Received: 22 November 2022 | Accepted: 1 August 2024 | Published online: 2 December 2024
DOI: 10.59797/ijsc.v52.i2.168

ORIGINAL ARTICLE
Indian Journal of Soil Conservation

Integrated water quality assessment of Ur watershed in Bundelkhand region (India) based on water quality index and multivariate statistical techniques

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Handling Editor :
Dr P.P. Adhikary

ABSTRACT

This study was designed to apply an integrated approach to evaluate the spatial variation of water quality in Ur watershed, Tikamgarh district, Madhya Pradesh (India). To assess the water quality, surface water and groundwater were analyzed for their physicochemical and biological constituents. The chemical data generated was analyzed by water quality index (WQI) and multivariate statistical tools (principal component analysis/factor analysis and hierarchical cluster analysis). From the collective results of WQI and multivariate analysis, it can be concluded that 57% of the total surface water samples and 53% of the total groundwater samples are fit for human consumption. Principal component analysis illustrates three factors extracted for both surface water and groundwater, which explains 81.29% variance of total surface water samples and 67.14% of total variance of groundwater samples. The outcome of cluster analysis classified water quality samples into two similar clusters, each for surface water and groundwater. Chemical analysis of the samples indicates that a major problem of turbidity has been observed in both surface water and groundwater samples. The primary source of contamination was related majorly to anthropogenic activities. The results of this study will be useful to water managers in locating water quality hotspots, identifying the major sources of water pollution, understanding the complex nature of water quality parameters, and developing an effective water resources management plan for water-challenged areas.

Key words:
Bundelkhand-India
Groundwater
Hierarchical cluster analysis
Principal component analysis
Surface water
Water quality

HIGHLIGHTS

- Assessment of hydro-chemical properties of surface and groundwater.
- Evaluation through water quality index & statistical approaches to characterize water quality.
- Surface water was better suited for irrigation and fishing while groundwater for drinking.
- Study lays emphasis on periodic monitoring and evaluation of water quality.
- Study flags the need of management practices for protection of the sources of drinking water

1 | INTRODUCTION

The surface and groundwater quality are susceptible issues and one of the most prominent factors affecting human health as well as the natural systems (Wang *et al.,* 2013). The quality of surface water is governed by anthropogenic factors such as urbanization, industrial and agricultural practices, and natural processes such as regional climatic conditions, weathering processes, and soil erosion. Similarly, groundwater quality depends on many factors, such as the topography of the region, soil characteristics, manner of groundwater circulation through rock types and human activities on the ground (Molla *et al.,* 2015). Contaminated water reduces its availability for drinking, irrigation and other important ecosystem activities and leads to water scarcity impairment (Das and Verma, 2018). Hence, it is of great concern to understand and assess the quality of surface water and groundwater for not only drinking and domestic purposes but also for irrigation for the sustainable development of society.

The assessment of water quality includes various physical, chemical and biological characteristics. It compares these characteristics with the standards recommended for drinking water by several organizations such as the World Health Organisation (WHO), Bureau of Indian Standards (BIS), Central Pollution Control Board (CPCB), Indian Council of Medical Research (ICMR) (Patil *et al.,* 2012). The water quality of different sources is then communicated based on calculated water quality indices. Water Quality Index (WQI) is an effective tool to assess water quality and its suitability for human consumption. It transforms extensive water quality data into a single score, which expresses the overall quality spatially and temporally. The single score generated is simple and easy for decision-makers and concerned citizens to understand (Dohare *et al.,* 2014).

Several reports also emphasize the importance of multivariate statistical analysis in treating analytical and environmental data (Molla *et al.,* 2015). The application of different multivariate statistical techniques, such as principal component analysis (PCA), factor analysis (FA) and cluster analysis (CA), helps in the interpretation of complex data matrices to better understand the water quality and ecological status of the studied systems. It allows the identification of possible factors that influence water environment systems and offers a valuable tool for reliable management of water resources as well as rapid solution to pollution problems (Shrestha and Kazama, 2007; Varol and Şen, 2009; Zhang *et al.,* 2009; Das *et al.,* 2023).

Tikamgarh district is located in the northern part of Madhya Pradesh and lies in the central part of the Bundelkhand plateau. The water resource availability to the district is in the form of rivers and streams, as well as surface storage (reservoirs and dams), soil moisture, and groundwater (stored in aquifers). Tikamgarh district is rich in ponds and sand tanks, which form important sources of irrigation and recharging the groundwater reserve. About 421 tanks exist in the district (TIFAC, 2019).

Despite the existing infrastructures supporting water availability, there are significant challenges in ensuring the sustainability of the sources for various reasons. The most important among them is a significant drop in the groundwater table. In most villages, it has been observed that sources start to dry up from January onwards, and the situation worsens in the peak summer months (TIFAC, 2019). The traditional practice of de-silting the tanks in the dry season has gradually dried out, leading to the deposition of thick, impermeable clay layers, hindering underground aquifers' recharge. In addition, heavy application of fertilizers and poor sanitation practices in the region add to the woes by spoiling the water quality (Development Alternatives, 2007).

As per past studies, the Central Ground Water Board (CGWB) reported nitrate and electrical conductivity values beyond the permissible BIS standards based on samples collected from 14 hydrograph stations (maintained by CGWB for groundwater data collection) in the district for the year 2011 (CGWB, 2013). Development Alternatives conducted a primary survey in 2014 and reported that most of the groundwater samples were contaminated with either nitrate, coliform, iron, or fluoride, which made the water unfit for human consumption without any prior treatment. Due to the consumption of poor-quality drinking water, medical cases were reported for diseases like diarrhoeal infection, cholera, typhoid, Hepatitis A, gastro-enteritis, skin diseases, and dental problems (TIFAC, 2019). As assessed by CGWB for 2015-16, Groundwater quality reported electrical conductivity values greater than the BIS acceptable limit. Water was classified as hard to very hard for household use and drinking purposes, as the total hardness values were higher than the desired limits of the BIS standards. The samples also displayed high concentrations of nitrate, fluoride, calcium and iron in a few of the samples (CGWB, 2016). Gupta *et al.,* 2017 reported a declining trend in groundwater quality for drinking purposes from 2014 to 2016. It was also reported that water was somewhat suitable for irrigation purposes. According to the above studies, it can be concluded that water quality for drinking and irrigation purposes and water quality management are major concerns in the Tikamgarh district.

This study aims to assess the nature and spatial distribution of physicochemical parameters in the surface and groundwater resources of the Ur watershed, located in Tikamgarh district, Madhya Pradesh, India. Various statistical approaches were applied to the hydrochemical data to evaluate the water's suitability for drinking, domestic use, irrigation, and fish cultivation.

2 | MATERIALS AND METHODS

2.1 | Study Area

Ur watershed is located in the Tikamgarh district of Madhya Pradesh. It lies on the Bundelkhand plateau between the Jamani (a tributary of Betwa) and Dhasan rivers (Fig. 1). The watershed area extends between latitudes 2435'0” N and 2505'0” N and between 7850'0” E and 7910'0” E longitudes. The total geographical area of the Ur watershed is 991 km^2 and falls under four development blocks of the Tikamgarh district (Jatara, Palera, Baldeogarh and Tikamgarh). The study area comprises 190 villages with a total population of 2,95,116, which is 20% of the total population of the district (Directorate of Census Operations, 2011). The topography is undulating, comprising very high hills along the ridge line with the elevation varying between 200 m to 400 m above mean sea level (MSL).

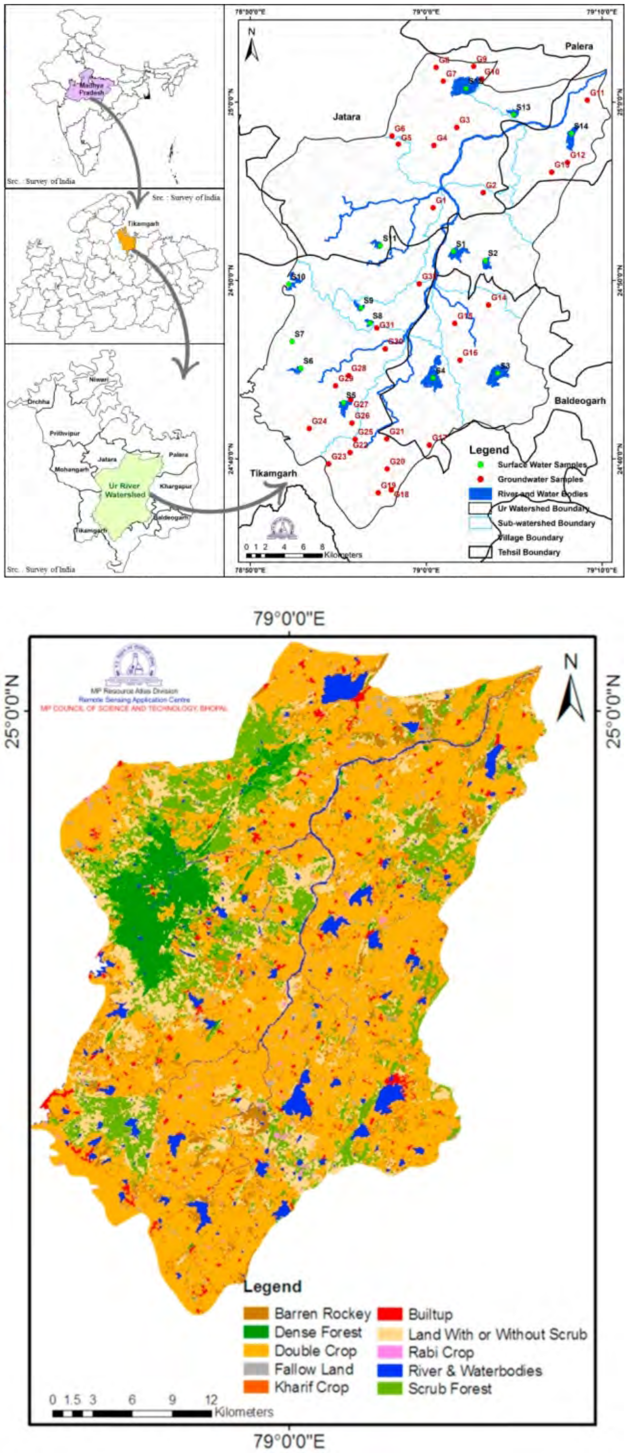

FIGURE 1 **Location map along with distribution of samples and LULC of Ur watershed**

The watershed has a dendritic drainage pattern with the highest stream order of five. Moreover, it has a low drainage density of 0.564/km, indicating a coarse drainage network of the watershed. The Ur river rises in the hills of Tikamgarh, collects water from small streams and flows northeast to meet the Dhasan river.

The climate of the Ur watershed is semi-arid, characterized by hot summers and general dryness except during the monsoons. The mean temperature for the hottest month (May) is 41.8 °C, while that of the coolest month (January) is 7.0°C. The average annual rainfall in the watershed is approximately 808 mm (1999-2016). The rainfall pattern is erratic, irregular and uncertain, often causing drought, a standard feature. The average drought frequency varies between 1 in 3 years in the watershed (TIFAC, 2019).

Agriculture is the main occupation of inhabitants of this area and covers a major percentage, *i.e.,* 49% of the total watershed area. This is because of the large number of tanks that cater to the irrigation and domestic demands. The principal crops are rice, wheat, maize, soybean, mustard and black gram. The soils in the watershed area have a thin soil cover with a fine sandy texture. Nearly 635 km^2 of the area is covered with sandy loam soil, and another 267 km^2 is covered with sandy clay loam soil. The entire watershed is subject to soil erosion risk.

Geologically, the Ur watershed is almost entirely composed of massive granites. The granites are crisscrossed by several quartzite and quartz reefs, which limits the process of groundwater recharge. Geomorphologically, the area is dominated by pediplains formed by the erosion of granites and is moderately buried by weathered material, offering good support for agriculture. To the northeast of Tikamgarh tehsil, several small denudational hills are interspersed with patches of flat land. These ridges act as barriers against the flow of surface and groundwater. Several large water bodies in this district are built along these ridges.

Tikamgarh district has a net groundwater availability of 630 MCM/year (CGWB, 2013). The average level of groundwater development in the district is almost 86%, and the district falls under the semi-critical category. The water table has gone to 50 meters below ground level in a large part of the watershed area.

2.2 | Water Sampling

Seventy samples were collected from fourteen ponds in November 2015 for surface water, and thirty-two water samples (four wells and twenty-eight hand pumps) were groundwater and analysed in March 2016. The locations of the samples collected in the study area are shown in Fig. 1. The land use/land cover map is also shown in Fig.1. It shows that out of a total of 991 km^2 of land dense forest is only 4.37% while the scrub forest is 15.87% and for agriculture area double crop is 48.01%, rabi crop is 1.79% and *kharif* crop is 2.39%. The land with or without scrub is 12.96%, barren rocky land is 7.15% and built up area is 1.54%. Fallow land is 2.33%, and river and water bodies cover

3.58% of the total area (LISS-IV Satellite imagery, 5.8 m resolution). It is evident from the data that the major landuse of the watershed is agriculture.

2.3 | Analytical Techniques

Surface water samples were analysed for temperature, pH, electrical conductivity (EC), turbidity, dissolved oxygen (DO), and blue-green algae (BGA) using a multi-parameter Sonde (YSI, 2014). Some other water quality parameters, viz. alkalinity, hardness, nitrate, and total dissolved solids (TDS), were determined using a field water testing kit developed by the Tamil Nadu Water Supply and Drainage Board (TWAD Board, 2014).

The groundwater samples were tested for nine parameters: pH, turbidity, fluoride, nitrate, iron, hardness, chloride, and TDS. They were additionally tested for iron and fluoride. Sampling and chemical analysis was done using the Jal Tara Water Testing Kit developed by TARA Enviro (SGS, 2004), adapting standard methods from APHA (APHA, 2012). The Jal Tara Water Testing Kit provides an analysis of nine parameters in one attempt for each sample.

The assessment results are compared with standards set by BIS 10500 2012 (BIS, 2012) for drinking water and CPCB standards (CPCB, 2007) for irrigation and fishing.

2.4 | Water Quality Index

The water quality index (WQI) is calculated for both surface water and groundwater using the weighted arithmetic index method, as suggested by Ramakrishnaiah *et al.* (2009) and Tyagi *et al.* (2013). According to the relative importance of the chemical parameters in the overall quality of water for drinking purposes, specific weights *(w_i)* are assigned to them for surface and groundwater, as indicated in Tables 1 and 2, respectively. It is to be noted that the specific weights assigned with the help of the literature surveyed related to assigning weights to surface water quality and groundwater quality parameters (Molla *et al.*, 2015; Wang *et al.*, 2013). The relative weight (W_i) is computed using eq. 1.

$$W_i = \frac{w_i}{\sum_{1=1}^{n} w_i} \qquad ...(1)$$

The water quality and suitability for drinking and domestic purposes can be examined by determining its quality index. The quality rating *(qi)* is then determined for each parameter using eq. 2, which is further used to determine the WQI using eq. 3.

$$q_i = \frac{C_i - C_{i_o}}{S_i - C_{i_o}}\ x\ 100 \qquad ...(2)$$

$$WQI = W_i \times q_i \qquad ...(3)$$

Here, Ci is the concentration of each chemical parameter in each water sample in NTU or mg/L, Cio is the ideal value of the parameter in pure water, and S_i is the drinking water standard for each chemical parameter in NTU or mg/L as per the BIS 10500-2012 guidelines. The ideal value, C_{io}, for pH and fluoride are 7.0 and 1.0, respectively; for the remaining parameters, it is 0.

The calculated WQI values for surface water and groundwater quality are categorized into five classes, as shown in Tables 3 and 4.

TABLE 1 **Relative weight for each surface water quality indicator**

Parameters	S_i	w_i	W_i
pH	8.50	**3**	0.13
Turbidity	5.00	**2**	0.09
Chlorides	250.00	**3**	0.13
Alkalinity	200.00	**2**	0.09
Hardness	200.00	**3**	0.13
TDS	500.00	**5**	0.22
Nitrate	45.00	**5**	0.22
		23	**1.00**

TABLE 2 **Relative weight for each groundwater quality indicator**

Parameters	S_i	w_i	W_i
pH	8.50	**4**	0.14
Turbidity	5.00	**2**	0.07
Nitrate	45.00	**5**	0.18
Hardness	200.00	**2**	0.07
Chloride	250.00	**3**	0.11
TDS	500.00	**4**	0.14
Iron	0.30	**4**	0.14
Fluoride	1.50	**4**	0.14
		28	**1.00**

TABLE 3 **Categorisation for water quality index (WQI) for surface water samples**

WQI Value	Class	Water Quality
0-25	I	Excellent
26-50	II	Good
51-75	III	Poor
76-100	IV	Very Poor
>100	V	Unsuitable for drinking

Source: Sajitha and Vijayamma, 2016

TABLE 4 **Categorisation for water quality index (WQI) for groundwater samples**

WQI Value	Class	Water Quality
0-50	I	Excellent
50-100	II	Good
100-200	III	Poor
200-300	IV	Very Poor
>300	V	Unsuitable for drinking

Source: Ramakrishnaiah et al., 2009

2.5 | Statistical Analysis

Water quality data was subjected to univariate analysis - mean, range, standard deviation, minimum and maximum and multivariate analysis - principal component analysis / factor analysis and cluster analysis. The statistical computations were done using the software package SPSS 21.0 (for Windows; IBM USA), Microsoft Office Excel 2016 and Minitab Release 14.1. The multivariate methods applied are discussed in the next section.

2.5.1 | Principal component analysis (PCA) and factor analysis (FA)

PCA is a statistical tool used to reduce the dimensions of the multivariate datasets (Zhang *et al.,* 2009). It retains the maximum informative value of the input data intact while trying to reduce its dimensions. PCA is designed to transform the original variables into new, uncorrelated variables (axes), called the principal components, which are linear combinations of the original variables. FA follows PCA. The main purpose of FA is to reduce the contribution of less significant variables to simplify even more of the data structure coming from PCA (Shrestha and Kazama, 2007).

2.5.2 | Cluster analysis

Cluster analysis (CA) is a group of multivariate techniques whose primary purpose is assembling objects based on their characteristics. CA classifies objects so that each object can be similar to the others in the cluster for a predetermined selection criterion (Shrestha and Kazama, 2007). Hierarchical agglomerative clustering is the most common approach, which provides intuitive similarity relationships between any one sample and the entire data set and is typically illustrated by a dendrogram (McKenna, 2003). The dendrogram provides a visual summary of the clustering processes, presenting a picture of the groups and their proximity, dramatically reducing the dimensionality of the original data (Varol and Şen, 2009).

3 | RESULTS AND DISCUSSION

3.1 | Hydrochemical Characteristics

Tables 5 and 6 present the univariate overview of surface and groundwater chemistry, respectively, in the Ur watershed. The surface water temperature observed was relatively higher than that of the groundwater. The minimum temperature value for the surface water samples was more than the maximum for the groundwater samples. The observed pH ranges of the surface and groundwater in the study area were 7.60 to 9.00 and 7.00 to 8.50, respectively. As per BIS, the maximum permissible limits of pH for drinking are 6.50 to 8.50, and as per CPCB, the maximum permissible limits of pH for irrigation and fish cultivation or fishery are 6.50 to 8.50 and 6.50 to 9.00, respectively.

All groundwater samples were within the permissible limit. However, nine surface water samples were beyond the

TABLE 5 Descriptive statistics of surface water quality for the Ur watershed

	Mean	Minimum	Maximum	Standard Deviation	Coefficient of variation	Standard Error
Temperature (°C)	25.94	24.48	27.81	1.00	3.86	0.27
pH	8.50	7.60	9.00	0.45	5.29	0.12
Turbidity (NTU)	13.23	1.05	44.35	12.71	96.07	3.40
Chloride (mg/L)	19.95	4.41	35.64	10.08	50.53	2.69
Alkalinity (mg/L)	90.71	60.00	160.00	24.33	26.82	6.50
Hardness (mg/L)	87.86	50.00	130.00	25.77	29.33	6.89
TDS (mg/L)	226.13	125.40	310.80	58.51	25.87	15.64
Nitrate (mg/L)	0.20	0.20	0.20	0.00	0.00	0.00
EC (mg/L)	354.00	201.90	479.54	91.20	25.76	24.37
DO (mg/L)	8.92	5.62	12.49	2.01	22.53	0.54
BGA (mg/L)	2.59	0.21	10.26	3.06	118.15	0.82

TABLE 6 Descriptive statistics of groundwater quality for Ur watershed

	Mean	Minimum	Maximum	Standard Deviation	Coefficient of variation	Standard Error
Temperature (°C)	19.81	19.00	22.00	0.97	4.90	0.17
pH	7.41	7.00	8.50	0.37	4.99	0.07
Turbidity (NTU)	15.78	10.00	50.00	10.93	69.26	1.93
Chloride (mg/L)	63.28	0.00	100.00	37.86	59.83	6.69
Alkalinity (mg/L)	500.00	40.00	2640.00	501.27	100.25	88.61
Hardness (mg/L)	120.64	28.36	496.30	106.69	88.44	18.86
TDS (mg/L)	511.16	86.00	1370.00	277.92	54.37	49.13
Iron (mg/L)	0.27	0.00	1.00	0.23	85.19	0.04
Fluoride (mg/L)	0.60	0.60	0.60	0.00	0.00	0.00

acceptable BIS standards, making them unsuitable for drinking and irrigation but suitable for fish culture. The turbidity values in the present study ranged from 1.05 to 44.35 NTU for surface water and 10 to 50 NTU for groundwater samples. Ten sampling sites observed high turbidity in surface water, while all the groundwater samples reported turbidity higher than the permissible levels of the BIS standards. Low TDS (125.40 to 310.80 mg/L) was observed for surface water, and high TDS (86.00 to 1370 mg/L) was observed for groundwater samples. About 44% of groundwater samples had TDS values beyond the acceptable limit of BIS standards. The geological formations in Bundelkhand, primarily consisting of granite and gneiss, contain various minerals. As water percolates through these rocks, it dissolves minerals such as calcium, magnesium, sodium, and potassium, leading to higher TDS levels in groundwater. Also, due to low rainfall in the region, groundwater recharge is low, which can lead to higher concentrations of dissolved solids over time.

As per BIS 10500 - 2012 standards, the acceptable limit of total hardness value is 200 mg/L, which can be extended to 600 mg/L without an alternate source. The total hardness in the surface water samples ranged from 50 to 130.00 mg/L and was well within the acceptable limit. In the case of groundwater samples, the hardness values ranged from 40 to 2640.00 mg/L. 72% of the groundwater samples (23 samples) were above the acceptable limit and 16% samples (five samples) were beyond the permissible limits of BIS standards and correspond to very hard type of water. The nitrate and chloride concentration in surface water was observed to be too low than the standards. However, 47% of the groundwater samples observed nitrate values higher than the permissible limit and 9% of samples reported chloride concentration above the acceptable BIS standards.

In this study, the alkalinity values for surface water samples ranged between 60 and 160 mg/L; for EC, the values ranged between 201.90 µS/cm to 479.54 µS/cm. However, none of the samples exceeded the BIS-recommended levels (Alkalinity: 200 to 600 mg/l and EC: 1500 µS/cm). Most ponds showed high DO values ranging from 5.62 to 12.49 mg/L, resulting in high oxygen solubility. Blue Green Algae (BGA) yields ranged from 0.21 to 10.26 µg/L of chlorophyll. Iron and fluoride concentrations for groundwater samples were well within the standards.

3.2 | Interrelations of Water Quality Parameters

In this study, the relationship between various parameters was studied separately for surface water samples and groundwater samples, using Pearson's Correlation Matrix, and it was significant at a 95% confidence level. The resultant matrix for surface water quality (Table 7) shows a strong correlation of TDS with EC (r = 1.00). Hardness positively correlated with TDS (r = 0.88) and EC (r = 0.86). Alkalinity exhibited a good positive correlation with TDS (r = 0.71), EC (r = 0.70) and hardness (0.68). The correlation matrix (Table 8) exhibits a positive correlation between chloride and TDS (r = 0.93) for groundwater quality. Nitrate with pH (r = 0.33) and chloride (r = 0.30) also showed a positive correlation.

TABLE 7 Correlation matrix of surface water quality for Ur watershed

	Temp	pH	Turbidity	Chloride	Alkalinity	Hardness	TDS	EC	DO	BGA
Temp	**1.00**									
pH	0.43	**1.00**								
Turbidity	**0.61**	0.32	**1.00**							
Chloride	0.09	0.26	0.40	**1.00**						
Alkalinity	-0.08	-0.12	-0.09	0.18	**1.00**					
Hardness	-0.33	-0.06	-0.04	-0.05	**0.68**	**1.00**				
TDS	-0.09	0.03	0.03	-0.03	**0.71**	**0.88**	**1.00**			
EC	-0.02	0.07	0.08	-0.01	**0.70**	**0.86**	**1.00**	**1.00**		
DO	**0.60**	**0.89**	0.48	0.48	-0.08	-0.19	0.01	0.06	**1.00**	
BGA	0.11	0.52	0.42	**0.71**	0.10	0.04	0.09	0.10	**0.73**	**1.00**

TABLE 8 Correlation matrix of groundwater quality for Ur watershed

	Temp	pH	Turbidity	Nitrate	Hardness	Chloride	TDS
Temp	**1.00**						
pH	-0.05	**1.00**					
Turbidity	-0.20	0.14	**1.00**				
Nitrate	0.13	**0.33**	-0.11	**1.00**			
Hardness	-0.10	0.14	0.04	0.07	**1.00**		
Chloride	0.05	0.09	-0.09	**0.30**	0.18	**1.00**	
TDS	0.09	0.08	-0.08	0.29	0.17	**0.93**	**1.00**

3.3 | Water Quality Assessment Based on WQI

The weighted arithmetic index method was used to evaluate the surface and groundwater quality according to the BIS 10500 2012 standards. Seven parameters, such as pH, turbidity, chlorides, alkalinity, hardness, TDS, and nitrate, were used to evaluate surface water quality. The surface water quality index range was then classified into five categories. The overall surface water quality index results for the fourteen ponds are shown in Fig. 2. The groundwater quality was assessed using the concentrations of eight parameters: pH, turbidity, nitrate, hardness, chloride, TDS, iron, and fluoride. The groundwater quality index provides information on a rating scale of 0 - 300 and is categorized into five classes for determining suitability for drinking purposes. The WQI results for the groundwater samples are shown in Fig. 3.

3.4 | Principal Component Analysis and Factor Analysis

Factor Analysis was performed using the extraction method (PCA) and was executed for ten parameters for surface water samples and seven parameters for groundwater samples. The rotation of the principal components was carried out using the Varimax method with Kaiser Normalisation. Significant PCs were then selected based on the Kaiser principal and the scree plot. As per Kaiser's principle, only components with eigenvalues >1 would be accepted as possible sources of variance in the data, with the highest priority ascribed to a component with the highest eigenvector sum. With the scree test, the eigen values associated with each component are plotted and we look for a breakpoint. The components that appear before the break are assumed to be meaningful and are retained for rotation.

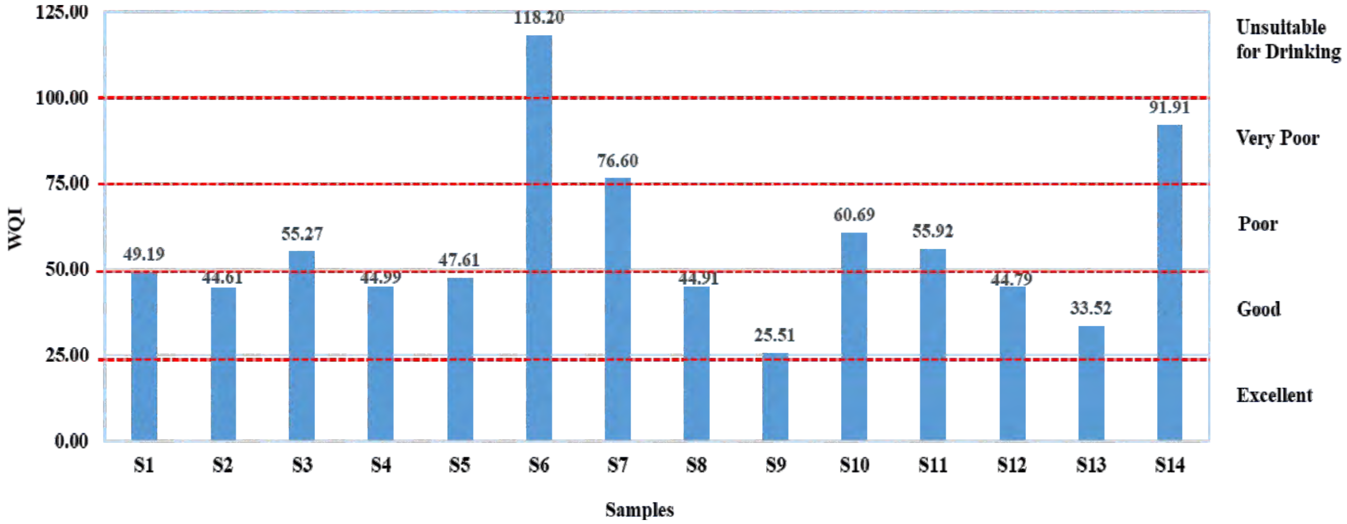

FIGURE 2 WQI for surface water of Ur watershed

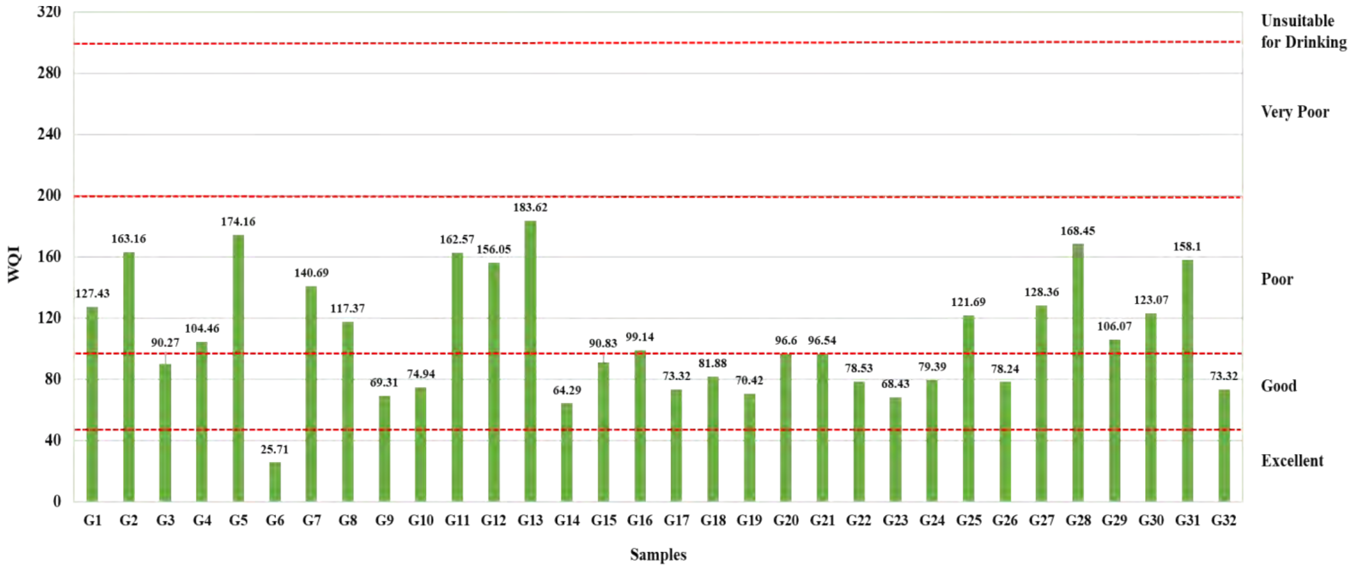

FIGURE 3 WQI for groundwater of Ur watershed

Tables 9 and 10 present corresponding variable loadings and explained variance for surface water and groundwater samples, and strong loading values have been highlighted.

3.5 Cluster Analysis (CA)

To detect spatial similarity among groups, CA was performed separately on 14 sampling sites of surface water and 32 sampling sites for groundwater. In this study, Hierarchical Agglomerative CA was performed by applying Ward's method (linkage between groups), using squared Euclidian distance as a similarity measure. The results are illustrated by dendrograms (Figs. 4 and 5), where each group indicates sites of similar physico-chemistry.

3.6 | Water Quality for Drinking

The drinking suitability of surface and groundwater was evaluated using the water quality index, determined by the weighted arithmetic index method, following the BIS 10500 2012 standards. Eight surface water samples (S1, S2, S4, S5, S8, S9, S12 and S13) are considered suitable for drinking, contributing 57% of the total samples. The samples within classes III, IV and V contributed 21%, 14% and 7% of total surface water samples, respectively. Overall, the WQI values ranged from 25.51 to 118.20, where S6, located in the upstream area close to Tikamgarh town, reported the highest WQI and was found to be the most unsuitable for drinking purposes. In this pond, turbidity concentration was much higher than the standards, making it unfit for human consumption. The sources of turbidity can be attributed to rainfall runoff reaching the ponds with soil particles from overgrazed pastures and bare croplands, livestock trampling on and wading in the ponds, bathing and washing clothes along the banks, etc.

TABLE 9 Loading for varimax rotated factor matrix for three component model explaining 81.29% of the total variance for surface water

Rotated Component Matrix^a			
	Component		
	1	2	3
pH	-.003	.724	.351
Turbidity	.017	.696	.230
Chloride	.000	.118	.891
Alkalinity	.809	-.131	.137
Hardness	.928	-.167	.006
TDS	.979	.052	-.026
EC	.974	.121	-.031
DO	-.039	.800	.516
BGA	.086	.321	.880
Temperature	-.120	.895	-.151
Eigenvalues	3.445	2.628	2.056
% of variance	34.452	26.278	20.561
Cumulative %	34.452	60.730	81.291

TABLE 10 Loading for varimax rotated factor matrix for three component model explaining 67.15% of the total variance for groundwater

Rotated Component Matrix^a			
	Component		
	1	2	3
Temp	.026	.143	-.735
pH	-.024	.847	.241
Turbidity	-.139	.090	.677
Nitrate	.263	.751	-.243
Hardness	.330	.134	.444
Chloride	.961	.097	-.028
TDS	.957	.091	-.055
Eigenvalues	2.037	1.347	1.316
% of variance	29.104	19.238	18.805
Cumulative %	29.104	48.342	67.147

The groundwater samples within classes I, II and II contributed 3%, 50% and 47% of total samples, respectively. The computed WQI ranges from 25.71 to 183.62, with the minimum value recorded from sample G6 and the maximum value from G13. As per the results, pH and fluoride parameters are well within the acceptable limits of BIS standards for drinking purposes. Further, the chemical analysis reveals that turbidity values have exceeded the permissible limits at all 32 locations. The two physico-chemical parameters, nitrate and hardness, have also been found to exceed the allowable limits of BIS. The high values show that natural and anthropogenic sources contaminate the study area's groundwater. High turbidity values can be attributed to the fact that there is over-pumping of water, which disturbs the sediments, causes weathering of rocks, releases fine particles into the groundwater and may cause the water to become turbid. The high concentration of nitrate and hardness indicates the over-application of fertilizers in agricultural lands and seepage and runoff from soils.

3.7 | Water Quality for Irrigation

The irrigation water quality was evaluated using pH and electrical conductivity parameters for surface water samples. With the hazardous effects of the total salt concentration, all fourteen samples fall in the low category as the EC values are much below 1500 µmhos/cm per BIS 11624 standards (BIS, 1986; Reaffirmed, 2009). Following the CPCB water quality criteria for designated best use (CPCB, 2007), S2, S5, S7, S9 and S13 meet the requirements of pH and EC and, thus, are considered suitable for irrigation purposes.

3.8 | Water Quality for Fishery

The suitability of the fishery was analysed for surface water samples using the CPCB water quality criteria (CPCB, 2007). Two parameters, pH and DO, were considered for the assessment. According to the standards, all the ponds are deemed suitable for fishery. The fishes suitable for breeding

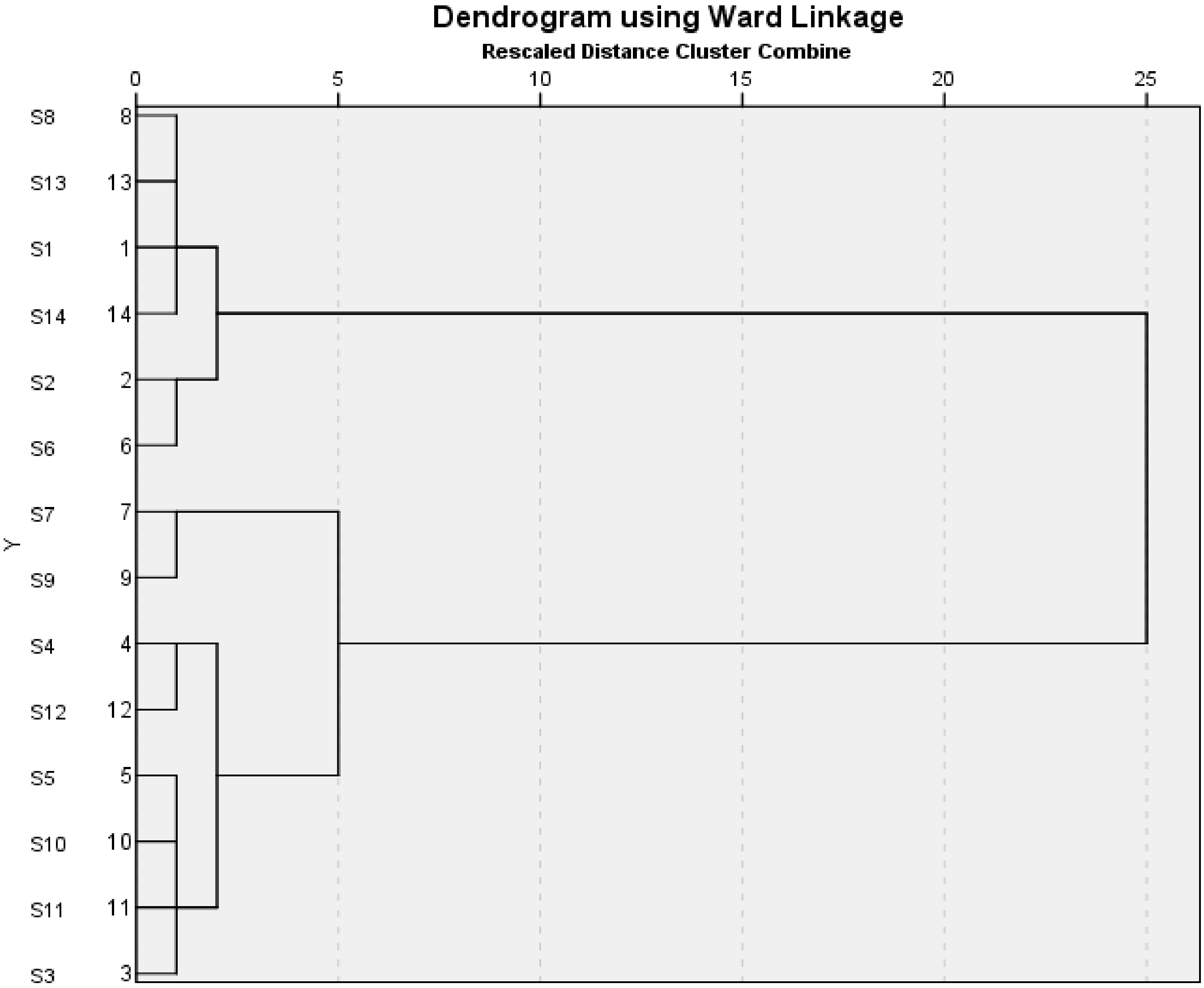

FIGURE 4 **Dendrogram of relationship among sampling sites for surface water**

here are Catla (Catla catla), Rohu (Labeo rohita), Mrugal (Cirrhinus mrigala), Common Carp, Grass carp and Silver Carp.

3.9 | PCA (Data structure determination and source analysis)

3.9.1 | Surface water

The result of PCA/FA indicates three main controlling factors underlying the surface water chemistry in the study area. These three factors explain about 81.291% of the total sample variance summarised in Table 9. Factor 1 accounts for 34.45% of the total variance and strongly loads TDS, EC, alkalinity and hardness. A strong correlation between TDS, EC, alkalinity and hardness suggests a common source. This factor may be related to anthropogenic pollution through domestic (pollution due to wastewater) and agricultural processes (use of fertilizers and pesticides). Factor 2 accounts for 26.28% of the total variance with a strong loading of temperature, DO pH and Turbidity. Factor 3 explains 20.56% of the total variance of the data set and has a more substantial contribution from chloride and BGA. Factors 2 and 3 represent the seasonal impact of temperature and natural processes.

3.9.2 | Groundwater

The PCA / FA for groundwater physicochemical variables produced three factors accounting for 67.14 % of the total variance for the dataset, summarised in Table 10. Factor 1 accounts for 29.10 % of the total variance of the data set and shows strong loading from chloride and TDS. It can be ascribed to the hydro-geochemical evolution of groundwater by groundwater-geological medium interaction. Factor 2 explains 19.24% of the total variances and has a stronger

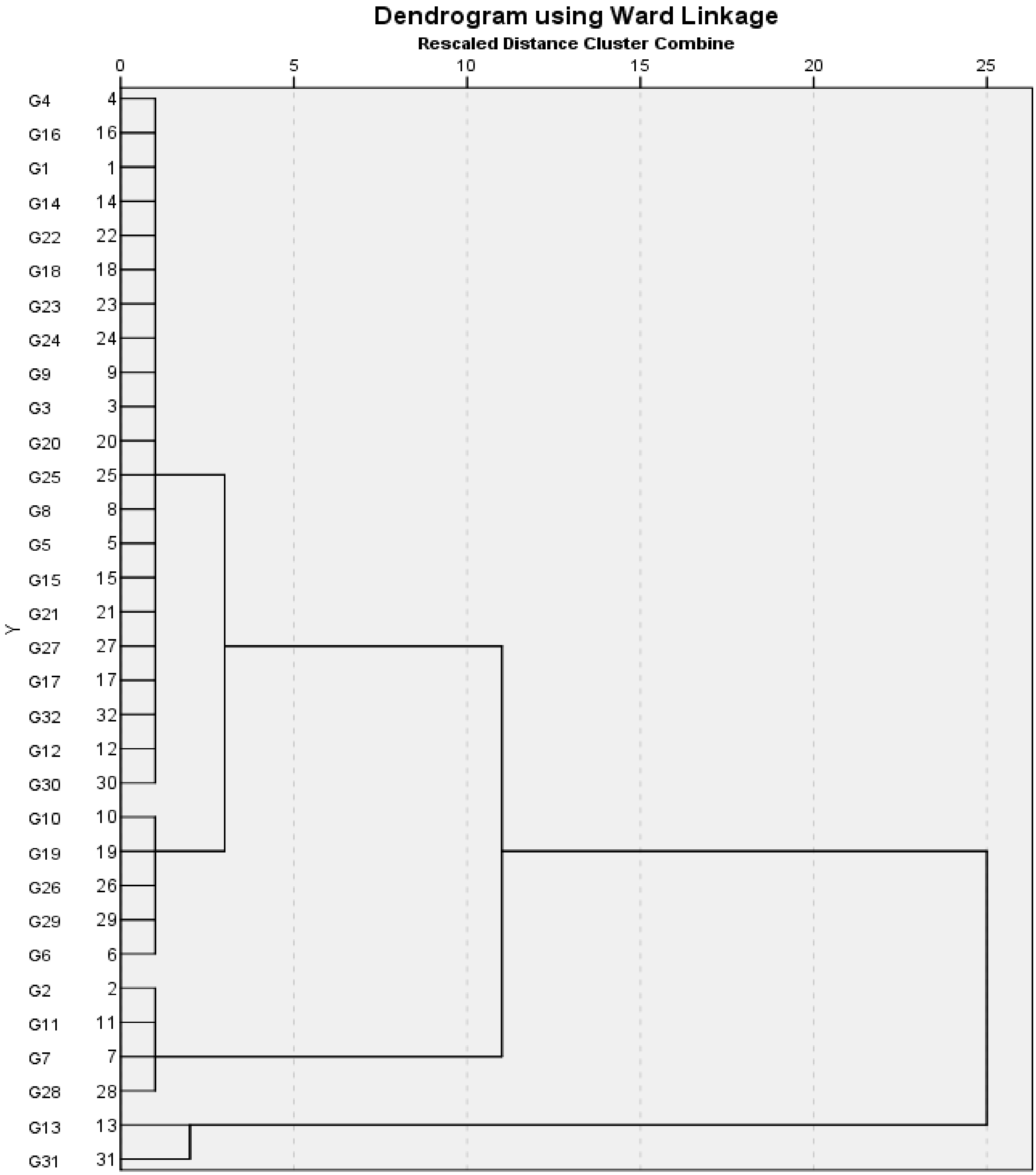

FIGURE 5 **Dendrogram of relationship among sampling sites for groundwater**

contribution from pH and nitrate. Farmers use nitrogenous fertilizers in these areas, which undergo a nitrification process and reach groundwater through leaching, polluting the source. Factor 3 accounts for 18.81% of the total variance of the data set, with a stronger loading from temperature, turbidity and hardness.

3.10 | HCA (Spatial similarity and sample site grouping)

3.10.1 | Surface water

The 14 sampling sites for surface water fell into two major clusters - Cluster A and Cluster B. Cluster A groups 42.85%

of the total samples into two sub-cluster groups A1 and A2. These sampling sites were located close to the main Ur river. Sub - cluster A1 consists of four samples (S8, S13, S1 and S14) and sub - cluster A2 contains two samples (S2 and S6). This cluster is completely explained by Principal Component 1, which explains strong loading from high concentrations of EC, TDS, hardness and alkalinity.

Cluster B consists of 57.14% of the total samples located away from the Ur river and its tributaries. Cluster B was divided into two sub-clusters, B1 and B2. Cluster B1 includes two samples (S7 and S9). Cluster B2 is subdivided into two clusters and contains six samples (S4, S12, S5, S10, S11, S3). Cluster B explains the principal components 2 and 3, which explain high-temperature values, pH, DO, turbidity and chloride values.

3.10.2 | Groundwater

Two significant clusters, Cluster A and Cluster B, were generated from hierarchical agglomerative cluster analysis of the thirty-two groundwater samples. Cluster A groups 93.75% of the total samples into clusters A1 and A2. Most groundwater samples were classified in the sub-cluster A1 (81.25%), corresponding to good-quality water sites. Sub-cluster A2 includes four sample sites. These samples exhibit incredibly high levels of hardness concentration, which is beyond the permissible limits of drinking water standards. The samples also report high chloride and TDS concentrations, which exceed the acceptable limits. The principal component 1, thus, explains the Cluster A2 grouping.

The two sampling sites, S13 and S31, fall in Cluster B (6.25% of the total samples), corresponding to poor-quality water sites. The sites record the maximum values of hardness concentration, which is beyond the permissible limits of drinking water standards. Even the turbidity levels were found to be high in the samples. Thus, Cluster B is explained by the principal component 3.

3.11 | Overall Findings of PCA and HCA

Multivariate statistical techniques were applied to establish the nature and spatial distribution of surface and groundwater samples within the Ur river watershed. The principle component analysis and factor analysis assisted to extract and recognize the factors responsible for water quality. Three principal components were extracted for surface water samples using ten parameters (pH, turbidity, chloride, alkalinity, hardness, TDS, EC, DO, BGA and temperature). The first principal component highlighted the impact of anthropogenic activities and the second and third component together was governed by effects of natural processes and climate variability. Similarly, PCA for groundwater also extracted three components using seven parameters (pH, turbidity, nitrate, hardness, chloride, TDS and temperature). The first two components indicate the excessive use chemical fertilisers in the area that have led to higher concentrations of chloride, nitrate and TDS in the groundwater. The third component explains the impact of natural factors. Hierarchical cluster analysis helped to group 14 sampling sites of surface water into 2 major clusters and 32 groundwater sampling sites into 2 major clusters based on their water quality characteristics. WQI analysis for surface water among the 2 major clusters showed that Cluster B was of better quality than Cluster A. For groundwater, the WQI analysis among 2 clusters showed that Cluster A had a majority of the samples and had varying water quality whereas Cluster B included inferior quality groundwater samples.

4 | CONCLUSIONS

This study comprehensively evaluates water quality in the Bundelkhand region for drinking, irrigation, and fishery purposes, utilizing the WQI and multivariate statistical analyses. The results indicate that while a significant portion of surface water samples meets the drinking water standards, concerns arise from high turbidity levels and exceedances in nitrate and hardness concentrations. Specifically, surface water samples exhibited a WQI range from 25.51 to 118.20, with the highest values indicating unfit conditions for consumption due to turbidity caused by anthropogenic activities. Groundwater quality showed a concerning trend, with 47% of samples classified in a moderate category, and critical exceedances of permissible limits for turbidity, hardness, and nitrate were observed. This suggests contamination from natural processes and human activities, particularly the over-application of fertilizers in agricultural practices. For irrigation purposes, all surface water samples were deemed suitable, reflecting acceptable pH and electrical conductivity levels, which can aid in sustainable farming practices. Furthermore, the study confirmed that all surface water bodies are ideal for fisheries, providing a favourable environment for species such as Catla (*Catla catla*), Rohu (*Labeo rohita*), and Mrugal (*Cirrhinus mrigala*). The Principal Component Analysis (PCA) revealed significant factors influencing water quality, highlighting the roles of anthropogenic pollution and seasonal impacts. The Hierarchical Cluster Analysis (HCA) illustrated clear spatial groupings of water quality, indicating areas needing targeted management strategies. This study underscores the importance of continuous monitoring and managing water resources to ensure their safety and usability. Implementing best practices in land use and agricultural inputs can help mitigate water quality issues in the Bundelkhand region.

ACKNOWLEDGEMENTS

This work was carried out at the National Institute of Hydrology (NIH) under a project supported by Technology Information, Forecasting and Assessment Council (TIFAC), Department of Science and Technology, Government of India. The authors would like to acknowledge Sh. Lokesh Patel, Senior Project Officer, NIH and the team of Development Alternatives for providing help during sampling and Madhya Pradesh Council of Science and Technology for generating the GIS database for Ur river watershed.

DATA AVAILABILITY STATEMENT

The data of the analysis will be made available on request.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AUTHOR'S CONTRIBUTION

Meeta Gupta and Jyoti P. Patil: Study conception and design; Omkar Singh: Data collection; Meeta Gupta, Jyoti P. Patil, V.C. Goyal and Omkar Singh: Analysis and interpretation of results; Meeta Gupta, Jyoti P. Patil: Draft manuscript preparation.

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How to cite this article: Gupta, M., Patil, J.P., Singh, O. and Goyal, V.C. 2024. Integrated water quality assessment of Ur watershed in Bundelkhand region (India) based on water quality index and multivariate statistical techniques. *Indian J. Soil Cons.,* 52(2): 135-146.