Mineralization and Hardness Characteristics of Borewell Water in Hanumangarh District, Rajasthan, India: Implications for Domestic Suitability

Nidhi[1], Dr. Rahna yadav[2]

[1]Research Scholar, Shri Khushal Das University, Hanumangarh, Rajasthan, India
[2]Assistant Professor and Research Supervisor, Shri Khushal Das University, Hanumangarh, Rajasthan, India

Highlights

- Borewell water from twelve rural and urban locations of Hanumangarh district was evaluated for mineralization and hardness-related parameters.
- TDS exceeded the acceptable limit in 11 of 12 samples, while total hardness exceeded the acceptable limit in 11 of 12 samples.
- Urban samples showed higher mean TDS, EC, hardness, alkalinity, chloride, sulphate and fluoride than rural samples.
- Strong correlations among TDS, EC, hardness and chloride indicate a common dissolved-ion/mineralization control.
- The major domestic suitability concerns were mineral load, hardness, scaling tendency and fluoride monitoring rather than selected heavy metal contamination.

Abstract:
Groundwater mineralization and hardness are important determinants of domestic water suitability, especially in arid and semi-arid regions where borewell water is widely used. The present study evaluated the mineralization and hardness characteristics of selected borewell water samples collected from rural and urban areas of Hanumangarh district, Rajasthan, India. Twelve borewell water samples, consisting of six rural and six urban samples, were analysed internally during February 2026 for selected physicochemical and chemical parameters. The present paper focuses on total dissolved solids (TDS), electrical conductivity (EC), total alkalinity, total hardness, calcium hardness, magnesium hardness, chloride, sulphate and fluoride. Analytical results were interpreted with reference to BIS IS 10500:2012 drinking-water limits wherever applicable, while EC was used as a supportive mineralization indicator. TDS values ranged from 440 to 1470 mg/L, and total hardness ranged from 140 to 390 mg/L as $CaCO_3$. Except one sample, all samples exceeded the acceptable limit for both TDS and total hardness, although all remained within permissible limits. Urban samples showed higher mean TDS (1106.67 mg/L), EC (1761.67 µS/cm), hardness (321.67 mg/L), alkalinity (248.33 mg/L), chloride (151.67 mg/L), sulphate (125.00 mg/L) and fluoride (0.90 mg/L) than rural samples. A strong positive correlation between TDS and EC ($r = 0.99$) confirmed that dissolved ions controlled the mineralization pattern. The results indicate that selected borewell water samples are mainly affected by dissolved mineral load and hardness, with implications for taste, scaling, appliance life and treatment requirement. Regular monitoring and household-level treatment are recommended in locations showing high TDS and very hard water.

Keywords: borewell water; mineralization; total dissolved solids; hardness; alkalinity; groundwater; Hanumangarh; domestic suitability.

1. Introduction

Groundwater is a major source of drinking and domestic water in many rural and urban areas of India. In arid and semi-arid regions, dependence on borewell water is particularly high because surface water availability may be limited and seasonal. Although groundwater is often considered more protected than surface water, its quality is strongly influenced by geological formations, groundwater residence time, evaporation, recharge conditions and local human activities.

Mineralization is one of the most common groundwater quality issues in regions with low rainfall, high evaporation and significant groundwater extraction. As groundwater moves through soil and rock formations, it dissolves minerals and salts. This hydrochemical process may increase total dissolved solids, electrical conductivity, hardness, alkalinity, chloride, sulphate and fluoride (Freeze & Cherry, 1979; Hem, 1985; Todd & Mays, 2005). These parameters may not always indicate acute toxicity, but they strongly influence the acceptability and usability of water for drinking and domestic purposes.

Hardness is mainly caused by calcium and magnesium salts. Hard water may not necessarily be unsafe for consumption at moderate levels, but it creates domestic problems such as scaling in utensils, water heaters, pipelines and appliances. It also reduces soap lathering and increases detergent consumption. Therefore, hardness assessment is important not only from a drinking-water standard perspective but also from a household suitability perspective (Sawyer et al., 2003).

Total dissolved solids and electrical conductivity are widely used indicators of dissolved ionic load in groundwater. Elevated TDS can affect taste and acceptability. High EC indicates higher ionic concentration and is often associated with higher TDS, hardness and salinity-related parameters. The World Health Organization notes that total dissolved solids and hardness may affect acceptability of drinking water even when health-based guideline values are not established for them (WHO, 2026).

Rajasthan has several groundwater quality challenges due to its climatic and hydrogeological conditions. Arid and semi-arid environments can promote accumulation of dissolved salts in groundwater. Central Ground Water Board observations have also noted salinity and fluoride issues in several parts of India, including arid and semi-arid regions such as Rajasthan (CGWB, 2025). Local work from Rawatsar, Hanumangarh has also reported elevated dissolved constituents in groundwater and surface water (Kaur & Bala, 2020). Hanumangarh district, located in northern Rajasthan, includes both agricultural rural settlements and urban areas, making it suitable for examining rural-urban differences in groundwater mineralization.

The present paper is derived from a broader physicochemical assessment of borewell water in Hanumangarh district. Unlike a broad water quality paper, this manuscript specifically focuses on mineralization, hardness and domestic suitability. The objective was to evaluate TDS, EC, alkalinity, hardness fractions, chloride, sulphate and fluoride in selected rural and urban borewell water samples and to interpret their implications for domestic use.

2. Materials and Methods

2.1 Study area and sampling design

The study was conducted in selected rural and urban locations of Hanumangarh district, Rajasthan, India. The sampling design included six rural and six urban borewell water samples. Rural samples were coded R1 to R6, while urban samples were coded U1 to U6. All samples represented borewell water sources.

The samples were collected during February 2026. Individual exact sampling dates were not recorded separately. Samples were analysed internally within 24-48 hours after collection. The study was limited to physicochemical and chemical parameters relevant to mineralization, hardness and domestic suitability.

Microbiological parameters and untested special parameters such as uranium were not included in the present manuscript.

Table 1. Sampling locations and source type.

Sample code	Category	Sampling location	Source type
R1	Rural	Masita Vali	Borewell water
R2	Rural	7 STG SKD	Borewell water
R3	Rural	4 STG SKD	Borewell water
R4	Rural	Makkasar	Borewell water
R5	Rural	Panditvali	Borewell water
R6	Rural	Sangaria	Borewell water
U1	Urban	Civil Lines	Borewell water
U2	Urban	Bhatner Fort	Borewell water
U3	Urban	Azad Vatika	Borewell water
U4	Urban	Satipura	Borewell water
U5	Urban	Market Area, Hanumangarh Junction	Borewell water
U6	Urban	District Park	Borewell water

2.2 Analytical parameters

The present paper focuses on selected mineralization and hardness-related parameters: TDS, EC, total alkalinity, total hardness, calcium hardness as $CaCO_3$, magnesium hardness as $CaCO_3$, chloride, sulphate and fluoride. The wider thesis dataset also included additional physicochemical and metal parameters, but only those directly relevant to mineral load and domestic suitability were used for this manuscript.

Analytical reliability was supported through clean sample handling, analysis within 24-48 h of collection and routine internal checks of instruments, glassware and reagents. pH and electrical conductivity measurements were verified using standard calibration practice, while hardness and alkalinity-related analyses were performed using standardized titrimetric procedures. Internal consistency was checked by comparing interrelated mineralization indicators such as TDS, EC, total hardness, calcium hardness, magnesium hardness and chloride. No external certified laboratory validation or seasonal replication was performed; this limitation is considered while interpreting the results.

Results were compared with BIS IS 10500:2012 drinking-water limits wherever applicable. EC was used as a supportive parameter because it does not have a direct BIS drinking-water limit in the same form as TDS or hardness. The analytical approach followed standard water quality practice, and methods were aligned with commonly used procedures described in Standard Methods for the Examination of Water and Wastewater (APHA, AWWA, and WEF, 2017).

Table 2. Standard and reference framework for interpretation.

Parameter	Unit	Acceptable limit	Permissible limit/reference	Basis
Total dissolved solids	mg/L	500	2000	BIS IS 10500:2012
Total hardness as $CaCO_3$	mg/L	200	600	BIS IS 10500:2012
Total alkalinity as $CaCO_3$	mg/L	200	600	BIS IS 10500:2012

Parameter	Unit	Acceptable limit	Permissible limit/reference	Basis
Chloride	mg/L	250	1000	BIS IS 10500:2012
Sulphate	mg/L	200	400	BIS IS 10500:2012
Fluoride	mg/L	1.0	1.5	BIS IS 10500:2012
Electrical conductivity	µS/cm	No direct limit	Supportive indicator	Interpreted with TDS and ions

2.3 Classification and statistical treatment

TDS results were interpreted using BIS acceptable and permissible limits. Hardness was interpreted using BIS limits and a commonly used hardness classification in which water is considered moderately hard at 75-150 mg/L as $CaCO_3$, hard at 150-300 mg/L and very hard above 300 mg/L. Descriptive statistics, rural-urban mean comparison and Pearson correlation analysis were used to interpret the mineralization pattern. Since the sample size was limited, the results were interpreted descriptively rather than as district-wide statistical proof.

3. Results

3.1 Mineralization and hardness data

The values of major mineralization and hardness-related parameters are presented in Tables 3(a) and 3(b). The results show that TDS, EC, total hardness and alkalinity varied considerably across the selected borewell water samples.

Table 3(a). Mineralization and hardness-related values of rural borewell water samples.

Sample	Location	TDS	EC	Alk.	TH	Ca-H	Mg-H	Cl	SO_4	F
R1	Masita Vali	440	680	120	140	80	60	30	45	0.4
R2	7 STG SKD	890	1390	240	220	180	140	80	75	0.7
R3	4 STG SKD	1210	1890	290	340	200	190	140	110	0.9
R4	Makkasar	1430	2230	250	340	220	120	210	130	1.1
R5	Pandit vali	940	1480	180	260	140	120	80	85	0.8
R6	Sangaria	1030	1620	190	320	230	80	120	145	1.0

Table 3(b). Mineralization and hardness-related values of urban borewell water samples.

Sample	Location	TDS	EC	Alk.	TH	Ca-H	Mg-H	Cl	SO_4	F
U1	Civil Lines	920	1430	210	280	180	100	90	100	0.7

Sample	Location	TDS	EC	Alk.	TH	Ca-H	Mg-H	Cl	SO_4	F
U2	Bhatner Fort	1180	1840	260	340	210	120	150	130	0.9
U3	Azad Vatika	760	1180	200	230	150	90	100	80	0.6
U4	Satipura	1390	2180	280	380	230	130	190	140	1.1
U5	Market Area, Hanumangarh Junction	1470	2320	310	390	250	120	250	190	1.3
U6	District Park	920	1620	230	310	180	110	130	110	0.8

3.2 TDS and electrical conductivity

TDS values ranged from 440 mg/L to 1470 mg/L. Only R1 was within the acceptable limit of 500 mg/L. All remaining samples exceeded the acceptable limit but remained within the permissible limit of 2000 mg/L. The highest TDS was recorded at U5, Market Area, Hanumangarh Junction. This indicates that most selected borewell water samples had moderate to high dissolved mineral load.

EC values ranged from 680 µS/cm to 2320 µS/cm. The lowest EC was recorded in R1 and the highest in U5. The EC trend was consistent with TDS, indicating that dissolved ions were the major contributors to mineralization. The strong TDS-EC correlation further supports this interpretation, although the relationship should be treated as descriptive because of the limited sample size.

3.3 Total hardness, calcium hardness and magnesium hardness

Total hardness values ranged from 140 mg/L to 390 mg/L as $CaCO_3$. R1 was the only sample within the acceptable hardness limit of 200 mg/L. All other samples exceeded the acceptable limit but remained within the permissible limit of 600 mg/L. Based on hardness classification, one sample was moderately hard, four samples were hard and seven samples were very hard.

Calcium hardness ranged from 80 mg/L to 250 mg/L as $CaCO_3$, whereas magnesium hardness ranged from 60 mg/L to 190 mg/L as $CaCO_3$. The contribution of both calcium and magnesium salts explains the elevated total hardness in most samples. The hardness pattern has practical importance because it directly influences scaling tendency and domestic usability.

3.4 Alkalinity, chloride, sulphate and fluoride

Total alkalinity ranged from 120 mg/L to 310 mg/L as $CaCO_3$. Several samples exceeded the acceptable limit of 200 mg/L but all remained within the permissible limit of 600 mg/L. Higher alkalinity may be associated with bicarbonate and carbonate minerals in groundwater.

Chloride values ranged from 30 mg/L to 250 mg/L. All samples were within the acceptable limit, although U5 reached the acceptable limit of 250 mg/L. Sulphate values ranged from 45 mg/L to 190 mg/L and were within the acceptable limit in all samples. Fluoride ranged from 0.4 mg/L to 1.3 mg/L. R4, U4 and U5 exceeded the acceptable limit of 1.0 mg/L but remained within the permissible limit of 1.5 mg/L.

3.5 Rural-urban comparison

Table 4. Rural-urban mean comparison of mineralization indicators.

Parameter	Unit	Rural mean	Urban mean	Higher mean
TDS	mg/L	990.00	1106.67	Urban
EC	µS/cm	1548.33	1761.67	Urban
Alkalinity	mg/L	211.67	248.33	Urban
Hardness	mg/L	270.00	321.67	Urban
Chloride	mg/L	110.00	151.67	Urban
Sulphate	mg/L	98.33	125.00	Urban
Fluoride	mg/L	0.82	0.90	Urban

The rural-urban comparison indicates that urban samples had higher mean values for all selected mineralization indicators included in Table 4. Urban mean TDS, EC, total hardness, alkalinity, chloride, sulphate and fluoride were higher than rural mean values. This suggests comparatively greater dissolved mineral load and domestic suitability concern in selected urban borewell water samples.

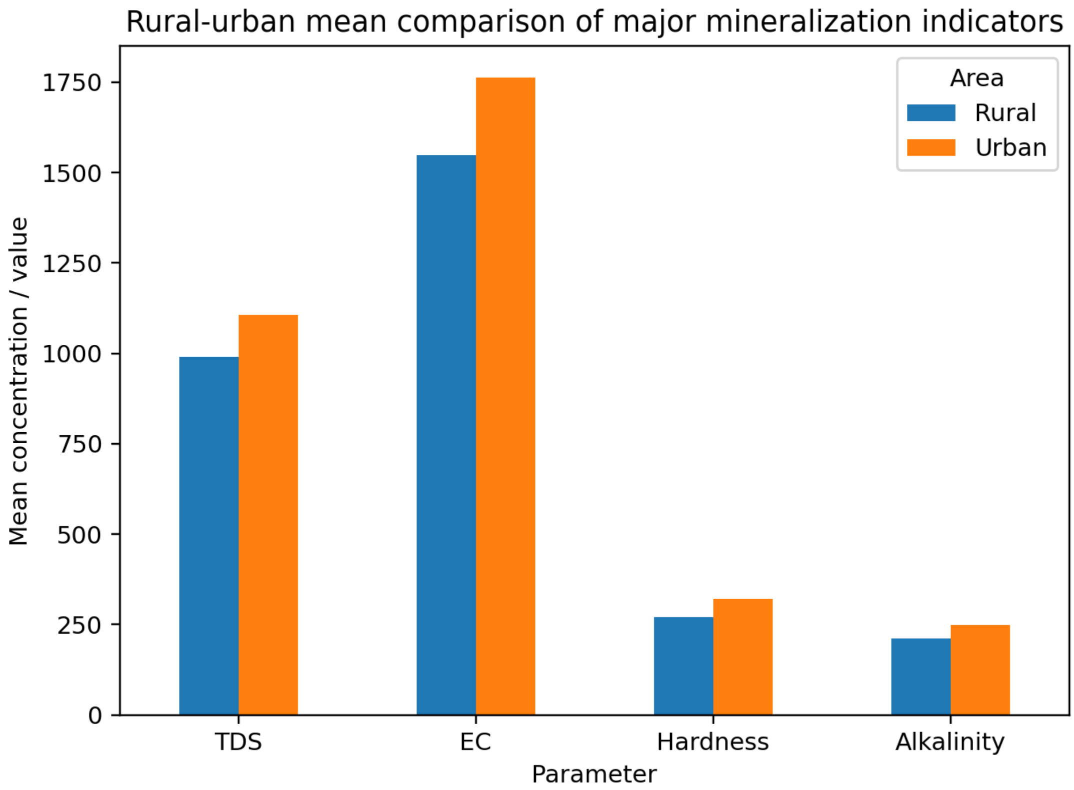

Figure 1. Rural-urban mean comparison of major mineralization indicators.

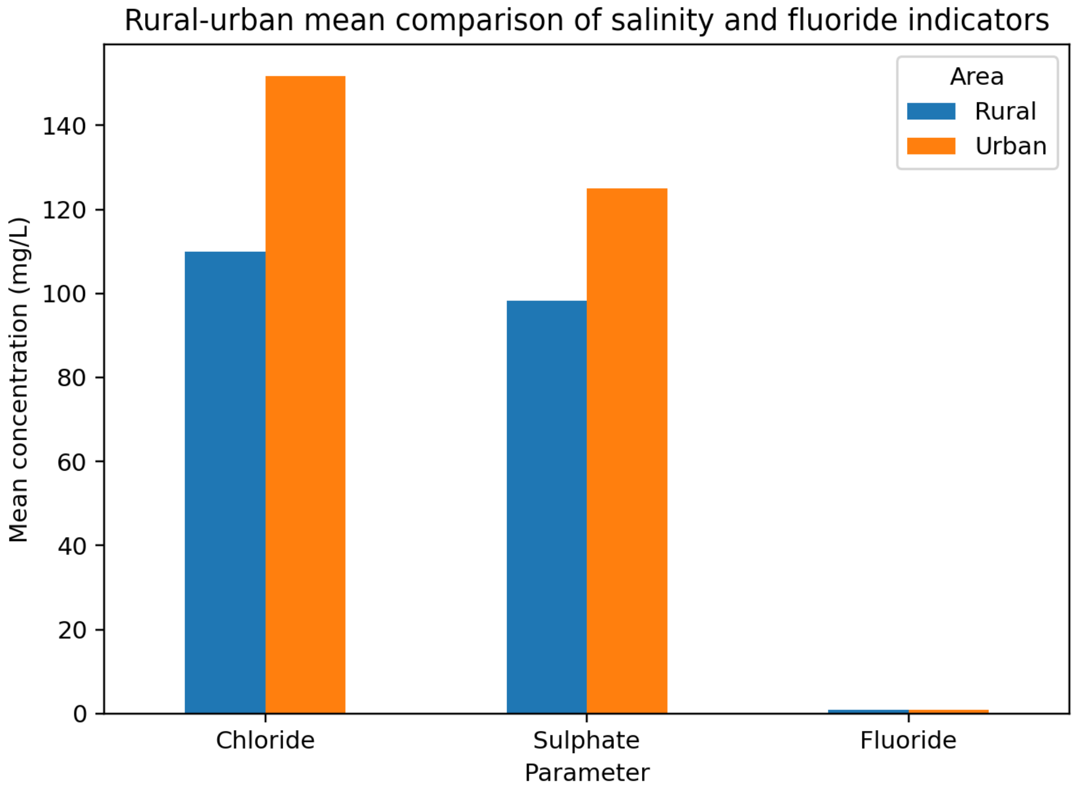

Figure 2. Rural-urban mean comparison of chloride, sulphate and fluoride.

3.6 Classification of samples for domestic suitability

Table 5. Domestic suitability classification based on mineral load and hardness.

Sample	Location	TDS status	Hardness class	Domestic suitability note
R1	Masita Vali	Within acceptable limit	Moderately hard	Low concern
R2	7 STG SKD	Above acceptable; within permissible	Hard	Moderate treatment/monitoring priority
R3	4 STG SKD	Above acceptable; within permissible	Very hard	High domestic treatment priority
R4	Makkasar	Above acceptable; within permissible	Very hard	High domestic treatment priority
R5	Panditvali	Above acceptable; within permissible	Hard	Moderate treatment/monitoring priority
R6	Sangaria	Above acceptable; within permissible	Very hard	High domestic treatment priority

Sample	Location	TDS status	Hardness class	Domestic suitability note
U1	Civil Lines	Above acceptable; within permissible	Hard	Moderate treatment/monitoring priority
U2	Bhatner Fort	Above acceptable; within permissible	Very hard	High domestic treatment priority
U3	Azad Vatika	Above acceptable; within permissible	Hard	Moderate treatment/monitoring priority
U4	Satipura	Above acceptable; within permissible	Very hard	High domestic treatment priority
U5	Market Area, Hanumangarh Junction	Above acceptable; within permissible	Very hard	High domestic treatment priority
U6	District Park	Above acceptable; within permissible	Very hard	High domestic treatment priority

The classification shows that most samples require monitoring or treatment from a domestic suitability perspective. Samples with high TDS, very hard water and fluoride above the acceptable limit require greater attention. U5 showed the highest domestic treatment priority because it had the highest TDS, EC, hardness, alkalinity, chloride, sulphate and fluoride values among the selected locations.

3.7 Correlation among mineralization indicators

Table 6. Pearson correlation matrix of mineralization indicators.

Parameter	TDS	EC	Alkalinity	Hardness	Chloride	Sulphate	Fluoride
TDS	1.00	0.99	0.87	0.94	0.94	0.87	0.95
EC	0.99	1.00	0.88	0.95	0.95	0.88	0.96
Alkalinity	0.87	0.88	1.00	0.84	0.83	0.73	0.78
Hardness	0.94	0.95	0.84	1.00	0.90	0.92	0.93
Chloride	0.94	0.95	0.83	0.90	1.00	0.90	0.93
Sulphate	0.87	0.88	0.73	0.92	0.90	1.00	0.95
Fluoride	0.95	0.96	0.78	0.93	0.93	0.95	1.00

The correlation matrix shows strong positive relationships among major mineralization indicators. TDS showed a very strong correlation with EC ($r = 0.99$), hardness ($r = 0.94$), chloride ($r = 0.94$) and fluoride ($r = 0.95$). EC was also strongly correlated with hardness ($r = 0.95$) and chloride ($r = 0.95$). These relationships indicate that the selected borewell water samples were influenced by a common dissolved-ion load rather than isolated variation of individual parameters.

4. Discussion

The results indicate that the primary water quality issue in the selected borewell samples is not extreme toxicity but mineralization and hardness. This pattern is typical of groundwater in semi-arid regions, where low recharge, evaporation and prolonged contact between water and aquifer materials can increase dissolved ionic content (Freeze & Cherry, 1979; Hem, 1985; Todd & Mays, 2005). The exceedance of acceptable limits for TDS and hardness in most samples suggests that the water may affect taste, scaling and domestic acceptability.

The close agreement between TDS and EC confirms that EC can serve as a rapid field indicator of dissolved mineral load in the study area. Samples with high TDS also showed high EC, hardness, alkalinity and chloride. This suggests that dissolved salts and hardness-causing ions were the main contributors to the observed mineralization pattern.

Hardness was a major domestic concern. Most samples were hard or very hard. Very hard water can produce scaling in pipelines, storage tanks, geysers, utensils and heating appliances (Sawyer et al., 2003). It may also reduce soap lathering and increase detergent consumption. Therefore, from a practical household perspective, treatment or softening may be needed even though the values remained below the BIS permissible limit.

Urban samples had higher mean values for most mineralization indicators. This may be due to a combination of natural and anthropogenic influences. Urban borewell water may be affected by higher extraction pressure, domestic wastewater seepage, drainage proximity, market activity and storage or distribution conditions. However, the role of natural aquifer chemistry cannot be excluded because all samples were groundwater sources.

The fluoride values require monitoring. Although no sample exceeded the permissible limit of 1.5 mg/L, three samples exceeded the acceptable limit of 1.0 mg/L. In Rajasthan, fluoride in groundwater is often linked with geogenic conditions and water-rock interaction. Long-term monitoring is therefore advisable, particularly at R4, U4 and U5.

Chloride and sulphate did not exceed acceptable limits in any sample. However, U5 reached the acceptable limit for chloride and also recorded the highest sulphate value. This pattern, together with high TDS, EC, hardness and fluoride, suggests that U5 should be treated as a priority location for continued monitoring.

The study has limitations. The dataset was generated through internal physicochemical and chemical analysis and not through external certified laboratory validation. Sampling was limited to February 2026 and does not represent seasonal variation. The sample size was also limited to twelve locations. Therefore, the results should be interpreted as a localized assessment of selected borewell water sources rather than a complete district-wide groundwater quality survey.

5. Conclusion

The present study assessed mineralization and hardness characteristics of selected borewell water samples collected from rural and urban areas of Hanumangarh district, Rajasthan. The findings show that the major domestic suitability concerns were associated with TDS, EC, total hardness, alkalinity and fluoride. TDS exceeded the acceptable limit in 11 of 12 samples, while total hardness exceeded the acceptable limit in 11 of 12 samples. However, all samples remained within the relevant permissible limits for these parameters.

Urban samples showed comparatively higher mean values of TDS, EC, hardness, alkalinity, chloride, sulphate and fluoride than rural samples. This suggests greater dissolved mineral load in selected urban borewell water samples. Strong correlations among TDS, EC, hardness and chloride indicate that the observed variation was largely controlled by dissolved ionic content and groundwater mineralization.

The results indicate that selected borewell water samples may require treatment or conditioning for domestic use, especially where TDS and hardness are high. Water softening, reverse osmosis, blending or other suitable treatment approaches may be considered depending on local needs and affordability. Periodic testing is recommended to monitor TDS, hardness, fluoride and related mineralization indicators, particularly in high-priority locations such as U5, U4 and R4.

6. Recommendations

1. Regular monitoring of TDS, EC, hardness, alkalinity, chloride, sulphate and fluoride should be carried out in borewell water sources.
2. Locations with very hard water and high TDS should be prioritized for domestic treatment options such as softening, reverse osmosis or blending with better-quality water.
3. Fluoride should be monitored periodically in locations where values are close to or above the acceptable limit.
4. Borewell surroundings should be protected from wastewater stagnation, open drains, chemical storage and solid waste dumping.
5. Future studies should include seasonal sampling, larger sample numbers and external certified laboratory validation.

Declarations

Funding

No external funding was received for this study.

Conflict of interest

The authors declare that they have no known conflict of interest.

Data availability

The data used for this manuscript are included in the tables. Additional supporting information may be provided by the corresponding author on reasonable request.

Ethical approval

Not applicable. The study involved water quality analysis and did not involve human participants or animal subjects.

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