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Rural-Urban Variation in Physicochemical Characteristics of Borewell Water in Hanumangarh District, Rajasthan, India

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Abstract:
Groundwater quality is a major environmental and public-health concern in arid and semi-arid regions where borewell water is widely used for drinking and domestic purposes. The present study assessed rural-urban variation in the physicochemical quality of borewell water in Hanumangarh district, Rajasthan, India. Twelve borewell water samples were considered, including six rural samples from Masita Vali, 7 STG SKD, 4 STG SKD, Makkasar, Panditvali and Sangaria, and six urban samples from Civil Lines, Bhatner Fort, Azad Vatika, Satipura, Market Area and District Park. Samples were collected during February 2026 and analysed internally within 24-48 h for selected physicochemical and chemical pollution-indicator parameters. Results were compared with BIS IS 10500:2012 drinking-water specifications wherever applicable. All samples were unobjectionable in odour and had pH values within the acceptable range of 6.5-8.5. Chloride, sulphate, nitrate and selected heavy metals were within acceptable or relevant limits in all samples. However, total dissolved solids exceeded the acceptable limit in eleven samples, and total hardness exceeded the acceptable limit in eleven samples. Total alkalinity exceeded the acceptable limit in eight samples, turbidity exceeded the acceptable limit in five samples, and fluoride exceeded the acceptable limit in three samples, although all remained within the corresponding permissible limits. Urban samples showed higher mean values for TDS, electrical conductivity, total hardness, alkalinity, chloride, nitrate, fluoride, COD and phosphate than rural samples. The findings indicate that the selected borewell waters are mainly influenced by groundwater mineralization, with moderate local anthropogenic influence in urban locations. Regular monitoring, borewell protection and treatment of high TDS/hardness water are recommended.

Keywords: Borewell water; groundwater quality; Hanumangarh; physicochemical parameters; TDS; hardness; fluoride; rural-urban comparison.

Highlights

- Twelve borewell water samples from rural and urban Hanumangarh were assessed.
- TDS and hardness exceeded acceptable limits in most samples but stayed within permissible limits.
- Urban samples showed comparatively higher mineral-load and pollution-indicator values.

- Selected heavy metals were within acceptable/relevant limits; cadmium and mercury were below detectable level.
- The study indicates groundwater mineralization with moderate local environmental influence.

1. Introduction

Groundwater is one of the most important sources of drinking and domestic water in India, particularly in rural and semi-urban regions where dependence on borewells and tube wells is high. Its suitability for use depends not only on availability but also on physicochemical quality. Water that appears clear and acceptable in taste may still contain elevated dissolved solids, hardness-causing minerals, nitrate, fluoride or trace metals. For this reason, systematic assessment of water quality is necessary for identifying suitability, treatment requirements and possible long-term concerns, and similar studies commonly use physicochemical datasets for drinking-water interpretation (Jha et al., 2020; Olasoji et al., 2019; Verma et al., 2020).

Water quality in arid and semi-arid regions is influenced by natural and human-related factors. Natural factors include low recharge, high evaporation, rock-water interaction, aquifer lithology and groundwater residence time. These factors may increase total dissolved solids (TDS), electrical conductivity (EC), alkalinity, hardness, chloride, sulphate and fluoride. Human-related factors such as intensive agriculture, fertilizer use, irrigation return flow, domestic wastewater, sewage seepage, solid-waste disposal and groundwater over-extraction may further alter groundwater chemistry.

Rajasthan represents a water-stressed region where groundwater is widely used and where mineral-related water-quality concerns such as salinity, hardness, fluoride and nitrate have been reported. Hanumangarh district has both agricultural rural areas and urban settlements, making it useful for rural-urban comparison. Earlier local studies in Hanumangarh and Rawatsar reported hydrogeochemical variability and elevated dissolved constituents, emphasizing the need for local water-quality studies (Kaur & Bala, 2020; Kumar et al., 2016; Maurya, 2017). Regional water studies also show that parameters such as pH, EC, TDS, DO, BOD, COD, turbidity and major ions are useful indicators of hydrochemical status and anthropogenic influence (Singh et al., 2024).

The present study was designed to assess physicochemical and selected chemical pollution-indicator parameters in rural and urban borewell water samples from Hanumangarh district. The study compares observed values with BIS IS 10500:2012 drinking-water specifications, examines rural-urban variation and identifies parameters requiring monitoring or treatment. The study is chemistry-oriented and does not include microbiological testing or untested special geogenic parameters such as uranium.

2. Materials and Methods

2.1 Study area and sampling design

The study was conducted in selected rural and urban areas of Hanumangarh district, Rajasthan, India. Hanumangarh has agricultural rural settlements as well as urban localities with residential, commercial and public-use areas. A total of twelve borewell water samples were considered for the study. Six samples were from rural locations and six samples were from urban locations.

All samples represented borewell water sources. The samples were collected during February 2026. Individual point-wise sampling dates were not recorded separately; however, the samples were analysed internally within 24-48 h of collection to reduce possible changes in parameters such as pH, temperature, DO, BOD and COD.

Table 1. Sampling locations and sample codes.

Sample code	Category	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 selected analytical parameters included colour, odour, pH, turbidity, temperature, total alkalinity, total hardness, calcium hardness as $CaCO_3$, magnesium hardness as $CaCO_3$, chloride, sulphate, nitrate, fluoride, TDS, EC, DO, BOD, COD, phosphate, iron, manganese, arsenic, lead, chromium, cadmium and mercury. Calcium hardness and magnesium hardness were treated as hardness fractions expressed as $CaCO_3$ and were not compared directly with calcium as Ca or magnesium as Mg drinking-water limits.

The analysis was based on internal physicochemical and chemical testing. BIS IS 10500:2012 was used as the primary drinking-water standard wherever applicable. Parameters without direct BIS drinking-water limits, including EC, temperature, DO, BOD, COD and phosphate, were interpreted as supportive or pollution-indicator parameters.

Analytical reliability was maintained through standardized internal laboratory procedures. Samples were collected in clean containers, protected from external contamination and analysed within 24-48 h of collection. Measurement instruments and glassware were checked before analysis, and routine calibration or standardization was carried out as applicable for pH, electrical conductivity and titrimetric procedures. The results were reviewed for internal consistency by comparing related parameters such as TDS with EC and total hardness with calcium and magnesium hardness. The internal analytical approach was aligned with commonly used procedures described in Standard Methods (APHA, AWWA, & WEF, 2017). The study did not include external inter-laboratory validation; therefore, the findings should be interpreted as a localized internal assessment of selected borewell water sources.

Table 2. Standard and reference limits used for interpretation.

Parameter	Unit	Acceptable limit	Permissible limit/reference
Colour	Hazen	5	15
Odour	-	Agreeable	Agreeable
pH	-	6.5-8.5	No relaxation
Turbidity	NTU	1	5
Alkalinity	mg/L as $CaCO_3$	200	600
Hardness	mg/L as $CaCO_3$	200	600
Chloride	mg/L	250	1000
Sulphate	mg/L	200	400
Nitrate	mg/L	45	No relaxation
Fluoride	mg/L	1.0	1.5
TDS	mg/L	500	2000
Iron	mg/L	0.3	No relaxation
Manganese	mg/L	0.1	0.3
Arsenic	mg/L	0.01	0.05
Lead	mg/L	0.01	No relaxation
Chromium	mg/L	0.05	No relaxation
Cadmium	mg/L	0.003	No relaxation
Mercury	mg/L	0.001	No relaxation
Electrical conductivity	µS/cm	No direct BIS limit	Supportive parameter
Temperature	°C	No direct BIS limit	Field parameter
Dissolved oxygen	mg/L	No direct BIS limit	Supportive parameter
BOD	mg/L	No direct BIS limit	Pollution-indicator parameter
COD	mg/L	No direct BIS limit	Pollution-indicator parameter
Phosphate	mg/L	No direct BIS limit	Nutrient/supportive indicator

2.3 Data treatment

The dataset was treated using descriptive statistics. For each parameter, rural and urban values were summarized as range and mean ± standard deviation. The results were compared with acceptable and permissible limits prescribed under BIS IS 10500:2012 wherever relevant. Because the sample size was limited to six rural and six urban locations and seasonal replication was not included, the rural-urban comparison was interpreted descriptively rather than as a district-wide inferential statistical conclusion.

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3. Results

3.1 Descriptive statistics of analysed parameters

The descriptive statistics of selected physicochemical and chemical parameters are presented in Table 3. The data show that most rural and urban borewell water samples were slightly alkaline and had moderate to high dissolved mineral content.

Table 3(a). Rural-urban descriptive statistics for general physicochemical parameters.

Parameter	Unit	Rural range	Rural mean ± SD	Urban range	Urban mean ± SD
pH	-	7.54-7.78	7.707 ± 0.095	7.68-7.90	7.768 ± 0.077
Turbidity	NTU	1.00-2.00	1.33 ± 0.52	1.00-3.00	1.67 ± 0.82
Temperature	°C	26-28	26.42 ± 0.87	25-28	26.62 ± 1.28
Alkalinity	mg/L as $CaCO_3$	120-290	211.67 ± 60.47	200-310	248.33 ± 42.62
Hardness	mg/L as $CaCO_3$	140-340	270.00 ± 79.75	230-390	321.67 ± 61.13
Calcium hardness	mg/L as $CaCO_3$	80-230	175.00 ± 56.48	150-250	200.00 ± 36.88
Magnesium hardness	mg/L as $CaCO_3$	60-190	118.33 ± 45.79	90-130	111.67 ± 14.72
Chloride	mg/L	30-210	110.00 ± 61.97	90-250	151.67 ± 60.14
Sulphate	mg/L	45-145	98.33 ± 37.10	80-190	125.00 ± 38.34
Nitrate	mg/L	4-15	9.17 ± 4.40	10-26	17.33 ± 6.02
Fluoride	mg/L	0.40-1.10	0.817 ± 0.248	0.60-1.30	0.900 ± 0.261
TDS	mg/L	440-1430	990.00 ± 334.25	760-1470	1106.67 ± 285.49

Table 3(b). Rural-urban descriptive statistics for EC, pollution-indicator and metal parameters.

Parameter	Unit	Rural range	Rural mean ± SD	Urban range	Urban mean ± SD
EC	µS/cm	680-2230	1548.33 ± 523.50	1180-2320	1761.67 ± 438.47
DO	mg/L	3.20-5.20	4.13 ± 0.73	4.10-5.30	4.52 ± 0.46
BOD	mg/L	0.70-2.40	1.683 ± 0.671	1.00-2.60	1.667 ± 0.609
COD	mg/L	7-30	18.83 ± 7.76	10-32	20.00 ± 8.29
Phosphate	mg/L	0.040-0.150	0.090 ± 0.041	0.050-0.150	0.098 ± 0.039
Iron	mg/L	0.070-0.220	0.158 ± 0.055	0.090-0.250	0.150 ± 0.058
Manganese	mg/L	0.030-0.080	0.052 ± 0.017	0.030-0.080	0.050 ± 0.018
Arsenic	mg/L	0.002-0.006	0.004 ± 0.001	0.003-0.007	0.005 ± 0.001
Lead	mg/L	0.001-0.003	0.002 ± 0.001	0.002-0.003	0.003 ± 0.001

Parameter	Unit	Rural range	Rural mean ± SD	Urban range	Urban mean ± SD
Chromium	mg/L	0.003-0.004	0.003 ± 0.001	0.003-0.005	0.004 ± 0.001

3.2 Physical parameters and pH

Colour values were low in all samples and odour was unobjectionable in all rural and urban locations. Turbidity ranged from 1 to 3 NTU. Five samples (R3, R6, U2, U4 and U5) exceeded the acceptable turbidity limit of 1 NTU, but all samples remained within the permissible limit of 5 NTU. The highest turbidity was recorded at U5, representing the market area.

The pH values ranged from 7.54 to 7.90, indicating slightly alkaline conditions. All samples were within the BIS acceptable range of 6.5-8.5. The rural mean pH was 7.707 ± 0.095, while the urban mean pH was 7.768 ± 0.077. The slightly alkaline character is consistent with carbonate and bicarbonate influence in groundwater.

3.3 Mineral-load parameters

TDS ranged from 440 to 1470 mg/L. Only R1 was within the acceptable limit of 500 mg/L, while the remaining eleven samples exceeded the acceptable limit but remained within the permissible limit of 2000 mg/L. The rural mean TDS was 990.00 ± 334.25 mg/L and the urban mean TDS was 1106.67 ± 285.49 mg/L. The high TDS values indicate substantial dissolved mineral load in the selected borewell waters.

Total hardness ranged from 140 to 390 mg/L as $CaCO_3$. Except R1, all samples exceeded the acceptable limit of 200 mg/L but remained within the permissible limit of 600 mg/L. The rural mean total hardness was 270.00 ± 79.75 mg/L, while the urban mean was 321.67 ± 61.13 mg/L. The results indicate moderately hard to hard water conditions in most samples.

Total alkalinity ranged from 120 to 310 mg/L as $CaCO_3$. Eight samples exceeded the acceptable limit of 200 mg/L, but no sample exceeded the permissible limit of 600 mg/L. Alkalinity was higher in urban samples (248.33 ± 42.62 mg/L) than in rural samples (211.67 ± 60.47 mg/L).

Chloride, sulphate and nitrate were within acceptable limits in all samples. However, the highest chloride concentration (250 mg/L) was recorded in U5, which reached the acceptable limit. Urban samples showed higher mean chloride, sulphate and nitrate than rural samples, suggesting comparatively greater ionic and local anthropogenic influence in urban borewell water.

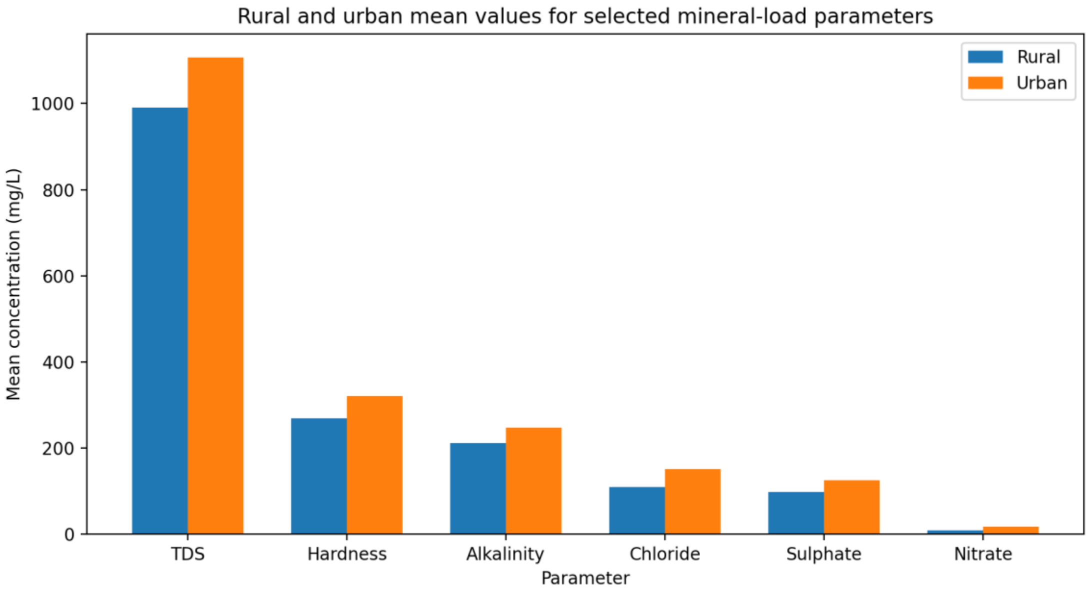

Figure 1. Rural and urban mean values for selected mineral-load parameters.

3.4 Fluoride and selected metals

Fluoride ranged from 0.4 to 1.3 mg/L. Three samples (R4, U4 and U5) exceeded the acceptable limit of 1.0 mg/L but remained within the permissible limit of 1.5 mg/L. R6 was exactly at the acceptable limit. The fluoride trend indicates the need for monitoring because fluoride in groundwater is often linked with geogenic conditions and longer water-rock interaction.

Iron, manganese, arsenic, lead and chromium were within acceptable or relevant limits in all samples. Cadmium and mercury were below detectable level in all samples. Thus, selected heavy metal contamination was not a major concern in the present dataset.

3.5 Pollution-indicator parameters

DO ranged from 3.2 to 5.3 mg/L. Because borewell water has limited direct contact with atmospheric oxygen, moderate DO values are expected. BOD ranged from 0.7 to 2.6 mg/L, while COD ranged from 7 to 32 mg/L. The highest BOD and COD values were recorded at U5. These results suggest minor local organic or chemical pollution influence at selected locations, particularly in urban sites; however, severe organic pollution was not indicated by the dataset. Phosphate values were low, ranging from 0.04 to 0.15 mg/L.

3.6 Compliance with acceptable limits

The sample-wise exceedance pattern for important BIS acceptable limits is summarized in Table 4. The major exceedances were observed for TDS, total hardness, alkalinity, turbidity and fluoride.

Table 4. Exceedance of acceptable limits for selected parameters

Parameter	Unit	Acceptable limit	Samples above acceptable limit	Sample codes above acceptable limit
Turbidity	NTU	1	5/12	R3, R6, U2, U4, U5
Alkalinity	mg/L as $CaCO_3$	200	8/12	R2, R3, R4, U1, U2, U4, U5, U6
Hardness	mg/L as $CaCO_3$	200	11/12	R2, R3, R4, R5, R6, U1, U2, U3, U4, U5, U6
Chloride	mg/L	250	0/12	None
Sulphate	mg/L	200	0/12	None
Nitrate	mg/L	45	0/12	None
Fluoride	mg/L	1.0	3/12	R4, U4, U5
TDS	mg/L	500	11/12	R2, R3, R4, R5, R6, U1, U2, U3, U4, U5, U6
Iron	mg/L	0.3	0/12	None
Manganese	mg/L	0.1	0/12	None
Arsenic	mg/L	0.01	0/12	None
Lead	mg/L	0.01	0/12	None
Chromium	mg/L	0.05	0/12	None

4. Discussion

The results show that the selected borewell water samples are mainly affected by dissolved mineral load rather than by selected heavy metals. The predominance of TDS, EC, hardness and alkalinity reflects the influence of natural groundwater mineralization, which is common in arid and semi-arid hydrogeological settings (Tiwari et al., 2017). Low recharge, longer groundwater residence time and dissolution of carbonate, bicarbonate and other mineral salts can increase dissolved solids and hardness.

The higher mean TDS, EC, hardness, alkalinity, chloride, nitrate, fluoride, COD and phosphate in urban samples indicates comparatively greater mineral-load and pollution-indicator values in urban borewell water. This may be associated with domestic wastewater seepage, drainage conditions, market activity, storage or distribution influence and higher groundwater extraction. However, natural groundwater chemistry also contributes substantially to these parameters, and therefore anthropogenic influence should be interpreted cautiously.

The observations are consistent with earlier local work from Rawatsar, Hanumangarh, where groundwater and surface water samples showed elevated dissolved constituents and required treatment before end use (Kaur & Bala, 2020). The present findings also align with broader water-quality literature indicating that EC, TDS, hardness, chloride, nitrate, DO, BOD and COD are important indicators for distinguishing natural mineralization from pollution influence (Singh et al., 2024; WHO, 2026).

Fluoride values above the acceptable limit in R4, U4 and U5 are important from a monitoring perspective. Although none of the samples exceeded the permissible limit, regular monitoring is necessary because long-term fluoride exposure is a recognized groundwater-quality concern in several regions of Rajasthan. TDS and hardness exceedance of acceptable limits in most samples suggests that treatment or blending may be needed for improved palatability and domestic usability.

The selected heavy metal values were within acceptable or relevant limits, and cadmium and mercury were below detectable level. This indicates that the principal quality issues in the selected samples were not related to metal toxicity but to mineral-load characteristics and selected local pollution indicators. These findings suggest that management efforts should prioritize regular monitoring of TDS, hardness, alkalinity, fluoride and turbidity, along with source protection and periodic testing.

5. Limitations

The study has certain limitations. First, the sample size was limited to twelve borewell water samples, with six rural and six urban locations. Therefore, the findings represent selected sampling points and should not be generalized to the entire district without further sampling.

Second, the study was based on samples collected during February 2026 only. Seasonal variation could not be assessed. Future studies should include pre-monsoon, monsoon and post-monsoon sampling.

Third, the dataset was generated through internal physicochemical and chemical analysis rather than external certified laboratory validation. External validation for selected parameters would strengthen future publication and policy use.

Fourth, microbiological parameters, pesticide residues and special geogenic contaminants such as uranium and radon were not included. These parameters may be considered in future expanded studies.

6. Conclusion

The present study assessed rural-urban variation in physicochemical and selected chemical pollution-indicator characteristics of borewell water in Hanumangarh district, Rajasthan. All samples were physically acceptable in odour and showed pH values within the acceptable range. Chloride, sulphate, nitrate and selected heavy metals were within acceptable or relevant limits in all samples.

The main concerns were TDS, total hardness, total alkalinity, turbidity and fluoride. TDS and total hardness exceeded acceptable limits in most samples but remained within permissible limits. Fluoride exceeded the acceptable limit in three samples but did not exceed the permissible limit. Urban samples generally showed higher mean values for mineral-load and pollution-indicator parameters than rural samples.

The findings indicate that selected borewell water samples are primarily influenced by groundwater mineralization, with moderate local anthropogenic influence in urban areas. Regular monitoring, borewell protection, treatment of high TDS/hardness water and fluoride surveillance are recommended for safe and sustainable use of borewell water in the study area.

Practical implications

Borewell water users in the study area should not rely only on appearance, taste or odour to judge water suitability. Periodic testing for TDS, hardness, alkalinity, fluoride, nitrate and selected metals should be carried out. Where TDS and hardness are high, treatment methods such as reverse osmosis, softening or blending with better-quality water may be considered. Borewell surroundings should be protected from stagnant wastewater, solid waste, animal waste and drainage seepage.

Declarations

Ethical approval: Not applicable. The study did not involve human participants, animals or clinical samples.

Consent to participate: Not applicable.

Consent for publication: Not applicable.

Competing interests: The authors declare no competing interests.

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Data availability: The dataset used in the study is available from the corresponding author on reasonable request.

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