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A Comparative Study on Usage of Piper and Durov Diagrams to Interpret Hydro Chemical Processes in Groundwater of Bichhiya Tehsil, Mandla District, Madhya Pradesh, India

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***Abstract*: In the present study, an attempt has been made to evaluate and identify hydro geochemistry of groundwater and the responsible mechanism/hydrochemical processes in the study area, using Piper, Durov and Gibbs diagrams. The dominant hydro chemical facies is Mixed type identified by both methods/diagrams. Piper's diagram indicated the dominance of mixed water type while Durov specified the dominance of simple dissolution or mixing with no dominant major anion or cation in the groundwater samples. Gibbs diagram reflected the dominance of weathering of source rocks in the study area. Thus, both the diagrams signify non-identification of the water types with neither the dominance of anion nor the dominance of cations. Dominance of mixed facies suggests that the fresh water is the ground water resource in the study area.**

***Keywords*: piper diagram, durov diagram, mixed type, dissolution, gibbs diagram, weathering**

1. Introduction

The primary source of water is groundwater or subsurface water. It is used for domestic, agricultural and industrial uses. The contamination of groundwater has been recognized as one of the most serious problems (Belkhiri et al., 2010). The paper discusses the hydro chemical facies and the mechanism responsible for the dominant water type prevailing in the study area. The groundwater quality has been discussed with special reference to fluoride. Geogenically, the groundwater quality is dependent on the nature of bedrock, topography, geology, soils, climate, atmospheric precipitation and quality of the recharged water. Groundwater quality could also be affected further by means geochemical reactions such as weathering, dissolution, precipitation, ion exchange and various biological processes taking place beneath the surface (Todd, 1980; Sakram et al., 2013). Hydro chemical facies are the distinct zones that have cation and anion concentration of diagnostic chemical character of water solutions in hydrologic systems, which can be described within defined composition categories. It can signify the chemical character of water in a particular area. The facies reflect the effect of complex hydro-chemical processes occurring in the subsurface (Sajil Kumar, 2013) between the minerals constituting the lithological unit and groundwater. It plays a vital role in identifying the spatial variability of groundwater chemistry in terms of hydro chemical evolution. The Piper trilinear diagram (Piper, 1944) evaluates the evolution of the river water and the relationship between the rock types and water composition while Durov diagram is advantageous over the Piper diagram in revealing some geochemical processes that could affect groundwater genesis (Lloyd and Heathcoat, 1985). The present study is aimed at hydro geochemical study and it involves presentation of geochemical data in the form of graphical charts like Piper and Durov diagrams to assess the geochemical processes controlling the water chemistry and to delineate variation in hydro chemical facies. Further, the various physicochemical parameters are used to generate zonation map to delineate vulnerable zones in the study area.

2. Study Area

The study area, Bichhiya Tehsil of Mandla District, Madhya Pradesh, India extends within 22o 0' to 23o 0' N Latitude and 80o 15' to 81o 50' E Longitude (Survey of India Toposheet No. 64 B/6, 64 B/7, 64 B/10, 64 B/11, 64 B/14, 64 B/15, 64 F/2, 64 F/3) and is severely affected by fluoride contamination. The total area of Bichhiya Tehsil is 2759 sq. km. It is hilly and densely forested. The major part of the study area is almost a gentle undulating landscape with a linear strap of hills running in almost east- west direction. dividing the region into equal halves. The region has a plain interspersed with isolated low hills. The climate is tropical with moderate winter and severe summers and well distributed rainfall received from southwest monsoon. The oldest rock formations exposed in the area are the granite gneiss, granulite and migmatites belonging to the Precambrian Basement of Archaean age. The geological formations found in the area comprises of a basement of granite gneiss, granulite of Precambrian age overlaid by the basaltic rocks of Deccan traps.

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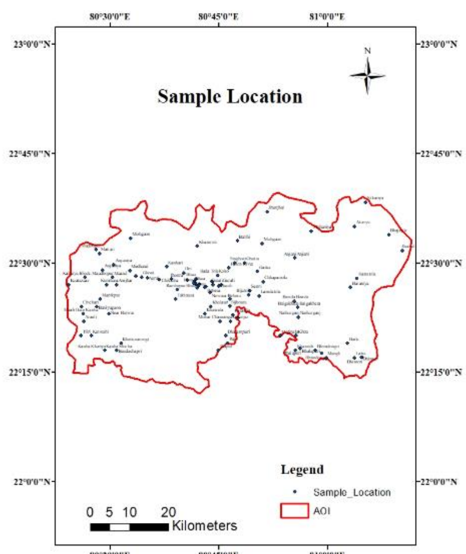
3. Material and Method

A total of 110 water samples are collected from different bore wells, within the study area and the spatial (longitude, latitude and elevation) details are recorded and located in map using GIS (Map 1). A hand-held Garmin GPS is used to note the well location of the samples with respect to latitude, longitude and altitude. The Physico-Chemical analysis is conducted in accordance with the standards of American Public Health Association APHA (1995). The results obtained are evaluated in accordance with the drinking water standards prescribed as IS: 105000 (BIS 1998). The physico-chemical data of the groundwater samples of the study area is subjected to graphical treatment by plotting them in Piper Trilinear Diagram (Figure 1) and Durov diagram (Figure 2) using Rockware16 software for better understanding of hydro geochemistry, water quality and its evaluation by comparing the water types. Gibbs Diagram is plotted to analyze the mechanism/ hydro geochemical processes prevailing in the study area.



Map. 1. Sample Locations in the Study area

4. Results and discussion

The major sequence of cation dominance in the groundwater of the study area has the order $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ (Table 1). The major cations concentration (Na^+, Ca^{2+}, Mg^{2+}, K^+) in all the groundwater samples are within the permissible limits of BIS (1998) and WHO (1996, 2004) for drinking water standards. The major sequence of anion dominance in ground water of the study area has the order $HCO^-_3 > Cl^- > SO_4^{2-} > CO^-_3 > F^-$. Concentration of HCO^-_3 is highest in the groundwater samples followed by Cl^-, SO_4^{2-} and F^- in the order of decreasing abundance. The hydrochemical parameters along with the range and average are given in Table 1.

The chemical analysis data of the groundwater samples of the study area, indicates that Fluoride is the only constituent in the groundwater samples of the study area that is in excess and is above the permissible limit of 1.5 mg/l. Fluoride is imperative in little quantity to supply necessary minerals for the development of bones and tooth enamel (Bell and Ludwig, 1970); (Fung et al., 1999); (Shomar et al., 2004). The presence of Fluoride, in quantities both less or excess of limits is a serious matter of concern from public health point of view. In India, 19 states are found to have high concentration of Fluoride in underground water (CGWB, 2010). Areas with semi-arid climate, crystalline igneous rocks and alkaline soils are mostly affected by high Fluoride (Handa, 1975). In other words, bedrock mineralogy, is in general, the primary factor for the variations in Fluoride content of groundwater (Chae et al; 2007). The contamination of groundwater with Fluoride is a function of different factors like pH, concentration of calcium and bicarbonate ions in groundwater etc. (Chandra et al., 1981; Largent, 1961).

Table 1
Range and Average of hydrochemical parameters
(all concentration in mg/L except pH and EC)

Parameter	Minimum	Maximum	Mean/Average
EC	34	1501	431.48
pH	6.85	8.85	7.85
F	0	6	0.97
Ca	5	72	34.30
Mg	4	55	16.66
Na	58	91	75.96
K	0.6	1	0.82
CO_3	0	22	9.70
HCO_3	60	360	179.13
Cl^-	0	200	74.52
SO_4	0	66.6	20.14
TDS	39	747	225.86
Total Hardness	32	440	170.94

5. Hydro geochemical facies

In India and various parts of the world, numerous studies have been carried out to assess the geochemical characteristics of groundwater (Graniel et al. 1999; Umar and Sami Ahmad, 2000).

The geochemical evolution of groundwater can be better understood by constructing Piper (1944) trilinear diagram and Durov (1948) plot. Therefore, the hydrochemical data of the analyzed samples collected from the study area are plotted on Piper Trilinear and Durov diagram using Rockwork16 software, for visual comparison, delineation of hydrochemical facies and type deduction of mechanism that controls the geochemistry of groundwater in the study area.

The Piper trilinear diagram illustrates the relative concentrations of cations (left diagram) and anions (right diagram) in each sample. For the purpose of a Piper diagram, the cations are grouped into three major divisions: Sodium (Na^+) plus Potassium (K^+), Calcium (Ca^{++}), and Magnesium (Mg^{++}). The Anions are similarly grouped into three major categories: Bicarbonate (HCO_3^-) plus Carbonate (CO_3^{--}), Sulfate (SO_4^{--}), and Chloride (Cl^-). Each sample will be represented by a point in each trilinear diagram. Concentrations entered in the source data file in units of milligrams per liter are converted to milli-equivalents per liter for display on the diagram.

The diamond field is designed to show both anion and cation groups. For each sample, a line is projected from its point in the cation and anion trilinear diagrams into the upper region; where the lines intersect, the symbol is plotted. Circles may be plotted around each point to illustrate total dissolved solids ("TDS") for the sample. The total dissolved solid computation will include all components listed in the data file ("standard" ions and additional ions).

In contrast, Durov diagram is a composite plot consisting of 2 ternary diagrams where the milliequivalents percentages of the cations of interest were plotted against that of anions of interest; sides form a central rectangular, binary plot of total cation vs. total anion concentrations.

Both the diagrams reveal similarities and differences among water samples because those with similar qualities will tend to plot together as groups (Todd, 2001). In Piper diagram, it is the data plotted on the subdivisions of diamond-shaped field that decides the water type / hydrochemical facies in a water sample. Contrast to this, in Durov diagram, intersection of lines extended from the points in ternary diagrams and projected on the sub-divisions of binary plot defines the hydrochemical processes involved along with the water type present in the study area.

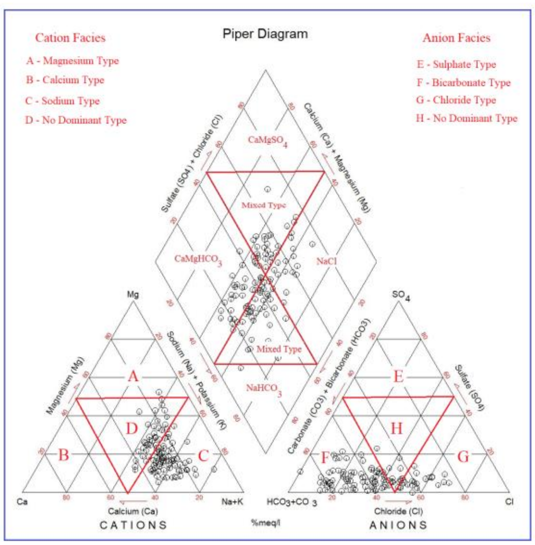


Fig. 1. Piper Diagram (Piper;1944) of Groundwater Samples of the Study Area

Based on Piper Diagram (Figure 1), the dominant water type in the study area is Mixed type (Piper, 1944). Most of the samples fall in mixed type hydrochemical facies and limited samples are clustered in Calcium-Magnesium-Bicarbonate (Ca^{++}- Mg^{++} - HCO_3^-) and Sodium Chloride (NaCl) segments. It is also apparent from the diagram that majority of the samples belong to mixed water type where water types cannot be identified as either anions or cations dominant Dominance of mixed facies suggests that the ground water is fresh water.

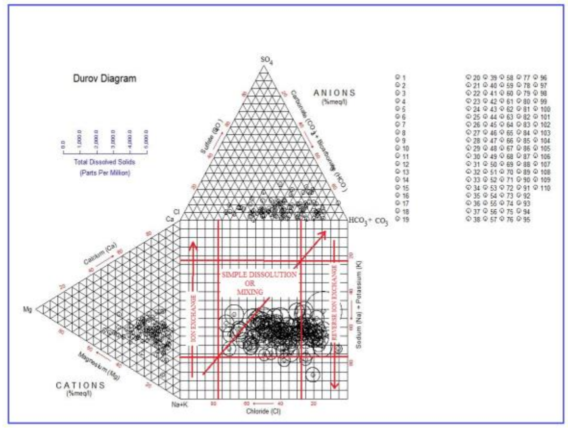


Fig. 2. Durov plot depicting hydrochemical processes involved (Lloyd and Heathcoat (1985)

The fact that mixed water type prevails in the study area is also supported by data plotted on Durov diagram (Figure 2), where majority of the samples plot along the simple dissolution or mixing line (Lloyd and Heathcoat, 1985). Based on the classification of Lloyd and Heathcoat (1985), this trend can be attributed to fresh water recharge exhibiting simple dissolution or mixing with no dominant major anion or cation. Few samples show Cl and Na as dominant anion and cation respectively, indicating that the ground waters be related to reverse ion exchange of Na-Cl waters. Saxena and Ahmed (2003), based on a study of geochemical parameters of groundwater and rock samples from 58 fluoride-rich areas in different parts of India, pointed out that the dissolution process determines the fluoride concentration in groundwater rather than an abundance of fluoride-bearing minerals in the host rocks.

6. Mechanism controlling geochemistry

The distribution of groundwater sample point largely in the central part of Gibbs (1970) plot based on ratios of (Na+K)/(Na+K+Ca) and Cl/(Cl+HCO3) as a function of TDS, reflected the dominance of weathering of source rocks with some influence of evaporation crystallization in controlling the geochemistry of water samples from the study area (Figure 3a and 3b). None of the data points lie in the lower-right side of the boomerang, where water composition is dominated by atmospheric precipitation process. Mukherjee and Singh (2018) have reviewed the various studies on fluoride in groundwater and discussed the contaminant mechanisms.

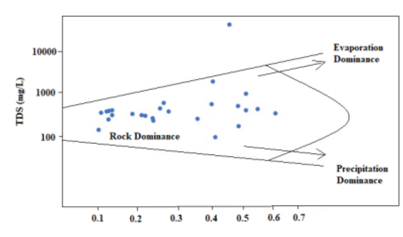


Fig. 3(a). Gibbs Diagram showing the mechanism controlling the dominant anions in Groundwater of the study area

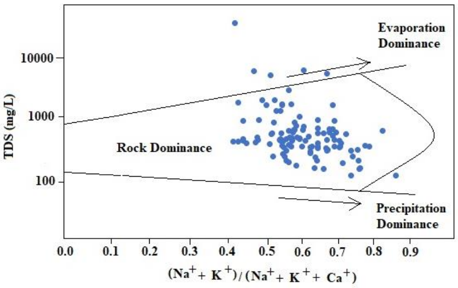


Fig. 3(b). Gibbs Diagram showing the mechanism controlling the dominant cations in Groundwater of the study area

7. Conclusion

Results of the hydrochemistry suggest that the dominant hydro chemical facies in the study area is Mixed Type. Groundwater types assessed and compared with Durov and Piper diagrams illustrated that simple mineral dissolution or mixing process is mainly responsible for variation in hydro geochemistry of groundwater in the study area. According to Gibbs diagram, the water quality in the study area is controlled by the weathering of host rocks with some influence of evaporation-crystallization. The excessive concentration of Fluoride in the groundwater samples of the study area can be attributed to the weathering (Ramesam, V. and Rajagopalan, K., 1985) of host rocks i.e. Precambrian crystalline basement and the circulation/mixing of this geogenically fluoridated water with overlying basaltic aquifer of Deccan Trap (Singh et al. 2019). In the study area, the groundwater samples with high Fluoride content is not recommended for drinking purpose especially children under the age of 7 and expecting/lactating mothers.

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