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Study Of Groundwater Quality For Irrigation Purpose – A Case Study Of Paliganj Distributary, Bihar, India

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Abstract

If irrigation water becomes polluted, the circulation of water in the soil is reduced and plant development is hampered. The purpose of this study was to determine the quality and suitability of groundwater in the Paliganj distributary of Bihar, India for irrigation. A total of forty groundwater samples are collected from the hand pump and dug well during March 2020 and October 2020 and analyzed for pH, TDS, Ca^{2+}, Mg^{2+}, Na^{+}, CO_3^{-2}, NO_3^{-}, TH, F^{-}, SO_4^{2-}, K^{-}, Cl^{-}, and HCO_3^{-}. The chemical characteristics of groundwater are analyzed by piper diagram. Irrigation water quality was analyzed by using Sodium Absorption Ratio (SAR), Permeability Index (PI), Magnesium Absorption Ratio (MAR), Sodium percentage (SSP), Residual Sodium Carbonate (RSC), Kelley's ratio (KR) and Potential salinity index. After analyzing the samples by piper diagram, 95% of samples in pre monsoon and 86% of samples in post monsoon, belong to Ca^{2+}- HCO_3^{-} type and remaining samples belong to Ca^{+2} - Na^{+}-HCO_3^{-} type of water. According to the USSL diagram, the majority of pre- and post-monsoon samples fall into the C_1S_1 and C_2S_1 categories, indicating that groundwater samples are acceptable for irrigation. Only four samples are in the C_3S_1 and C_3S_2 salinity categories, which range from mild to high and may be utilized for irrigation in a variety of soils with sodium exchange. All samples were suitable for irrigation based on their potential salinity and MAR.

Keywords: Water quality; Piper diagram; Irrigation; Wilcox diagram.

1. INTRODUCTION

Groundwater is the largest reservoir of freshwater readily available to humans. In arid, semiarid, and dry regions, the groundwater is only source of water supply. Due to huge development in agriculture sectors, vast growth in population, and extension of industries, the consumption of groundwater tremendously increased [2, 14]. In the 21st century, the accessibility of using fresh water is a challenging task [27, 32]. Therefore, many researchers have focused on groundwater quality analysis and its quality and suitability for irrigation purpose [10, 11, 15, 18 20-22, 24].

In different quantities, groundwater includes numerous types of dissolved inorganic chemical components. The different indices like SAR, SSP, RSC, MHS, PI and KR is used to analyze the groundwater samples for irrigation purpose [19, 33, 36]. U S Salinity laboratory diagram and Wilcox Diagram also used to analyze the groundwater quality for irrigation [1, 3-6, and 28-30]. Agricultural activities have an adverse effect on groundwater quality. Irrigation water should have appropriate salt contaminations and it should be free from chemical and biological pollutants. The salt water increases the osmotic pressure in the soil water and there by restricts the water uptake by plants. The present paper investigates the status of groundwater quality for irrigation purpose. To the state of art, no research on the analysis of irrigation water quality from the Paliganj distributary in Patna district of Bihar has been conducted, particularly with regard to dug well and hand pump water. As a result, the purpose of this study is to determine the suitability of groundwater for irrigation in the Paliganj distributary in Bihar.

2. **MATERIAL AND METHODS**

To investigate seasonal variance, a total of forty groundwater samples were obtained from the Paliganj block in both seasons in the year 2020 in the same sites. A new clean 1000 ml polyethylene bottles is used to collect the groundwater samples. At the time of collection of groundwater samples, the bottles were thoroughly rinsed three times with the same collection of samples. All groundwater samples were taken from hand pumps and dug wells. The groundwater samples collected from the hand pump, after 5 min of pumping. The stored groundwater in the well has been removed by this process. At the time of sample collection, the pH, EC, and Total Dissolve Solids readings were measured by using a portable field kit. As a result, these factors fluctuate with time (WHO, 1996). The laboratory test was done in Central Groundwater Board (CGWB), Patna. By using a flame photometer, the major cat-ions like Na, Ca, Mg, and K were determined. Thermo-Orion bench top ion electrode is used to determine fluoride. The total hardness and bicarbonate were determined by titration. The Standard procedure given by APHA [7] is used to analyze chemicals.

2.1. **The Study Area**

The Sone command area aggregate catchment zone of the waterway is 71,259 sq. km, of which 17,651 sq. km lies in Bihar shown in fig.1. The remaining 53,608 sq. km lies in Chhattisgarh, Madhya Pradesh, Uttar Pradesh and Jharkhand states of India. The Paliganj Distributary is part of the Sone Canal System in South Bihar shown in fig. 2. The Sone River flows north-eastward from the Deccan Plateau before joining the Ganges not far from the city of Patna. The Sone Canal System diverts water from the river to irrigate a design command area of over 700,000 ha. The Paliganj distributary is a part of Sone irrigation system in south Bihar; it is around 60 km from the city of Patna, the capital of Bihar in Eastern India. The Paliganj area lies wholly within the Gangetic plain. About 1000mm of rain falls every year mostly during kharif season i.e., June to October. A smaller amount of rain falls in Rabi season i.e., November to March. The Paliganj distributary is a branch of Patna Canal, 75 km in the downstream direction from its head from Sone Barrage. Chandos and Bharatpura are being its two sub distributaries. The complete length of this system (including sub distributaries) is around 40 km and a total of 4500 ha of agricultural land is irrigated by it. Channels of this system meander through Paliganj and Dulhania Bazar blocks in Patna and Arwal block of Arwal district which incorporates more than 50 villages.

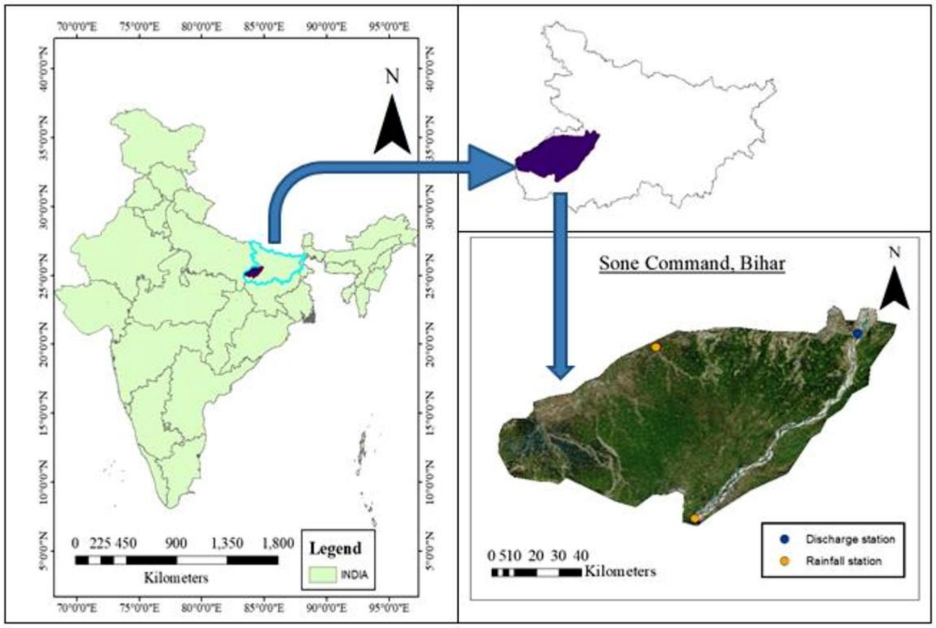

Figure 1. Sone Command Area

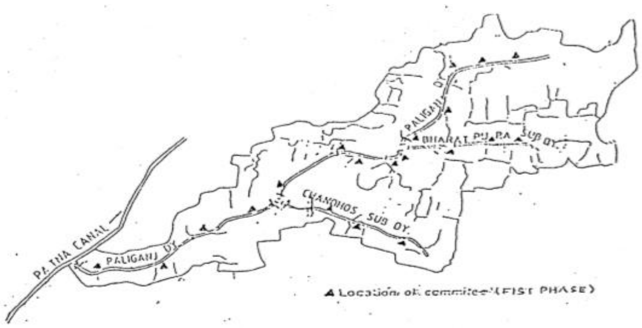

Figure 2. Index Map of Paliganj Distributary, Sone canal system
(**Source:** Bihar State Second Irrigation Commission)

2.2. **Irrigation Water Indices**

Sodium Absorption Ratio (SAR): The irrigation water containing a high quantity of sodium is a hazard to represent the relative percentage of sodium with calcium and magnesium [25]. Sodium Absorption Ratio is defined as follows

$$\mathrm{SAR} = \left[\mathrm{Na^{+}} / \sqrt{(\mathrm{Ca^{+2}} + \mathrm{Mg^{+2}})/2}\right] \quad (1)$$

Where, all ion concentrations are in mg/l.

Sodium Percentage (Na %): The sodium percentage [35] is used to classify water for irrigation purposes. Excess sodium reduces the movement of water in the soil and harms plant growth. Sodium Percentage is defined as follows

$$\%Na = [(Na^{+} + K^{+})/(Na^{+} + K^{+} + Ca^{+2} + Mg^{+2})] \times 100 \qquad (2)$$

Where, all ion concentraions are in mg/l.

Residual Sodium Carbonate (RSC): Residual sodium carbonate is the concentration of CO_3^- and HCO_3^- ions exceeds the concentrations of Ca^{+2} and Mg^{+2} ions in irrigation water [23]. Excess of RSC indicates an increase the sodium absorption on the soil. Residual sodium carbonate is defined as follows

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{+2} + Mg^{+2}) \qquad (3)$$

Where, CO_3^{2-}, Mg^{+2}, Ca^{+2} and HCO_3^- are in meq/l.

Kelley's Ratio (KR): Based on Kelley's ratio the groundwater is classified for irrigation purposes [16]. KR >1 indicates an excess of sodium is present. Therefore, greater than 1 is not suitable for irrigation. Kelley's Ratio is defined as follows

$$KR = [(Na^{+})/(Ca^{+2} + Mg^{+2})] \qquad (4)$$

Where all ion concentration are in mg/l.

Permeability Index (PI): The PI is the water quality index is used for the assessment of water for irrigation purpose [12]. Irrigation water affects soil permeability because it includes Mg^{+2} Na, Ca^{+2}, and HCO_3^- ions in the soil. PI is defined as follows

$$PI = \left[\left(Na^{+} + \sqrt{HCO_3^{-}}\right)/(Ca^{+2} + Mg^{+2} + Na^{+})\right] \times 100 \qquad (5)$$

Where, Na^+, Ca^{2+}, Mg^{+2} and HCO_3^- are in mg/l.

Potential Salinity (PS): PS is indicator for the suitability of water for irrigation purposes [12]. PS is less than 3 recommended for irrigation purposes. Potential salinity is defined as follows

$$PS = Cl^{-} + \sqrt{SO_4^{-2}} \qquad (6)$$

Where, Cl^- and SO_4^{-2} are in meq/l.

Magnesium Absorption Ratio (MH): Magnesium Absorption ratio is one of the qualitative parameters in the suitability of irrigation water by magnesium content in relation to calcium and magnesium. Excess of magnesium effect the crop yield. MH greater than 50 is not suitable for irrigation purposes [17]. Magnesium Absorption ratio is defined as follows

$$MH = \left[[(Mg^{+2})/(Ca^{+2} + Mg^{+2})] \times 100\right] \qquad (7)$$

Where, Ca^{2+} and Mg^{+2} are in mg/l. Irrigation Water Classification based on different indices is shown in Table-1.

Table 1. Irrigation Water Classification based on different indices

Sl. No.	Index	Range	Class of water
1.	SAR [25]	< 10 10 – 18 18 – 26 >26	Excellent Good Doubtful Unsuitable
2.	%Na [35] .	>80 60 – 80 40 – 60 20 – 40 < 20	Unsafe Doubtful Permissible Good Excellent
3.	RSC [23]	< 1.25 1.25 – 2.5 > 2.5	Good Doubtful Unsuitable
4	PI [12]	>75 % 25 - 75 % < 25 %	Suitable Good Unsuitable
5.	KR [16]	< 1 >1	Safe Unsafe
6.	PS [12]	<3 >3	Suitable Unsuitable
7.	MH [17]	<50 >50	Safe Unsafe

3. Results and Discussion

3-1- pH

The pH parameter is used to represent the acidity or alkalinity of a solution. The pH levels in the research area range from 6.62 to 8.35. As a result, all groundwater tests in Paliganj were found safe for irrigation [8].

3.2. Groundwater **based on the chemical characteristics**

After analyzing laboratory results of groundwater samples, in pre monsoon, the concentration of cat-ions, Ca^{2+} ranges from 18 to 80 mg/l, Mg^{2+} ranges from 4.9 to 71.7 mg/l, Na^{+} ranges from 11 to 81 mg/l and K^{+} ranges from 0.7 to 4.3 mg/l (Table-2). In post monsoon, the concentration of cat-ions, Ca^{2+} ranges from 22 to 86 mg/l, Mg^{2+} ranges from 3 to 45 mg/l, Na^{+} ranges from 11 to 90 mg/l and K^{+} ranges from 1.0 to 6.5 mg/l (Table-3). For irrigation purpose, the allowable limits for cat-ions, Calcium, Magnesium, sodium and Potassium is 80 mg/l, 35 mg/l, 200 mg/l and 30 mg/l respectively [13, 26]. On this basis almost all groundwater samples were suitable for irrigation purpose.

The allowable limit for anions bicarbonate and chloride is 250 mg/l [13, 26]. In pre monsoon, the bicarbonate values in between 98 to 566 mg/l, the chloride values in between 0.1 to 23.8 mg/l. By analyzing the HCO_3^-, in pre monsoon, 50 percent of samples and in post monsoon, and 65 percent of samples are suitable for irrigation. In pre and post monsoon, all samples having Cl^- values below the permissible range, which indicates that all samples are suitable for irrigation.

3.3. **Irrigation Water Indices**

. The sodium adsorption ratio (SAR) is an essential component in determining whether water is suitable for irrigation. Excess of sodium is affecting the plant growth and reduce the soil permeability. In the present study all 100 percent samples in pre and post-monsoon data come under the excellent to good category.

Sodium percentage (%Na) was a significant parameter for irrigation water. Excess of sodium in the water it creates leaching problem and reduces soil permeability and leads to the formation of alkaline soils [31]. In this study, in pre-monsoon 95 percent of samples come to excellent to permissible category, whereas in post-monsoon 60 percent of samples come to permissible and remaining 40 percent of samples come to doubtful to unsuitable because of high sodium content.

Residual sodium carbonate (RSC), the higher concentration of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) also influences the irrigation water. From table-4 and 5, in pre-monsoon 75 percent of samples are good for irrigation purpose and the remaining 25 percent of samples are not suitable for irrigation purposes. Whereas in post-monsoon 95 percent o samples come under the good for irrigation purpose but only one location cone under the doubtful category.

Permeability Index (PI) is used for irrigation water. The use of irrigation water containing Ca, Mg, Na ions, it affects the permeability of soil. The present study maximum and minimum permeability index is 68.8 % to 19.4%, 77% to 36% in pre and post-monsoon respectively.

Kelley's ratio (KR) is very less to use for irrigation purpose. KR greater than 1 is unsafe for irrigation. In this study 95 percent of samples come in safe for irrigation purpose in both pre and post-monsoon respectively in table-4 and 5.

Potential Salinity (PS) index is chlorine and sulphate dominant index. PS index is less than 3 is suitable for irrigation. In this study 100 percent and 85 percent of samples come in the suitable for irrigation purpose in both pre and post-monsoon respectively in table-4 and 5.

Magnesium absorption ration (MH/MAR) is calcium and magnesium-based index. MH is greater than 50 percent is not suitable for irrigation. In this study 95% and 100 % samples come in safe for irrigation purpose in both pre and post monsoon respectively in table-4 and 5.

Table 2. Laboratory results of chemical parameters of pre-monsoon groundwater samples

Location	**pH**	**EC**	**TDS**	**F^-**	**Cl^-**	**HCO_3**	**SO_4**	**NO_3^-**	**Ca^{+2}**	**Mg^{+2}**	Na^+	**K^+**
Paipura	7.41	273	177	0.4	7.2	209	18	33.6	44	17.5	30	4.3
Fathepur	7.34	440	286	0.4	11.6	197	24	22.7	36	19.4	26	1.0
Kurkuri	7.5	393	255	0.5	0.2	215	6	15.0	40	18.2	17	0.8
Sarsi	7.36	184	120	0.2	0.2	129	12	13.8	26	10.9	12	0.9
Shiyarampur	7.31	349	227	0.2	0.8	154	42	14.1	40	15.8	15	0.7
Bara	6.62	204	133	0.2	0.1	123	12.	7.1	22	9.7	12	0.9
Satpura	6.76	606	394	0.2	0.7	277	12	16.7	52	24.3	20	0.7
Pipardah	7.31	241	157	0.3	0.2	135	6	2.3	22	8.5	11	2.1
Lalganj	7.17	750	487	3.8	10.7	431	9	8.2	38	30.4	61	1.0
Gulitar	6.91	1117	726	0.2	12.1	566	37	12.6	34	71.7	80	0.9
Makmilpur	7.14	1126	732	0.4	12.3	504	47	61.5	68	52.2	79	0.8
Baratpura	7.27	532	346	0.5	0.6	308	1	9.5	48	26.7	21	1.5
Achhua	7.47	627	407	0.9	21.5	338	10	4.5	36	7.3	81	1.1
Dulhin Bazar	7.31	1014	660	0.1	23.8	289	33	114.0	80	43.7	22	1.0
Ular Pond	7.34	421	274	0.4	1.7	228	17	5.2	32	12.2	39	0.9
BhimniChak	7.47	461	300	0.3	0.7	258	5	15.5	44	20.7	18	0.9
Harpura	7.31	536	348	0.4	1.1	314	5	14.8	54	24.3	20	0.9
Nabi Nagar	7.39	529	344	0.6	1.4	283	8	19.3	42	23.1	26	1.3
Aktiyarpur	7.43	403	260	0.2	0.2	240	3	5.3	46	18.2	12	1.2
Khapura	7.47	138	90	0.2	0.1	98	4	1.9	18	4.9	12	0.9

3.4. **Piper Diagram**

The piper (1944) diagram is used as graphical representation of geo-chemicals of water samples. In this diagram the concentration of anions and cat-ions are shown in bottom two triangle plots. The apex of the cat-ion plot is Ca^{+2}, Mg^{+2}, and Na^{+}+K^{+} cat-ions. In the apex of anion plot is Cl^{-}, SO_4^{-} and HCO_3^{-} + CO_3^{-} anions. The piper plot of Paliganj showed that 95 percent of samples of March 2020 (Pre-monsoon) fell in zone-1 that is the Ca-HCO_3 type of water shown in fig. 3 and 5 percent fell in zone-3 that is mixed Ca-Na-HCO_3type of water. It is clearly evident from the pre-monsoon plot that Ca and HCO_3 are dominant cat-ion and anion. In October 2020 (Post-monsoon) 86 percent of samples fall in zone-1 that is the Ca-HCO_3 type of water shown in fig. 4, 9 percent of samples fall in zone-3 that is mixed Ca-Na-HCO_3 type of water and 5 percent of samples fall in zone-4 that is mixed Ca^{+2}-Mg^{+2}-Cl^{-} type of water.

Table 3. Laboratory results of chemical parameters of pre-monsoon groundwater samples

location	**pH**	**EC**	**TDS**	**F^{-}**	**Cl^{-}**	**HCO_3**	**SO_4**	**NO_3^{-}**	**Ca^{+2}**	**Mg^{+2}**	Na^{+}	**K^{+}**
Paipura	7.41	273	177	0.4	7.2	209	18	33.6	44	17.5	30	4.3
Fathepur	7.34	440	286	0.4	11.6	197	24	22.7	36	19.4	26	1.0
Kurkuri	7.5	393	255	0.5	0.2	215	6	15.0	40	18.2	17	0.8
Sarsi	7.36	184	120	0.2	0.2	129	12	13.8	26	10.9	12	0.9
Shiyarampur	7.31	349	227	0.2	0.8	154	42	14.1	40	15.8	15	0.7
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Gulitar	6.91	1117	726	0.2	12.1	566	37	12.6	34	71.7	80	0.9
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Nabi Nagar	7.39	529	344	0.6	1.4	283	8	19.3	42	23.1	26	1.3
Aktiyarpur	7.43	403	260	0.2	0.2	240	3	5.3	46	18.2	12	1.2
Khapura	7.47	138	90	0.2	0.1	98	4	1.9	18	4.9	12	0.9

Table 4. Calculated parameters of irrigation groundwater indices (pre-monsoon)

location	SAR	Na%	RSC	KR	PI	MH	PS
Paipura	5.4	35.6	-0.2	0.5	36.9	28.5	0.8
Fathepur	5.0	33.0	-0.2	0.5	37.3	35.1	1.0
Kurkuri	3.1	23.0	0.03	0.3	27.2	31.3	0.4
Sarsi	2.7	25.2	-0.1	0.3	32.2	29.6	0.5
Shiyarampur	2.8	22.0	-0.8	0.3	26.8	28.3	1.0
Bara	3.0	29.0	0.1	0.4	38.1	30.6	0.5
Satpura	3.2	21.2	-0.1	0.3	24.9	31.8	0.5
Pipardah	2.7	29.4	0.4	0.3	44.0	27.9	0.4
Lalganj	10.5	47.7	2.6	0.9	54.2	44.4	0.7
Gulitar	11.0	43.4	1.7	0.8	47.9	67.8	1.2
Makmilpur	10.2	39.9	0.6	0.7	42.2	43.4	1.3
Baratpura	3.4	23.0	0.4	0.3	31.0	35.8	0.2
Achhua	17.4	65.4	3.1	1.9	68.8	16.8	1.1
Dulhin Bazar	2.8	15.5	-2.8	0.2	19.4	35.3	1.5
Ular Pond	8.4	47.8	1.1	0.9	52.5	27.5	0.6
BhimniChak	3.2	23.0	0.3	0.3	27.9	31.9	0.4
Harpura	3.2	21.1	0.4	0.3	25.8	31.0	0.4

Nabi Nagar	4.6	29.5	0.6	0.4	32.3	35.5	0.4
Aktiyarpur	2.0	16.6	0.1	0.2	19.5	28.4	0.3
Khapura	3.5	35.6	3	0.5	33.1	21.3	0.3

Table 5. Calculated parameters of irrigation groundwater indices (post-monsoon)

Location	SAR	%Na	RSC	KR	PI	MH	PS
Satpura	2.5	31.0	-0.3	0.3	44	30.3	1.59
Pipardah	2.6	32.5	2.1	0.3	55	30.3	1.51
Fathepur	2.6	33.6	0.4	0.3	49	31.8	1.51
Khapura	3.1	42.7	-0.8	0.4	53	30.6	3.48
Akhtiyapur	5.6	62.7	0.1	0.6	55	36.0	1.62
Bhimlichak	2.4	25.0	0.7	0.2	43	27.7	1.60
Paipura	2.6	29.8	-0.4	0.3	43	27.5	1.53
Shiyarampur	8.8	65.0	-1.5	0.6	50	48.4	3.66
Kurkuri	4.4	40.7	1.0	0.4	47	13.2	1.56
Bara	7.8	69.9	0.7	0.7	56	23.3	2.33
Sarsi	4.1	38.5	0.4	0.3	43	26.5	1.73
Lalganj	11.2	84.4	-1.1	0.8	55	23.8	1.78
Baratpura	12.3	85.2	-0.5	0.8	55	18.4	3.17
Achhua	11.1	147.6	0.8	1.5	77	12.4	1.12
Harpur	6.1	58.1	0.5	0.6	53	34.8	0.91
Ular Pond	6.4	62.9	-0.1	0.6	53	28.3	1.33
GulliTanr	4.3	31.7	-1.3	0.3	36	33.3	2.08
Makhmilpur	2.7	28.1	-0.3	0.3	40	32.4	1.17

Dulhin Bazar	6.6	65.9	0.8	0.6	57	23.3	0.90
Nabi Nagar	5.0	53.2	-0.5	0.5	51	40.0	1.65

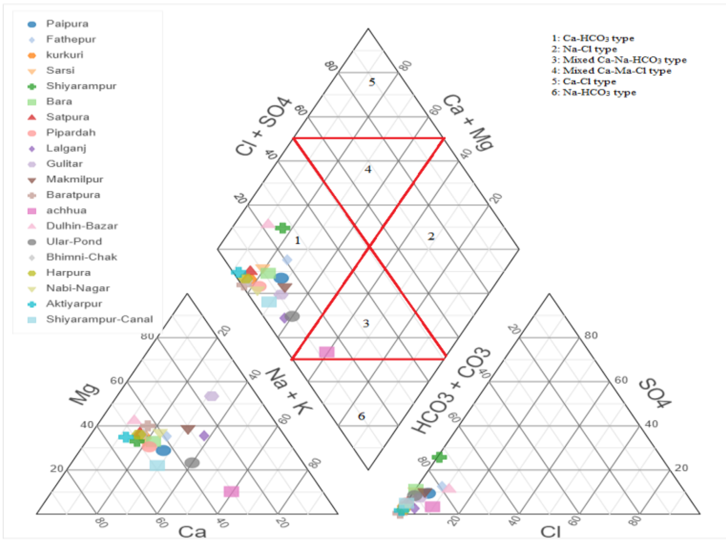

Figure 3. Pre-monsoon Piper diagram

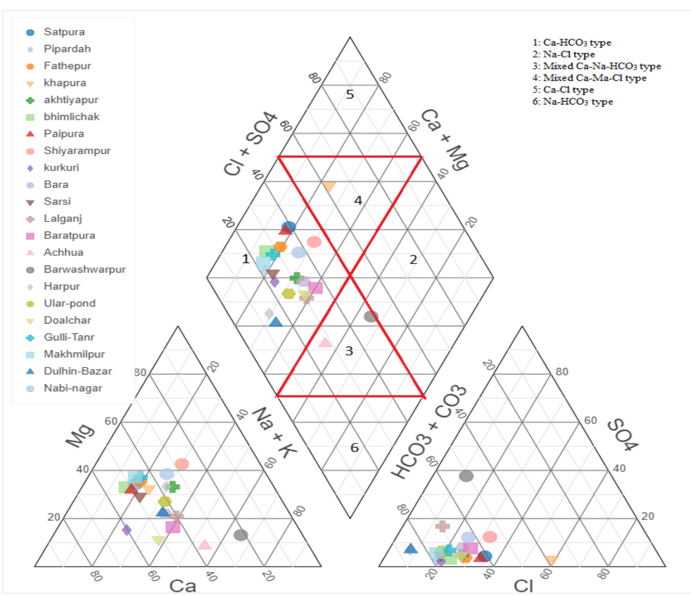

Figure 4. Post-monsoon Piper diagram

3.5. **Wilcox Diagram**

The Wilcox diagram is a graphical illustration of the relationship between the EC and the proportion of salt in water used for irrigation [35]. In the pre-monsoon period, 85 percent of samples are excellent to good, with the remainder falling within the good to permitted group shown in fig. 6. After the monsoon, 75% of samples go into the excellent to good category, while 35% fall into the permitted to dubious group, indicating that appropriate drainage is necessary owing to the high salt content shown in fig. 6. As a result, the vast majority of samples in both seasons fall into the excellent to good category, indicating that the groundwater samples in this research region are adequate for irrigation.

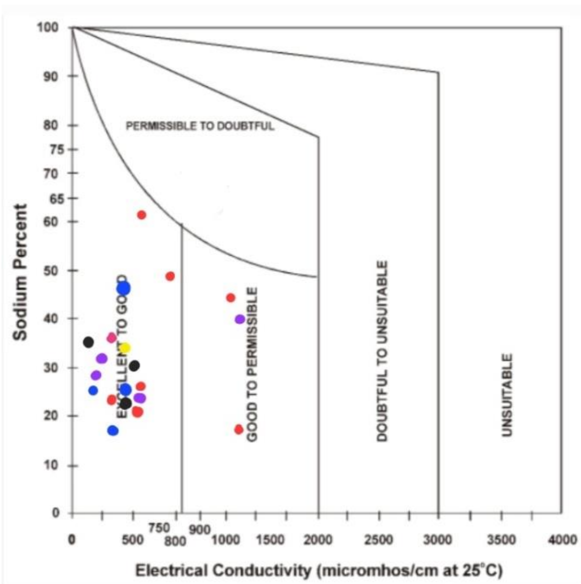

Figure 5. Wilcox diagram of pre-monsoon data

3.6. **U S Salinity laboratory Diagram**

The USSL diagram, which is used to determine the feasibility of using groundwater for irrigation, divides irrigation water into two categories based on electrical conductivity and SAR values [34]. The pre-monsoon SAR and EC values of groundwater samples were plotted in a graphical representation, and it was discovered that four samples fall into C1S1 (low salinity to low sodium hazard), eleven samples fall into C2S1 (medium salinity to low sodium hazard), one sample falls into C3S1 (high salinity to low sodium hazard), three samples fall into C3S3 (high salinity to high sodium hazard) shown in fig. 7. In post monsoon, the values of SAR and EC were plotted in the graphical representation, it is found that 3 samples fall in C1S1, 11 samples fall in C2S1, one sample in C3S1, 3 samples in C3S3 and one sample in C2S2 shown in fig. 8. Therefore, in the both seasons more than 65 % of samples fall in the C1S1 and C2S1, which indicates it is suitable for irrigation purpose.

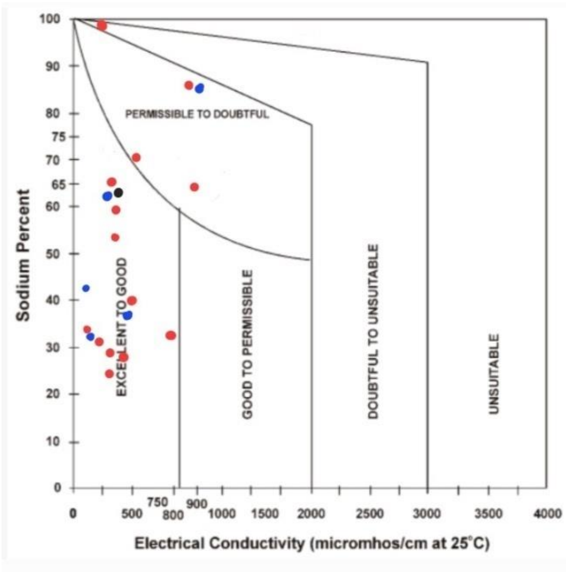

Figure 6. Wilcox diagram of post-monsoon data

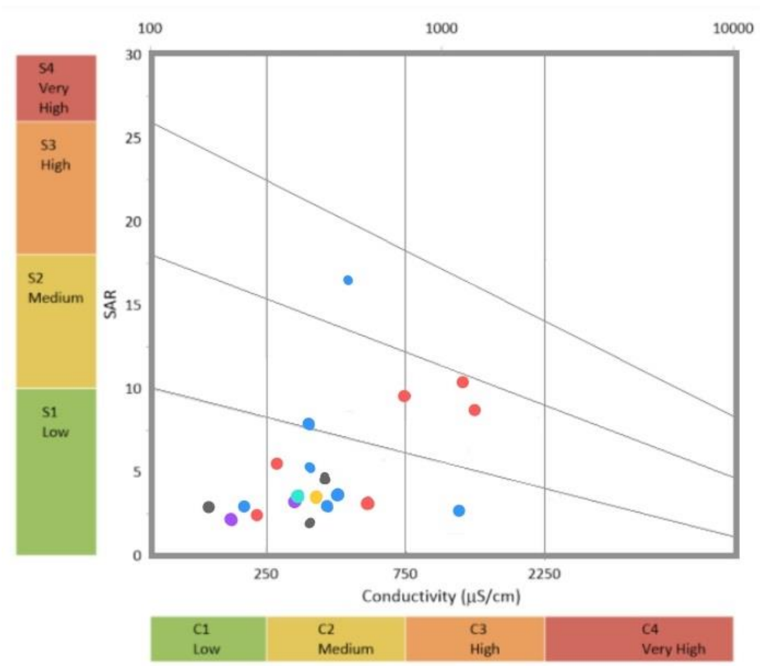

Figure 7. U S Salinity laboratory staff diagram of pre-monsoon data

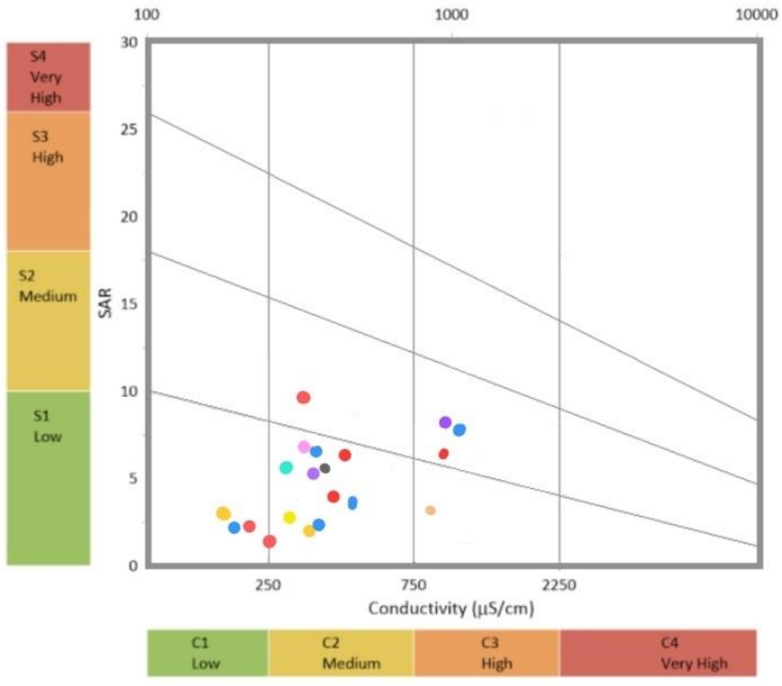

Figure 8. U S Salinity laboratory staff diagram of post-monsoon data

4. Conclusions

The assessment of groundwater for irrigation in this study was done using different indices. In the Piper tri-linear diagram, the majority of samples in the study area belong to the Ca^{+2} - HCO_3^- type water and remaining samples are Ca^{+2}- Na^+- HCO_3^- type. According to the USSL diagram, the majority of the samples are in C_1S_1 and C_2S_1 categories, indicating medium salinity to low sodium threat. According to the Wilcox diagram, the majority of groundwater samples are excellent to good for irrigation, with just three samples in good to permissible group during the pre-monsoon period and five samples in permissible to doubtful category. All groundwater samples were found suitable for irrigation after analysis using SAR, RSC, SSP, PI, MAR, and KR. The water quality at most of the locations in this area belongs to Ca^{2+}- Mg^{2+}- Na^+- HCO_3^- type of water. The dominant cations in the study area were Ca^{2+}, Mg^{2+}, Na^+ and dominant anions were HCO_3^-> NO_3^->Cl^->SO_4^- and CO_3^{2-}. The studied groundwater samples found to be suitable for irrigation purpose according to their physico-chemical characteristics.

5. References

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