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Water Quality Assessment of River Tawi, Jammu Using Water Quality Index and Multivariate Statistical Techniques

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Abstract—The present study explores the water quality status, hydrogeochemical characteristics and factors affecting the water quality of Tawi River in Jammu. More accurate information of water quality was obtained by applying the hydrochemical plot like Piper's diagram, Water Quality Index and Multivariate Statistical Techniques such as Principal Component Analysis (PCA) on various physicochemical parameters. All the analyzed parameters were well within the permissible limits of Bureau of Indian Standards (BIS 2012) for drinking and domestic purposes for pre and post monsoon season. Based on the inferences obtained from Piper's diagram, Ca–Mg–HCO_3 type predominated in the study area during both seasons. Most dominant cations were Ca^{2+} and Mg^{2+} whereas HCO_3^- and Cl^- were the dominant anions in the analyzed water samples. The computed WQI values of the surface water ranged from 60.05 to 107.60 and from 75.25 to 123.38 during pre and post monsoon season respectively and fall under good to poor category. Varifactors obtained from PCA indicated that water quality variation was primarily due to the dissolution of minerals from rock water interactions, secondary effect of anthropogenic activities and ion exchange processes in water. These results provide fundamental and baseline information for developing more effective water pollution abatement strategies for River Tawi.

Keywords: surface water quality, hydrochemical plot, water quality index, multivariate statistical techniques

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INTRODUCTION

Rivers are the precious water resources as they are directly used for drinking, domestic, agriculture, transportation, power generation, recreation, and other human activities including waste disposal [30]. Many ancient civilizations settled along river banks were based on the availability of freshwater sources and most developmental activities are still dependent upon them. But in recent years, the river water quality is increasingly degraded in many parts of the world especially in developing countries like India due to the increase in population and accelerated pace of urbanization [12, 13]. Studies revealed that the deterioration of river water quality has been attributed to both natural and anthropogenic processes but man-made processes like urbanization, agriculture, domestic and industrial activities are considered to be significant sources of river water pollution [4, 5, 16, 23]. The surface runoff, being a seasonal phenomenon is greatly affected by climate in the basin whereas wastewater discharge by the municipal and industrial units is still the perennial factor of surface water pollution [22, 25]. Rivers are the most vulnerable water bodies to pollution due to their role of carrying off the industrial and runoff from agricultural land in their drainage basins. Since rivers are the main source of freshwater to humans, it is important to regularly monitor and evaluate the river water quality for sustainable water management and safeguarding the public health. Also, the prevention and control of water pollution rely on the water quality information and identification of pollutant sources for effective management.

With the increasing awareness and concern about the river water pollution all over the world, new approaches and methods have been developed to identify hydrochemical characteristics and possible factors which offer a valuable aid for the reliable management of water resources and rapid solutions to pollution problems. The most basic method to determine the water quality status in an area is to evaluate its physical and chemical parameters. In the present study, the River Tawi which flows through Jammu was selected for its water quality evaluation. The main objectives of this study were to assess the overall water quality and identifying the factors affecting the hydrochemistry of the river. A popular Water Quality Index (WQI) approach was applied in this study in order to determine the status of water quality in the area under investigation. Multivariate statistical techniques namely PCA were employed in this study which is the efficient method to analyze the water samples and

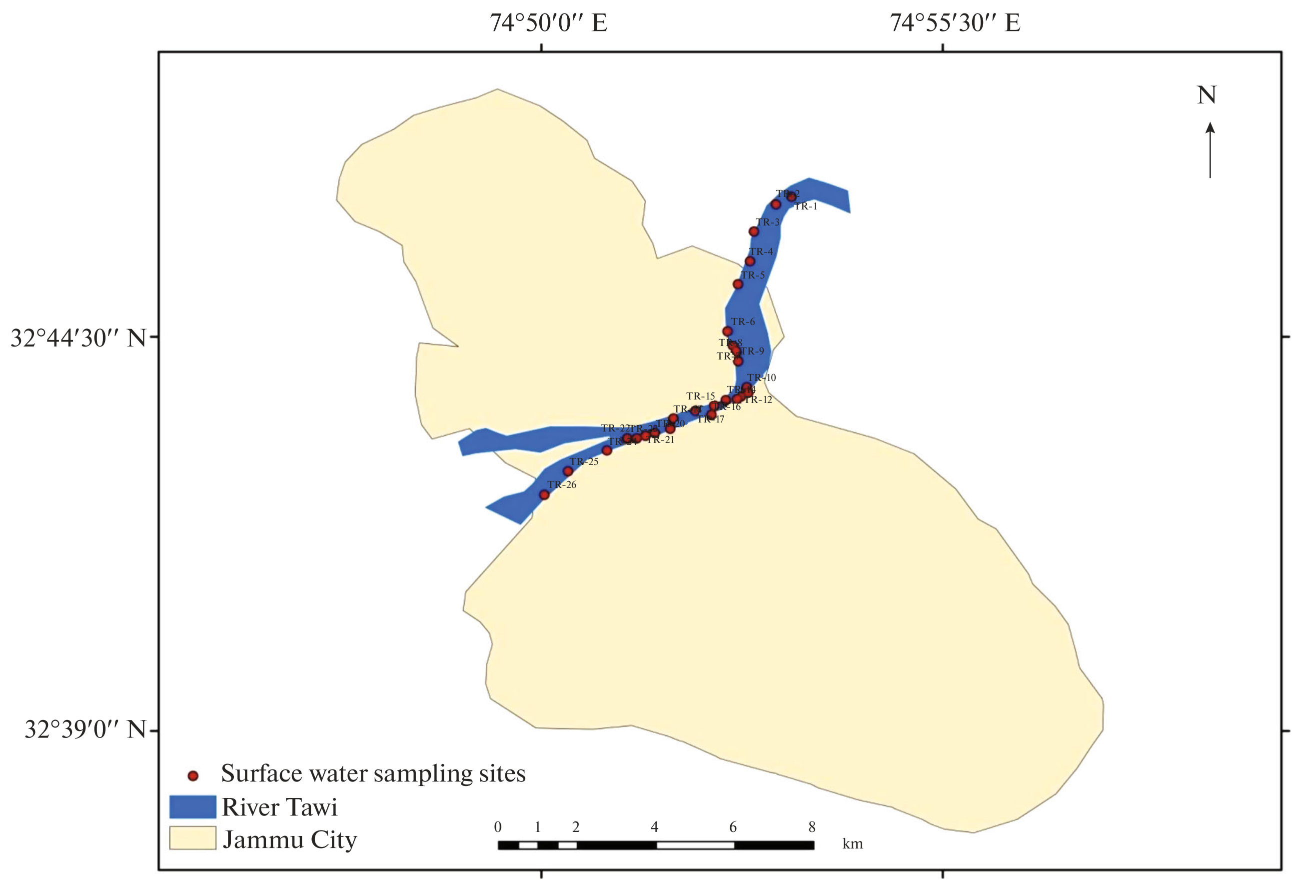

Fig. 1. Map showing sampling points in the study area.

characteristics of hydrochemistry [25]. These techniques help in the interpretation of complex data to better understand the water quality status of the studied systems. These techniques have also been proved as successful tools to detect the possible factors/sources that influence water systems [14, 24, 29, 31, 32].

MATERIALS AND METHODS

Study Area

The study area lies between 32°39′0″ N latitude and 74°55′30″ E longitude (Fig. 1). It falls in the Jammu district which is the winter capital of the union territory of Jammu and Kashmir. It lies at uneven ridges of low heights at the Shiwalik Hills. It is surrounded by the Shiwalik Range to the north, east and southeast direction and by Trikuta Range in the northwest direction. The topography of the study area is from plain to undulating. The topographic gradient of the area is generally low with average elevation varying from 280–450 m amsl. River Tawi which is a major water source to the people of Jammu flows through the study area. It is the left bank tributary of River Chenab which originates from Kali Kund glacier located on the southwest of Bhaderwah in the Doda district of J&K at an altitude of nearly 4000 m amsl. The predominant climate of the area is humid subtropical type. The average annual temperature is approximately 24°C with maximum of 47°C in summer and minimum of 4°C in winter. The average annual rainfall is 1246 mm with the majority of precipitation occurring from June to end of the September and in rest of the months the rainfall is sporadic and scanty. Mostly alluvial soils are found in the study area, which contain high magnesium content with small quantity of lime. Geologically the area is underlain by older and younger Alluvium of Quaternary age. This formation comprises of unconsolidated sediments in the form of terraces and coalescent alluvial fans developed by seasonal streams draining the Shiwaliks.

Data Collection and Analytical Methods

Water samples were collected during pre monsoon (May, 2019) and post monsoon (October, 2019) season at 26 sampling sites along Tawi River. The samples were analysed for 13 parameters including pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Hardness (TH), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}), Potassium (K^{+}), Bicarbonate (HCO_3^-), Chloride (Cl^-), Sulphate (SO_4^{2-}), Nitrate (NO_3^-) and Fluoride (F^-) according to the standard methods enlisted in the American Public Health Association (APHA) [1].

Water samples were collected in high density polyethylene (1000 mL) plastic bottles pre-washed with 10% nitric acid (HNO_3) and further the bottles were rinsed two to three times with water to be sampled before each sampling to ensure minimum composition variations. The samples were stored in the laboratory at (<4°C) temperature as per recommended protocols of APHA 21st edition [1]. pH, EC, TDS were detected by using Hanna's multi parameter water kit. HCO_3^-, Cl^-, TH were determined by titration and SO_4^{2-}, F^-, NO_3^- were quantified by spectrophotometric techniques. Na^+ and K^+ were measured by the flame photometer. The accuracy of the chemical ion data was examined using charge balance error (CBE) equation (Eq. (1)) and values were within the acceptable limit of ±5% [9].

$$\text{CBE\%} = \frac{(\text{Cations})(\text{meq/L}) - (\text{Anions})(\text{meq/L})}{(\text{Cations})(\text{meq/L}) + (\text{Anions})(\text{meq/L})} \times 100. \quad (1)$$

Piper Trillinear Diagram

Water type assessment is very helpful in providing a preliminary idea regarding the complex hydrochemical processes or the nature of water. The main endeavour in this direction was made by Hill which is further modified by Piper [19]. In the present study, Piper diagram was developed with hydrochemical data of surface water samples. It was made in such a way that the milliequivalents percentage concentrations of the major cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) and anions (HCO_3^-, CO_3^{2-} SO_4^{2-}, and Cl^-) are plotted in two separate triangular fields. These plotted points are then projected further into the central diamond field, which provides the overall character of the water.

Water Quality Index (WQI)

Water quality index (WQI) is a significant and distinctive rating to represent the general water quality status in a single term that is useful for the selection of proper treatment method to meet the concerned issues [2]. However, WQI showed the composite influence of water quality parameters on the overall quality of water and communicates water quality information to the public and legislative decision makers [27]. WQI for surface water was calculated by employing weighted arithmetic index method. In this study, the mean values of 10 physicochemical parameters of water were selected (pH, TDS, TH, HCO_3^{2-}, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, NO_3^- and F^-) for the WQI calculation according to their importance in water quality. The weight value was assigned for each parameter between 1 and 5 depending on the water quality effects and the importance for human health. To calculate the WQI the BIS standards [3] were used and was calculated by using the following Eqs. (2)–(5) [27].

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}, \quad (2)$$

where, W_i is the relative weight, w_i is the weight of each parameter.

$$Q_i = \frac{C_i}{S_i} \times 100, \quad (3)$$

where, Q_i is the quality rating, C_i is the concentration of each chemical parameter in each water sample in mg/L and S_i is the BIS [3] standard for each chemical parameter in mg/L.

Then, the Sub-indices (SI) were calculated by multiplying the relative weight (W_i) and quality rating (Q_i):

$$\text{SI}_i = W_i Q_i, \quad (4)$$

WQI were calculated by adding to sub-indices (Eq. (5)):

$$\text{WQI} = \sum_{i=1}^{n} \text{SI}_i. \quad (5)$$

Multivariate Statistical Techniques

Multivariate statistical techniques were employed for the evaluation and interpretation of the water quality dataset of multiple variables monitored during different seasons at different sampling stations. Principal component analysis (PCA) was incorporated in the present study using IBM SPSS 25 software. Principal component analysis was employed with the objective to identify the possible sources influencing the water chemistry. PCA is an incisive technique which derives linear relationships of multiple quantitative variables that explicate the largest percentage of variation amongst those variables [20, 24]. It is designed to convert the original complex data set containing variables into the new uncorrelated variables called principal components which focuses on the information from the most significant parameters and can explain the whole data set through data reduction with least loss of original information [7, 9, 15, 18, 25, 28, 29]. The principal components produced are in decreasing order of their contributions to the variance. In this study, standardization of all the data was done by z-scale transformation to ensure normal distribution [6, 22]. Further the data was checked for normality by performing Kaiser Meyer Olkin (KMO) and Bartlett's

Table 1. Statistical analysis of the parameters analyzed at different locations

Parameters	Pre monsoon				Post monsoon					
	minimum	maximum	mean	SD	minimum	maximum	mean	SD	BIS [3]	
									AL	PL
pH	7.08	8.73	7.96	0.32	7.69	8.26	8.01	8.265	6.5–8.5	–
EC, μS/cm	239	397	316.07	46.84	380	558	462.34	53.47	–	–
TDS, mg/L	157.74	262.02	208.61	30.92	250.80	368.28	305.15	35.29	500	2000
TH, mg/L	163.15	337.52	266.97	52.41	225.18	416.71	320.10	53.28	200	600
Ca^{2+}, mg/L	13.82	41.80	28.67	8.35	20.04	55.21	41.45	10.61	75	200
Mg^{2+}, mg/L	31.36	61.20	46.41	8.14	42.70	67.96	52.79	7.03	30	100
Na^+, mg/L	9.40	23.20	13.44	2.83	2.50	26.30	7.88	5.27	–	–
K^+, mg/L	0.50	4.80	1.30	1.17	1.00	13.10	3.27	3.28	–	–
HCO_3^-, mg/L	155	285	233.96	39.29	160	285	208.46	33.63	200	600
Cl^-, mg/L	24.20	72.90	45.78	13.13	55.80	133.90	96.73	25.08	250	1000
SO_4^{2-}, mg/L	13.16	18.81	15.58	1.72	11.83	19.83	13.47	1.76	200	400
NO_3^-, mg/L	1.33	8.79	3.57	2.18	1.14	4.90	2.37	1.07	45	–
F^-, mg/L	0.15	0.30	0.19	0.04	0.21	0.32	0.23	0.02	1	1.5

Sphericity tests to examine the suitability of data for factor analysis.

RESULTS AND DISCUSSION

Water Quality Evaluation Using Physicochemical Parameters

The acceptable limit (AL) and permissible limit (PL) of BIS 2012 and hydrochemical analysis of the measured variables in the water samples of River Tawi for the pre and post monsoon season in terms of minimum, maximum, mean and standard deviation are listed in Table 1. The measured pH values varied between 7.08–8.73 and 7.69–8.26 with a mean of 7.96 and 8.01 during pre and post monsoon respectively and are within the prescribed limits of BIS [3] except at few sites in pre monsoon which showed the alkaline nature of water. EC values were recorded in the range between 239–397 μS/cm with a mean of 316.07 μS/cm in pre monsoon season and 380–558 μS/cm with a mean of 462.34 μS/cm during post monsoon. Variation in the EC values of samples is linked to silicate weathering, rock water interaction and associated geochemical processes. High values of EC may be attributed to the dominance of magnesium, calcium and chloride ions.

The range of TDS of analyzed water samples during pre monsoon period varied between 157.74–262.02 mg/L. Also, the post monsoon samples were found in the range of 250.8–368.28 mg/L. The total hardness of the sampled water in the study area remained within the permissible limit of BIS [3] and varied from 163.15–337.52 mg/L in pre monsoon season and from 225.18–416.71 mg/L in post monsoon season respectively. According to Sawyer and McCarty's classification for hardness [21], 23.07% of samples in pre monsoon and 65.38% of samples in post monsoon season belonged to very hard water category (Table 2). Significant temporal variations with higher average values were observed in post monsoon, which may be associated with the leaching of minerals containing calcium and magnesium [8]. Among the cations, the surface water samples were largely dominated by Mg^{2+} which has a concentration ranging from 31.36–61.2 mg/L in pre monsoon season and from 42.70–67.96 mg/L in post monsoon season respec-

Table 2. Classification of water on the basis of total hardness by Sawyer and McCarty

Total Hardness, mg/L	Nature of water	Percentage and number of analyzed samples (Pre monsoon)	Percentage and number of analyzed samples (Post monsoon)
0–75	Soft	Nil	Nil
75–150	Moderate	Nil	Nil
150–300	Hard	76.92% (20)	34.61% (9)
>300	Very Hard	23.07% (6)	65.38% (17)

tively. The concentration of Ca^{2+} varied from 13.82–41.80 mg/L during pre monsoon season which is lower than the range of concentration found in post monsoon season i.e. 20.04–55.21 mg/L. The entire values of the Ca^{2+} concentration were found to be within the permissible limit of BIS [3] in both seasons. Na^+ values varied from 9.4–23.2 and 2.5–26.3 mg/L in pre and post monsoon season respectively and none of the samples exceeded its permissible limit. Similarly, the concentration of K^+ in the observed samples varied from 0.5–4.8 mg/L in pre monsoon and 1–13.1 mg/L in post monsoon season. The analytical results showed that HCO_3^- was the most dominated anion and its concentration ranged from 155–285 mg/L in pre monsoon and 160–285 mg/L in post monsoon season respectively. The concentrations of all other anions i.e. Cl^-, SO_4^{2-}, NO_3^-, F^- were well within the permissible limit (BIS 2012) and ranged from 24.2–72.9, 13.16–18.81, 1.33–8.79, 0.15–0.30 mg/L for pre monsoon and 55.8–133.90, 11.83–19.83, 1.14–4.90 and 0.21–0.32 mg/L during post monsoon season respectively.

Hydrochemical Evolution

The chemical data for the surface water samples collected from the study area were plotted in a Piper's diagram for pre and post monsoon (Fig. 2). The Piper's diagram depicted the overall main hydrochemical types of surface water in the study area. $Ca–Mg–HCO_3$ type of surface water samples was found in pre monsoon which accounted for 100% of water samples indicating temporary hardness. In post monsoon season, $Ca–Mg–HCO_3$ type was the most dominant type which accounted for 73.07% of water samples, and the $Ca–Mg–Cl–SO_4$ type which accounted for 26.92% of water samples indicating temporary and permanent hardness. Most of the samples were characterized by significantly more alkaline earth elements (Ca^{2+}& Mg^{2+}) than the alkali elements (Na^+ & K^+) and weak acids (HCO_3^-) exceeded strong acids (SO_4^{2-} & Cl^-). The cationic triangle revealed that all the surface water samples were located in Magnesium type during pre and post monsoon season. In the anionic triangle, bicarbonate type of water was predominated during pre monsoon with 100% samples and during post monsoon with 80.76% samples while 15.38% of samples were found in no dominant type and 3.84% in chloride type respectively.

Water Quality Assessment Using WQI

The computed WQI values are classified into five categories as given in Table 3 and the calculated relative weights (W_i) of each parameter are given in Table 4 for water quality determination. The overall values of WQI of each water sample for both seasons are presented in Table 5. The computed values of WQI ranged from 60.05 to 107.60 with an average value of 86.32 in pre monsoon season and from 75.25 to 123.38 with an average value of 97.16 in post monsoon season respectively.

According to the WQI classification as given in Table 3, 88.46% of the samples fall under good category and 11.53% of samples were under poor category during pre monsoon whereas during post monsoon season 53.84% of the samples fall under good category and remaining 46.15% samples were under poor category. The increased values of WQI were observed in post monsoon due to the higher concentration of EC,

Table 3. Classification of WQI range and water quality status

WQI range	Water Quality Status
<50	Excellent
50–100	Good
100–200	Poor
200–300	Very Poor
>300	Unsuitable for drinking purposes

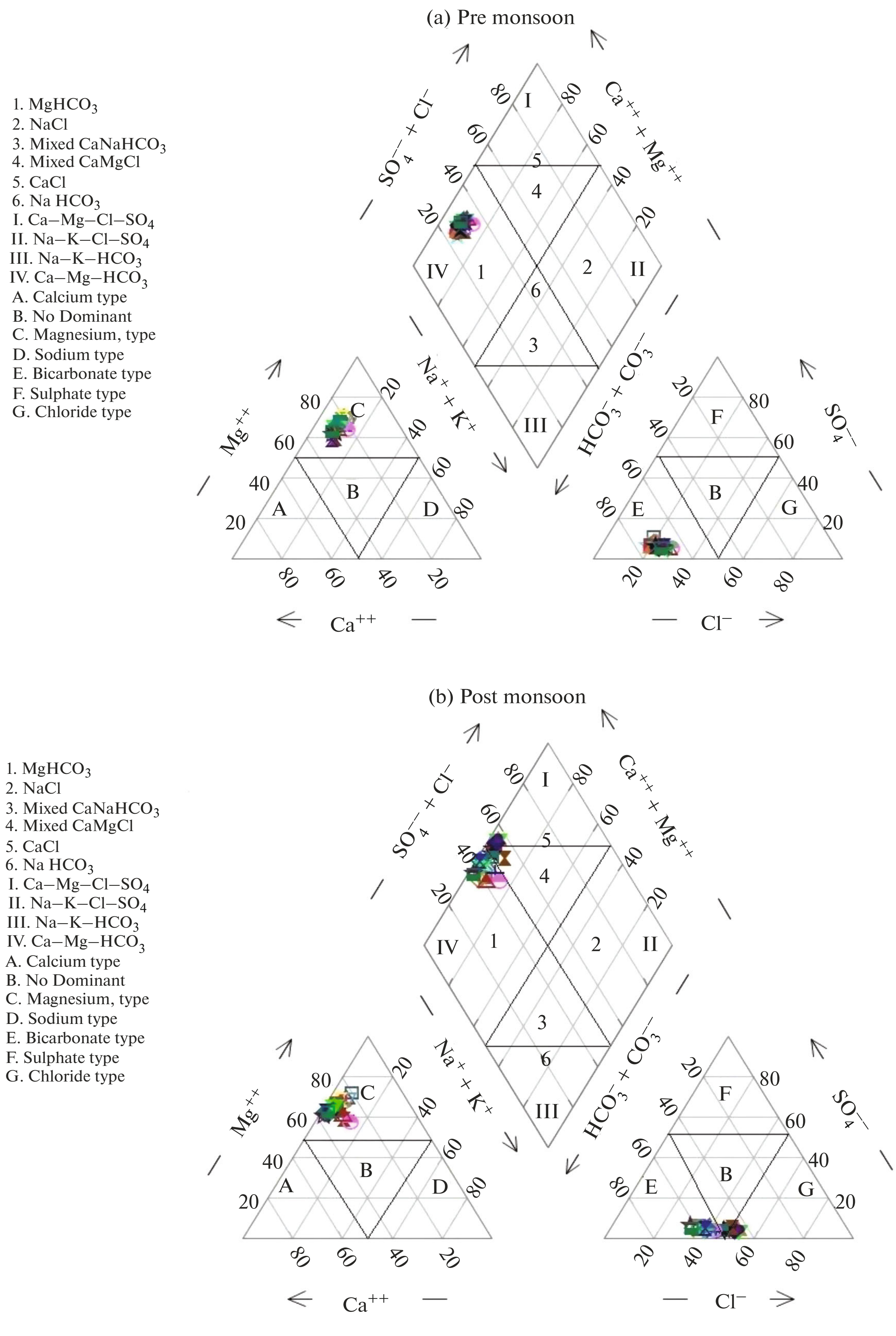

Fig. 2. Piper diagram of the chemical facies of surface water in pre and post monsoon season of the study area.

TDS, TH, Ca^{2+}, Mg^{2+}, Na^+, K^+ and Cl^-. The WQI values in the study area may be attributed to natural and man-made activities. Higher values of WQI in post monsoon season indicating poor dilution of ions.

Source Identification of Monitored Variables

Principal component analysis was performed on 13 variables for different sampling stations in two seasons to identify the characteristics of important seasonal water quality parameters. Liu et al. [11] classified the factor loadings as "strong," "moderate," and "weak" corresponding to absolute loading values of >0.75, 0.75–0.50, and 0.50–0.30, respectively. The Scree plot was used to identify the number of PCs to be retained in order to comprehend the underlying data structure [30]. In the present study, the Scree plot (Fig. 3) showed a pronounced change of slope after the third eigenvalue in both seasons. Three components in both seasons with eigenvalues greater than 1 have been extracted and the variables with eigenvalues less than 1 were neglected due to their low significance from the principal component matrix after varimax rotation (Kaiser Normalization) which explains about 85.37 and 84.46% of the total variance in pre and post monsoon season respectively. The calculated component loadings, cumulative percentage and percentages of variance explained by each factor are listed in Table 6 where strong loading values have been highlighted.

During pre monsoon, the first factor (PC1) accounting 56.05% of the total variance showed high positive loadings of EC, TDS, TH, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, and NO_3^-. This indicated mixed source of pollution from natural and anthropogenic activities like weathering of rocks and minerals and agricultural runoff [17]. Factor two (PC2) explained 20.98% of total variance. It had strong positive loadings on K^+ and SO_4^{2-} and moderate loadings on Na^+ indicating natural weathering of silicate minerals and various ion exchange processes in the river water system [26]. Additionally, 8.33% of the total variance is explained by factor three (PC3). It had strong positive loadings on F^- and is related to natural factors. The rotated component plot of the pre monsoon season is shown

Table 4. Relative weight of each parameter for WQI determination

Parameters	Water quality standards (BIS)	Relative weight (W_i)
pH	8.5	0.12903
TDS, mg/L	500	0.09677
TH, mg/L	200	0.16129
Ca^{2+}, mg/L	75	0.06451
Mg^{2+}, mg/L	30	0.16129
HCO_3^-, mg/L	200	0.16129
Cl^-, mg/L	250	0.09677
NO_3^-, mg/L	45	0.06451
SO_4^{2-}, mg/L	200	0.06451
		$\sum_{i=1}^{n} W_i = 1$

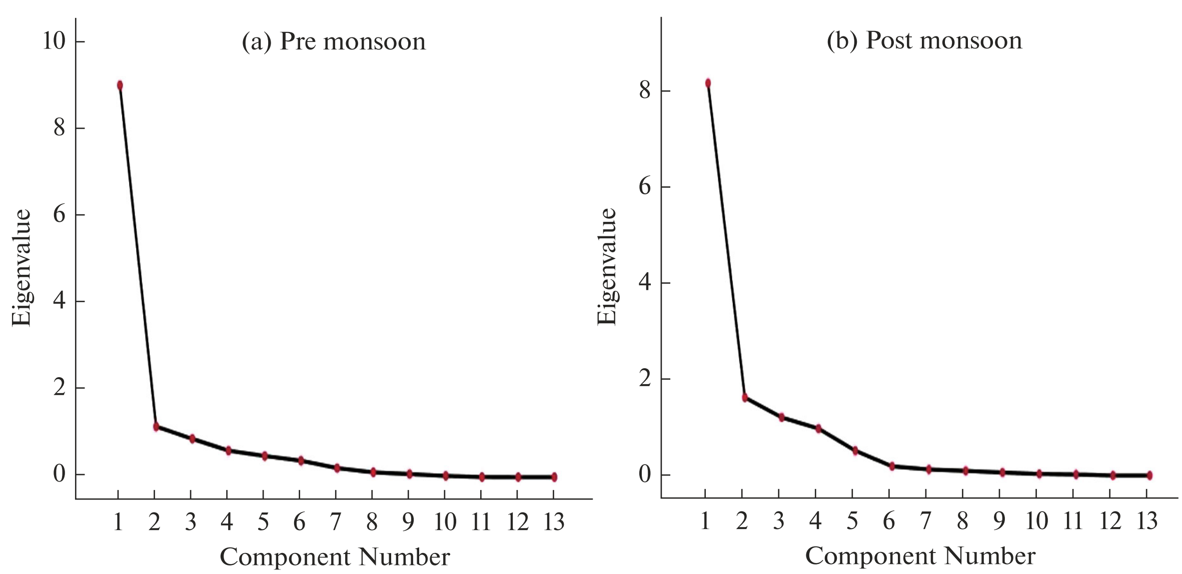

Fig. 3. Scree plot of eigenvalues for pre and post monsoon season.

Table 5. Summary of WQI of Tawi River in pre and post monsoon season

Sample no.	Surface water			
	pre monsoon		post monsoon	
	WQI values	class	WQI values	class
1	60.0499	Good	75.2571	Good
2	62.1086	Good	80.2047	Good
3	63.6469	Good	79.7792	Good
4	66.8393	Good	81.5326	Good
5	70.4854	Good	84.1685	Good
6	73.1250	Good	82.3965	Good
7	83.8105	Good	85.3621	Good
8	76.6012	Good	91.3152	Good
9	75.5682	Good	88.3940	Good
10	78.4827	Good	91.3538	Good
11	80.0854	Good	94.1085	Good
12	91.0501	Good	104.968	Poor
13	90.9115	Good	102.759	Poor
14	92.8162	Good	102.089	Poor
15	95.6282	Good	107.248	Poor
16	96.5301	Good	99.8793	Good
17	96.1967	Good	105.829	Poor
18	97.6786	Good	114.042	Poor
19	102.259	Poor	114.010	Poor
20	107.602	Poor	123.388	Poor
21	98.8094	Good	114.539	Poor
22	95.5587	Good	107.613	Poor
23	94.3459	Good	102.205	Poor
24	93.4326	Good	98.3204	Good
25	101.613	Poor	102.548	Poor
26	99.1516	Good	93.0362	Good

in Fig. 4a. It was established that first three eigenvalues greater than 1 confirming their significance.

For post monsoon, first factor (PC1) contributed 49.94% of the total variance and showed strong positive loading of pH, EC, TDS, TH, Ca^{2+}, Mg^{2+}, Na^+, and Cl^- indicating the natural factor and have a common source of origin and mineral composition of water. Moderate positive score on NO_3^- indicating the contamination from domestic sewage or by agricultural source. Factor two (PC2), which explained 22.55% of the total variance, had strong positive loadings on Na^+ and K^+. It is related to the natural factor and may result from the weathering of rocks. Lastly, 11.96% of the total variance was explained by third factor (PC3) indicating strong positive loading on SO_4^{2-} and is marked by natural processes of oxidation of sulphite ores or dissolution of gypsum. The rotated component plot of the post monsoon season (Fig. 4b) showed three eigenvalues, which are greater than 1 and hence significant.

CONCLUSIONS

The quality assessment of surface water of River Tawi showed that in general, the water was found to be suitable for domestic purposes. However, values of pH, TH, Mg^{2+}, HCO_3^- (both seasons) and K^+ (post monsoon) at some sites are above the desirable limits of BIS 2012. In majority of surface water samples, concentration of alkaline earth metals (Ca^{2+}& Mg^{2+}) exceeded alkali metals (Na^+& K^+) and weak acids (HCO_3^-) exceeded strong acids (SO_4^{2-} & Cl^-). The prominent water chemistry type was Ca–Mg–HCO_3 in both the seasons. The WQI showed that majority of the samples fall in good category and few samples fall in the category of poor water quality. The statistical analysis and data plotted on the Piper diagram suggested that the surface water chemistry was largely controlled by rock weathering with minor contributions from anthropogenic sources. The outcomes of the PCA exhibited that weathering of aquifer material and anthropogenic influx from agricultural activities were the dominant controlling processes in the study region. These results provide a basis for ecological restoration and protection of river environments in the study area.

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Table 6. Varimax rotated component matrix of analysed water samples

Variables	Component (Pre monsoon)			Component (Post monsoon)		
	PC1	PC2	PC3	PC1	PC2	PC3
pH	.660	.482	.034	.910	.238	–.007
EC	.943	.151	–.018	.906	.272	.172
TDS	.943	.151	–.018	.906	.272	.172
TH	.916	.339	.071	.931	.328	–.065
Ca^{2+}	.816	.396	.179	.957	.146	.082
Mg^{2+}	.929	.285	.001	.839	.471	–.196
Na^{+}	.697	.581	.077	.085	.914	–.082
K^{+}	.277	.852	.145	.493	.822	–.029
HCO_3^-	.903	.328	.087	.588	.612	.213
Cl^-	.835	.443	.025	.758	.153	–.481
SO_4^{2-}	.236	.778	–.002	.266	.254	.751
NO_3^-	.756	.343	.167	.519	.615	.458
F^-	.054	.090	.990	–.164	–.156	.623
Eigenvalue	9.046	1.168	1.083	8.153	1.621	1.207
Variance, %	56.055	20.983	8.331	49.941	22.554	11.965
Cumulative, %	56.055	77.038	85.370	49.941	72.495	84.460

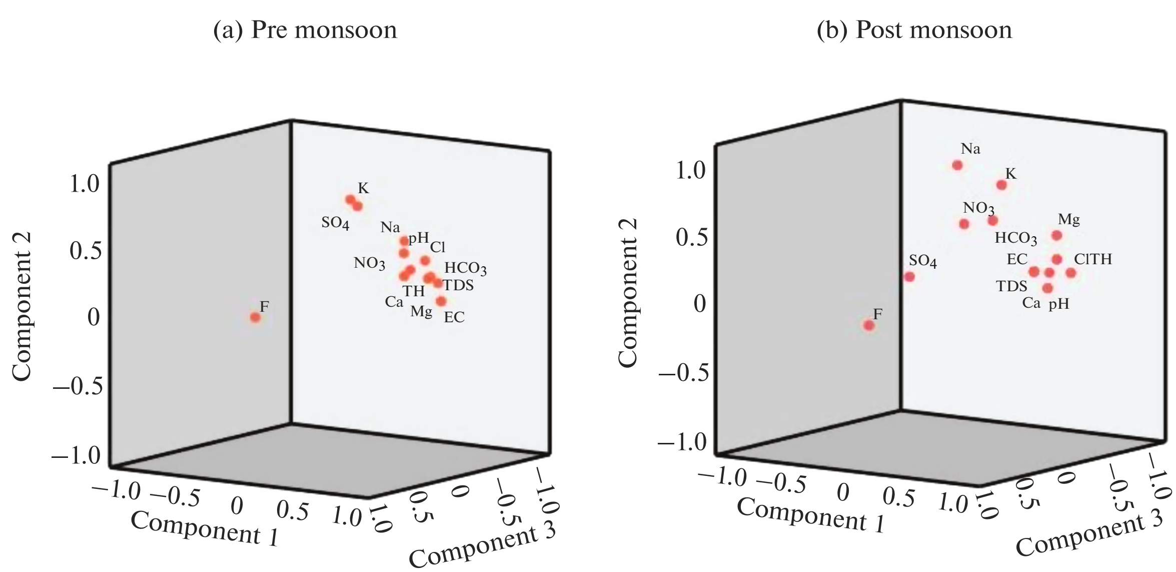

Fig. 4. Principal component plot in rotated space for pre and post monsoon season.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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