

# Groundwater quality evaluation for drinking and irrigation purposes in and around Bemetera Block, Chhattisgarh, India

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**Abstract:** The quality of groundwater in an area is just as essential as the quantity. The groundwater quality of the Bemetera Block of Chhattisgarh State, in terms of domestic and irrigation use was studied. The hydrogeochemical evaluation, demonstrates that except of TH, SO<sub>4</sub><sup>2-</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, and Fe, all measured physical parameters in the study area fell within the Bureau of Indian Standards (BIS) limit. Further, certain sampling locations, such as S5 (Deep Aquifer), S9, S13, and S20, have a negative influence on drinking water quality as compared to others (shallow aquifer). Along with water quality analysis for the drinking purpose, the irrigation water quality of the area was examined using several methods, and observed that most of the samples are suitable for domestic and irrigation purposes and some are not suitable.

**Index terms:** Water Quality, Soluble Sodium Percentage, SAR

## I. INTRODUCTION

The hydrogeochemistry is concerned with the processes and features of water in relation to its geoenvironment. It necessitates a thorough understanding of all chemical processes. The rising human intervention on groundwater systems has recently drew the attention of hydrogeochemists to the numerous challenges related to groundwater pollution. Groundwater is an essential natural resource for all living things on the Earth. For a variety of reasons, there is always a growing demand for the development of high-quality groundwater. As the population grows, available water resources that have been set aside for the future use are likely to be depleted. Anthropocentric activities have progressed to the point that they are a threat to water resources in terms of quality and availability (Moosavirad et al., 2013). Consequently, new sources of water need to be developed to provide potable water. The quality of water is dependent on the type of soil and rock that

are located below the soil horizon (Elango and kannan, 2007; Dehnavi et al., 2011; Kumar et al 2020). The water originates from precipitation, infiltrates through soil to reach groundwater reservoir. Normally, the quality of groundwater in hilly terrain and uplands are comparatively better than that of water collected from plain land due to the enhanced breakdown of different salts during its transit under diverse geological formations. Furthermore, high rates of evaporation from shallow dug wells may result in precipitation and greater salt concentrations in the water sources (Gupta et al., 2005; Bouzourra et al 2015).

In terms of pollution control and environmental management, water quality issues are crucial. The overall occurrence of diverse chemical elements present in groundwater determines groundwater quality. The nature of groundwater is determined by the extent to which it has reacted with country rock (Edmunds and Gaye, 1994). The quality of groundwater is a function of multiple parameters and processes such as evaporation, selective uptake by vegetation, oxidation/reduction, wet and dry depositions of atmospheric salts, soil/rock-water interactions, cation exchange, dissociation of minerals, precipitation of secondary minerals, mixing of waters, pollution of lake/sea, leaching of fertilizers and manure, and other biological process (Eraifej and Abu-Jaber 1999; Singh et al., 2005; Arumugam and Elangovan 2009; Ravikumar et al., 2010; Ravikumar et al., 2011, Fattah 2012; Sivakarun et al., 2020). Regular monitoring of quality parameters allows for the maintenance of a healthy ecosystem balance while also ensuring the long-term management of water resources. Quantity of dissolved constituents is higher in groundwater than that of surface water as it is exposed to soluble

minerals of geological formations (Todd, 1980). The quality of water is also affected by organic decomposition in the soil (Langmuir, 1997). Many workers have attempted to understand the chemistry of water under various environmental settings (Chandrasekharam, 1989; Rengrajan and Balasubramanian, 1990; Campanella et al., 1994; Rao et al., 1997; Howari, 2005; Srinivasamoorthy et al., 2008; Latha and Rao, 2012; Tziritis et al., 2017; Luo et al., 2018; Naik, 2018).

The hydrochemical evaluation and geospatial distribution of various chemical parameters in the block Bemetara, Saja and Berla has been attempted in this study. All the major chemical quality parameters have been analysed for its spatial variability. Water samples from five deep wells and 16 open wells were collected during the year 2015 (Table I, Fig. 1), for pre-monsoon season and were analyzed in laboratory. The details of location of ground water samples are shown in Fig. 1.

II. METHOD OF CHEMICAL ANALYSIS

A systematic water sampling technique was employed to collect the samples from the study area during the pre-monsoon season of 2015. A total of 21 groundwater samples were collected from shallow and deep aquifers in pre-washed polythene bottles (Table I), and the bottles were rinsed twice before sampling. Water samples were taken after pumping out water for around 10 minutes to remove stagnant water from the bore wells.

Table I. Location details of groundwater samples.

Well No	Location	Source	Lat	Long
S1	Amora	BW	21.6486	81.5617
S2	Barga	BW	21.7250	81.4389
S3	Dhara	BW	21.7436	81.5892
S4	Jhal	BW	21.7914	81.5544
S5	Khurusbod	BW	21.8147	81.4633
S6	Baba Mohtara	DW	21.7653	81.4953
S7	Bahera	DW	21.9083	81.6083
S8	Baiji	DW	21.5881	81.4014
S9	Bemetara	DW	21.8122	81.4647
S10	Bitkuli	DW	21.7153	81.5892
S11	Jeora	DW	21.7628	81.4828
S12	Khati	DW	21.7619	81.5142
S13	Khurmuri	DW	21.7167	81.5333
S14	KoresarDw	DW	21.5250	81.4806
S15	Sagona	DW	21.7750	81.6675
S16	Chilphi	DW	21.8769	81.4644
S17	Dadhi	DW	21.8958	81.4750
S18	Nawagarh	DW	21.6653	81.4125
S19	Deorbija	DW	21.6378	81.6228
S20	Parpoda	DW	21.7778	81.4375
S21	Berla	DW	21.7125	81.6139

BW: Bore Well, DW: Dug Well, Lat:Latitude, Long: Longitude

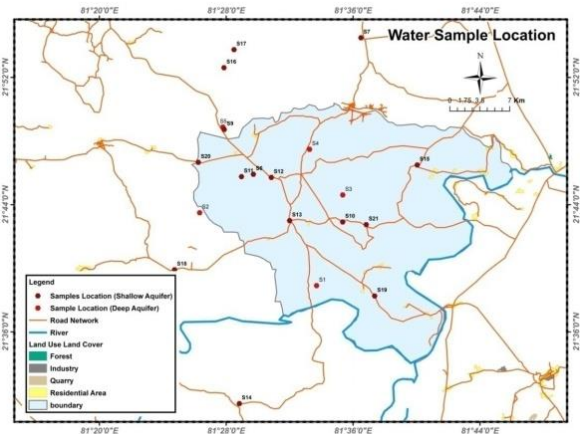


Fig.1 location of groundwater samples collected during the study.

The chemical and physical parameters of groundwater samples were analysed by following the APHA standards of drinking water, and irrigation water use (BIS 2012 and WHO).

III. RESULT AND DISCUSSION

Parameters such as pH, Electrical Conductivity (EC), TDS, Alkalinity, Carbonate (CO<sub>3</sub><sup>2-</sup>), Bi-carbonate (HCO<sub>3</sub><sup>-</sup>), Chloride (Cl<sup>-</sup>), Sulphate (SO<sub>4</sub><sup>2-</sup>), Fluoride (F<sup>-</sup>), Calcium (Ca<sup>2+</sup>), Magnesium (Mg<sup>2+</sup>), Sodium (Na<sup>+</sup>), Potassium (K<sup>+</sup>) and Iron (Fe) were analyzed (Table IIa,b).

A. Drinkingwater Quality

In order to analyse the overall state of the groundwater, many governmental organisations have set quality criteria for drinking purpose (Table. III). The current study used the Indian standards of drinking water (BIS, 2012 Table IV a, b).

Table IIa Physicochemical parameters of Groundwater Samples from Deep Aquifer and Shallow Aquifer (Physical parameters and Cations).

Sl No	Sample No.	pH	EC	TH	TA	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	Fe
<b>Deep Aquifer</b>										
1	S1	8	532	215	189	40	28	21	1.2	0.6
2	S2	8	488	220	220	44	26	9	0.8	0.6
3	S3	8	828	330	165	40	55	56	1.7	0.7
4	S4	8	609	245	159	70	17	18	1.4	0.9
5	S5	8	136 4	820	128	26 4	38	48	2	0.9
<b>Shallow Aquifer</b>										
1	S6	8.2	488	185	140.2	26	29.2	25.5	2.2	N D
2	S7	8.1	875	265	145.1	44	37.7	73.3	1.6	1.6
3	S8	8.1	481	170	180.3	30	23.1	36.2	1.4	N D
4	S9	7.8	227 0	118 5	36 50	36 4	67.3	59.9	2.4	N D
5	S10	8	641	275	125.4	78	19.6	20.2	3.8	0.3
6	S11	8	676	280	119.7	66	28	27.4	1.7	N D

7	S1	7.	203	660	100	15	64.6	154.	30.	N
	2	8	0	107		8		5	5	D
8	S1	8	225	107	45.1	30	78.2	38.4	2.2	N
	3	8	0	0		0				D
9	S1	7.	805	280	100	48	39	54.3	8.4	N
	4	9								D
10	S1	8	881	300	140.	66	32.9	64.1	1.3	0.6
	5	8			2					
11	S1	8.	145	525	75.4	11	60.9	105.	1	0.9
	6	1	5			0		8		
12	S1	7.	108	410	95.1	11	31.7	54.2	2	N
	7	9	5			2				D
13	S1	8.	940	335	130.	44	54.8	62.1	4.8	N
	8	1			3					D
14	S1	8.	595	230	75.4	52	24.4	34.1	2	N
	9	2								D
15	S2	7.	186	830	69.7	16	104.	63	2.3	0.7
	0	8	6			0	7			
16	S2	7.	127	500	90.2	11	53.6	62.5	3	N
	1	8	0			2				D

Table IIb Physicochemical parameters of Ground Water Samples from Deep Aquifer and Shallow Aquifer (Anions).

Sl No	Sample No.	CO <sub>3</sub> <sup>2-</sup>	HCO <sub>3</sub> <sup>-</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	F <sup>-</sup>
<b>Deep Aquifer</b>						
1	S1	Nd	189	21	76	Nd
2	S2	Nd	220	7	31	Nd
3	S3	Nd	165	14	262	Nd
4	S4	Nd	159	11	154	Nd
5	S5	Nd	128	25	721	Nd
<b>Shallow Aquifer</b>						
1	S6	0	171	14.2	64.5	0.3
2	S7	177	0	32	213.4	0.5
3	S8	220	0	35.5	12.8	0.8
4	S9	0	61	21.3	720	0.3
5	S10	153	0	49.7	121.6	0.6
6	S11	146	0	32	163.4	0.6
7	S12	122	0	312.4	453.4	BDL
8	S13	55	0	53.3	1047.4	0.3
9	S14	0	122	124.3	68.3	0.1
10	S15	171	0	60.4	3.3	1
11	S16	92	0	95.9	477.6	0.6
12	S17	116	0	39.1	384	0.2
13	S18	159	0	71	219.4	0.6
14	S19	0	92	67.5	98.5	0.3
15	S20	85	0	53.3	772.8	0.6
16	S21	110	0	35.5	492.2	BDL

Table III Drinking Water Standards

Sl.No	Parameters	Units	WHO-1984 (2013)	USEPA-2009 (2016)	BIS-1991 (2012)
1	pH	pH units	6.5-8.5	7-7.3	6.5-8.5
2	EC	µS/cm	-	-	-
3	TDS	mg/l	600	500	500
4	Total Hardness	mg/l	-	-	300
5	Ca	mg/l	0.01	0.01	75
6	Mg	mg/l	50		30
7	Na	mg/l	-	-	-
8	K	mg/l	-	-	-
9	HCO <sub>3</sub>	mg/l	-	-	-
10	SO <sub>4</sub>	mg/l	200	250	200
11	Cl	mg/l	-	250	250
12	NO <sub>3</sub>	mg/l	-	10	45
13	F	µg/l	-	2000	600
14	Fe	µg/l	300	300	300

Table IVa Statistical Analysis and comparison of the analysed results with the BIS standard of shallow aquifer

Parameter	BIS Standard (2012)		Min	Max	Mean	Median	Std-dev
	Acceptable Limit	Permissible Limit					
pH	6.5-8.5	No Relaxation	7.8	8.2	8.0	8	0.1
EC	NA	NA	481	2270	1163.0	910.5	624.5
TH	200	600	170	1185	468.8	3175	313.3
TA	200	600	45.08	180.33	105.1	100	37.4
Ca <sup>2+</sup>	75	200	26	364	110.6	72	96.5
Mg <sup>2+</sup>	30	100	19.55	104.74	46.9	38.35	23.7
K <sup>+</sup>	NA	NA	1	30.5	4.4	2.2	7.2
Fe	0.3	No Relaxation	0.27	1.6	0.8	0.73	0.5
CO <sub>3</sub> <sup>2-</sup>	NA	NA	0	220	100.4	113	71.6
HCO <sub>3</sub> <sup>-</sup>	NA	NA	0	171	27.9	0	54.1
Cl <sup>-</sup>	250	1000	14.2	312.4	68.6	51.5	70.8
SO <sub>4</sub> <sup>2-</sup>	200	400	3.3	1047.4	332.0	216.4	308.3
F <sup>-</sup>	1	1.5	0.1	1	0.5	0.55	0.3

Table IVb Statistical analysis of deep aquifers and comparison of the analysed results with the BIS standards 2012

Parameter	BIS Standard (2012)		Min	Max	Mean	Median	Std-dev
	Acceptable Limit	Permissible Limit					
pH	6.5-8.5	No Relaxation	7.7	8	7.88	7.9	0.13
EC	NA	NA	488	1364	764.2	609	359.9
TH	200	600	215	820	366	245	257.96
TA	200	600	128	220	172.2	165	34.45
Ca <sup>2+</sup>	75	200	40	264	91.6	44	97.18
Mg <sup>2+</sup>	30	100	17	55	32.8	28	14.48
Na <sup>+</sup>	NA	NA	9	56	30.4	21	20.4
K <sup>+</sup>	NA	NA	0.8	2	1.42	1.4	0.46
Fe	0.3	No Relaxation	0.6	0.9	0.74	0.7	0.15
CO <sub>3</sub> <sup>2-</sup>	NA	NA	NA	NA	NA	NA	NA
HCO <sub>3</sub> <sup>-</sup>	NA	NA	128	220	172.2	165	34.45
Cl <sup>-</sup>	250	1000	7	25	15.6	14	7.33
SO <sub>4</sub> <sup>2-</sup>	200	400	31	721	248.8	154	278.13
F <sup>-</sup>	1	1.5	NA	NA	NA	NA	NA

1) pH

The concentration of hydrogen ions in water is measured as pH. It's a metric for hydrogen ion activity, or, to put it another way, it is the acidity or alkalinity of the sample. It's the base ten inverse of the logarithm of hydrogen ion concentration. The pH of natural water is determined mostly by free carbon dioxide, bicarbonate, and carbonate ions. The pH scale ranges from one to fourteen. A pH of 7 denotes neutrality, while a value less than 7 indicates an acidic range and a value more than 7 indicates an alkali range. Groundwater pH is normally between 6.5 and 8.5, while surface water pH is usually between 6 and 8. In the field, a portable pH metre is used to monitor pH (Sethy et al., 2016).

In the case of deep aquifer the pH values ranges between a minimum of 7.7 and a maximum of 8 and for shallow aquifer the

values are ranging from 7.8 to 8.2. From the analysis of both shallow and deep aquifer, it is interpreted that the pH value is decreasing with increasing depth of aquifer.

### 2) Electrical Conductivity (EC)

The electrical conductivity of natural water is due to the presence of salts that dissociate into cations and anions. It refers to the ability of a solution to conduct electricity. A portable EC meter is used to assess the EC of water samples in the field. At 25 degrees Celsius, the EC unit is measured in micro-Siemens/cm (S/cm).  $TDS = EC \times K$  (where  $K = 0.64$ ) is a rough formula for calculating EC and TDS. The electrical conductivity of the groundwater in the area ranges from 481 to 2270 S/cm in the shallow aquifer and 488 to 1364 S/cm in the deeper aquifer at a temperature of 25°C.

### 3) Total Dissolved Solids (TDS)

TDS refers to the total concentration of all constituents present in ground water, excluding suspended sediments, colloids, and dissolved gases.

The relation between Total Dissolved Solids (TDS) and EC is expressed as  $S = EC * K$ , where EC is in  $\mu S/cm$ . The considered K value for the calculation in the current study is 0.65. The deep Aquifer posses high TDS value and varies from 312 to 1475mg/l, while in shallow aquifer the values ranging from 317 to 886mg/l.

### 4) Total Hardness (TH)

Because of its potential to create scales with long-term usage in heaters, pipelines, and other equipment, water with a high hardness value is not regarded acceptable potable water. In this study the total hardness of the shallow and deep aquifers ranges from 170 to 1185 mg/l and 215 to 820 mg/l as  $CaCO_3$ . Four samples from the shallow aquifer (S9, S12, S13 & S20) and 1 sample (S5) from the deep aquifer are exceeding the standard limit prescribed by the BIS.

### 5) Total Alkalinity (TA)

The presence of bicarbonates, carbonates, and hydroxides in the water is measured in terms of total alkalinity. It indicates the ability of the water to neutralise an acid. The water's alkalinity is influenced by the path it takes, particularly the rock and soil it passes through. The deep aquifer in the study area has a higher alkalinity (128-220 mg/l) than the shallow aquifers (45-180 mg/l).

### 6) Carbonate ( $CO_3^{2-}$ ) & Bicarbonate ( $HCO_3^-$ )

When atmospheric carbon dioxide is dissolved in rainwater, carbonic acid is formed, which dissolves more  $CO_2$  from the soil and helps to enhance the concentration of carbonate species when it reaches the soil. The presence of each carbonates species is mostly determined by the pH of the water; for example, carbonic acid is stable at pH 4.5 or below, whereas increasing pH from 4.5 to 8.2 promotes the creation of  $HCO_3^-$  species. The same has existence up to the pH of 8.3 and introduce the new species carbonate, when it reaches the pH of 8.2 or above.

The shallow aquifer had carbonate and bicarbonate ionic concentrations of 0- 220 mg/l and 0-171 mg/l, respectively, but the deep aquifer was evaluated by only bicarbonate ion because the pH of the samples was less than 8.

### 7) Chloride ( $Cl^-$ )

Among the major ions, chloride is one of the most important ionic species.  $Cl^-$  concentrations in natural water is very low, however mechanisms such as saltwater intrusion, evaporate dissolution, trapping of water within the sediments, and

anthropogenic activities can cause large fluctuations in its concentration.

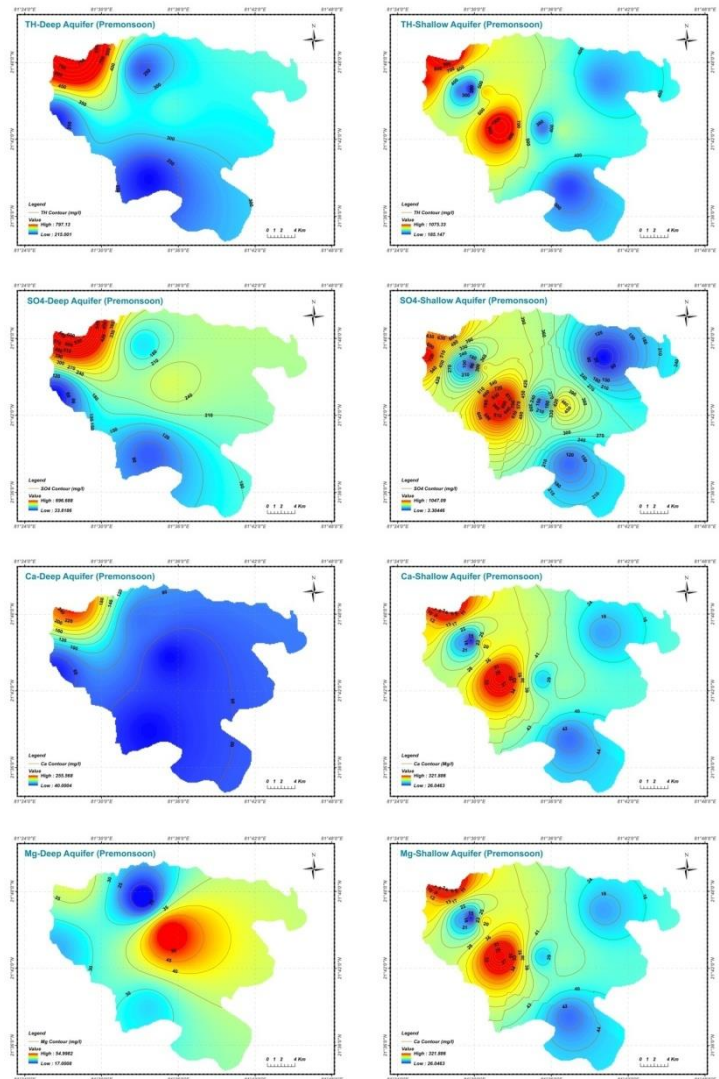
As the present study area is unrelated to any of these mechanisms, the analysis yields low  $Cl^-$  concentrations in both the shallow and deep aquifers, ranging from 14.2 to 312 mg/l and 7 to 25 mg/l, respectively.

### 8) Sulphate ( $SO_4^{2-}$ )

Water flowing through a rock with a high sulphur content concentration oxidises the sulphur to sulphate and transports it throughout the flow route. The interaction of water with sulphide bearing minerals of igneous, metamorphic, and sedimentary rocks is one of the principal sources of sulphate. Because sulphate is one of the primary ions, the results suggest that several of the samples (S5, S9, S12, S13, S16, S20, and S21) from each aquifer exceed the permissible limit of sulphate specified by Indian standards.

### 9) Fluoride ( $F^-$ )

The reported concentration of fluoride in water has generally found below 1.5 mg/l. Elevated concentration of the ion mainly associates with the presence of fluoride minerals. This, in turn, may have an adverse effect on human health in the form of fluorosis disease in various parts of the body, including the teeth, skeleton, and skin.





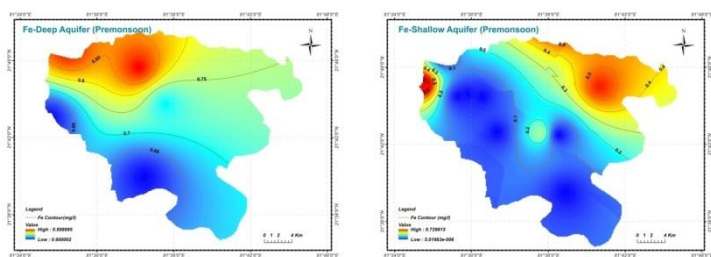


Fig 2 Spatial Variation of parameters exceeded the standard limit of drinking water quality.

The concentration of fluoride in samples collected from the shallow aquifer demonstrates that the majority of the samples fall within the acceptable range, while one sample deviates and falls within the allowable range. The fluoride concentration was measured at a maximum of 1 mg/l and a minimum of 0.1 mg/l, with mean values of 0.49.

10) Calcium ( $Ca^{+2}$ )

One of the key components that contribute to the hardness of water is calcium. Calcium concentration in water is normally created through the interaction of rock and water (limestone, marble, calcite, dolomite etc). Scale formation in vessels and water containers are as a result of an excess concentration of  $Ca^{2+}$  in water induced by the breakdown of carbonate minerals. The permissible limit of Ca in drinking water as per the Indian standard is 200 mg/l. Most of the samples taken from both aquifers had concentrations that are below the allowable limit. Exceptionally, two shallow aquifer samples (S9 & S13) and one deep aquifer sample (S5) reported concentrations over the allowed limit.

11) Magnesium ( $Mg^{+2}$ )

Magnesium, one of the elements that contributes to water hardness, can have a laxative effect when present in excessive amounts. The normal allowable concentration specified by Indian guidelines for usage in domestic purposes, particularly drinking purposes, is 30 mg/l, with a maximum concentration of 100 mg/l as the permissible limit.

Magnesium is formed by the weathering of silicate minerals, particularly dark-colored ferromagnesian minerals found in igneous rocks. Magnesium from non-silicate sources is mostly found in dolomite and magnetite.

Magnesium concentrations in both the aquifers are within the permissible limit. One sample from the shallow aquifer (S20) which had a value of 104 mg/l is an exception.

12) Sodium ( $Na^{+}$ )

One of the most common ions in natural water is sodium. Most minerals and rocks require it, and its dissolution contributes to their concentration. The  $Na^{+}$  concentration in shallow water aquifers ranges from 20.2 mg/l to 154.5 mg/l, with a mean of 58.47 mg/l, whereas the deep aquifer's concentration ranges from 9 mg/l to 56 mg/l, with an average of 30.4 mg/l.

13) Potassium ( $K^{+}$ )

Potassium, like sodium, is not subject to Bureau of Indian Standards restrictions. The interaction of water with rock is the primary source of potassium in water. The higher the dissolved concentration, the longer the water has been in contact with it. On the other hand, potassium is absorbed by clay particles and negatively charged colloidal particles. These two methods lower the dissolved concentration of  $K^{+}$  in the water, resulting in lower concentration of  $K^{+}$  compared to  $Na^{+}$ . As previously indicated, potassium concentrations vary between 1- 30 mg/l in shallow aquifers and 0.8-2 mg/l in deep aquifers, with average values of 4.41 mg/l and 1.42 mg/l, respectively.

14) Iron ( $Fe$ )

Iron, although a minor ion, has its own relevance among the ionic species due to its widespread existence. Because it is a significant constituent in soil rocks, its interactions have an impact on the constituent distribution in groundwater that comes into contact with them. Iron can be found in two states in nature: ferric (oxidized) and ferrous (unoxidized) (reduced). The iron is most likely present in the form of ferric, which quickly generates iron oxide, iron hydroxide, and other compounds. However, the reducing atmosphere aids in the retention of iron in the water in dissolved ferrous forms, which causes staining on plumbing materials and clothing.

The concentration of Fe in the samples are beyond the permissible limit set by BIS (year) as 1.6mg/l and 0.9mg/l respectively.

B. Irrigation water quality

This study was also attempted to understand the suitability of water for irrigation purpose in the same way as it looked into the suitability of groundwater for drinking purpose. Some of the computed metrics utilised in the evaluation are Soluble sodium percentage (SSP), sodium absorption ratio (SAR), residual sodium carbonate (RSC), percent Na, Kelley's ratio, and MR (Magnesium Ratio). Standard guidelines of the irrigation water quality are given in the Table V.

Table V Guidelines for evaluation of quality of irrigation water

	Sodium ( $Na$ )%	Electrical Conductivity: $\mu$ hos/cm at 25°C	SAR	RSC (meq/l)		KI		MR			
				Good	<1.25	Suitable	>1	Suitable	<50		
Suitable	<60	Excellent	<250	Excellent	<10	Good	<1.25	Suitable	>1	Suitable	<50
		Good	250-750	Good	Oct-18						
Unsuitable	>60	High	750-2250	Doubtful	18-26	Doubtful	1.25-2.5	Unsuitable	>1	Unsuitable	>50
		Very High	>2250	Suitable Not	>26						

1) Soluble Sodium Percentage (SSP):

Sodium is one of the ions, in excess in water that can stimulate the base exchange process, which reduces permeability by replacing Ca in the soil in the water. As a result, calculating the proportion of soluble sodium in water before using it on agricultural land is critical. The percentage of soluble sodium in water can be calculated by,

$$SSP = \frac{Na}{(Ca + Mg + Na)} * 100 \quad 1$$

Two samples Nawagarh (S7) and Baiji (S12) have exceeded the acceptability limit of 50. Other than this rest of the samples are suitable for the irrigation purpose.

2) Sodium Adsorption Ratio (SAR)

The Sodium Adsorption Ratio is used to determine the suitability of water for irrigation. It involves the calculation of sodium danger (Li et al 2016; Aravinthasamy, 2021). SAR is used to determine the suitability of water for irrigation in the same way as soluble sodium percentage is. The four categories of SAR are excellent (<10), good (10-18), doubtful (18-26), and not suitable (>26). SAR values can be determined as follows:

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}} \quad 2$$

The calculation's parameters must be in the Meq/l unit.

The SAR calculation used to determine suitability shows that the entire sample is in good condition, indicating its acceptability for irrigation.

3) Residual Sodium Carbonate (RSC)

It's crucial to test Sodium's activity in the presence of HCO<sub>3</sub> ions. In general, increased Bicarbonate concentrations enhance the sodium danger of the soil (Raju et al., 2015). When comparing the amount of carbonate and bicarbonate to the sum of Ca and Mg, the risk of unsuitability increases. The RSC has calculated by the provided formula (eq 3), concentration of each parameter have expressed in meq/l.

$$RSC = (CO_3 + HCO_3) - (Ca + Mg) \quad 3$$

Calculated data shows that whole samples except one sample (S8) from the calculation table, falls under the excellent category. This sample located at the shallow aquifer has the elevated concentration of 3.93, is above the limit of 2.50 (unsuitable).

4) Percent Sodium (%Na)

% Na is another indicator which helps to determine the suitability of water for the irrigation. Likewise, the RSC, SSP and SAR, the percentage of Na in water can decrease the permeability by the base exchange process; as a result the internal drainage and circulation in the soil get decreases. It can be determined by computing the percentage of sum of Na and K to the Sum of cations such as Na, K, Mg and calcium (eq.4).

$$\% Na = \frac{Na + K}{(Na + K + Mg + Ca)} * 100 \quad 4$$

As per the % Na all of the samples fall in the categories of medium, good and excellent which indicates its suitability for irrigation.

Table VI. Quality of ground water for irrigation

Sl No	Sample name	Site Name	SSP	SAR	RSC	%Na	Kelley's ratio	Magnesium ratio
1	S1	Amora	29.82	1.25	-1.2	30.17	0.42	53.58
2	S2	Barga	15.3	0.53	-0.73	15.63	0.18	49.35
3	S3	Dhara	42.76	2.7	-3.82	42.98	0.75	69.39
4	S4	Jhal	24.25	1	-2.29	24.67	0.32	28.59
5	S5	Khurusbod	20.39	1.46	-14.2	20.59	0.26	19.18
6	S6	KoresarDw	37.48	1.63	-0.9	38.06	0.6	64.94
7	S7	Nawagarh	54.6	3.92	0.6	54.76	1.2	58.58
8	S8	Parpoda	48.08	2.42	3.93	48.36	0.93	55.97
9	S9	Sagona	18.02	1.51	-22.7	18.2	0.22	23.36
10	S10	Baba Mohtara	24.21	1.06	-0.4	25.21	0.32	29.24
11	S11	Bahera	29.85	1.42	-0.73	30.23	0.43	41.2
12	S12	Baiji	50.45	5.23	-9.14	51.86	1.02	40.28
13	S13	Bemetara	13.5	1.02	-19.57	13.7	0.16	30.05
14	S14	Berla	45.75	2.82	-3.6	46.86	0.84	57.24
15	S15	Bitkuli	48.17	3.22	-0.3	48.32	0.93	45.11
16	S16	Chilphi	46.71	4.02	-7.44	46.78	0.88	47.73
17	S17	Dadhi	36.51	2.33	-4.33	36.76	0.57	31.85
18	S18	Deorbija	44.63	2.95	-1.4	45.19	0.81	67.24
19	S19	Jeora	39.2	1.96	-3.09	39.61	0.64	43.6
20	S20	Khati	24.82	1.9	-13.77	25.02	0.33	51.91
21	S21	Khurmuri	35.22	2.43	-6.34	35.54	0.54	44.12

5) Kelley's Ratio (KI)

Kelley's cation-based formula can be used to estimate the effect of sodium content in irrigation water. This is usually referred to as Kelley's Ratio/Index, and it is calculated as follows:

$$\text{Kelley's Ratio} = \frac{Na}{(Mg+Ca)} \quad 5$$

According to Kelley's ratio, samples with a ratio more than 1 are unsuitable for irrigation, whereas samples with a ratio less than 1 are suitable. The Kelley's Ratio in the study area reveals that except two samples (S7- Nawagarh and S12- Baiji), all other samples with ratio <1, are suitable for irrigation.

6) Magnesium Ratio (MR)

Magnesium ratio helps to identify the dominant alkaline earth in the water sample and it is calculated as,

$$MR = \frac{Mg}{(Ca+Mg)} * 100 \quad 6$$

Among 21 samples, 7 samples are unsuitable with > 50% are unsuitable for irrigation and others are suitability for the irrigation use.

7) USSL Diagram

The United States Salinity Laboratory team introduced the US salinity diagram to classify water usage for irrigation based on electrical conductivity and SAR. According to the USSL diagram, samples in the C1S1 field are the most ideal for irrigation, while those in the C5-S4 field are the least suitable.

The distribution of samples in the C2-S1 and C3-S1 fields is illustrated by plotting samples from the current investigation against the USSL map. C2-S1 and C3-S1 differ from one another in terms of electrical conductivity variation. Even though the SAR

value is below the USSSL's allowed level, the variable electrical conductivity aids irrigation activities by allowing farmers to select crops that are compatible for the water quality. Samples from the C2-S1 field can be used on crops with intermediate salt tolerance, whilst samples from the C3-S1 field require additional attention to salinity control and the cultivation of high salt tolerant plants. However, one sample (S12) deviates from the others by having a high SAR value when compared to the others.

8) Wilcox Diagram

The Wilcox diagram, which was created by plotting the samples against electrical conductivity and percentage sodium, shows that deep aquifer samples are in the excellent to good and good to permissible categories, while shallow aquifer samples are in the excellent to good, good to permissible, and doubtful to unsuitable categories. Three samples (S9, S12, and S13) were found in the Soagona, Baiji, and Bemetera, respectively, in the doubtful-unsuitable categories.

The quality of water for irrigation purposes was assessed and compared to WHO criteria, revealing that 3 samples from the deep aquifer and 8 samples from the shallow aquifer are totally appropriate for irrigation, while other sampling locations had one or more quality issues as per %Na, SAR, Kelleys ratio, MR, RSP and SSP.

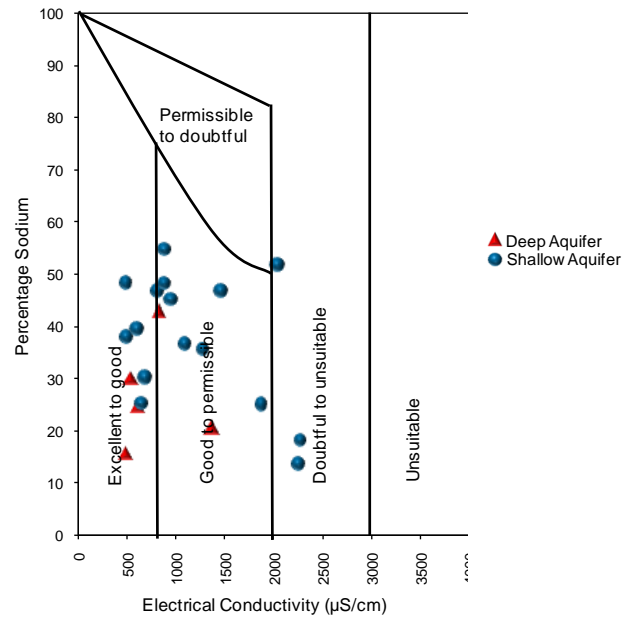


Fig. 4 Wilcox Diagram of Irrigation water suitability

C. Gibb's diagram

The basic mechanism controls the water quality of the area can be easily identified by plotting the samples on the Gibb's diagram (1970). The three fields in gibb's diagram indicate three major factors that control the water chemistry, such as; precipitation, Rock water interaction and evaporation.

Samples plotted on the Gibbs diagram falls within the field of rock water interaction and near to evaporation. Samples from the deep aquifer falls under the field of rock water interactions, whereas the sample from the shallow aquifer shows the combination of both rock water as well as the evaporation.

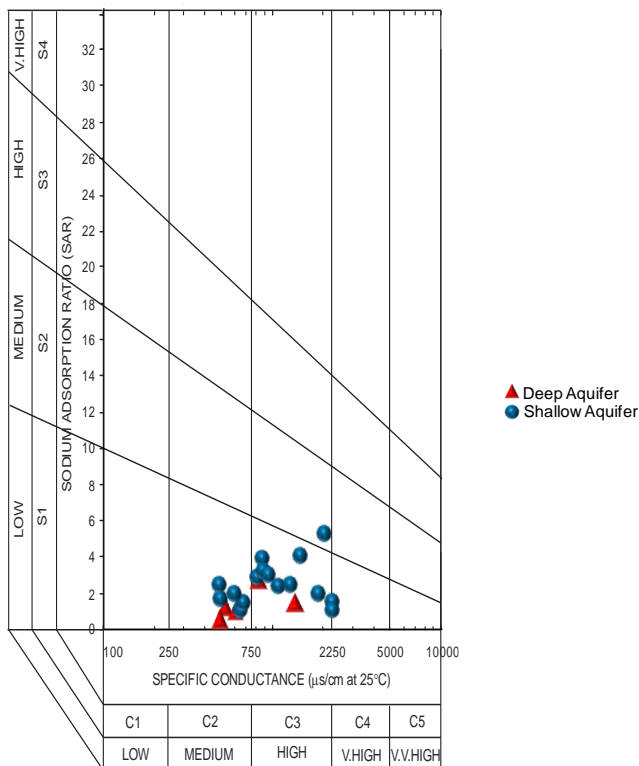


Fig. 3 USSL Diagram of Irrigation water suitability

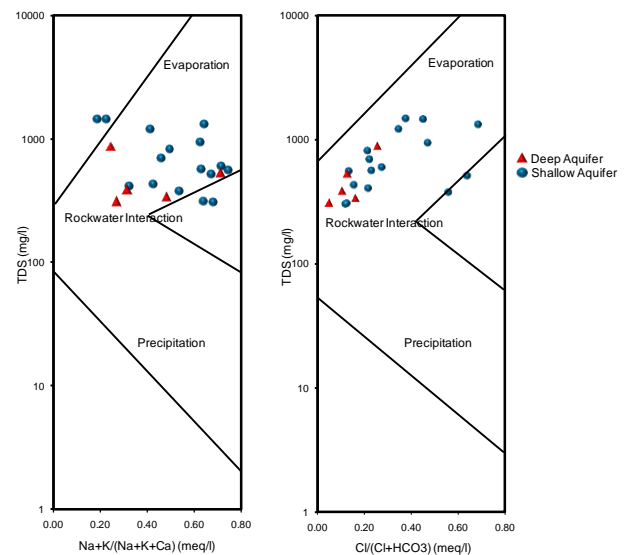


Fig. 5 Gibb's Diagram: (a) Cations and (b) Anions

D. Piper Trilinear Diagram

By mapping the samples on the piper diagram, the hydrogeochemical facies of the area can be identified (Piper, 1944). Instead of accumulating locally, the samples displayed on the diagram have scattered across several fields.

However, with the exception of one sample, deep aquifer samples are primarily dispersed in the field of mixed water chemistry, whereas shallow water falls into other categories.

It is obvious from the diagram that over 90% of the samples fell in field-1, indicating the presence of alkali earth metals (Ca<sup>2+</sup>/Mg<sup>2+</sup>) rather than alkali metals (Na<sup>+</sup>, K<sup>+</sup>). More over half of the sample falls into the fourth field of the graphic, which represents acid strength (strong).

It was discovered that 33%, 19%, and 48% of the samples fell within the fields of 5, 6, and 9, respectively. The samples in field 5 are of the Ca-Mg-HCO<sub>3</sub> type, while the samples in field 6 are of the Ca-Mg-SO<sub>4</sub> type, and the rest of the samples in field 9 are of mixed sorts.

The grouping of deep and shallow aquifer samples in field D (No dominant) and shallow samples in field B (No dominant) is visible in the samples plotted on the cation triangle field (calcium type). The samples in the anion triangle are spread in several fields, such as field D (no dominating type), Field E (sulphate type), and field F (bicarbonate type). (sulphate type), and Field F (bicarbonate type).

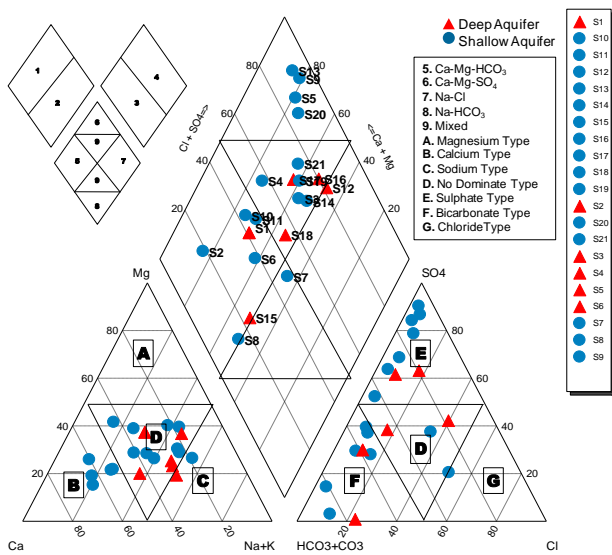


Fig 6 Piper Trilinear Diagram showing different facies

CONCLUSIONS

The current study was an attempt to assess the overall water quality of the study area, by comparing the data with the Indian standards for drinking and irrigation purpose. Most of the measured physical parameters fall within the Bureau of Indian Standards (BIS), except TH, SO<sub>4</sub><sup>2-</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup> and Fe. Among these the concentration of Fe in the area is comparatively high, in the sense, except one sample rest of the whole samples have falls out of the limit as per the BIS which can make negative impact on human health as well as on the household materials. Evaluations

of ionic concentration of samples revealed that some of the samples (deep aquifer - S5 and shallow aquifer - S9, S13, S20) have a negative impact compared to the others as per the drinking water standards.

Soluble sodium percentage calculated for checking irrigation water quality in the study area shows that samples from Nawagarh and Baiji are exceeding the suitability criteria. Calculated SAR value and %Na of samples meets the prescribed suitability limit of the SAR and %Na, hence suitable for irrigation purpose as per their criteria. Among the whole sample only one sample exceeded this limit hence falls in the unsuitable category of RSC. Kelley's Ratio calculated in the current study found out that, two locations (S7- Nawagarh & S12- Baiji) within the study area are unsuitable for irrigation. MR calculated for 21 samples among that 7 have fallen under the unsuitable category which has ratio above 50% while rest of the samples falls below 50% indicates its suitability for the irrigation use. USSL diagram plotted for the samples in the area has displayed the distribution of the samples in the C2-S1 and C3-S1 fields indicates that the sampling locations are safer as per the SAR but need to take care according to the varying conductivity of groundwater in the sample's locations. Wilcox diagram plotted to find out the condition of the samples according to the combined effect of the conductivity as well as sodium percentage shows that except S9 (Bemetara), S12 (Khati) & S13 (Khurmuri) locations, rest of the sampling locations are agreeing with the criteria of irrigation water. From these it can conclude that even though most of the samples fall under the suitable category there are samples that falls out the suitable zone indicates the necessity of evaluation of the suitability of cropping pattern before its implication.

The hydrogeochemical evolution of the groundwater was carried out with the help of Gibb's and Piper diagram. Both the diagrams reveals, rock-water interaction as the major mechanism that controls the groundwater chemistry of the study area. Some of the samples in the evaporation field of the Gibb's diagram promote the possibility of operation of the evaporative mechanism. The major hydrogeochemical facies of the study area is of mixed type, followed by Ca-Mg-HCO<sub>3</sub> and Ca-Mg-SO<sub>4</sub> facies.

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