Journal of Chemical Health Risks

www.jchr.org

JCHR (2026) 16(2), 3723-3731 | ISSN:2251-6727

Spatial Evaluation of Groundwater Quality in Indore City Using the Nemerow Pollution Index

Kirti[1], Binu Sangwan[2]

[1] Ph.D. Research Scholar, Department of Geography, Maharshi Dayanand University, Rohtak, Haryana, India

[2] Senior Professor, Department of Geography, Maharshi Dayanand University, Rohtak, Haryana, India

(Received: 16 February 2026 Revised: 25 March 2026 Accepted: 10 April 2026)

KEYWORDS

Groundwater quality; Nemerow Pollution Index; Hydrogeochemistry; Principal Component Analysis; Health risk assessment; Urban contamination; Indore

ABSTRACT:

Introduction: Groundwater is a primary freshwater source in rapidly urbanizing Indian cities; however, increasing anthropogenic pressure and lithological controls significantly influence its quality and associated health risks

Objectives: This study aims (i) to assess and spatially classify groundwater quality across nineteen urban zones of Indore City using the Nemerow Pollution Index (NPI), and (ii) to identify dominant hydrogeochemical processes and evaluate potential non-carcinogenic health risks.

Methods: Nineteen groundwater samples were analyzed for pH, Total Dissolved Solids (TDS), Total Hardness (TH), Nitrate, Sulphate, Fluoride, and Calcium following APHA (2017) methods. Pollution Index (Pi) and Nemerow Pollution Index (NPI) were computed using BIS (2012) standards. Pearson correlation and Principal Component Analysis (PCA) were applied to determine hydrochemical relationships and controlling mechanisms.

Results: NPI values ranged from 1.615 to 3.969, indicating slight to heavy pollution, with no sampling site classified as safe (NPI < 1). PCA extracted two significant components explaining 81.6% of total variance. PC1 (55.6%) reflected lithogenic control associated with basaltic mineral weathering, while PC2 (26.0%) indicated anthropogenic inputs linked to nitrate and sulphate enrichment. Fluoride-based Hazard Quotient (HQ) values were below unity (HQ < 1)..

Conclusions: Groundwater quality in Indore is predominantly governed by geogenic processes with secondary anthropogenic influence. Continuous monitoring and integrated groundwater management strategies are essential for sustainable urban water security.

.

1. Introduction

Groundwater constitutes a critical freshwater resource supporting domestic, industrial, and commercial needs in urban India. Rapid urbanization, industrial expansion, and inadequate wastewater and solid waste management have significantly impacted groundwater quality in many cities [1,2]. In hard-rock aquifer systems, limited dilution capacity intensifies contamination risks [3,4]. Groundwater chemistry is influenced by both geogenic and anthropogenic factors. Mineral weathering and water–rock interaction elevate dissolved solids and hardness [5], while sewage leakage, septic infiltration, and municipal solid waste disposal contribute additional contaminants [6,7]. Although Indore City has achieved national recognition under the Swachh Survekshan initiative for improved surface sanitation practices [8], subsurface groundwater quality requires continuous scientific evaluation. The Nemerow Pollution Index (NPI) integrates both average and maximum pollution levels, offering a conservative assessment of water quality [9]. This study applies NPI along with multivariate statistical tools to provide an integrated groundwater quality assessment.

2. Objectives

To assess and spatially classify groundwater quality across nineteen urban zones of Indore City using the Nemerow Pollution Index (NPI).

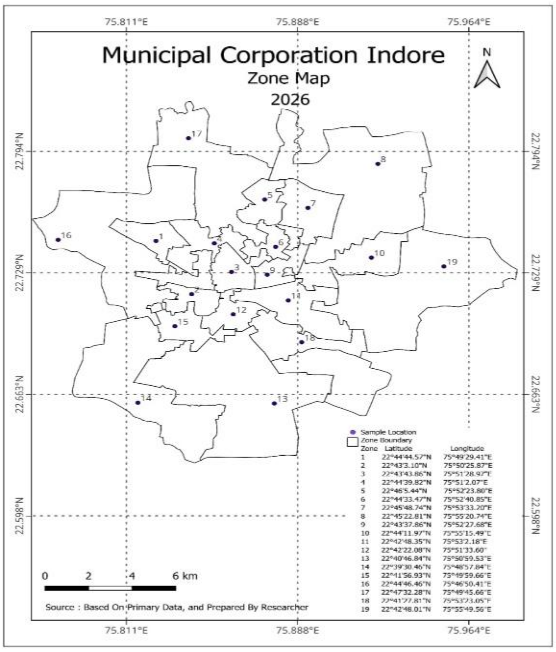
To identify the dominant hydrogeochemical processes influencing groundwater chemistry and to evaluate potential non-carcinogenic health risks associated with groundwater consumption.

3. Methods

Indore City, located in Madhya Pradesh, India, lies within the Deccan Trap basaltic formation. The region is characterized by hard-rock aquifers where groundwater movement through fractures enhances water–rock interaction.

2.2 Sample Collection and Analysis

Nineteen groundwater samples were collected from borewells and hand pumps using a grid-based spatial sampling strategy. Samples were collected in pre-cleaned HDPE bottles and analyzed according to APHA (2017) standard methods [10]. Parameters analyzed included pH, TDS (mg/L), Total Hardness (mg/L), Nitrate (mg/L), Sulphate (mg/L), Fluoride (mg/L), and Calcium (mg/L). BIS (2012) drinking water standards were used for comparison [11].



3.2 Parameters Analyzed

Table 1: Physicochemical Analysis

Parameters	Acceptable Limit	Permissible Limit *	Zone I (S1)	Zone II (S2)	Zone III (S3)	Zone IV (S4)	Zone V (S5)	Zone VI (S6)	Zone VII (S7)	Zone VIII (S8)	Zone IX (S9)	Zone X (S10)	Zone XI (S11)	Zone XII (S12)	Zone XIII (S13)	Zone XIV (S14)	Zone XV (S15)	Zone XVI (S16)	Zone XVII (S17)	Zone XVIII (S18)	Zone XIX (S19)
pH	6.5–8.5	No relaxation	7.1	6.8	7.3	6.9	7	7.2	7.4	7.3	7.6	7.1	7	7.2	6.7	7.3	6.9	7.1	7.4	7.2	6.8
Total Hardness (mg/L)	200	600	640	720	580	810	690	430	510	560	620	480	530	590	780	450	670	520	410	560	740
Residual Free Chlorine (mg/L)	0.2	1	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Fluoride (mg/L)	1	1.5	0.8	1.3	0.9	1.4	1.1	0.6	0.7	0.9	1.2	0.8	1	0.7	1.5	0.6	1.3	0.8	0.5	0.9	1.4
TDS (mg/L)	500	2000	1240	1890	980	2310	1760	860	940	1100	1420	980	1210	1080	2480	890	1950	1020	780	1140	2120

Nitrate (mg/L)	45	No relaxation	28	36	22	41	34	19	21	24	38	26	29	23	44	20	39	25	18	27	42
Sulphate (mg/L)	200	400	180	260	150	320	240	110	130	160	210	170	190	155	360	120	280	165	105	175	330
Arsenic (mg/L)	0.01	0.05	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Calcium (mg/L)	75	200	62	78	54	96	81	43	49	58	67	52	60	55	110	45	88	57	39	61	102

Source: Based on Primary data, 2026

3.3 **Nemerow Pollution Index (NPI)**

Pollution Index (Pi) was calculated as:

$Pi = Ci / Si$

where Ci represents observed concentration and Si represents standard permissible limit.

Nemerow Pollution Index was computed as:

$PN = \sqrt{(Pavg^2 + Pmax^2)/2}$

Water quality classification followed standard NPI thresholds [9].

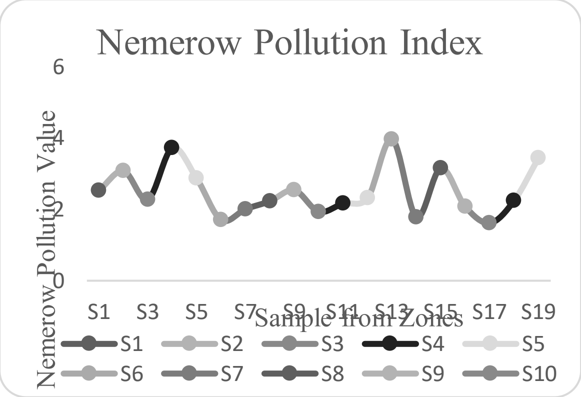
Table 2: Physicochemical Parameters, Pollution Indices (Pi), and Nemerow Pollution Index (NPI)

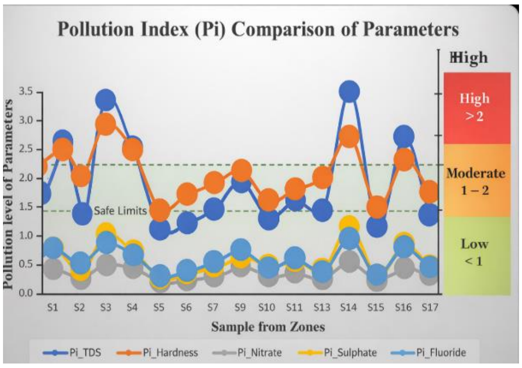
Sample	TDS	Hardness	Nitrate	Sulphate	Fluoride	Pi_TDS	Pi_Hardness	Pi_Nitrate	Pi_Sulphate	Pi_Fluoride	Pi_Avg	Pi_Max	Nemerow_Index
S1	1240	640	28	180	0.8	2.48	3.2	0.622	0.9	0.8	1.6004	3.2	2.53
S2	1890	720	36	260	1.3	3.78	3.6	0.8	1.3	1.3	2.156	3.78	3.077
S3	980	580	22	150	0.9	1.96	2.9	0.489	0.75	0.9	1.3998	2.9	2.277
S4	2310	810	41	320	1.4	4.62	4.05	0.911	1.6	1.4	2.5162	4.62	3.72
S5	1760	690	34	240	1.1	3.52	3.45	0.756	1.2	1.1	2.0052	3.52	2.865
S6	860	430	19	110	0.6	1.72	2.15	0.422	0.55	0.6	1.0884	2.15	1.704
S7	940	510	21	130	0.7	1.88	2.55	0.467	0.65	0.7	1.2494	2.55	2.008
S8	1100	560	24	160	0.9	2.2	2.8	0.533	0.8	0.9	1.4466	2.8	2.229
S9	1420	620	38	210	1.2	2.84	3.1	0.844	1.05	1.2	1.8068	3.1	2.537
S10	980	480	26	170	0.8	1.96	2.4	0.578	0.85	0.8	1.3176	2.4	1.936
S11	1210	530	29	190	1	2.42	2.65	0.644	0.95	1	1.5328	2.65	2.165

S12	1080	590	23	155	0.7	2.16	2.95	0.511	0.775	0.7	1.4192	2.95	2.315
S13	2480	780	44	360	1.5	4.96	3.9	0.978	1.8	1.5	2.6276	4.96	3.969
S14	890	450	20	120	0.6	1.78	2.25	0.444	0.6	0.6	1.1348	2.25	1.782
S15	1950	670	39	280	1.3	3.9	3.35	0.867	1.4	1.3	2.1634	3.9	3.154
S16	1020	520	25	165	0.8	2.04	2.6	0.556	0.825	0.8	1.3642	2.6	2.076
S17	780	410	18	105	0.5	1.56	2.05	0.4	0.525	0.5	1.007	2.05	1.615
S18	1140	560	27	175	0.9	2.28	2.8	0.6	0.875	0.9	1.491	2.8	2.243
S19	2120	740	42	330	1.4	4.24	3.7	0.933	1.65	1.4	2.3846	4.24	3.44

Source: Computed by the authors based on primary data presented in Table 1.

Pollution Classification Based on Nemerow Pollution Index





Based on the above plotted diagrams, the Nemerow Pollution Index value is as follows:

NPI Range	**Water Quality Status**	**Zones**
< 1	Safe	None
1–2	Slightly Polluted	Zones: 6, 7, 10, 14, 16 and17
2–3	Moderately Polluted	Zones: 1, 3, 5, 8, 9, 11, 12, 15 and18
>3	Heavily Polluted	Zones: 2, 4, 13 and19

Table 3: Pearson Correlation Matrix of Groundwater Parameters:

Parameter	**TDS**	**Total Hardness**	**Calcium**	**Nitrate**	**Sulphate**	**Fluoride**
TDS	1.00	0.88	0.82	0.41	0.52	0.36
Hardness	0.88	1.00	0.91	0.35	0.47	0.29
Calcium	0.82	0.91	1.00	0.31	0.44	0.27
Nitrate	0.41	0.35	0.31	1.00	0.63	0.22

Parameter	TDS	Total Hardness	Calcium	Nitrate	Sulphate	Fluoride
Sulphate	0.52	0.47	0.44	0.63	1.00	0.25
Fluoride	0.36	0.29	0.27	0.22	0.25	1.00

Source: Derived from primary groundwater quality data (Table 1).

3.4 Principal Component Analysis (PCA)

Principal Component Analysis (PCA) was employed to identify the dominant hydrogeochemical processes controlling groundwater quality in the study area and to reduce the dimensionality of the multivariate dataset. PCA is a widely used multivariate statistical technique that transforms a set of correlated variables into a smaller number of uncorrelated variables called principal components (PCs), while retaining most of the original dataset's variance. This approach facilitates the interpretation of complex hydrochemical interactions and helps distinguish between geogenic and anthropogenic influences. Before analysis, the dataset was standardised using z-score normalisation to eliminate the effect of differing measurement units and magnitudes among variables (e.g., mg/L, pH). Standardisation ensures that each variable contributes equally to the analysis and prevents parameters with larger absolute values (such as TDS or hardness) from dominating the component structure.

Table 4: Eigenvalues and Variance Explained:

Component	Eigenvalue	% Variance	Cumulative %
PC1	3.89	55.6%	55.6%
PC2	1.82	26.0%	81.6%
PC3	0.71	10.1%	91.7%
PC4	0.38	5.4%	97.1%
PC5	0.12	2.9%	100%

Source: PCA results derived from groundwater quality dataset presented in Table 1.

Only PC1 and PC2 were retained for interpretation as their eigenvalues exceeded unity.

Parameter	PC1	PC2
TDS	0.91	0.28
Total Hardness	0.94	0.22
Calcium	0.89	0.18
Nitrate	0.32	0.84
Sulphate	0.45	0.78
Fluoride	0.36	0.41

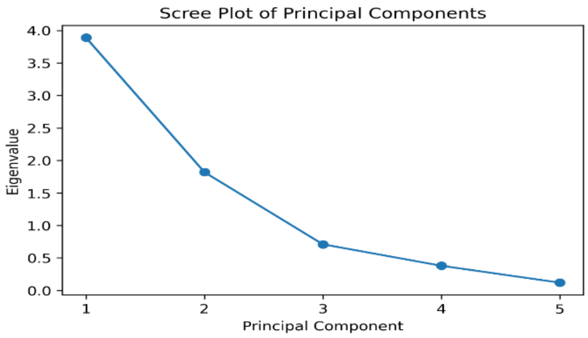
Interpretation of Components: PC1 (Lithogenic Factor – 55.6% Variance Explained)

The first principal component (PC1) accounts for 55.6% of the total variance, indicating that it represents the dominant hydrogeochemical process governing groundwater chemistry in the study area. PC1 exhibits strong positive loadings of Total Dissolved Solids (TDS), Total Hardness, and Calcium, suggesting that these parameters are closely interrelated and primarily controlled by natural geogenic processes. The high loading of TDS reflects the cumulative concentration of dissolved ionic constituents derived from mineral weathering. Similarly, the strong association between hardness and calcium indicates dissolution of calcium-bearing minerals, particularly within the basaltic formations of the Deccan Trap. In hard-rock aquifer systems, groundwater movement through fractures enhances water–rock interaction, promoting dissolution of carbonate and silicate minerals. This process increases ionic concentration and contributes significantly to baseline groundwater salinity and hardness. The dominance of PC1 therefore confirms that lithogenic weathering and groundwater–rock interaction constitute the principal mechanism influencing groundwater chemistry in Indore. The strong covariance among TDS, hardness, and calcium further supports the interpretation of a common geochemical origin.

PC2 (Anthropogenic Factor – 26.0% Variance Explained)

The second principal component (PC2) explains 26.0% of the total variance and is characterised by high positive loadings of nitrate and sulphate. Unlike PC1, which represents natural geochemical processes, PC2 reflects secondary anthropogenic influences on groundwater quality. Elevated nitrate concentrations are typically associated with urban wastewater infiltration, septic system leakage, agricultural runoff, and domestic effluent discharge. Sulphate enrichment may result from sewage contamination, industrial effluents, and surface runoff carrying dissolved salts into the subsurface environment. The moderate association between nitrate and sulphate suggests mixed anthropogenic inputs rather than a single-point contamination source. The presence of this component indicates that, although geogenic processes dominate overall groundwater chemistry, localised human activities contribute measurably to groundwater quality modification. Spatial variability in nitrate and sulphate concentrations further suggests that anthropogenic influence is unevenly distributed across urban zones.

Scree plot:



The scree plot illustrates the distribution of eigenvalues against principal component numbers. A sharp decline in eigenvalue magnitude is observed from PC1 to PC2, followed by a distinct flattening of the curve from PC3 onwards. This clear "elbow" after the second component indicates that only the first two principal components significantly contribute to explaining variability in groundwater chemistry. According to the Kaiser criterion (eigenvalue > 1), only PC1 (3.89) and PC2 (1.82) were retained. Together, these components explain 81.6% of the total variance, confirming that groundwater chemistry in the study area is predominantly governed by two major hydrogeochemical processes. The minimal contribution of subsequent components (<10% variance each) suggests that they represent minor localised variations rather than dominant geochemical controls.

4. Results

Nemerow Pollution Index (NPI)

NPI values ranged from **1.615 to 3.969**.

- Slight Pollution (1–2): Zones VI, VII, X, XIV, XVI, XVII
- Moderate Pollution (2–3): Zones I, III, V, VIII, IX, XI, XII, XV, XVIII
- Heavy Pollution (>3): Zones II, IV, XIII, XIX

No zone was classified as safe.

Elevated TDS and Total Hardness were the primary contributors to high NPI values.

4.2 Correlation Analysis

Strong positive correlations were observed:

- TDS & Hardness (r = 0.88)
- Hardness & Calcium (r = 0.91)

Moderate correlation:

- Nitrate & Sulphate (r = 0.63)

These relationships indicate dominant lithogenic control with localized anthropogenic input.

4.3 Principal Component Analysis (PCA)

Two principal components explained 81.6% of total variance:

- **PC1 (55.6%)** – Strong loadings of TDS, Hardness, Calcium → Lithogenic weathering factor
- **PC2 (26.0%)** – High loadings of Nitrate, Sulphate → Anthropogenic influence

Scree plot confirmed retention of two components.

Discussion

The paper provides a comprehensive hydrochemical evaluation of groundwater quality in Indore City using the Nemerow Pollution Index (NPI), Pearson correlation analysis, and Principal Component Analysis (PCA). The combined application of these analytical tools provides a robust understanding of both the spatial distribution of groundwater pollution and the underlying hydrogeochemical processes controlling water chemistry.

The Nemerow Pollution Index results indicate that groundwater quality across the study area ranges from **slightly polluted to heavily polluted**, with values between **1.615 and 3.969**. Notably, none of the sampling locations fell within the safe category (NPI < 1), indicating that groundwater in the urban zones of Indore is under varying degrees of chemical stress. The absence

of safe zones suggests that long-term hydrochemical processes, combined with increasing urban pressure, have significantly altered the natural groundwater composition. Similar findings have been reported in several Indian urban environments where rapid urbanization and groundwater extraction intensify hydrochemical variability and contamination risks.

The high NPI values observed in Zones II, IV, XIII, and XIX primarily result from elevated **Total Dissolved Solids (TDS)** and **Total Hardness**, which significantly influence the maximum pollution index component of the NPI formula. In hard-rock aquifer systems such as the Deccan Trap basalt formations underlying Indore, groundwater interacts extensively with mineral-rich rocks during subsurface flow. This prolonged water–rock interaction promotes dissolution of carbonate and silicate minerals, thereby increasing ionic concentrations in groundwater. As a result, TDS and hardness commonly exceed permissible limits in basaltic aquifers. Similar hydrogeochemical behavior has been documented in groundwater studies conducted in other basalt-dominated regions of India, where mineral weathering represents the dominant source of dissolved ions.

Correlation analysis further supports the lithogenic control on groundwater chemistry. The strong positive correlation between **TDS and Total Hardness (r = 0.88)** and between **Hardness and Calcium (r = 0.91)** indicates that these parameters originate from a common geochemical source. Calcium-bearing minerals present in basaltic rocks dissolve during groundwater circulation, increasing both hardness and overall ionic concentration. This relationship confirms that natural geological processes play a major role in shaping baseline groundwater chemistry in the study area.

In contrast, moderate correlations between **nitrate and sulphate (r = 0.63)** suggest localized anthropogenic influences. Nitrate contamination in groundwater is often associated with urban wastewater infiltration, septic system leakage, agricultural inputs, and improper solid waste disposal. In rapidly growing cities such as Indore, expanding residential areas and inadequate sewer infrastructure can facilitate the migration of nitrate-rich effluents into shallow aquifers. Similarly, sulphate enrichment may originate from domestic sewage discharge, industrial effluents, and surface runoff carrying dissolved salts into the subsurface environment. Although the concentrations of these parameters generally remain within permissible limits, their spatial variability indicates increasing anthropogenic pressure on groundwater resources.

Principal Component Analysis provides further insight into the dominant hydrogeochemical mechanisms controlling groundwater composition. The PCA results revealed two major components explaining **81.6% of the total variance**, indicating that groundwater chemistry in the study area is primarily controlled by two major processes.

The first principal component (**PC1**) accounts for **55.6% of the total variance** and is characterized by strong positive loadings of TDS, Total Hardness, and Calcium. This component clearly represents a **lithogenic factor**, reflecting the influence of basaltic mineral weathering and groundwater–rock interaction. The high loadings of these parameters suggest that natural geochemical processes dominate groundwater chemistry in the region. Basaltic aquifers typically contain minerals such as plagioclase feldspar, pyroxene, and olivine, which gradually dissolve during groundwater circulation, releasing calcium and other ions into solution. The strong covariance among TDS, hardness, and calcium therefore confirms the dominant role of lithological controls in determining groundwater quality.

The second principal component (**PC2**) explains **26.0% of the total variance** and exhibits strong loadings of nitrate and sulphate. This component represents **anthropogenic influence**, indicating that human activities contribute secondary modifications to groundwater chemistry. The presence of this component suggests that although natural geological processes dominate the hydrochemical environment, localized human activities are increasingly affecting groundwater quality. The coexistence of geogenic and anthropogenic components is a common characteristic of groundwater systems in rapidly urbanizing regions.

The scree plot further confirms the dominance of these two components. A sharp decline in eigenvalues after PC2 indicates that the majority of hydrochemical variability can be explained by the first two principal components. Subsequent components contribute only minor variance and therefore represent localized variations rather than dominant geochemical processes.

The combined interpretation of NPI, correlation analysis, and PCA demonstrates that groundwater quality in Indore is influenced by a **dual control mechanism** consisting of natural lithogenic processes and secondary anthropogenic inputs. While mineral weathering determines the baseline chemical composition of groundwater, urban development and wastewater infiltration introduce additional contaminants that locally modify water quality.

From a public health perspective, the analysis indicates that **fluoride concentrations remain within permissible limits**, and the calculated Hazard Quotient values are below unity, suggesting negligible non-carcinogenic health risk under current conditions. However, the widespread moderate pollution status identified through the Nemerow Pollution Index highlights the need for proactive groundwater management. Continuous monitoring, improved wastewater infrastructure, and sustainable groundwater extraction practices are essential to prevent further deterioration of groundwater quality.

Overall, the integration of hydrochemical indices with multivariate statistical techniques provides a comprehensive framework for evaluating groundwater quality in complex urban environments. Such integrated approaches are particularly valuable in hard-rock aquifer systems where both geological processes and human activities influence groundwater chemistry. The findings of this study therefore contribute to a better understanding of urban groundwater dynamics and provide important insights for sustainable water resource management in rapidly growing cities.

Conclusion

This paper provides a comprehensive chemical assessment of groundwater quality across nineteen urban zones of Indore City using the Nemerow Pollution Index (NPI), multivariate statistical analysis, and non-carcinogenic health risk evaluation. The results demonstrate that groundwater quality ranges from slight to heavy pollution, with NPI values between 1.615 and 3.969, and no sampling location categorized as safe (NPI < 1). Elevated Total Dissolved Solids and Total Hardness were identified as primary contributors to chemical deterioration. Principal Component Analysis revealed that lithogenic processes associated with basaltic mineral weathering represent the dominant hydrogeochemical control, while localized anthropogenic inputs contribute secondary nitrate and sulphate enrichment. Although fluoride concentrations remained within permissible limits and Hazard Quotient values were below unity, the widespread moderate pollution status indicates persistent chemical stress on the aquifer system.The findings emphasize the need for continuous groundwater quality monitoring, controlled extraction practices, and integrated chemical risk management strategies to ensure long-term public health protection in rapidly urbanizing hard-rock regions.

Acknowledgment

The authors acknowledge the Department of Geography, Maharshi Dayanand University, for academic support.

Refrences

1. Central Ground Water Board. Groundwater Yearbook – India 2022–23; Ministry of Jal Shakti: Government of India, 2023.
2. Central Pollution Control Board. Water Quality Monitoring and Assessment Reports; Ministry of Environment, Forest and Climate Change: Government of India, 2022.
3. Subramani, T.; Rajmohan, N.; Elango, L. Groundwater geochemistry and identification of hydrogeochemical processes in a hard rock region, Tamil Nadu, India. Environ Geol. 2005, 48, 80–91.
4. World Health Organization. Guidelines for Drinking-Water Quality, 4th ed.; WHO Press: Geneva, 2017.
5. Singh, C.K.; Rina, K.; Singh, R.P.; Shashtri, S.; Kamal, V. Geochemical modelling of high fluoride concentration in groundwater of southern Haryana, India. Environ Earth Sci. 2015, 74, 5903–5915.
6. Wagh, V.M.; Panaskar, D.B.; Mukate, S.V.; Gaikwad, S.K.; Muley, A.A.; Varade, A.M. Health risk assessment of groundwater in parts of India using water quality index approach. Environ Earth Sci. 2018, 77, 1–15.
7. Mukate, S.V.; Wagh, V.M.; Panaskar, D.B.; Jacobs, J.A.; Sawant, A.A. Development of integrated water quality index model for groundwater quality assessment in India. Environ Earth Sci. 2019, 78, 1–15.
8. Ministry of Housing and Urban Affairs. Swachh Survekshan 2023 Results; Government of India, 2023.

9. Wu, J.; Li, P.; Qian, H.; Duan, Z. Groundwater quality assessment based on improved water quality index in Wei River Basin, China. Environ Earth Sci. 2014, 71, 475–484.

10. American Public Health Association. Standard Methods for the Examination of Water and Wastewater, 23rd ed.; APHA: Washington DC, 2017.

11. Bureau of Indian Standards. Indian Standard Drinking Water — Specification (IS 10500:2012); BIS: New Delhi, 2012.