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Groundwater quality status and Hydrochemical processes in Arda Panchayat, Jharsuguda, Odisha

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Abstract

Groundwater quality study are essential for maintaining water resource sustainability and environmental safety. This study assessed groundwater quality for its potential use in irrigation and domestic use. Thirty groundwater samples (both tubewell and dug well) were analyzed the physico-chemical parameter. Analyzed parameters reveal that pH is neutral to slightly alkaline and TDS is ranges from 65 to 470 mg/l, which indicate the fresh water. Only one sample exceed the desirable limit of magnesium which located in Gambharidihi village. Two groundwater samples exhibited bicarbonate concentrations beyond the acceptable limit, while total alkalinity values exceeded the acceptable limit in three samples. Irrigation indices like salinity hazard show five sample are excellent, twenty five sample are good. According to %Na, eighteen sample are good, eleven are permissible and only one sample is doubtful. Twenty four sample is suitable and six sample is unsuitable by MAR. According to PI sixteen are good and fourteen are moderate for irrigation. Geochemical facies reveal that Ca^{2+} - HCO_3^- and mixed dominant type, controlled by lithological interaction mixed carbonate-silicate weathering and reverse ion exchange.

Keywords: Groundwater, Irrigation, Water quality, Piper diagram, Gibb's diagram

1. Introduction

Groundwater is one of the most vital sources of freshwater worldwide, providing water for drinking, agriculture, and domestic use, particularly in arid, semi-arid, and developing regions where surface water resources are either scarce or polluted [1, 2, 3, 4, 5]. It is estimated that, in India 70% of water is used for irrigation. Over time, the use of groundwater has increased because surface water sources are not always sufficient. At the same time, rapid urbanization and the expansion of agricultural activities have gradually worsened groundwater quality [6, 7]. Groundwater is an important water resource that fulfills about 80-95% of rural drinking water needs, nearly 50% of agricultural requirements, and around 50% use for drinking purpose. Comparatively, groundwater serves as a major source of drinking water in countries such as France and China, contributing approximately 50% and 70% of their potable water needs, respectively [8, 9, 10].

In the locality of Jharsuguda, groundwater is the main source of water for domestic and agriculture use. The availability of clean and adequate groundwater plays an important role in supporting these people and their future [11]. However, natural geological factors, rapid urbanization, intensive agriculture, and industrial development have gradually polluted and stressed groundwater resources, creating serious concerns about their long-term safety and reliability [12, 13, 14, 15, 16, 5]. The current study therefore aimed at assessing the groundwater quality of Arda Panchayat for sustainable growth of agriculture and domestic uses.

1.1 Study Area

The study area lies between latitudes $21^{\circ}52'30''\text{N}$ to $21^{\circ}56'30''\text{N}$ and longitude $84^{\circ}4'15''$ to $84^{\circ}7'45''\text{E}$ in the Survey of India topographical map 73C/6. The study area map is shown in Fig.1 The area contains 6 numbers of revenue villages with a population of 7201. The climate condition varies from time to time. The temperature fluctuates between 35°C - 45°C during summer time. The study area experiences monsoon from June to September, during which the temperature remains pleasant, whereas winter temperatures fluctuate

between 11°C and 35 °C. In the study area the minimum temperature in summer is 34 °C and in winter months temperature ranges from 11 °C to 35 °C. This area has no high hills and the average height ranges between 500 ft to 750 ft above the mean sea level. Crystalline and sedimentary

rocks are underline in the study area and these rocks are belonging mainly to Precambrian and Permo-carboniferous age. The area comprise of various litho units of diverse composition, such as granite gneiss, sandstone, shale of lower Gondwana and metasedimentary of Precambrian age.

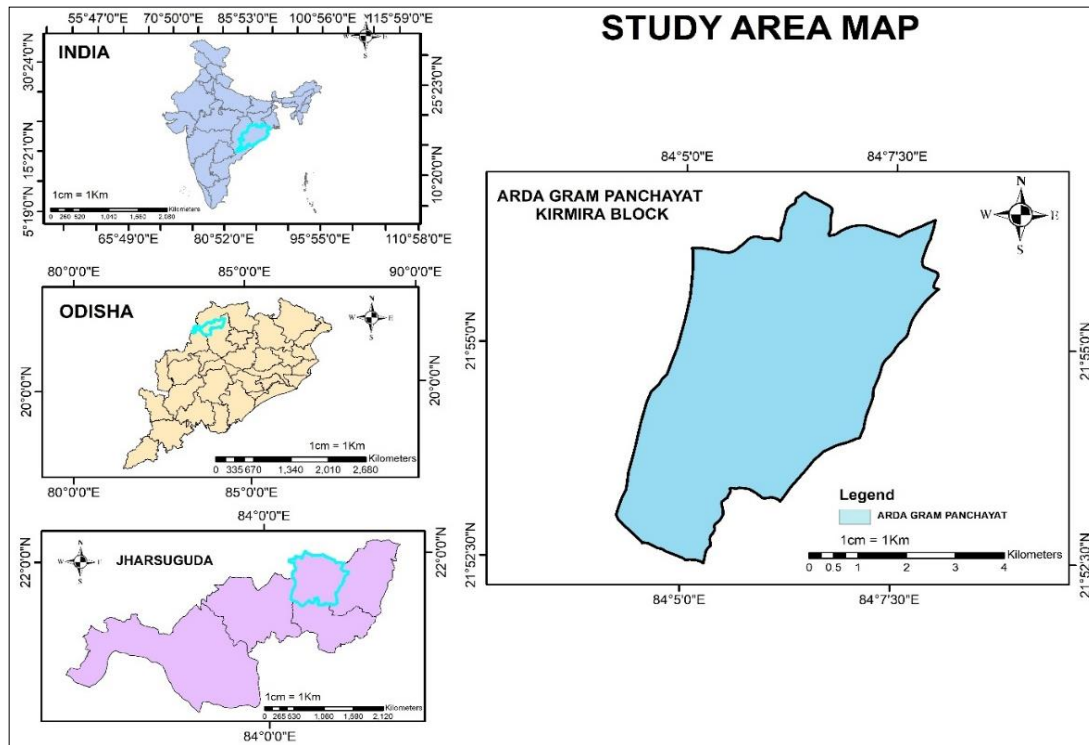


Fig 1: Study area map

2. Materials and Methods

A total of 30 groundwater samples were collected from the study area during the post-monsoon season of 2025. Sample location map shown in Fig. 2. Table no.1 illustrate the sampling point of study area. hydrogen ion concentration (pH), total dissolved solids (TDS), and electrical conductivity (EC) were analyzed in the field following by the standard procedures of the American Public Health Association (APHA, 1992) [17] using digital pH, TDS, and EC meters. The remaining physicochemical parameters were subsequently analyzed in the laboratories of the Department of Earth Sciences, Sambalpur University.

Total hardness (TH) as CaCO_3 and calcium (Ca^{2+}) were analyzed titrimetrically, using standard EDTA [18, 19]. Magnesium (Mg^{2+}) was calculated by the differential of total hardness and calcium hardness. Sodium (Na^+) and potassium (K^+) were determined using a flame photometer. Total alkalinity (TA) as CaCO_3 , carbonate (CO_3^{2-}), and bicarbonate (HCO_3^-) were estimated through titration with standard HCl solution. Chloride (Cl^-) was analyzed by argentometric titration using standard AgNO_3 solution. Sulphate (SO_4^{2-}) was determined by titrimetric method, while fluoride (F^-)

concentration was measured using a spectrophotometer [18]. The ion balance error (IBE) was evaluated following APHA standard procedures, and the obtained results were found to be within the range of 5% to 10% (Fig.3).

$$\text{IBE}\% = \frac{(\sum \text{CATION} - \sum \text{ANION})}{(\sum \text{CATION} + \sum \text{ANION})} \times 100$$

There are different procedure for evaluating the groundwater quality for irrigation are %Na, SAR, KR, MAR, RSC etc. According to the concept proposed by Gibbs (1970) [21], groundwater chemistry is mainly governed by factors such as precipitation, rock-water interaction, and evaporation-crystallization processes. The Piper Diagram was used to identify the hydrochemical characteristics of groundwater samples. In the Gibbs Diagram, TDS values were plotted against $\text{Na}^+ / (\text{Na}^+ + \text{Ca}^{2+})$ and $\text{Cl}^- / (\text{Cl}^- + \text{HCO}_3^-)$ ratios in two separate diagrams, shown in Fig. 5a and Fig. 5b, respectively. The plot of TDS versus $\text{Na}^+ / (\text{Na}^+ + \text{Ca}^{2+})$ indicated that the majority of the groundwater samples fall within the “rock dominance” field. Similarly, the plot of TDS against $\text{Cl}^- / (\text{Cl}^- + \text{HCO}_3^-)$ also revealed that most of the samples are controlled by rock dominance processes.

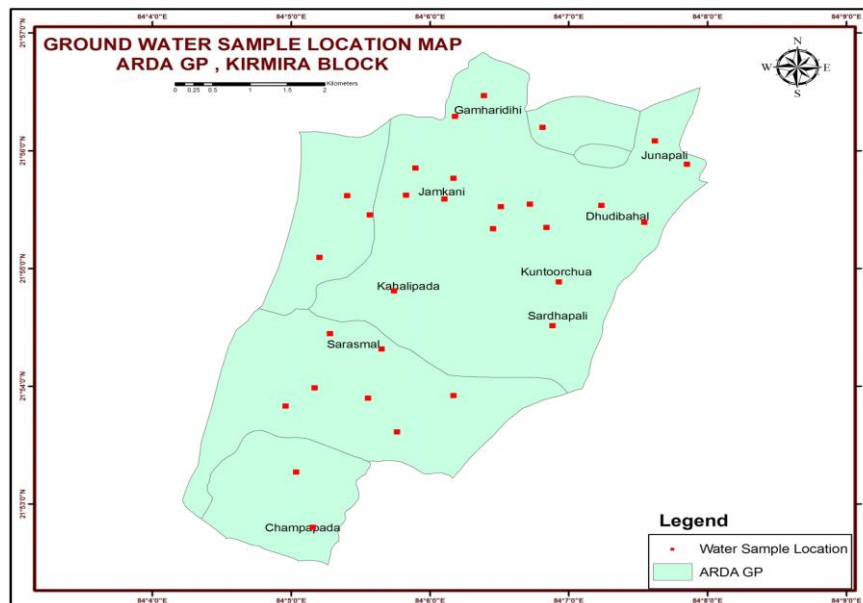


Fig 2: Sample location map

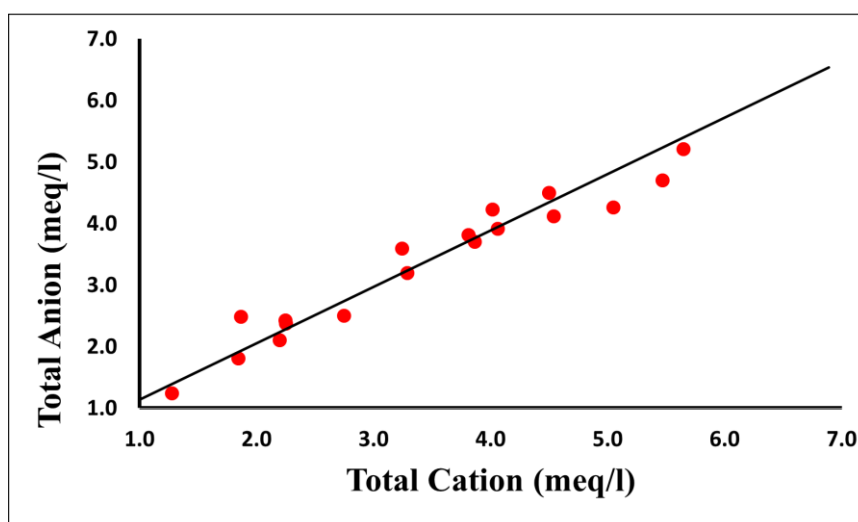


Fig 3: The analytical results were validated by comparing the total cation and anion concentrations

Table 1: Water sample location

Sample id	Village	Sample id	Village
T1	Jamkani	T16	Dhuttra
T2	Jamkani	T17	Dhuttra
T3	Kunturachua	T18	Dhuttra
T4	Sardhapali	T19	Arda
T5	Dhudibahal	D1	Jamkani
T6	Dhudibahal	D2	Jamkani
T7	Bhaidihi	T20	Arda
T8	Kahalipada	T21	Arda
T9	Gambharidihi	T22	Kankaramunda
T10	Gambharidihi	T23	Kankaramunda
T11	Sarasmal	D3	Dhuttra
T12	Sarasmal	T24	Junapali
T13	Saraspali	T25	Junapali
T14	Champapada	D4	Arda
T15	Dhuttra	D5	Kankaramunda

3. Results and Discussion

The groundwater in the research area has a mean pH of 7.64 and ranges from 6.58 to 8.42. Most of the natural water have pH value varying from 6.5 to 8.0, but rarely have 5.5. Water having pH value 7.0 to 7.3 are normally regarding as neutral

[20]. It implies that the ground water of the study area is neutral to slightly alkaline. In normal water, alkalinity is generally less than 10 mg/l but it may increase up to 250 mg/l in high sodium water. The total alkalinity (TA) of ground water of the study area in between 35 to 270 mg/l. The hardness (TH)

of ground water of the study area ranges from 25 to 215 mg/l and the average value is 119 mg/l. The specific conductance of ground water of the study area varies from 96.9 to 734 micro mho/cm with an average of 403.2 micromho/cm (Table-2). A good relationship between chloride and specific conductance is a common feature in ground water such relationship is observed in the present study, beside this specific conductance has positive relationship with total hardness, alkalinity, sodium and magnesium (Fig.4) indicate that the conductivity is due to salts of sodium, potassium and magnesium. TDS of ground water sample can be measured from specific conductance of water sample or from actual measurement of residue left after evaporation of filtered water sample or from addition of all the ions or from the alkalinity by multiplying a factor 0.64 when carbonates and bicarbonates are absent or directly by electro potential method. The TDS in the study area varies from 65 to 470 with an average of 267.5. Among the cations Ca^{2+} , Mg^{2+} , Na^{+} and K^{+} ions range from 4 to 52 mg/l, 0.01 to 42.52 mg/l, 8.4 and 68 mg/l and 0.6 to 56 mg/l with a mean of 27.5, 11.7, 29.8, and 9 mg/l respectively. Dissolved anions, CO_3^{2-} , HCO_3^{-} , Cl^{-} , SO_4^{2-} , and F^{-} lie between 0 to 18, 42.7 to 260, 7.1 to 198, 0.05 to 82 mg/l and 0 to 0.7 mg/l with a mean of 1.2, 126.8, 45.6, 17.3 mg/l and 0.3 mg/l respectively.

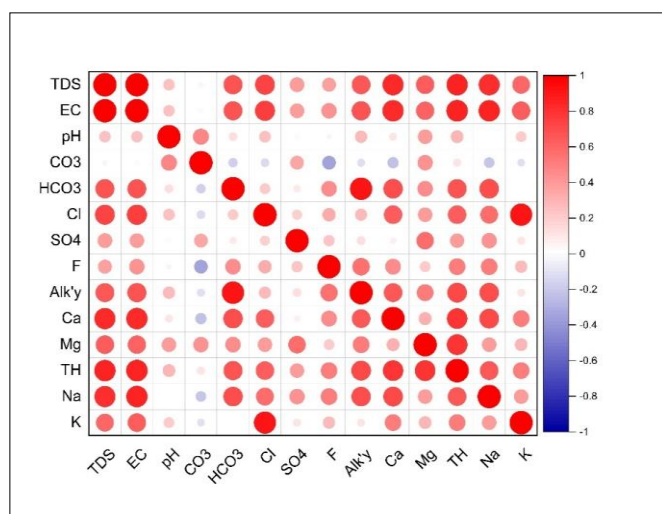


Fig 4: Correlation of parameters

Table 2: Minimum, maximum and average value of parameters

Parameters	Minimum	Maximum	Average
Temp.	29	34	31.5
pH	6.58	8.42	7.64
TDS	65	470	265.7
EC	96.9	734	403.2
TA	35	270	127.3
TH	25	215	119
Na^{+}	8.4	68	29.8
K^{+}	0.6	56	9
Ca^{2+}	4	52	27.5
Mg^{2+}	0.01	42.52	11.7
HCO_3^{-}	42.7	260	126.8
CO_3^{2-}	0	18	1.2
Cl^{-}	7.1	198	45.6
SO_4^{2-}	0.05	82	17.3
F^{-}	0	0.74	0.37

3.1. Mechanisms Controlling Groundwater Chemistry

Gibbs diagrams, which plot the ratios of $\text{Na}^{+}/(\text{Na}^{+} + \text{Ca}^{2+})$ and $\text{Cl}^{-}/(\text{Cl}^{-} + \text{HCO}_3^{-})$ against TDS, are commonly used to identify the major mechanisms controlling groundwater chemistry, including precipitation dominance, rock dominance, and evaporation dominance [21,18]. The sample points are plotted in Gibbs's diagrams (Fig. 5a) and (Fig.5b). It is found that maximum of the samples falls within the region of "Rock dominance" and only two samples are plotted in the "precipitation dominance". The hydrogeochemical facies of the groundwater has been determined using Piper's trilinear classification. This diagram is considered one of the most important graphical methods for studying groundwater quality [22]. It interprets the groundwater's chemical nature in the study area. In this diagram, all the major ions are expressed in epm value. Piper trilinear diagram consists of two triangular sections and one central diamond-shaped portion. The diamond-shaped portion is further divided into six distinct fields [23, 24]. In the study area, most of the groundwater samples fall within the calcium-bicarbonate ($\text{Ca}^{2+}\text{-HCO}_3^{-}$) facies, with a few samples showing mixed water type characteristics, while only one sample belongs to the $\text{Na}^{+}\text{-Cl}^{-}$ type. The diagram further indicates that alkaline earth elements (Ca^{2+} and Mg^{2+}) dominate over alkali metals (Na^{+} and K^{+}), and weak acidic anions (HCO_3^{-}) are more abundant than strong acidic anions (Cl^{-} and SO_4^{2-}). (Fig. 6).

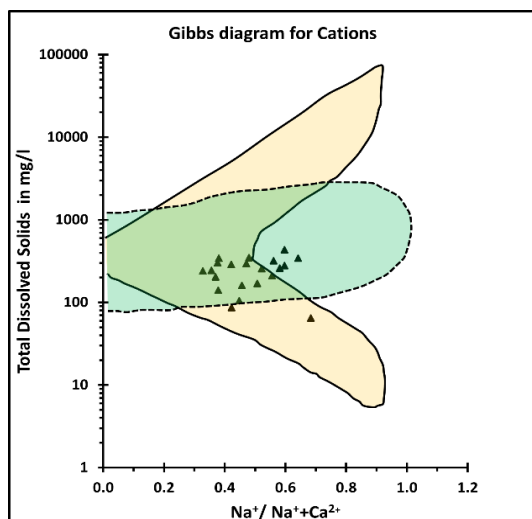


Fig 5a: Gibb's diagram (cation)

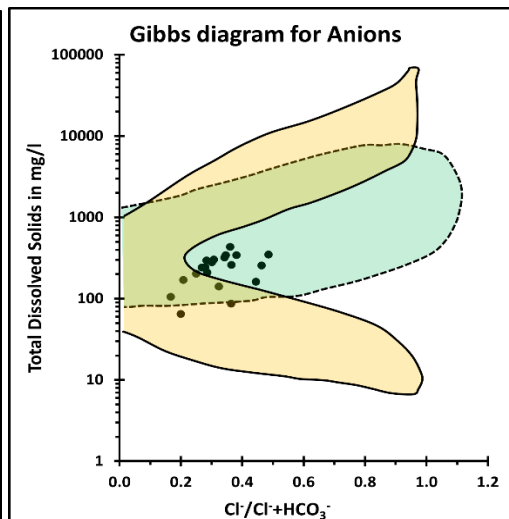


Fig 5b: Gibb's diagram (anion)

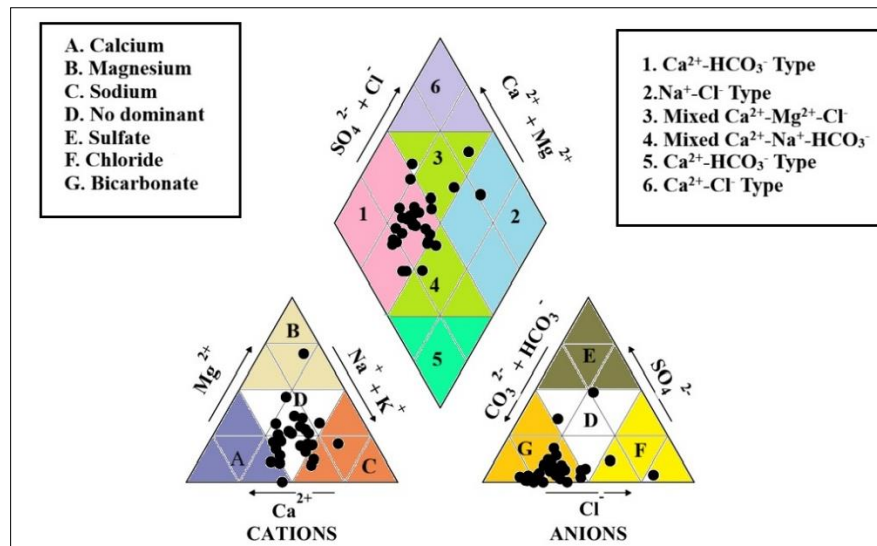
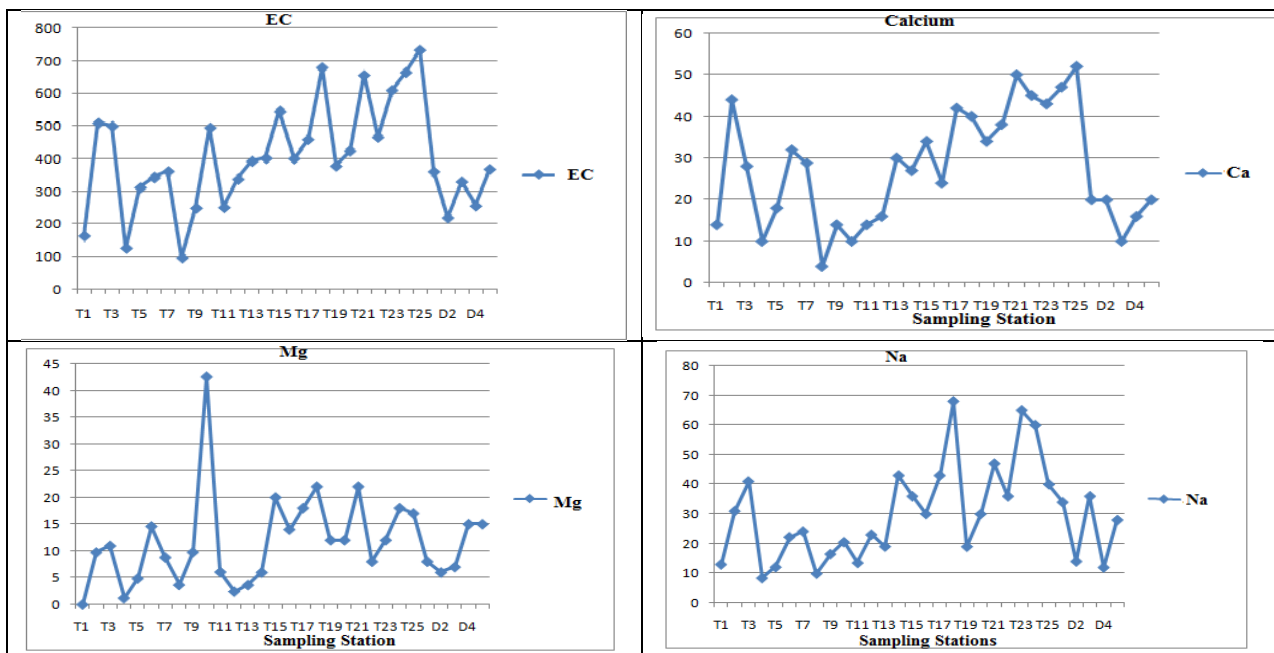


Fig 6: Piper trilinear diagram

3.2. Groundwater Quality for Drinking

Groundwater of the study area does not pass any smell or colour, but varies in taste from place to place. Chemical quality standards have been established for suitability of water for domestic purposes by various organizations like BIS, WHO, USPHS, ICMR, ISI etc. In the present study BIS, 2012 standards have been adopted. Comparison of result of chemical analysis with that of BIS, 2012 standard for drinking water reveals that more groundwater samples from the study area are fit for drinking with only few exceptions. Most groundwater samples in the study area exhibited pH values that fall within the acceptable limits, while all the groundwater samples come under allowable limit. The TDS of the groundwater in most of the

cases are within the acceptable limit. Hardness of the groundwater has no adverse effect on health; however, some evidences have been given to indicate its role in the heart diseases. It is found that groundwater sample from this area can be classified as moderately soft. The total alkalinity of the sample Id. T18, T20, T21 are beyond acceptable (Table-3). limit. The calcium content is within the acceptable limit except few but all are within the maximum allowable limit. The bicarbonate content is well except the samples Id. 18 and 21 (Table-3). All groundwater samples from the study area exhibited chloride, fluoride and sulphate levels within the acceptable limit. The graphical representation of all parameters are shown in Fig. 7a to 7j



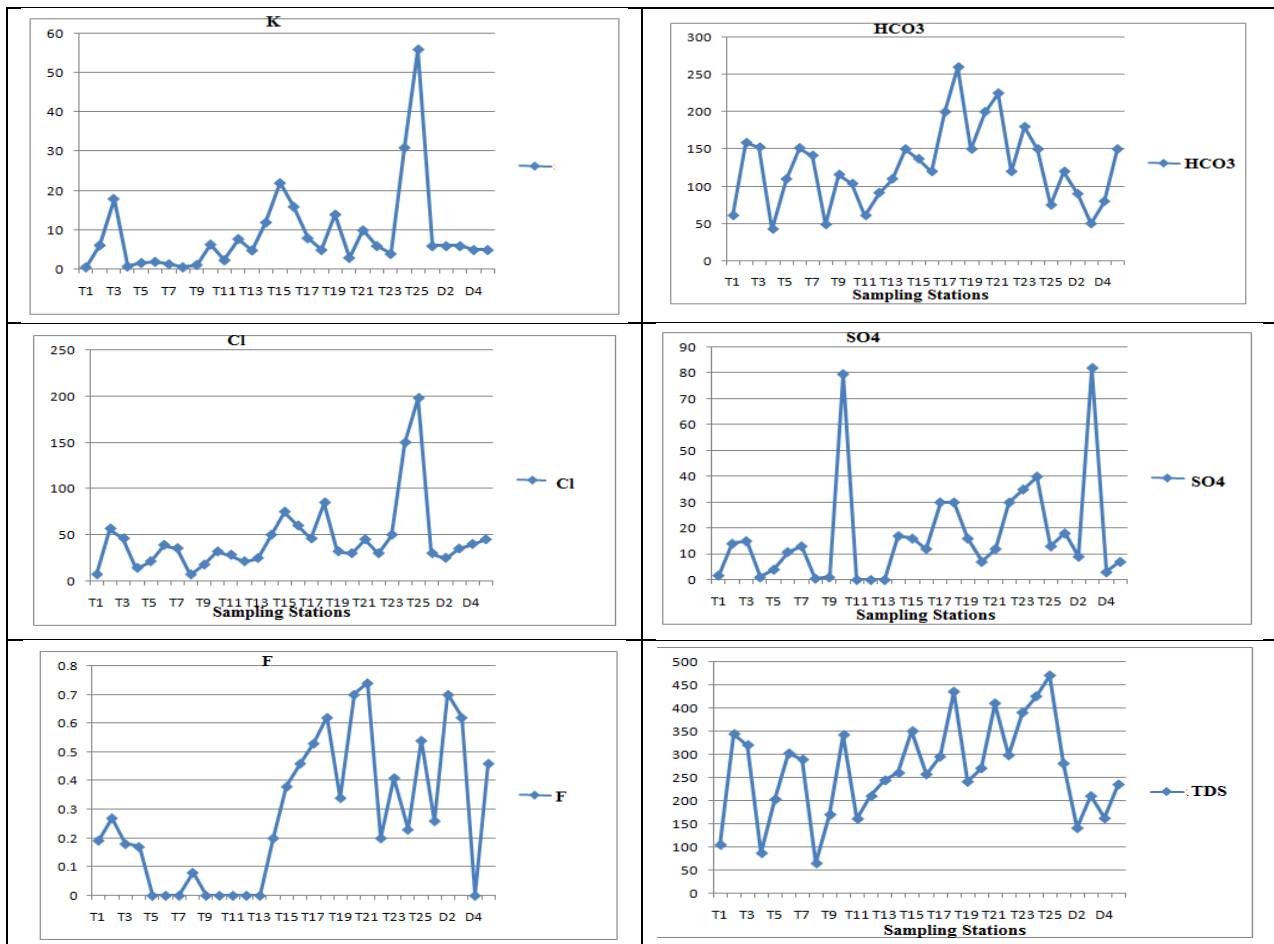


Fig 7: a-EC, 7b-Ca²⁺, 7c-Mg²⁺, 7d-Na⁺, 7e-K⁺, 7f-HCO₃⁻, 7g-Cl⁻, 7h-SO₄²⁻, 7i-F⁻, 7j-TDS

Table 3: Parameters compare with BIS standard, 2012

Parameter	BIS 10500		Range	
	Highest Desirable	Maximum Permissible	No. of sample exceed desirable limit	No. of sample exceed permissible limit
pH	6.5	8.5	00	00
TDS (mg/l)	500	2000	00	00
Calcium (mg/l)	75	200	00	00
Magnesium (mg/l)	30	100	01	00
Sulphate (mg/l)	200	400	00	00
Chloride (mg/l)	250	1000	00	00
Alkalinity (mg/l)	200	600	04	00
Total Hardness (mg/l)	300	600	01	00
Fluoride (mg/l)	1.0	1.5	00	00

3.3. Quality of Groundwater for Irrigation

3.3.1. Sodium adsorption ratio (SAR)

Electrical conductivity and sodium concentration play a significant role in determining the suitability of groundwater for agriculture purpose. High salt concentration in irrigation water increases the osmotic pressure of the soil solution [25], which reduces the ability of plant roots to absorb water through osmosis. As a result, water uptake by plants decreases, adversely affecting plant growth. The osmotic pressure is directly related to the salinity hazard or total dissolved salt content in irrigation water. Apart from directly influencing plant growth, dissolved salts also alter soil properties such as structure, permeability, and aeration, thereby indirectly affecting crop productivity. Based on the total dissolved soluble salts, irrigation water is divided into four salinity classes: low salinity (C1), medium salinity (C2), high salinity (C3), and very high salinity (C4). These classes

are determined according to electrical conductivity (EC) values, where EC less than 250 $\mu\text{S}/\text{cm}$ indicates C1, 250-750 $\mu\text{S}/\text{cm}$ represents C2, 750-2250 $\mu\text{S}/\text{cm}$ corresponds to C3, and values exceeding 2250 $\mu\text{S}/\text{cm}$ fall under C4. [26, 18] (Fig. 8). Water with high EC values contributes to the development of saline soils. Another important parameter used to evaluate irrigation water quality is sodium hazard, commonly expressed as the Sodium Adsorption Ratio (SAR). SAR is calculated using ionic concentrations expressed in milliequivalents per litre (meq/l), as represented by the following equation.

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

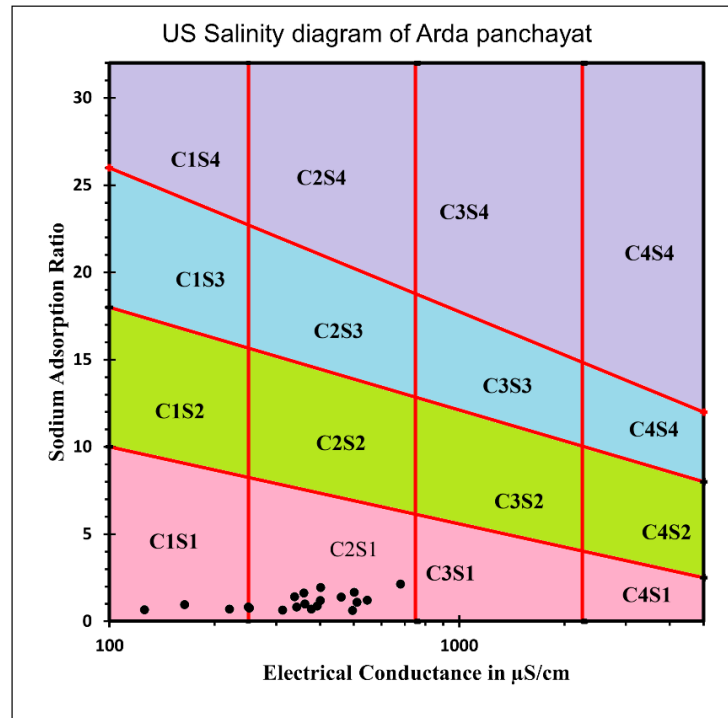


Fig 8: U.S.Salinity diagram

3.3.2. Percent Sodium (%Na)

Irrigation water containing high concentrations of sodium, potassium, calcium, and magnesium salts is detrimental to plants [27]. The sodium content in irrigation water is commonly expressed as percentage sodium (%Na) [28], which can be calculated using the following formula.

$$\%Na = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}}$$

Where all ionic concentrations are expressed in milliequivalents per liter (meq/l).

The percentage sodium (%Na) values in the study area range from 20.89 to 61.53 meq/l. Wilcox introduced a method for classifying irrigation water on the basis of %Na with respect to electrical conductivity. The plotting of parameter for well water of the study area is shown in the Fig.9. Table 3 presents the classification of groundwater according to the Wilcox classification system. It is found that majority of the sample of the study area fall under good to permissible class. Only one sample is fall under the doubtful (Fig.9).

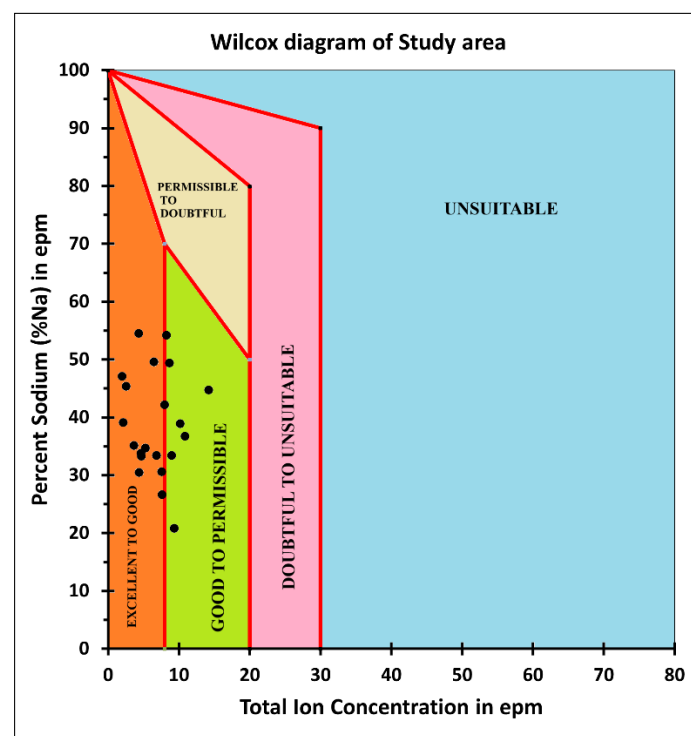


Fig 9: Wilcox diagram

3.3.3. Residual Sodium Concentration (RSC)

Residual sodium carbonate (RSC) was purposed by Eaton as

a basis for classifying groundwater suitability for irrigation. Sodium hazard to crops increases considerably with increasing bicarbonate concentration. Water containing high levels of bicarbonate and carbonate causes precipitation of calcium and magnesium in the form of carbonates, thereby increasing the relative sodium content and reducing soil permeability, RSC can be calculated by following equation-

$$\text{"RSC} = (\text{CO}_3^{2-} + \text{HCO}_3^-) - (\text{Ca}^{2+} + \text{Mg}^{2+})"$$

Where all ionic concentrations are expressed in milliequivalents per liter (meq/l).

The results of the study reveal that the groundwater is fit for irrigation purposes. (Table-4)

Table 4: Groundwater classification for irrigation and industrial purpose

Class		Range	Water class	Number of samples
Salinity hazard	C1	>250 $\mu\text{S/cm}$	excellent	5
	C2	250-750 $\mu\text{S/cm}$	good	25
	C3	750-2250 $\mu\text{S/cm}$	Permissible	00
	C4	>2250 $\mu\text{S/cm}$	Unsuitable	00
% Na		<20	Excellent	00
		20-40	Good	18
		40-60	Permissible	11
		60-80	Doubtful	1
		>80	Unsuitable	0
MAR		<50	Suitable	24
		>50	Unsuitable	6
RSC		<1.25	Good	100
		1.25-2.50	Doubtful	00
		>2.5	Unsuitable	00
PI	I	>75	Good	16
	II	75-25	Moderate	14
	III	<25	Poor	00

3.3.4. Magnesium adsorption ratio (MAR)

The magnesium adsorption ratio (MAR) is expressed by the given formula. It represents the ratio of magnesium ions to the combined concentration of calcium and magnesium ions [29, 18].

$$\text{MAR} = \frac{\text{Mg}^{2+}}{\text{Ca}^{2+} + \text{Mg}^{2+}} \times 100$$

Where all ionic concentrations are expressed in milliequivalents per liter (meq/l).

Elevated magnesium concentration in irrigation water has harmful effects on soil quality because it causes the soil to become more alkaline, which reduces crop yield [29, 30]. If the MAR value is below 50%, the water is considered suitable for irrigation purposes [31]. In this study, 24 water samples are found to fit for irrigation due to the determined value of MAR being less than 50 and 6 samples are unsuitable (Table-4).

3.3.5. Permeability index (PI)

Irrigation water also depends on the permeability of the soil. Doneen (1964) developed a criterion to assess the suitability of water for irrigation based on the permeability index which is given by the equation -

$$\text{PI} = \frac{\text{Na}^+ + \sqrt{\text{HCO}_3^-}}{\text{Na}^+ + \text{Ca}^{2+} + \text{Mg}^{2+}} \times 100$$

All the equations are expressed in meq/l.

Irrigation water is classified into three classes by Doneen [32]. Class I is good for irrigation where PI is more than 75, class II is moderate where the PI value is between 75 to 25, class III is poor and here PI value is less than 25. In the study area the PI values range from 44.91 to 142.27. During this period, 16 samples are in good and only 4 samples are in moderate category (Fig.10).

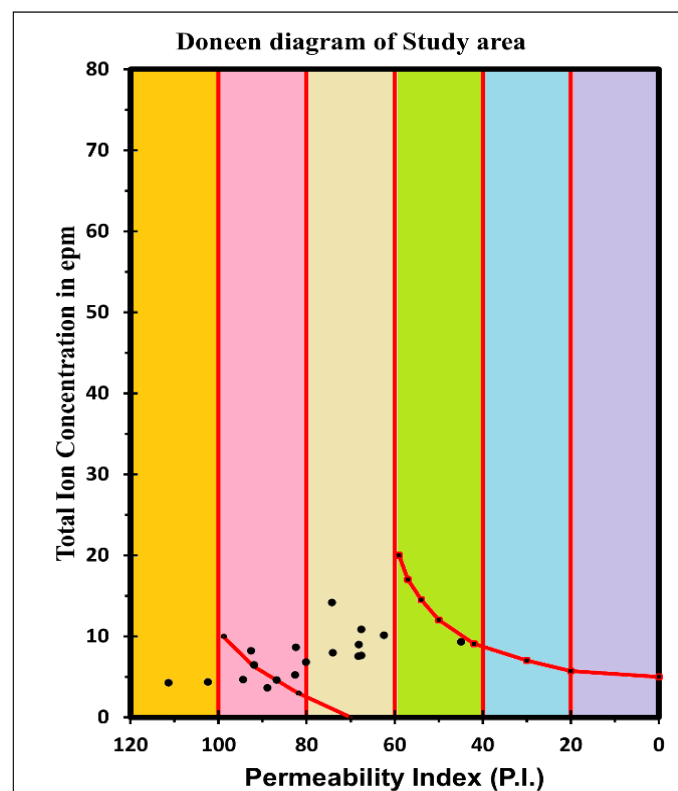


Fig 10: Doneen diagram

4. Conclusion

The quality of groundwater that is physical, chemical and biological characters of the groundwater decides its suitability or unsuitability for a particular use that is domestic and irrigation. Quality aspect of groundwater for utilization purposes such as agriculture and domestic purposes are thoroughly discussed by processing the chemical data.

According to drinking water standards, the magnesium of groundwater is beyond desirable limit in the village of Gambharidihi (T-10), bicarbonate value is exceed there desirable limit in Dhutra and Arda (T-18, 21) and beyond the desirable limit of total total alkalinity in the village of Dhutra and Arda (T-18, 20, 21) in the study area. Except for a few cases, the percentage sodium (%Na) of samples remained within the permissible range. According to the SAR classification, all groundwater samples are found to be suitable for irrigation and belong to the excellent to good class. According to MAR, twenty four sample are suitable and six are unsuitable and PI have sixteen samples are good and fourteen are moderate for irrigation. Geochemical facies reveal that Ca^{2+} - HCO_3^- and mixed dominant type, controlled by lithological interaction mixed carbonate-silicate weathering and reverse ion exchange.

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