ISSN : 0974 - 7451 Volume 7 Issue 3

Trade Science Inc.

Environmental Science
An Indian Journal

Current Research Paper

ESAIJ, 7(3), 2012 [93-102]

Assessment of irrigation potential of groundwater in and around Durgapur, West Bengal, India

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Received: 15th December, 2011 ; Accepted: 17th January, 2012

ABSTRACT

Durgapur, West Bengal is characterized by semiarid climate and due to insufficient surface water resources, groundwater is the main source of water supply in this region. In order to evaluate the major suitability of water for irrigation, the chemical characteristics of groundwater in Durgapur have been investigated and evaluated. Water samples from tube wells and dug wells are collected and analyzed for electrical conductivity (EC), total dissolved solids (TDS), Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO^{3-}, Cl^-, and SO_4^{2-}. To understand the water quality and utilitarian aspects of groundwater, chemical indices like percent sodium, Sodium Adsorption Ratio (SAR), Wilcox diagram and Salinity diagram were calculated based on the analytical results. According to the EC and SAR calculation the most dominant classes (C2-S1, C3-S1) were found. Salinity hazard in 31% and 26% of water samples is regarded as good in pre and postmonsoon season respectively while in 52% and 57% of water samples in pre and postmonsoon season is classified as waters, that are not suitable for irrigation under normal condition and further action for salinity control is required in remediating such problem. Sodium content in 83.20% postmonsoon samples are of good to permissible type and 62.5% premonsoon samples are of permissible to doubtful type. The result suggests greater sodium hazard in premonsoon season. According to geochemical classification, the groundwater of Durgapur is in general Ca-Mg-HCO3 and Ca-Mg-Cl type. With respect to time salinity of water increases through out the study area.

KEYWORDS

Electrical conductivity (EC);
Irrigation;
Percent sodium;
Salinity hazard;
Sodium Adsorption Ratio (SAR);
Total dissolved solids (TDS);
Wilcox diagram.

INTRODUCTION

Groundwater becomes contaminated from natural source or numerous human activities. Residential, municipal, commercial, industrial and agricultural activities affect groundwater quality. This study is related to water quality which is becoming more serious due to population explosion, increasing agriculture and improved standard of living. As the inadequate quantity of surface water does not fulfill the needs of the people, the search for and exploitation of groundwater is a must. Aquifer depletion has been reported for many semi arid and arid regions worldwide and can be attributed to agricultural usage[12, 19, 28].

Groundwater sustains almost 60% of the country's irrigated land. On a local level, an increasing number of districts today have larger shares of irrigated land under groundwater irrigation than under surface-water irrigation. This change in usage in India has been extremely rapid since the 1970s. In just two decades, the groundwater irrigated lands in India have increased by 105%[13].

The landuse pattern of the present study area is characterized by industries, agriculture, forest, urban and rural residential hubs. The effluents of numerous industries of various natures present around the agricultural lands may have control on the quality of groundwater which is used for agriculture.

The objectives of the present study are: i) to evaluate water quality parameters with respect to irrigation potential, ii) to classify the study area depending upon the combinations of water quality parameters with respect to suitability for irrigation. Hydro geochemical data are used in the analysis are Electrical Conductivity (EC), Total Hardness (TH) and Sodium Adsorption Ratio (SAR), percent sodium, residual sodium carbonate, and chloro-alkaline indices. It was observed that the criteria used in the classification of waters for a particular purpose considering the individual concentration may not find its suitability for other purposes and better results can be obtained only by considering the combined chemistry of all the ions rather than individual or paired ionic characters[4, 5, 15, 24].

Study area

The area under investigation belongs to the survey of India toposheet (1: 50,000 scale) No 73M/6 and 73M/7 lying between latitudes 23°25´N and 23°48´N and longitudes 87°10'E and 87°35'E, total area coverage is almost 600 sq Km (Figure 1). The area shows more or less undulating topography. The study area comprises of unconsolidated and semi consolidated Quaternary and Tertiary alluvial deposits overlying Gondwana sedimentaries and Archean basement of rocks[1, 9, 21].

The climate of the area is semi arid and tropical. It is characterized by a hot and dry summer from middle

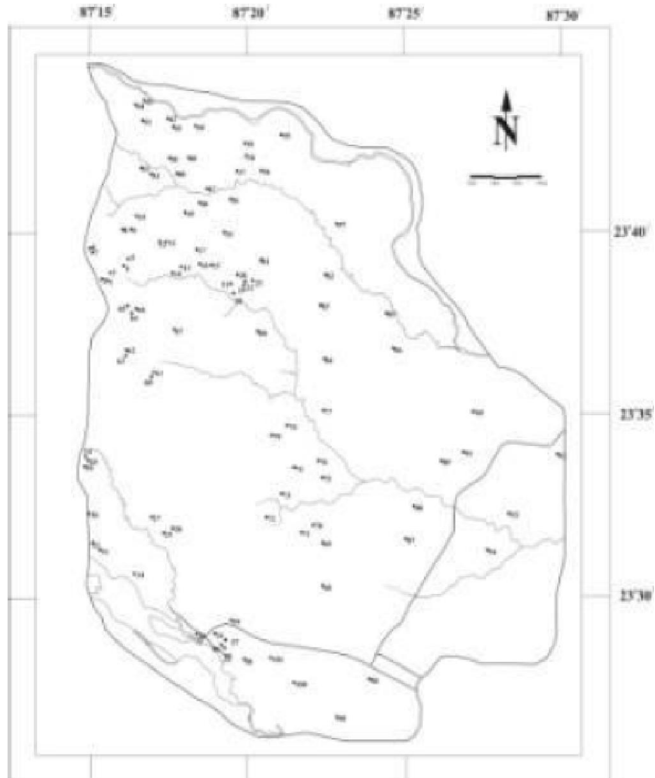

Figure 1 : Study area

of April to May, the rainy season was from middle of June to September and a cool pleasant winter from October to February.

MATERIALS AND METHOD

Ground water samples were collected from the selected sampling points. Electrical conductivity and p^H of the samples were measured within 4 hours of sample collection. Analyses for parameters like chloride, nitrate, potassium, sodium, magnesium, calcium, p^H, electrical conductivity (EC), sulphate, bicarbonate were carried out in the laboratory.

Analysis of samples has been done according to standard methods adopted by[3]. The p^H and EC were measured by means of p^H meter (EUTECH p^H1100) and conductivity meter (EUTECH Con 510) respectively. TDS were computed from EC multiplied by a factor (0.55–0.75), depending on relative concentrations of ions. Na^+ and K^+ were determined by flame photometer (TECHCOMP UV-2300). NO_3^- and SO_4^{2-} were analyzed by spectrophotometer. TH and TA as $CaCO_3$, Ca^{2+}, HCO_3^- and Cl^- were analysed by titrimetric method. Mg^{2+} was calculated from TH and Ca^{2+}

contents. The ion-balance-error computation, taking the relationship between the total cations (Ca^{2+}, Mg^{+2}, Na^{+}, K^{+} and Fe^{2+}) and the total anions (PO_4^{3+}, NO_3^{-}, SO_4^{2-}, CO_3^{2-}, $HCO_3^{-}$and Cl^{-}) for each set of complete analyses of water sample, is observed to be within the range of acceptability (±5%) used in most laboratories[25].

RESULT AND DISCUSSION

TABLE 1, depicting the hardness of water samples, indicates that most of the water samples (70% in premonsoon season and 77.3% in postmonsoon) in the study area fall under hard to very hard water category[10, 27].

The sodium in irrigation water is usually denoted as percent sodium and can be determined using the following formula

$\% Na = (Na^{+}) \times 100/(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})$

Where, the quantities of Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} are expressed in milliequivalents per litre (epm). The classification of groundwater samples in terms of percent sodium

(TABLE 2) exhibits that postmonsoon samples (83.2%) fall under good to permissible as most of the premonsoon samples (62.5%) are of permissible to doubtful category. The result suggests greater sodium hazard in premonsoon season. In irrigation water sodium propitiates the dispersion of colloids or clays when it comes in contact with soil and displaces the divalent cations Ca^{2+} and Mg^{2+}. This has a negative effect on the structure of the soil and reduces its capacity to conduct water and air through its profile[20]. This in turn damages soil fertility because in addition to affecting aeration it also increases p^{H} and reduces the availability of metals like Fe and Zn. Wilcox diagram (Figure 2) based on electrical conductivity and percentage sodium, suggests that the samples of postmonsoon season are mostly(88.23%) in excellent to good and good to permissible category (Figure 2.a). But a considerable portion (23%) of samples in premonsoon season has de-

TABLE 1 : Classification of water based on hardness by Sawyer and McCarthy

Hardness as $CaCO_3$	Water Class	Pre-monsoon samples	Post-monsoon samples
0-75	Soft	14 samples	12 samples
75-150	Moderate	15 samples	15 samples
150-300	Hard	32 samples	40 samples
>300	Very hard	38 samples	52 samples

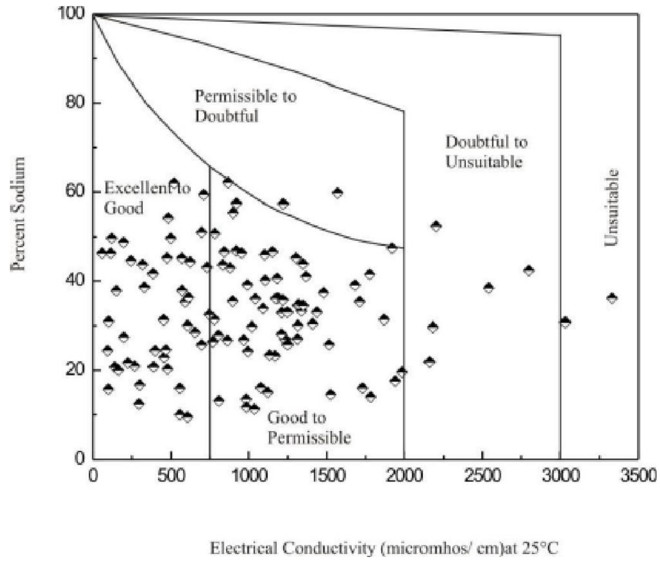

Figure 2a : Rating of Postmonsoon groundwater samples on the basis of electrical conductivity and percent sodium[22]

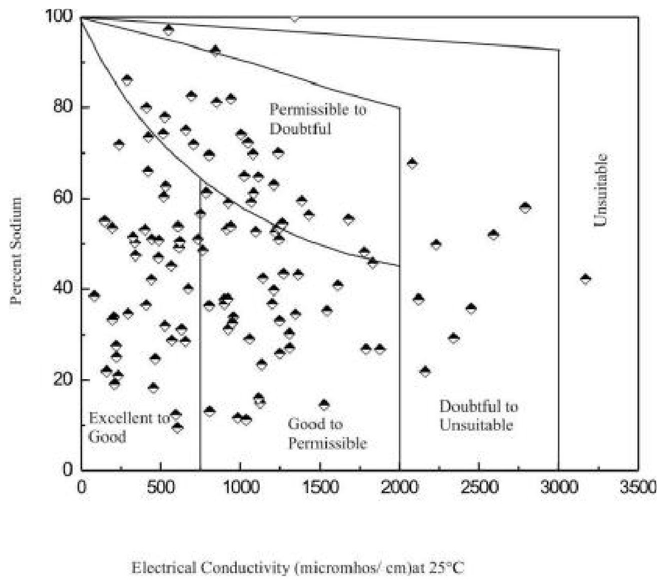

Figure 2b : Rating of Pre-monsoon groundwater samples on the basis of electrical conductivity and percent sodium[22]

Figure 2 : Wilcox Diagram

TABLE 2 : Sodium percent water class

Sodium (%)	Water Class	Pre-monsoon samples	Post-monsoon samples
<20	Excellent	02 samples	17 samples
20-40	Good	28 samples	63 samples
40-60	Permissible	40 samples	36 samples
60-80	Doubtfull	22 samples	03 samples
>80	Unsuitable	07 samples	Nil

graded into permissible to doubtful (Figure 2.b) category. The agricultural yields are observed to be generally low in lands irrigated with waters belonging to permissible to doubtful category. This is probably due to the presence of sodium salts, which cause osmotic effects in soil plant system. While a high salt content (high EC) in water leads to formation of saline soil and high sodium content (SAR) leads to development of an alkaline soil. The sodium or alkali hazard in the use of water for irrigation is expressed by determining the sodium adsorption ration (SAR) and it can be estimated by the formula.

$$\text{Sodium Adsorption Ratio (SAR)} = \frac{Na}{\sqrt{Ca+Mg/2}}$$

Where all ionic concentrations are expressed in epm. Causes of the increase in salts and sodium in groundwater with time are possibly due to rise in the concentration of certain salts in ground water as piezometric levels are reduced. Similar conditions have been reported from as in the case of SE Spain, South Texas and North Chihuahua. In this cases water is extracted from moderate depths, such waters may be older or may have circulated through rocks containing more highly soluble minerals[17]. Over exploration of ground water has given rise to reductions in piezometric levels as much as 3- 4 m/ yr in some regions. Relationship between reduction of piezometric levels and the chemical evolution of ground water has not yet been analysed, but considering the examples of other aquifers in the world as mentioned, this may be a possibility in the present area also.

There are other possibilities as well, such as influence of local, intermediate and regional flow systems of ground water upon chemical evolution[18]. The influence

TABLE 3 : Sodium hazard classes based on USSL classification

Sodium Hazard Class	SAR in equivalents per mole	Remark on quality	Pre-monsoon samples	Post-monsoon samples
S1	10	Excellent	97	119
S2	10-18	Good	02	Nil
S3	18-26	Doubtful	Nil	Nil
S4 and S5	>26	Unsuitable	Nil	Nil

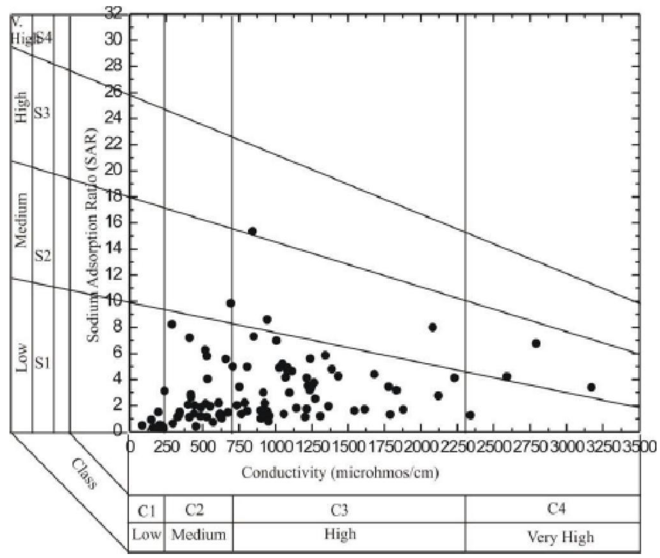

Figure 3a : USSL Diagram for Premonsoon samples

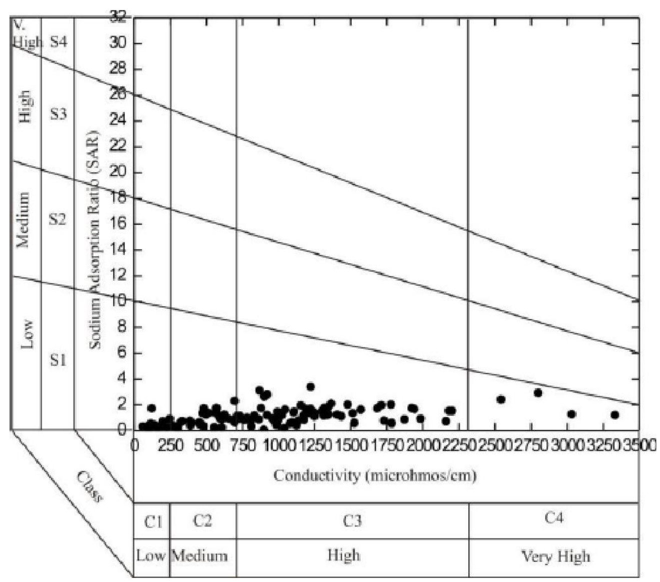

Figure 3b : USSL Diagram for Post monsoon

of the pressure and temperature of ground water or the incorporation of salts[16] and the age of groundwater and modification of natural systems as the degree of exploitation of the aquifers is intensified[2, 26]. The classification of water for irrigation has been suggested by graphically plotting the SAR and specific conductance values on the US[29] salinity (USSL) diagram of pre and post monsoon samples (Figure 3a & 3b). This indicates that groundwater of Durgapur is in general of Ca-Mg-HCO3 and Ca-Mg-Cl type during both pre and postmonsoon seasons of the year 2009-2010. About 85% of the samples are grouped within C2S1 and C3S1 classes in both post and premonsoon. For the purpose of diagnosis and classification, the total concentration

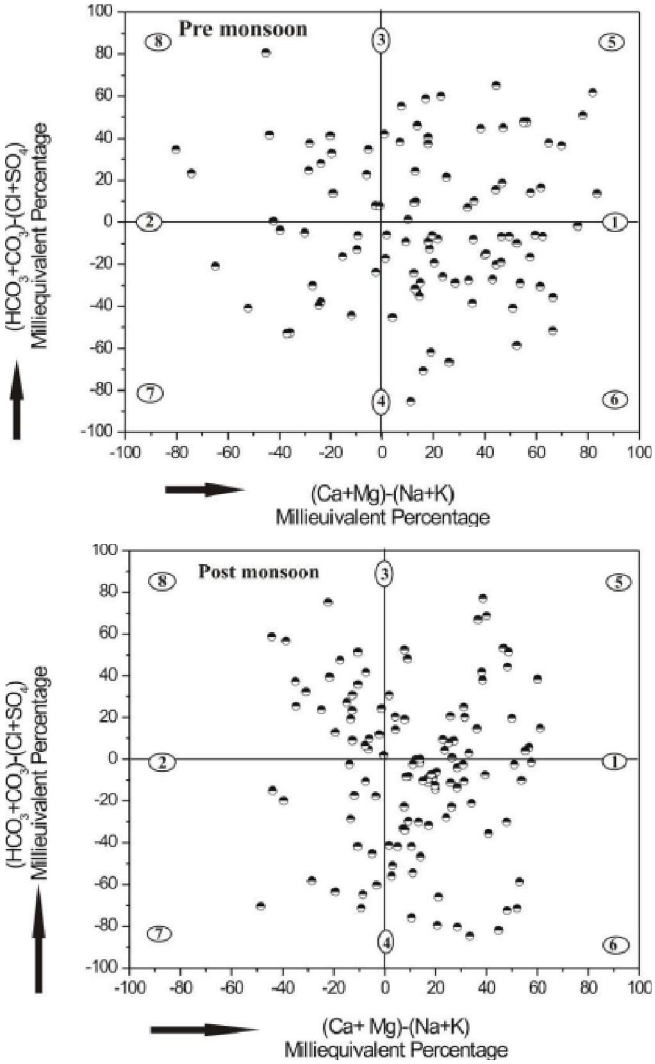

Figure 4 : Diagram showing geochemical classification and hydrochemical parameters of groundwater[7].

TABLE 4 : Salinity hazard classes based on USSL classification

Salinity Hazard Class	EC in micro-mohs per cm	Remark on quality	Pre-monsoon samples	Post-monsoon samples
C1	100-250	Excellent	11	13
C2	250-750	Good	31	31
C3	750-2250	Doubt ful	52	68
C4 and C5	>2250	Unsuitable	05	07

of soluble salts (salinity hazard) in irrigation water can be expressed in terms of specific conductance. The classification of water samples based on SAR as per US[29] Salinity (USSL) for irrigation purposes is presented in TABLE 3. It is observed that almost all the samples fall in excellent class. Classification of groundwater based on salinity hazard is presented in TABLE 4. EC values of only 5 samples during pre-monsoon and 7 samples during post-monsoon were found to be unsuitable for irrigation purposes. According to the conductance, water quality is mostly good to doubtful for irrigation.

For geochemical classification, a diagram after Chadha[7] has been used. The rectangular field of the plot describes the primary character of the water including the permanent and temporary hardness domain. The rectangular field is divided into eight sub-fields, each of which represents a water type and hardness domain (Figure 4), which are as follows: (1) Alkaline earths exceed alkali metals. (2) Alkali metals exceed alkaline earths. (3) Weak acidic anions exceed strong acidic anions. (4) Strong acidic anions exceed weak acidic anions. (5) Alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions, respectively. Such water has temporary hardness. The positions of data points in this domain represent Ca^{2+}–Mg^{2+}–HCO_3^- water type. (6) Alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions. Such water has permanent hardness and does not deposit residual sodium carbonate in irrigation use. The positions of data points in this domain represent Ca^{2+}–Mg^{2+}–Cl^- type of waters. (7) Alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions. Such water generally creates salinity problems both in irrigation and drinking uses. The positions of data points in this domain represent Na^+–Cl^- type and Na^+–$SO4^-$ type of waters. (8) Alkali metals exceed alkaline earths and weak acidic anions exceed strong acidic anions. Such waters deposit residual sodium carbonate during irrigation use and cause foaming problems. The positions of data points in this region represent Na^+–HCO_3^- type waters. Overall distribution of dataset on the plot suggests that most of the sampling point (almost 40.30% in postmonsoon and 41.40 % in premonsoon) exhibits permanent hardness (Ca^{2+}–Mg^{2+}–Cl^- type) i.e. domain 6, though few sampling points of both the seasons fall under domain 5, i.e. Ca^{2+}–Mg^{2+}–HCO_3^- water type (Figure. 4). In Durgapur, the groundwater is generally Ca- Mg-HCO_3 and Ca-Mg-Cl type, which is mainly due to the lithology of the area comprising of consolidated and semi consolidated quaternary and tertiary alluvial deposits overlying Gondwana rocks. Ground water in the study area oc-

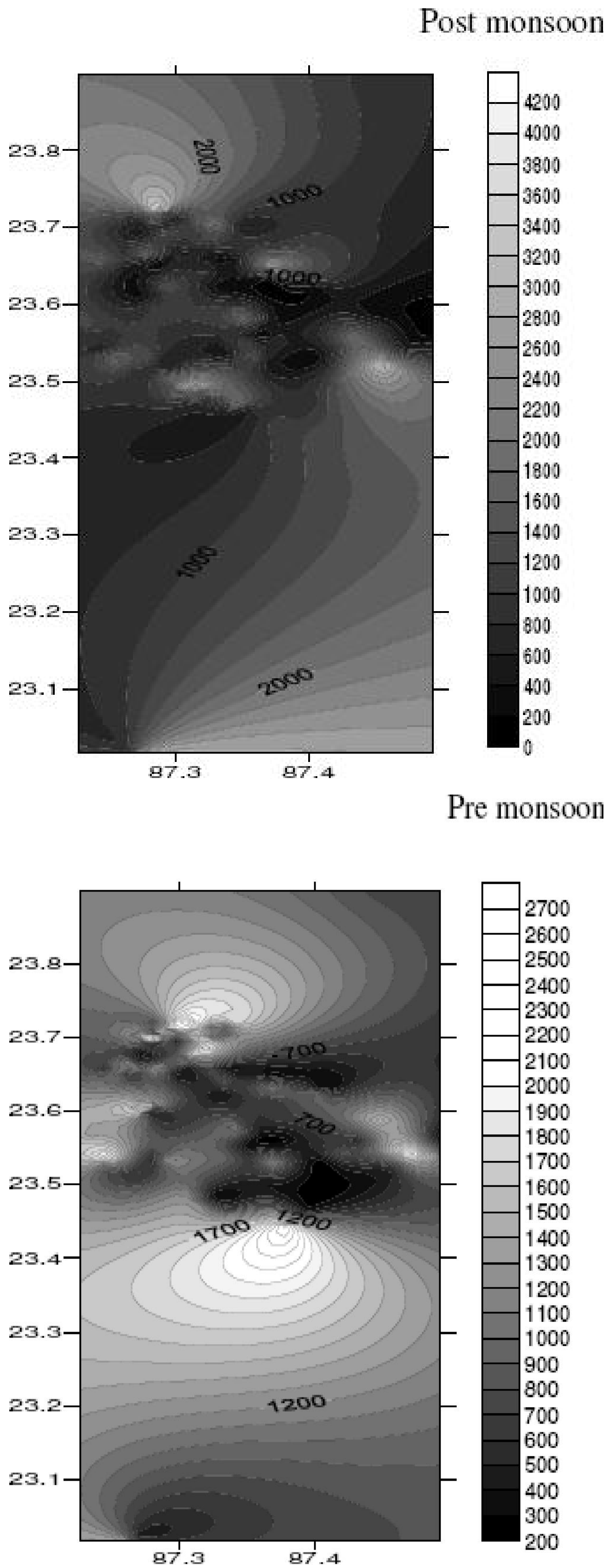

Figure 5a : Electrical Conductivity

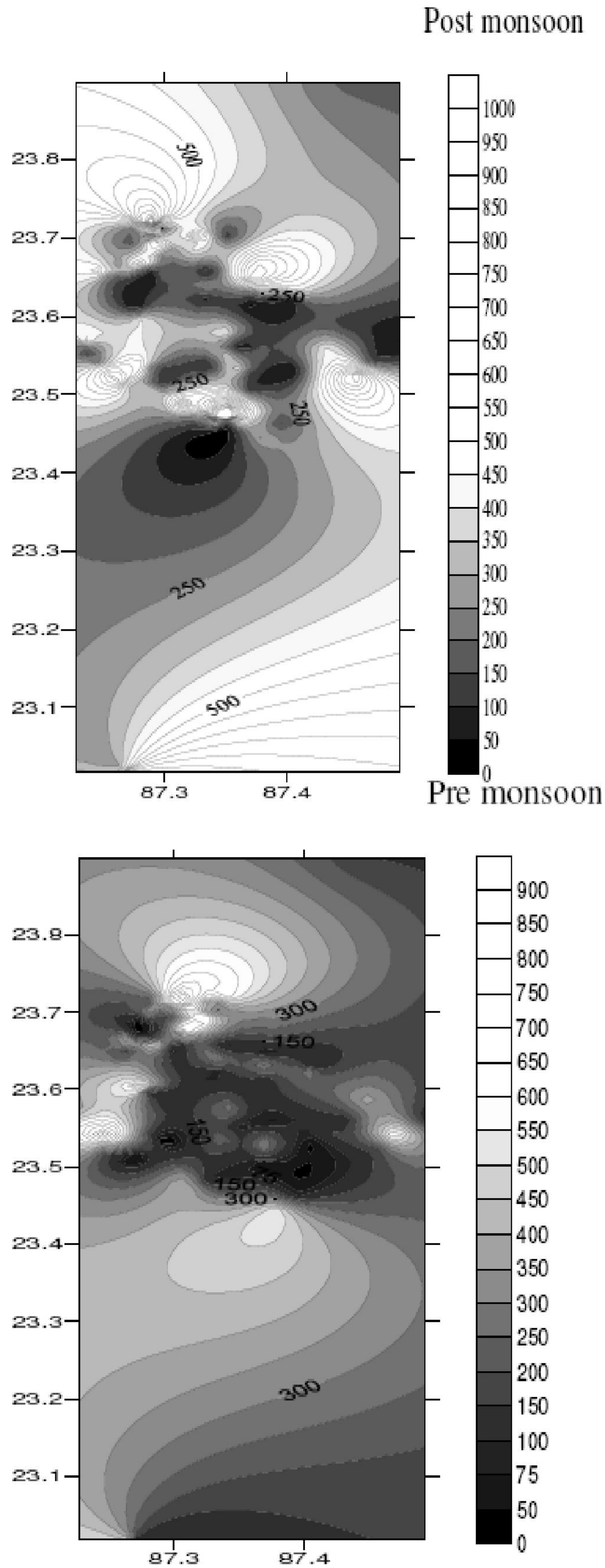

Figure 5b : Total Hardness

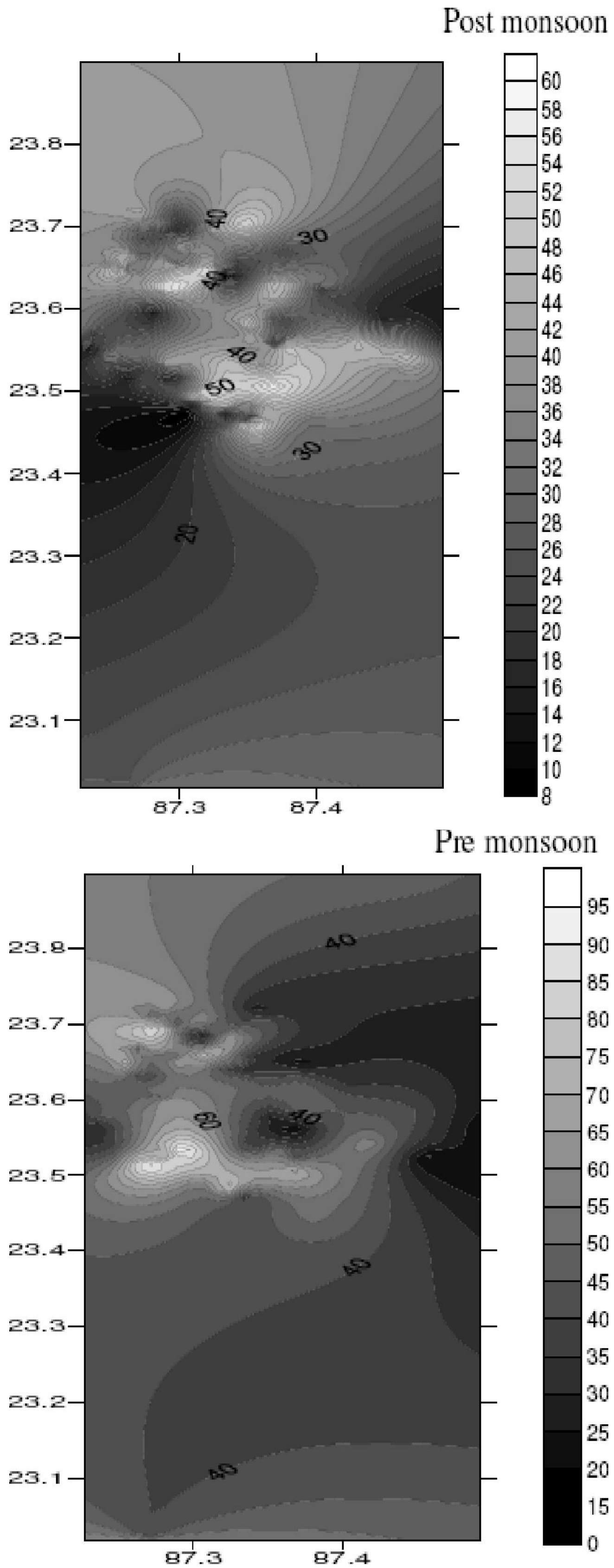

Figure 5c : Percent Sodium

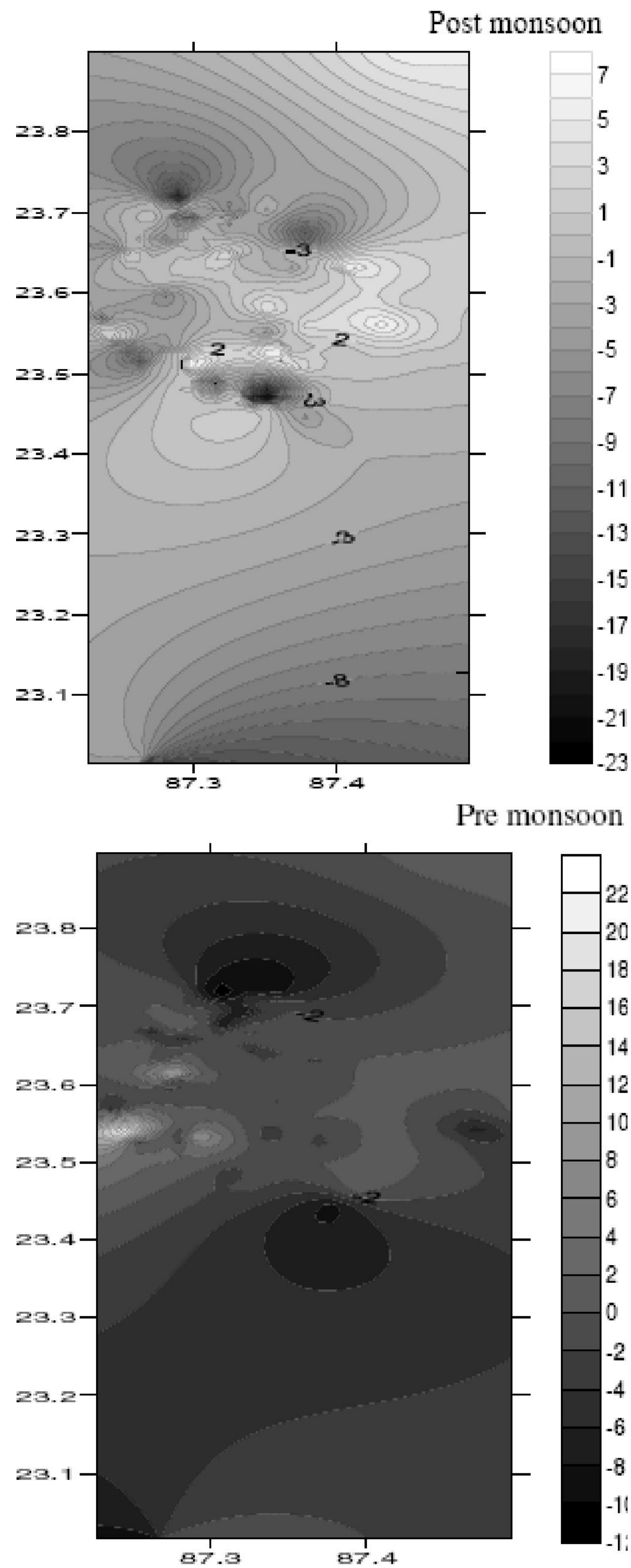

Figure 5d : Residual Sodium Carbonate

Figure 5 : Distribution of important chemical parameters for irrigation through the study area

TABLE 5 : Groundwater quality based on RSC (Residual Sodium Carbonate)

RSC (epm)	Remark on quality	Pre-monsoon samples	Post-monsoon samples
<1.25	Good	88 samples	96 samples
1.25-2.5	Doubtful	04 samples	11 samples
>2.5	Unsuitable	07 samples	12 samples

curs under water table conditions in the Panchet and Supra Panchet formation of Gondwana.

Such observation suggests that there is no significant effect of monsoon on hardness of groundwater. All the sampling points represent permanent hardness along with some temporary hardness.

Residual sodium carbonate (RSC) can be used as a criterion for finding the suitability of irrigation waters. According to the US Department of Agriculture[23], water having more than 2.5 epm of RSC is not suitable for irrigation purposes. RSC values of the groundwater of the present area for both pre- and post-monsoon seasons have been presented in TABLE 5. Based on RSC values, 88 samples (88% samples) of premonsoon RSC values less than1.25 and are considered safe for irrigation purpose. During post-monsoon 96 samples (i.e., 80.67% samples) were safe for irrigation.7 samples in the pre-monsoon and 12 samples in the post-monsoon with more than 2.5 epm RSC are unsuitable for irrigation. Increase in RSC may be increase due to lithological composition that is rich in bicarbonate. Water having excess carbonate and bicarbonate over alkaline earth mainly Ca, Mg in excess of allowable limits affects agriculture unfavourbly[8].

Knowledge of the various changes that occur brought about in the chemical composition of the groundwater during its travel underground is important[6, 14].

The ion exchange between the groundwater and its host environment during residence or travel can be understood by studying the chloroalkaline indices: CAI-I = [Cl – (Na + K)]/Cl and CAI-II = [Cl – (Na + K)]/(SO4 + HCO3 + CO3 + NO3)[11]. CAI is negative when there is exchange between sodium and potassium (Na + K) in water with calcium and magnesium (Ca + Mg) in rocks. If the ratio is positive, then there is no base exchange. CAI values (TABLE 6) indicate that 43 % and 73 % water samples show positive ratios in the pre and postmonsoon, respectively, while 57% and 27% of the respective seasons belong to negative ratios depicting the type of base exchange. Concentration of different parameters like electrical conductivity, total hardness, percent sodium and residual sodium concentration of groundwater are plotted in the form of shaded contours to show the overall distribution of those parameters in the study area (Figure 5a- d). The Figures represent a marked seasonal change in concentration of the parameters. Electrical conductivity and total hardness increase in premonsoon season (Figure 5.a-5.b) than postmonsoon. Places with lower total hardness in postmonsoon season changed to higher concentration in premonsoon season (Figure 5.b). Though monsoonal changes are also prominant in percent sodium concentration (Figure 5.c), moderate to high concentration of percent sodium is dominant in the area. Residual sodium carbonate concentration decreases in premonsoon season (Figure 5.d).

TABLE 6 : Chloro alkalinity index

	(CAI I) [Cl – (Na + K)]/Cl		(CAI II) [Cl – (Na + K)]/ (SO4 + HCO3 + CO3 + NO3)	
	-ve	+ve	-ve	+ve
Pre-monsoon samples	57%	43%	57%	43%
Post-monsoon samples	27%	73%	28%	72%

CONCLUSION

The water quality data from the study area for both pre and post monsson seasons revealed that almost all the samples in the study area are suitable for irrigation purposes. Based on Electrical conductivity, 43 % of 119 samples are very hard, 33% samples are hard and rest 24% represent soft to moderate type; in premonsoon, out of 99 samples collected 38 % are very hard, 32% are hard and rest 30 % samples are soft to moderate type. Greater sodium hazard in premonsoon season is suggested by Percent Sodium in the samples where almost 62.5% premonsoon samples are under permissible to doubtful category. Wilcox classification has shown that most of the samples of postmonsoon fall under the excellent to permissible category while two samples are under the permissible to doubtful category, five samples belong to doubtful to unsuitable category and two samples are of to unsuitable category. Though most of the premonsoon samples fall under excellent to permissible category, a large number of samples change to permissible to doubtful type. Eight samples fall into doubtful to unsuitable category and only one sample is unsuitable for irrigation purpose.

In terms of SAR values groundwater of both post and premonsoon are excellent for irrigation purpose. The positive values of chloro alkaline indices (CAI) are indicating a cation–anion exchange reaction and negative values indicating that the host rocks are primary sources of dissolved solids in the water. CAI (TABLE 6) indicate that 43 % and 73 % water samples have positive ratios in the pre and postmonsoon, respectively, while 57% and 27% of the respective seasons belong to negative ratios depicting the type of base exchange. Distribution of the groundwater samples in different subdivisions of rectangular diagram (Chadha diagram) reveals that about 45% of the groundwater samples in both seasons fall under the calcium–magnesium–bicarbonate category (such water has temporary hardness) and remaining samples fall under the calcium–magnesium–chloride (such water has permanent hardness) category. The seasonal variation in groundwater quality is due to agricultural and domestic activities and through infiltration and percolation during monsoon. Ground water suitability for agriculture depends on the effect of different mineral constituents of water on plant and soil. Soils can stop growth of plants physically and also damage plant growth chemically by effects of toxic substances upon metabolic process.

The US[29] salinity diagram illustrates that most of the groundwater samples fall in the field of C3S1, indicating high salinity and low sodium water, that can be used for irrigation on almost all type of soil with little danger of exchangeable sodium. According to RSC values, 88% and 80.67% samples are safe for irrigation in pre and postmonsoon season respectively. Overall groundwater quality map signifies groundwater of the study area being excellent to good in nature and absolutely safe for irrigation purpose though in some areas around coalmines and industries, the groundwater is doubtful to unsuitable for irrigation nature.

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