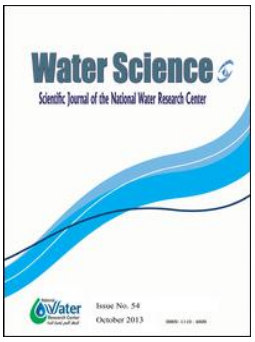

Water Science

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/twas20

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To cite this article: Arun Kumar Pramanik , Deepanjan Majumdar & Abhik Chatterjee (2020) Factors affecting lean, wet-season water quality of Tilaiya reservoir in Koderma District, India during 2013–2017, Water Science, 34:1, 85-97, DOI: 10.1080/11104929.2020.1765451

To link to this article: https://doi.org/10.1080/11104929.2020.1765451

WATER SCIENCE
2020, VOL. 34, NO. 1, 85–97
https://doi.org/10.1080/11104929.2020.1765451

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Factors affecting lean, wet-season water quality of Tilaiya reservoir in Koderma District, India during 2013–2017

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ABSTRACT

The reservoir at the Tilaiya Dam constructed on the Barakar river is one of the most important freshwater resources in the Koderma District in the state of Jharkhand in India. Its water is used primarily in agriculture, pisiculture, industry, regional thermal power plant, and various domestic errands viz. cooking, washing, and drinking. The reservoir also supports a wide variety of flora, fauna, and birds. This work reports the variation in seasonal water quality (pH, turbidity, DO, TDS, electrical conductivity, total hardness, iron, chloride, calcium, magnesium, alkalinity, phosphate, sulfate, fluoride, total bacterial count, and fecal coliform count) trends over a 4-year long period (July 2013–July 2017). Conspicuous dilution effect on water quality was observed during and just after the monsoon season while concentrations of TDS, electrical conductivity, iron, chloride, calcium, magnesium, phosphate, sulfate, and fluoride increased during summer. Principal Component Analysis/Factor Analysis (PCA/FA) identified three factors in the data structure, explaining about 71.5–77.9% of total variance in dataset. Run-off from catchment areas was one of the major factors that influenced water quality during the monsoon seasons. The *t test* indicated that except between summer and post-monsoon in 2013 and 2014, seasonal DO values had statistically significant difference. Also, turbidity in summer, post-monsoon and winter seasons had statistically significant differences while total hardness (TH) was statistically different in summer over winter but not in summer over post-monsoon. On the other hand, TDS did not have statistically significant seasonal shifts. Water quality index (WQI), pollution index (PI), comprehensive pollution index (CPI), computed over the study years revealed that water quality of the reservoir could be categorized as 'Good' but is gradually deteriorating. This calls for greater attention and proper management of the Tilaiya reservoir in the interest of environmental and regional sustainability of Koderma.

ARTICLE HISTORY
Received 14 May 2019
Revised 27 April 2020
Accepted 3 May 2020

KEYWORDS
Factor analysis; seasonal variation; water quality index; pollution index; comprehensive pollution index

Introduction

Two important reservoirs have been constructed on the Barakar River in India; the Tilaiya Dam Reservoir and the Maithon Dam Reservoir. The Tilaiya reservoir along the dam is situated about 208 km above the point it meets the river Damodar (Central Inland Fisheries Research Institute [CIFRI], 1966). Catchment of Tilaiya dam is among the five sub-catchments in the catchment of Damodar-Barakar in upper Damodar Valley (Trivedi & Singh, 2005). Tilaiya reservoir with its catchment area falls under the Jharkhand state, many of the residents of which do not have access to safe drinking water and only about 30% of habitation has partial access to drinking water supplies (Govt. of Jharkhand, http://www.jharkhand.gov.in/abou-more-water). The Jharkhand state is rich in natural resources and boasts of steel plants, coal mines, mica mines, thermal power plants, etc. The dams in the state were constructed for hydroelectric power generation, flood control, and irrigation while in recent years, demand of dam water has increased many folds due to ever-growing agriculture, industrial activity and hydropower generation. Industrial growth in the region has triggered a slow growth in population, urbanization, cattle breeding, irrigation, etc. Water quality of the Tilaiya Reservoir is therefore critical for agriculture, regional environmental sustainability, and human health. Mukherjee et al., (2012) have evaluated the water quality index (WQI) for evaluating potability of the Damodar river water in Jharkhand and West Bengal in India and reported pollution of Damodar river from various sources. Presence of dam is critical for river water quality and negative impact of dam construction on water quality has been reported by Santucci et al., (2011) who found fluctuations in dissolved oxygen (DO) and pH (2.5–18.0 mg/L and 7.0–9.4, respectively) in impounded reaches of low-head dams on the Fox river in Illinois. Wei et al. (2009) reported that the Manwan Reservoir water quality deteriorated from prior to dam construction to the first 7 years after dam completion on the Lancang River in China while in next 5 years, water quality improved due to self-purification of the reservoir. Kurunc et al., (2006) reported that select water quality parameters during

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the pre-construction period of the Kilickaya dam were different significantly from post-dam period in Turkey, underlining likely influence of dam construction on river water quality.

No comprehensive information is available on medium to long-term water quality trends of the Tilaiya reservoir that puts a roadblock to the understanding of possible impacts on its water quality and the likelihood of growing pollution, leading to potential risks to regional agricultural and residential sectors. Therefore, water quality of the Tilaiya reservoir water was extensively studied over a period of several years to understand water quality trends and prepare a likely scenario of growing pollution. Apart from studying the trends in physicochemical characteristics of reservoir water and their correlation, WQI, pollution Index (PI), and comprehensive pollution index (CPI) of dam water were determined for evaluating water quality. This is the first comprehensive reporting of water quality, WQI, PI, and CPI of the Tilaiya reservoir water in the lean and wet seasons over several continuous years and suitability of reservoir water for various services in this region. Factor analysis (FA) based on a varimax rotation technique was used as a statistical tool for identifying various factors that governed reservoir water quality by extracting minimum acceptable Eigenvalue >1.

Material and methods

Study area

In 1953, Damodar Valley Corporation (DVC) constructed the Tilaiya Dam (24°19′26″ N 85°31′16″ E), a concrete gravity dam of 30.2 m (99 ft) tall above the river bed, across the Barakar River (a tributary of Damodar River) at 64.4 km downstream of latter in the Koderma District of Jharkhand State in India (Figure 1). Tilaiya dam has a catchment area of 984 sq. km and a discharge of about 9.23 $m^3 s^{-1}$ (Singh et al., 2005) and dead storage and conservation storages of 75 and 141 million cubic meters, respectively. The catchment area mostly comprises of villages, forested areas, wasteland, pastures, and cultivated land in hilly terrains (Tyagi et al., 2014). Tilaiya dam has a maximum discharge capacity of 3852 $m^3 s^{-1}$ primarily targeted for agriculture during the dry season (Tyagi et al., 2014). Tilaiya hydropower station (two generating units of 2 MW each) is also located on one side of the Tilaiya dam. It is located in a zone receiving 112 cm annual rainfall on an average and annual average run-off of 432 million cubic meters (Damodar Valley Corporation, http://www.dvcindia.org.in/dvcwebsite_new1/dams-barrages/index.html).

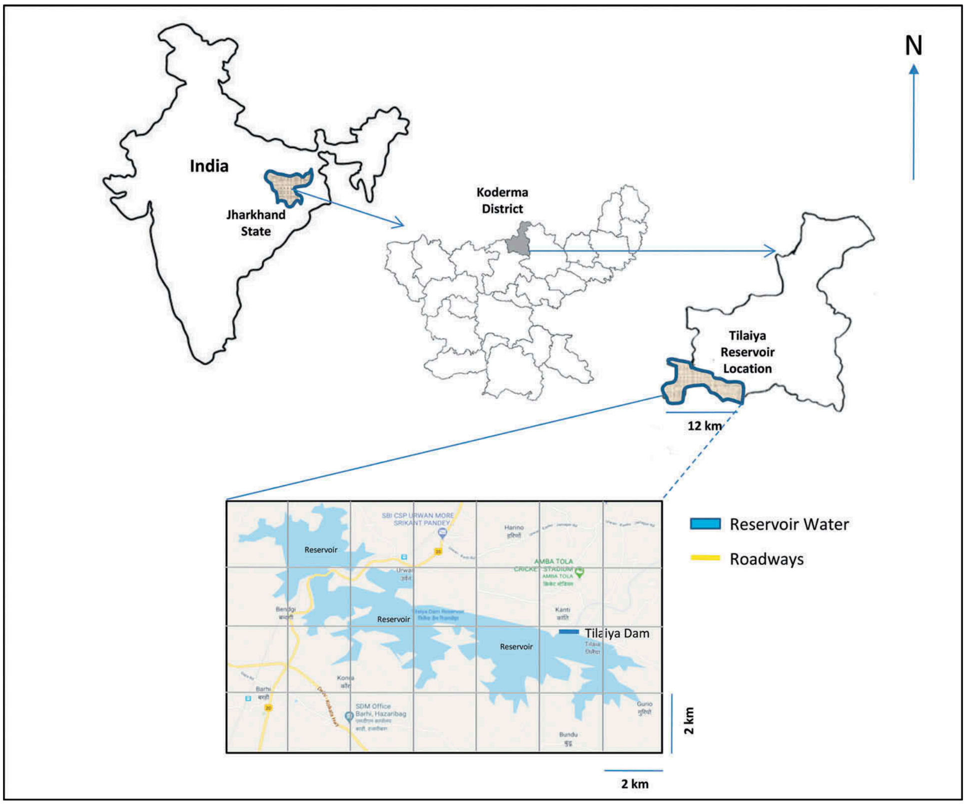

Figure 1. Location of the Tilaiya Dam and Reservoir *vis a vis* state of Jharkhand in India.

Sampling and analysis

Water was sampled in triplicate at a select sampling station in the Tilaiya reservoir on the dam at least twice in every month at an approximate interval of 2 weeks during July 2013 to July 2017. Samples were collected from 40 to 50 cm depth in polypropylene bottles for physicochemical analyses and sterilized glass bottles for bacteriological analyses as per standard methods (APHA, 1999; CPCB, 2007). Measurement of temperature, electrical conductivity, pH, turbidity, and DO was undertaken at the sampling site by portable conductivity meter (HANNA, France), pH meter (TOSHCON), Turbidity meter (HANNA, France), DO meter (WTW) and a mercury thermometer, respectively. The other parameters viz. total hardness (TH), alkalinity, calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), F^-, sulfate ($SO_4^{=}$), TDS, etc. were analyzed as per standard methods (APHA, 1999). Total Bacterial Count (TBC) and Fecal Coliform (FC) count were determined by a Microbe Detection Device (BACTASLYDE, Rakiro Biotech System Pvt. Ltd.) having a lowest detection limit of 100 colony mL^{-1} water.

The study reflected reservoir water quality trend over a four-year period from mid-2013 (July) to mid-2017 (July) and also, definite trends in specific water parameters. Also, seasonal water quality assessment determined its suitability for various purposes. The results were compared to standards for drinking water prescribed by Bureau of Indian Standards (IS 10500, 2012) in India and WHO (BIS, 2012; WHO, 2011) as the water is also used for drinking in the region. Further, various water quality indices were calculated to evaluate reservoir water quality in terms of its suitability for various uses.

Computation of water quality indices

Water quality index (WQI)

Apart from determination of individual parameters to understand water quality, quality of the water was also measured in terms of various water quality indices to ascertain its suitability for drinking, domestic, agricultural, and industrial (Alobaidy et al., 2010; Bharti & Katyal, 2011; Debels et al., 2005). Weighted Arithmetic Water Quality Index Method, British Columbia Water Quality Index (BCWQI), US National Sanitation Foundation Water Quality Index (NSFWQI), Smith's index, Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), Bhargava water quality index method, Overall Index of Pollution (OIP), Oregon Water Quality Index (OWQI), etc. have been formulated and used worldwide for water quality evaluation (Alobaidy et al., 2010; Asadi et al., 2007; Bharti & Katyal, 2011; Debels et al., 2005; Hasan et al., 2015; Imneisi & Aydin, 2016; Javid et al., 2014; Jindal & Sharma, 2011; Kumari & Rani, 2014; Moscuzza et al., 2007; Muntasir et al., 2012; Patki et al., 2013; Sharifi, 1990; Singh et al., 2011; Tirkey et al., 2015; Zandagba et al., 2017). A weighted arithmetic index method calculation involves estimation of 'unit weight' of each water parameter and then by assigning unit-weights on such parameters, the quality rating of the parameters was calculated by using standard and ideal value of the parameters. The Water Quality Index (WQI) was calculated by using Weighed Arithmetic Index Method (Bharti & Katyal, 2011; Hasan et al., 2015; Javid et al., 2014; Kumari & Rani, 2014):

$$\mathrm{WQI} = \frac{\sum_{i=1}^{n} \mathrm{QnWn}}{\sum_{i=1}^{n} \mathrm{Wn}} \tag{1}$$

where Q_n is the quality rating value corresponding to the n^{th} water quality parameter and W_n is the unit weight of the n^{th} parameter·

Quality rating value (Q_n) is the number that reflects relative value of those parameters with respect to its standard permissible value.

$$\mathrm{Qn} = 100\frac{(\mathrm{Vn} - \mathrm{Vi})}{(\mathrm{Sn} - \mathrm{Vi})} \tag{2}$$

where, V_n is the observed value of the n^{th} parameter of the given water sampling, S_n is the Standard permissible value of the n^{th} parameter, and V_i is the ideal value of the n^{th} parameter in pure water. Unit weight (W_n) of various water quality parameters is inversely proportional to the recommended standard value (S_n) i.e. standard permissible value of the corresponding parameters:

$$W_n = \frac{K}{S_n} \tag{3}$$

where, K is the proportionality constant and it is calculated by the following equation:

$$K = \left(\frac{1}{\sum \frac{1}{(S_n)m}}\right) \text{ and } m = 1, 2, 3 \ldots\ldots n.$$

The ranges of the WQI, the corresponding status of the water quality, grading of the water quality and their possible use (Asadi et al., 2007; Bharti & Katyal, 2011; Hasan et al., 2015; Tirkey et al., 2015) are summarized in Table 1.

Pollution index (PI)

PI (Mishra et al., 2016) was also estimated for the samples of reservoir water. Classification of water quality according to PI is presented in Table 2. This index indicates the pollution status of water on the water quality to help take the necessary actions to improve water quality. The PI was calculated by the equation given below (Sidabutar et al., 2017):

Table 1. Water quality index (WQI) and corresponding water quality status, grading, and possible uses.

WQI	Status	Grading	Possible uses
0–25	Excellent	A	Drinking, Irrigation, and Industrial
26–50	Good	B	Domestic, Irrigation, and Industrial
51–75	Fair	C	Irrigation and Industrial
76–100	Poor	D	Irrigation
101–150	Very Poor	E	Restricted use for Irrigation
Above 150	Unfit for Drinking	F	Proper treatment required before use

Table 2. Classification of water quality status based on pollution index.

PI	Category
0.0< Plj≤ 1.0	Good water quality
1.0 < Plj ≤ 5.0	Lightly polluted
5.0 < Plj≤ 10.0	Polluted
Plj>10.0	Extremely polluted

$$\mathrm{PIj}=\sqrt{\frac{(\mathrm{Ci/Lij})_{\mathrm{M}}^{2}+(\mathrm{Ci/Lij})_{\mathrm{R}}^{2}}{2}} \tag{4}$$

where,

L_{ij} = Concentration of parameter specified in raw water

C_i = Concentration of obtained parameter

PI_j = Pollution Index for allotment

R = Average

M = Maximum

Comprehensive pollution index (CPI)

CPI is also an essential tool to evaluate water quality of water bodies (Kumar & Sharma, 2015; Sidabutar et al., 2017; Wang et al., 2018; Yadav et al., 2018). It is calculated as per the following equation:

$$\mathrm{Pli}=\frac{\mathrm{Ci}}{\mathrm{Si}} \tag{5}$$

$$\mathrm{CPI}=\frac{1}{N}\sum_{i=1}^{n}(Ci/Si) \tag{6}$$

Where,

PI_i = pollution index of the i^{th} parameter of the water.

C_i = concentration of the i^{th} parameter of the water .

Si = standard permissible concentration of the i^{th} parameter in the water; and

N = total number of parameters.

The ranges of the CPI, the corresponding status of the water quality and their possible use (Liu et al., 2010; Md. Bodrud-Doza et al., 2016; Ramakrishnaiah et al., 2009; Tiwary et al., 2017) are summarized in Table 3.

Statistical and factor analysis

The 4-year water quality database was analyzed for descriptive statistics, inter-parameter correlation, and regression to evaluate trends in reservoir water quality. Correlation analysis, that reveals coherence pattern among water quality parameters (Thirupathaiah et al., 2012) through Pearson's correlation coefficients (*r*), was undertaken among all the related water quality parameters. *T*-test was conducted on the seasonal water quality dataset of each parameter to determine the statistical similarity/difference in dataset means over various seasons. To quantify the increasing trends in some critical parameters over the years (2013–2016), the Mann-Kendall test, a nonparametric test for monotonic trends, was conducted and rate of change in trends was computed by Sen's slope method. Sen's slope is a nonparametric linear regression model, used for estimating slopes of trends and is extensively used in hydrological trend analysis (Kişi et al., 2018; Kumar & Rathnam, 2019).

Factor analysis (FA) provides in-depth scenario on a given dataset (Belkhiri & Mouni, 2012). PCA was undertaken as the first step before FA to extract various factors. The PCA/FA analysis groups parameters on common attributes to assist in evaluation of each group's influence on any water quality variation. Eigenvalues >1 were considered for principal component extraction. PCA has been applied on water quality data earlier (Kuppusamy & Giridhar, 2006; Nakano et al., 2008; Ouyang, 2005; Parinet et al., 2004; Varol et al., 2012; Zarei & Bilondi, 2013). The varimax rotation was undertaken (Zarei & Bilondi, 2013) to ensure

Table 3. Comprehensive pollution index (CPI), water quality classification and uses.

Comprehensive Pollution Index (CPI)	Class/Status	Water Quality and uses
0.0–0.20	Clean	Very good and use as Drinking, Irrigation, and Industrial purpose
0.21–0.4	Sub clean	Good and use as Domestic, Irrigation, and Industrial
0.41–0.8	Qualified	Some pollutants are detected but their concentrations accord with the standard i.e. fair Quality and use as Irrigation and Industrial purpose
0.81–1.0	Basically Qualified	Concentrations of some pollutants exceed the standard i.e. poor quality and use as Irrigation purpose only
1.01–2.0	Polluted	Concentrations of quite a part of pollutants exceed the Standard i.e. very poor quality(polluted) and Restricted use for Irrigation
≥2.01	Seriously Polluted	Concentrations of quite a part of pollutants exceed the standard many times i.e. very polluted quality and Proper treatment required before use

contribution of environmentally important principal components (Razmkhah et al., 2010).

Results and discussion

Reservoir water was visibly clear during samplings in pre- and post-monsoon seasons while turbidity was conspicuous and increased during the monsoon seasons due to mixing of run-off water from catchment areas carrying soil and mud. All samples of reservoir water over four years were colorless on the Pt-Co scale. The 4 year long range in water temperature was 15.8–-32.1°C (average: 25.64°C), the minimum observed in January 2017 while the maximum was recorded in June 2014. Water sampling time was between 10 am and 12 am and the minimum temperatures over the years were mostly recorded during the month of January and ranged from 15.8°C to 18.7°C. The maximum temperature was observed during May–July but mostly in June over the years. On the other hand, pH and electrical conductivity over the 4-year period ranged from 8.09 to 8.31 and 136.3 to 225.7 µs cm^{-1}, respectively (Table 4). While pH is buffered in natural water bodies, electrical conductivity (EC) might increase due to sewage or effluent mixing, erosion of specific geologic materials like gypsum and halite (Zarei & Bilondi, 2013), evaporation and subsequent increase in concentration of salts or decrease via dilution effects by fresh water inputs through rainfall. The entire water quality data were divided into seasonal data sets under summer (April–June), monsoon and post-monsoon (July–Oct), and winter (Oct–Feb) seasons to understand seasonal variation in water quality. Impact of dilution on salinity manifested by conductivity (i.e. EC) in monsoon and post-monsoon seasons (July–October) and evaporation effect during the summer months (April–June) was clearly visible (Figure 2). As Cl^- is integrally related to salinity and EC, it also showed similar seasonal trends as EC. TDS followed a similar pattern (ranged from 81.78 to 135.42 mg L^{-1} during 4-year period), being also dependent on the concentration of Cl^- salts in water. TH varied between 50 and 76 mg L^{-1}while Ca and Mg hardness were found to range from 32 to 52 mg L^{-1} and 20 to 24 mg L^{-1}, respectively. TH and Ca^{2+} followed identical seasonal and 4-year trends as the former is controlled by the concentration of the latter. The monthly values of DO (2 per month) showed clear influence of temperature, showing higher values in winter that sometimes indicated supersaturation (>9 mg L^{-1}) (Table 4). DO supersaturation in upstream of river or upriver due to low presence of oxygen-consuming substances and strong phytoplankton photosynthesis has been reported by Huang et al. (2017). It may be noted that CIFRI (1966) had reported presence of planktons (*Anabena* sp., *Microsystis* sp., *Brachionus* sp., *Keratella* sp., *Diaptomus* sp. etc.) at a concentration of 19 per liter in Tilaiya reservoir water. Strong influence of photosynthetic activity of aquatic plants and algae on DO in water has been reported by others (Shanthi et al., 2002). In summer, DO dropped down below 7 mg L^{-1}. Interestingly, though turbidity was low (3.49 to 9.39 NTU over the 4-year period), reservoir water had higher turbidity in the post-monsoon season every year, indicating possible mixing of run-off water carrying soil and mud into the Barakar river or the reservoir directly from adjoining catchment areas. Seasonal or 4-year tends of F^-, Fe, Mg^{2+}, $PO_4^=$ and alkalinity did not have any specific seasonal attribute or trend. Microbiological attributes like TBC and TC (total coliform) counts were always below 100 per milliliter of water, indicating low mixing of sewage or manifestation of dilution effect by great volume of water stored in the reservoir against little volume of sewage that could have reached the river or the reservoir directly from the sparse population in the immediately adjoining areas within the catchment. Interestingly, TDS, TH, Ca^{2+}, and EC showed clear and strong increasing trends between the summer of 2013 to the summer of 2016 (Figure 3). Sen's slope indicated that EC had highest increasing rate at 3.52 per year followed by TDS (2.67 per year), TH (2 per year), and Ca^{2+} (0.75 per year). However, increasing rate was weakened after the summer of 2016. The Barakar river water has reportedly contained about 41 mg L^{-1} Cl^-, 1452 µg L^{-1} Fe in summer at points where mixing of waste streams were prevalent (Banerjee & Gupta, 2012). Open access data of the Govt. of India (https://data.gov.in/resources/water-quality-tributary-streams-damodar-barakar-rupanarayan-dwarakeshwar-dwarka-silabati-0) shows that at the sampling point in the Barakar river (water intake point, Asansol Town, West Bengal state), there have been events of DO super saturation while Biological Oxygen Demand (BOD) reached a maximum level of 4.5 mg L^{-1}. Importantly, total (max of 160,000 100 mL^{-1}) and fecal coliform (max of 90,000 100 mL^{-1}) were high, possibly due to perpetual sewage inputs from the nearby populous town of Asansol.

The *t test* indicated that except between the summer and post-monsoon seasons of 2013 and 2014, DO values in all other seasons had statistically significant difference from each other in constant agreement with water temperature at 5% level of significance, indicating significant shifts in DO with seasonal changes along with water temperature. Arrival of the post-monsoon season ensured higher mixing of soil and mud into reservoir water through run-off water from the catchment area that resulted in statistically significant difference in turbidity in between summer and post-monsoon and post-monsoon and winter seasons while there was no significant difference in turbidity between summer and winter. TDS, that may be expected to decrease during post-monsoon season

Table 4. Water quality of the Tilaiya Reservoir during 2013–2017.

Time		Water Quality Parameter																	
Year	Month	Temp (ºC)	EC (µs cm^{-1})	pH	TH (mg L^{-1})	Turbidity (NTU)	TDS (mg L^{-1})	Fe (mg L^{-1})	^{a}Cu (mg L^{-1})	Ca^{2+} (mg L^{-1})	Mg^{2+} (mg L^{-1})	Cl^{-} (mg L^{-1})	SO$_4^{=}$ (mg L^{-1})	F^{-} (mg L^{-1})	^{b}PO$_4^{=}$ (mg L^{-1})	Alkalinity (mg L^{-1})	D.O (mg L^{-1})	^{c}Res. Cl (mg L^{-1})	^{d}TBC (per mL)	^{e}Total coliform (per mL)
2013	July	29.8–30.4	164.9–165.3	8.28–8.32	54–56	7.31–8.69	99.18–98.94	0.036–0.044	<0.02	13.6	6.3	11.0–11.2	10	0.2	<0.03	74–76	7.77–7.9	<0.2	<100	<100
	Aug	29.1–29.5	165.7–166.8	8.26–8.31	54–56	8.03–8.47	99.4–100.1	0.062–0.078	<0.02	12.8–13.6	6.3–6.4	10.5–11.0	10–12	0.2	<0.03	68–70	8–8.2	<0.2	<100	<100
	Sept	27.6–28.5	156.3–159.7	8.2–8.22	51–56	7.23–7.83	93.8–95.8	0.079–0.084	<0.02	13.6	6.3–6.5	9.9–10.0	10	0.2	<0.03	65–68	8.7–8.8	<0.2	<100	<100
	Oct	26.1–26.4	159.4–160.2	8.1–8.12	50–52	6.78–7.37	95.6–96.1	0.06–0.063	<0.02	12.8	5.7	9.2–9.9	10–12	0.2	<0.03	88–90	8.8	<0.2	<100	<100
	Nov	24.2–24.8	174.2–176.8	8.09–8.1	50–52	5.68–6.93	104.5–106.0	0.063–0.064	<0.02	12.8–13.6	5.7–5.8	9.6–10	10–12	0.2–0.3	<0.03	88–92	9–9.2	<0.2	<100	<100
	Dec	18.8–19.2	187.5–193.0	8.23–8.25	54–56	3.56–5.17	112.5–115.8	0.060.068	<0.02	13.6	6.5–6.6	9.0–9.6	12–13	0.4	<0.03	90–94	9.4–9.6	<0.2	<100	<100
2014	Jan	16.6–18.2	185.8–188.7	8.2–8.23	54–56	4.98–5.32	111.5–113.2	0.066–0.067	<0.02	12.8–14.4	6.3	4.54.6	10–13	0.4	<0.03	91–94	9.9–10.2	<0.2	<100	<100
	Feb	17.9–19.2	187.8–188.6	8.22–8.26	58–60	4.68–4.82	112.7–113.2	0.07–0.073	<0.02	15.2–16.0	6.3–64	6–7.2	12–13	0.4	<0.03	86–90	9.8–9.9	<0.2	<100	<100
	Mar	23.6–26.2	194.5–195.3	8.33–8.37	60–62	3.98–4.06	116.7–117.18	0.077–0.08	<0.02	15.2–16.0	6.3	7.2–8.0	10–12	0.4	<0.03	90–92	8.72–8.57	<0.2	<100	<100
	Apr	26.9–27.8	193.6–193.8	8.41–8.46	60–62	4.62–4.87	116.2–116.2	0.069–0.076	<0.02	16	6.3–6.5	8.5–9.0	10.0–12	0.4	<0.03	84–88	7.6–7.9	<0.2	<100	<100
	May	28.5–28.5	190.3–194.7	8.44–8.45	54–58	3.87–4.86	114.2–116.8	0.078–0.088	<0.02	14.4–14.6	6.3	12.0–12.1	10.0–12	0.4	<0.03	82–84	7.6–7.7	<0.2	<100	<100
	June	29.9–32.1	194.5–195.6	8.46–8.48	54–60	4.84–4.98	116.7–117.4	0.075–0.11	<0.02	15.2	6.2–6.3	13–13.5	10.0–12	0.4	<0.03	80–84	6.8–7.44	<0.2	<100	<100
	July	29.0–29.3	191.5–193.9	8.30–8.34	60–62	5.11–5.96	114.9–116.3	0.108–0.12	<0.02	15.2–16.0	6.3	12–12.2	14.8–15	0.4	<0.03	81–84	8.0–7.99	<0.2	<100	<100
	Aug	29.2–30.2	177.0–181.9	8.29–8.32	60–62	8.6–9.39	106.2–109.1	0.099–0.11	<0.02	15.2–16.0	6.3–6.4	11.0	10.0–12	0.3–0.4	<0.03	80–82	8.1–8.3	<0.2	<100	<100
	Sept	27.9–28.3	182.3–184.9	8.22–8.24	51–56	8.68–8.98	109.4–110.9	0.0880.106	<0.02	14.4	5.7	9.0–10.0	10.0–12	0.4	<0.03	74–76	8.33–8.4	<0.2	<100	<100
	Oct	27.6–28.1	180.7–182.9	8.2–8.21	56–58	5.77–8.45	108.4–109.7	0.082–0.09	<0.02	14.4–15.2	5.7–6.3	9.0–10.0	10.0–12	0.4	<0.03	71–74	8.78–8.88	<0.2	<100	<100
	Nov	24.1–24.7	167.8–170.3	8.11–8.22	52–56	4.83–4.77	100.7–102.2	0.077–0.09	<0.02	14.4	6.3	9.0–9.2	9.2–10	0.3	<0.03	68–70	8.4–9.1	<0.2	<100	<100
	Dec	19.9–20.6	171.6–172.9	8.21–8.23	60–62	4.0–4.9	102.96–103.7	0.076–0.088	<0.02	15.2–16.0	6.3	8.0–8.1	9.5–10	0.3	<0.03	71–72	9.0–9.6	<0.2	<100	<100
2015	Jan	17.8–18.7	177.9–178.8	8.28–8.29	60–62	3.89–4.31	106.74–107.28	0.074–0.078	<0.02	16.0	61–6.3	4.2–6.0	10.0–12	0.3	<0.03	78–80	9.88–10.2	<0.2	<100	<100
	Feb	20.2–22.8	180.1–182.6	8.29–8.3	61–62	4.11–4.3	108.06–109.56	0.072–0.084	<0.02	16.1–16.4	6.3–6.4	5.8–6.0	10.0–12	0.3	<0.03	82–84	9.12–9.22	<0.2	<100	<100
	Mar	25.7–26.1	188.9–191.5	8.32–8.33	60–64	3.96–4.08	113.34–114.99	0.069–0.071	<0.02	16.0–16.1	6.9	8.0–9.0	9.8–10	0.3–0.4	<0.03	82–84	8.4–8.84	<0.2	<100	<100
	Apr	26.3–27.5	190.5–195.9	8.33–8.36	64–66	3.9–3,95	114.3–117.54	0.066–0.068	<0.02	16–16.8	6.9	11.0–13.0	12	0.4	<0.03	83–84	7.8–7.9	<0.2	<100	<100
	May	28.5–30.1	199.8–200.9	8.37–8.38	66	4.21–4.71	119.88–120.54	0.063–0.072	<0.02	16.8–17.6	6.28–6.8	13.0–13.5	12–13	0.4	<0.03	86	7.7–7.7	<0.2	<100	<100
	June	29.8–31.3	206.3–206.8	8.46–8.48	68	5.79–5.9	123.78–124.08	0.081–0.104	<0.02	17.6	6.9	11.0–14.2	12	0.4	<0.03	88	7.11–7.32	<0.2	<100	<100
	July	27.8–29.7	207.3–208.3	8.51–8.53	70	6.11–6.12	124.38–124.98	0.11–0.13	<0.02	18.4–18.6	6.9	11.0	11–12	0.4	<0.03	90	7.3–7.63	<0.2	<100	<100
	Aug	29.2–29.9	187.1–194.4	8.28–8.3	68	7.93–8.34	12.26–116.64	0.081–0.078	<0.02	18.4–18.5	6.3	9.9–10.0	9–10	0.4	<0.03	86–88	8–8.2	<0.2	<100	<100
	Sept	28.2–28.9	185.3–186.5	8.22–8.23	64	6.887.88	111.18–111.9	0.076–0.077	<0.02	17.6–17.8	5.7–5.8	10.0–10.1	10	0.4	<0.03	76–78	8.4–8.5	<0.2	<100	<100
	Oct	27.6–28.0	172.1–175.5	8.23–8.24	64	6.3–6.78	103.26–105.3	0.068–0.072	<0.02	17.6	5.7–5.8	9.0–10.0	10	0.3	<0.03	76–78	8.8	<0.2	<100	<100
	Nov	23.2–24.3	176.8–177.0	8.28–8.31	60–62	6.03–6.12	106.08–106.2	0.071–0.078	<0.02	16.8–16.9	5.7–5.8	9.0	8–10	0.3	<0.03	80	9.0–9.2	<0.2	<100	<100
	Dec	19.7–20.1	183.5–186.3	8.28–8.29	64	3.71–5.67	110.1–111.78	0.071–0.08	<0.02	17.6	5.7	8.0	10	0.3	<0.03	84–86	9.5–9.58	<0.2	<100	<100
2016	Jan	16.3–18.2	187.5–189.3	8.33–8.35	68	4.12–4.32	112.5–113.58	0.068–0.077	<0.02	18.2–18.4	6.3	4.0–5.5	8–10	0.3–0.4	<0.03	86–88	9.8–9.9	<0.2	<100	<100
	Feb	18.1–18.8	201.1–201.9	8.34–8.35	72	3.47–4.66	120.66121.14	0.07–0.076	<0.02	19.2–19.3	6.9–7.0	6.0–7.2	10–12	0.4	<0.03	88	9.12–9.2	<0.2	<100	<100
	Mar	25.2–26.1	203.3–207.8	8.34–8.35	72	4.83–5.03	121.98–124.68	0.072–0.082	<0.02	19.2–19.3	6.9–7.0	7.5–8.0	12	0.4	<0.03	86–88	8.0–8.72	<0.2	<100	<100
	Apr	26.4–26.8	215.2–215.5	8.4–8.45	76	4.32–4.98	129.12–129.3	0.066–0.069	<0.02	20.8	6.9–7.1	9.0–10.0	15–20	0.5	<0.03	88	7.8–7.9	<0.2	<100	<100
	May	28.9–30.8	211.3–214.8	8.48–8.52	76	4.01–4.68	126.78–128.88	0.07–0.077	<0.02	20.8–21.0	6.9	11.0–13.0	12	0.5	<0.03	88	6.6–7.6	<0.2	<100	<100
	June	30.2–31.9	221.2–225.7	8.55–8.61	72–74	5.01–5.76	132.72–135.42	0.075–0.079	<0.02	19.2–20.0	6.8–6.9	15.0–15.5	15–20	0.6	<0.03	90	7.33–7.43	<0.2	<100	<100
	July	29.7–30.2	210.1–216.3	8.38–8.39	74–76	5.98–7.89	126.06–129.78	0.13–0.18	<0.02	20.0–20.8	6.9	12	15	0.5	<0.03	86	7.88–7.92	<0.2	<100	<100
	Aug	29.3–29.8	215.6–217	8.38–8.4	74	8.39–8.97	129.36–130.2	0.13–0.19	<0.02	20	6.7–6.9	11	11–12	0.4–0.5	<0.03	94	8.0–8.3	<0.2	<100	<100
	Sept	27.9–28.3	212.1–214.3	8.38–8.4	69–72	8.13–8.96	127.26–128.58	0.109–0.13	<0.02	19.2	6.9–7.0	9.0–10.0	12	0.4	<0.03	90	8.4–8.44	<0.2	<100	<100
	Oct	27.1–27.3	182.3–184.1	8.29–8.3	60–61	7.33–7.98	109.38–110.46	0.077–0.078	<0.02	16	6.1–6.3	9.0–10.0	10–12	0.4	<0.03	74	8.34–8.8	<0.2	<100	<100
	Nov	22.9–23.8	136.3–145.2	8.2–8.3	56–58	3.88–5.89	81.78–87.12	0.06–0.07	<0.02	15.2	6.3	6.2–9.0	8–10	0.2–0.3	<0.03	68	8.7–9.1	<0.2	<100	<100
	Dec	19.9–20.2	138.2–142.1	8.1–8.2	56	4.99–5.32	82.92–85.26	0.052–0.054	<0.02	15.0–15.3	5.7–5.8	6.0–7.2	8–10	0.2	<0.03	72–74	9.12–10.3	<0.2	<100	<100

(*Continued*)

Table 4. (Continued).

Time		Water Quality Parameter																		
Year	Month	Temp (ºC)	EC (μs cm^{-1})	pH	TH (mg L^{-1})	Turbidity (NTU)	TDS (mg L^{-1})	Fe (mg L^{-1})	[a]Cu (mg L^{-1})	Ca^{2+} (mg L^{-1})	Mg^{2+} (mg L^{-1})	Cl^{-} (mg L^{-1})	$SO_4^{=}$ (mg L^{-1})	F^{-} (mg L^{-1})	[b]$PO_4^{\overline{\overline{=}}}$ (mg L^{-1})	Alkalinity (mg L^{-1})	D.O (mg L^{-1})	[c]Res. Cl (mg L^{-1})	[d]TBC (per mL)	[e]Total coliform (per mL)
2017	Jan	15.8–16.4	143.4–146.9	8.1–8.2	60	4.22–5.73	86.04–88.14	0.07–0.078	<0.02	15.2	6.3	3.2–4.0	10	0.2–0.3	<0.03	76–78	9.9–10	<0.2	<100	<100
	Feb	19.2–19.9	147.6–148.9	8.2–8.2	62	4.19–4.39	88.56–89.34	0.077–0.082	<0.02	16	6.1–6.3	5.0–6.0	10	0.3	<0.03	80	9.7–9.8	<0.2	<100	<100
	Mar	21.8–22.8	155.3–159.7	8.2–8.2	64	5.01–5.12	93.18–95.82	0.082–0.086	<0.02	15.8–16.0	6.28–6.85	7.0–8.0	10	0.3	<0.03	80	8.5–8.85	<0.2	<100	<100
	Apr	26.2–28.3	164.6–169.3	8.2–8.2	68	5.12–5.36	98.76–101.58	0.088–0.089	<0.02	17.6	6.9–7.1	9.9–10	9–10	0.3	<0.03	82–84	7.7–7.9	<0.2	<100	<100
	May	28.8–29.8	171.7–175.9	8.38–8.41	68–70	5.16–6.32	103.02–105.54	0.077–0.087	<0.02	17.6–18.4	6.9	11.9–12	10	0.3–0.4	<0.03	92	7.3–7.35	<0.2	<100	<100
	June	29.9–30.6	174.3–179.8	8.48–8.5	72	6.29–6.57	104.58–107.88	0.086–0.089	<0.02	18.4	6.9	12	10–12	0.4	<0.03	88–90	7.4–7.43	<0.2	<100	<100
	July	28.8–29.7	174.6–178.8	8.47–8.52	72–74	7.91–8.73	104.76–107.28	0.097–0.139	<0.02	19.1–20	6.28–6.85	9.9–11.0	12	0.4	<0.03	84–90	7.67–7.88	<0.2	<100	<100
Minimum		15.8	136.3	8.09	50	3.47	81.78	0.04	-	12.8	5.7	3.2	8	0.2	-	68	6.6	-	-	-
Maximum		32.1	225.7	8.61	76	9.39	135.42	0.78	-	20.8	6.8	15.5	20	0.6	-	94	10.3	-	-	-
Average		25.6	183.9	8.3	63.5	5.8	110.3	0.09	-	16.5	6.4	9.4	11.3	0.4	-	83.1	8.5	-	-	-

[a] LDL: 0.02 mg L^{-1}

[b] LDL: 0.03 mg L^{-1}

[c] LDL: 0.2 mg L^{-1}

[d] LDL: 100 mL^{-1}

[e] LDL: 100 mL^{-1}

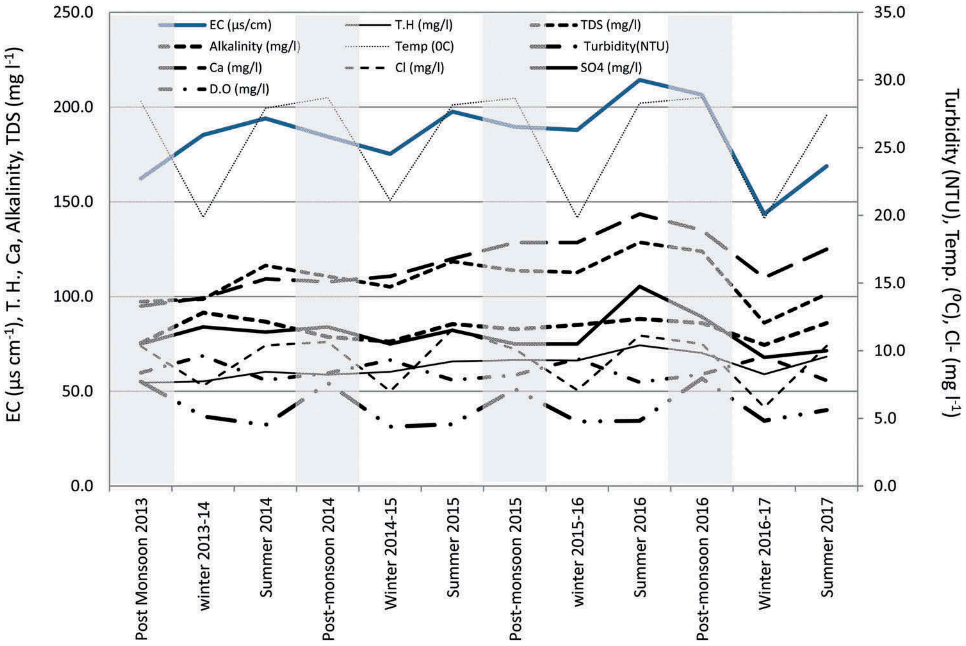

Figure 2. Seasonal and yearly pattern of water quality parameters of the Tilaiya Reservoir.

due to freshwater inputs through rainfall, did not have statistically significant seasonal shifts in post-monsoon over summer or winter every year. The TH of water had statistically significant change in summer over winter but the same was not true for summer and post-monsoon seasons. Singh (2016) assessed the seasonal variation in water quality of the Kanke Dam of Ranchi in India for 1 year to reveal that water turbidity was higher during winter accompanied by rising water levels and attributed it to suspended sediment inputs through surface run-off during the monsoon season. Deterioration in river water quality during the monsoon season has also been reported by Gupta, Pandey, and Hussain (2017) in the river Narmada in India, who attributed it to turbulent flow, soil erosion, and run-off into the river.

Historical data (CIFRI, 1966) showed that DO levels at specific points in the Tilaiya reservoir were highly variable during the June–August months, ranging from a low 4.7 to 8.3 while pH were slightly acidic to neutral (6.7–7.3). In the Panchet Dam, which is located on the Damodar river about 165 km downstream of Tilaiya, DO levels were found to be low for a freshwater reservoir, ranging from 4.89 to 6.02

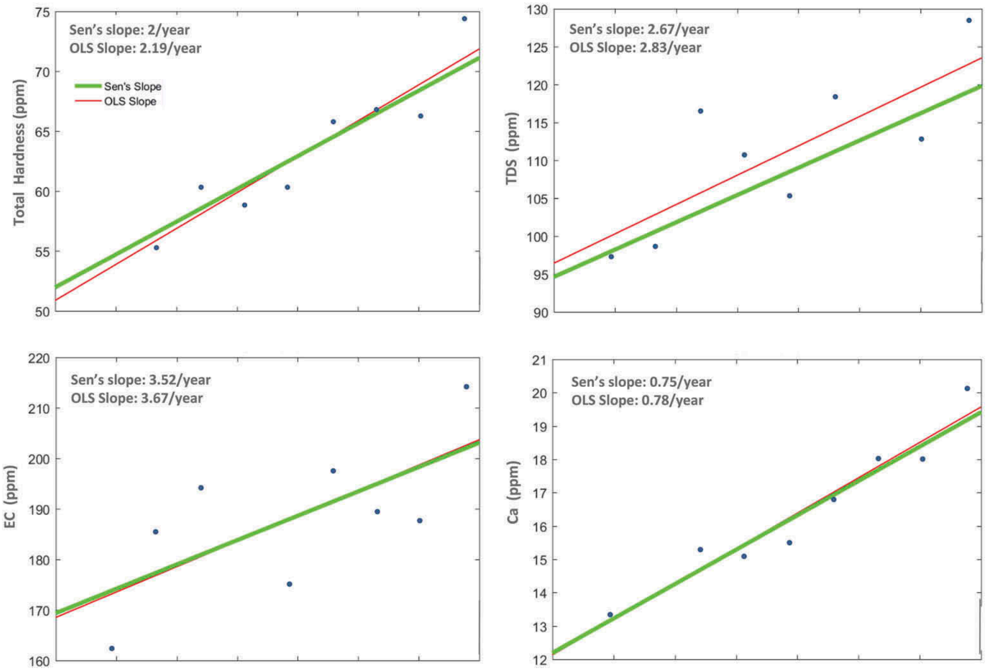

Figure 3. Sen's slopes and ordinary least square (OLS) slopes indicating increasing rates in Ca, EC, TDS and TH in the Tilaiya reservoir water during summer 2013 and summer 2016.

Table 5. Variables and factor loadings after varimax rotation for post-monsoon season.

Variable	Factor 1	Factor 2	Factor 3
Temperature	0.11	0.85	0.21
EC	0.93	0.29	−0.05
pH	0.62	0.65	−0.01
TH	0.91	0.29	0.07
Turbidity	−0.02	0.10	0.88
TDS	0.93	0.28	−0.05
Fe	0.38	0.02	0.40
Ca^{2+}	0.93	0.15	0.06
Mg^{2+}	0.57	0.62	0.06
Cl^{-}	0.08	0.87	−0.29
$SO_4^{=}$	0.46	0.38	−0.67
F^{-}	0.85	0.06	−0.08
Alkalinity	0.74	0.14	−0.07
DO	−0.23	−0.87	0.02
Eigenvalue	7.35	2.01	1.51
% of total variance	52.53	14.38	10.79
Cumulative %	52.53	66.91	77.7

Extraction method: principal component analysis. Rotation method: Varimax with Kaiser Normalization.

Table 6. Variables and factor loadings after varimax rotation for winter season.

Variable	Factor 1	Factor 2	Factor 3
Temperature	−0.28	0.88	−0.13
EC	0.87	0.11	0.34
pH	0.39	0.06	0.78
TH	0.06	−0.28	0.91
Turbidity	−0.07	0.46	−0.50
TDS	0.34	0.30	0.46
Fe	−0.05	0.15	0.58
Ca^{2+}	−0.05	−0.14	0.87
Mg^{2+}	0.27	−0.39	0.48
Cl^{-}	0.18	0.91	−0.13
$SO_4^{=}$	0.89	−0.08	−0.03
F^{-}	0.85	−0.18	0.26
Alklainity	0.87	−0.19	−0.15
DO	0.12	−0.84	−0.17
Eigenvalue	4.84	2.64	2.53
% of total variance	34.6	18.84	18.04
Cumulative %	34.63	53.48	71.52

Extraction method: principal component analysis. Rotation method: Varimax with Kaiser Normalization.

during the summer of 1964. Singh et al. (2005) reported TDS of 162.4 mg L^{-1}, pH of 7.6–8.5, EC of 143–187 μs cm^{-1}, F^{-} of 0.75–1.35 mg L^{-1},Cl^{-} of 4.3–7.5 mg L^{-1} and $SO_4^{=}$ of 2.5–5.1 mg L^{-1} in the Tilaiya reservoir water in 2003. They found reservoir water to be excellent for irrigation, based on SAR (sodium absorption ration) and RSC (residual sodium carbonate) values. They also reported that the catchments of the Tilaiya, Konar, and Maithon reservoirs constructed on tributaries of the Damodar river i.e. the Barakar and the Konar Rivers, had less reactive granites and granitic gneisses with no coal-bearing rocks, leading to low conductivity and $SO_4^{=}$ concentrations. In their opinion, the relatively higher TDS in Tilaiya reservoir water could be originating from domestic sewage discharges from the nearby town of Hazaribagh. They reported that about 45–70% of yearly discharge from the Tilaiya dam occurs during the monsoon season and only about 1–12% during Jan–March while annual solute flux and chemical denudation rates were 47 × 10^{3} tons and 48tons/km^{2}/year, respectively.

In terms of drinking water quality, the critical parameters tested were Fe, F^{-}, and TDS. Fe (0.036–0.19 mg L^{-1}), TDS (0.2–0.6 mg L^{-1}), F^{-} (0.2–0.6 mg L^{-1}), and TDS (11.5–135.4 mg L^{-1}) were within safe limits for drinking water (IS 10500) as per Bureau of Indian Standards (BIS, 2012). Concentration of Cl^{-}, one of the most abundant in organic anions in natural water, coming primarily through sewage in river water (Singh et al., 2005), ranged from 3.2 to 15.5 mg L^{-1} that were well within the safe limit set for drinking water by BIS. On the other hand, sulfate ($SO_4^{=}$) ranged from 8.0 to 20.0 mg L^{-1}, that were within the maximum allowable limit for potable water. Concentration of inorganic phosphate in the reservoir was always <0.03 mg L^{-1},that was within the safe limit of 0.1 mg L^{-1} phosphate for drinking water (BIS, 2012), indicating negligible influence of fertilizers, detergents, and domestic sewage (Yadav et al., 2018).

Factor analysis explained 71.5–77.9% of variance in water quality data during the various seasons. For interpretation of results, high factor load >0.75 and

Table 7. Variables and factor loadings after varimax rotation for summer season.

Variable	Factor 1	Factor 2	Factor 3
Temperature	0.18	0.93	0.06
EC	0.92	0.22	0.12
pH	0.53	0.77	0.09
TH	0.29	0.10	0.93
Turbidity	−0.46	0.54	0.47
TDS	0.92	0.22	0.12
Fe	−0.54	0.46	−0.08
Ca^{2+}	0.39	0.11	0.88
Mg^{2+}	−0.01	−0.01	0.85
Cl^{-}	0.24	0.84	0.02
$SO_4^{=}$	0.73	0.16	0.24
F^{-}	0.84	0.35	0.23
Alklainity	0.34	0.35	0.34
DO	−0.12	−0.88	−0.14
Eigenvalue	6.16	2.62	2.14
% of total variance	44.01	18.7	15.26
Cumulative %	44.01	62.7	77.9

Extraction method: principal component analysis. Rotation method: Varimax with Kaiser Normalization.

Table 8. Computed water quality index, pollution index and comprehensive pollution index of the Tilaiya reservoir water in different calendar years.

Year	Water Quality Index(WQI)	Pollution Index(WQI)	Comprehensive Pollution Index(CPI)	Quality Category
2013 (July to Dec)	31.408	0.282	0.263	Good
2014 (Jan to Dec)	31.643	0.303	0.276	Good
2015 (Jan to Dec)	29.976	0.307	0.279	Good
2016 (Jan to Dec)	33.138	0.341	0.297	Good
2017 (Jan to June)	31.750	0.308	0.273	Good
2013 (July) to 2017 (July).	32.557	0.347	0.282	Good

Table 9. Correlation matrix representing correlationcoefficientsamongst various water quality parameters.

	Temp	EC	pH	T.H.	Turbidity	TDS	Fe	Ca	Mg	Cl^-	$SO_4^=$	F^-	Alkalinity	D.O.
Temp	1.00													
EC	0.37	1.00												
pH	0.57**	0.75**	1.00											
T.H.	0.29	0.62**	0.65**	1.00										
Turbidity	0.52**	0.00	0.03	−0.02	1.00									
TDS	0.40	0.76**	0.63**	0.55**	0.02	1.00								
Fe	0.35	0.40**	0.33	0.44**	0.41	0.35	1.00							
Ca^{2+}	0.26	0.60**	0.59**	0.98**	0.01	0.53**	0.43	1.00						
Mg^{2+}	0.27	0.50**	0.59**	0.72**	−0.14	0.40	0.32	0.58**	1.00					
Cl^-	0.88**	0.44**	0.62**	0.27	0.33	0.46**	0.27	0.23	0.29	1.00				
$SO_4^=$	0.25	0.64**	0.49**	0.41	−0.06	0.47**	0.25	0.39	0.39	0.39	1.00			
F^-	0.32	0.84**	0.67**	0.65**	−0.07	0.61**	0.41	0.63**	0.50**	0.40	0.65**	1.00		
Alkalinity	0.05	0.64**	0.46**	0.46**	−0.15	0.39	0.21	0.42	0.41	0.15	0.40	0.56**	1.00	
D.O.	−0.89	−0.46	−0.73	−0.45	−0.25	−0.46	−0.29	−0.39	−0.49**	−0.87**	−0.34	−0.44**	−0.21	1.00

**Significant at 1% level of significance.

mean factor load between 0.4 and 0.75 were considered (Zarei & Bilondi, 2013). Investigation of the factors with Eigenvalue >1 for summer, monsoon, and post-monsoon combined and winter indicated that three factors influenced the Tilaiya reservoir water quality. The winter season Scree plot exhibited a radical shift in slope after the third Eigenvalue, implying the importance of three components. For the monsoon and post-monsoon season combined, three factors explained 77.7% of the total variance (Table 5) where Factor 1 explained 52.53% of the variance. The EC, TH, TDS, Ca^{2+}, F^- and alkalinity were strongly correlated while pH and Mg^{2+} were moderately correlated with Factor 1. Temperature and Cl^- had strong inter-correlation with Factor 2 and turbidity with Factor 3. In winter, three factors accounted for 71.52% of the total variance (Table 6). Factor 1 accounted for 34.6% of the variance while three factors together accounted for 71.52% of variance. EC, $SO_4^=$, F^-, alkalinity were found to correlate with Factor 1, while temp., Cl^- and DO strongly correlated with Factor 2. The pH, TH, and Ca correlated well with Factor 3. In summer, factor analysis revealed that 3 factors accounted for 77.9% of total variance (Table 7). Strong correlations were found in between EC, TDS, F^- with Factor 1; Temp., pH, Cl^-, DO with Factor 2 and TH, Ca^{2+}, Mg^{2+} with Factor 3. It is observed that Factor 1 has substantial loading of Ca^{2+}, Mg^{2+}, F^-, $SO_4^=$ over all seasons and especially post-monsoon, hinting at possible role of soil mixing through surface run-off during the monsoon season as the catchment area is comprised of vast stretches of land. But, decrease in EC in the monsoon and post-monsoon seasons combined indicated that surface run-off from the catchment areas did not carry and unload any special mineral capable of increasing salinity into the reservoir, as reported by Zarei & Bilondi (2013). On the other hand, Factor 2 was heavily loaded with Cl^- in all seasons, pointing to mixing of domestic sewage into river water or the reservoir directly.

WQI of reservoir water was calculated to be 32.5 during the entire study period while WQI of the reservoir on each year during the study is also reported (Table 8). All the results of WQI showed that the water sample could be classified under Good quality (25<WQI≤50) and hence could be regarded suitable for domestic, irrigation and industrial uses. But, the WQI values of consecutive years showed that the dam water quality is slowly deteriorating with time. Further, 11 important water quality parameters from 48 samples during this four year study were selected for the calculation of PI. Generally, PI-based water quality status is dependent on independent parameters with score for each parameter (Sidabutar et al., 2017). Here, the PI value of reservoir water was found to be 0.347 for the 4-year period, which could be classified as 'Good' along with year-wise values as well. But, PI values of consecutive years confirmed a slow decline in reservoir water quality. For calculation of CPI, 11 important water quality parameters were selected. The CPI (0.282) puts the reservoir water quality in the 'Good' category i.e. Sub clean (CPI = 0.21–0.4) quality of water. CPI values of consecutive years re-confirmed slow deterioration of reservoir water.

Correlation analysis (Table 9) revealed that TDS correlated well and significantly with EC, TH, Ca (r = 0.76, 0.55, 0.53, respectively) at 1% level of confidence. These parameters are known to be integrally influenced by each other. TH and Ca (r = 0.96) and TH and Mg (r = 0.72) were correlated positively as Ca and Mg salts contribute to TH. Statistically significant positive correlation was also observed between Ca and Mg (r = 0.58), indicating that these parameters have mix sources of origin. Positive and statistically significant correlation was also observed between EC and TH (r = 0.623), Ca^{2+} (r = 0.600), Mg^{2+} (r = 0.50), Cl^- (r = 0.44), $SO_4^=$ (0.64), and alkalinity (r = 0.64), indicating EC and consequently salinity, were influenced by Ca^{2+}, Mg^{2+}, Cl^{-}, $SO_4^{=}$, and alkalinity of water. DO and temperature were significantly correlated negatively (r = −0.89), confirming the inverse relationship between the two parameters.

Conclusions

From the seasonal variation and trends in water quality of the Tilaiya Reservoir over 4 years during 2013–2017, we can conclude that: (i) No selected water quality parameter breached the acceptable limits of BIS and WHO standards for drinking water; (ii) Computation of WQI, PI, and CPI rendered the reservoir water as ‘Good’; (iii) The water quality indices over the study years indicated slow deterioration in reservoir water quality; (iv) Some water quality parameters showed conspicuous dilution effects during the monsoon season and post-monsoon season while during the summer season, water remained in its poorest quality in terms of the selected parameters but did not breach any water quality standard for drinking or irrigation; (v) Factor analysis revealed the role of surface run-off and sewage mixing on reservoir water quality and was useful in analysis and elucidation of water quality data and recognition of possible sources of pollution.

Water quality indices indicated a slow degradation over 2013-2017 and therefore, there is a need for: (i) Protection of the Tilaiya reservoir or the Barakar river water from direct human influences such as sewage input, bathing, washing of animals and cloths, etc.; (ii) Minimization of disposal of industrial effluents; (iii) Plantation and maintenance of riparian zones along the river to effectively trap soil and surface run-off; (iv) Regular and proper monitoring of the catchment areas near the dam to protect from wanton waste and effluent dumping through drains into the dam water; (v) Routine monitoring of reservoir water to understand its deterioration and formulate a necessary action plan for reservoir management. The results obtained from this work could be useful in future management of the reservoir, its water and also, the activities in the catchment area.

Acknowledgments

The senior author acknowledges the kind co-operation and guidance provided by Chemistry Department of Raiganj University, West Bengal, India. CSIR-NEERI Knowledge Resource Centre (KRC) Number of manuscript is CSIR-NEERI/KRC/2020/APRIL/KZC/2

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Alobaidy, A., Maulood, B., & Kadhem, A. (2010). Evaluating raw and treated water quality of Tigris river within baghdad by index analysis. *Journal of Water Resource and Protection*, *2*(7), 629–635. doi:10.4236/jwarp.2010.27072

APHA. (1999). *Standard methods for the examination of water and wastewater*. Washington DC, USA: American Public Health Association, American Water Works Association, Water Environment Federation.

Asadi, S. S., Vuppala, P., & Reddy, M. A. (2007). Remote sensing and GIS techniques for evaluation of groundwater quality in municipal corporation of Hyderabad (Zone-V), India. *International Journal of Environmental Research and Public Health*, *4*(1), 45–52. doi:10.3390/ijerph2007010008

Banerjee, U. S., & Gupta, S. (2012). Monitoring and assessment of river pollutants: A study on river Damodar and river Barakar of India using factor analysis. *The Journal of Environment & Development*, *6*, 638–644.

Belkhiri, L., & Mouni, L. (2012). Hydrochemical analysis and evaluation of groundwater quality in El Eulma area, Algeria. *Applied Water Science*, *2*(2), 127–133. doi:10.1007/s13201-012-0033-6

Bharti, N., & Katyal, D. (2011). Water quality indices used for surface water vulnerability assessment. *International Journal of Environmental Science and Technology*, *2*(1), 154–173.

BIS. (2012). *IS 10500: Indian Standard, Drinking Water – Specification (Second Revision)*. New Delhi, India: Bureau of Indian Standards.

Central Inland Fisheries Research Institute (CIFRI). (1966). Observations on breeding of major carps in the Tilaiya Dam and Panchet reservoirs. *Bulletin No. 9*. Barrackpore, India,

CPCB. (2007). Guideline for water quality monitoring. Retrieved from http://cpcb.nic.in/openpdffile.php?id=UmVwb3J0RmlsZXMvTmV3SXRlbV8xMTZfR3VpZGVsaW5lc29mIHdhdGVycXVhbGl0eW1vbml0b3JpbmdfMzEuMDcuMDgucGRm

Debels, P., Figueroa, R., Urruti, R., Barra, R., & Niell, X. (2005). Evaluation of water quality in the Chillan River (Central Chile) using physicochemical parameters and a modified water quality index. *Environmental Monitoring and Assessment*, *110*(1–3), 301–322. doi:10.1007/s10661-005-8064-1

Gupta, N., Pandey, P., & Hussain, J. (2017). Effect of physicochemical and biological parameters on the quality of river water of Narmada, Madhya Pradesh, India. *Water Science*, *31*(1), 11–23. doi:10.1016/j.wsj.2017.03.002

Hasan, H. H., Jamil, N. R., & Aini, N. (2015). Water quality index and sediment loading analysis in Pelus River,Perak, Malaysia. *Procedia Environmental Sciences*, *30*, 133–138. doi:10.1016/j.proenv.2015.10.024

Huang, J., Yin, H., Chapra, S. C., & Zhou, Q. (2017). Modelling dissolved oxygen depression in an urban river in China. *Water*, *9*(7), 520. doi:10.3390/w9070520

Imneisi, I. B., & Aydin, M. (2016). Water quality index (WQI) for main source of drinking water (Karaçomak Dam) in Kastamonu City, Turkey. *Journal of Environmental & Analytical Toxicology*, *6*(5), 2–8. doi:10.4172/2161-0525.1000407

Javid, A., Yaghmaeian, K., Abbasi, E., & Roudbari, A. (2014). An evaluation of water quality from Mojen river by NSFWQI index. *Journal of Ecological Engineering*, *15*, 1–6.

Jindal, R., & Sharma, C. (2011). Studies on water quality of Sutlej River around Ludhiana with reference to physicochemical parameters. *Environmental Monitoring and Assessment*, *174*(1–4), 417–425. doi:10.1007/s10661-010-1466-8

Kişi, O., Santos, C. A. G., da Silva, R. M., & Zounemat-Kermani, M. (2018). Trend analysis of monthly streamflows using Şen's innovative trend method. *Geofizika*, *35* (1), 53–68. doi:10.15233/gfz.2018.35.3

Kumar, A., & Sharma, M. P. (2015). Assessment of water quality of Ganga River Stretch near Koteshwar Hydropower Station, Uttarakhand, India. *International Journal of Mechanical and Production Engineering*, *3*(8), 82–85.

Kumar, K. S., & Rathnam, E. V. (2019). Analysis and prediction of groundwater level trends using four variations of mann kendall tests and ARIMA modelling. *Journal of the Geological Society of India*, *94*(3), 281–289. doi:10.1007/s12594-019-1308-4

Kumari, S., & Rani, R. (2014). Assessment of water quality index of ground water in Smalkhan, Haryana. *International Journal of Latest Research in Science and Technology*, *3*, 169–172.

Kuppusamy, M. R., & Giridhar, V. V. (2006). Factor analysis of water quality characteristics including trace metal speciation in the coastal environmental system of Chennai Ennore. *Environment International*, *32*(2), 174–179. doi:10.1016/j.envint.2005.08.008

Kurunc, A., Yurekli, K., & Okman, C. (2006). Effects of Kilickaya Dam on concentration and load values of water quality constituents in Kelkit Stream in Turkey. *Journal of Hydrology*, *317*(1–2), 17–30. doi:10.1016/j.jhydrol.2005.05.006

Liu, X., Li, G., Liu, Z., Guo, W., & Gao, N. (2010). Water pollution characteristics and assessment of lower reaches in Haihe River Basin. *Procedia Environmental Sciences*, *2*, 199–206. doi:10.1016/j.proenv.2010.10.024

Md. Bodrud-Doza, A. R. M., Islamb, T., Ahmed, F., Das, S., Saha, N., & Rahman, M. S. (2016). Characterization of groundwater quality using water evaluation indices, multivariate statistics and geo statistics in central Bangladesh. *Water Science*, *30*(1), 19–40. doi:10.1016/j.wsj.2016.05.001

Mishra, S., Sharma, M. P., & Kumar, A. (2016). Assessment of surface water quality in surha lake using pollution index, India. *Journal of Materials and Environmental Science*, *7*, 713–719.

Moscuzza, C., Volpedo, A. V., Ojeda, C., & Cirelli, A. F. (2007). Water quality index as an tool for river assessment in agreement areas in the pampean plains of Argentina. *Journal of Urban and Environmental Engineering*, *1*(1), 18–25. doi:10.4090/juee.2007.v1n1.018025

Mukherjee, D., Lata Dora, S., & Tiwary, R. K. (2012). Evaluation of water quality index for drinking purpose in the case of damodar river, Jharkhand and West Bengal Region, India. *Journal of Bioremediation & Biodegradation*, *3*, 161.

Muntasir, S. Y., Chowdhur, R. M., & Musabbir, S. R. (2012, October 12- 3-14). Assessment of water quality index of water bodies along Dhaka-Mawa-Bhanga road. *3rd International Conference on Environmental Aspects of Bangladesh (ICEAB)*. Japan.

Nakano, T., Tayasu, I., Yamada, Y., Hosono, T., Igeta, A., Hyodo, F., … Yachi, S. (2008). Effect of agriculture on water quality of Lake Biwa tributaries, Japan. *Science of the Total Environment*, *389*(1), 132–148. doi:10.1016/j.scitotenv.2007.08.042

Ouyang, Y. (2005). Evaluation of river water quality monitoring stations by principal component analysis. *Water Research*, *39*(12), 2621–2635. doi:10.1016/j.watres.2005.04.024

Parinet, B., Lhote, A., & Legube, B. (2004). Principal component analysis: An appropriate tool for water quality evaluation and management-application to a tropical lake system. *Ecological Modelling*, *178*(3–4), 295–311. doi:10.1016/j.ecolmodel.2004.03.007

Patki, V. K., Shrihari, S., & Manu, B. (2013). Water quality index in municipal distribution system for Solapur city, Maharashtra State, India. *International Journal of Environmental Protection and Policy*, *3*(6), 16–23.

Ramakrishnaiah, C. R., Sadashivaiah, C., & Ranganna, G. (2009). Assessment of Water Quality Index for the Groundwater in Tumkur Taluk, Karnataka State, India. *E-Journal of Chemistry*, *6*(2), 523–530. doi:10.1155/2009/757424

Razmkhah, H., Abrishamchi, A., & Torkian, A. (2010). Evaluation of spatial and temporal variation in water quality by pattern recognition techniques: A case study on Jajrood River (Tehran, Iran). *Journal of Environmental Management*, *91*(4), 852–860. doi:10.1016/j.jenvman.2009.11.001

Santucci, V. J., Jr., Gephard, S. R., & Pescitelli, S. M. (2011). Effects of multiple low-head dams on fish, macroinvertebrates, habitat, and water quality in the Fox River, Illinois. *North American Journal of Fisheries Management*, *25*(3), 975–992. doi:10.1577/M03-216.1

Shanthi., K, & Ramasamy, P. (2002). Hydrological study of singanallur lake at coimbatore. *Nature environment & pollution technology, 1*(2), 97–101.

Sharifi, M. (1990). Assessment of surface water quality by an index system in Anzali basin. *The Hydrological Basis for Water Resources Management*, *197*, 163–171.

Sidabutar, N. V., Hartono, D. M., Soesilo, T. E. B., & Hutapea, R. C. (2017). The quality of raw water for drinking water unit in Jakarta- Indonesia. *AIP Conference Proceedings*, *1823*, 020067.

Singh, A. K., Mondal, G. C., Singh, P. K., Singh, S., Singh, T. B., & Tewary, B. K. (2005). Hydrochemistry of reservoirs of Damodar River basin, India: Weathering processes and water quality assessment. *Environmental Geology*, *48*(8), 1014–1028. doi:10.1007/s00254-005-1302-6

Singh, P. K., Tiwary, A. K., Panigary, B. P., & Mahato, M. K. (2011). Water quality indices used for water resources vulnerability assessment using GIS technique: a review. *International Journal of Earth Sciences and Engineering*, *6* (1), 1594–1600.

Singh, U. K. (2016). Water quality assessment using physico-chemical parameters of Kanke Dam, Ranchi, Jharkhand. *International Journal of Civil Engineering and Technology*, *7*(4), 269–275.

Thirupathaiah, M., Samatha, C., & Sammaiah, C. (2012). Analysis of water quality using physico-chemical parameters in lower Manair reservoir of Karimnagar district, Andhra Pradesh. *International Journal of Environmental Science and Technology*, *3*(1), 172–180.

Tirkey, P., Bhattacharya, T., & Chakraborty, S. (2015). Water quality indices- important tools for water quality assessment: A review. *International Journal of Advanced Chemistry*, *1*, 1–10.

Tiwary, A. K., Singh, A. K., Singh, A. K., & Singh, M. P. (2017). Hydrogeochemical analysis and evaluation of surface water quality of Pratapgarh district, Uttar Pradesh, India. *Applied Water Science*, *7*(4), 1609–1623. doi:10.1007/s13201-015-0313-z

Trivedi, H. V., & Singh, J. K. (2005). Application of grey system theory in the development of a runoff prediction model. *Biosystems Engineering*, *92*(4), 521–526. doi:10.1016/j.biosystemseng.2005.09.005

Tyagi, S., Singh, P., Sharma, B., & Singh, R. (2014). Assessment of water quality for drinking purpose in district Pauri of Uttarakhand, India. *Applied Ecology and Environmental Sciences*, *2*(4), 94–99.

Varol, M., Gökot, B., Bekleyen, A., & Sen, B. (2012). Spatial and temporal variations in surface water quality of the dam reservoirs in the Tigris River basin, Turkey. *Catena*, *92*, 11–21. doi:10.1016/j.catena.2011.11.013

Wang, X. Q., Juan, W., Chen, P. H., & Liu, N. N. (2018). Monitoring and assessment of Youshui river water quality in Youyang. *IOP Conference Series: Earth and Environmental Science*, *113*, 012069. doi:10.1088/1755-1315/113/1/012069

Wei, G. L., Yang, Z. F., Cui, B. S., Li, B., Chen, H., Bai, J. H., & Dong, S. K. (2009). Impact of dam construction on water quality and water self-purification capacity of the Lancang River, China. *Water Resources Management*, *23*(9), 1763–1780. doi:10.1007/s11269-008-9351-8

WHO. (2011). *Guidelines for drinking water quality* (4th ed.). Geneva: World Health Organization.

Yadav, N. S., Kumar, A., Mishra, S., & Singh, S. (2018). Assessment of water quality using pollution-index in the study stretch of river Chambal, India. *International Journal of Advanced Research*, *5*(1), 20–25.

Zandagba, J. E. B., Adandedji, F. M., Lokonon, B. E., Chabi, A., Dan, O., & Mama, D. (2017). Application use of water quality index (WQI) and multivariate analysis for nokoué lake water quality assessment. *American Journal of Environmental Science and Engineering*, *1*(4), 117–127.

Zarei, H., & Bilondi, M. P. (2013). Factor analysis of chemical composition in the Karoon River basin, southwest of Iran. *Applied Water Science*, *3*(4), 753–761. doi:10.1007/s13201-013-0123-0