Spatial Variability and Public Health Implications of Groundwater Fluoride in Jodhpur District, Rajasthan

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Abstract
The availability of safe drinking water is a pressing global issue, particularly for the 1.5 billion people who rely on groundwater. Fluoride contamination, a significant problem, poses severe health risks such as kidney, brain and liver damage, as well as skeletal fluorosis. This study evaluates water purity by analysing physicochemical parameters in the rural areas surrounding the Jodhpur district of Rajasthan, focusing on fluoride pollution and the computation of the Water Quality Index (WQI). In 2022-2023, ninety water samples were collected from various locations in the Bilara, Balesar and Phalodi tehsils.

The results indicate that the physicochemical parameters did not meet the standards set by the Bureau of Indian Standards (BIS), making them unsuitable for drinking water. Additionally, nearly all the samples exceeded the permissible fluoride levels established by the World Health Organization (WHO) and BIS for drinking water. The highest WQI recorded was 444.30 in Phalodi and the maximum fluoride concentration was 5.5 mg/L in Bilara. Furthermore, statistical analysis revealed a significant linear correlation and a high correlation coefficient among various water quality parameters. These findings underscore the urgent need for water quality improvement measures in the studied areas to safeguard public health.

Keywords: Physico-chemical parameters, Fluoride, WQI, Correlation coefficient.

Introduction

India's rapid population growth, industrialisation and urbanisation have significantly increased groundwater demand. However, human-induced factors such as overexploitation and improper waste disposal rapidly deteriorate groundwater availability and quality[8]. This urgent situation, exacerbated by current farming practices, poses serious health risks due to the excessive use of fertilisers, unhygienic conditions and sewage contamination of groundwater. The World Health Organisation in the year 2017 estimated that approximately 80% of all human illnesses are water-borne, underscoring the pressing need for immediate and decisive action. This research aims to highlight the urgency of this situation and the need for immediate and decisive action[14]. Fluoride contamination is another groundwater issue affecting over 25 million people in India[1].

According to a WHO assessment, 20% of the world's fluoride-affected population resides in India. Rajasthan, India's largest state, has been identified as an endemic region for fluorosis despite having only 1% of the nation's water resources and 5.2% of its population. In Rajasthan, 91% of the drinking water comes from groundwater and the State alone accounts for 10% of fluoride-affected households worldwide. Fluoride contamination, with an average concentration of 2 mg/L, impacts nearly every district in Rajasthan[9].

The abnormally high fluoride concentrations in Rajasthan's groundwater are not due to human activity but are instead the result of the natural prevalence of fluoride-bearing rocks and sediments. Significant rocks include basalts, gneisses, schists, phosphorite, shales, acid igneous rocks and limestone. These rocks contain fluorotic minerals, contributing to average fluoride concentrations ranging from 180 to 3100 ppm (on an average). F is thought to be caused mainly by chemical behaviour, including breakdown, dissociation and interaction with water. The WHO recommended a fluoride recommendation value of 1.5 mg/L for drinking water. Fluoride is crucial for healthy bone and tooth preservation. However, it has been discovered that extended exposure to high fluoride concentrations is harmful to the teeth, bones and internal organs[17].

This research aims to identify the rate at which the water quality of the various villages surrounding the Jodhpur district in Rajasthan is deteriorating and to offer information about the key factors influencing this rate. As a result, an attempt has been undertaken in the present study to evaluate the drinking water quality index of 90 samples from different villages of Bilara, Balesar and Phalodi Tehsil. The Karl-Pearson correlation coefficient (R^2)[18] was calculated as part of the statistical analysis to determine the significance of each parameter's impact on the water quality of the available drinking water.

Material and Methods

Research area: The most significant and possible aquifer is the Bilara limestone, which comprises of shale, calcium carbonate and limestone. Bilara is located at latitude 26.18067 and longitude 73.7055, southeast of the Jodhpur district. Its 1451.89 square kilometre territory is bordered to the east, south and northwest by the Pail district and to the northeast by the Nagaur district borders. The climate in the Tehsil ranges from semiarid to subhumid.

https://doi.org/10.25303/295rjce066076

Balesar is a Tehsil in Jodhpur District, Rajasthan, at approximately 26°23’ North latitude and 72°30’ East longitude. It relies on sandstone and alluvium aquifers for water supply, with fresh and saline water sources. Surface bodies of water are absent, making the area dependent on rainwater and water supply systems for its water needs. Water conservation and recharge systems include rooftop rainwater harvesting, wells, tube wells, hand pumps, check dams, farm ponds, percolation tanks and tanks.

Phalodi experiences an arid desert climate. The town is approximately 135 kilometres from Jodhpur and is known for its extreme temperatures, with scorching hot summers and cool winters. It lies between latitude 27.13° N and longitude 72.36° E. Groundwater in Phalodi tends to be saline, posing challenges for water availability. Traditional water conservation methods such as Baoris (step wells) and jihads (small earthen check dams) are vital for storing water. Phalodi is also renowned for the nearby Khichan village, which hosts thousands of demoiselle cranes during their migratory season. Figure 1 shows all three sampling stations selected for research.

Figure 1: Site description of sampling stations

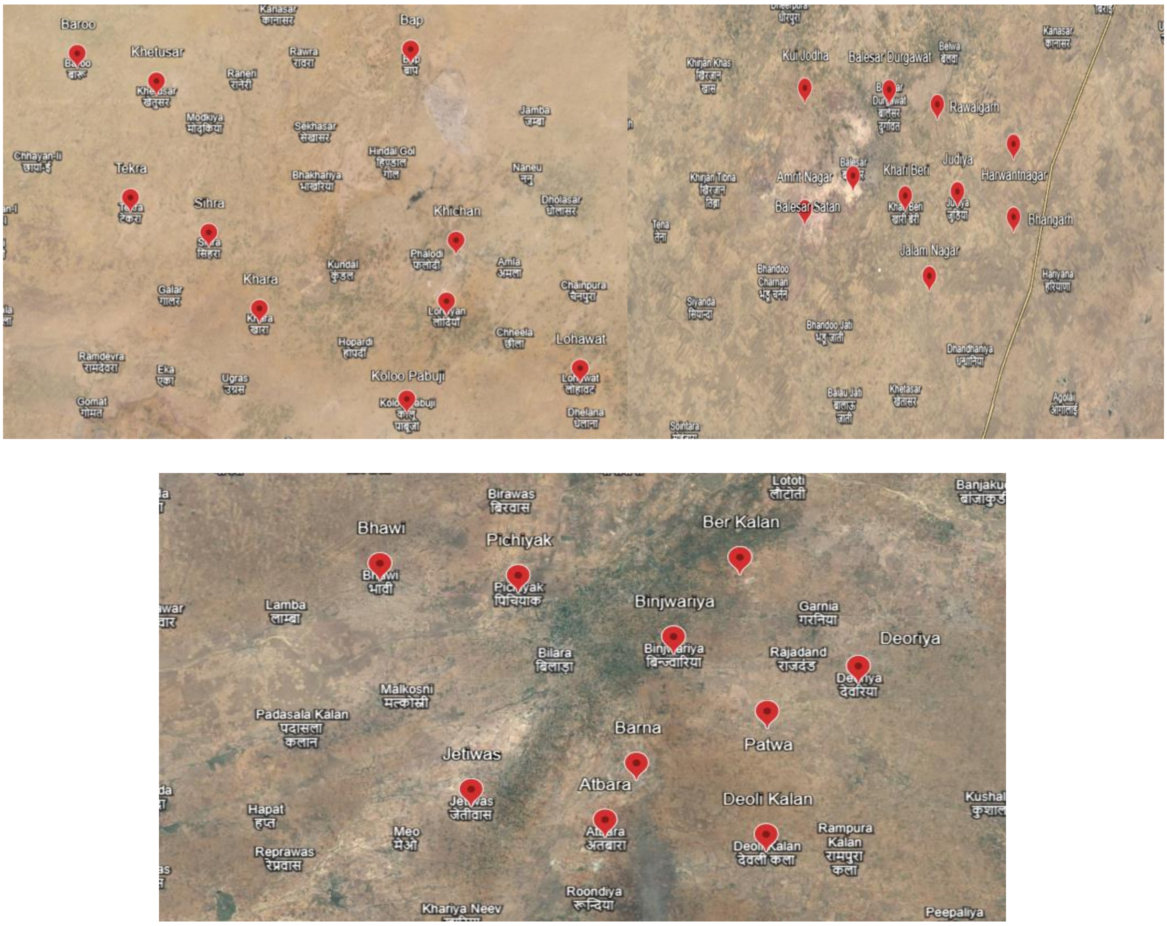

Figure 2: Sampling location of Bilara, Balesar and Phalodi tehsils

Sampling and Analytical Method: Ninety groundwater samples were collected from various sites in Bilara, Balesar and Phalodi Tehsils (Figure 2). The samples were gathered in previously cleaned bottles and given a second washing at the sampling locations. The pH values of the samples were recorded on the spot. The samples were transported to Jodhpur's Public Health Engineering Department (PHED) for further analysis. The analysis of the physicochemical parameters was conducted using standard techniques, ensuring the reliability of the results. Table 1 summarizes the water quality parameters for the 90 water samples. The testing methods followed the standard approach recommended by the American Public Health Association in 2007 including titrimetric, colourimetric and atomic Spectrophotometric techniques. The Water Quality Index (WQI)[20] and statistical analysis were utilized to understand and evaluate the water quality of all samples.

WQI refers to the relative importance and influence of various water quality indicators on overall water quality. The WQI was determined using the BIS 2012 standards. Correlation matrix studies were conducted to identify the most critical water quality measurements and the relationship between key parameters and other factors. Using Excel 2007, the correlation matrix for ten factors and the WQI value for the 90 water samples was calculated. Correlation analysis, an essential descriptive tool, assessed the degree of relationship among the various study variables. The correlation matrix displays the degree of linear relationship between water quality parameters and is expressed as a coefficient (R)[15].

Results and Discussion

pH: It is a critical indicator of its acidity or alkalinity, essential for assessing water quality and its impact on infrastructure. In the current study, water samples exhibited pH values ranging from 7 to 9.1, with a mean of 7.89, indicating neutral to essential water. Most of the samples were within the BIS permissible range of 6.5 to 8.5, but some exceeded this limit. The highest pH of 9.1 was found in Khari Beri and Balesar Durgawati samples, while the lowest pH of 7 was recorded in samples from Barna, Baroo and Pichiyak. These variations highlight the need for monitoring and potential treatment to maintain water safety and prevent infrastructure damage due to corrosion or scaling [10].

Electrical conductivity (EC): EC measures the ability of water to conduct electric current, which is influenced by its ionic composition[6]. Major ions like N^{a+}, Ca^{2+}, K^{+}, Mg^{2+}, Cl^{-}, SO_4^{2-} and CO_3^{2-} and HCO_3^{-} significantly impact EC levels. The study's EC values ranged from 1120 to 9450 µS/cm, averaging 4591.42 µS/cm. The highest EC was 9450 µS/cm in an open well sample from Judiya and the lowest was 1120 µS/cm in a tube well sample from Sihra. These variations highlight differing ionic concentrations across sampling locations.

Table 1
Summarized results of water quality parameters of groundwater

S.N.	Parameters	Range	Mean	SD	*CV*	Standard desirable limits	standard permissible value in the absence of alternate	% samples exceeding desirable standard	% samples exceeding permissible standards
1	pH	7-9.1	7.88	0.566	*0.071*	6.5-8.5	6.5-9.2	14.44	0
2	Total alka	150-990	380.72	160.98	*0.42*	200	600	95.55	10
3	TH	150-1050	525.88	178.6	*0.339*	200	600	98.8	25.55
4	CaH	60-600	264.11	115.08	*0.432*	75	200	96.66	65.55
5	MgH	80-640	261.77	100.13	*0.382*	30	100	100	97.77
6	Cl	230-4000	1152.11	680.03	*0.590*	250	1000	97.77	37.77
7	NO_3	4-380	96.5	83.3	*0.863*	45	100	55.55	45.55
8	F	0.2-5.5	1.93	1.16	*0.601*	1	1.5	80	53.33
9	TDS	750-7420	2785.26	1285.311	*0.461*	500	2000	100	73.33
10	EC	1120-9450	4591.42	1571.99	*0.342*	750	2250	100	94.44
11	Na	160-2250	1058.7	525.72	*0.496*	6.52	8.71	100	100
12	SO_4	110-2840	430.96	500.13	*1.160*	200	400	60	31.11

TDS (Total Dissolved Solids): According to WHO, TDS stands for the combined quantity of substances i.e. inorganic and organic, which are dissolved in water and affect taste. Natural factors like water flow rate, turbidity and bedrock chemistry influence TDS levels, with water below 1000 mg/L generally considered fresh. In this study, TDS varied from 750 to 7420 mg/L, averaging 2785.26 mg/L. The maximum TDS value, 7420 mg/L, was recorded in an open well sample from Judiya village, while the lowest, 750 mg/L, was found in a hand pump sample from Lordiyan and a tube well sample from Sihra. Anthropogenic factors such as municipal waste, industrial discharge and water treatment chemicals can also impact TDS concentrations[5].

Total Alkalinity: The ability of water to neutralise acids or hydrogen ions (H^+) is expressed by total alkalinity, primarily due to the presence of bicarbonates, carbonates and hydroxide complexes of calcium, sodium and potassium[2]. Although hydroxide ions are found in deficient concentrations, they still contribute to water's alkalinity. TA indicates the natural salts present as minerals from the soil dissolved into the water. In this study, TA ranged from 150 to 990 mg/L, with an average concentration of 380.722 mg/L. The highest TA value of 990 mg/L was recorded in a hand pump sample from Deoli Kalan village, while the lowest TA value of 150 mg/L was observed in an open well sample from Sihra village. High alkalinity levels may be attributed to agricultural runoff containing fertilisers, pesticides and manure from nearby areas.

Total Hardness: It is the characteristic of water that prevents it from forming a lather with soap and raises its boiling point. It measures the presence of polyvalent cations, primarily the divalent cationic salts of calcium and magnesium, with smaller contributions from strontium, iron, zinc, barium and manganese salts[11]. In this study, total hardness ranged from 150 to 1050 mg/L, with an average concentration of 525.88 mg/L. The highest total hardness value of 1050 mg/L was recorded in a hand pump sample from Atbara village while the lowest value of 150 mg/L was observed in a tube well sample from the same town. Agricultural practices, including the percolation of irrigation water containing pesticides and other waste, may contribute to the total hardness values in the area.

Chloride: Chloride is a significant anion in varying concentrations in natural water and wastewater. Its levels typically increase with mineral content and can indicate pollution from sewage and industrial waste when present in high amounts. Significant sources of chloride in surface waters include domestic sewage, human and animal waste, fertilizers and organic decomposition[13]. The chloride concentration of the present study varied from 230 to 4000 mg/L, with an average value of 1152.11 mg/L.

Nitrate: Nitrate, the oxidised form of nitrogen, exists in various inorganic forms in soil and water, with sources varying based on local activities. Fertilizers containing phosphorus and nitrogen used in agriculture primarily contribute to elevated nitrate levels in groundwater and surface water. Additionally, nitrogenous waste from human excrement can lead to nitrate contamination[12]. Elevated nitrate-nitrogen levels reduce dissolved oxygen, negatively impacting aquatic life, plants and algae. In the present study, nitrate concentrations ranged from 4 to 380 mg/L, averaging 96.55 mg/L. The maximum nitrate concentration, 380 mg/L, was recorded in a hand pump sample from Bhawi village, while the lowest concentration, four mg/L, was found in aquifer samples from Khichan and Baroo villages.

Fluoride: Fluoride, derived from minerals such as fluorite, fluorapatite and cryolite, is abundant in the Earth's crust and is typically found as fluoride compounds. Industrial activities, including aluminium, steel, phosphate fertilizer and glass production, can introduce fluoride into the environment through emissions and wastewater discharge[7]. Chronic exposure to high fluoride levels from natural sources like groundwater or industrial sources can cause health issues including dental fluorosis (tooth discolouration and pitting) and skeletal fluorosis (joint and bone problems)[19].

In the current study, fluoride concentrations ranged from 0.2 to 5.5 mg/L, averaging 1.93 mg/L. The highest fluoride concentration of 5.5 mg/L was recorded in a hand pump sample from Deoli Kalan village. In comparison, the lowest concentration of 0.2 mg/L was found in an open well sample from Sihra village. Table 2 can categorise the fluoride concentration results of a given water sample to assess the associated health risks accordingly.

Sulphate: Sulphate ions (SO_4^{2-}) are important polyatomic anions in natural water sources, especially in high-salt regions like arid and semi-arid areas. Their presence mainly results from geological processes including pyrite oxidation and various sulphides in rocks.

Table 2
Classification of fluoride concentration of groundwater affecting the human body

S.N.	Categories	Fluoride range (mg/L)	Effect on human health	Representing samples	Percentage
1.	Low	0.1-0.5	Dental caries	1 sample	1.1%
2.	Permissible	0.5-1.5	Prevents tooth decay	41 samples	45.55%
3.	High	1.5-3.0	Dental fluorosis	40 samples	44.44%
4.	Very high	3.0-10	Skeletal fluorosis	Eight samples	8.8%
5	Severe	Ten or more	Crippling skeletal fluorosis	None	-

https://doi.org/10.25303/295rjce066076

Sulphates naturally occur in minerals like metallic sulphides found in igneous, sedimentary and metamorphic rocks and form when natural sulphur reacts with oxygenated water[16].

In this study, sulphate concentrations ranged from 110 to 2840 ppm, averaging 430.96 ppm. The highest sulphate concentration, 2840 ppm, was recorded in an aquifer sample from Atbara village, while the lowest, 110 ppm, was observed in hand pump samples from Koloo Pabuji village and tube healthy samples from Rawalgarh village. Figure 3 describes the comparative graphs of various physicochemical parameters of the Phalodi, Balesar and Bilara tehsils.

Statistical analysis

Correlation and regression analysis: The study employed the Karl Pearson correlation coefficient (r)[3] in Excel 2007 to analyse the relationships between 13 water quality parameters across 90 water samples from Bilara, Balesar and Phalodi tehsils (Tables 3, 4 and 5).

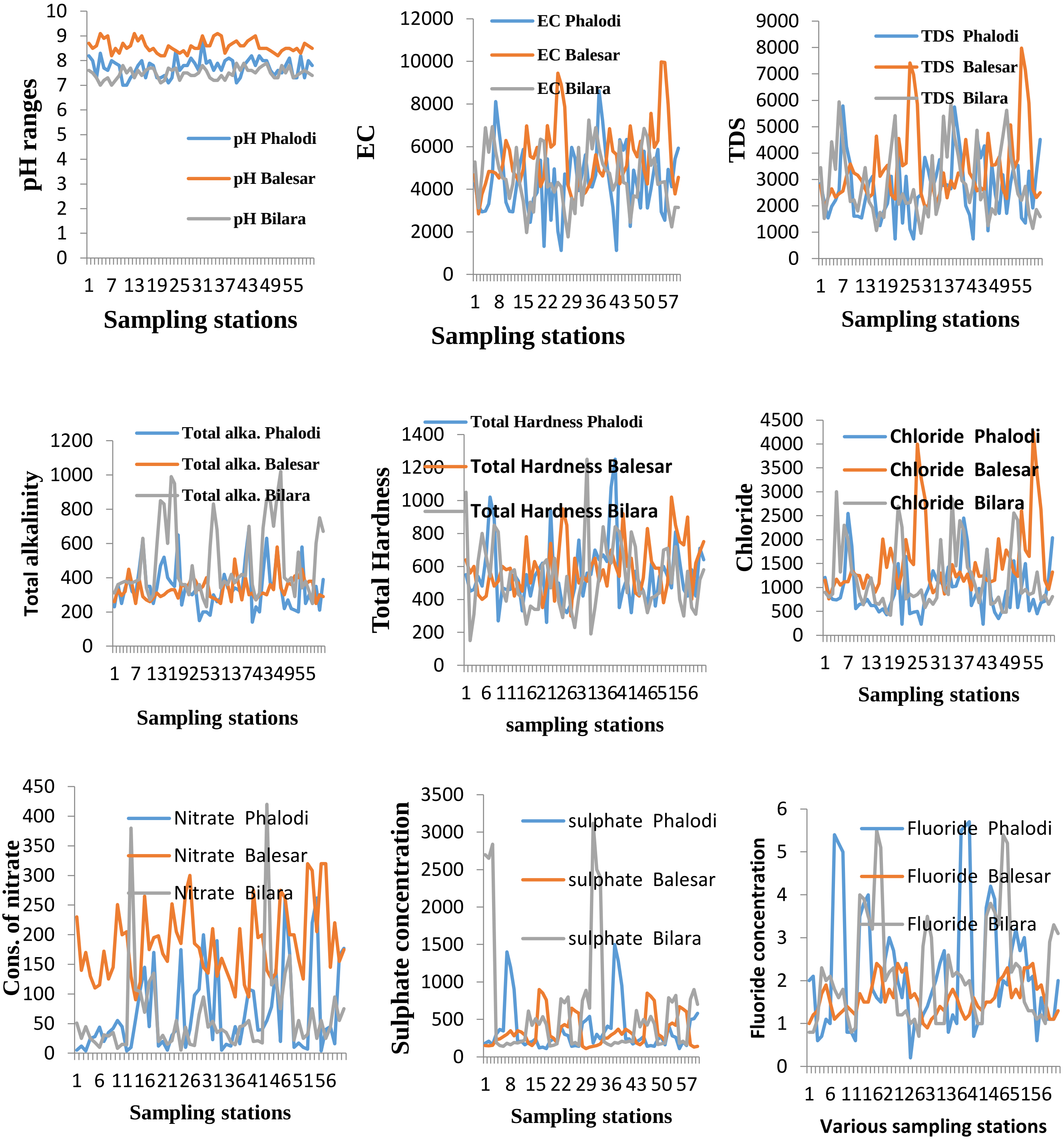

Figure 3: Physico-chemical analysis of water samples of Phalodi, Balesar and Bilara Tehsil

Table 3
Pearson correlation matrix of Phalodi

	pH	**total Alka**	**TH**	**CaH**	**MgH**	**Cl**	**NO_3**	**F**	**TDS**	**EC**	**Na**	**K**	**SO_4**
pH	1												
total alka	-0.02606	1											
TH	0.016092	0.004646	1										
CaH	-0.0202	0.006604	0.842976	1									
MgH	0.04166	0.002029	0.901619	0.527363	1								
CL	0.09455	-0.10606	0.874743	0.739789	0.786754	1							
NO_3	0.295181	0.002797	0.020642	-0.02356	0.051544	-0.07771	1						
F	0.242502	0.556169	0.336075	0.326247	0.268483	0.409079	-0.06996	1					
TDS	0.32716	0.197783	0.712937	0.535645	0.695336	0.83132	0.183025	0.677456	1				
EC	0.272396	0.238875	0.659216	0.548823	0.599894	0.773094	0.272216	0.669668	0.967273	1			
Na	-0.06601	0.195575	0.345922	0.206518	0.380302	0.40072	0.218917	0.479723	0.55841	0.558303	1		
K	0.041909	0.162471	0.493253	0.392773	0.463241	0.688832	-0.01085	0.481404	0.674941	0.609667	0.623268	1	
SO_4	0.253394	0.210063	0.574924	0.464243	0.534768	0.727846	-0.0402	0.677878	0.797984	0.713552	0.444403	0.833793	1

Table 4
Pearson correlation matrix of Balesar

	pH	**total Alka**	**TH**	**CaH**	**MgH**	**Cl**	**NO_3**	**F**	**TDS**	**EC**	**Na**	**K**	**SO_4**
pH	1												
total alka	-0.0206	1											
TH	-0.2002	-0.2641	1										
CaH	0.1458	-0.3810	0.8322	1									
MgH	-0.4922	-0.0439	0.8108	0.3503	1								
CL	-0.3446	0.2948	0.5602	0.2867	0.64378	1							
NO_3	-0.3669	-0.0795	0.7408	0.5033	0.72031	0.67696	1						
F	0.0080	0.5810	0.0566	-0.1100	0.21190	0.30134	0.2240	1					
TDS	-0.3435	0.2519	0.5755	0.3164	0.63829	0.96980	0.7341	0.3012	1				
EC	-0.2802	0.2613	0.5341	0.2732	0.61384	0.91045	0.7534	0.4141	0.954	1			
Na	-0.3628	0.1210	0.3954	0.0822	0.58125	0.51234	0.7231	0.5408	0.537	0.6182	1		
K	-0.0128	0.2024	0.1641	-0.0456	0.32547	0.36066	0.4592	0.5466	0.401	0.5371	0.842	1	
SO_4	-0.2952	0.2814	0.3884	0.0465	0.60702	0.66159	0.5774	0.6147	0.672	0.7078	0.813	0.7170	1

Table 5
Pearson correlation matrix of Bilara

	pH	**total Alka**	**TH**	**CaH**	**MgH**	**Cl**	**NO_3**	**F**	**TDS**	**EC**	**Na**	**K**	**SO_4**
pH	1												
total alka	0.2145	1											
TH	-0.2565	-0.2134	1										
CaH	-0.1493	-0.2627	0.92706	1									
MgH	-0.3441	-0.0828	0.834631	0.567247	1								
CL	-0.7433	-0.3505	0.42223	0.289473	0.502201	1							
NO_3	0.0193	0.5437	-0.06469	0.016308	-0.16605	-0.19818	1						
F	0.0707	0.9074	-0.18166	-0.26571	-0.00866	-0.11474	0.637558	1					
TDS	-0.6178	-0.3630	0.589043	0.45719	0.622225	0.863323	-0.10227	-0.1285	1				
EC	-0.6069	-0.3668	0.619914	0.530613	0.582165	0.823524	-0.02051	-0.1646	0.9282	1			
Na	0.4930	-0.3022	-0.14831	-0.00982	-0.31135	-0.44087	0.012412	-0.4560	-0.286	-0.15	1		
K	0.0865	-0.0198	-0.00651	0.070016	-0.11717	-0.23134	0.424308	-0.0882	-0.055	0.072	0.6012	1	
SO_4	0.1763	-0.054	-0.08307	0.045273	-0.24899	-0.28491	0.05631	-0.1981	-0.209	-0.154	0.5733	0.607	1

The correlation matrices for Phalodi, Balesar and Bilara tehsils reveal significant relationships between water quality parameters. In Phalodi, TDS strongly correlates with EC and positively with hardness and chloride, indicating that higher TDS is associated with elevated salts and increased conductivity. Chloride and total hardness are also strongly related, suggesting that controlling chloride can help to manage water hardness. Nitrates show a weak correlation with other parameters, indicating separate influencing factors. Fluoride is moderately correlated with total alkalinity, implying that fluoride levels rise with increased alkalinity.

In Balesar, TDS strongly correlates with EC and chloride, while fluoride shows moderate correlations with potassium and sulphate. In Bilara, EC is strongly related to TDS and chloride, with pH negatively correlating with these parameters. Fluoride strongly correlates with total alkalinity, highlighting its association with water's alkaline conditions. Overall, these correlations emphasize the interdependence of water quality parameters and can guide effective water management strategies.

Water quality index (WQI): WQI offers a single number (a grade) that represents overall water quality at a specific area based on a variety of parameters of water quality[4]. It is estimated that many water characteristics will be used to evaluate the local water quality for consumption. The term "WQI" was first introduced by Horton and afterwards expanded upon by numerous academicians. Ninety groundwater samples were used to calculate the WQI value, which was used to validate the research area's groundwater quality. BIS 2012 standards were used as the base value for each site's WQI computation.

Table 6 lists the typical water quality metrics and WQI calculation for a village in Phalodi Tehsil. Similar calculations are made for all other sites (Table 8). Figure 4 illustrates the comparative graph of WQI in all three stations: Phalodi, Balesar and Bilara. The calculated WQI indicated a low state of water quality for every sample, varying from 45.19 to 528.88. Table 7 illustrates the classification of water quality based on WQI value.

Schoeller diagram: In hydrogeology and geochemistry, a Schoeller diagram is a graphical tool used to compare the concentrations of significant ions in various water samples. It helps to identify water types, contamination, or geochemical processes, it plots ion concentrations on a logarithmic scale with various ions grouped along the X-axis. It then connects the values with lines to see patterns, similarities, or differences between samples. Fifteen logarithmic scales with equal spacing are used to plot the data in this format, as shown in figure 5. High concentrations are observed for parameters such as Total Dissolved Solids (TDS) and Chloride (Cl), suggesting significant contributions from dissolved minerals or possible contamination sources like seawater intrusion, agricultural runoff, or industrial discharge.

Low concentrations for parameters like nitrate (NO_3^-) may indicate limited agricultural or sewage impact or effective natural filtration processes that reduce nitrate levels. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) levels could point to processes like carbonate dissolution. At the same time, the presence of chloride (Cl^-) and sodium (Na^+) may indicate influences from saline water or anthropogenic activities.

Conclusion and Recommendations

Most of the results obtained from testing water samples were above the Bureau of Indian Standards (BIS) recommended limits for physicochemical parameters.

Table 6
Water Quality Index of one site at Phalodi Tehsil

Parameters	BIS Standard (Sn)	1/Sn	å1/Sn	K=1/(å1/Sn)	Wn=K/Sn	Ideal value(V0)	Mean Conc. Value(Vn)	Vn/Sn	Qn= Vn/Sn*100	WnQn
pH	8.5	0.117647	1.202203	0.831807	0.09786	7	8.2	0.8	80	7.828767
Total Alka	200	0.005	1.202203	0.831807	0.004159	0	230	1.15	115	0.478289
TH	200	0.005	1.202203	0.831807	0.004159	0	550	2.75	275	1.143734
CaH	75	0.013333	1.202203	0.831807	0.011091	0	250	3.333333	333.3333	3.696918
MgH	30	0.033333	1.202203	0.831807	0.027727	0	300	10	1000	27.72688
CL	250	0.004	1.202203	0.831807	0.003327	0	1210	4.84	484	1.610377
NO3	45	0.022222	1.202203	0.831807	0.018485	0	5	0.111111	11.11111	0.205384
F	1	1	1.202203	0.831807	0.831807	0	2	2	200	166.3613
TDS	500	0.002	1.202203	0.831807	0.001664	0	2850	5.7	570	0.948259
EC	500	0.002	1.202203	0.831807	0.001664	0	4270	8.54	854	1.420726
		1.204536			1.001941					211.4206

Table 7
Classification of water quality based on WQI

S.N.	WQI range	WQI category	Sampling station	No. of villages	%
1	<50	Excellent	25	1	1.1%
2	50-100	Good	3,12,62,71,87	5	5.5%
3	100-200	Poor	4,5,6,10,11,16,17,18,23,26-45,49,50,51,57,58,59,60,61,63,67,68,69,70,72,79,82,83,84,85,86	49	54.44%
4	200-300	Very poor	1,2,19,20,21,22,24,46,47,48,52,53,54,55,56,64,65,66,76,80,81,88,90,	23	25.5%
5	>300	Unsuitable	7,8,9,13,14,15,73,74,75,77,78,89	12	13.33%

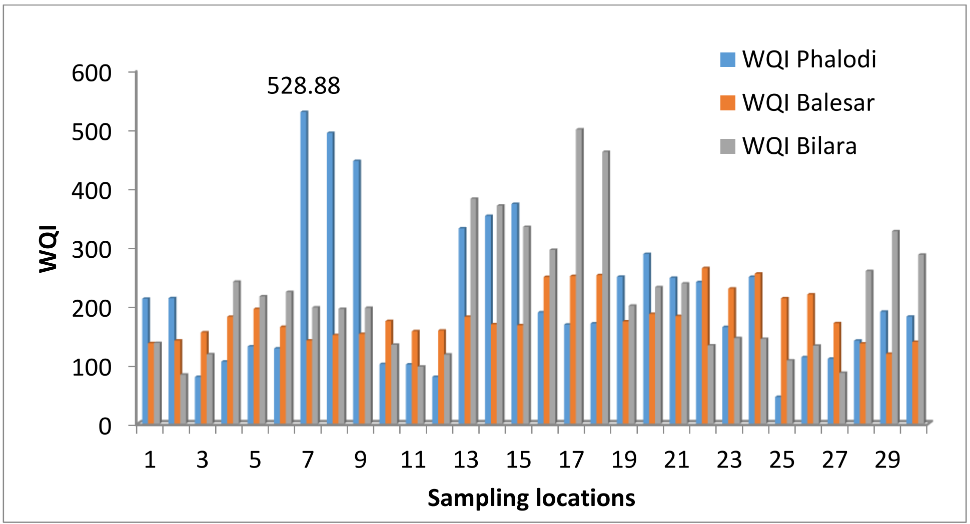

Figure 4: Comparative graph of WQI of Bilara, Balesar and Phalodi tehsils

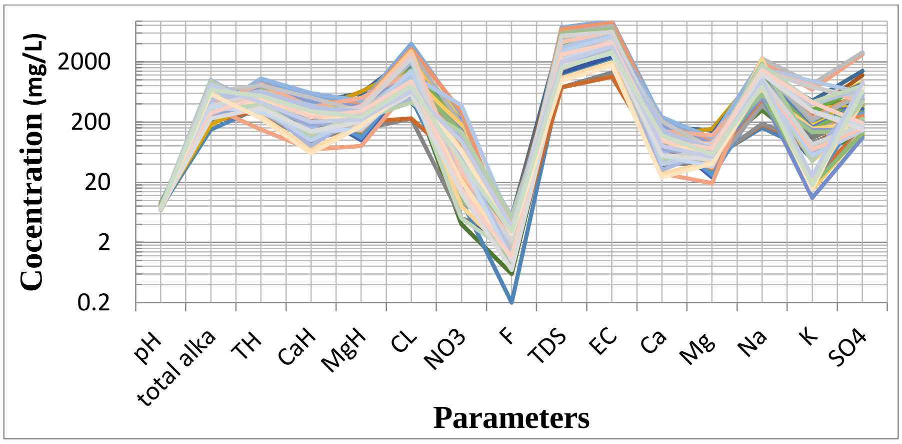

Figure 5: Schoeller diagram comprising of all the parameters

Based on the Water Quality Index (WQI) study conducted across Phalodi, Balesar and Bilara Tehsils, the findings indicate a concerning state of water quality; only 1.1% of water samples was classified as "Excellent" and 5.5% as "Good", while a significant portion (54.44%) fell into the "Poor" category and 25.5% were deemed "Very Poor". The WQI is increased by untreated effluent, pet waste, domestic solid waste and industrial emissions associated with the potential water supply system's drainage channel. A single facility faces a fluoride issue, with sample results highlighting varying impacts. Among the samples, 1 (1.1%) falls within a range associated with dental caries risk, 41 (45.55%) fall within a range beneficial for preventing tooth decay, 40 (44.44%) fall within a range that could lead to dental fluorosis and 8 (8.8%) fall within a range linked to skeletal fluorosis. Groundwater fluoride poisoning has gained significant research attention due to its toxicity, persistence and bioaccumulation.

Factors such as geological conditions, ion exchange reactions, leaching of contaminants, weathering rates and the presence of fluoride-bearing reservoirs, all influence

https://doi.org/10.25303/295rjce066076

fluoride levels in groundwater. Prolonged exposure to elevated fluoride concentrations can lead to fluorosis and can adversely affect the human urinary, renal, hormonal, nervous and reproductive systems. Therefore, fluoride treatment filters are recommended to mitigate these risks. Yearly checking and maintaining drinking water quality is imperative.

Acknowledgement

We thank the Public Works Department, Jodhpur (Rajasthan) and the Department of Chemistry, Jodhpur (Rajasthan), for generously providing the necessary space to conduct experiments and for their unwavering logistical support throughout this study.

References

1. Adimalla N., Venkatayogi S. and Das, S.V.G., Assessment of Fluoride Contamination and Distribution: A Case Study from a Rural Part of Andhra Pradesh, India, *Applied Water Science*, **9(4)**, doi: 10.1007/s13201-019-0968-y **(2019)**

2. Ahmad S., Umar R. and Ahmed I., Assessment of groundwater quality using Entropy-Weighted Quality Index (EWQI) and multivariate statistical techniques in Central Ganga plain, India, *Environment Development and Sustainability*, **26(1)**, doi:10.1007/s10668-022-02776-8 **(2022)**

3. Gaikwad S.K., Kadam A.K., Ramgir R.R., Kashikar A.S., Wagh V.M., Kandekar A.M., Gaikwad S.P., Madale R.B., Pawar N.J. and Kamble K.D., Assessment of the Groundwater Geochemistry from a Part of West Coast of India Using Statistical Methods and Water Quality Index, *Hydro Research*, **3**, 48–60 **(2020)**

4. Gautam S.K., Gautam P., Yadav A.K., Choudhary P. and Kumar S., Groundwater Quality Characterization Using an Integrated Water Quality Index (WQI) and Multivariate Statistical Techniques: A Case Study of Jakham River Basin, Rajasthan, India, *PLoS One*, **18(10)**, doi:10.1371/journal.pone.0294533 **(2023)**

5. Jayana U., A Study on Assessment of Groundwater Quality and Its Suitability for Drinking in Dungarpur District of Rajasthan, Using Statistical Techniques, *EPH - International Journal of Applied Science*, **9(2)**, 1–11 **(2023)**

6. Kachhwaha V., Sharma G., Tanwar P. and Mishra P., Assessment of Water Quality Indices of Heavy Metal Pollution in Jojari River (Jodhpur) Using Multivariate Statistics, *Ecology Environment and Conservation*, **28(Suppl. Issue)**, S301–S310 **(2022)**

7. Kesari T., Pant D., Roy A., Sinha U.K., Jaryal A., Singh M. and Jain S.K., Fluoride Geochemistry and Exposure Risk Through Groundwater Sources in Northeastern Parts of Rajasthan, India, *Archives of Environmental Contamination and Toxicology*, **80(1)**, 294–307 **(2021)**

8. Kumar P., Meena P.L., Meena A.S. and Meena K.S., Assessment of Water Quality Using Physico-Chemical Parameters of Groundwater of Bhilwara City and Periphery Villages (Rajasthan), *International Archive of Applied Sciences and Technology*, **6(1)**, 17–21 **(2015)**

9. Mishra P., Singh S. and Soni R., Physicochemical Analysis of Ground Water of Jodhpur District Areas Having Excess of Fluoride and Nitrate, *Journal of Chemical Biology and Physical Science*, **6(4)**, 1196–1202 **(2016)**

10. Mishra P. and Singh S., Assessment of Groundwater Quality of Villages Around Mogra Near Jodhpur, *Journal of Applied Chemistry*, **7(1)**, 11–15 **(2020)**

11. Mukhopadhyay A., Duttagupta S. and Mukherjee A., Emerging organic contaminants in global community drinking water sources and supply: A review of occurrence, processes and remediation, *Journal of Environmental Chemical Engineering*, **10(3)**, doi:10.1016/j.jece.2022.107560 **(2022)**

12. Raheja H., Goel A. and Pal M., Assessment of groundwater quality and human health risk from nitrate contamination using a multivariate statistical analysis, *J Water Health*, **22(2)**, 350–366 **(2024)**

13. Ravikumar P., Aneesul Mehmood M. and Somashekar R.K., Water quality index to determine the surface water quality of Sankey tank and Mallathahalli Lake, Bangalore urban district, Karnataka, India, *Applied Water Science*, **3**, 247–261 **(2013)**

14. Selvarajan G. and Sangeetha S., Physico-Chemical Parameters and Quality Assessment of Groundwater Near Municipal Solid Waste Dumpsite, Mayiladuthurai, Tamilnadu – A Correlation Study, *Journal of Chemistry and Chemical Sciences*, **8(3)**, 377–382 **(2018)**

15. Sharma G., Tanwar P. and Mishra P., Spatiotemporal Dynamicity of Environmental Variables and Water Quality Index in Aquifers and Groundwater of Blue City Using Multivariate Statistical Technique, *RASAYAN Journal of Chemistry*, **15(03)**, 1867–1875 **(2022)**

16. Sharma S. and Bhattacharya A., Drinking water contamination and treatment techniques, *Applied Water Science*, **7(3)**, doi: 10.1007/s13201-016-0455-7 **(2016)**

17. Srivastava S. and Flora S.J.S., Fluoride in Drinking Water and Skeletal Fluorosis: A Review of the Global Impact, *Current Environmental Health Reports*, **7(2)**, 140–146 **(2020)**

18. Tanwar P. and Mishra P., Seasonal Variation Analysis of Groundwater Quality of "Salt City" of Rajasthan, India, Using Water Quality Index (WQI) and Pearson Correlation Matrix, *Asian Journal of Organic & Medicinal Chemistry*, **7(2, Special Issue V)**, 427–434 **(2022)**

19. Yadav A., Sahu Y.K., Rajhans K.P., Sahu P.K., Chakradhari S., Sahu B.L., Ramteke S. and Patel K.S., Fluoride Contamination of Groundwater and Skeleton Fluorosis in Central India, *Journal of Environmental Protection*, **7(6)**, 784–792 **(2016)**

20. Yadav A.K., Khan P. and Sharma S.K., Water Quality Index Assessment of Groundwater in Todaraisingh Tehsil of Rajasthan State, India—A Greener Approach, *E-Journal of Chemistry*, **7(S1)**, S428–S432 **(2010)**.

(Received 09th January 2025, accepted 10th February 2025)