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Assessment Of Irrigation Water Quality Kariari River Sub-Basin, Satna District, Madhya Pradesh, India

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Abstract:
The groundwater resources of Kariari River Sub-Basin were comprehensively evaluated for irrigation suitability during pre-monsoon and post-monsoon seasons of 2025. Forty sampling locations were analysed to assess hydrochemical characteristics and seasonal variations influencing agricultural usability. Key parameters including Electrical Conductivity (EC), major ions, and derived irrigation quality indices such as Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), Residual Sodium Carbonate (RSC), Kelly's Ratio (KR), Magnesium Adsorption Ratio (MAR), Permeability Index (PI), and Corrosivity Ratio (CR), were determined. Results revealed a pronounced seasonal dilution effect from the south-west monsoon, reducing mean EC by approximately 11%. Pre-monsoon samples predominantly fell in the high salinity (C3) category (75%), improving to medium salinity (C2) in 40% of locations post-monsoon. Sodicity and alkalinity hazards remained negligible throughout the year, with SAR values consistently below critical thresholds, negative RSC indicating no bicarbonate risk, and low to moderate magnesium hazard. Permeability Index classified the water as "Good" (Class II) in both seasons. Wilcox and USSL diagrams confirmed favourable clustering, with post-monsoon shifts toward "Good" to "Excellent" categories and dominance of C2-S1 and C3-S1 classes, signifying low sodium hazard but occasional salinity management needs in select areas. However, elevated Corrosivity Ratio in pre-monsoon conditions, driven by higher chloride and sulphate levels, indicated aggressive behaviour toward metallic irrigation infrastructure, posing risks of corrosion to pipes, pumps, and casings. Overall, the groundwater is highly suitable for irrigation across diverse soil types and crops, with excellent long-term soil health prospects. Recommendations include adopting corrosion-resistant materials (PVC/HDPE), implementing managed aquifer recharge under NAQUIM guidelines, and following FAO water-wise practices to enhance sustainability amid rising demand and climate variability. This study establishes a scientific foundation for effective groundwater governance in the sub-basin.
Keywords: *Groundwater quality, Irrigation suitability, Seasonal variation, Salinity hazard, Corrosivity ratio*

I. Introduction

Water quality is a critical determinant of irrigation suitability, directly influencing soil health, crop productivity, and agricultural sustainability, particularly in regions reliant on river systems for farming. In India's Madhya Pradesh, where agriculture dominates the economy and groundwater supplements surface water amid growing stresses, assessing river water quality and its variations is essential for informed resource management. This study focuses on the Kariari River Sub-Basin in Satna District, evaluating irrigation water quality parameters and their seasonal fluctuations to guide sustainable practices.

The chemical quality of groundwater is governed by a combination of natural and environmental factors. Chief among these are the physical and chemical characteristics of the aquifer materials, including the mineral composition of rocks and soils through which groundwater flows (Freeze and Cherry, 1979; Hem, 1985). The geological evolution of a region plays a crucial role in determining groundwater chemistry by influencing rock–water interactions over long time scales (Todd and Mays, 2005; Tiwari, 2016). Climatic and meteorological factors such as rainfall intensity, evaporation, and temperature further affect groundwater recharge and solute concentration. Biological activity, particularly microbial processes, can modify groundwater composition through redox reactions and organic matter degradation (Tiwari and Mishra, 2011; Chaurasia et al., 2018; Boukich et al., 2025). In addition, surface conditions such as topography, vegetation cover, and soil properties control infiltration rates and the mobility of dissolved constituents. When certain chemical constituents exceed permissible limits, groundwater may become unsuitable for domestic consumption, agricultural irrigation, or industrial applications due to potential health risks and adverse impacts on crops and infrastructure (Tiwari 2017; Goel et al., 2018; Kumar and Maurya, 2023; Hemalatha et al., 2025).

Numerous studies across different agro-climatic regions have emphasized the importance of evaluating irrigation water quality using a combination of physicochemical parameters and indices. Commonly used parameters include electrical conductivity (EC), sodium adsorption ratio (SAR), residual sodium bicarbonate or carbonate, percent sodium (%Na), magnesium hazard (MH), permeability index (PI), and Kelly's ratio (KR). These parameters are often interpreted using graphical tools such as Wilcox and USSL diagrams and integrated indices like the Irrigation Water Quality Index (IWQI) to classify irrigation suitability (Adimalla and Venkatayogi, 2018; Singh et al., 2020; Agrawal et al., 2021; Saravanan et al., 2023). Seasonal variations significantly influence irrigation water quality, with monsoon rainfall diluting dissolved salts and reducing EC, while dry seasons intensify evaporation, leading to increased salinity, SAR, and sodium-related hazards (Yadav et al., 2018; Khan and Jhariya, 2018; Raheja et al., 2022). Assessment of hydrochemical characteristics of groundwater is critical for sustainable regional water resource management. Detailed analysis of major, minor, and trace elements, combined with statistical methods and geospatial mapping, has proven effective in identifying groundwater quality deterioration and pollution sources (Malakar et al., 2019; Mishra et al., 2012; Ribinu et al., 2023). Both geogenic processes such as mineral dissolution and anthropogenic activities including intensive agriculture, urbanization, and wastewater disposal significantly affect groundwater chemistry (Ahamad et al., 2018; Sharma et al., 2022; Tegegne et al., 2023).

Karst aquifers are particularly vulnerable to contamination due to their high permeability, rapid recharge, and limited filtration capacity. Increasing groundwater abstraction, coupled with improper land-use practices, has heightened the risk of contamination in karstic regions, especially under changing climatic conditions (Tiwari, 2018; Shanmugamoorthy et al., 2023; Vahith et al., 2023). Agricultural activities involving excessive use of fertilizers and pesticides, along with unmanaged wastewater discharge, can directly impact groundwater quality and pose risks to soil health, crop productivity, and food safety (Tiwari et al., 2014; Sinduja et al., 2023; Teja et al., 2024). Given that agriculture accounts for a major share of freshwater consumption, evaluating groundwater suitability for irrigation is essential. The combined use of single-parameter indices (SAR, Na%, MAR, PI, KR) and multi-parameter indices such as IWQI provides a comprehensive framework for irrigation water quality assessment (Tiwari et al., 2015; Dimple et al., 2022; Nguyen et al., 2023; Raheja et al., 2024). Integration of hydrochemical indices with GIS-based spatial analysis further enhances understanding of groundwater quality distribution and supports effective groundwater management and sustainable irrigation planning (Bera et al., 2023; Mishra et al., 2024; Pareta et al., 2024; Sharma et al., 2025; Tejashvini et al., 2024; Majee et al., 2026).

Despite hydrogeological mappings, surface water quality for irrigation in Kariari Sub-Basin remains underexplored, especially seasonally. Existing indices like IWQI (using EC, Na+, Cl-, HCO3-, SAR) classify water but overlook sub-basin specifics. This study assesses key parameters (EC, SAR, RSC, %Na, MAR, etc.), computes indices, analyses monsoon variations, and proposes management amid climate pressures. Findings aim to enhance water use efficiency, aligning with FAO's water-wise farming and NAQUIM plans for recharge.

Study Area

Kariari River sub-basin is a part of Tons River basin, which belongs to the broader Ganga River basin. Encompassing an area of roughly 592 km², it lies primarily within Satna district of Madhya Pradesh, with minor portions extending into Rewa district. The sub-basin is situated between latitudes 24°30' and 24°46' N, and longitudes 81°00' and 81°16' E. Geologically, the area is dominated by shale and limestone formations, with a small section characterized by stromatolitic limestone. The climate features hot and generally dry summers, except during the south-west monsoon period. The region experiences four well-defined seasons throughout the year. Satna district receives an average annual rainfall of approximately 1050 mm, with the majority of this precipitation concentrated during the south-west monsoon season.

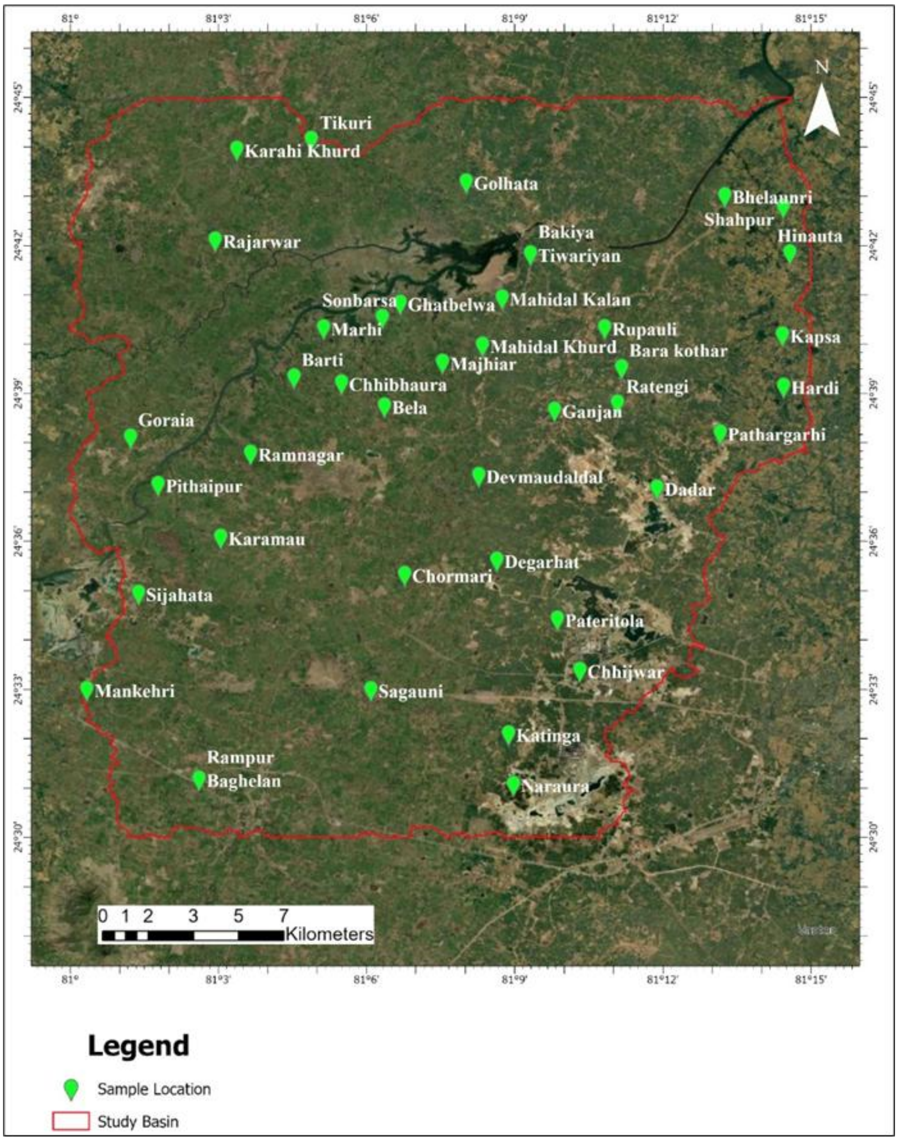

Figure 1: Water Sample Location Map

II. Material And Methods

Groundwater samples were collected from forty locations across the study area during the pre-monsoon and post-monsoon seasons of 2025. The samples were obtained from wells tapping shallow to deep aquifers, with depths ranging from approximately 10 to 40 m. Field measurements of pH and total dissolved solids (TDS) were carried out immediately after sample collection to minimize physicochemical changes. Electrical conductivity (EC) was also measured in situ to assess salinity conditions. In addition to the primary sampling, supplementary groundwater quality data were obtained from the Public Health Engineering (PHE) Departments of Rewa and Satna districts, Madhya Pradesh, for research purposes. Selected samples were further analysed for quality assurance and validation in PHE laboratories and other certified testing facilities. All laboratory analyses were conducted following the standard protocols prescribed in the Standard Methods for the Examination of Water. Appropriate sample preservation techniques were employed, and strict precautions were taken throughout collection, transportation, and analysis to prevent contamination. Groundwater suitability for irrigation was evaluated using key physicochemical parameters, including pH, EC, and TDS, along with laboratory-determined major cations and anions that govern salinity, hardness, and ionic composition. Statistical analyses, correlation studies, and geochemical interpretation tools were applied to elucidate hydrochemical characteristics and controlling processes. Irrigation suitability was further assessed using Wilcox and USSL diagrams, which classify groundwater based on salinity and sodium hazards, thereby providing practical guidance for irrigation management and agricultural planning.

Table 1. Geochemical analysis of groundwater in pre-monsoon period (2025)

No	Village	Longitude	Latitude	Source	pH	EC	TDS	TH	Na	K	Ca	Mg	F	Cl	SO4	HCO3	NO3
1	Bakiya Tiwariyan	81.155318°	24.692743°	Dugwell	8.69	792.88	506.84	410.2	71.76	10.95	100.3	35.43	0.46	121.71	99.28	270.81	14.8
2	Bara kothar	81.186082°	24.654337°	Dugwell	8.33	1229.08	786.61	459.7	68.24	1.34	112.25	44.04	0.5	106.23	66.59	315.68	16.5
3	Barti	81.07550938°	24.65117368°	Handpump	8.88	996.66	637.86	339.7	70.36	0.28	69.59	40.44	0.48	111.67	111.99	110.19	15.9
4	Bela	81.10604575°	24.64133878°	Dugwell	8.49	768.22	491.66	328	71.04	11.35	100.52	39.02	0.71	115.66	133.88	226.54	30.2
5	Bhelaunri	81.22089452°	24.71241914°	Handpump	8.46	910.17	582.51	392.2	76.76	3.43	79.27	46.2	0.55	119.92	82.83	266.36	18.1
6	Chhibhaura	81.09156095°	24.64913508°	Borewell	8.6	1009.38	646	413.2	76	10	100.2	49.54	0.7	128	148	237.95	29.6
7	Chhijwar	81.17200375°	24.5520358°	Borewell	8.53	806.84	516.38	233.2	66.82	4.7	60.93	27.35	0.68	114.89	112.71	270.83	27.8
8	Chormari	81.11284922°	24.58445298°	Dugwell	8.37	950.3	608.19	325	63.56	9.4	105.58	37.86	0.73	119.62	162.39	211.52	33.5
9	Dadar	81.198019°	24.613662°	Dugwell	8.35	575.61	368.39	324.8	71.57	8.89	80.66	36.31	0.69	78.73	144.62	172.93	29.1
10	Degarhat	81.14397797°	24.58926396°	Borewell	8.57	749.19	479.48	418.9	79.03	6.48	90.22	40.15	0.75	120.39	126.92	150.83	35.2
11	Devmau daldal	81.13787708°	24.6178783°	Handpump	8.55	750.53	480.34	385.7	69.71	7.26	97.74	45.7	0.72	101.91	109.92	140.24	31.3
12	Ganjan	81.163455°	24.639958°	Handpump	8.4	825	528	350.2	64	2	85.49	42.57	0.74	99	124	184.37	32.8
13	Ghatbelwa	81.11135447°	24.676113°	Borewell	8.53	550.02	352.01	240.2	74.74	2.8	54.34	25.81	0.52	115.76	120.41	126.83	17.6
14	Golhata	81.13363958°	24.71708192°	Handpump	8.45	695	444.8	439.9	84.43	7.78	96.08	47.48	0.6	115.41	94.93	334.85	19.7
15	Goraia	81.02035548°	24.63084008°	Dugwell	8.5	650	416	263.9	60	2.1	90.32	30.56	0.67	99	102	150.31	27.2
16	Hardi	81.24075693°	24.64801051°	Borewell	8.57	652.52	417.61	244.6	65.33	0.61	48.25	28.73	0.56	105.46	99.83	250.73	18.9
17	Hinauta	81.242864°	24.693117°	Borewell	8.6	665.63	426	260.7	72	1.8	55.28	29.35	0.47	114	99	175.76	14.3
18	Kapsa	81.24036°	24.665403°	Borewell	8.17	658.84	421.66	307.7	65.42	7.56	60.8	37.6	0.53	125.4	87.38	249.26	17.8
19	Karahi Khurd	81.05621847°	24.72810292°	Handpump	8.26	1324.75	847.44	252.2	74.54	1.31	50.49	30.28	0.57	117.56	87.37	333.31	19.1
20	Karamau	81.05077333°	24.59701106°	Dugwell	8.3	825	528	339.3	68	1.4	95.84	40.4	0.69	102	98	226.11	28.4
21	Katinga	81.14792319°	24.53057611°	Dugwell	8.18	1000.73	640.47	346.5	78.29	4.05	87.06	38.31	0.74	111.5	136.98	220.25	32.6
22	Mahidal Kalan	81.145765°	24.677893°	Handpump	8.57	751	480.64	561.4	64.85	4.99	109.81	70.39	0.59	129.33	69.63	233.09	19.5
23	Mahidal Khurd	81.13913°	24.66194°	Dugwell	8.53	757.06	484.52	299.9	60.51	7.07	80.05	35.76	0.78	131.3	93.56	152.68	37
24	Majhiar	81.12561541°	24.6561488°5	Borewell	8.3	800	512	374	75	1.6	78.4	43.69	0.55	128	92	206.88	18
25	Mankehri	81.005581°	24.545594°	Handpump	8.33	865.55	553.55	289.4	85.48	7.27	58.14	34.62	0.58	116.65	135.64	189.92	19.2
26	Marhi	81.08549393°	24.66778479°	Borewell	8.26	616.86	394.79	235.3	62.18	4.76	75.44	30.46	0.71	111.86	113.87	236.46	30.7
27	Naraura	81.149572°	24.513472°	Dugwell	8.48	838.47	537.02	360.2	60.69	0.66	91.33	32.26	0.65	82.71	87.37	325.32	26
28	Pateritola	81.1644007°	24.56934797°	Handpump	8.48	969.44	620.44	390	65.12	3.14	80.79	44.4	0.82	101.49	109.55	153.53	38.5
29	Pathargarhi	81.219351°	24.632275°	Dugwell	8.45	886.33	567.25	356.6	70.93	6.82	95.23	39.38	0.77	91.6	130.16	172.93	36.3
30	Pithaipur	81.02962239°	24.61481405°	Borewell	8.43	897.63	574.48	403.5	56.24	1.4	82.36	47.05	0.73	115.62	99.49	178.69	33.1
31	Rajarwar	81.04891398°	24.69743277°	Dugwell	8.03	384.14	245.85	491	75.49	2.1	100.63	40.06	0.64	104.28	82.77	374.91	20
32	Ramnagar	81.06087064°	24.62539091°	Handpump	8.2	759.38	486	349.5	63	8.2	67.9	42.43	0.49	102	87	198.85	15.6
33	Rampur Baghelan	81.04344942°	24.51529549°	Dugwell	8.51	898.58	575.09	397	61.56	3.87	118.31	47.23	0.7	127.8	124.89	320.91	29.5
34	Ratengi	81.184653°	24.64239°	Dugwell	8.69	792.88	506.84	410.2	71.76	10.95	106.83	41.81	0.46	121.71	99.28	134.42	14.8

35	Rupauli	81.180348°	24.667825°	Handpump	8.61	1169.5	748.48	294.5	64.61	1.82	60.21	33.86	0.74	110.83	92.62	195.94	34.2
36	Sagauni	81.10146238°	24.54550211°	Borewell	8.3	784.38	502	297	75	1.8	71.02	34.33	0.5	114	88	180.37	15.9
37	Shahpur	81.240661°	24.708718°	Dugwell	8.5	948.03	606.74	183.2	74.63	2.99	96.81	43.5	0.62	130.49	161.54	150.56	19.8
38	Sijahata	81.02304475°	24.57807564°	Borewell	8.36	1316.64	842.65	409	70.14	5.94	85.05	42.41	0.58	110.07	103.8	284.07	19.3
39	Sonbarsa	81.10531187°	24.67130894°	Handpump	8.6	1237.5	792	623.4	68	14	126.44	74.29	0.63	118	158	219.78	20
40	Tikuri	81.081342°	24.731456°	Handpump	8.6	1237.5	792	623.4	68	14	126.44	74.29	0.6	118	158	219.78	20

Table 2. Geochemical analysis of groundwater in post-monsoon period (2025)

No	Village	Longitude	Latitude	Source	pH	EC	TDS	TH	Na	K	Ca	Mg	F	Cl	SO4	HCO3	NO3
1	Bakiya Tiwariyan	81.155318°	24.692743°	Dugwell	8.27	745.67	521.89	703.2	65.78	4.23	207.78	45.95	0.47	103.45	110.23	434.69	17.6
2	Bara kothar	81.186082°	24.654337°	Dugwell	8.44	956.78	669.56	812.3	65.78	10.89	217.43	65.5	0.34	112.34	122.34	691.3	10.5
3	Barti	81.07550938°	24.65117368°	Handpump	8.23	922.23	607.56	493.2	62.12	5.67	108.37	54.19	0.31	102.34	99.56	305.86	9.2
4	Bela	81.10604575°	24.64133878°	Dugwell	8.39	934.56	654.23	926.2	65.12	11.23	252.97	70.64	0.37	111.89	119.45	498.02	11.8
5	Bhelaunri	81.22089452°	24.71241914°	Handpump	7.95	689.34	482.12	399	60.78	4.12	100.3	35.74	0.28	95.67	84.23	219.08	7.6
6	Chhibhaura	81.09156095°	24.64913508°	Borewell	8.35	623.45	436.78	408	61.45	2.89	93.6	42.72	0.46	100.56	105.67	209.91	16.8
7	Chhijwar	81.17200375°	24.5520358°	Borewell	8.22	769.56	538.9	446.9	62.45	4.56	102.71	46.36	0.29	105.56	97.89	292.35	8.2
8	Chormari	81.11284922°	24.58445298°	Dugwell	8.3	900	643	611.8	74.2	8	167.38	47.15	0.51	107.92	135.3	408.83	20.4
9	Dadar	81.198019°	24.613662°	Dugwell	8.38	667.89	467.56	590.4	63.45	3.45	162.66	45.93	0.49	101.67	107.89	448.51	18.9
10	Degarhat	81.14397797°	24.58926396°	Borewell	8.19	801.23	560.89	405.4	67.89	5.45	85.54	46.17	0.53	105.78	115.34	240.24	22.3
11	Devmaudaldal	81.13787708°	24.6178783°	Handpump	8.46	578.9	405.23	350.3	59.12	1.67	74.77	40.2	0.44	98.34	100.45	165.45	15.2
12	Ganjan	81.163455°	24.639958°	Handpump	8	812	502	592.6	59	1.2	155.87	50.65	0.43	85	112	251.29	14.5
13	Ghatbelwa	81.11135447°	24.676113°	Borewell	8.35	845.67	591.89	463.1	63.45	7.89	90.51	56.98	0.32	108.56	108.9	220.91	9.8
14	Golhata	81.13363958°	24.71708192°	Handpump	8.5	526	416	276.5	60.14	2.1	57.45	32.26	0.4	99.4	102.26	235.53	13.8
15	Goraia	81.02035548°	24.63084008°	Dugwell	8.05	734.56	514.23	588.6	61.23	6.34	169.93	40.97	0.27	100.78	92.67	378.83	7
16	Hardi	81.24075693°	24.64801051°	Borewell	8.12	756.89	529.67	434.7	62.78	3.12	93.02	50.09	0.3	101.23	95.34	197.8	9.1
17	Hinauta	81.242864°	24.693117°	Borewell	8.33	592.67	414.89	339.5	60.34	2.34	74.79	36.17	0.45	99.78	103.56	208.19	17.2
18	Kapsa	81.24036°	24.665403°	Borewell	8.2	712	442	511	58	1.3	105.68	60.22	0.41	99.4	98.3	276.99	14.8
19	Karahi Khurd	81.05621847°	24.72810292°	Handpump	7.89	678.9	475.34	328	59.89	1.89	68.34	37.65	0.26	93.45	81.23	180.6	6.8
20	Karamau	81.05077333°	24.59701106°	Dugwell	8.29	811.23	567.89	646	64.56	9.23	164.77	55.92	0.33	110.45	117.56	370.47	10.2
21	Katinga	81.14792319°	24.53057611°	Dugwell	8.2	562	402	317.1	64	1.3	76.41	30.87	0.24	88	78.3	213.11	6.1
22	Mahidal Kalan	81.145765°	24.677893°	Handpump	8.15	789.45	552.67	519.3	68.12	5.67	118.4	53.93	0.42	106.34	114.56	287.97	15.1
23	Mahidal Khurd	81.13913°	24.66194°	Dugwell	8.28	732.34	512.67	646.7	65.23	3.78	184.77	45.03	0.5	102.89	109.34	519.26	21
24	Majhiar	81.12561541°	24.6561488°5	Borewell	8.4	900	532	619.1	59.24	1.2	141.97	63.83	0.34	102	92	367.33	10.7
25	Mankehri	81.005581°	24.545594°	Handpump	8.11	701.23	490.89	464.7	60.45	2.34	120.19	40.4	0.29	97.45	85.67	222.75	8.9
26	Marhi	81.08549393°	24.66778479°	Borewell	8.43	611.78	428.23	507	58.9	1.89	136.46	40.72	0.38	97.56	99.78	438.16	12.6
27	Naraura	81.149572°	24.513472°	Dugwell	8.31	833.45	583.23	662.6	64.34	6.78	180.41	51.41	0.31	107.89	106.78	349	9.5

28	Pateritola	81.1644007°	24.56934797°	Handpump	8.37	648.9	454.23	607.7	62.34	2.78	169.55	45.1	0.44	100.45	104.67	448.51	16.3
29	Pathargarhi	81.219351°	24.632275°	Dugwell	8.3	705.67	493.89	617.9	64.78	4.12	172.46	45.44	0.46	103.23	108.9	528.98	17.9
30	Pithaipur	81.02962239°	24.61481405°	Borewell	8.26	787.34	551.12	427.8	63.89	8.45	82.64	53.81	0.35	106.78	101.23	213.62	11.1
31	Rajarwar	81.04891398°	24.69743277°	Dugwell	8.07	645.23	451.78	558.1	61.89	7.12	160.63	38.08	0.25	98.67	88.45	411.83	6.7
32	Ramnagar	81.06087064°	24.62539091°	Handpump	8	612	488	415.8	62.25	8	87.25	48.75	0.3	102.2	86.24	269.06	8.3
33	Rampur Baghelan	81.04344942°	24.51529549°	Dugwell	8.24	778.34	544.56	585.8	66.78	4.89	159.9	45.63	0.45	104.56	113.45	287.97	17.5
34	Ratengi	81.184653°	24.64239°	Dugwell	8.16	723.45	506.34	560.9	63.12	5.67	147.67	46.63	0.33	103.12	94.56	287.97	10.1
35	Rupauli	81.180348°	24.667825°	Handpump	8.41	689.12	481.23	358.4	64.23	3.89	72.94	42.92	0.49	102.34	111.78	203.95	18.1
36	Sagauni	81.10146238°	24.54550211°	Borewell	7.9	782	442	251	58	2	51.74	29.95	0.26	99.4	90	178.89	7.2
37	Shahpur	81.240661°	24.708718°	Dugwell	8.4	1104	782	871.2	63.46	12	235.63	70.16	0.39	113.6	126.6	381.33	12
38	Sijahata	81.02304475°	24.57807564°	Borewell	8.18	740.89	518.56	399.7	62.34	4.78	80.9	48.72	0.31	102.45	93.78	247.16	9.4
39	Sonbarsa	81.10531187°	24.67130894°	Handpump	8.39	635.78	445.12	377.7	60.89	2.45	85.81	39.39	0.43	100.12	102.45	164.21	15.9
40	Tikuri	81.081342°	24.731456°	Handpump	8.4	1104	782	871.2	63.46	12	235.63	70.16	0.39	113.6	126.6	381.33	12

III. Result And Discussion

The irrigation quality of groundwater is primarily governed by its concentration of dissolved salts and ionic composition, as these factors directly influence soil physicochemical characteristics and the ability of plants to absorb water effectively (Dimple et al., 2022; Bera et al., 2023). In semi-arid regions where agriculture depends heavily on groundwater for irrigation, regular assessment of irrigation water quality becomes critical to avoid soil salinization, sodicity development, and progressive reductions in crop yields over time (Mishra et al., 2012; Nguyen et al., 2023). The suitability of groundwater for irrigation is shaped by local geo-environmental conditions, including the underlying lithology, degree of rock weathering, groundwater residence time, and intensity of water–rock interactions (Dimple et al., 2022; Sharma et al., 2025). Various geochemical processes—such as dissolution of minerals, cation exchange, and evaporative concentration—modify the concentrations and proportions of major ions (e.g., Na^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, SO_4^{2-}), thereby controlling key irrigation quality parameters like salinity hazard, sodium hazard, and derived indices essential for long-term agricultural sustainability.

Table 3. Assessment of Groundwater Samples for Irrigation Indices and Ratios in the Pre-Monsoon Season (2025)

No	Village	SAR	SSP	RSC	KR	MAR	PI	CR	RSBC
1	Bakiya Tiwariyan	1.57	30.01	-3.49	0.39	36.77	47.30	1.57	-0.58
2	Bara kothar	1.38	24.52	-4.06	0.32	39.24	42.95	1.09	-0.44
3	Barti	1.66	31.05	-5.00	0.45	48.89	44.62	3.80	-1.67
4	Bela	1.52	29.09	-4.52	0.37	38.99	44.28	2.02	-1.31
5	Bhelaunri	1.69	30.61	-3.40	0.43	48.96	48.88	1.50	0.40
6	Chhibhaura	1.55	28.15	-5.19	0.36	44.87	42.60	2.13	-1.11
7	Chhijwar	1.79	36.35	-0.86	0.55	42.49	61.11	1.58	1.39
8	Chormari	1.35	26.35	-4.93	0.33	37.12	41.45	2.38	-1.81
9	Dadar	1.66	32.23	-4.19	0.44	42.56	47.32	2.21	-1.20
10	Degarhat	1.74	31.55	-5.34	0.44	42.28	44.51	3.05	-2.04
11	Devmaudaldal	1.46	27.11	-6.35	0.35	43.49	38.93	2.80	-2.59
12	Ganjan	1.41	26.70	-4.76	0.36	45.05	42.81	2.19	-1.25
13	Ghatbelwa	2.09	40.69	-2.76	0.67	43.88	57.99	3.47	-0.64
14	Golhata	1.76	30.76	-3.22	0.42	44.86	48.57	1.21	0.69
15	Goraia	1.39	27.47	-4.57	0.37	35.77	43.35	2.49	-2.05
16	Hardi	1.84	37.42	-0.67	0.59	49.50	63.90	1.55	1.70
17	Hinauta	1.95	38.01	-2.30	0.60	46.64	58.10	2.32	0.12
18	Kapsa	1.62	33.12	-2.05	0.46	50.45	54.19	1.68	1.05
19	Karahi Khurd	2.05	39.49	0.45	0.65	49.68	67.56	1.20	2.94
20	Karamau	1.47	26.94	-4.41	0.36	40.96	44.08	1.67	-1.09
21	Katinga	1.76	31.85	-3.90	0.45	42.01	48.62	2.05	-0.74
22	Mahidal Kalan	1.19	20.71	-7.46	0.25	51.34	33.85	1.74	-1.67
23	Mahidal Khurd	1.41	28.82	-4.44	0.38	42.37	43.99	2.89	-1.50

24	Majhiar	1.68	30.52	-4.12	0.43	47.84	47.35	2.09	-0.53
25	Mankehri	2.19	40.40	-2.64	0.65	49.50	57.86	2.43	0.21
26	Marhi	1.53	31.03	-2.40	0.43	39.93	52.02	1.78	0.10
27	Naraura	1.39	26.89	-1.89	0.37	36.77	50.18	0.97	0.77
28	Pateritola	1.44	27.45	-5.18	0.37	47.50	41.97	2.54	-1.52
29	Pathargarhi	1.54	28.93	-5.17	0.39	40.50	43.00	2.28	-1.93
30	Pithaipur	1.22	23.69	-5.06	0.31	48.46	39.83	2.30	-1.19
31	Rajarwar	1.61	28.60	-2.18	0.39	39.59	49.62	0.97	1.11
32	Ramnagar	1.48	29.98	-3.63	0.40	50.71	47.21	1.82	-0.14
33	Rampur Baghelan	1.21	22.07	-4.54	0.27	39.65	39.83	1.48	-0.65
34	Ratengi	1.49	27.91	-6.58	0.36	39.18	38.68	3.17	-3.14
35	Rupauli	1.65	33.00	-2.59	0.48	48.07	53.46	1.99	0.20
36	Sagauni	1.83	34.15	-3.42	0.51	44.31	51.68	2.18	-0.59
37	Shahpur	1.58	28.29	-5.95	0.39	42.52	41.28	3.52	-2.37
38	Sijahata	1.55	29.25	-3.09	0.39	45.08	48.25	1.42	0.40
39	Sonbarsa	1.19	21.04	-8.83	0.24	49.17	31.54	2.25	-2.72
40	Tikuri	1.19	21.04	-8.83	0.24	49.17	31.54	2.25	-2.72

Table 4. Assessment of Groundwater Samples for Irrigation Indices and Ratios in the Post-Monsoon Season (2025)

No	Village	SAR	SSP	RSC	KR	MAR	PI	CR	RSBC
1	Bakiya Tiwariyan	1.07	17.32	-7.04	0.20	26.69	32.47	0.91	-3.26
2	Bara kothar	1.00	16.18	-4.93	0.18	33.15	32.56	0.63	0.46
3	Barti	1.22	22.37	-4.86	0.27	45.15	39.27	1.24	-0.40
4	Bela	0.93	14.45	-10.30	0.15	31.49	26.71	0.86	-4.48
5	Bhelaunri	1.32	25.67	-4.37	0.33	36.97	42.81	1.57	-1.42
6	Chhibhaura	1.32	25.09	-4.75	0.33	42.90	41.65	1.83	-1.24
7	Chhijwar	1.28	24.03	-4.16	0.30	42.63	42.04	1.32	-0.34
8	Chormari	1.30	21.88	-5.55	0.26	31.68	37.57	1.08	-1.67
9	Dadar	1.13	19.29	-4.56	0.23	31.73	37.28	0.87	-0.78
10	Degarhat	1.47	27.68	-4.14	0.37	47.05	44.76	1.70	-0.34
11	Devmaudaldal	1.37	27.05	-4.33	0.36	46.95	43.85	2.24	-1.03
12	Ganjan	1.05	17.83	-7.84	0.21	34.85	31.63	1.41	-3.67
13	Ghatbelwa	1.29	24.31	-5.59	0.30	50.89	38.93	1.84	-0.90
14	Golhata	1.57	32.56	-1.67	0.47	48.03	56.25	1.60	0.99
15	Goraia	1.09	19.22	-5.66	0.22	28.41	35.47	0.97	-2.29
16	Hardi	1.30	24.25	-5.53	0.31	46.99	39.38	1.88	-1.41
17	Hinauta	1.43	28.55	-3.30	0.39	44.32	47.87	1.82	-0.33
18	Kapsa	1.11	19.97	-5.70	0.25	48.40	36.46	1.34	-0.74
19	Karahi Khurd	1.44	28.93	-3.56	0.40	47.56	47.42	1.85	-0.46
20	Karamau	1.11	19.16	-6.77	0.22	35.84	33.69	1.14	-2.17
21	Katinga	1.56	30.68	-2.87	0.44	39.94	50.87	1.49	-0.33
22	Mahidal Kalan	1.30	23.07	-5.64	0.29	42.85	38.55	1.42	-1.20
23	Mahidal Khurd	1.11	18.47	-4.43	0.22	28.63	36.46	0.76	-0.73
24	Majhiar	1.04	17.42	-6.33	0.21	42.53	33.69	1.00	-1.08
25	Mankehri	1.22	22.36	-5.68	0.28	35.62	37.94	1.57	-2.36
26	Marhi	1.14	20.41	-2.99	0.25	32.94	41.15	0.84	0.36
27	Naraura	1.09	18.31	-7.53	0.21	31.93	32.33	1.15	-3.30
28	Pateritola	1.10	18.58	-4.84	0.22	30.45	36.39	0.85	-1.12
29	Pathargarhi	1.13	19.12	-3.69	0.23	30.25	37.95	0.74	0.05
30	Pithaipur	1.34	25.91	-5.06	0.32	51.73	41.00	1.84	-0.63
31	Rajarwar	1.14	20.46	-4.41	0.24	28.07	38.17	0.86	-1.28
32	Ramnagar	1.32	25.79	-3.96	0.32	47.91	43.38	1.34	0.05
33	Rampur Baghelan	1.20	20.49	-7.03	0.25	31.96	34.64	1.40	-3.27
34	Ratengi	1.16	20.48	-6.50	0.24	34.20	35.21	1.30	-2.66
35	Rupauli	1.47	28.72	-3.84	0.39	49.20	46.34	1.94	-0.30
36	Sagauni	1.59	33.74	-2.12	0.50	48.79	55.91	2.01	0.35
37	Shahpur	0.93	14.87	-11.30	0.16	32.89	25.89	1.16	-5.53
38	Sijahata	1.35	26.02	-4.00	0.34	49.78	43.88	1.51	0.01
39	Sonbarsa	1.36	26.46	-4.84	0.35	43.04	42.12	2.30	-1.60
40	Tikuri	0.93	14.87	-11.30	0.16	32.89	25.89	1.16	-5.53

Electrical Conductivity (EC)

According to the USSL/Wilcox classification, groundwater salinity in study area falls into medium (C2) and high (C3) categories only, with no samples in low (C1) or very high (C4) classes. Pre-monsoon results show 75% of samples in high salinity (C3) and 25% in medium (C2). Post-monsoon, this improves to 40% in C2 and 60% in C3, reflecting dilution from rainfall recharge Across 40 villages, electrical conductivity (EC) decreases noticeably after the monsoon. Pre-monsoon EC ranges from 384 to 1325 µS/cm (mean 843 µS/cm), dropping post-monsoon to 526–1104 µS/cm (mean 749 µS/cm), an average reduction of ~11% (94 µS/cm). Variability also declines, with standard deviation falling from 212 to 136 µS/cm. Pre-monsoon dry conditions and evaporation elevate EC, with eight villages exceeding 1000 µS/cm. Post-monsoon, the maximum drops to 1104 µS/cm. Notable reductions occur in Karahi Khurd and Sonbarsa/Tikuri (both 49%) and Shahpur (16%), while Rajarwar shows a 68% increase, suggesting local variations in recharge, geology, or contamination.

Sodium Adsorption Ratio (SAR)

It measures the relative abundance of sodium (Na^{+}) compared with calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in groundwater and is calculated as:

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

The statistical analysis indicates consistently low SAR values across all seasons. Pre-monsoon SAR ranges from 1.19 to 2.19 with a mean of 1.58, while post-monsoon values decline to 0.93–1.59 with an average of 1.23, reflecting an approximate 22% reduction due to rainfall recharge. The standard deviation decreases from 0.24 to 0.17, indicating improved uniformity. Even villages with the highest SAR values remain well below critical thresholds, confirming minimal sodium hazard and excellent suitability for sustainable irrigation without risks of soil degradation.

Soluble Sodium Percentage (SSP)

SSP represents proportion of sodium relative to total concentration of major cations in water and is widely applied to assess sodium hazard in irrigation water. It is commonly calculated as:

$SSP = \frac{Na^{+}+K^{+}}{Ca^{2+}+Mg^{2+}+Na^{+}+K^{+}} \times 100$, with all ionic concentrations in milliequivalents per liter

In the study area, SSP values are classified as excellent (<20), good (20–40), permissible/doubtful (40–60), and unsuitable (>60). Analysis of 40 villages in 2025 shows SSP values remain within safe limits in both seasons, with notable improvement after the monsoon. Pre-monsoon SSP ranges from 20.71 to 40.69, averaging 29.83, while post-monsoon values decline to 14.45–33.74 with a mean of 22.55, reflecting an overall reduction of about 24% due to recharge and dilution. Standard deviation remains similar, indicating consistent variability but lower sodium levels post-monsoon. Before the monsoon, 95% of villages fall in the "good" category and 5% are permissible, whereas post-monsoon conditions improve further, with 37.5% classified as excellent and the remainder as good. No village enters the unsuitable class. Although higher SSP values were initially observed in a few locations, monsoonal dilution significantly reduced them.

Kelly's Ratio (KR)

It is an irrigation water quality index that evaluates sodium hazard by relating concentration of sodium ions to combined concentrations of calcium and magnesium ions, all expressed in milliequivalents per liter. It is calculated as:

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

KR values across the study area indicate excellent irrigation suitability during both seasons. Pre-monsoon KR ranges from 0.24 to 0.67 with a mean of 0.42, while post-monsoon values decline to 0.15–0.50, averaging 0.28. This represents an approximate 33% reduction after monsoonal recharge, accompanied by an 18% decrease in variability, reflecting more uniform water quality. All villages record KR values well below the threshold of 1, classifying every sample as suitable for irrigation. Higher pre-monsoon values observed in villages such as Ghatbelwa, Karahi Khurd, Mankehri, Hardi, and Hinauta decrease substantially after the monsoon, with reductions of 25–62%. Post-monsoon maxima remain safely low. These results are consistent with low SAR values (<2.2) and moderate SSP levels, confirming minimal sodicity risk.

Residual Sodium Carbonate (RSC)

It evaluates alkalinity hazard of irrigation water by measuring excess of carbonate and bicarbonate ions relative to calcium and magnesium ions. It is calculated as:

$RSC = \left({CO_3}^{2-} + {HCO_3}^{2-}\right) - (Ca^{2+} + Mg^{2+})$, where concentrations are in meq/L.

Across the 40 villages, RSC values indicate highly favourable irrigation water quality in both seasons. Pre-monsoon RSC ranges from –8.83 to 0.45 with a mean of –4.12, while post-monsoon values shift further negative (–11.30 to –1.67), averaging –5.34. This trend reflects improved ionic balance and stronger dominance of calcium and magnesium after monsoonal dilution. During the pre-monsoon period, all villages fall within the safe category (RSC <1.25), with only Karahi Khurd showing a small positive yet safe value. Post-monsoon, all villages record negative RSC, completely eliminating bicarbonate hazard. Villages with relatively higher RSC values, including Karahi Khurd, Ghatbelwa, Hardi, and Chhijwar, show marked improvement after the monsoon. The consistently negative RSC aligns with low SAR, moderate SSP, and KR <1, confirming negligible alkalinity risk. Overall, groundwater is highly suitable for irrigation year-round, with post-monsoon conditions particularly favourable.

Residual Sodium Bicarbonate (RSBC)

It assesses alkalinity hazard of irrigation water due to excess bicarbonate relative to calcium, especially in low-salinity waters where carbonate is typically negligible (Vahith et al., 2023). RSBC is commonly calculated as:

$RSBC = {HCO_3}^{2-} - Ca^{2+}$, with all ions expressed in meq/L.

Nearly all groundwater samples fall within the satisfactory range, indicating minimal concern. Pre-monsoon RSBC values range from –3.14 to 2.94 meq/L with a mean of –0.65, while post-monsoon values range from –5.53 to 0.99 meq/L, averaging –1.41. Monsoonal recharge shifts RSBC toward more negative values, reflecting stronger dominance of calcium and magnesium. Positive RSBC indicates potential bicarbonate hazard, whereas negative values denote safe conditions. During the pre-monsoon period, only Karahi Khurd shows a moderately positive value, with 97.5% of villages remaining safe. Post-monsoon conditions improve further, with only Golhata recording a slight positive value and none nearing the unsuitability threshold. Seasonal improvements are evident, and integration with low SAR, low KR, and negative RSC confirms negligible bicarbonate-induced sodicity risk across the study area.

Magnesium Adsorption Ratio (MAR)

It indicates the proportion of magnesium to the total of calcium plus magnesium in irrigation water, and serves to assess the possible harmful impact of excessive magnesium on soil structure and crop growth (Malakar et al., 2019).

$MAR = \frac{Mg^{2+}}{Ca^{2+}+Mg^{2+}} \times 100$, with ionic concentrations in meq/L.

Pre-monsoon MAR values ranged from 35.77% to 51.34%, indicating balanced to slightly magnesium-affected Ca:Mg ratios. Post-monsoon, MAR showed wider variation (25.89–51.73%), reflecting a 12% decrease in average but a 65% increase in variability. Pre-monsoon, 80% of villages had MAR <50% (safe), with 20% exceeding the threshold (highest at Mahidal Kalan and Pithaipur). Post-monsoon improved to 85% safe, only 15% unsafe (high values at Pithaipur and Ghatbelwa). Notable reductions occurred in Mahidal Kalan (24%) and Karahi Khurd (14%), while Shahpur and Tikuri showed increases, suggesting localized geochemical influences. Overall, magnesium hazard is low to moderate.

Permeability Index (PI)

It is a key hydrochemical parameter for evaluating the long-term suitability of groundwater for irrigation. It assesses the combined effects of sodium, calcium, magnesium, and bicarbonate ions on soil permeability and infiltration (Sharma et al., 2022).

$$PI = \frac{Na^{+} + \sqrt{{HCO_3}^{2-}}}{Ca^{2+} + Mg^{2+} + Na^{+}} \times 100$$

Groundwater in study area remains generally suitable for irrigation in both seasons, consistently falling in the good suitability category (Class II) based on Permeability Index. Pre-monsoon PI values average around 47%, indicating better soil permeability maintenance under dry conditions, despite moderate variability. Post-monsoon, mean PI decreases to approximately 39%, reflecting a marginal decline after monsoonal recharge, typical in monsoon-dominated regions. No samples enter unsuitable (<25%) or excellent (>75%) classes, confirming stable moderate-to-good suitability year-round. Greater spatial heterogeneity occurs pre-monsoon. Lower post-monsoon PI values in villages like Shahpur and Tikuri approach the lower threshold but remain within safe limits.

Corrosivity Ratio (CR)

CR is used to assess the potential of groundwater to cause corrosion in irrigation infrastructure, particularly metal components such as iron and steel pipes, fittings, and equipment (Singh et al., 2020; Sinduja et al., 2023; Tegegne et al., 2023). Corrosive water can significantly reduce the lifespan of irrigation systems, increase maintenance costs, and impair overall efficiency. It is calculated as

$$CR = \frac{\left(\frac{CL^{-}}{35.5} + 2 \cdot \frac{{SO_4}^{2-}}{96}\right)}{2 \cdot \left(\frac{{HCO_3}^{2-} + {CO_3}^{2-}}{100}\right)}, \text{ with all values in } \frac{\text{meq}}{\text{L}}$$

Across 40 villages, groundwater shows distinct seasonal corrosivity differences. Pre-monsoon, most samples are corrosive, with CR exceeding 1 in 37 locations (mean CR = 2.10). Elevated chloride and sulfate concentrations during the dry period heighten risks to irrigation pipes and metallic fittings. Post-monsoon, corrosivity decreases markedly (mean CR = 1.37), with only 32 samples slightly above 1, reflecting dilution from monsoonal recharge. Non-corrosive sites rise from 3 (Naraura, Rajarwar) pre-monsoon to 8 post-monsoon. Villages like Barti, Shahpur, and Ratengi record notably high pre-monsoon CR values. Overall, moderate to high corrosion risk prevails, especially in dry seasons. Use of corrosion-resistant materials (PVC/HDPE) and regular monitoring are recommended to protect irrigation infrastructure.

Wilcox and USSL classification indices

The **Wilcox diagram** is a hydrochemical plot used to evaluate groundwater suitability for irrigation on the basis of salinity and sodium hazards. It classifies water into categories from excellent to unsuitable using electrical conductivity and sodium percentage (Khan and Jhariya, 2018; Dimple et al., 2023). Wilcox proposed this diagram to relate soil–water problems to the combined effect of total salinity and relative sodium content in irrigation water. EC represents the salinity hazard, while %Na indicates the sodium hazard that can deteriorate soil structure and permeability.

Wilcox diagram classifies irrigation water into five quality zones, ranging from Excellent to Bad. Analysis of the plotted groundwater samples indicates that the dominant water quality during the study period falls within the Good to Admissible categories. Out of the 40 sampled locations, most are distributed within these two zones, suggesting that the groundwater is generally suitable for irrigation use. Electrical conductivity (EC) values of the majority of samples range between approximately 800 and 1300 µS/cm, indicating moderate mineralization. Sodium percentage (Na%) values mostly lie between 20% and 40%, which are relatively low and imply minimal risk of adverse effects on soil structure and permeability. Spatially, a dense clustering of samples is observed near the boundary between the Excellent, Good, and Admissible zones. This distribution suggests that although groundwater quality is largely acceptable, it is tending toward higher salinity levels, a condition typically associated with pre-monsoon periods when reduced recharge leads to solute concentration. A few samples (notably 22, 29, 30, and 39) show slightly elevated EC values exceeding 1200 µS/cm; however, their low sodium percentages ensure they remain within Good category. Importantly, none of the samples fall within the Poor or Bad zones, indicating favorable conditions for agricultural use during the dry season. In the post-monsoon season, a noticeable shift in groundwater quality is evident, reflecting the impact of monsoonal recharge on groundwater chemistry. While the same sampling locations are represented, their positions on the Wilcox diagram have shifted, indicating changes in salinity and sodicity. EC values display a wider range, extending from about 800 to 1600 µS/cm, with some samples moving closer to the Admissible boundary. Conversely, sodium percentages generally decrease, with most values falling between 15% and 35%, reflecting dilution due to freshwater recharge.

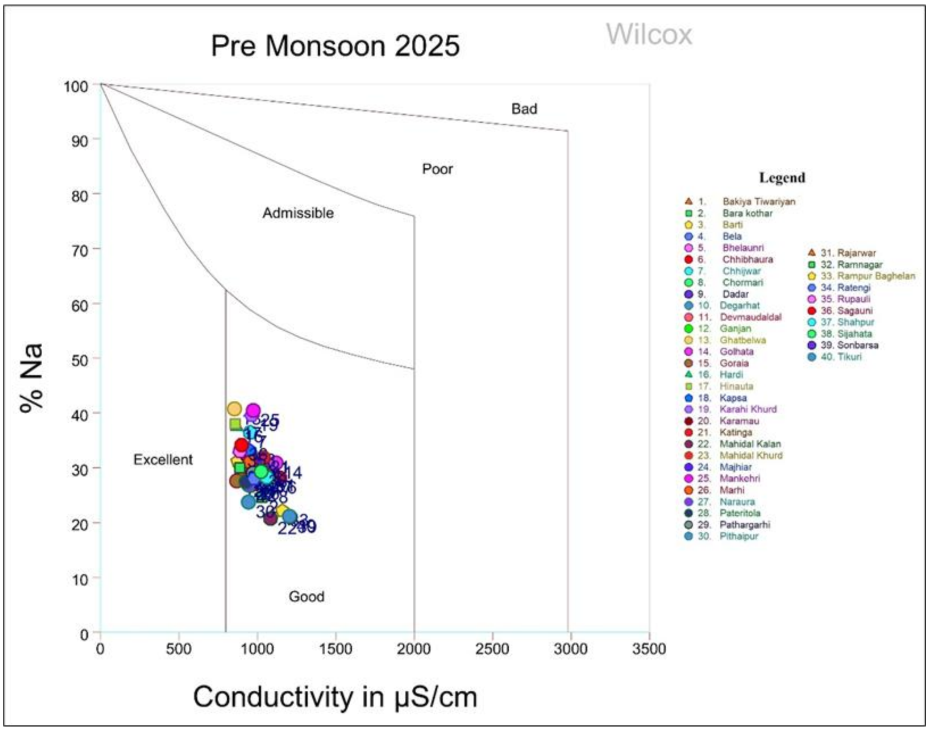

Figure 2. Wilcox Diagram for Pre Monsoon 2025

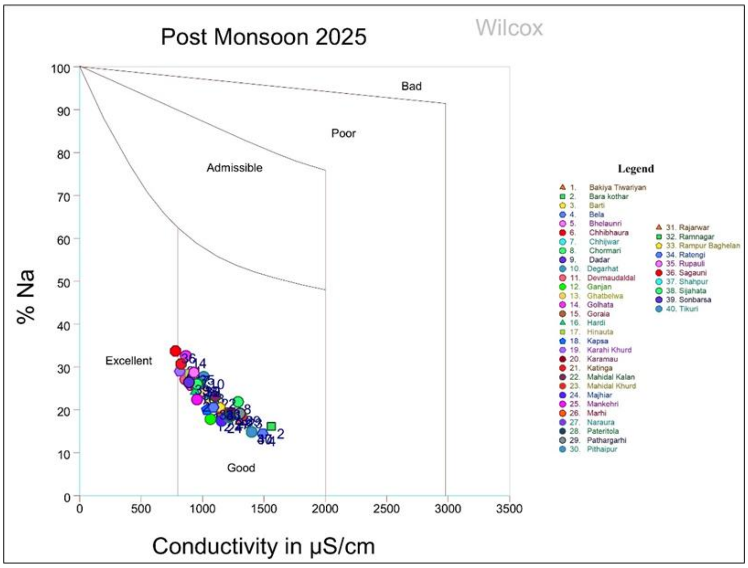

Figure 3. Wilcox Diagram for Post Monsoon 2025

The **US Salinity Laboratory diagram**, also known as the Riverside diagram, is a widely used classification tool for evaluating the suitability of groundwater or irrigation water based on its salinity and sodium (alkalinity) hazards. Low salinity water has EC values below 250 µS/cm, medium salinity ranges from 250–750 µS/cm, high salinity from 750–2,250 µS/cm, and very high salinity exceeds 2,250 µS/cm. As EC increases, the risk of salt accumulation in soils rises, potentially reducing crop yields and plant growth. Sodium Adsorption Ratio (SAR), ranging from 0 to about 32, where values below 10 indicate low sodium hazard, 10–18 medium, 18–26 high, and above 26 very high sodium hazard (Yadav et al., 2018; Vahith et al., 2023; Tejashvini et l., 2024).

Groundwater quality assessment for both the Pre-Monsoon and Post-Monsoon 2025 periods reveals uniformly excellent suitability for agricultural use across all 40 sampled locations. Based on the USSL (Riverside) classification, groundwater samples from villages such as Bakiya Tiwariyan, Bara Kothar, and Chhibhaura consistently plot within the C1–S1 and C2–S1 zones, indicating low to medium salinity and low sodium hazard. Electrical Conductivity values predominantly range between 100 and 750 µS/cm, while Sodium Adsorption Ratio values remain low (0–8), suggesting minimal risk of salt accumulation or soil structural degradation. Notably, even during the pre-monsoon period—when evapotranspiration and groundwater extraction typically concentrate dissolved ions—the water quality remains fresh and stable. Post-monsoon results closely mirror pre-monsoon conditions, with negligible seasonal variation in salinity or sodicity. The persistent clustering of samples in favorable zones indicates that monsoon recharge neither diluted nor degraded groundwater chemistry. Overall, the groundwater is suitable for all soil types and crops, including salt-sensitive varieties, without requiring special management practices.

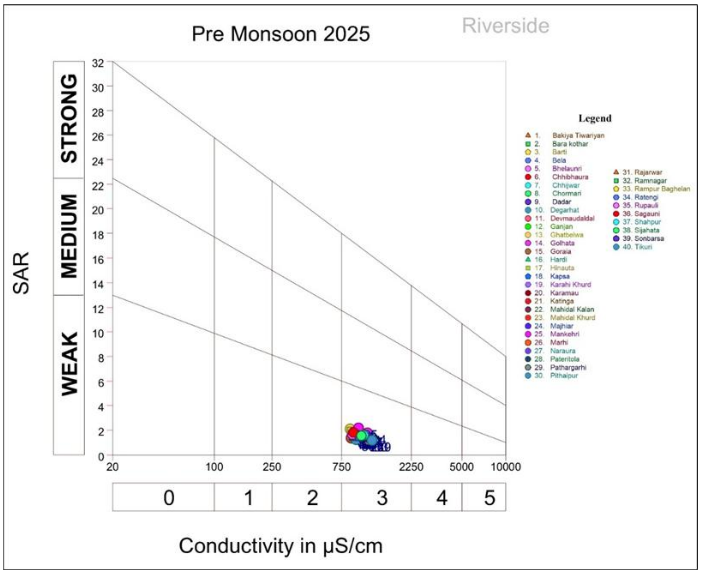

Figure 4. USSL Diagram for Pre Monsoon 2025

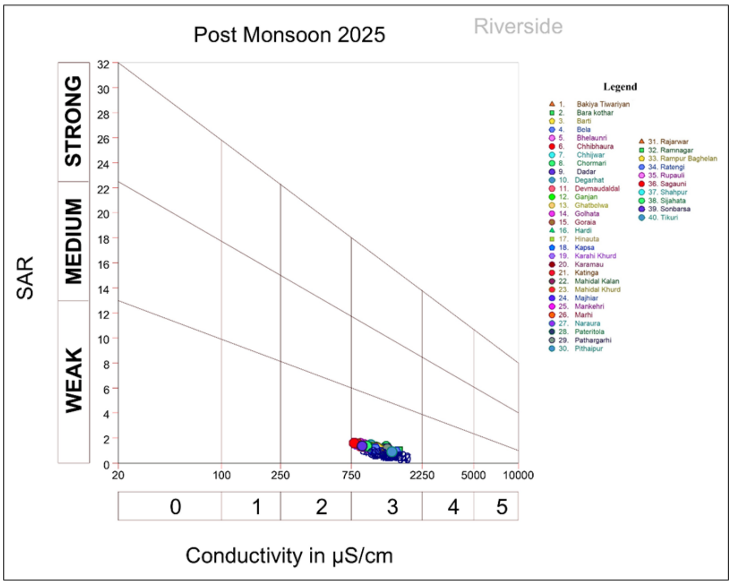

Figure 5. USSL Diagram for Post Monsoon 2025

IV. Conclusion

The comprehensive assessment of groundwater quality in Kariari River Sub-Basin, provides critical insights into the hydrochemical dynamics governing irrigation suitability. Agriculture remains the backbone of the regional economy, and as surface water resources face increasing pressure, the reliance on groundwater has become paramount. This study, conducted through the pre-monsoon and post-monsoon seasons of 2025 across 40 sampling locations, reveals a groundwater system that is fundamentally robust and highly suitable for agricultural applications, albeit subject to seasonal fluctuations and localized geochemical influences.

The research highlights a clear seasonal rhythm in groundwater chemistry, primarily driven by the "dilution effect" of the south-west monsoon. Electrical Conductivity (EC), the primary indicator of salinity hazard, showed a notable mean reduction of approximately 11% following the monsoon rains. While pre-monsoon conditions saw 75% of samples falling into the High Salinity (C3) category, the post-monsoon recharge improved the profile significantly, with 40% of the area shifting to the Medium Salinity (C2) category. Evaluation through multiple established indices, including Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), Kelly's Ratio (KR), and Magnesium Adsorption Ratio (MAR), consistently points toward excellent irrigation suitability regarding sodicity and alkalinity hazards. The SAR values remained well below critical thresholds in both seasons, indicating a negligible risk of sodium-induced soil dispersion. Similarly, the consistently negative Residual Sodium Carbonate (RSC) values across all locations post-monsoon confirm the absence of bicarbonate hazards. This suggests that the groundwater will not lead to buildup of sodium in the soil, preserving soil structure and permeability for long-term cultivation. Furthermore, Permeability Index (PI) categorized water as "Good" (Class II) year-round, ensuring that infiltration rates remain healthy, while the Magnesium Adsorption Ratio indicated that magnesium hazard remains low to moderate across the majority of the sub-basin. Wilcox and USSL (Riverside) diagrams further validates these findings, showing a dense clustering of samples in favourable zones. On the Wilcox plot, the transition from pre-monsoon to post-monsoon saw a shift from "Admissible" toward "Good" and "Excellent" categories as sodium percentages declined. In USSL classification, dominance of C2-S1 and C3-S1 classes confirms that while salinity requires occasional leaching management in certain pockets, sodium hazard is virtually non-existent. This dual-hazard assessment reinforces the conclusion that the groundwater is suitable for almost all soil types and a wide variety of crops.

However, a significant technical challenge identified in this study is the prevailing Corrosivity Ratio (CR). The pre-monsoon period, characterized by higher concentrations of chlorides and sulfates, presents a "corrosive" environment for metallic irrigation infrastructure. This poses a tangible economic risk to farmers through the premature degradation of well casings, pipes, and pump components. To mitigate these risks, study recommends a transition from metallic components to corrosion-resistant materials such as PVC or High-Density Polyethylene (HDPE). According to study, water is geochemically safe for plant physiology, it is chemically aggressive toward metal. By aligning local farming practices with FAO's "water-wise" principles and investing in managed aquifer recharge (MAR) as suggested by NAQUIM plans, the region can safeguard its productivity. This research provides a scientific baseline for policymakers to implement sustainable groundwater governance, ensuring that the Kariari Sub-Basin remains a resilient agricultural hub amidst the uncertainties of climate change and increasing water demand.

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