International Journal of Advanced Research and Development
ISSN: 2455-4030, Impact Factor: RJIF 5.24
www.advancedjournal.com
Volume 1; Issue 6; June 2016; Page No. 04-07

Mapping of hydrochemical facies of an urban area: A case study of Raipur City, Chhattisgarh, India

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Abstract

Raipur, the capital city of Chhattisgarh is located between 21° 10' and 21° 21' N latitudes and 81° 32' to 81° 44' E longitudes. The city has an area of around 193 sq. km. Physiographically the area is situated in the South Central part of Chhattisgarh basin having gentle undulating topography. The area is underlain by limestone, shale and sandstone of Chhattisgarh Supergroup of rocks which form the major aquifers in the area. Groundwater samples from 29 locations in the city were collected during pre-monsoon period of 2010 and were analysed for major ion concentrations. Hydrochemical facies mapping in the area shows that the groundwater in the area is not much evolved and the predominant water type in the area is Ca-HCO_3 type.

Keywords: Groundwater, Hydrochemical facies, Cations and Anions

Introduction

Distinct zones within aquifers having defined water chemistry properties are referred to as hydrochemical facies (Freeze and Cherry, 1979). Determining the nature and distribution of hydrochemical facies can provide insights into how ground-water quality changes within and between aquifers. The graphical representation of hydrogeochemical data of an area provides a useful tool for visually describing differences in major-ion chemistry in groundwater flow systems. Hydrochemical facies mapping involves two steps; first groundwater samples are classified using a proper classification scheme and then they are plotted on a map in the form of separate regions representing different water types. The study area covers Raipur, the capital city of Chhattisgarh along with its outgrowths which lies between 21° 10' and 21° 21' N latitudes and 81° 32' to 81° 44' E longitudes with an area of around 193 sq. km. Physiographically the area is situated in the South Central part of Chhattisgarh basin having gentle undulating topography. This paper is an attempt to delineate hydrochemical facies using the methods of Piper (1944) and Walton (1970).

Hydrogeological Setup of the Study Area

Raipur is situated on Proterozoic Chandi Formation of Raipur group (Chhattisgarh Super Group), comprising of limestone, shale and sandstone which is at places intruded by dolerite intrusives. Chandi Formation comprises of horizontal to gently dipping Niwari stromatlitic limestone and Deodongar shale and sandstone member. The limestone is generally massive to thickly bedded, jointed, karstic in nature showing fractures, solution cavities and sink holes. Deodongar member overlies the limestone. Deondonger member consists of khaki to purple colored shale, inter-bedded with layers of sandstone. The sandstones are ortho-quartzite with siliceous cement and ferruginous coating, compact, thinly to thickly bedded. The sandstones are generally covered with lateritic soil. The geology of the area is presented in fig. 1.

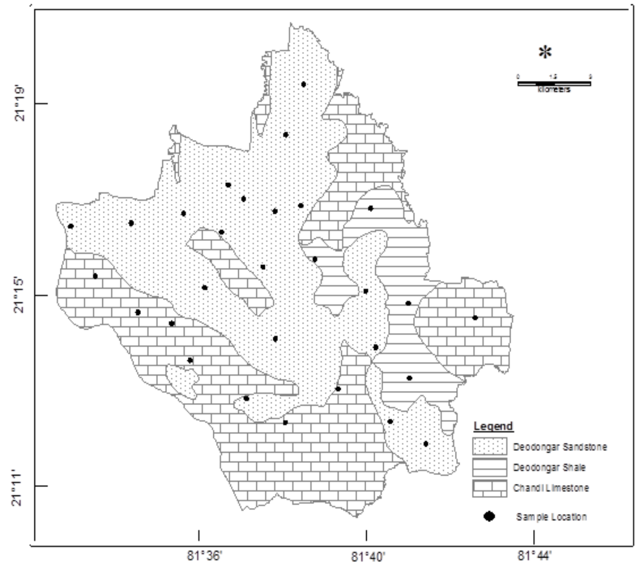

Fig 1: Geology and sample location

Limestone, shale and sandstone of Chandi Formation comprise the major aquifers in the area. Ground water in Chandi Formation occurs both under phreatic and semi-confined to confined condition. The water level during the pre-monsoon period varies between 1.92 m bgl and 14.3 m bgl in the phreatic zone During the pre-monsoon period, in the phreatic aquifer, maximum number of wells i.e. 45% shows depth to water (DTW) in the range of 5 to 10 m bgl; 17% show DTW in the range of 0 to 3 m bgl; 13% show DTW in the range of 3 to 5 m bgl and 25% of wells show DTW in the range of 10 to 15 mbgl. Similarly, the water level in the phreatic zone during the post-monsoon period varies between 1.7 m bgl and 8.9 m bgl. During the post-monsoon period, in the phreatic aquifer, 53% of wells have water level within 3 m bgl, 29% of wells have DTW in the range of 3 to 5 m bgl; and 18% have DTW in the range of 5 to 10 m bgl.

Materials and Method

The study is based on 29 groundwater samples representing the study area collected during May 2010. The samples were analysed in the laboratory of regional office of Central Ground Water Board (Ministry of Water Resources, Govt. of India) situated at Raipur, Chhattisgarh. The samples, in general are low in total dissolved solids. Charge Balance Errors (CBE) was calculated for all the samples and only those with CBE within ± 10 % were considered for interpretations.

The formula for calculation of CBE (Freeze and Cherry, 1979) is Table: Summary of chemical analysis and charge balance error

$$CBE = \frac{\sum meq_c - \sum meq_a}{\sum meq_c + \sum meq_a} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where meq_c and meq_a represent the concentrations in millequivalents per litre of cations and anions respectively.

Table: Summary of chemical analysis and charge balance error

Parameters	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	CO_3 (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	CBE %
n	29	29	29	29	29	29	29	29	29
Min	20	2	4	1.7	11	0	122	0	-3.46
Max	250	54	240	7.4	422	9	366	575	7.18
Mean	79.17	19.86	61.62	3.29	103.86	0.72	188.48	90.21	1.43
SD	51.16	11.18	46.25	1.57	81.17	2.07	59.52	105.53	2.67

Before plotting on the trilinear diagram, the concentrations of the six ions of interest are converted into milliequivalents per liter (meq/L). Each cation value is then plotted, as a percentage of the total concentration (meq/L) of all cations under consideration, in the lower left triangle of the diagram. Likewise, individual anion values are plotted, as percentages of the total concentration of all anions under consideration, in the lower right triangle. Sample values are then projected into the central diamond-shaped field. Fundamental interpretations of the chemical nature of a water sample have been done based on the location of the sample ion values within the central diamond field.

Subsequently, maps of individual cation and anion with relative percentage more than 50% have been prepared in GIS environment. The final hydrochemical facies map of the area is prepared by overlaying cation and anion maps.

Results and Discussion

Walton (1970) described a simple but useful classification scheme that divides the central part of the diagram into five subdivisions. In the first four of these subdivisions, the concentration of a specific cation-anion combination exceeds 50 percent of the total milliequivalents per liter (meq/L). Five basic hydrochemical facies can be defined with these criteria:

1. Primary Hardness; Combined concentrations of calcium, magnesium and bicarbonate exceed 50 percent of the total dissolved constituent load in meq/L. Such waters are generally considered hard and are often found in limestone aquifers or unconsolidated deposits containing abundant carbonate minerals.
2. Secondary Hardness; Combined concentrations of sulfate, chloride, magnesium and calcium exceed 50 percent of total meq/L.
3. Primary Salinity; Combined concentrations of alkali metals, sulfate and chloride are greater than 50 percent of the total meq/L. Very concentrated waters of this hydrochemical facies are considered brackish or (in extreme cases) saline.
4. Primary Alkalinity; Combined sodium, potassium and bicarbonate concentrations exceed 50 percent of the total meq/L. These waters generally have low hardness in proportion to their dissolved solids concentration (Walton, 1970).
5. No specific cation-anion pair exceeds 50 percent of the total dissolved constituent load. Such waters could result from multiple mineral dissolution or mixing of two chemically distinct ground-water bodies.

The plotting of samples on the Hill-Piper diagram (fig. 2) shows that almost all the samples fall in the 2nd and 5th fields of the central diamond shape indicating two major hydrochemical facies in the area. This shows that half of the samples which fall in the 2nd field of the central diamond shape have secondary hardness where combined concentrations of sulfate, chloride, magnesium and calcium exceed 50 percent of total meq/L. The rest half of the samples fall in the 5th field of the diamond shape indicating no specific cation-anion pair exceeds 50 percent of the total dissolved constituent load. Such waters could result from multiple mineral dissolution or mixing of two chemically distinct ground-water bodies. A few samples fall in the 3rd field of the central diamond shape which is indicative of higher concentration of alkali metals, sulfate and chloride.

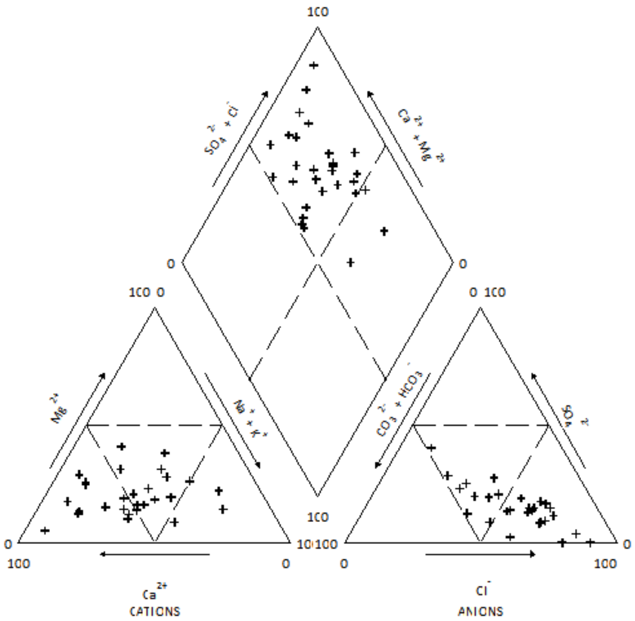

Fig 2: Piper plot of the samples

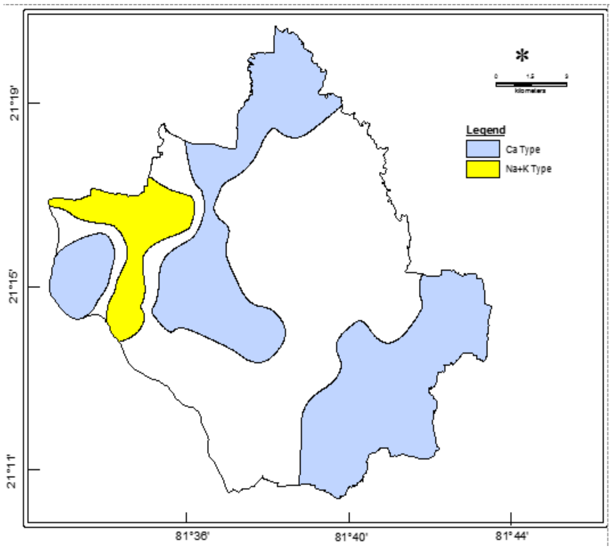

Fig 3: Cation map

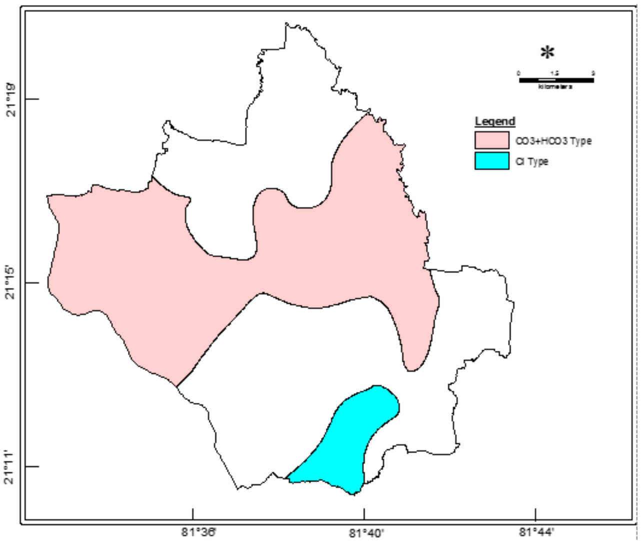

Fig 4: Anion map

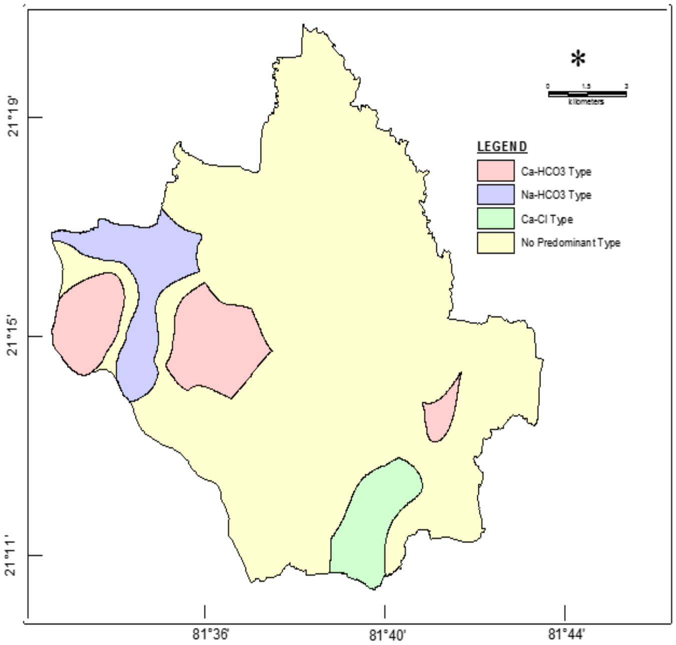

Fig 5: Hydrochemical facies map

Based on the relative percentage of cations and anions there are nine possible types of water that can be found in any area. The possible types of water are given in the table 1**.** The water which does not fall into any of these nine categories is termed as no-predominant type. From these nine possible classes, three types of water are found in the study area. The resultant cation, anion and hydrochemical facies map of the area are presented in fig. 3, 4 & 5. From the figures it is evident that Ca-HCO$_3$ type of water is the most predominant one which covers 9.8 % of total area, followed by (Na+K)-HCO$_3$ type which covers 6.2 % area and Ca-Cl type covers 4.1 % of the area. "No predominant" is the most common type of water which has the maximum areal extent of 79.8 %. From the areal extent of different water types in the area, it is evident that the water in the area is not much evolved.

Table 1: Possible water types

S. No.	Relative Percentage of ions						Water Type
	Ca	Mg	Na+K	HCO$_3$	SO$_4$	Cl	
1	> 50	-	-	> 50	-	-	Ca-HCO$_3$ type
2	> 50	-	-	-	> 50	-	Ca SO$_4$ type
3	> 50	-	-	-	-	> 50	Ca-Cl Type
4	-	> 50	-	> 50	-	-	Mg-HCO$_3$ type
5	-	> 50	-	-	> 50		Mg SO$_4$ type
6	-	> 50	-	-	-	> 50	MgCl type
7	-	-	> 50	> 50	-	-	Na-HCO$_3$ type
8	-	-	> 50	-	> 50	-	Na SO$_4$ type
9	-	-	> 50	-	-	> 50	NaCl type

Conclusion

Occurrence and movement of ground water in the area is controlled mainly by fractures and solution cavities in the shale, sandstone and limestone. "No predominant" type water is the most common type of water available in the area followed by Ca-HCO$_3$ type of water. Large areal extent of no predominant type water in the area shows that the water in the area is not much evolved.

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