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Safeguarding the Human Health and Agriculture: A Multiparameter Assessment of Groundwater Quality and its Hydrochemical Characterization in Chhatarpur Tehsil, MP, India

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Abstract: Examining the groundwater quality for drinking and irrigation purposes is critical for human health. The study was carried out in the Chhatarpur tehsil of Madhya Pradesh, India. 18 water samples were collected from different locations in the Chhatarpur tehsil. Various physiochemical parameters were examined such as pH, turbidity, TDS, electrical conductivity, cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) and anions (Cl^{-}, SO_4^{2-}, CO_3^{2-}, HCO_3^{-}, F^{-}, NO_3^{-}) to assess the suitability of groundwater for drinking purposes. To check suitability for agriculture, SAR, KR and USSL diagram were used. The pH, TDS, and EC were found to be within safe limits although turbidity was ranging above the safe limit. The suitability of groundwater for drinking was found to be safe, with slight deterioration in a few pockets of the study area where F^{-} and NO_3^{2-} exceeded the safe limit. KR, SAR and USSL diagram suggest suitable water for agriculture. To understand the hydrochemical type of groundwater Piper and Chadha plots were used. Rock-water interaction was found in the study area according to Gibbs Plot. To check the anthropogenic factors involved in determining groundwater chemistry, a bivariate plot of TDS vs NO_3+ Cl/ HCO_3 was used. This research can help to provide a long-term water resource management strategy for this study area.

Keywords: Groundwater quality, Hydrochemical type, Suitability, GIS, Thematic mapping.

1. Introduction

Society is consuming groundwater without the proper knowledge of its suitability for drinking and agriculture. Many contaminants which are present in the groundwater originate from geogenic factors such as the dissolution of naturally occurring minerals in the crust of the earth (Subba Rao et al., 2020). The quality of groundwater is controlled by the property of aquifer rock and soil (Acheampong & Hess, 1998). Different physicochemical properties of the groundwater are being controlled by different hydrochemical processes

(Bhuiyan et al., 2016). As the population, infrastructure and industrialization are increasing at a rapid pace there is an involvement of non-geogenic factors which is causing deterioration in the quality of the groundwater. Blue baby Syndrome, Chlorosis, Cancer, and stone are very few of the numerous examples of diseases/disorders which can be caused by contaminated water consumption. The WHO (CUMINGS, 1962) suggests that 80% of diseases in the human body are waterborne. In developing and developed countries water is the most important factor causing illness and infant mortality (Jones & Watkins, 1985). Infants and children are more prone to the effects of contaminants than adults (Zhou et al., 2021). Approximately 260 million people around 28 countries suffer from Fluorosis (Ayoob & Gupta, 2006). Nitrate is a very well-known environmental pollutant that arises both naturally and anthropogenically (Rahman et al., 2021). According to the BIS standard, 45 mg/L is the safe limit for nitrate intake in the groundwater. Calcium is essential for human body functions although its high-level intake can lead to kidney stones and other disorders. Like calcium, magnesium is essential as well for the human body, low amounts of Mg^{2+} in water can lead to heart attack-like threats (Rosanoff, 2013). Health issues such as high blood pressure, cardiovascular disease, and kidney problems can result from the intake of high concentrations of Sodium (He & MacGregor, 2009). Over-exceeding levels of sodium can lead to fatal heart issues. Excessive concentrations of potassium may lead to serious kidney and heart problems. The excess intake of Fluoride causes fluorosis, the weakening of bones, and several other lethal malfunctions in the body (Saleem et al., 2016). A case report shows 3 infants suffering diarrhoea due to a sulphate concentration of 630-1150 mg/L (Chien et al., 1968). Groundwater plays a significant role in domestic and irrigational purposes in India (Chakraborty et al., 2022). In India, agriculture contributes about 16% of total GDP and ten 10% of total exports (Wagh & Dongre, 2016). According to a study, almost 80% of groundwater is consumed for domestic use and 50% of groundwater is for irrigation purposes (Kundu & Nag, 2018). High groundwater salinity is one of the causes of soil salinization (Wu et al., 2014). Agricultural land can suffer from barrenness from using unsuitable water for a long period.

Hence, to find out the quality of the groundwater we must test the physiochemical parameters of the groundwater so we can get an idea of the condition of the water which is being consumed by the population of that specific area. After acquiring the data, the values needed to be compared against the standard that should determine whether the sample water is suitable for consumption. This standard suggests acceptable limits and permissible limits in the absence of an alternate source (BIS, 2012) and WHO guidelines.

2. Materials and Methods

2.1.Study Area

The study area is a Tehsil named Chhatarpur, in Chhatarpur district which is in the central portion of the plateau of Bundelkhand in M.P, India. Bundelkhand is one of the regions in India which suffers from scarcity of water (Pant et al., 2021). The study area covers an area of 1058.89 km^2 having a recharge area of 933.89 km^2 with thin soil cover (Mathur & Paramasivam, 2018), laying between north latitudes 24˚ 48' and 24˚ 58' and east longitude 79˚ 21' and 79˚42'. The study area is a part of the Archean-Paleoproterozoic Bundelkhand Granitoid Complex, having coarse-grained porphyritic granite, medium and fine-grained granites, granite gneiss, migmatites, and syenite (Figure 1). Archean rocks present in the study area consist of hard rocks which lead to poor permeability and hence forming poor aquifers (Central Ground Water Board, 2022).

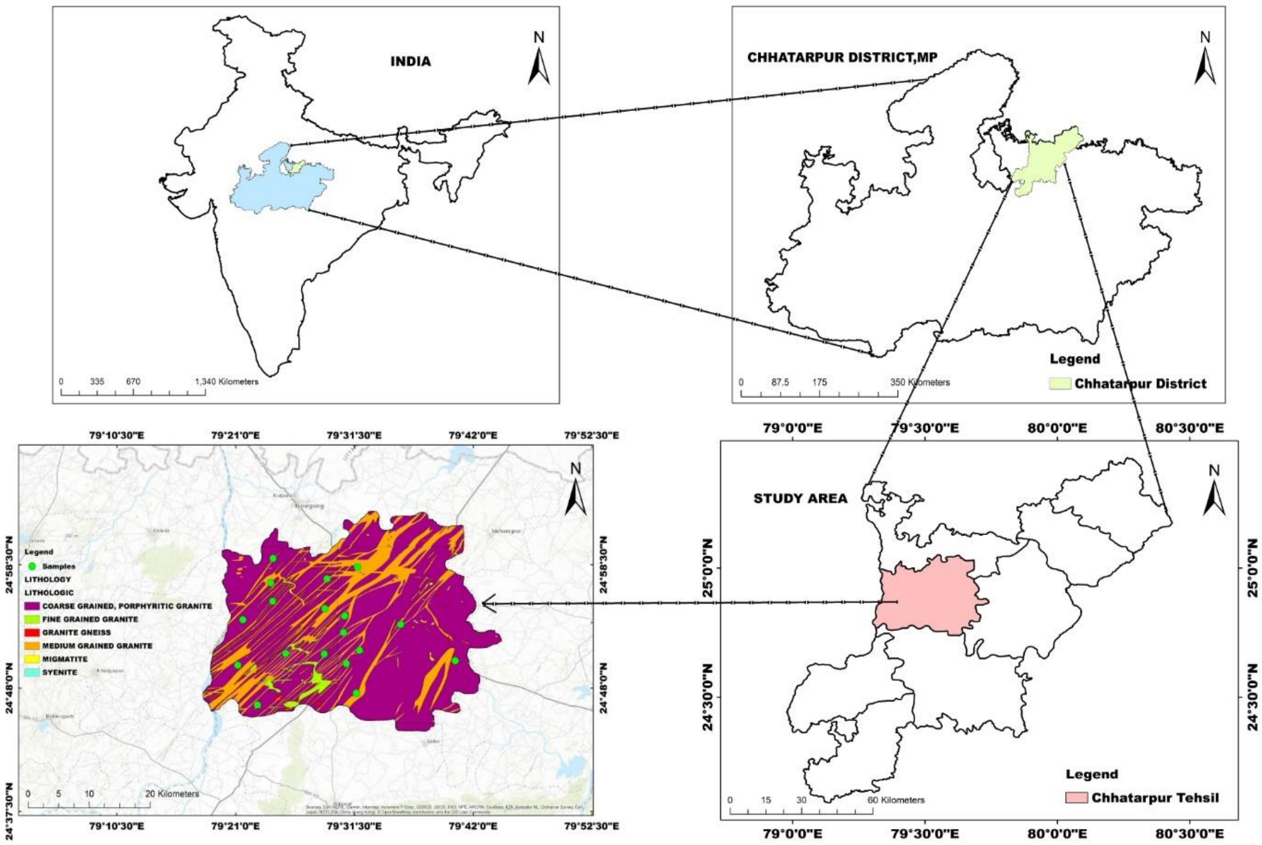


Figure 1: Study Area.

2.2.Sample collection and its analysis

A total of 18 groundwater samples were collected during January 2024 post-monsoon season. The HDPE (High-Density Polyethylene) sampling bottles were used to collect the samples and marked with respective code names along with recording their GPS location during sampling. A flame photometer (BWB, U.K) was used to analyze the cations (Ca^{2+}, K^{+} and Na^{+}), and Mg^{2+} analysis was done using an atomic absorption spectrometer (AAS). CO_3^{2-} and HCO_3^{-} analysis was done through titration using hydrochloric acid, phenolphthalein, and methyl orange indicator. Titration analysis was also used for Cl^{-} using silver nitrate. Nitrate and Fluoride analysis using sensitive electrodes. The portable meter was used to measure pH, TDS, and Conductivity. To analyze sulphate, HI 96751C portable sulphate photometer was used. The Piper triplot was prepared by the Golden Software Grapher and other graphs were prepared using MS Excel.

2.3.GIS operations

ArcGIS (Ver.10.7.1) was used to carry out the spatial analysis of the multi-parameters examined in this study. An inverse distance weighted (IDW) interpolation technique was used in which the IDW calculates the values of each grid note by examining the surrounding data points within a user-defined search radius (Burrough & McDonnell, 1998). MS Excel and Grapher software were used to generate different plots.

3. Results and Discussion

The maximum, minimum and average concentration of the various physiochemical parameters is mentioned in Table 1. The cation concentration was Ca^{2+}>Na^{+}> Mg^{2+}> K^{+} and anions concentration was found to be HCO_3^-> Cl^->SO_4^{2-}>NO_3^->CO_3^{2-}>F^-. A correlation matrix was prepared (Table 2; Green colour for positive and Red for negative correlation) to understand the correlation between the physiochemical parameters assessed. A strong positive correlation between EC and Nitrate suggests salinity may be controlled by nitrate. A positive correlation between Nitrate and Magnesium and Nitrate and Chloride suggests deterioration in the groundwater quality due to infiltration of the wastewater.

Table 1: The statistics of the physiochemical parameters examined in this study.

PARAMETERS	MAXIMUM VALUE	MINIMUM VALUE	AVERAGE VALUE
pH	7.74	6.6	7.11
TDS (mg/L)	1090	150	497.7
EC (µS/cm)	2180	300	954.4
Turbidity (NTU)	93.33	0	20.47
Sodium (mg/L)	191	0.7	42.76
Potassium (mg/L)	174	0.1	5.45
Calcium (mg/L)	310.5	3.2	94.15
Magnesium (mg/L)	93.4	3.2	30.48
Chloride (mg/L)	208.46	4.25	69.8
Fluoride (mg/L)	2.22	0.15	0.75
Nitrate (mg/L)	69.17	2.29	19.16
Carbonate (mg/L)	240	0	16.17
Bicarbonate (mg/L)	366	24.4	224.6
Sulphate (mg/L)	102	2	33.26

Table 2: Correlation matrix of the groundwater samples(Green colour for Positive and Red colour for negative correlation)

	Turbidity (NTU)	*pH*	*TDS (ppm)*	*EC*	*Ca*	*Mg*	*Na*	*K*	*CO3*	*HCO3*	*SO4*	*Cl*	*F*	*NO3*
Turbidity (NTU)	1													
pH	0.167811	1												
TDS (ppm)	-0.19546	-0.30067	1											
EC	-0.13379	-0.2796	0.942678	1										
Ca	-0.25259	-0.2907	0.835849	0.793914	1									
Mg	0.125693	-0.04771	0.690792	0.671069	0.299888	1								
Na	-0.1758	0.010949	0.466945	0.46445	0.128875	0.366298	1							
K	-0.1022	-0.24539	0.10444	0.08403	-0.01479	0.083834	0.12345	1						
CO3	0.632592	0.448425	0.012695	0.030683	-0.12063	0.304452	-0.05353	-0.05312	1					
HCO3	-0.55584	-0.10366	0.268797	0.241331	0.256067	0.269704	0.092442	0.298159	-0.59649	1				
SO4	-0.40278	-0.37291	0.887852	0.856471	0.643498	0.588206	0.642713	0.158101	-0.28836	0.421634	1			
Cl	-0.292	-0.34131	0.928874	0.888245	0.764813	0.557055	0.544681	0.054421	-0.10469	0.156697	0.912219	1		
F	-0.20548	0.337041	0.25344	0.294307	-0.00447	0.246483	0.677257	-0.18173	-0.06652	0.216928	0.455074	0.272731	1	
NO3	-0.14757	-0.46739	0.785512	0.755196	0.792098	0.383605	-0.01058	0.26869	-0.07259	0.198189	0.662686	0.722046	-0.13819	1

3.1.Drinking Suitability

The pH of groundwater is a measure of its acidity or alkalinity. A pH of 7 is neutral, while values below 7 indicate acidity and values above 7 indicate alkalinity. Changes in pH can affect the solubility and obtainability of many chemicals in groundwater. Each pH number represents 10-fold changes in acidity/basicity i.e., a sample with a pH of 5 is 10 times more acidic than the pH of 6. According to BIS 2012, the range of pH values suitable for drinking purposes is 6.2-7.5. The pH values lie within the range of 6.6-7.11 in the study area. (Figure 2a). Turbidity is a measure of the cloudiness or haziness of groundwater caused by suspended particles such as clay, silt, organic matter, and microorganisms. High turbidity levels can affect water quality and aesthetics, as well as indicate potential contamination. The higher the value of suspended density the higher the level of turbidity (Azis et al., 2015). The acceptable limit for TDS is 1NTU (Nephelometric Turbidity Unit) and 5 NTU permissible limit as per BIS standard 2012, in the study area the turbidity exceeded the permissible limit in 55.55% of the samples shown in Figure 2b.

Total dissolved solids (TDS) are a measure of all dissolved solids in groundwater, including minerals and organic matter. High TDS levels can make water unsuitable for drinking and irrigation, as it can cause scaling in pipes and equipment. For drinking suitability, the value of TDS must lie below 300 mg/L as the desirable limit and about 1300 mg/L as the permissible limit. The value of TDS ranges from 150-1090 mg/L which is very well under the safe limit (Figure 2c). Electrical Conductivity is a measure of the electrical conductivity of groundwater. It is a function of the dissolved ions present and is an indicator of water quality. High conductivity values indicate high salt concentrations, which can affect water usage for agriculture and industry. The EC can be classified as type I, if the enrichments of salts are low (EC < 1,500 μmhos/cm); type II, if the enrichment of salts is medium (EC 1,500 and 3,000 μmhos/cm); and type III, if the enrichments of salts are high (EC >3,000 μmhos/cm); (Sarath Prasanth et al., 2012). The electrical conductivity is very much under a safe zone with a maximum range is at 2180μS/cm (Figure 2d).

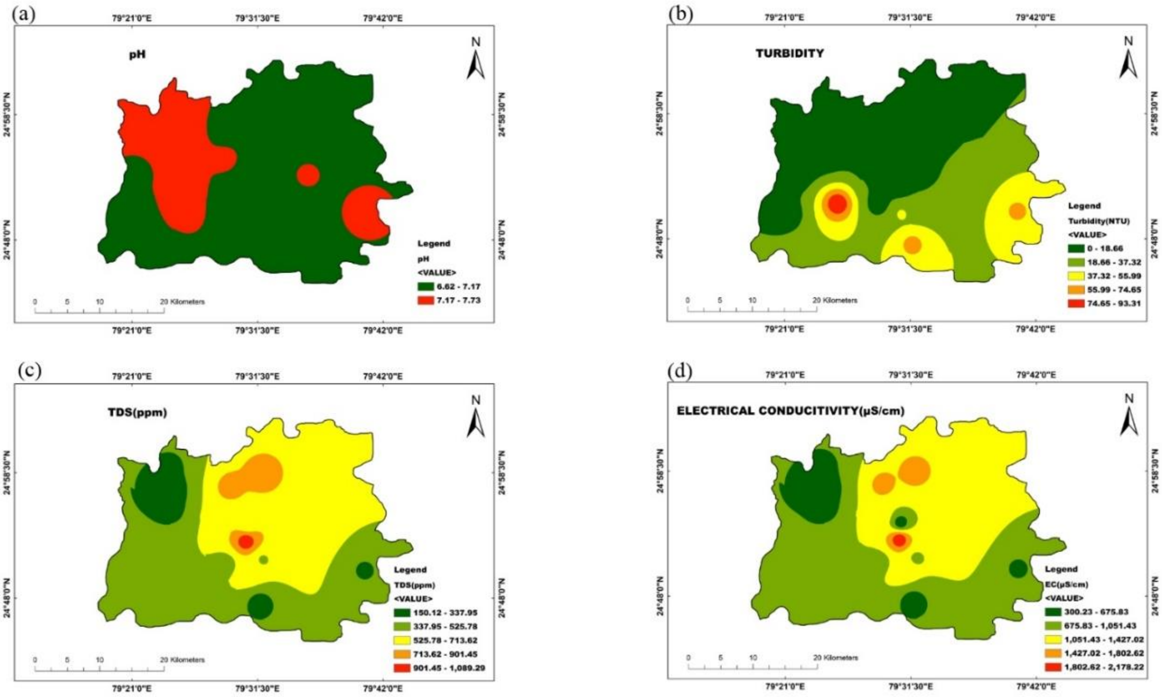


Figure 2: Distribution in the (a) pH (b) Turbidity (c) TDS (d) EC in the study area.

The acceptable limit for Ca^{2+} is 75 mg/L and the permissible limit is 200 mg/L. The study area shows that most of the concentration of Ca^{2+} is under the permissible limit which is <200mg/L, only 1 out of 18 samples showed a higher value than the permissible limit of BIS, 2012 standards (Figure 3a).

Overall, the values of Mg^{2+} concentration were in the range of 3.2-93.4 mg/L represented in Figure 3b. BIS standard limit for Mg^{2+} for drinking suitability is 30 mg/L as the acceptable limit and 100 mg/L as a permissible limit. None of the samples in the study area showed a higher concentration than the permissible limit of BIS, 2012. Dissolution of minerals may lead to magnesium occurrence in groundwater.

Na^{+} is the study area as shown in Figure 3c and it ranges from 0.7-191 mg/L which is safe for drinking. All the samples showed the concentration of sodium residing within the safe limit of WHO guidelines which is at 200 mg/L. Weathering of minerals and the use of fertilizers can lead to the occurrence of sodium in the groundwater. The safe consumption range according to BIS is 200 mg/L for K, and the study area has a concentration of K in the range of 0.1-174 mg/L (Figure 3d). Agricultural runoff, sewage and mineral weathering and its dissolution can lead to potassium occurrence in the groundwater.

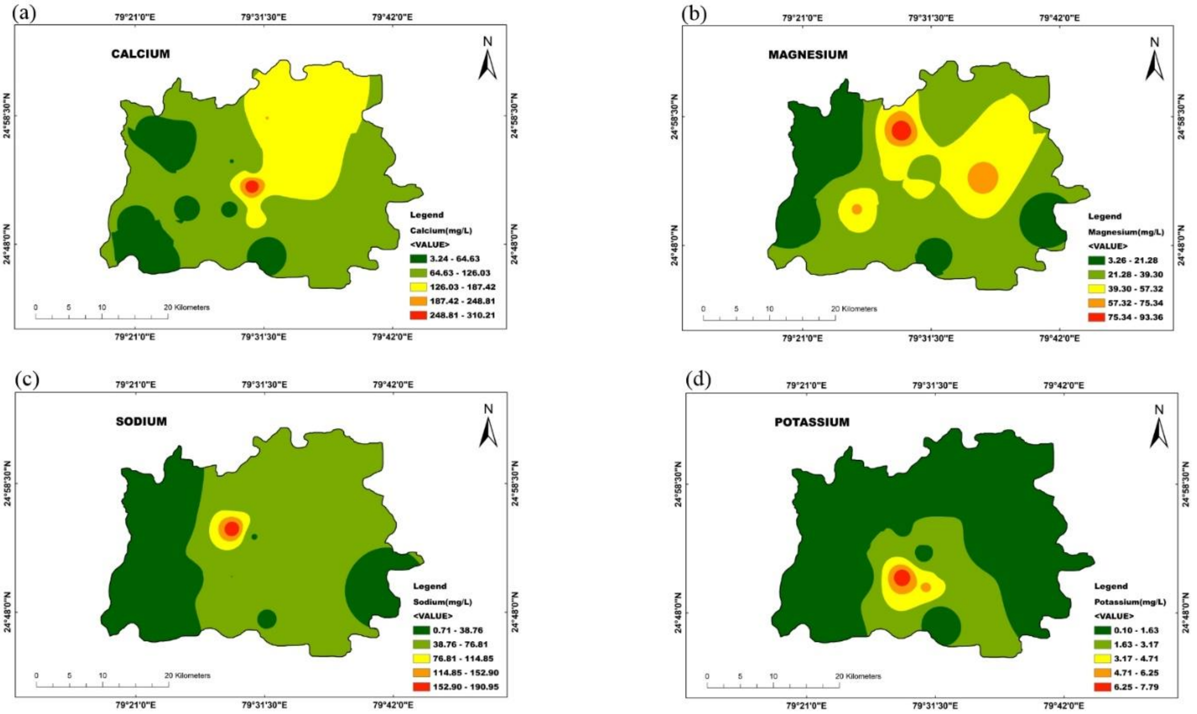


Figure 3: Distribution in the cations such as (a) Calcium (b) Magnesium (c) Sodium, and (d) Potassium in the study area.

The fluoride safe limit for suitability for drinking purposes is 1.0 mg/L as the acceptable limit and 1.5 mg/L as the permissible limit. In the study area, one of the samples had a concentration of F^- beyond the permissible limit (Figure 3b). In the region, there is no industrialization so the presence of fluoride input in the study area comes from the rock-water interaction (Avtar et al., 2013). Nitrate is one of the most hazardous contaminants in the groundwater, chemical fertilizers are one of the chief causes of its abundance in the groundwater. The value of concentration in the study area lies between 2.29-69.17 mg/L (Figure 3e). The acceptable and permissible limit of Nitrate in GW is 45 mg/L, with 16.66% of samples shown exceeding the limit of nitrate, which is not good for consumption. The acceptable limit of chloride according to BIS standards is 250 mg/L and the permissible limit is 1000 mg/L. The study area had a Chloride concentration between 4.5-208.46 mg/L (Figure 4a). The source of Chloride may result from sewage, animal waste or the minor constituents of igneous, metamorphic rock (Sarath Prasanth et al., 2012). No samples showed Chloride limit exceeding the permissible limit of BIS, 2012.

Sulphate is present in the sulfide-bearing minerals in igneous and metamorphic rocks which can be found in the groundwater by the dissolution of such minerals, also use of chemical fertilizer is the probable source of sulphate in the groundwater. The study area has a sulphate concentration of 2-102 mg/L which is in the safe zone limit as the BIS standard for safe drinking concentration is 250 mg/L and the permissible limit is 400 mg/L (Figure 3f).

The carbonate concentration ranges from 0-240 mg/L in the study area which is under the safe limit of WHO (Figure.4c). The value of bicarbonate in the study area is from 24.4-366 mg/L (Figure.4d). Although the maximum limit is 506.4 mg/L according to WHO, none of the samples showed concentration greater than the safe limit.

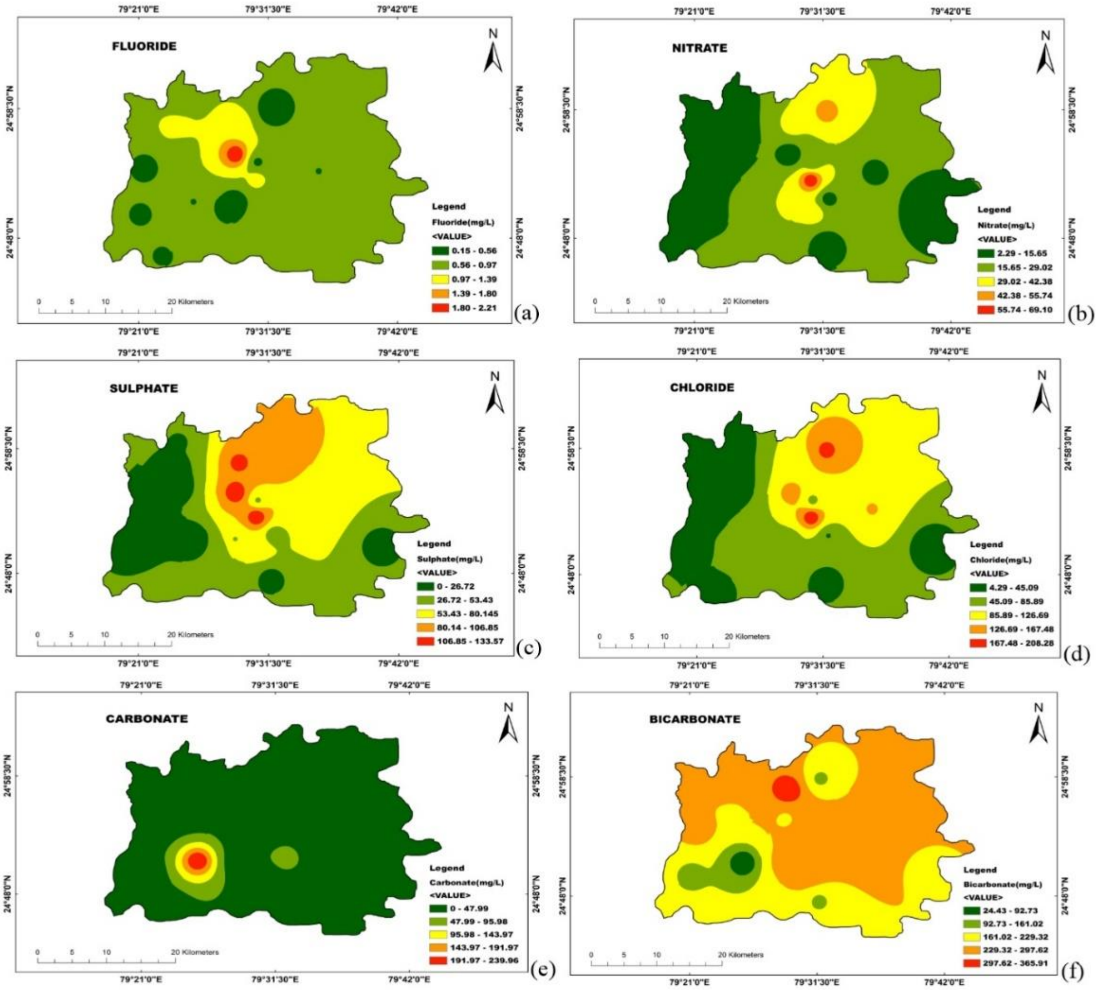


Figure 4: Distribution in the concentration of anions such as (a) Fluoride (b) Nitrate (c) Sulphate (d) Chloride (e) Carbonate (f) Bicarbonate in the study area

3.2. Suitability for Agriculture

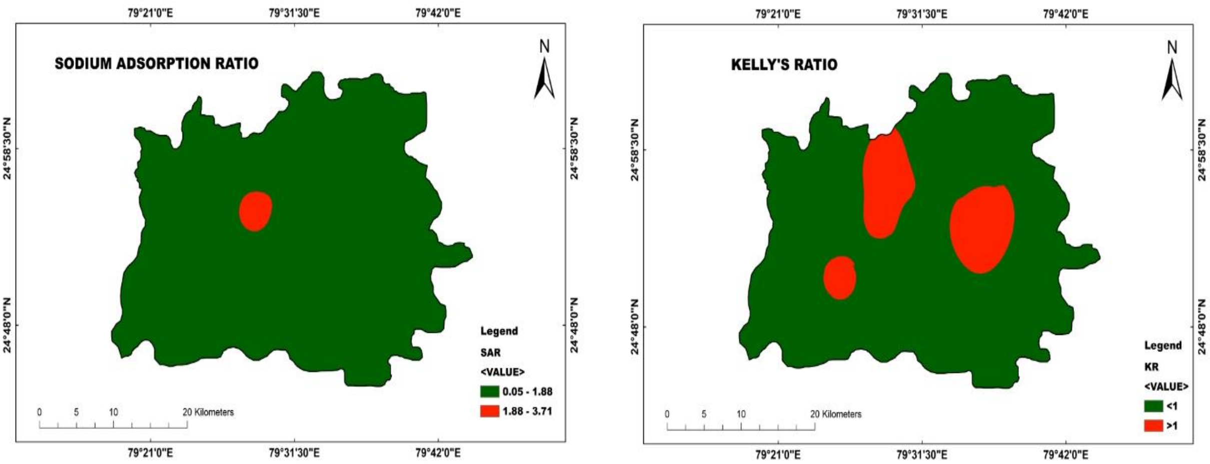
Several parameters are used in this study to detect the suitability of the groundwater in the study area for its use for agricultural purposes (McGeorge, 1954).

$$SAR = \frac{Na^{2+}}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \quad (1)$$

$$KR = \frac{Na^{2+}}{Ca^{2+}+Mg^{2+}} \quad (2)$$

The Sodium Adsorption Ratio (SAR) measures the sodicity present in the groundwater. Na^+ and K^+ cause the decrease in the permeability of the soil which leads to decreases of the soil quality. It also leads to determining alkaline presence against the alkaline earth in the groundwater sample. It is determined by the formula (1). In the study area, SAR varied from 0.05-3.71 meq/L as in Figure 5a. The suitable range for SAR is <10 meq/L. Na^+ was measured against the Ca^{2+} and Mg^{2+} cations, formula (2) (KELLEY, 1963). It leads to a decrease in the permeability of the soil. A suitable range for KR is <1. Much of the region was under the suitable range of KR, which is good for agricultural purposes, as can be seen in Figure 5b. According to the USSLs diagram (McGeorge, 1954), the detection of the quality of groundwater for its suitability in agriculture was done. The

SAR can be classified as Low(S1), Medium(S2), High(S3) and Very high(S4) (Subba Rao et al., 2017). 55.55% of samples were in C2S1 and 44.45% were present in C3S1 as in Figure 6. Hence, we can see that most of the samples were low in alkalinity and high in salinity. In totality, the groundwater is suitable for its usage in agriculture in the study area.



(a) (b)

Figure 5: Distribution of (a) SAR and (b) KR and in the study area.

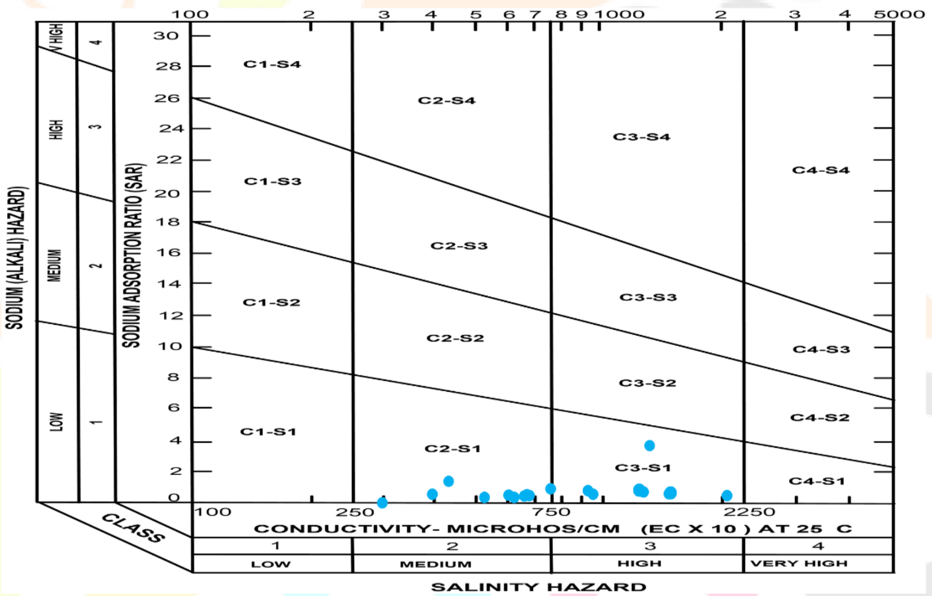


Figure 6:USSL diagram for classification of irrigation waters (United States Salinity Laboratory Staff, 1954).

3.3.Hydrochemical type assessment

Piper triplot (“A Graphic Procedure in the Geochemical Interpretation of Water-Analyses,” 1944) (Figure 7) was used to investigate the hydrochemical type of the study area. The data points show that most of the samples fall towards calcium and magnesium in the cation triangle and bicarbonate dominancy is shown in anions.

Hence, Ca-Mg-HCO_3 is the chemical type of the groundwater samples in the study area. Weathering and rock dissolution are taking place causing calcium and bicarbonate dissolution from silicate rocks. The Chadha Plot (Chadha, 1999) (Figure 8) helps to understand the chief geochemical process occurring in the study area which is determining the water type in the region. The plot is divided into four quadrants, Reverse ion exchange (Ca-Mg-Cl) water type, Recharging water type (Ca-Mg-HCO_3), Ion exchange water type (Na-HCO_3), and seawater (NaCl) type. In the analysis and plotting of the graph, the data points represent the recharging type of water, in this recharging type of water, the water percolates down from the surface while carrying HCO_3^- with itself and Ca^{2+} which is geochemically active. Hence, the Chadha plot also confirms the hydrochemical type suggested by the Piper triplot diagram.

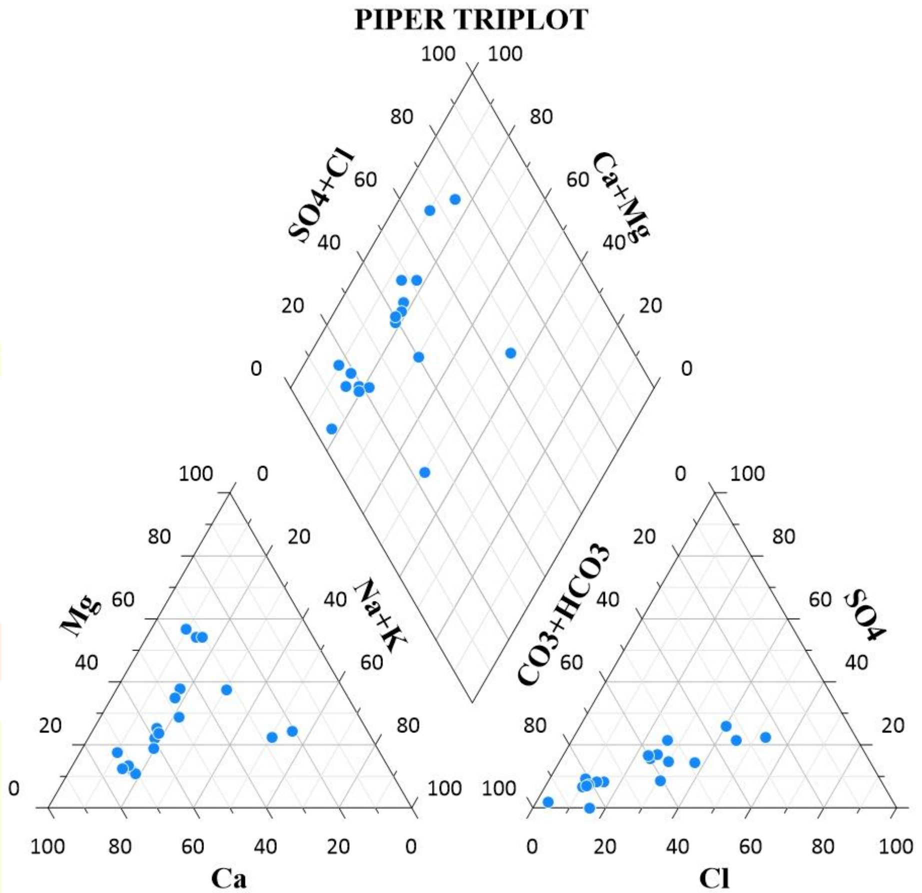


Figure 7:Piper plot representing the hydrochemical type in the study area.

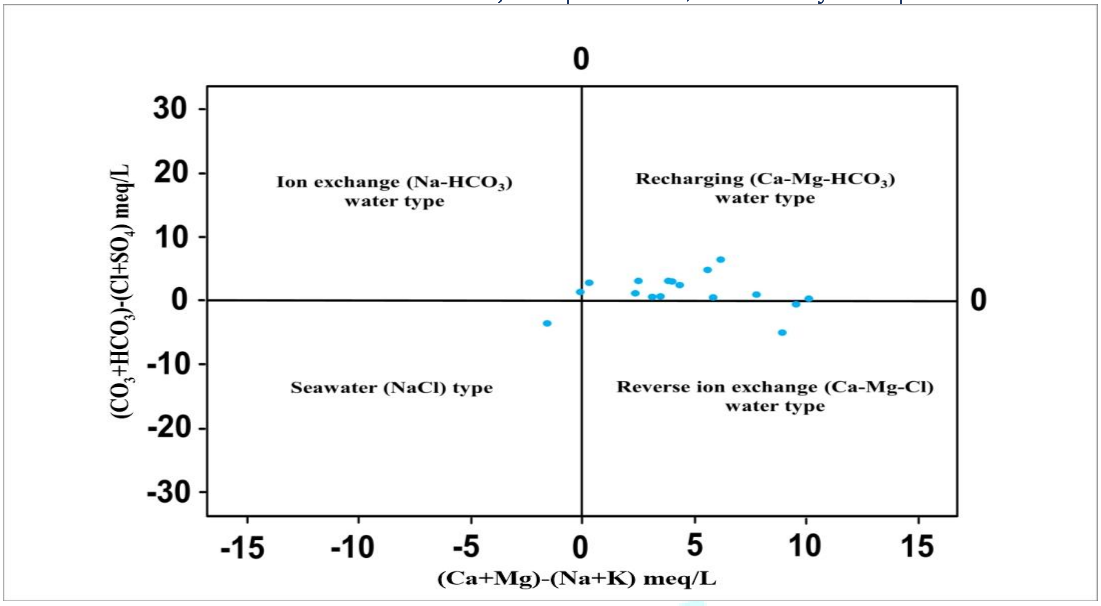


Figure 8*:* Chadha plot for understanding groundwater type.

4. **Factors controlling groundwater chemistry.**

4.1.Geogenic Factors

To understand the natural factors involved in groundwater chemistry, the Gibbs Plot is used. We can identify whether Rock-Water Interaction, Precipitation, or Evaporation is playing a role in determining the groundwater's chemistry (Gibbs, 1970). The data points plotted suggest that the groundwater chemistry is being controlled by rock-water interaction, i.e., due to the weathering of rock minerals (Figure 9).

4.2.Anthropogenic Factors

Not only the geogenic factors responsible for determining the chemistry of the groundwater but also anthropogenic factors led to the change in the water chemistry too. To understand the anthropogenic factors a bivariate plot (Figure 10) of TDS vs NO_3^-+Cl^-/HCO_3 is used (Li et al., 2019). The linear trend was present which tells that the anthropogenic factors are also playing a role in determining the chemistry of groundwater in the study area.

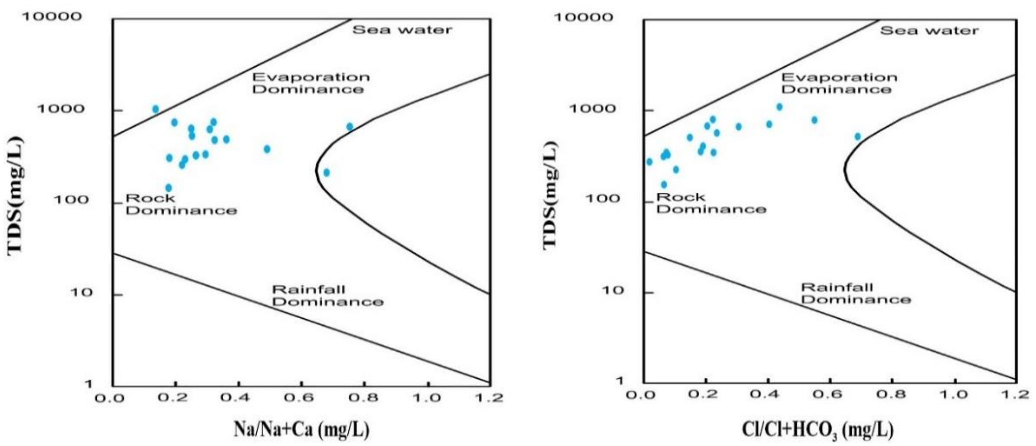


Figure 9: Gibbs Plot (1970) to understand the process affecting the groundwater chemistry.

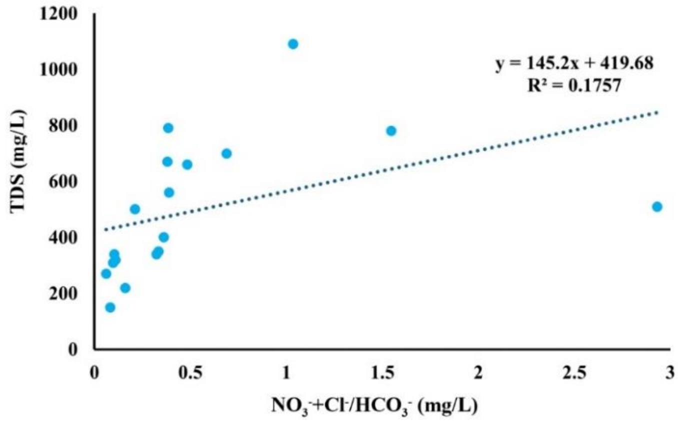


Figure 10: Bivariate plot of TDS vs NO_3+Cl/HCO_3

5. Conclusion

In the study area of Chhatarpur tehsil after the analysis of the geochemical characteristics, the water type is found to be recharging water where both the geogenic and anthropogenic factors are affecting the chemistry of the groundwater. The cation concentration was Ca^{2+}>Na^{+}> Mg^{2+}> K^{+} and anions concentration was found to be HCO_3^-> Cl^->SO_4^{2-}>NO_3^->CO_3^{2-}>F^-. The Piper plot and Chadha plot suggest the Ca-Mg-HCO_3 water type in the study area. In the study, water chemistry is controlled by both the geogenic and anthropogenic factors which are found out by Gibbs plot (1970) and a bivariate plot of TDS vs NO_3+Cl/HCO_3 respectively. Physiochemical parameters such as pH, turbidity, TDS, electrical conductivity, cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) and anions (Cl^-, SO_4^{2-}, CO_3^{2-}, HCO_3^-, F^-, NO_3^-) suggest that the study area has groundwater suitable for drinking. However, groundwater samples had high turbidity in greater than half of the samples, one of the samples exceeded the F^- permissible limit of BIS, 2012 and 16.67% of samples showed unsafe levels of NO_3^-.

The correlation matrix was used, in which we observed correlations between the parameters examined of the groundwater samples which suggested the involvement of wastewater causing damage to the quality of groundwater. Agricultural suitability of the groundwater is evident in most of the region as results show adequate values for SAR, KR and USSLs diagram. Hence, in this study overall the suitability of the groundwater is safe for drinking water and few of the samples have shown.

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