**RESEARCH ARTICLE**

# Water quality characterization and pollution source apportionment in the Himalayan river flowing through Jammu City, India, using multivariate statistical approach and geospatial techniques

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## Abstract

The present study evaluates and characterizes the water quality of River Tawi in Jammu city of Union Territory of J&K, using water quality index, multivariate statistical methods, and geospatial techniques. Water quality parameters were measured at fourteen selected sites along a 12 km (approx.) stretch of river (passing through the city) over two seasons (pre-monsoon and post-monsoon) using standard methods. Water quality index (*WQI*) results demonstrated spatial and temporal variations and the pollution level of the river increased from upstream to downstream sites. Calculated *WQI* revealed 35.71% of the water samples in the unfit for drinking category, 28.57% in good and poor category each, and 7.14% samples in very poor drinking water category during the study period. Comparison of analysis results with the drinking water standards prescribed by the World Health Organization and Bureau of Indian standards recorded elevated ranges of parameters like turbidity, BOD, total alkalinity, nitrate, and faecal coliform beyond the permissible limits. Hierarchical cluster analysis has transformed the sites into two clusters during pre-monsoon and three clusters during post-monsoon season indicating more water quality variation during post-monsoon season. Principal component analysis resulted in two PCs for the water quality, explaining 80.827% and 73.672% of the variance for pre-monsoon and post-monsoon periods. The prepared *WQI* maps confirmed and depicted deterioration of river water quality towards the midstream and downstream sites of the river basin. Entry of major sewage drains from the city particularly at the midstream sites and dumping of solid waste and agricultural runoff towards the downstream sites of the river constituted the main anthropogenic sources that decreased the river water quality. The study establishes first step towards spatial zoning of River Tawi based on pollution level which would help in improving the river water quality through proper basin management. The study also recommends installation of sewage treatment plants particularly at the midstream and downstream sites.

**Keywords** Tawi River · Water quality · Spatio-temporal variability · Water quality index · Multivariate statistical analysis · Geospatial analysis

**Highlights**
• The study is an attempt to evaluate the water quality of the River Tawi in Jammu city.
• Fifteen water quality parameters of Tawi water were analysed using standard methods.
• The water quality for drinking purposes was evaluated using the water quality index (*WQI*) method.
• Turbidity, BOD, total alkalinity, nitrate, and faecal coliform are the most effective water quality parameters.
• River Tawi raw water is not suitable for supplying to the city without proper treatment.

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## Introduction

Rivers are the lifelines for the humans, and major human habitations as well as agricultural centres have established close to them since time immemorial (Fathi et al. 2018). Healthy rivers in terms of water quality are indicators of sustainable economic development (Opperman et al. 2018). Rivers regulate floods and provide water for drinking, irrigation, recreation, transportation, propagation of fish, and production of food and other goods besides being habitat to many plants and animal species (Willi and Back 2018). Increased use of water resources due to population explosion, rapid industrialization, and urbanization has caused abnormal changes in the water quality conditions in the surface water systems (Shah et al. 2015;

Soo et al. 2016). Anthropogenic pressures in the form of various point and non-point sources like discharge of liquid wastes, dumping of domestic and industrial wastes, agricultural runoff, energy generation, and other activities further deteriorate the freshwater resources (Zhang et al. 2010; Rashid et al. 2018; Ferronato and Torretta 2019; Liu et al. 2020) and affect the aquatic as well as human health (Mateo-Sagasta et al. 2017). Also, many parts of the world face challenge due to uneven distribution and limited freshwater resources (Mancosu et al. 2015). Literature is booming with plethora of examples where various studies have been undertaken to assess the water quality of different Indian rivers, and these studies revealed the deteriorating trend of water quality throughout India (Shah and Joshi 2017; Dutta et al. 2018; Bowes et al. 2020; Patel et al. 2020; Sharma et al. 2021). Key parameters that determine the water quality of any waterbody are temperature, pH, electrical conductivity, turbidity, total dissolved solids, total hardness, dissolved oxygen, biological oxygen demand, chloride, nutrients (nitrate and phosphate), and faecal coliform (USGS 2001; Uddin et al. 2014). Pathogens in surface waters are derived from both point and diffuse sources with concentrations varying significantly in time. Wastewater discharges from the municipality and considerably polluted tributaries within a river system comprises the point sources of contamination, whereas diffuse sources include agricultural and forestry runoff with microbial constituents from domestic and wild animals in the catchment area (Kinzelman et al. 2004). The surface waters may be a significant disease transmission vehicle owing to the exposure of users to pathogenic organisms present in the water bodies, and the health risk associated with the presence of these microorganisms depends on the pathogen form, type and concentration (Levantesi et al. 2012). According to the World Health Organization (WHO) report on drinking water in the year 2017, nearly 159 million people depend on water from surface sources like rivers, and consumption of such microbiologically unsafe water leads to several water-related diseases like typhoid, diarrhoea, dysentery, and paratyphoid (Osiemo et al. 2019). Monitoring and controlling surface water pollution can ensure availability of good-quality water for various uses (Dunca 2018; Fathi et al. 2018). The spatial and temporal zoning of river water quality reflects the trends of pollution changes across the river in terms of time and space (Abdollahi et al. 2020) and helps in devising strategies for basin management and pollution control (de Andrade et al. 2020).

Water quality index (WQI) is a very useful and efficient method widely used to indicate drinking water quality (Rabeiy 2017). Computation of water quality index using relative weight and quality rating scale has been presented by workers like Brown et al. (1970, 1972), Rabeiy (2017),

Kundan and Slathia (2018), and El Najjar et al. (2019). As a comprehensive indicator, WQI provides overall summaries of water quality and potential trends on a simple and scientific basis (Kaurish and Younos 2007).

Geographical information system (GIS) is an effective tool for the analysis of spatial and non-spatial data to derive useful outputs (Gupta and Srivastava 2010). It provides both spatial and temporal information of surface water characteristics and, hence, has an advantage over the traditional water quality monitoring measurements (O'sullivan and Unwin 2014). WQI-based GIS studies for water quality characterization of various water bodies have been carried out by workers like Selvam et al. (2013) and Jhariya et al. (2017). Furthermore, studies on river water quality characterization using the geospatial techniques have been carried out at national and international levels by various workers (Li et al. 2015; Yan et al. 2015; Madhloom et al. 2018; Oseke et al. 2021). In GIS, among various spatial interpolation techniques, inverse distance weighted (IDW) method has an edge over other interpolation methods for data assessment in waterbodies because of its high accuracy (Madhloom et al. 2018) and is being used extensively for water pollution modelling (Oke et al. 2013; Panwar et al. 2015; Ogbozige et al. 2018). Evaluation of the water quality characteristics of available water resources is necessary for their management. Jammu Province is endowed with diverse water resources in the form of lakes, rivers, and their tributaries. Water quality deterioration of these water resources is attributed to continuous economic expansion of Jammu, which is rated as fastest growing city, urban development, industrial growth, growing population pressure, and inadequate wastewater treatment facilities. The present study attempts to assess the impact of pollution load on surface water quality of River Tawi along the 12 km stretch in Jammu city and to identify the environmentally sensitive or damaged areas along with the probable causes in order to suggest various mitigative measures so that the health and hygiene of people residing in these areas is not further impaired due to lack of care in the assessment of pollution impacts. The study combines WQIs, multivariate statistical analysis, and spatial interpolation geospatial techniques to describe the water quality trends across River Tawi in Jammu city.

## Materials and methods

### Study area

Tawi River, an important surface water source in Jammu region, is located within the Chenab sub-basin of Indus Basin and is the longest left bank tributary of River

Chenab in western parts of the Himalayas. The catchment area of Tawi River is delineated by 32°35′–33°05′N and 74°.35′–75°.45′E. The river originates from Kailash Kund glacier and adjoining areas south-west of Bhaderwah in Doda district and flows through the districts of Doda, Udhampur and Jammu. Major portion of the Tawi River lies in the Siwalik range. The upper Siwalik range (maximum elevation of 4000 m) consists of boulder beds and sand rocks; the intermediate range (elevation of 700 to 1900 m) is composed of coarse sediments, boulders, and pebbles; and the lower Siwalik comprising the present study area lies in Jammu district and varies in elevation from 350 m at the upstream location to 275 m at the downstream site and is composed of fine sediments, gravel sand, silt, and clay (Aqualogus and Oiltech 2018).

River Tawi is perennial, but the water flow is generally lean except in monsoon season. The climate in the study area ranges from sub-humid to sub-tropical type and receives annual rainfall of 1246 mm. Upper catchment of the river is mostly snow fed, and the lower parts are rain fed. In addition, the perennial springs in the catchment area contributes to the water budget of the river. The major land cover class of the Tawi River basin is dominated by agricultural land (38%) followed by the mosaic of cropland and natural vegetation occupying 22% of the basin area. The studied stretch of the Tawi River in the Jammu city is dominated by habitations and the agricultural lands along the banks (Aqualogus and Oiltech 2018).

Being the only surface water source for Jammu city, River Tawi is the lifeline of Jammu as it caters to the drinking and domestic water requirements of population of around 7 lakhs in the Jammu city. Water from Tawi River in Jammu is lifted through Tawi pump house located near the midstream site into the Tawi canal (total length of 28 km) which is used for irrigation, thereby sustaining agricultural activities along its stretch. The river is also considered sacred, and many festivals and fairs are organized on its banks all the year round. On important religious days, thousands of people take holy dip in the river particularly at Har ki Paudi Ghat (Site 6).

## Methodology

### River water sampling

Fourteen sampling stations along River Tawi in Jammu city from Nagrota to Jammu (Raipur Satwari) were selected based on biotic pressure on the river, to have an overall view of water quality and impacts of pollutants on the river (Fig. 1). River monitoring at selected sites was performed during the pre-monsoon and post-monsoon periods in the year 2016, and the sites were further divided into the upstream sites (sites 1–4), midstream sites (sites

5–9), and downstream sites (sites 10–14). Geographical positions of sampling sites were fixed using a portable GPS system (Garmin Montana 680). Water samples were collected in properly cleaned polypropylene bottles (previously rinsed with deionized water) using methods as mentioned in APHA (2005; Part 1060A and 1060B.1a.).

### Analytical procedure

The physico-chemical analysis of water samples was done using standard techniques (APHA, 2005). Water temperature was measured in the field using mercury bulb thermometer (°C); electrical conductivity (EC), turbidity (turb.), total dissolved solids (TDS), and pH were determined by using standardized multi-parameter water analysis kit (Horiba U-52); total alkalinity (TA), dissolved oxygen (DO), chloride ($Cl^-$), calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), and total hardness were analysed using titration methods; biological oxygen demand (BOD) using 5-day test; and sodium ($Na^+$) by flame photometry (microprocessor flame photometer ESICO make). Nitrate ($NO_3^-$) was analysed by phenol disulphonic method using a double beam spectrophotometer. For bacteriological analysis, water samples were collected in sterilized wide mouth BOD bottles by plunging its neck downward below the surface that was later tilted upwards. The bottles were sealed and brought to the lab for analysis. Microbial analysis of water was done using multiple tube technique (APHA 2005). MPN/100 ml was calculated for faecal coliforms. Statistical analysis was carried out with the help of SPSS 17, PAST (v. 4.03) and AquaChem Software applications. Water quality of the samples was assessed by calculating *WQI* values and using several guidelines (WHO 2008; TSI-266, 2005).

### Water quality index (*WQI*)

The suitability of surface water for drinking purposes was evaluated by the Bureau of Indian Standard Water Quality Index (BIS-WQI) and by comparing the values of different water quality parameters with the standards laid down by the World Health Organization (WHO 2008) and Bureau of Indian Standard (BIS 2012) guidelines. BSI-WQI is the Indian national *WQI* standard parameters defined by the Government of India under IS: 10500. However, to identify the overall status of all the parameters, the widely accepted water quality index (*WQI*) technique has been used. Total thirteen water quality parameters, viz. pH, EC, turb., TDS, DO, BOD, TA, $Ca^{2+}$, $Mg^{2+}$, TH, $Na^+$, $Cl^-$, and $NO_3^-$, have been used to calculate *WQI* (Sener et al. 2017; Chakraborty et al. 2021).
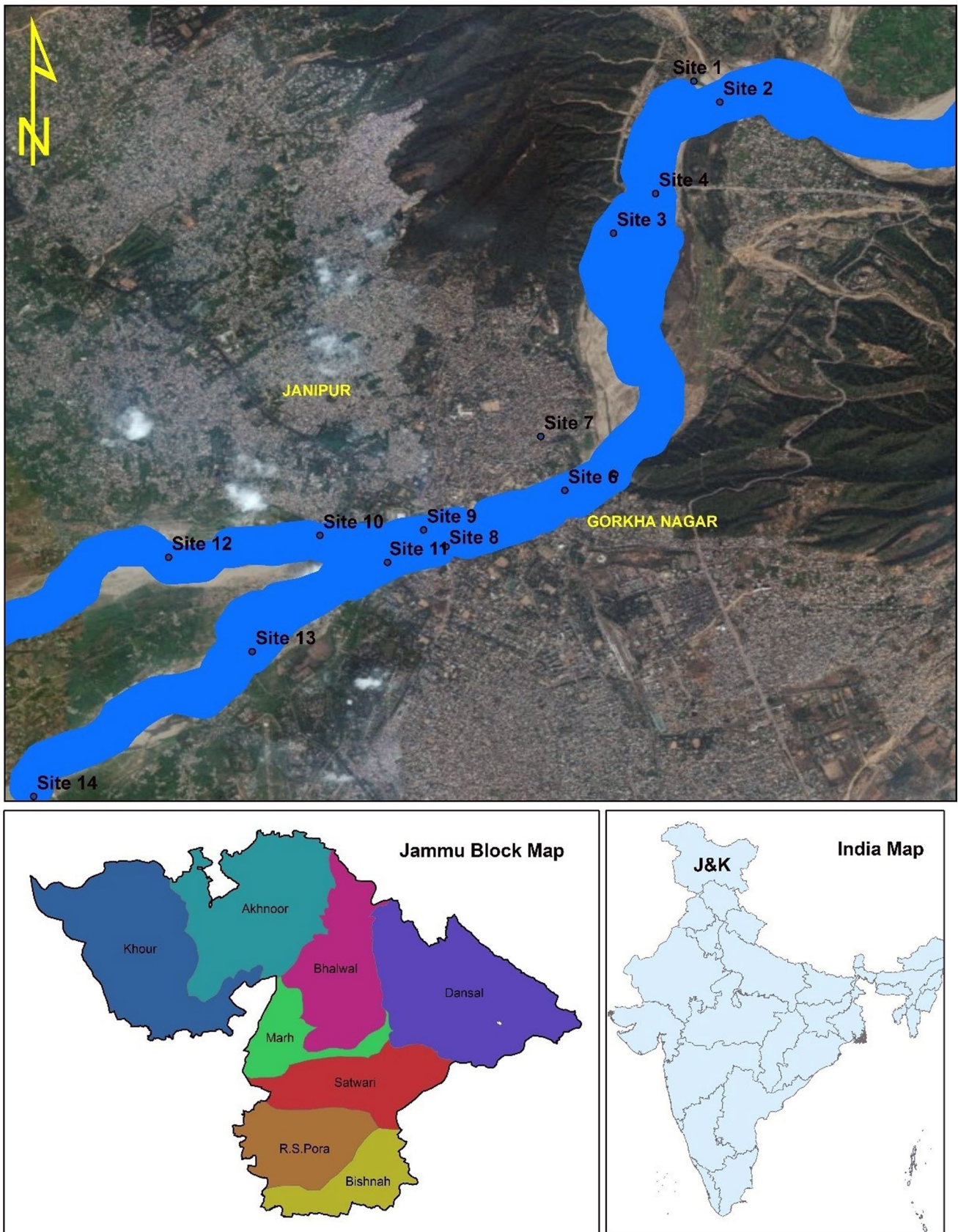
**Fig. 1** Map of study area showing the sampling locations

The categorization of *WQI* rating values was classified using following surface water suitability classification by the BIS-WQI method (Chakraborty et al. 2021):

| Water quality index | Water quality status |
| --- | --- |
| < 50 | Excellent |
| 51–100 | Good |
| 101–200 | Poor |
| 201–300 | Very Poor |
| > 300 | Unfit for drinking |

(Source: MPCB 2019; Chakraborty et al. 2021)

### Multivariate statistical analysis

Hierarchical cluster analysis (HCA) was used to investigate the grouping of the sampling sites along the Tawi River in Jammu into hydro-chemical clusters. Ward's method using squared Euclidean distances as a measure of similarity was used. Hierarchical CA presents a visual summary of the clustering processes in the form of dendrogram, with reduction in dimensionality of the original data (Zhou et al. 2007; Varol et al. 2012).

Principal component analysis (PCA) is a widely accepted statistical tool used to reduce multivariate dataset into fewer dimensions that are not correlated while retaining the maximum informative value of the input data. Principal component analysis (PCA) was conducted to characterize the loadings of all physico-chemical parameters for each of the PCs which were obtained. The quality of data for PCA analysis was confirmed with Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy test, and the rotation of PCs was made by a varimax-normalized algorithm (Fathi et al. 2018).

### Geospatial analysis and generating the water quality maps

The studied stretch of River Tawi falling in Jammu city was modelled using ArcGis 10.6.1 (Esri, Redlands, CA, USA) spatial analysis tools, and the inverse distance weighted (IDW) spatial interpolation technique of GIS to represent and delineate water quality under different constituents. IDW interpolation technique was used to create prediction maps of water quality constituents, viz. turbidity, TDS, BOD, $NO_3^-$, faecal coliform, and the overall surface water quality index (Jamwal and Slathia 2019). IDW interpolation fixes cell values using a linearly weighted combination of a set of sampling points with the variable being mapped showing decrease with distance from its sampled location (Ogbozige et al. 2018). The values of WQI were interpolated with the inverse distance weight (IDW) method by using ArcGIS for its spatial variation in two studied seasons.

## Results and discussion

### Assessment of water quality of river Tawi

A direct comparison of the water quality parameters at different sites was made for the two selected seasons in this study. The mean results of the physico-chemical characteristics of the samples collected from upstream, midstream, and downstream sites of River Tawi are presented in Table 1, with basic descriptive analysis of the fourteen sites shown in Table 2 and the comparison of mean values of physico-chemical parameters with various national and international standards in Table 3. Box plots in Fig. 2 represent the analysis results of different studied water quality parameters at the selected sites of the river. During the pre-monsoon season, the results of the analysis have revealed fairly good water quality indicated by low values of physico-chemical parameters like turbidity (7 NTU) and BOD (1.107 mg/L) and high DO concentration (9.08 mg/L) at the upstream sites, followed by midstream sites with comparatively high turbidity (25.06 NTU), BOD (3.73 mg/L), $NO_3^-$ (1.68 mg/L), and low DO (6.53 mg/L) content. However, at the downstream sites, much higher values of parameters like turbidity (83.62 NTU), BOD (8.73 mg/L), $NO_3^-$ (2.38 mg/L), and faecal coliform (MPN/100ml > 1600) and low DO (5.39 mg/L) during this period indicated high pollution load. Similar spatial variation pattern for these parameters has been observed along the river stretch during the post-monsoon season with comparatively higher values of these parameters during post-monsoon as compared to the pre-monsoon season (Table 1). These spatial variations in physico-chemical parameters from upstream to downstream sites are good indicators of the land use changes in the catchment (Meybeck and Helmer 1989). The upstream sites (1–4) of the Tawi River which are mainly the entry point of river into the Jammu city have very less habitation and therefore very less anthropogenic inputs as compared to the midstream (sites 5–9) and downstream (sites 10–14) stretches which are thickly populated. During its course in the Jammu city, the river receives direct sewage discharges from about 17 natural nullahs which in the past used to take flood water to the river but were later transformed into sewage drains along with several small drains carrying mixed domestic waste and agricultural runoff more towards the midstream and the downstream sites. Also, the untreated wastewater from households located in the old Jammu city, Rehari, Janipur, Gujjar Nagar, and Bhagwati Nagar areas find their entry into these nullahs which finally enter the river Tawi. Non-connectivity of most of the Jammu households with the sewer pipes, non-availability

**Table 1.** Mean surface water quality parameters at upstream, midstream, and downstream sites of River Tawi during two seasons

| Stations | | Seasons | WT °C | pH | EC μS/cm | Turb. NTU | TDS ppm | DO mg/L | BOD mg/L | TA mg/L | Ca$^{2+}$ mg/L | Mg$^{2+}$ mg/L | TH mg/L | Na$^{+}$ mg/L | Cl$^{-}$ mg/L | NO$_3^{-}$ mg/L | FC MPN/100 ml |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Upstream | Sites 1–4 | Pre-monsoon | 28.87 | 7.24 | 289.25 | 7 | 153 | 9.08 | 1.107 | 132.16 | 73.12 | 19.66 | 263.82 | 9.95 | 14.58 | 0.33 | 183 |
| | | Post-monsoon | 27.75 | 7.38 | 402.75 | 39.25 | 198.25 | 9.81 | 1.55 | 112.68 | 63.45 | 26.04 | 266.00 | 18.13 | 19.64 | 0.82 | 920 |
| Midstream | Sites 5–9 | Pre-monsoon | 29.34 | 7.80 | 500.1 | 25.06 | 318.74 | 6.53 | 3.73 | 154.70 | 38.78 | 15.05 | 158.93 | 14.93 | 18.54 | 1.68 | 983 |
| | | Post-monsoon | 28.1 | 7.49 | 855.20 | 158.76 | 533.70 | 5.97 | 13.58 | 225.42 | 40.34 | 15.08 | 163.90 | 14.64 | 37.52 | 2.67 | ≥1600 |
| Downstream | Sites 10–14 | Pre-monsoon | 30.2 | 7.42 | 376.74 | 83.62 | 234.20 | 5.39 | 8.73 | 212.87 | 48.60 | 16.17 | 188.14 | 18.73 | 23.90 | 2.38 | ≥1600 |
| | | Post-monsoon | 28.4 | 7.90 | 716.20 | 314.84 | 485.90 | 7.51 | 16.08 | 238.65 | 46.72 | 17.17 | 186.90 | 15.28 | 33.00 | 3.45 | ≥1600 |

of the sewage treatment plants (STPs) at the midstream sites, and non-functional status of STPs installed at the downstream sites also contribute to this pollution load. Jammu alone contributes around 100 MLD of sewage into River Tawi ("Polluting Tawi" 2017).

Among other physico-chemical parameters, pH with values ranging between (6.60 and 8.15) during pre-monsoon and (6.69–8.16) during post-monsoon observed very low variance (Table 3; Fig. 2e). The pH range was well within the permissible limits of drinking water quality during both the seasons. EC and TDS have shown a similar spatial as well as temporal fluctuation pattern. Direct relation between EC and TDS is already on record (Wetzel 2001) and is supported by their strong significant correlation during pre-monsoon ($r = 0.950$; $p < 0.01$) and post-monsoon ($r = 0.916$; $p < 0.01$) seasons (Tables 4 and 5). Turbidity increase particularly towards the midstream and downstream sites of River Tawi during both the seasons may be attributed to entry of sewage drains and illegal mining activities including collection of sand, gravels, pebbles, stones, and boulders ("Illegal mining" 2019) as this river is an important source of construction material to the Jammu city. High alkalinity at several sites (site 2, site 6, site 11) indicates high bicarbonate content in the water which is also contributed by groundwater as River Tawi is mainly spring fed. Among cations, calcium, and magnesium remained high at the upstream sites which are mainly contributed by the sediments from the surrounding Siwalik hills rich in calcareous deposits. Upstream sites observed less pollution due to low habitation and thus less anthropogenic pressures. Total hardness (TH) is one of the important factors of water quality. Hardness was observed to be high at site 3 (324.50 mg/L) and low at site 9 (100.55 mg/L). Hardness was found positively correlated with calcium ($r = 0.969, 0.869$; $p < 0.01$) and magnesium ($r = 0.839, 0.825$; $p < 0.01$) during pre-monsoon and post-monsoon seasons. Based on the TH values water of Tawi River may be classified as moderately hard (75–150 mg/L) to very hard waters (> 300 mg/L). The concentration of sodium in the studied river water remained high towards the midstream sites.

Among anions, high chloride content in the river water was observed at the downstream sites indicating increased human activities (Bansal and Dwivedi 2018). High chloride content and municipal contamination around the downstream sites relates with the work of Huchhe and Bandela (2016) who attributed high chlorides in water to dissolution of rocks and soils having natural salt formations or due to sewage contamination while studying water quality of Dr. Babashaeb Ambedkar Marathwada University, Aurangabad. Chloride showed a positive correlation with nitrate ($r = 0.763, 0.717$; $p < 0.01$) and BOD ($r = 0.727, 0.899$; $p < 0.01$). Nitrate also recorded high values towards the downstream sites which can be attributed to the location of dumping site and fertilizer application in the

**Table 2.** Descriptive statistics of water quality parameters of River Tawi showing range, mean, standard error (SE), standard deviation (SD), and variance at various sites of River Tawi

| Seasons | | Pre-monsoon | | | | | Post-monsoon | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameters | N | Range | Mean | SE | SD | Variance | Range | Mean | SE | SD | Variance |
| WT (°C) | 14 | 3.0 | 29.51 | 0.22 | 0.8474 | 0.718 | 3.0 | 28.11 | 0.23 | 0.858 | 0.737 |
| pH | 14 | 1.55 | 7.50 | 0.147 | 0.550 | 0.303 | 1.47 | 7.60 | 0.115 | 0.432 | 0.187 |
| EC (µS/cm) | 14 | 358 | 395.8 | 31.99 | 119.73 | 14335.91 | 680.0 | 676.28 | 66.70 | 249.60 | 62300.2 |
| Turb (NTU) | 14 | 161.70 | 40.81 | 11.80 | 44.18 | 1951.97 | 911.0 | 183.93 | 59.98 | 224.41 | 50359.82 |
| TDS (ppm) | 14 | 333.50 | 241.19 | 28.29 | 105.85 | 11204.30 | 791.0 | 420.79 | 64.188 | 240.16 | 57681.56 |
| DO (mg/L) | 14 | 9.89 | 6.85 | 0.681 | 2.55 | 6.51 | 9.73 | 7.61 | 0.875 | 3.274 | 10.725 |
| BOD (mg/L) | 14 | 18.34 | 4.76 | 1.24 | 4.66 | 21.76 | 55.27 | 11.03 | 4.417 | 16.529 | 273.21 |
| TA(mg/L) | 14 | 261.30 | 69.04 | 17.65 | 66.024 | 4359.05 | 283.74 | 197.93 | 24.69 | 92.40 | 8538.93 |
| $Ca^{2+}$ (mg/L) | 14 | 68.05 | 52.10 | 5.76 | 21.55 | 464.58 | 56.73 | 49.22 | 3.75 | 14.06 | 197.70 |
| $Mg^{2+}$ (mg/L) | 14 | 18.93 | 16.76 | 1.59 | 5.96 | 35.54 | 24.20 | 18.95 | 1.90 | 7.126 | 50.79 |
| TH (mg/L) | 14 | 223.95 | 199.33 | 19.46 | 72.82 | 5302.32 | 163.29 | 201.29 | 14.42 | 53.96 | 2911.63 |
| $Na^+$(mg/L) | 14 | 29.8 | 14.86 | 2.14 | 8.00 | 64.14 | 32.0 | 15.86 | 2.60 | 9.71 | 94.28 |
| $Cl^-$ (mg/L) | 14 | 30.03 | 19.32 | 2.31 | 8.64 | 74.78 | 53.34 | 30.79 | 4.74 | 17.74 | 314.87 |
| $NO_3^-$ (mg/L) | 14 | 3.47 | 1.54 | 0.32 | 1.21 | 1.47 | 4.86 | 2.42 | .37 | 1.40 | 1.95 |
| FC (MPN/100ml) | 14 | 1508.0 | 16115.0 | 1151.07 | 656.68 | 431233.61 | 1360.0 | 1405.71 | 131.99 | 493.87 | 243903.3 |

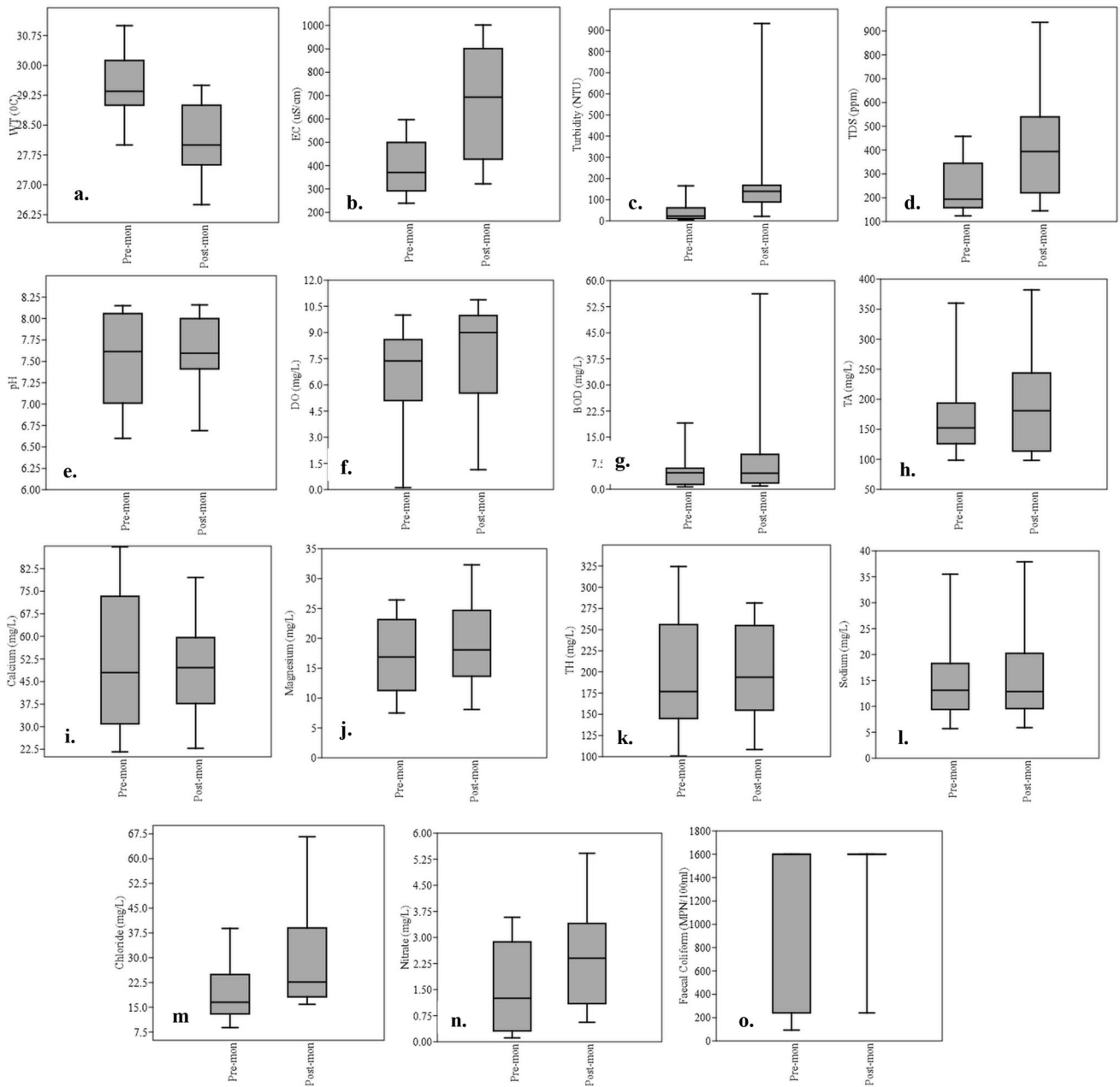**Table 3.** Comparison of water quality parameters of River Tawi with International and National standards

| Seasons | Pre-monsoon | | Post-monsoon | | WHO(2008) | | BIS(2012) | |
|---|---|---|---|---|---|---|---|---|
| Parameters | Min | Max | Min | Max | Desirable | Permissible | Desirable | Permissible |
| WT (°C) | 28.0 | 31.0 | 26.5 | 29.5 | - | - | - | - |
| pH | 6.60 | 8.15 | 6.69 | 8.16 | 6.5-8.5 | No relaxation | 6.5-8.5 | NR |
| EC (µS/cm) | 239.0 | 597.0 | 322.0 | 1002.0 | - | 1500 | - | 3000 |
| Turb (NTU) | 4.00 | 165.70 | 21.0 | 932.0 | - | - | 1 | 5 |
| TDS (ppm) | 124.0 | 457.50 | 145.0 | 936.0 | 600 | 1000 | 500 | 2000 |
| DO (mg/L) | 0.11 | 10.0 | 1.14 | 10.87 | 5** | - | - | - |
| BOD (mg/L) | 0.71 | 19.05 | 0.94 | 56.21 | 2 | - | 3 | - |
| TA(mg/L) | 98.71 | 360.01 | 98.26 | 382 | 300* | 600* | 200 | 600 |
| $Ca^{2+}$ (mg/L) | 21.67 | 89.72 | 22.80 | 79.53 | 100 | 300 | 75 | 200 |
| $Mg^{2+}$ (mg/L) | 7.50 | 26.43 | 8.10 | 32.30 | 30* | 150* | 30 | 100 |
| TH (mg/L) | 100.55 | 324.50 | 118.20 | 281.49 | 100 | 500 | 200 | 600 |
| $Na^+$(mg/L) | 5.70 | 35.50 | 5.9 | 37.9 | 50 | 200 | - | - |
| $Cl^-$ (mg/L) | 8.84 | 38.87 | 15.90 | 69.24 | 250 | 600 | 250 | 1000 |
| $NO_3^-$ (mg/L) | 0.11 | 3.58 | 0.56 | 5.42 | 50 | - | 45 | NR |
| FC (MPN/100 ml) | 92.0 | ≥1600.0 | 240.0 | ≥1600.0 | - | *Must not be detectable in any 100 ml sample | | NR |

*WHO,1997 standard

NR- No relaxation

surrounding agricultural fields near sites 12 and 13 (Brindha et al. 2012; Reda 2015). Nitrate also showed a positive correlation with BOD during pre-monsoon ($r = 0.724$; $p < 0.01$) and post-monsoon (0.732; $p < 0.01$) seasons. Nitrates were well within permissible limits prescribed by the WHO (2008). For unpolluted rivers, the concentration of nitrate should be 0.10 mg/L or less (Meybeck 1982). In our study area, the concentration of nitrate was found significantly high in both the seasons and was more than 0.1 mg/L for most of the sites which indicated that the river water in Jammu is highly contaminated particularly towards the downstream sites. MPN/100 ml of faecal coliform (MPN/100 ml) in the river water remained high at

**Fig 2.** Box plots for comparison of water quality parameters of River Tawi water during the pre-monsoon and post-monsoon seasons. **a** Water temperature, **b** electrical conductivity, **c** turbidity, **d** TDS, **e** pH, **f** DO, **g** BOD, **h** total alkalinity, **i** calcium, **j** magnesium, **k** total hardness (TH), **l** sodium, **m** chloride, **n** nitrate, **o** faecalcoliform

all the sites. Seasonally, it remained low during pre-monsoon as compared to the post-monsoon season but was beyond the permissible limits during the entire study period.

Among various studied sites, site 12 among the downstream sites showed highly deteriorated water quality indicated by low pH (6.6) and DO (0.11 mg/L) and with high values for EC (1002 µS/cm), turbidity (932NTU), BOD (56.21 mg/L), TA (382 mg/L), Cl⁻ (69.24 mg/L), NO₃⁻ (5.42 mg/L), and faecal coliform (MPN/100 ml ≥1600) which is

contributed by the leachate and runoff from Bhagwati Nagar solid waste dumping site located on the bank of River Tawi near this site. This site receives city waste including human excreta, animal excreta, organic matter, slaughter-houses waste, dead animals, etc. High faecal coliform at this site is contributed by the human excreta from the disposal site and animal dung that is applied as manure in large number to the agricultural fields in the vicinity to increase the productivity. The manure overflows into river Tawi during rains and adds

**Table 4.** Pearson correlation coefficient values ($r$) among water quality parameters along with significance levels during pre-monsoon

| Parameters | WT | pH | EC | Turb. | TDS | DO | BOD | TA | $Ca^{2+}$ | $Mg^{2+}$ | TH | $Na^+$ | $Cl^-$ | $NO_3^-$ | FC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WT | 1 | | | | | | | | | | | | | | |
| pH | -.247 | 1 | | | | | | | | | | | | | |
| EC | .061 | .181 | 1 | | | | | | | | | | | | |
| Turb. | .679** | -.257 | .262 | 1 | | | | | | | | | | | |
| TDS | .177 | .217 | .950** | .323 | 1 | | | | | | | | | | |
| DO | -.706** | .164 | -.584* | -.785** | -.653* | 1 | | | | | | | | | |
| BOD | .675** | -.208 | .326 | .948** | .378 | -.861** | 1 | | | | | | | | |
| TA | .475 | -.379 | .200 | .731 | .128 | -.661* | .820** | 1 | | | | | | | |
| $Ca^{2+}$ | -.127 | -.587* | -.706** | -.352 | -.755** | .488 | -.347 | -.021 | 1 | | | | | | |
| $Mg^{2+}$ | .109 | -.568* | -.326 | -.208 | -.300 | .137 | -.169 | -.014 | .678** | 1 | | | | | |
| TH | -.057 | -.626* | -.633* | -.331 | -.660* | .407 | -.314 | -.020 | .969** | .839** | 1 | | | | |
| $Na^+$ | .765** | -.344 | .305 | .658* | .333 | -.846** | .767** | .658* | -.249 | -.045 | -.199 | 1 | | | |
| $Cl^-$ | .529 | -.324 | .387 | .639* | .465 | -.785** | .727** | .543* | -.371 | -.128 | -.317 | .833 | 1 | | |
| $NO_3^-$ | .556* | .125 | .510 | .712** | .595 | -.849** | .724** | .424 | -.724** | -.456 | -.690** | .691** | .763** | 1 | |
| FC | .626* | .229 | .521 | .554* | .544* | -.634* | .560* | .357 | -.585* | -.262 | -.522 | .478 | .458 | .704** | 1 |

to coliform contamination (Thelin and Gifford 1983; Guber et al. 2006) indicated by high *E. coli* during post-monsoon season. Also, water level decline due to bifurcation of River Tawi into two (Nikki Tawi and Wadi Tawi) just 1.5 Km upstream of this site increases the leachate concentration and hence high nutrient level at this site (Fig. 1.). Similar impacts on the water quality were observed on the other downstream sites also.

Comparison of studied water quality parameters of river Tawi with the WHO (2008) and BIS (2012) drinking water standards has shown elevated values for parameters like turbidity, BOD, total alkalinity, nitrate, and faecal coliform (Table 3).
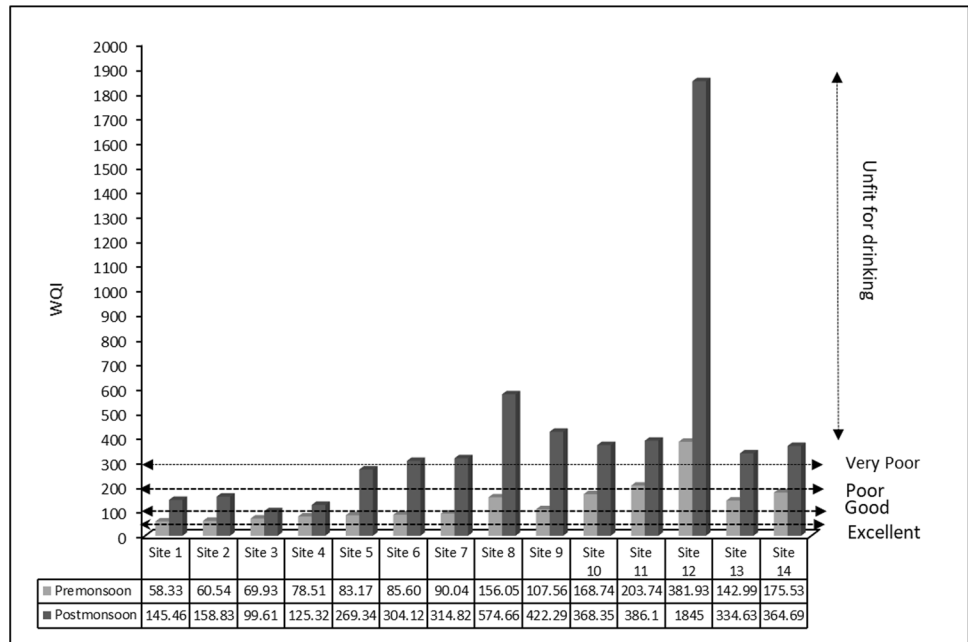
## Water quality index (*WQI*)

Figure 3 represents the *WQI* along with the water quality status of different sites. Relative weights calculated for the studied parameters and the water quality status based on *WQI* have been tabulated in Table 6. *WQI* index observations revealed that 50% of samples fall under the category of good, 35.71% in the poor, and 7.14% each under the

**Table 5.** Pearson correlation coefficient values ($r$) among water quality parameters along with significance levels during post-monsoon

| Parameters | WT | pH | EC | Turb. | TDS | DO | BOD | TA | $Ca^{2+}$ | $Mg^{2+}$ | TH | $Na^+$ | $Cl^-$ | $NO_3^-$ | *FC* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WT | 1 | | | | | | | | | | | | | | |
| pH | -.079 | 1 | | | | | | | | | | | | | |
| EC | .360 | .101 | 1 | | | | | | | | | | | | |
| Turb. | .558* | -.008 | .495 | 1 | | | | | | | | | | | |
| TDS | .441 | .072 | .916** | .692** | 1 | | | | | | | | | | |
| DO | -.589* | .154 | -.682** | -.678** | -.695** | 1 | | | | | | | | | |
| BOD | .547* | -.090 | .562* | .833** | .682** | -.856** | 1 | | | | | | | | |
| TA | .602* | -.145 | .600* | .740** | .646* | -.833** | .867** | 1 | | | | | | | |
| $Ca^{2+}$ | .052 | -.250 | -.477 | -.195 | -.348 | .165 | -.144 | -.175 | 1 | | | | | | |
| $Mg^{2+}$ | -.341 | -.193 | -.531 | -.433 | -.605* | .417 | -.335 | -.358 | 0.439 | 1 | | | | | |
| TH | -.157 | -.266 | -.599* | -.365 | -.562* | .330 | -.278 | -.319 | .869** | .825** | 1 | | | | |
| $Na^+$ | .405 | -.213 | .216 | .574* | .367 | -.608* | .821** | .570* | 0.260 | .121 | .228 | 1 | | | |
| $Cl^-$ | .604* | -.020 | .592* | .686** | .704** | -.875** | .899** | .847** | -0.083 | -.398 | -.278 | .749** | 1 | | |
| $NO_3^-$ | .553* | .227 | .820** | .745** | .885** | -.679** | .732** | .791** | -0.308 | -.538* | -.503 | .353 | .717** | 1 | |
| FC | .053 | -.079 | .347 | .299 | .329 | -.320 | .239 | .421 | -0.233 | -.575* | -.463 | -.209 | .195 | .467 | 1 |

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

**Fig 3.** Water quality index (*WQI*) and water quality status at different sites of River Tawi during the pre-monsoon and post-monsoon seasons



| | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 | Site 8 | Site 9 | Site 10 | Site 11 | Site 12 | Site 13 | Site 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Premonsoon | 58.33 | 60.54 | 69.93 | 78.51 | 83.17 | 85.60 | 90.04 | 156.05 | 107.56 | 168.74 | 203.74 | 381.93 | 142.99 | 175.53 |
| Postmonsoon | 145.46 | 158.83 | 99.61 | 125.32 | 269.34 | 304.12 | 314.82 | 574.66 | 422.29 | 368.35 | 386.1 | 1845 | 334.63 | 364.69 |

category of very poor and unfit for drinking during pre-monsoon. However, during the post-monsoon, 7.14 % of samples were categorized as good and very poor each, 21.42% as poor, and the maximum, i.e. 64.28% of the samples as unfit for drinking. The findings revealed that high BOD and turbidity were the main contributory factors to deteriorating water quality and hence high *WQI*. Among the altitudinal gradient, the upstream sites observed good water quality during pre-monsoon season but poor water quality during post-monsoon season (Fig. 3). The water quality deteriorated towards the downstream sites (site 12) indicated by the high *WQI* values which has its correlation with high

**Table 6.** Relative weights of the chemical parameters for *WQI*

| Parameters | Standard value | Weight ($w_i$) | Relative weight ($W_i$) |
|---|---|---|---|
| pH | 6.5–8.5 | 4 | 0.071 |
| EC | 300 | 5 | 0.089 |
| Turb | 5 | 5 | 0.089 |
| TDS | 500 | 5 | 0.089 |
| DO | 6 | 5 | 0.089 |
| BOD | 5 | 5 | 0.089 |
| TA | 200 | 3 | 0.054 |
| $Ca^{2+}$ | 75 | 4 | 0.071 |
| $Mg^{2+}$ | 30 | 3 | 0.054 |
| TH | 300 | 4 | 0.071 |
| $Na^+$ | 100 | 3 | 0.054 |
| $Cl^-$ | 250 | 5 | 0.089 |
| $NO_3^-$ | 45 | 5 | 0.089 |
| | | $\sum w_i = 56$ | $\sum W_i = 1.0$ |

pollution load in terms of the physico-chemical parameters like turbidity, BOD, and faecal coliform observed at this site as discussed in the preceding section.

## Hierarchical cluster analysis

According to the prepared dendrogram, 28 monitoring stations could be grouped into two statistically significant clusters in a distant connection (Dlink / Dmax) × 100. Hierarchical CA rendered a dendrogram where all the sites were clustered into two main clusters during pre-monsoon and three during post-monsoon seasons as illustrated in Fig. 4(a and b). Cluster 1 during the pre-monsoon consisted of mostly upstream less polluted sites (1, 2, 3, 4, 7) along with site 13 where pollution was less and the cluster 2 (5, 6, 8, 9, 10, 11, 14) where pollution level was comparatively high due to entry of sewage drains. Site 12 showed the highest level of pollution as it showed dissimilarity with other sites. During post-monsoon, cluster 1 consisted of sites 5, 6, 7, 10, 11, 13, and 14; cluster 2 consisted of sites 1, 2, 3, and 4; and cluster 3 consisted of sites 8, 9, and 12. Based on the cluster analysis, it can be interpreted that cluster 1 represents low polluted sites (mostly upstream), cluster 2 moderate polluted sites (midstream), whereas cluster 3 represents highly polluted sites (downstream sites). The cluster analysis further confirmed that the leachate and runoff from the dumping site (site 12) contributed higher pollution load compared to other sites; hence, the site was dissimilar with the other sites. These findings are also in conformity with the values obtained for

**Fig. 4.** Dendrogram of cluster analysis of study sites into low, moderate, and high pollution areas. **a** Pre-monsoon. **b** Post-monsoon
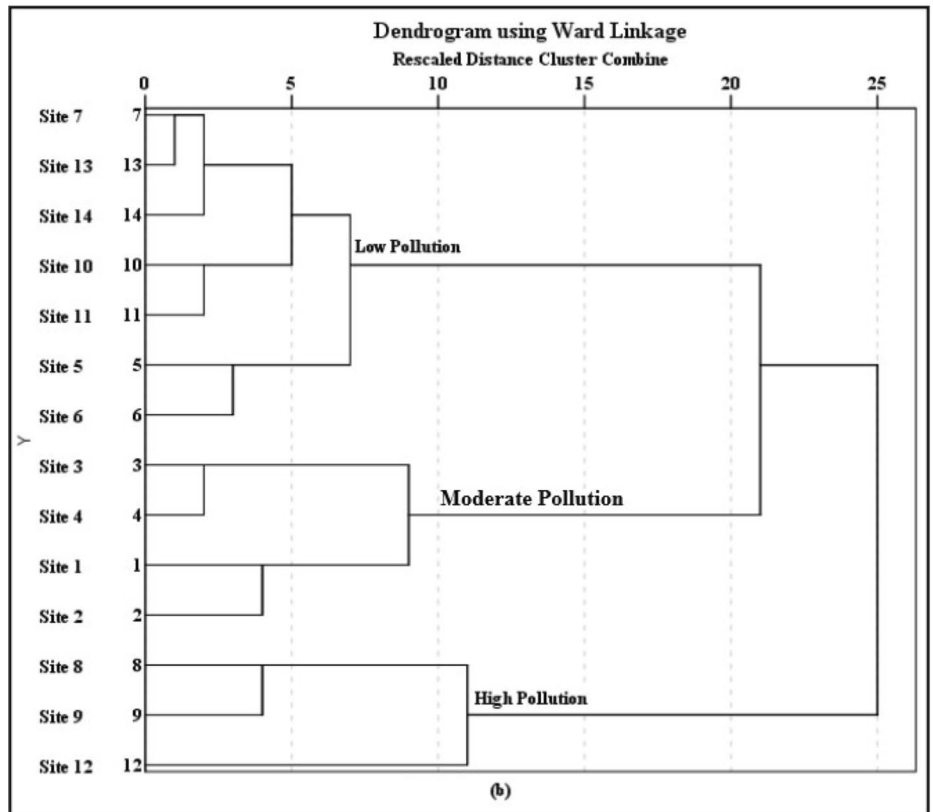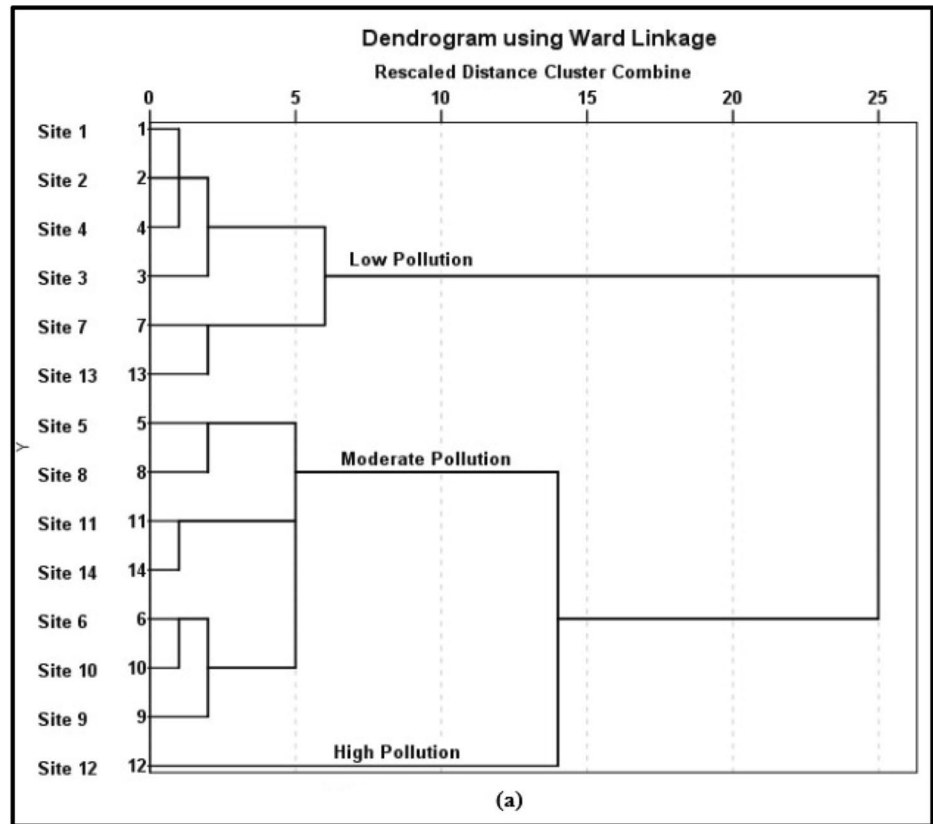
*WQI*. Therefore, for a rapid water quality assessment, only one site from each cluster is enough, and it can serve as a good indicator of water quality for the whole group.

## Principal component analysis

Table 7(a and b) shows the component loading factors, cumulative percentage, and percentage of variance explained by each principal component. Standardized datasets were employed for performing PCA, and in varimax rotated component matrix, only two PCs were obtained for the water quality during both the seasons with eigenvalue larger than 1, explaining 80.827% and 73.672% of the variance for pre-monsoon and post-monsoon periods. The first PC for water quality in

**Table 7.** Rotation component matrix for water quality parameters in Tawi River waters

| Parameter | Component | |
|---|---|---|
| | 1 | 2 |
| a Pre-monsoon | | |
| Total hardness (mg/l) | **.955** | -.136 |
| $Ca^{2+}$ (mg/l) | **.939** | -.215 |
| Conductivity(uS/cm) | **-.796** | .137 |
| $Mg^{2+}$ (mg/l) | **.773** | - |
| TDS (ppm) | **-.760** | .387 |
| $Na^+$ (mg/l) | | **.939** |
| DO (mg/l) | .340 | **-.903** |
| $Cl^-$ (mg/l) | -.202 | **.880** |
| BOD (mg/l) | | **.873** |
| $NO_3^-$ (mg/l) | -.580 | **.714** |
| % of Variance | 56.238 | 24.589 |
| Cumulative % | 24.589 | 80.826 |
| b Post-monsoon | | |
| DO (mg/l) | .332 | **-.855** |
| Total hardness (mg/l) | **.934** | .092 |
| $Cl^-$ (mg/l) | -.407 | **.788** |
| Conductivity(uS/cm) | **-.776** | .414 |
| $Ca^{2+}$ (mg/l) | **.760** | .164 |
| BOD (mg/l) | -.122 | **.901** |
| $Mg^{2+}$ (mg/l) | **.827** | -.013 |
| $Na^+$(mg/l) | .311 | **.900** |
| $NO_3^-$ (mg/l) | **-.739** | .341 |
| pH | -.335 | -.535 |
| % of Variance | 43.202 | 30.469 |
| Cumulative % | 43.202 | 73.672 |

Extraction method: principal component analysis.

Rotation method: Varimax with Kaiser normalization[a]

a. Rotation converged in 3 iterations

pre-monsoon with high positive loadings for the TH, calcium, and magnesium but negatively loaded with electrical conductivity and TDS accounted for 56.238% of total variance. The second PC representing 24.589% of the total variance is positively loaded with sodium and chloride and negatively loaded with DO. During post-monsoon, the first PC for water quality has high positive loadings for the TH, calcium, and magnesium but is negatively loaded with electrical conductivity and nitrate and accounted for 43.202% of total variance. The second PC accounted for 30.469% of the total variance and observed positive loadings for chloride, BOD, and sodium and is negatively loaded with DO. In the present study, by performing PCA, the parameter number has been reduced from 15 to 10. Positive loadings on total hardness, calcium, and magnesium indicated that those enrichments on the Tawi River were derived from erosion due to deforestation of catchment, mining activities, and riverine runoff which was mostly observed at the upstream sites (sites 1–4) (Verma et al. 2012). The positive loading of chloride, BOD, and nitrate influenced DO which decreased and indicated sewage inflow which resulted in higher concentration of these nutrients and is observed for the midstream and downstream sites (sites 5–14).

## Geospatial analysis

The spatial distribution maps of parameters like turbidity, TDS, BOD, and nitrate during both the seasons are depicted in Fig. 5. Spatial distribution of faecal coliform and *WQI* of the monitored river during both the seasons are shown in Fig. 6 and have clearly depicted increase in pollution towards the midstream and downstream sites.

## Conclusions

River Tawi is a sacred river in Jammu city but is fast losing its original water quality characteristics and diversity and density of biota due to pollution. The spatial distribution pattern of the studied water quality parameters with higher concentration of BOD, chloride, nitrate, and faecal coliform at the sites near the sewage drains and disposal site (downstream) confirms substantial inputs of the contaminants possibly from the sewage drains and the waste dumping from Jammu city. From the *WQI* and the obtained results for physico-chemical parameters, it can be concluded that the Tawi River water in Jammu is polluted at the midstream and downstream sites and is mostly unsuitable for human use. The present study describes a methodical integrated approach using physico-chemical data for different sites of the river combined with data analysis based on
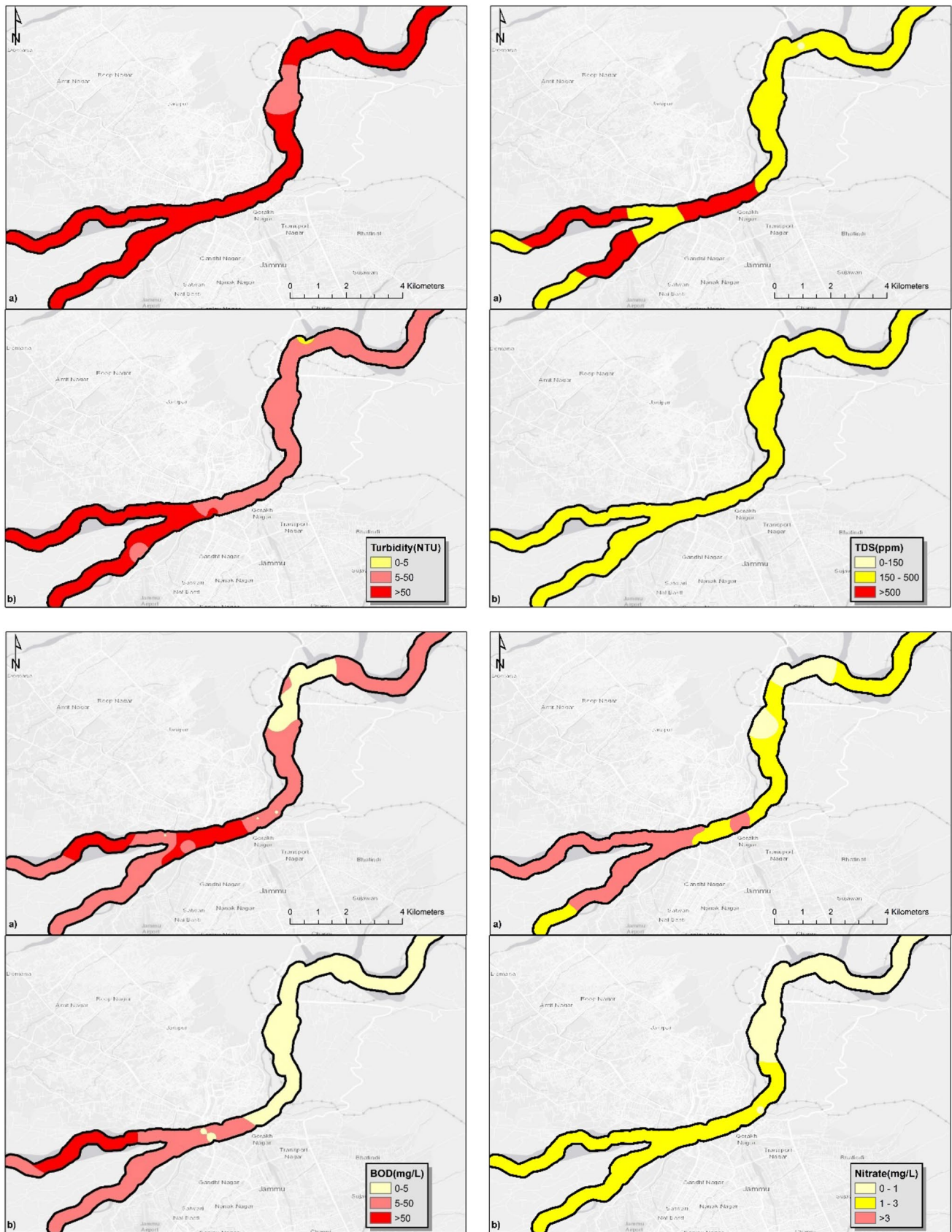
**Fig. 5** Spatial distribution of turbidity, TDS, BOD, and Nitrate during **a** pre-monsoon and **b** post-monsoon seasons
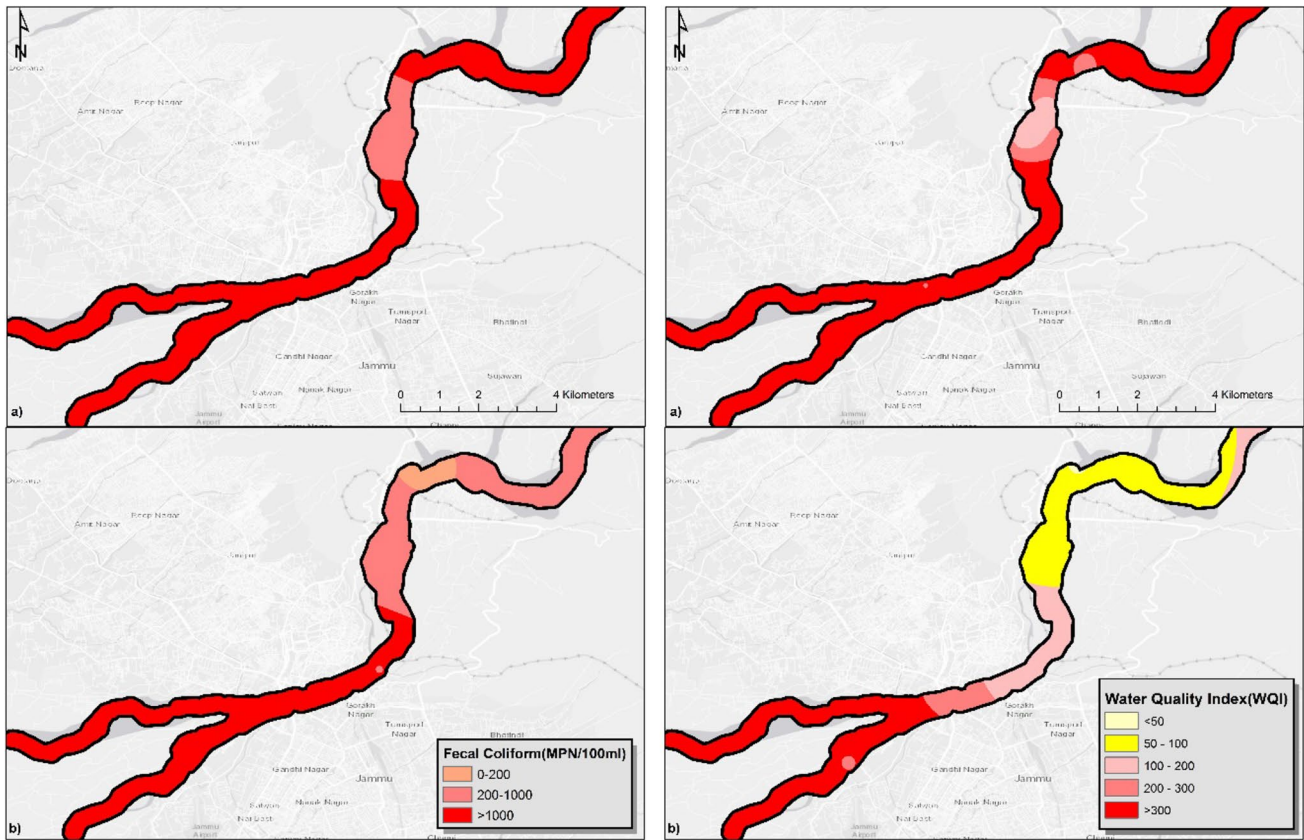
**Fig. 6** Spatial distribution of faecal coliform and *WQI* during **a** pre-monsoon and **b** post-monsoon seasons

methods like *WQI*, HCA, and PCA which have given complementary results and could be used in similar types of studies. PCA results have reduced the water quality parameter number from 15 to 10 which can be used for pollution source apportionment along the Tawi River stretch in Jammu region; the upstream being dominated by weathering and erosion indicated by positive loadings on parameters such as total hardness, calcium, and magnesium; midstream dominated by pollution load from the city sewage drains; and the downstream sites having high contamination levels due to combined wastes in the form of leachates from solid waste dumping site, entry of sewage drains, and agricultural runoff from the agricultural fields located in the Tawi floodplain which is indicated by the positive loading of parameters such as chloride, BOD, nitrate, and FC. It can also be summarized that the *WQI* value integrated with GIS can be directly used to analyse and compare conditions in different stretches of any river and to detect its quality by trends.

Based on the above finding, the study recommends installing sewage treatment plants at the midstream and the downstream sites (particularly near site 12) and improving the sewerage systems particularly of the Old Jammu city ensuring zero discharge of waste into the river, banning/ restricting the agricultural activities along the banks particularly at the river floodplain towards the downstream sites, establishment of sustainable urban drainage systems for all the drains entering into the river, riverfront development right from the upstream to the downstream sites, and creation of artificial aeration facilities particularly at site 12 to improve the DO levels in the river. Simultaneously, the flow in the river remains low except during the monsoon which must be augmented. The agricultural runoff which directly enters the river at the downstream sites can be reduced by constructing filter and buffer strips around the fields adjacent to the riverbank. In addition, afforestation along the riverbanks particularly towards the upstream sites would help in controlling siltation and erosion. River Tawi is mostly fed by natural springs which have vanished due to various anthropogenic pressures and measures should be taken to revive these springs. The results of the present study would be helpful for the environmental planners to design, formulate, and implement the pollution abatement strategies for the Tawi River.

## Declarations

**Ethics approval and consent to participate** Not applicable

**Consent for publication** Not applicable

**Competing interests** The authors declare no competing interests.

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