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Original Research Paper

Assessment of Water Quality Around Surface Coal Mine in India

V. Shinde, S. B. Nandgude and M. Singh
Agricultural and Food Engineering Department, IIT, Kharagpur-721 302, W.B. India

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ABSTRACT

The present study highlights techniques to identify suitability of water for different purposes such as domestic, irrigation and industrial uses. Water samples from Olidih watershed in Jharia coalfield were collected in pre-monsoon (PRM) and post-monsoon (POM) seasons and analysed for different physico-chemical properties. Water Quality Index (WQI), Sodium Adsorption Ratio (SAR), percent sodium (%Na) and total hardness (TH) were determined on the basis of various physico-chemical parameters in order to ascertain the suitability of water for domestic, irrigation and industrial uses. The WQI for the study area found to vary from 23.86 to 166.72 in PRM season and from 22.14 to 146.44 in POM season. In 16.3% and 11.4% of watershed area, water is found unfit for drinking during PRM and POM seasons respectively. The calculated values of SAR and %Na indicate 'excellent to permissible use' of water for irrigation uses during both the seasons. High salinity, %Na and Mg-hazard values at some sites limit use for irrigation purposes. Box plots were plotted to represent seasonal concentration of the major ions which shows increasing trend of Ca, Na, NO_3 and SO_4 during POM.

INTRODUCTION

The definition of water quality, to a great extent, is depending on the desired use of water. Different uses require different criteria of water quality as well as standard methods for reporting and comparing results of water analysis (Babiker 2007, Khodapanah 2009). In India, only 12% of people get quality drinking water (Kudesia 1980). The surface water bodies, which are the most important source of water for human activities are unfortunately under severe environmental stress and are being threatened as a consequence of developmental activities. For environmental impact assessment and monitoring of mining activities, multispectral satellite data and aerial photographic data have been used (Jhanwar 1996, Rathore & Wright 1993), and the method has proved to be quite effective in monitoring environmental pollution related to heavy metals (Stefouli & Tsombos 1998). Mining threatens the quality and quantity of surface water resources in many part of the world (Allen et al. 1996, Choubey 1991, Gupta 1999, Khan et al. 2005, Singh 1998, Tiwary 2001). Being the primary source of energy, coal has become essential to meet the energy demand of a country. There is no proper water management plan at most of the mines in India. Water from coal treatment plants is often discharged without any treatment or beneficial use. There, it may pollute the natural surface drainage and other water resources (Singh et al. 2007).

The quality of water is measured in terms of its physical, chemical and biological parameters. Ascertaining the quality is crucial before its use for various purposes such as drinking, agricultural, recreational and industrial uses, etc. (Sargaonkar & Deshpande 2003, Khan et al. 2003). Water Quality Index (WQI) is a very useful and efficient method for assessing the suitability of water for different purposes. It is also very useful method of communicating the information on overall quality of water (Asadi et al. 2007) to the concerned person and policy makers. Thus, WQI becomes an important parameter for the assessment and management of water quality. It reflects the combined influence of different water quality parameters and is calculated from the point of view of the suitability for human consumption. In general, WQI incorporate data from multiple water quality parameters into a mathematical equation that rates the health of water body with number (Yongera & Puttaiah 2008).

The objective of present study was to assess chemical water composition and its suitability for different uses (i.e. domestic, irrigation and industrial purposes) in the study area. Geographical Information System (GIS) uses a computer database to store large quantities of data and allows the integration of different types of information which serves as a decision support tool. The present study helps the public participation process, by providing easily understandable output information regarding quality of water for different purposes. The results of this study will be useful to decision makers for future coal mining, ensuring ecologically sustainable industrial development, particularly in a mine affected areas.

STUDY AREA

Jharia coalfields (JCF) is one of the most important coalfields in India, located in Dhanbad district of Jharkhand state, between latitude 23°39' to 23°48' N and longitude 86°11' to 86°27' E. It lies in the heart of Damodar valley along the north of Damodar river. The coal basin extends about 38 km in an east-west direction and 18 km in north-south direction, and covers an area of about 450 sq. km. This is the most exploited coalfields because of available metallurgical grade coal reserves. Due to the unhygienic conditions around Jharia coal belt, large population of it faces acute shortage of clean drinking water. Jharia coalfields fall in semi-arid tract which experiences severe drought every year and forces habitats to use mine-discharged water as potable water. It is in this context that an attempt has been made in present study to delineate areas stressed with degraded water quality, caused by coal mining activities in the coalfield. Olidih watershed falling in Jharia coalfield is taken as study area to carry out this analysis. Joriya river flowing through this area, is severely affected by adjacent mining activities. Watershed covers an area of 5725 ha and has an annual average rainfall of 800mm. The map of Olidih watershed and its location is shown in Fig. 1.

MATERIALS AND METHODS

Collection and analysis of water samples: Pre-monsoon (PRM) and post-monsoon (POM) season water samples from 30 sampling sites were collected in sterilized plastic sampling bottle by following standard procedures. Bottles were rinsed with the sample water before taking the samples at each site. After sample collection, bottles were sealed on site with proper labeling. These samples were used for analysis of physico-chemical parameters and concentration of trace metals in laboratory. The coordinates of each sampling location were recorded using a handheld GPS receiver. Out of 30 water samples, 15 were collected from mine affected areas and the remaining 15 were collected from the rivers, streams and nearby water bodies in unmine areas. All PRM samples were collected prior to the monsoon (in month of June), and POM samples at the end of monsoon season (in month of October). The samples were kept cool while being transported by train to the laboratory of the Agricultural and Food Engineering Department of IIT Kharagpur, where they were analysed.

In the laboratory, the water samples were filtered through 0.45 µm millipore membrane filters to separate suspended sediment. The samples were analysed for pH, electrical conductivity (EC), total dissolved solids (TDS), major cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}), major anions (Cl^{-}, SO_4^{2-}, NO_3^{-}) and trace metals (Cu^{2+}, Zn^{2+}, Fe^{2+}, Mn^{2-}) following standard analytical methods. To gain an understanding on the population parameters of various geochemical constituents of water samples, the parameters have been treated for univariate statistical analyses. pH was measured using SYSTEM 361 digital pH meter while electrical conductivity and TDS of the water samples was measured with 601E model EC meter and TDS meter respectively. The concentrations of major cations were determined using direct reading flame photometer at specific wavelength of 554nm, 285nm, 590nm and 760nm for Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} respectively. Whereas the concentrations of major anions were determined using direct reading spectrophotometer at specific wavelength of 400nm, 450nm and 515nm for NO_3^{-}, SO_4^{2-}, and Cl^{-} respectively. The concentrations of trace metals Cu^{2+}, Zn^{2+}, Fe^{2+}, and Mn^{2-} were determined using Atomic Absorption Spectrophotometer (AAS) method and each metal was analysed at specific wavelength of 328nm, 213.9nm, 248.3nm and 279nm respectively.

Water quality index (WQI): WQI is defined as a technique of rating that provides the composite influence of individual water quality parameter on the overall quality of water (Sarkar et al. 2006). Water quality in the watershed is degraded by many different factors such as poor development practices and sprawl, poor storm water management, destruction of wetlands, runoff from agricultural areas, point source pollution, etc. Water quality index aims at giving a single value to the water quality of a source on the basis of one or the other system which translates the list of constituents and their concentrations present in a sample into a single value. One can then compare different samples for quality on the

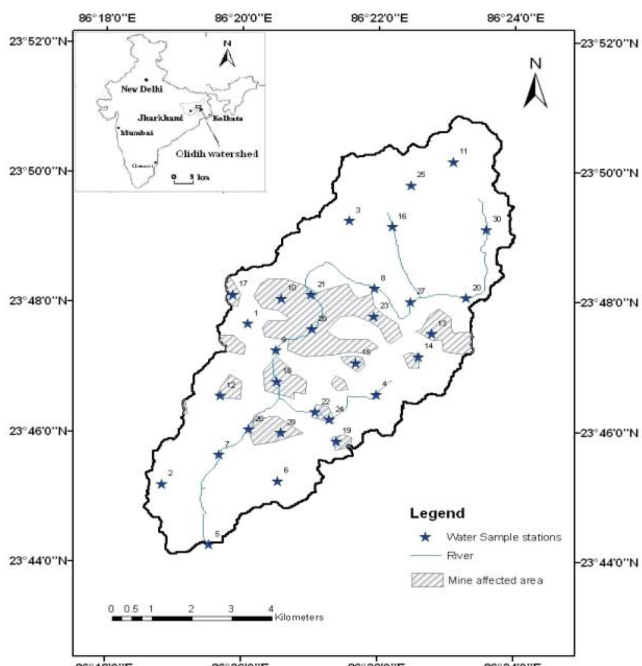

Fig. 1: Location of Olidih watershed.

Table 1: Relative weight and Indian drinking water standard values of chemical parameters.

Sr. No	Parameter	IS: 10500 (BIS 1991) Indian Standard (S_i)	Realative Weight (W_i)
1	pH	6.5-8.5	0.0816
2	EC*	300	0.0612
3	TDS	500	0.1020
4	Cl^-	250	0.1020
5	Na^+	200	0.0816
6	K^+	50	0.0408
7	NO_3^-	45	0.1020
8	Cu^{2+}	0.05	0.0408
9	Zn^{2+}	5	0.0408
10	Fe^{2+}	0.3	0.0612
11	Mn^{2-}	0.1	0.0612
12	Ca^{2+}	75	0.0612
13	Mg^{2+}	30	0.0612
14	SO_4^{2-}	150	0.1020

Values in mg/L except EC (µS/cm) and pH.

Table 2: Status categories of WQI (Brown et al. 1970).

WQI	Status of water
0 - 25	Excellent
26 - 50	Good
51 - 75	Poor
76 - 100	Very poor
> 100	Unfit for drinking

For developing WQI of Olidih watershed, the chemical analyses of water samples collected in PRM and POM seasons were considered. For computing WQI three steps were followed. In the first step, each of the parameters has been assigned a weight (w_i) according to its relative importance in the overall quality of water for drinking purposes or human consumption (Vasanthavigar et al. 2010, Rokbani et al. 2011). The maximum weight of 5 has been assigned to the parameters TDS, nitrate, chloride and sulphate due to their importance in water quality assessment (Srinivasamoorthy et. al 2008). In the second step, the relative weight (W_i) was computed for each parameter using equation 1:

$$W_i = w_i \Big/ \sum_{i=1}^{n} w_i \qquad ...(1)$$

Where, W_i is the relative weight; w_i is the weight of each parameter and n is the number of parameters. Calculated W_i values of each parameter are given in Table 1. In the third step, a quality rating scale (q_i) for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines laid down in the IS:10500 (BIS 1991) and the result is multiplied by 100 (equation 2).

$$q_i = \left(C_i / S_i \right) \times 100 \qquad ...(2)$$

Where, q_i is the quality rating; C_i is the concentration of each chemical parameter in each water sample in mg/L and S_i is the Indian drinking water standard for each chemical parameter in mg/L according to the guidelines of the BIS (1991).

For computing the WQI, the sub-index (SI) is first determined for each chemical parameter, which is then used to determine the WQI as per the equation 3.

$$SI_i = W_i \times q_i$$
$$WQI = \sum SI_i \qquad ...(3)$$

Where SI_i is the sub-index of i^{th} parameter; q_i is the quality rating based on concentration of i^{th} parameter and n is the number of parameters. The water samples in the study area are classified into five different status categories (Table 2) varying from excellent to unsuitable for drinking, based on computed WQI values.

In addition to this, SAR, %Na and TH were also determined on the basis of various physico-chemical parameters in order to ascertain the suitability of water for domestic, irrigation and industrial uses. Classification and suitability of water for irrigation were done by plotting US Salinity Laboratory hazard diagram and Wilcox diagram by correlating SAR-electrical conductivity and % Na-electrical conductivity, respectively.

RESULTS AND DISCUSSION

Water quality assessment: Water samples in PRM and POM seasons were collected from rivers and nearby water bodies and from mine affected areas. These samples were analysed for physico-chemical parameters and trace metals concentration. Statistics and % compliance with IS: 10500 values of water quality parameters of samples from unmine and mine area are presented in Table 3 and Table 4 respectively.

During the present investigation, average pH values were found 'neutral' (6.5-8.5) in both the seasons for mine and unmine areas. However, at some locations in mine area in PRM season, pH was found slightly acidic (6.1-6.5). In general, there was no specific trend found in the distribution of pH within study area. EC was measured in micro Siemens per centimetre (µS/cm) which is a measure of salt content of water in the form of ions (Karanth 1987). The TDS values ranged between 171 and 1626 mg/L.

A boxplot, or box and whisker diagram provides a simple graphical summary of a set of data. It shows a measure

Table 3: Statistics of water quality parameters of samples from unmine area.

S.No.	Parameter	PRM				POM			
		Min	Max	Mean	% Compliance	Min	Max	Mean	% Compliance
1	pH	6.9	9.2	7.9	86.7	7.0	8.7	7.8	80
2	EC	204	1104	708	-	372	2400	1157	-
3	TDS	192	953	600	66.	340	1028	748	53.3
4	Cl	14.5	71.6	41.77	100	9.858	143.03	42.53	100
5	Na	15.4	17.6	16.28	100	17.03	101.32	49.58	100
6	K	3.96	5.28	4.62	100	4.920	10.20	7.18	100
7	NO_3	0.1	2.3	0.69	100	0.291	12.90	3.08	100
8	Cu	0.006	0.216	0.04	80	0.011	0.04	0.02	66.7
9	Zn	0.014	0.14	0.04	100	0.034	0.18	0.07	100
10	Fe	0.008	0.65	0.17	100	0.255	1.00	0.49	80
11	Mn	0.001	1.03	0.21	86.7	0.011	0.33	0.06	66.7
12	Ca	5.3	132.9	53.77	86.7	27.560	132.90	73.43	73.3
13	Mg	7	104.5	47.90	66.7	38.148	110.98	72.63	60
14	SO_4	19.4	288.3	85.66	86.7	111.30	490.36	256.31	86.7

Values in mg/L except EC (µS/cm) and pH.

Table 4: Statistics of water quality parameters of samples from mine area.

S.No.	Parameter	PRM				POM			
		Min	Max	Mean	% Compliance	Min	Max	Mean	% Compliance
1	pH	6.2	7.9	7.1	66.7	6.8	8.7	7.6	80
2	EC	453	2645	838	-	542	2782	827	-
3	TDS	171	1626	727.10	60	172	873	545	53.3
4	Cl	13.6	97.8	45.21	100	9.312	79.61	51.59	100
5	Na	14.85	57.51	35.13	100	9.080	140.08	56.94	100
6	K	5.94	15.84	10.49	100	3.250	15.21	9.48	100
7	NO_3	0.1	3.7	1.29	100	1.256	12.10	5.35	100
8	Cu	0.01	0.263	0.06	100	0.007	0.02	0.01	80
9	Zn	0.012	0.289	0.07	100	0.018	0.06	0.03	100
10	Fe	0.003	1.16	0.25	80	0.071	0.36	0.18	80
11	Mn	0.001	0.997	0.15	80	0.005	0.08	0.02	100
12	Ca	3.6	92.7	31.52	86.7	5.610	148.28	69.86	66.7
13	Mg	4.3	89.6	28.45	86.7	6.930	41.48	21.29	73.3
14	SO_4	3.54	116.2	43.80	80	16.878	436.50	91.29	92.5

Values in mg/L except EC (µS/cm) and pH.

of central location (the median), two measures of dispersion (the range and inter-quartile range), the skewness (from the orientation of the median relative to the quartiles) and potential outliers (marked individually). Boxplots are a quick visualization approach for examining one or more data sets. Because they can easily reveal the limits of acceptable data and any extremes, it becomes very easy to explain trends and abnormalities and communicate the right information. Box plots were used to represent temporal concentration of the major ions (Fig. 2). It shows increasing trend of Ca, Na, NO_3, and SO_4 during POM season, which may be due to leaching from upper soil layers derived from industrial and domestic activities and dry climates (Srinivasamoorthy et al. 2008).

Suitability for domestic uses: Most of the diseases in human beings are caused by polluted water. Once the water is contaminated, its quality cannot be restored by stopping the pollutants from the source. It is, therefore, essential to regularly monitor the quality of water and derive ways to protect it. WQI is one of the most effective tools in assessing the suitability of water for various beneficial uses. The formulation and use of indices has been strongly advocated by agencies responsible for water supply and control of water pollution. Once the water quality data have been determined through sampling and analysis, a need arises to translate it into a form that is easily understood. Once the WQI are developed and applied, they serve as convenient tools to examine trends, to highlight specific environmental conditions,

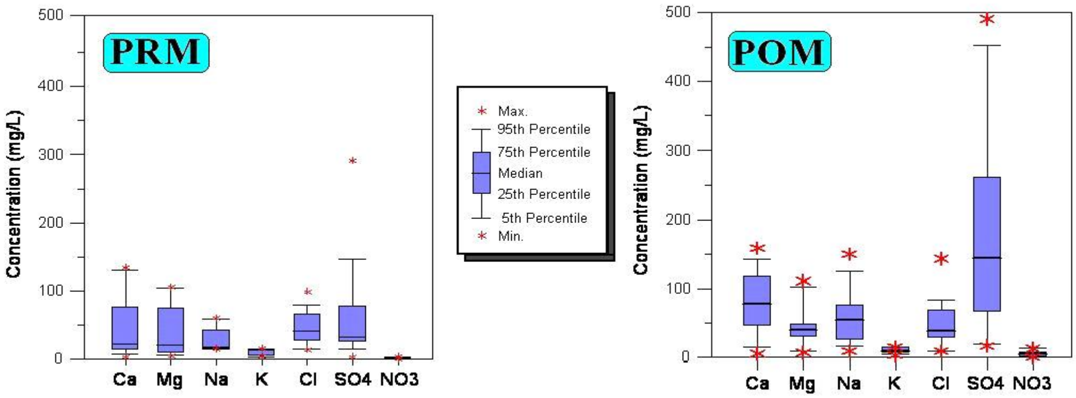

Fig. 2: Box plots for major ions (in mg L^{-1}) in PRM and POM seasons.

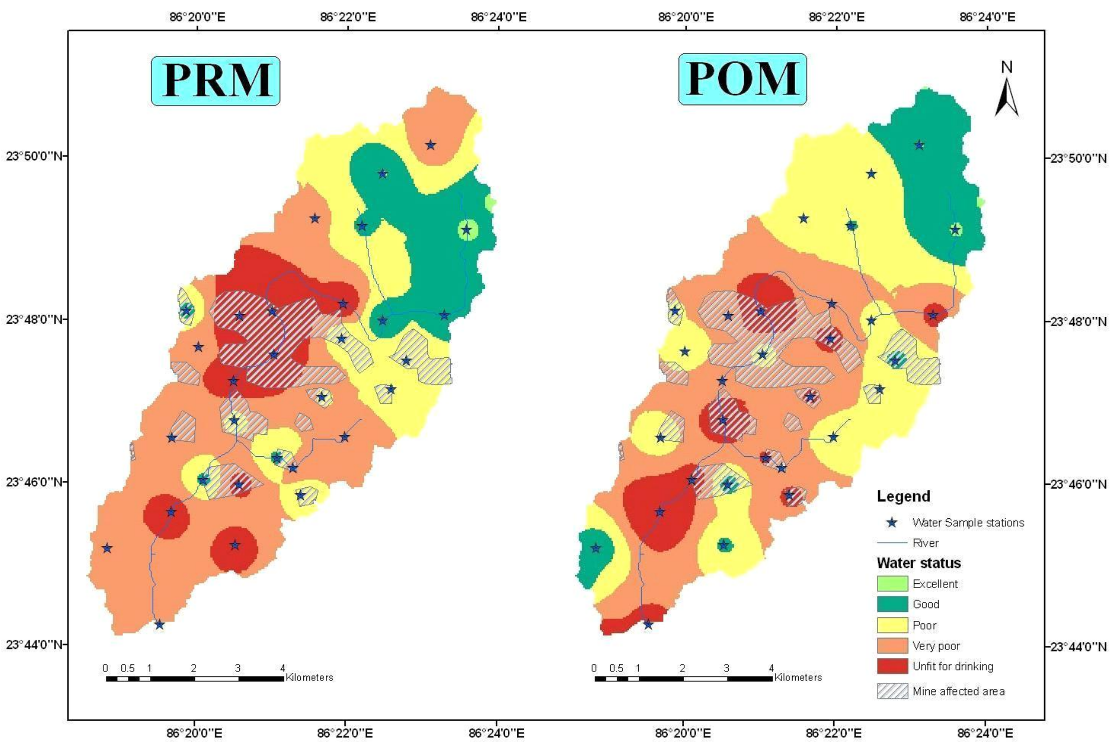

Fig. 3: WQI status map of Olidih watershed in PRM and POM seasons respectively.

and to help governmental decision-makers in evaluating the effectiveness of regulatory programmes. WQI for all the sampling stations in Olidih watershed were developed using analysed water quality parameters and procedure describe above. The spatial distribution map of the WQI in PRM and POM seasons is shown in Fig. 3.

The value of WQI was found to vary from 23.86 to 166.72 in PRM season and from 22.14 to 146.44 in POM season. Water from 53.6% and 28.2% mine affected area was found ‘unfit for drinking’ during PRM and POM seasons respectively. Two sampling stations in PRM and three sampling stations in POM season exhibit ‘Excellent’ quality water for domestic purposes. In 16.3% and 11.4% of watershed area, water was found ‘unfit for drinking’ during PRM and POM season respectively. The PRM samples exhibit poor quality in greater percentage when compared with POM due to effective leaching of ions, direct discharge of effluents, agricultural impact and elevated temperature and increased evaporation during the low water level period of the pre-monsoon season.

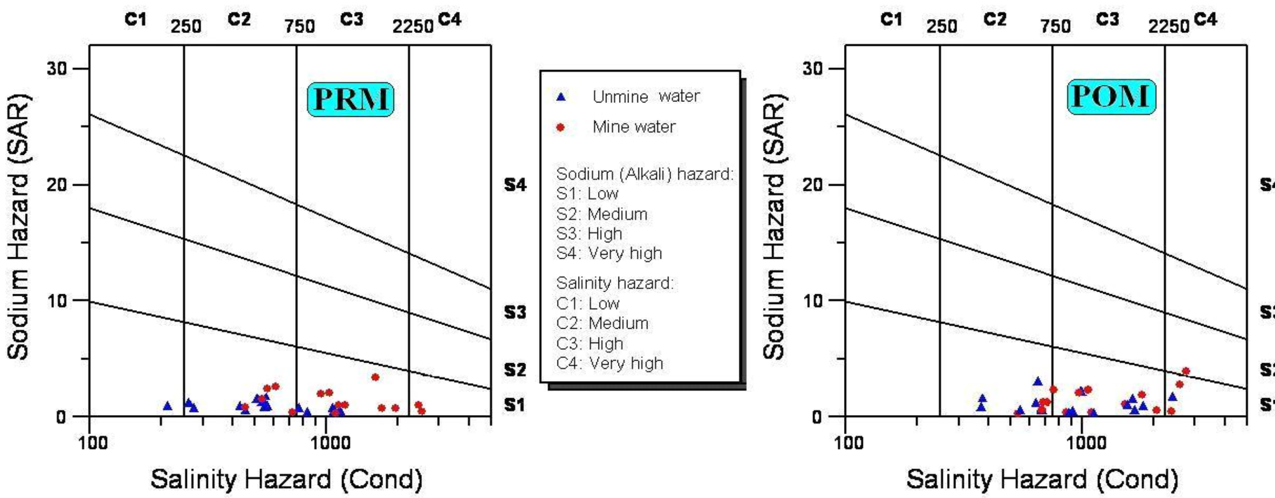

Fig. 4: US Salinity diagram for classification of irrigation waters.

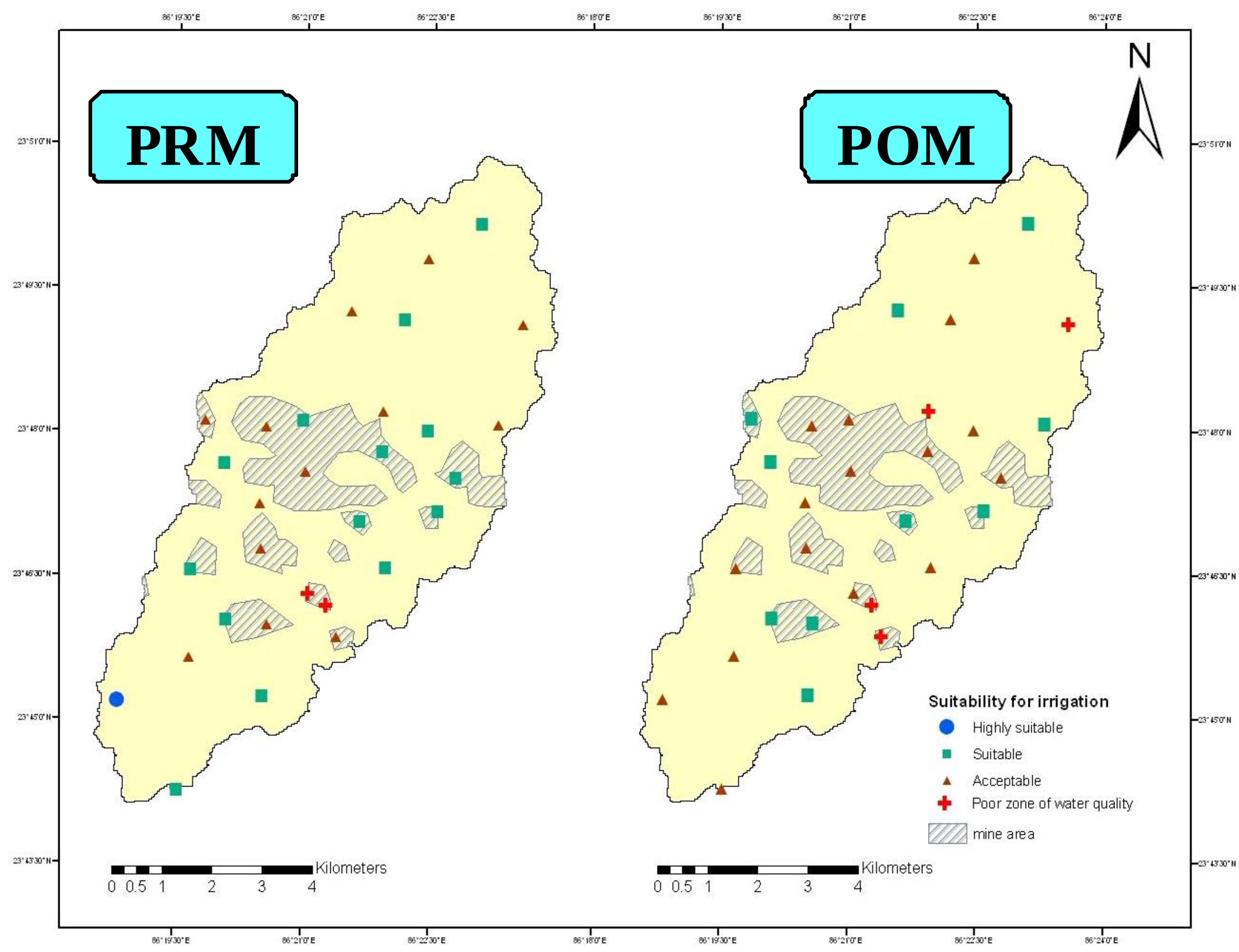

Fig. 5: Spatial distribution of suitability of water for irrigation based on US Salinity diagram.

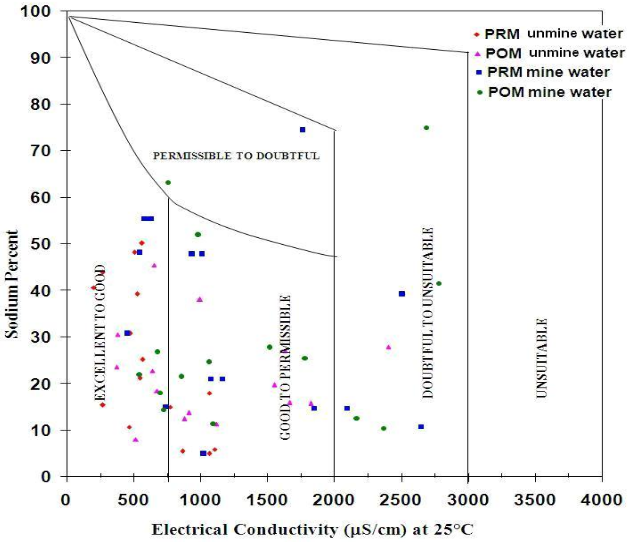

Fig. 6: Plot of sodium percentage and electrical conductivity (Wilcox 1955) for classification of water for irrigation uses.

Suitability for irrigation uses: The suitability of water for irrigation depends on the effect of mineral constituents of water on both plants and soil. Saline condition on irrigated lands is the major cause for low production and is one of the most prolific adverse environmental impacts associated with irrigation. Effects of salts on soil causing changes in soil structure, permeability and aeration indirectly affect plant growth. Plant growth is important for mine reclamation for several reasons: (i) it provides an erosion control measure for hill slope erosion and stream bank erosion, (ii) it allows for revegetation of reclaimed areas, and (iii) it can possibly aid in metals uptake by phytoremediation. The rate of salinity build up and its adverse effect on crops can be reduced by careful management suitable to local conditions. Wilcox (1955) and US Salinity Laboratory Staff (1954) proposed irrigational specifications based on hydro-chemical properties for evaluating the suitability of water for irrigation use.

Alkali and salinity hazard: There is a significant relationship between sodium adsorption ratio (SAR) values for irrigation water and the extent to which sodium is adsorbed by the soils. The higher the sodium adsorption ratio, the less suitable the water is for irrigation. Irrigation using water with high sodium adsorption ratio may require soil amendments to prevent long-term damage to the soil. Salinity problems are most likely to arise in soils where drainage is poor. This allows the water table to rise close to the root zone of plants, causing the accumulation of sodium salts in the soil solution through capillary rise following surface evaporation. If irrigation water with a high SAR is applied to a soil for years, the sodium in the water can displace the calcium and magnesium in the soil. This will cause a decrease in the ability of

Table 5: SAR, %Na and TH values for PRM and POM seasons.

Sample	PRM			POM		
No	SAR	% Na	TH	SAR	% Na	TH
Unmine water samples						
1	0.58	21.18	12.00	0.38	8.03	47.34
2	0.93	40.71	4.83	0.53	13.73	25.77
3	0.45	14.96	13.58	0.91	23.58	19.74
4	0.38	10.75	25.90	0.42	12.44	21.98
5	0.72	30.81	5.58	0.38	11.32	25.17
6	0.88	39.26	4.23	1.67	30.51	26.09
7	0.25	4.98	51.64	1.07	19.73	39.91
8	0.28	5.50	51.84	1.81	27.87	43.86
9	0.28	5.85	47.51	1.60	27.03	38.06
10	0.49	17.97	12.09	0.96	15.74	49.54
11	0.89	43.87	3.18	3.11	45.48	22.07
12	0.66	25.17	9.71	0.64	15.93	24.56
13	0.44	15.40	15.79	2.23	38.10	22.42
14	1.21	50.17	3.61	0.84	18.48	27.81
15	1.24	48.22	4.07	1.25	22.77	32.52
Mine water samples						
16	2.29	55.39	7.95	2.80	63.22	5.18
17	1.93	47.87	9.76	0.64	26.81	7.78
18	0.70	14.68	41.89	2.23	52.00	8.19
19	1.04	20.98	35.85	3.47	74.94	3.05
20	3.55	74.51	3.80	0.43	21.93	5.56
21	0.44	14.96	13.04	0.77	12.53	10.88
22	0.37	10.75	24.86	1.32	21.52	18.69
23	0.71	30.81	5.35	0.61	11.35	9.86
24	0.87	39.26	4.06	0.56	10.33	8.98
25	0.25	4.98	49.57	2.44	27.84	24.19
26	1.29	48.22	4.40	1.57	18.00	15.64
27	2.38	55.39	8.59	2.64	25.43	22.10
28	2.00	47.87	10.54	2.33	24.67	21.43
29	0.73	14.68	45.24	1.41	14.36	12.48
30	1.08	20.98	38.71	4.55	41.50	36.05

the soil to form stable aggregates and a loss of soil structure and tilth. This will also lead to a decrease in infiltration and permeability of the soil, leading to problems with crop production. SAR was computed using the equation 4, where all the concentrations are expressed in meq/L.

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}} \qquad ..(4)$$

The calculated value of SAR in PRM season ranges from 0.25 to 1.24 in water from unmine area and 0.25 to 3.55 in mine area, whereas in POM season it ranges from 0.38 to 3.11 in water from unmine area and 0.43 to 4.55 in mine area (Table 5). The total concentration of soluble salts in irrigation water can be categorized as low, medium, high and very high with EC values of <250 µS/cm, 250-750 µS/cm, 750-2,250 µS/cm and 2,250-5,000 µS/cm respectively. The electrical conductivity and SAR values were plotted on a US Salinity diagram (Fig. 4) for classification of irrigation waters, in which the EC is taken as salinity hazard

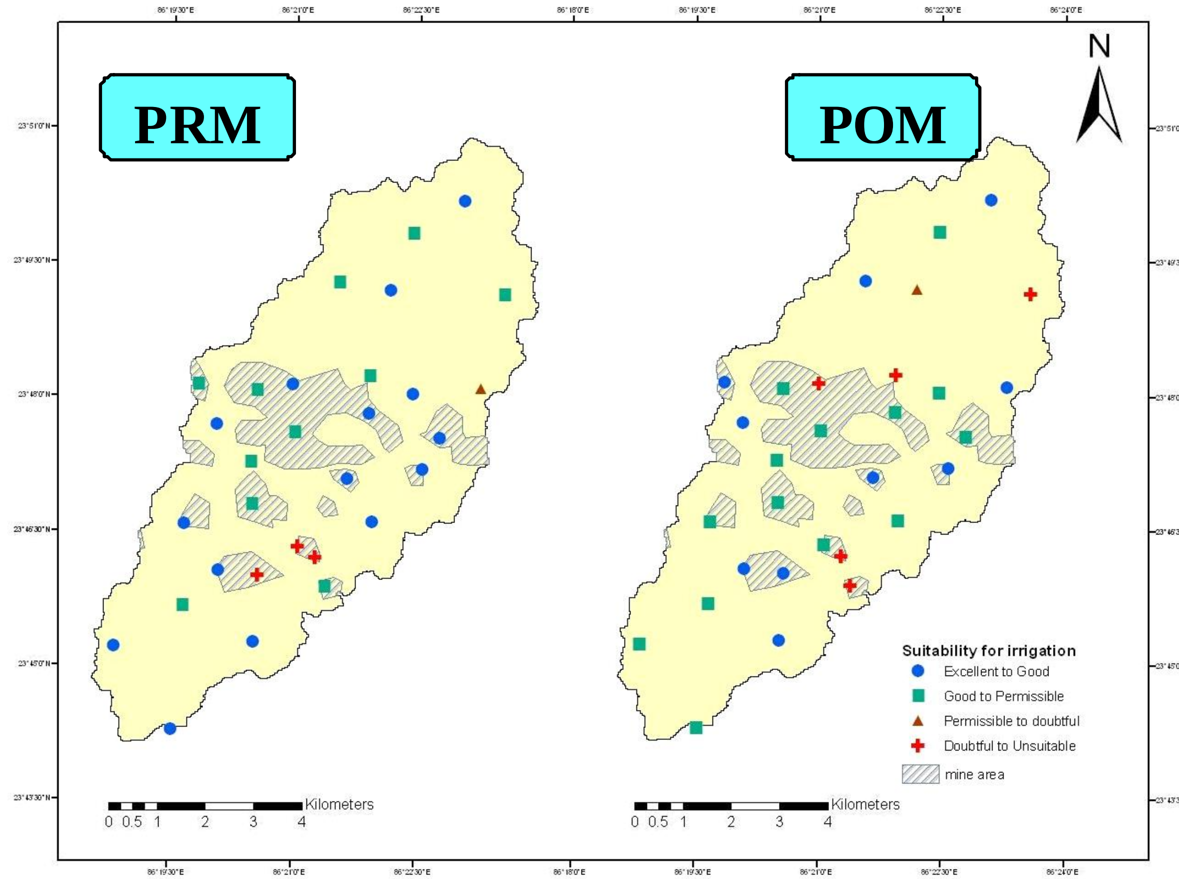

Fig. 7: Spatial distribution of suitability of water for irrigation based on Wilcox diagram.

and SAR as alkalinity hazard. The spatial distribution map of suitability of water for irrigation based on US Salinity diagram is shown in Fig. 5. It shows that during PRM season, at most of the places the water from unmine areas belongs to the category C2S1 (medium salinity and low alkalinity) and mine water of the area belongs to C3S1 (high salinity and low alkalinity) category. During POM season, at most of the places water of the area belongs to the categories C2S1 and C3S1. Both these categories fall in the suitable class for irrigation purposes. Some samples falling in category C3S1 and samples falling in C4S1 category are considered tolerable for irrigation use and poor zone of water quality respectively. High salinity water cannot be used on soils with restricted drainage and requires special management for salinity control. Plants with good salt tolerance should be selected for such areas.

EC and sodium percentage (%Na): EC and sodium concentration are very important in classifying irrigation water. The salts, besides affecting the growth of the plants directly, also affect soil structure, permeability and aeration, which indirectly affect plant growth. The sodium percentage (%Na) was calculated using equation 5, where all the concentrations are expressed in mg/L.

$$Na\% = \frac{Na^{+}}{(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})} \times 100 \qquad ...(5)$$

The calculated value of %Na in PRM season ranges from 4.98 to 50.17 % in water from unmine area and 4.98 to 74.51 % in mine area whereas in POM season it ranges from 8.03 to 45.48 % in water from unmine area and 10.33 to 74.94 % in mine area (Table 5). As per the Indian Standard (BIS 1991) recommendations, maximum limit of sodium for irrigation water is 60%. The Wilcox (1955) diagram (Fig. 6) relating EC and sodium percent shows that most of the unmine water samples in both the seasons fall in the category of 'excellent to good' and 'good to permissible' for irrigation. But in case of mine water 20% and 26% samples in PRM and POM respectively falls in the category of 'doubtful to unsuitable' for irrigation. This limits the use of water in mine affected area for irrigation purposes. The spatial distribution map of suitability of water for irrigation based on Wilcox diagram is shown in Fig. 7.

Total hardness: Hard water is unsuitable for domestic use and it is caused by a variety of dissolved polyvalent metallic ions, predominantly calcium and magnesium cations, although other cations (e.g., aluminium, barium, iron, manganese and zinc) also contribute. Hardness of water is defined as the inhibition of soap action in water due to precipitation of magnesium and calcium salts. It is most commonly expressed as milligrams of calcium carbonate equivalent per litre. Hardness of water limits its use for industrial purposes; it causes scaling of pots and boilers, closure to irrigation pipes, and may cause health problems to humans. Both calcium and magnesium are essential minerals and beneficial to human health in several respects. Inadequate intakes of these nutrients may increase risks of osteoporosis, nephrolithiasis (kidney stones), colorectal cancer, hypertension and stroke, coronary artery disease, insulin resistance and obesity. TH was calculated by using equation 6 (Todd 1980), where all the concentrations are expressed in mg/L.

$$TH(CaCO_3) = (2.497)Ca + (4.115)Mg \qquad ...(6)$$

During PRM, TH was ranging from 3.18 to 51.84 mg/L in unmine water and 3.8 to 49.57 mg/L in mine water. Whereas in POM, TH was ranging from 19.74 to 49.54 mg/L in unmine water and 3.05 to 36.05 mg/L in mine water (Table 5). Water containing calcium carbonate at concentrations below 60 mg/L is generally considered as soft; 60-120 mg/L, moderately hard; 120-180 mg/L, hard and more than 180 mg/L, very hard (McGowan 2000). The results revealed that the water in study area is 'soft water' in both the seasons.

Suitability for industrial use: Water quality requirements for industry differ significantly over the broad range of industrial operations. Such requirements usually depend on how water is to be used: for boiler feed water, cooling, processing or sanitary purposes. Specific water quality requirements have been identified for many industrial uses with maximum and/or range values. Such water quality considerations are particularly important at point of use as distinguished from point of intake. Water quality conditions that can cause the most problems for manufacturing processes are turbidity, hardness, high or low pH and dissolved solids (minerals). The high TDS and sulphate concentration in some samples of study area make this water unsafe for textiles, paper and allied industries. Food industries such as dairying, brewing and carbonated beverage canning must comply with drinking water standards with disinfections and treatment before use.

CONCLUSION

The present study assessed the surface water quality characteristics of Olidih watershed in Jharkhand state of India. The value of WQI varies from 23.86 to 166.72 in PRM season and from 22.14 to 146.44 in POM season. Water from 53.6% and 28.2% mine affected areas was found 'unfit for drinking' during PRM and POM season respectively. The PRM samples exhibit poor quality in greater percentage when compared with POM due to effective leaching of ions, direct discharge of effluents, agricultural impact and elevated temperature and increased evaporation during the low water level period of the pre-monsoon season. Box plot shows increasing trend of Ca, Na, NO_3 and SO_4 during POM season. The Wilcox diagram shows that most of the water in unmine area is 'excellent to permissible' for irrigation use whereas, in case of mine water 20% and 26% samples in PRM and POM respectively are 'doubtful to unsuitable' for irrigation. Estimation of TH of water samples shows that the water in study area is 'soft water' in both the seasons. Water quality in the study area is slowly reaching alarming stage so that proper planning is essential in this venture to preserve the fragile ecosystem.

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