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Suitability of Groundwater Quality for Irrigation Purpose using Geographical Information System: A Case Study of Durg Block Chhattisgarh

Lov Kumar Gupta[1*], Kapil Verma[2] and Shruti Verma[2]

[1]Soil and Water Engineering, [2]Farm Machinery and Power Engineering, Masturi, Bilaspur, Chhattisgarh-495551, India

**Corresponding author*

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An attempt has been made to understand the ground water quality and its suitability for irrigation purpose through Geographical Information System. The qualities of groundwater in 646.8 km2 area of Durg block were assessed for its suitability for irrigation purposes. Groundwater samples data are analyzed for ionic concentration of $C0_3^{2}$, $HC0_3^{-}$, CI^{-}, $S0_4^{2-}$, Ca_2, Mg_2^{+},$Na^{++}$and K^{+}. Parameters such as electrical conductivity (EC), sodium absorption ratio (SAR), % Na and residual sodium carbonate (RSC) were evaluated. Thematic maps of different parameters were prepared and Samples were plotted on US Salinity Diagram and H. Wilcox's Diagram for better understanding of suitability of groundwater for irrigation purpose. The EC values of water samples were found to be within good to permissible limits. The lowest EC in groundwater samples was observed in Bhilai (554 µS/cm)and the highest in Durg (1593 µS/cm). The output of SAR shows 100 percent of the samples fall under excellent to good category. The irrigational water quality was classified based on US salinity diagram indicating that in 4 samples fall under low to moderate saline and 6 samples fall under low to medium high salinity. The Wilcox diagram shows 4 samples fall under excellent to good category and 6 samples fall under good to permissible category. Samples were analyzed for water quality parameters like % Na, PI, RSC and KI and suitability of groundwater samples for irrigation is good to permissible in almost all cases. Contour maps of pH, EC, SAR, % Na and RSC were plotted to study spatial variability of these parameters in the block which is helpful to assess the irrigational water quality of study area.

Introduction

Ground water is the water present beneath Earth's surface in soil pore spaces and in the fractures of rock formations. Groundwater has become the major source of water supply for domestic, industrial and agricultural sectors of our country. It constitutes about two thirds of the fresh water resources of the world. In India, it is a major source for all purposes of water requirements. It plays a vital role in the country's economic development and in ensuring its food security. More than 90% of rural and nearly 30% of urban population depend on ground water for drinking water. It also accounts for nearly 60% of the total irrigation potential in the country. Groundwater plays an important role in Indian agriculture. The suitability of irrigation water depends upon many factors including the quality of water, soil type, salt tolerance characteristics of the plants, climate and drainage characteristics of the soil.

The quality of groundwater is deteriorating due to urbanization, increasing population, and agricultural chemicals. In addition, the civil works, landslides, and the change in the rate of rain infiltration into ground water are affecting the quality adversely (Ramesh and Elango, 2012). Groundwater always contains small amount of soluble salts dissolved in it.

The kind and quality of these salts depend upon the sources for recharge of the groundwater and the strata through which it flows. The excess quantity of soluble salts may be harmful for many crops. Hence, a better understanding of the chemistry of groundwater is very essential to properly evaluate groundwater quality for irrigation purpose.

Demand of groundwater has been increasing day by day for irrigation by bringing more area under cultivation. The chemical composition of water is an important factor for domestic or irrigation purposes. Salinity and Pollution of well water, either from point or non-point sources, has become a thing of health concern both in urban and rural areas.

Features that generally need to be considered for evaluation of the suitability of groundwater quality for irrigation are the EC, SSP, TDS, RSC and SAR. The Most important cation and anion in a groundwater resources are Ca^{2+}, Mg^{2+}, Na^{+}, HCO^{3-}, Cl^{-} and NO^{3-}. Suitability of irrigation water, with respect to salinity, is assessed on the basis of the ‘Electrical Conductivity’ (EC) or ‘specific conductance’ of a water sample.

Salts in soil or water reduce water availability to the crop and excessive nutrients reduce yield or quality. A Geographical Information System (GIS) is a system of hardware, software and procedures to facilitate the management, manipulation, analysis, modeling, representation and display of geo- referenced data to solve complex problems regarding planning and management of resources. Functions of GIS include data entry, data display, data management, information retrieval and analysis.

Geographic information system (GIS) has emerged as a powerful tool for storing, analyzing, and displaying spatial data and using these data for decision making in several areas including engineering and environmental fields (Stafford 1991; Goodchild 1993; Burrough and McDonnell 1998; Lo and Yeung 2003).Conventional surveys, apart from being unfeasible in the inaccessible and inhospitable terrain are tedious, time consuming and inaccurate in mapping many features of regional nature due to lack of regional perspective.

GIS have been increasingly used for recharge estimation, draft estimation, mapping of prospective Zones, identification of over exploited and under developed/ undeveloped areas and prioritization of areas for recharge structures which conjunctively facilitate systematic planning, development and management of ground water resources on a sustainable basis.

The spatial distribution maps generated for various physicochemical parameters using GIS techniques could be useful for planners and decision makers for initiating ground water quality development in the area. The knowledge of irrigation water quality is critical to understand what management changes are necessary for long-term and short-term productivity, particularly for crops that are sensitive to changes in quality with an adequate database, GIS can be a powerful tool for assessing water quality, developing solutions for water resource problems, and it is a decision-making tool for agriculture development.

Materials and Methods

Description of study area

The study area is in the western central part of Chhattisgarh, dist. Durg and bounded by the coordinates 21º1′40.55″N to 21º21′56.03″N latitude and 81º8′53.88″E to 81º25′37.02″E longitude. It covers total geographical area 646.8 km^2. Climate of the study area is tropical type.

Summer is a little bit hotter. Rise of temperature begins from the month of March to May. May is hottest amongst other. Annual average rainfall is 1052 mm. During the year, most rainfall occurs during the monsoon June to September. July is the month of highest rainfall.

Survey of India (SOI) toposheets (f44p3, f44p4,f44p7 and f44p8 in 1:50000 scale) were used for the preparation of the base map. For analyzing the chemical aspects of groundwater in the study area, observation wells have been selected for investigation.

These observation wells are regularly maintained by CGWB NCCR Raipur Chhattisgarh. Water quality data are utilized in the present study to analyze the groundwater chemistry.

Samples are analyzed in the laboratory of NCCR Raipur Chhattisgarh for the major ions chemistry employing standards methods. The range of analyzed parameters presented in table-1.

Important parameters for determining the suitability of groundwater for irrigation purposes

Sodium adsorption ratio

It indicates the degree to which irrigation water tends to enter into cation-exchange reactions in soil. Sodium replacing adsorbed calcium and magnesium is a hazard as it causes damage to the soil structure and becomes compact and impervious. SAR is defined as:

$$SAR = \frac{Na}{\sqrt{(Ca+mg)/2}}$$

Where, all the ionic concentrations are in meq/l.

Percent Na

Sodium concentration plays an important role in evaluating the groundwater quality for irrigation as sodium increases the hardness of the soil and reduces its permeability. The SSP values are calculated using the formula given below:

$$\%Na = \frac{(Na + K)*100}{Ca + Mg + Na + K}$$

Where, all ionic concentrations are expressed in meq/l.

Residual sodium carbonate (RSC)

An excess amount of sodium bi-carbonate and carbonate is considered to be detrimental to the physical properties of soils as it causes dissolution of organic matter in the soil, which in turn leaves a black stain on the soil surface on drying. This excess amount is denoted by Residual Sodium Carbonate (RSC) and is calculated by the following formula:

$$RSC= (HCO_3^- + CO_3^{--}) – (Ca^{++} + Mg^{++})$$

where, all the ionic concentrations are expressed in meq/l.

Kelly's index (KI)

In Kelly's Ration (KR), sodium is measured against calcium and magnesium to determine the suitability of irrigation water. When KI is >1, it indicates higher sodium and vice versa. KI is calculated by using the formula:

$$KI = \frac{Na}{Ca+Mg}$$

where, all ionic constituents are expressed in meq/l.

Permeability index (PI)

The soil permeability is affected by long-term irrigation influenced by Na+, Ca2+, Mg2+ and HCO3 contents of the soil. The permeability index values also indicate the suitability of groundwater for irrigation. PI is calculated as follows:

$$PI = \frac{(Na + \sqrt{HCO_3})*100}{Ca + Mg + Na}$$

Where, all ionic concentrations are expressed in meq/l.

Results and Discussion

In present study, it has been found that the pH in the study area has shown variation from 7.3 to 8 Almost all samples were within maximum permissible limit prescribed by BIS for study area. Electrical Conductivity in groundwater varies from 554 to 1400µs/cm. Values of SAR,% Na, RSC, KI and PI highest in Marauda. Classification of Samples according to Standards specified for Water Quality Indices shows, for EC 40 % samples fall under good category and 60 % samples are fall under permissible range. % Na values of study area 30% sample fall under Excellent, 60 % under good and 10 % samples are fall under permissible class. The values of SAR, RSC, KI and PI fall under 100% suitable for irrigation.

Spatial distribution of physio-chemical parameters of groundwater

pH

The pH value of natural water is a measure of its alkanity or acidity and The pH value is a measure of hydrogen ion concentration. The pH value of groundwater in study area varies from 7.3 to 8.0 with an average of 7.65, which indicates that water is almost natural in nature.

Electrical conductivity (EC)

Conductivity is the measure of capacity of a substance to conduct the electric current. Most of the salts in water are present in their ionic forms and capable of conducting current and conductivity is a good indicator to assess groundwater quality. The EC in study area varies from 554 to 1593 with an average of 1073.5 $^{\mu}$S/cm at 25º C. The lowest EC in groundwater samples was observe in Bhilai and the highest in Durg. Location specific variability of EC in the block is shown by spatial variable Map.

Sodium (Na)

Na is the sixth most abundant element on Earth and is widely distributed in soils, plants, water and foods. Groundwater contained some Na because most rocks and soils contains Na compounds from which Na is easily dissolved Na concentration range 15.5 to 85 mg/l with an average of 50.25 mg/l.

Location specific variability of Na in the block is shown by spatial variable Map.

Magnesium (Mg)

Mg is the eighth abundant natural element. The Mg concentration ranges between 4 to 38 mg/l with an average of 21 mg/l. Location specific variability of Mg in the block is shown by spatial variable Map.

Potassium (K)

K is an element commonly found in soils and rocks. In water K has no colour or smell, but may give water a salty test. Sources of K include weathering and erosion of K bearing minirals such as feldspar and leaching of fertilizer. The K concentration ranges varies between 0.5 to 18.2 mg/l. with an average value 9.25 mg/l. Location specific variability of K in the block is shown by spatial variable Map.

Bicarbonate (HCO_3)

The primary source of HCO_3 ions in groundwater is the dissolved carbon dioxide in rain and snow, which as enters the soil dissolves more carbon dioxide. The pH of water indicate the form in which carbon dioxide is present in water. The HCO_3 concentration ranges varies between 98 to 317mg/l. with an average of 207.5 mg/l. Location specific variability of HCO_3 in the block is shown by spatial variable Map.

Residual sodium carbonate (RSC)

The RSC concentration ranges vary between -11.78 to 0.72. More than 100% sample fall under Low RSC of an area 646.8km^2. Location specific variability of RSC in the block is shown by spatial variable Map.

Sodium absorption ratio (SAR)

There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If groundwater used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. The SAR values ranges from 0.43 to 2.47 and according to SAR classification 100% of water sample fall in the excellent category and can be used for irrigation on almost all soils. A more detailed analysis of the suitability of water for irrigation was made by plotting the data on US Salinity Laboratory diagram.

US salinity laboratory diagram

In order to assess the US Salinity laboratory (1954) has adopted an irrigation water classification based upon SAR and EC. The C and S classification adhere to the description of the diagram draw on semi log paper with SAR on ordinary scale. This classification is extensively used worldwide and consists of 16 groups of irrigation water C_1S_1, C_2S_2, S_2C_1, S_2C_2 etc. Based on the SAR values, all samples have low sodium hazard and on plotting over the U.S. Salinity diagram the water samples of study area fall in the C_2S_1classes and C_3S_1classes and hence can be consider suitable for irrigation with low sodium hazard and medium to high salinity hazard.

Percent sodium (%Na)

%Na in Groundwater is an important parameter in deciding the suitability of water for irrigation as Na reacts with soil resulting in decreasing permeability of soil. The % Na values ground water range from 10 to 45.

The %Na values in study area fall 30% in excellent class, 60% in good and 10% in permissible class. In the present investigation, the spatial distribution map (Fig.4.9) indicates that the “Excellent” cover an aerial extent of 267.05 km^2 and “Good” covers an aerial extent of 313.6 km^2 and “Permissible” cover an aerial extent of 53.3 km^2

H. Wilcox’s diagram

Another method for determination of suitability for agricultural use in groundwater is by calculating %Na (Wilcox,1955), because Na+ concentration reacts with soil to reduce its permeability (Todd, 1980).Percentage of sodium values of groundwater samples indicate that the four groundwater samples show Excellent to Good or 6 samples Good to Permissible category for irrigation use.

Suitability of groundwater for irrigation purposes

The groundwater quality of Durg block of Durg District, Chhattisgarh has been assessed for its suitability for irrigational purposes. The study has also demonstrated the utility of GIS technology combine with laboratory analysis in evaluation and mapping of groundwater quality in block. Hydro chemical facies analysis as well the pH of water, both indicates that groundwater in the area is natural in condition. The electrical conductivity values of water samples are found to be within good to permissible limits during sampling sessions.

Table.1 Chemical Analysis Results (2015)

S No.	Location	Lat.	Long.	pH	EC	TH	Na	K	Ca	Mg	HCo_3	Co_3
1	Ravelidih	21.3	81.3	7.3	578	250	15.5	0.6	78	13	128	Nil
2	Maroda	21.2	81.3	7.6	792	225	85	0.7	50	24	317	Nil
3	Anda	21.1	81.3	7.5	1400	525	58	4.5	182	17	256	Nil
4	Jeora-sirsa	21.3	81.3	7.7	788	310	38	18.2	104	12	195	Nil
5	Ganiyari	21.2	81.2	7.6	1127	465	21.7	1.3	122	38	244	Nil
6	Konari	21.2	81.3	8	704	250	49.7	1	94	4	268	Nil
7	Durg	21.2	81.3	7.5	1593	670	40	4	230	23	98	Nil
8	Utai	21.1	81.4	7.5	810	315	35.9	0.5	110	10	201	Nil
9	Bhilai	21.2	81.4	7.5	554	170	41.4	2.9	60	5	104	Nil
10	Kachandur	21.3	81.3	7.6	740	290	36	1.5	68	29	250	Nil

Table.2 Irrigation water quality parameters

Sl.	Location	pH	EC	SAR	SSP	%Na	RSC	KI	PI%
1	Ravelidih	7.3	578	0.43	11.94	12	-2.87	0.14	37.61
2	Marauda	7.6	792	2.47	45.23	45	0.72	0.83	73.13
3	Anda	7.5	1400	1.1	19.37	20	-6.3	0.24	35.1
4	Jeora-sirsa	7.7	788	0.94	21.07	25	-2.99	0.27	43.88
5	Ganiyari	7.6	1127	0.44	9.28	10	-5.23	0.1	28.94
6	Konari	8	704	1.36	30.05	30	-0.64	0.43	59.21
7	Durg	7.5	1593	0.67	11.49	12	-11.78	0.13	19.87
8	Utai	7.5	810	0.88	19.8	20	-3.02	0.25	42.82
9	Bhilai	7.5	554	1.38	34.54	35	-1.71	0.53	59.59
10	Kachandur	7.6	740	0.92	21.29	22	-1.69	0.27	48.83

Table.3 Classification of Samples according to Standards specified for Water Quality Indices

Parameters	Range	Class	Number of sample	% of sample
EC	< 250	Excellent	0	0
	250 - 750	Good	4	40
	750 - 2000	Permissible	6	60
	2000-3000	Doubtful	0	0
	> 3000	Unsuitable	0	0
SSP	< 20	Excellent	3	30
	20 - 40	Good	6	60
	40 - 60	Permissible	1	10
	60 -80	Doubtful	0	0
	> 80	Unsuitable	0	0
RSC	< 1.25	Low	10	100
	1.25 – 2.5	Medium	0	0
	> 2.5	High	0	0
SAR	0 - 10	Excellent	10	100
	10 -18	Good	0	0
	18 -26	Permissible	0	0
	> 26	Doubtful	0	0
MAR	≤ 50	Suitable	10	100
	> 50	Unsuitable	0	0
KI	< 1	Suitable	10	100
	> 1	Unsuitable	0	0
PI	25% - 75%	Suitable	10	100
	> 75%	Unsuitable	0	0

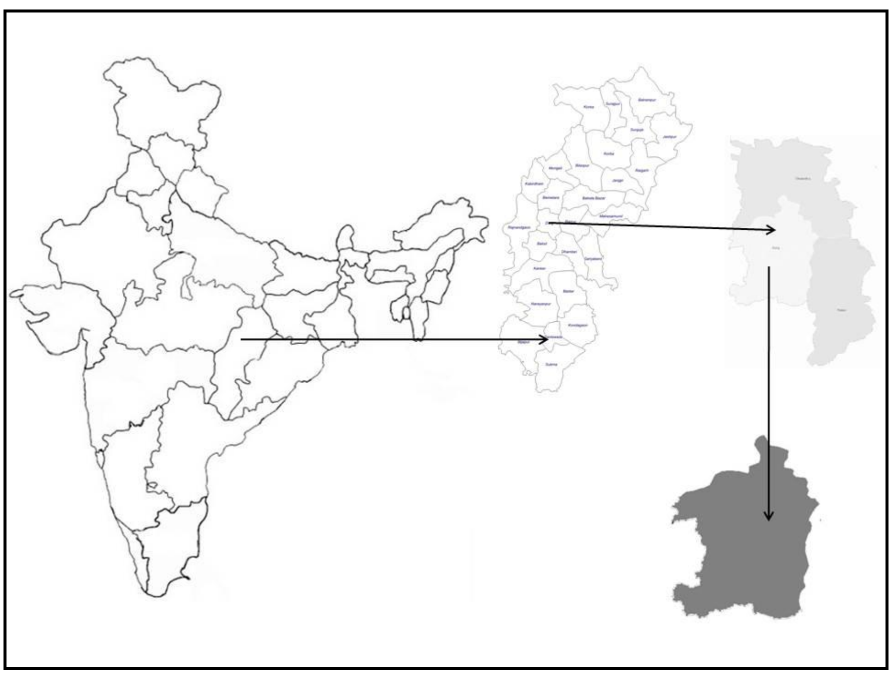

Fig.1 Map of the study area

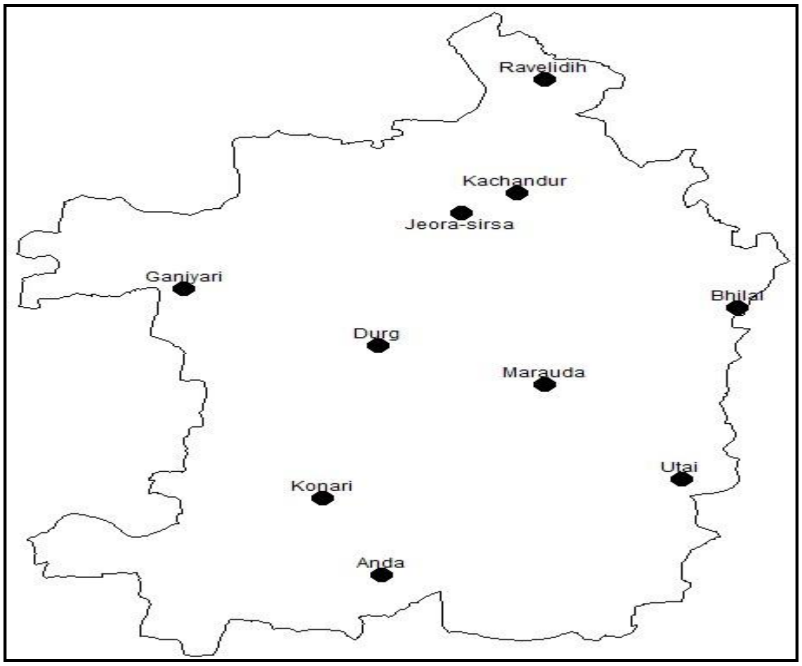

Fig.2 Location map of sampling point in Durg block

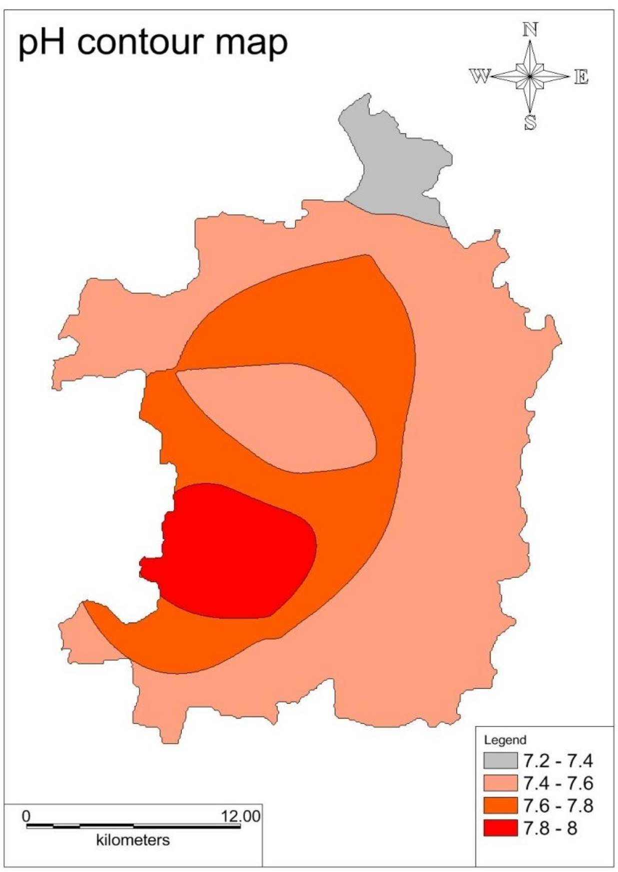

Fig.3 Spatial Distribution of pH

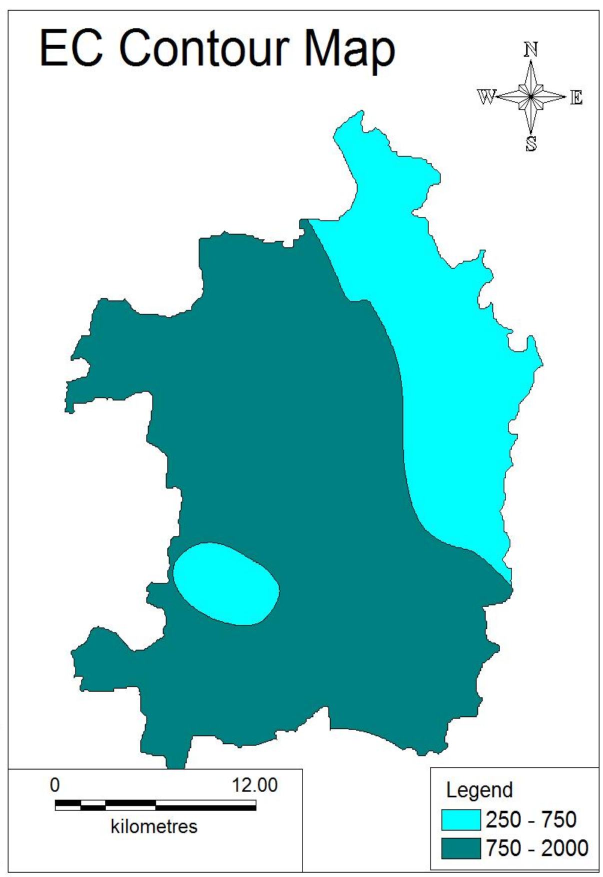

Fig.4 Spatial Distribution of EC

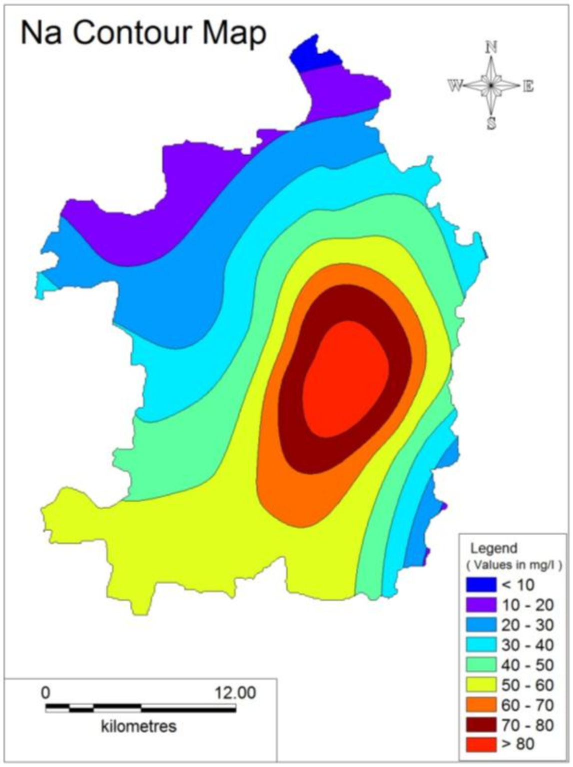

Fig.5 Spatial Distribution of Na

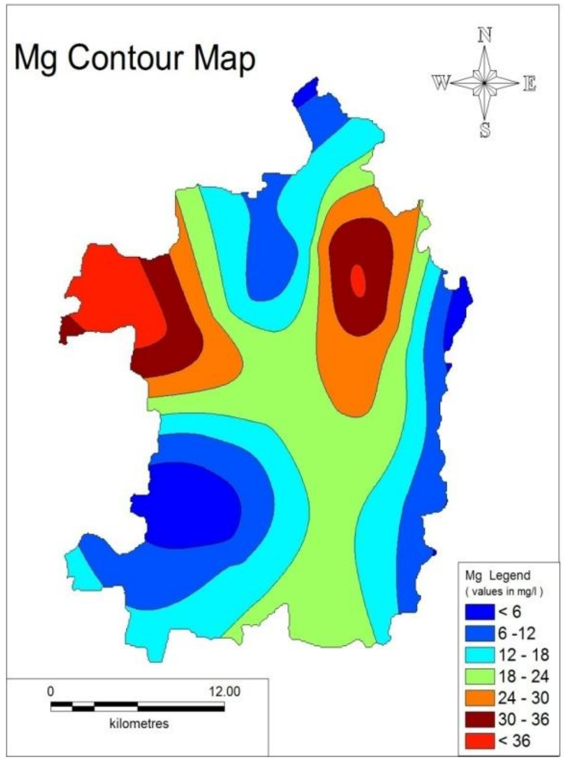

Fig.6 Spatial Distribution of Mg

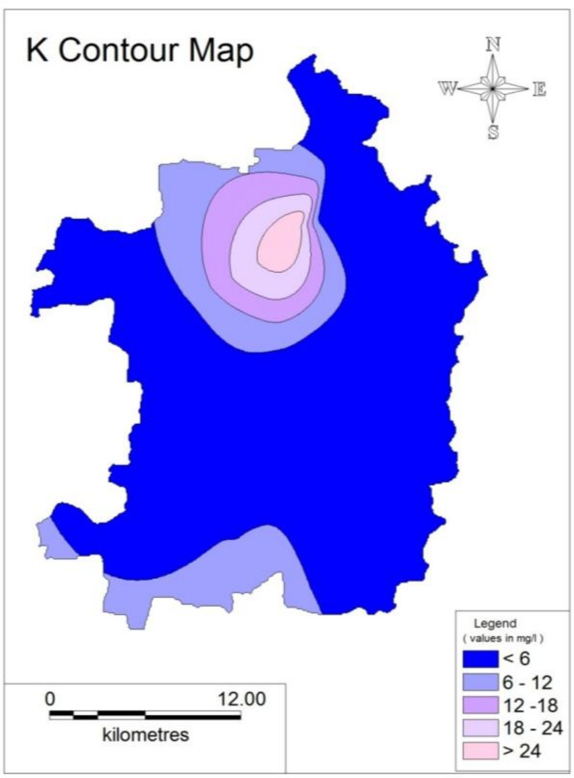

Fig.7 Spatial Distribution of K

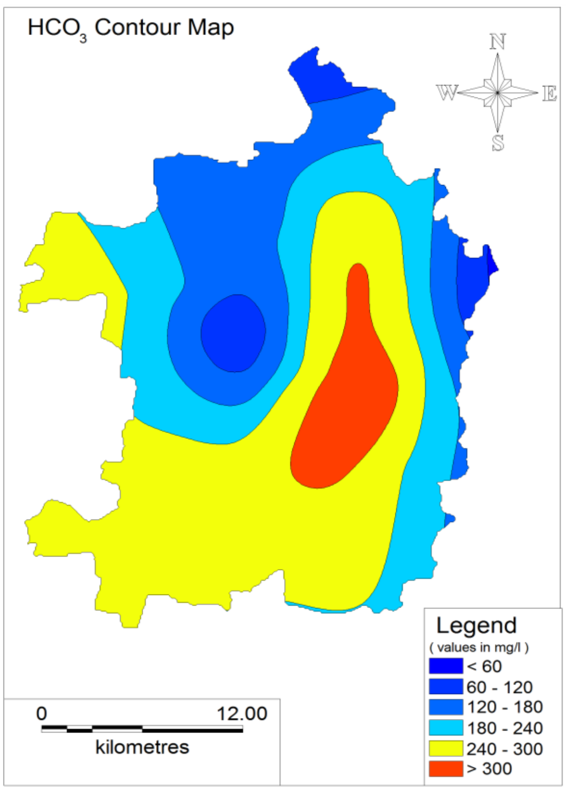

Fig.8 Spatial distribution of HCO_3

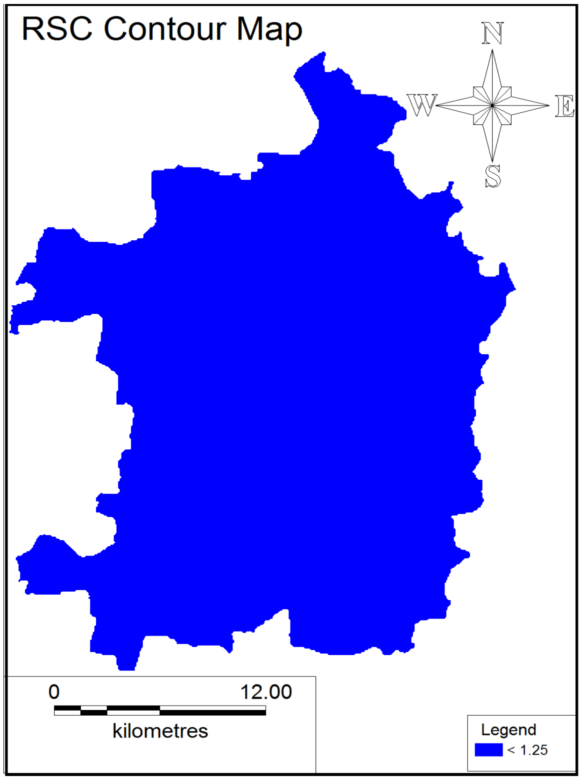

Fig.9 Spatial distribution of RSC

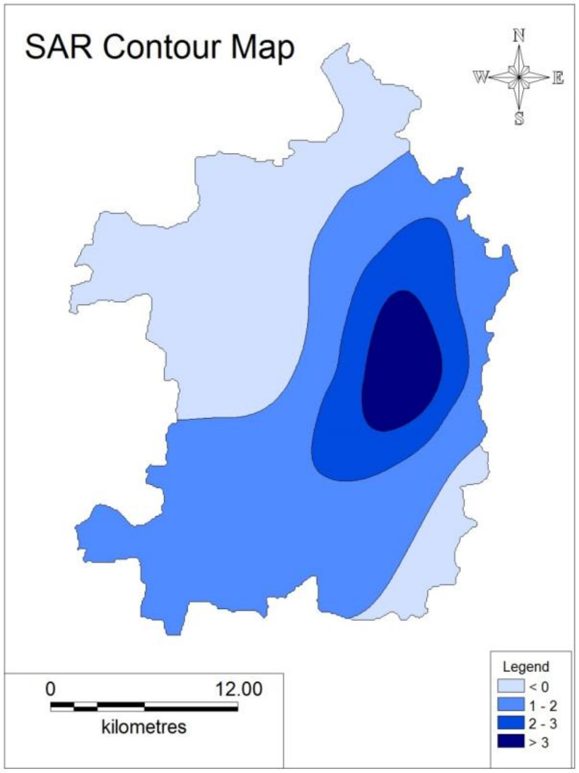

Fig.10 Spatial distribution of SAR

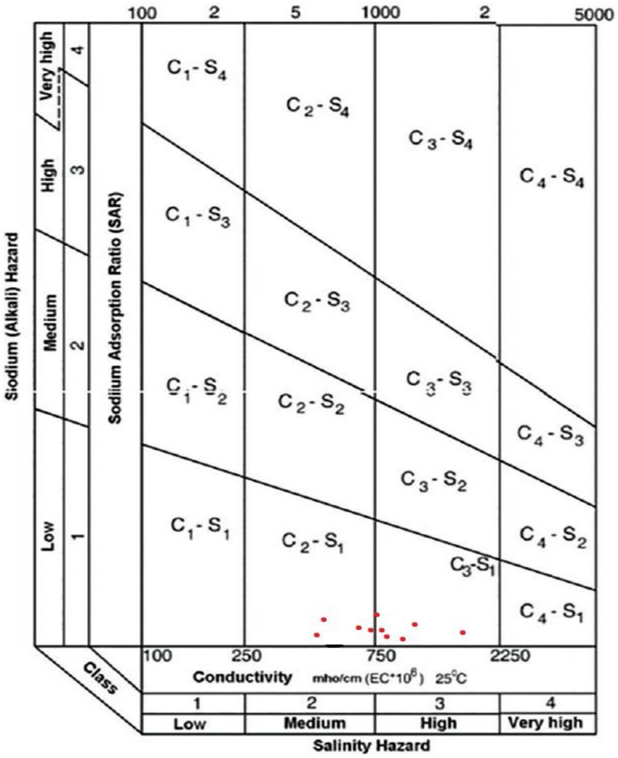

Fig.11 US Salinity Diagram

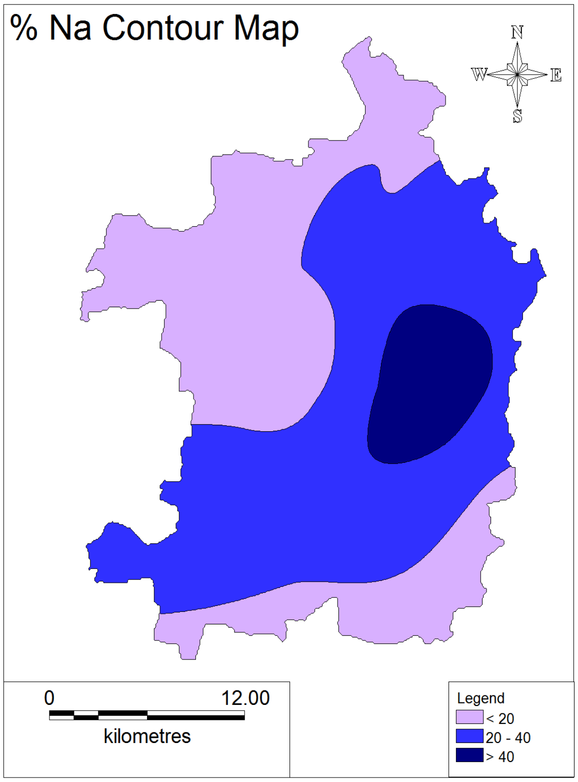

Fig.12 Spatial distribution of %Na

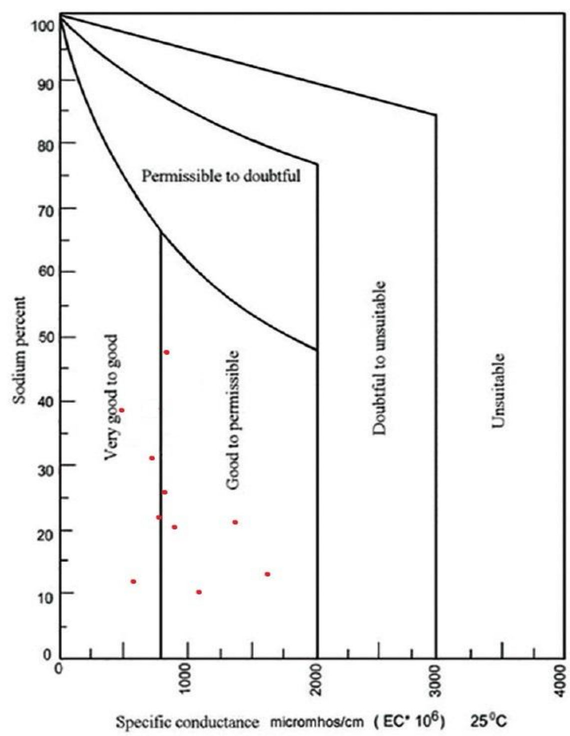

Fig.13 H. Wilcox's Diagram

The EC in study area varies from 554 to 1593 with an average of 1073.5 μS/cm. The lowest EC in groundwater samples was observe in Bhilai and the highest in Durg. The output of SAR shows 100 per cent of the samples fall under excellent to good category.

The irrigational water quality was classified based on US salinity diagram indicating that in 4 samples fall under C_2-S_1 class which shows low to moderate saline and 6 samples fall under C_3-S_1 class which shows low to medium high salinity. The Wilcox diagram shows 4 samples fall under excellent to good category and 6 samples fall under good to permissible category.

Based on the water quality parameters analyzed like %Na, PI, RSC and KI the suitability of groundwater samples for irrigation is good to permissible in almost all cases.The groundwater will neither cause salinity hazards nor have an adverse effect on the soil properties and are thus largely suitable for irrigational purpose.

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