mg/L	1.0	0	0.01	1	0.014	1	0.014
22	Phenolics	mg/L	0.001	0	0.001	1	0.014	100	1.4
23	Alkalinity	mg/L	200	0	208	4	0.054	104	5.62
24	Total hardness	mg/L	300	0	196	3	0.041	65.3	2.68
						$\sum wi = 74$	$\sum Wi = 1.019$	$\sum Qi = 1300.6$	$\sum Wi$ x $Qi = 60.713$

Data source: CMPDI (Central Mining Planning and Design Institute) records, 2015–2016

Alkalinity is a measure of the ability of the water to neutralize acids. The predominant chemicals present in natural water are carbonates, bicarbonates and hydroxides. Alkaline content in water is 208 mg/L which exceeded the desirable limit (200 mg/L). This value indicates non-acidic water of the study area. Alkalinity is not considered detrimental to humans, but high alkalinity water may have a distinctly flat and unpleasant taste.

The effect of this depends on the nature of the rocks. If coal seams have iron pyrites, sulphate and soluble metal ions are exposed to air and due to oxidation of the sulphide minerals form sulphuric acid which is called AMD. If they contain calcite or other carbonate minerals, the acidic mine water can be neutralized and metals may stay immobile. Commonly, however, the water dissolves any metal compounds present resulting in high concentrations of metals, particularly iron, zinc, copper, lead, cadmium, manganese and aluminium. The quality of mine waters varies considerably; they may be alkaline, acidic, ferruginous and highly saline or clean (Abandoned mines and the water environment Science project SC030136-41). However, carbonate minerals are not common in the study area. The anthropogenic sources may be the main sources of it. These sources can be related to the materials used in sealing of the coal mines, overburden dump consisting mainly of mining waste and lesser content of ash, garbage, slag, sludge, construction waste and industrial residue household waste (GLA-NRW, 1988). These materials often have a low amount of calcite. Dissolution of these carbonates reduces the oxidation of sulphide and changes the mine water from acidic to neutral conditions. In non-acidic mines, water quality shows high hardness, TSS, TDS bacterial contaminants and some heavy metals. These features are shown in the study area.

High *TSS* (*total suspended solids*) indicates mud, fine sand and microorganisms or decaying plants and animals. High TSS parameter indicates high level of pollution of water. The TSS value is 34 in summer season which exceeded the permissible limit of 25 mg/L, and annual mean value is 17 mg/L.

TDS (*total dissolved solids*) are the terms used to describe the inorganic salts and small amounts of organic matter present in water. If the TDS value is 500 mg/L, the water is considered as disagreeable (Indian standard IS 10500, 2012 by BIS). In the study area, the annual mean of TDS is 689 mg/L which exceeded the desirable limit. In this respect this water is not very suitable for drinking purposes. But due to lack of water resources, people of the study area have to drink this type of water.

COD (*chemical oxygen demand*) test is helpful in indicating toxic condition and presence of biologically resistant organic substances. In the present study, the annual mean of COD value is 24.3 mg/L which exceeded the standard value of 10 mg/L.

Turbidity is the degree of clarity to which the water loses its transparency due to presence of suspended particulates such as sediment and other contaminants. Turbidity is an indication of the presence of suspended inorganic matter. Turbidity nature of the study area's groundwater is 4.0 NTU which is below the permissible limit of 5–10 NTU. Higher turbidity results in increased BOD.

The BOD (*biochemical oxygen demand*) test is required to measure the amount of oxygen required by an organic matter for their decomposition. It gives a measure of the amount of organic matter in the water sample and their strength. It helps in assessing the pollution levels of the water sample. BOD >5 mg/L signifies the water is impure. In the study area, BOD value is found to be 3 mg/L which is less than the permissible limit.

Total hardness of water is a measure of the ability of water to cause precipitation of insoluble calcium and magnesium salts of higher fatty acids from soap solutions. The principal hardness-causing cations are calcium, magnesium bicarbonate, carbonate, chloride and sulphates. The hardness values of the present study were found to be 196 mg/L, whereas the permissible limit is 300 mg/L. The value of carbonate, chloride and sulphate of the present study is found within permissible limit, i.e. 49.6 mg/L (IS: 75 mg/L), 91 mg/L (IS: 250 mg/L) and 62 mg/L (IS: 200 mg/L).

13.4.2 Heavy Metal Pollution Index (HPI)

HPI is a very useful tool in evaluating the overall pollution of water bodies with respect to heavy metals (Prasad and Sangita 2008). Considering the classes of HPI, the study area falls under the low class (HPI < 15) 7.24. The present study reveals that groundwater sample is found less polluted with respect to heavy metal contamination (Table 13.5). The concentration of all heavy metals is within the desirable limit except for Mn content. Therefore this indicates the groundwater is not critically polluted with respect to heavy metal in Sangramgarh colliery area.

Table 13.5 Heavy metal pollution calculation for groundwater

Sl. No.	Heavy metals	Monitored value (*Mi*)	Ideal value	Highest permissible value	*wi*	*Qi*	*Wi* × *Qi*
1	Chromium	0.04	0.05	0.05	20	1	20
2	Copper	0.03	0.05	1.5	0.67	1.38	0.93
3	Zinc	0.06	5.0	15.0	0.067	49.4	3.31
4	Manganese	0.20	0.1	0.3	3.33	50	166.5
5	Iron	0.12	0.30	1.00	1.0	25.7	25.7
6	Arsenic	0.005	0.05	0.05	20	4.5	90
7	Lead	0.005	0.05	0.05	20	4.5	90
8	Nickel	0.10	3.0	6.0	0.17	96.67	16.4
9	Cadmium	0.001	0.003	0.005	20	100	2000
						∑333.15	∑2412.84

Data source: CMPDI (Central Mining Planning and Design Institute) records, 2015–2016

13.4.3 Seasonal Fluctuation of Water Parameters

The pH values of groundwater sample ranged from 6.79 in summer to 8.18 in pre-winter with an annual mean value for all periods of 7.65. TDS showed highest range of 865.5 mg/L in spring and lowest range of 475 mg/L in winter with an annual mean value of 689 mg/L, whereas TSS value is shown a high range of 34 mg/L in summer and low range of 6 mg/L in autumn with annual mean value of 17 mg/L. All studied parameters showed significant temporal differences of water quality (Table 13.6). The seasonal change in water quality is mostly influenced by trophicity, organic pollution, oxide-related process, erosion as well as anthropogenic activities (Fig. 13.2).

13.4.4 Groundwater Level

The groundwater level is a key parameter for evaluating spatial and temporal changes in groundwater environments. In Fig. 13.3, it is clearly shown that precipitation and evaporation affected the groundwater level in the study area. There is a positive correlation with precipitation and negative correlation with the evaporation of the groundwater level. During dry season, on January, November and May, a downward trend of the groundwater level is shown, whereas during wet season, on August, the groundwater level is increased gradually as most of rainfall falls in July–August month. Climate change, as reflected in precipitation and evaporation rates, influences the groundwater level fluctuation.

13.5 Conclusion

It is concluded that WQI can be used as a tool to assess the water quality of any area. Water quality index (WQI) is valuable and unique rating to depict the overall water quality status in a single term that is helpful for the selection of appropriate treatment technique to meet the concerned issues. HPI is also a very useful tool in evaluating the overall pollution of water bodies with respect to heavy metals. These all values give the public a general idea of the possible problems with water in a particular region and communicate the information on water quality trends to the policy makers and water quality management.

With the help of Weighted Water Quality Index Method, it is shown that WQI is 59.58 which indicates a poor water quality as per weighted arithmetic water quality index method, whereas HPI value is low ($HPI < 15$) (7.24) which indicates the groundwater is not critically polluted with respect to heavy metals in the study area. The groundwater quality in this mining area is significantly affected by abandoned Sangramgarh coal mines. Leaching of materials from overburden dumps, land

Table 13.6 Season-wise simple statistical analysis of some important water parameters

Water parameter	Seasons																		Standard Value	Annual Mean value
	Summer			Rainy			Autumn			Pre-winter			Winter			Spring				
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean		
pH	6.79	7.58	7.19	7.68	7.94	7.81	7.94	7.98	7.96	7.88	8.18	8.03	7.87	7.88	7.88	6.99	7.10	7.05	7.5	7.65
TSS	25	34	29.5	25	26	25.5	6	25	15.5	8	13	10.5	6	10	8	8	14	11	25 mg/l	17
TDS	798	823	810.5	812	825	818.5	518	810	664	484	506	495	475	486	480.5	861	870	865.5	500 mg/l	689
COD	20	24	22	16	32	24	16	32	24	12	28	20	24	32	28	24	32	28	10 mg/l	24.3

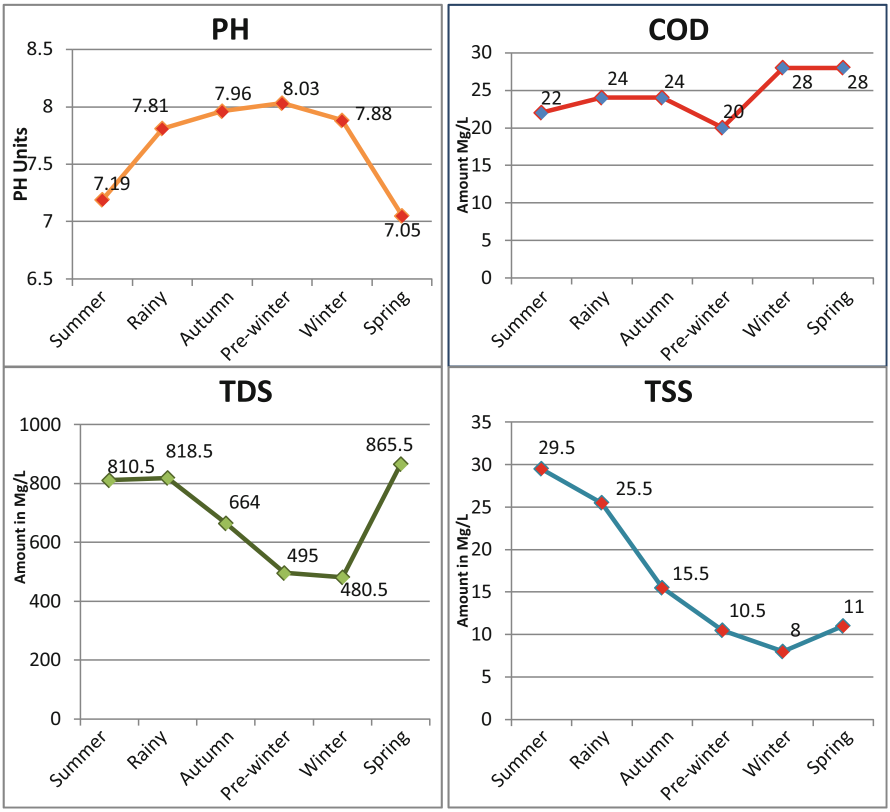

Fig. 13.2 Seasonal fluctuation of water parameters

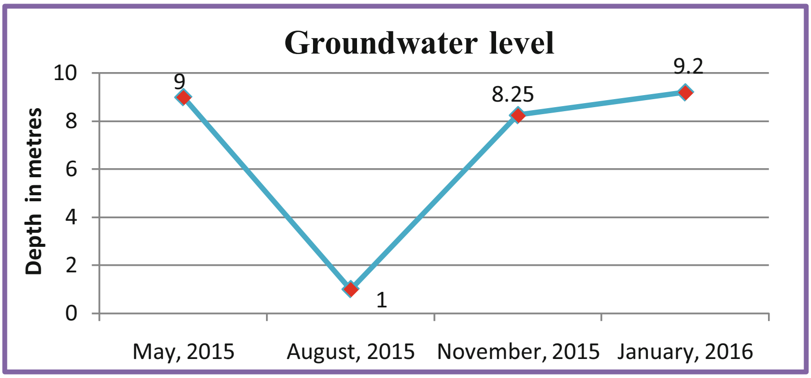

Fig. 13.3 Groundwater level of the study area in dry and wet seasons

filling, mine waste and heavy metals is mainly responsible for deteriorating the groundwater quality. The groundwater of this colliery area is also characterized by near-neutral to alkaline conditions, represented by predominance of calcium bicarbonate and sometimes calcium sulphate water types. Besides, groundwater scarcity is also the main problem here. So, quality and quantity both become a serious issue in this area which will be environmental threats unless all necessary measures are taken to reduce the impact:

- It is recommended to have further studies on the study area in order to shed more light on this area.
- Some parameters are required to add to cover as possible as the current status of the mining area.
- Create a strategic plan to aware the local people about pollution and how it can be prevented and save our environment from this important issue.
- Launch an environmental programme starting from primary school to the decision maker in the prevention and mitigation of water pollution.

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