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ORIGINAL ARTICLE

Assessment of water quality status of Doyang River, Nagaland, India, using Water Quality Index

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Abstract

The Doyang River of Wokha district, Nagaland, NE India, has a strong economic and traditional attachment to the local people. It provides sufficient fertile plains and slopes for cultivation, good grounds for community fishing and hunting. It is not only important for the people of Wokha but also for the state of Nagaland because of the rich natural resources it provides. This study was conducted to assess the Water Quality Index (WQI) of the Doyang River from eight selected sampling stations. Maximum WQI values were recorded during monsoon season in all the stations followed by pre-monsoon and post-monsoon. Sampling stations located in the upstream of the river experience deteriorating WQI due to the presence of hydroelectric dam, changing landuse practices, increasing settlements and deforestation in the catchment and river banks. The overall WQI values showed good water quality status indicating suitability for different human uses. The present study points out that pH, DO and BOD played a central role in affecting the WQI of the river; however, in case of nutrient elements no such significant roles were observed in affecting the water quality of the river. The condition of water quality in our present study felt the necessity to adopt proper management policy and conservation efforts along the riparian zones of Doyang River.

Keywords Doyang River · Water Quality Index (WQI) · Permissible limit · Seasonal values · Riparian forest

Introduction

Rivers are an important source of freshwater but are also vulnerable to kinds of pollution to both point and nonpoint sources. Anthropogenic activities related to extensive urbanization, agricultural practices, industrialization and population expansion have led to water quality deterioration in many parts of the world. The adjacent landscapes that act as an interface between the aquatic and terrestrial ecosystem called the 'riparian zones play a significant role in controlling water and chemical exchange between surrounding land and stream systems (Burt and Pinay 2005). Disturbances in this landscape can lead to deterioration of water quality as they influence the flows of energy and material between the terrestrial and aquatic (Fausch et al. 2010) interface. Riparian zones form a unique ecosystem and act as 'buffer zones' between upland and streams (Hill 1996; Lowrance 1998) and are vital to the health of the watershed. The riparian forest along the river that receives and processes water, sediments and nutrients transports from upslope areas and effectively functions as sinks for sediment and nutrients, thus regulating the nutrient loading to the aquatic system (Luke et al. 2007; Mayer et al. 2007). Water quality of any specific area or source may be assessed using physical, chemical and biological parameters; it is considered harmful and unfit for different human usage and other agricultural activities once they occur more than the well-defined limits (ICMR 1975; BIS 2003). Accordingly, the suitability of water for its usage may be categorized or described in terms of Water Quality Index (WQI), which is one of the most effective ways to describe the status of water quality. It is calculated from the point of aptness of surface water for human consumption (Atulegwu and Njoku 2004).

WQI is a single number that expresses water quality by aggregating the measurements of water quality parameters (such as dissolved oxygen, pH, nitrate and total hardness). It reduces the bulk of information from the several water quality parameters into a single value and expresses the data in a simplified and logical form (Semiromi et al. 2011). Assessment of water quality could provide us the overall information on the quality of the water bodies and its potential

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threat to various uses. The application of WQI is a useful method in assessing the water quality of the river. It helps to understand the overall water quality status of individual sampling stations at a certain time (Yogendra and Puttaiah2008) and its suitability for various beneficial uses. The concept of indices to represent gradation in water quality was first proposed by Horton (1965), since then numerous water quality indices have been formulated that can easily evaluate the overall water quality of an area promptly and efficiently. The general WQI developed by Brown et al. (1970) has undergone much improved modification suitable for a different purpose. Many workers like Debels et al. (2005), Yisa and Jimoh (2010), Akoteyon et al. (2011), Othman et al. (2012), Naubi et al. (2016), Ewaid (2017) and Bouslah et al. (2017) have worked out the study of WQI of different rivers. Similarly, in India, Yogendra and Puttaiah (2008), Kumar et al. (2011), Sharma and Kansal (2011), Singh and Kamal (2014) and Shah and Joshi (2017) have also worked on WQI of rivers in different states of India. So far only a few studies on WQI from the northeastern part of India, mainly confined to Assam and Manipur (Singh et al. 2016, Bora and Goswami 2017), have been reported.

Nagaland state is dissected by a number of seasonal and perennial rivers and rivulets. Major rivers that flow westward into Brahmaputra River of Assam are Dhansiri, Doyang and Dikhu. The Doyang River passes through a great part of Wokha district of Nagaland and is called 'POFU' by the local inhabitants (Lothas) which simply means 'encircle' because the river flows right through the middle of the district touching all the three ranges encircling the whole district. The Dam area of Doyang River is an important ecotourism spot for bird-watchers as it is a roosting place of a migratory bird Amur falcon (*Falco amurensis*). The falcons travel almost 22,000 km every year (October–November) from southeastern Siberia and Northern China in millions and spend nearly a month around the vicinity of the Dam. The river also has a strong economic and traditional attachment to the local people because of its sufficient fertile plains and slopes for cultivation. However, the changing landuse practices, increasing population and deforestation in the catchment and river banks, shifting cultivation along the river have threatened the riparian habitats as never before. This has drawn much attention in preserving the riparian vegetation along the streams and in other sensitive areas in order to protect the water quality and habitat value of these areas. Geomorphology and seasonal variation of physicochemical parameters of Doyang River had been worked out by Imnatoshi and Ahmed (2012); however, there has been no scientific investigation on water quality assessment of Doyang River till date. In the present study, the application of WQI would give us comparative results of the water quality status of Doyang River at different sampling stations in varying seasons. The main reason for using WQI in the present study is to test the hypothesis whether the riparian forest present along the stretch of Doyang River may help in improving the status of water quality besides several pockets of landuse practices being found. This study would provide us a comprehensive water quality status of the Doyang River. It would ultimately pave ways for future management and action plans so as to protect the riparian zones that face pressure from different landuse practices, and facilitate improvement of the water quality.

The study area

Nagaland has a total geographical area of 16,579 km^2 extending from 25°6′ N to 27°4′ N Latitude and 93°20′ E–95°15′ E Longitude. The state is bounded by Assam in the north and west, by Myanmar and Arunachal Pradesh in the east and by Manipur in the south. Nagaland experiences heavy rainfall, and the annual rainfall varies from 100 to 300 cm. The monsoon seasons last for a period of 5 months from May to September with June, July and August experiencing the highest rainfall. The Doyang River is one of the major rivers in Nagaland and runs along the southern boundary of the state. It originates from the Japfü Hill near the southern slope of Mao in Manipur and moves in a southwest direction passing through Kohima district and flows northward into Zunheboto and Wokha. The river has a length of 167 km (from Gariphema/Ghathashi area to Liphi) and a catchment area of 3283 km^2 (Laishram and Yumnam 2016). It passes through a great part of Wokha district of Nagaland and flows south westerly into Dhansiri in Sibsagar District of Assam and finally joins the mighty Brahmaputra River of Assam. The main tributaries of Doyang are Tsui, Tullo and Tishi. The present study was conducted within a stretch of 40–45 km of Doyang River under Wokha district, Nagaland. The Doyang hydroelectric project (DHEP) is located in this river at 26°14 N Latitude and 94°16 E Longitude of Wokha district. The large reservoir lake created for generating hydroelectric power is more than 20 km^2, and it also comes under the present study area. There are several landuse practices around the catchment area of the Doyang hydroelectric dam and along the riparian zone of the river. Figure 1 shows the landuse/landcover (LULC) map of the present study area. The characteristics features of the selected sampling stations, their coordinates and elevation along the Doyang River are presented in Table 1.

Materials and methods

Along the stretch of Doyang River, surface water samples were collected from the eight sampling stations. Sampling was done during the first week of each month from June 2016

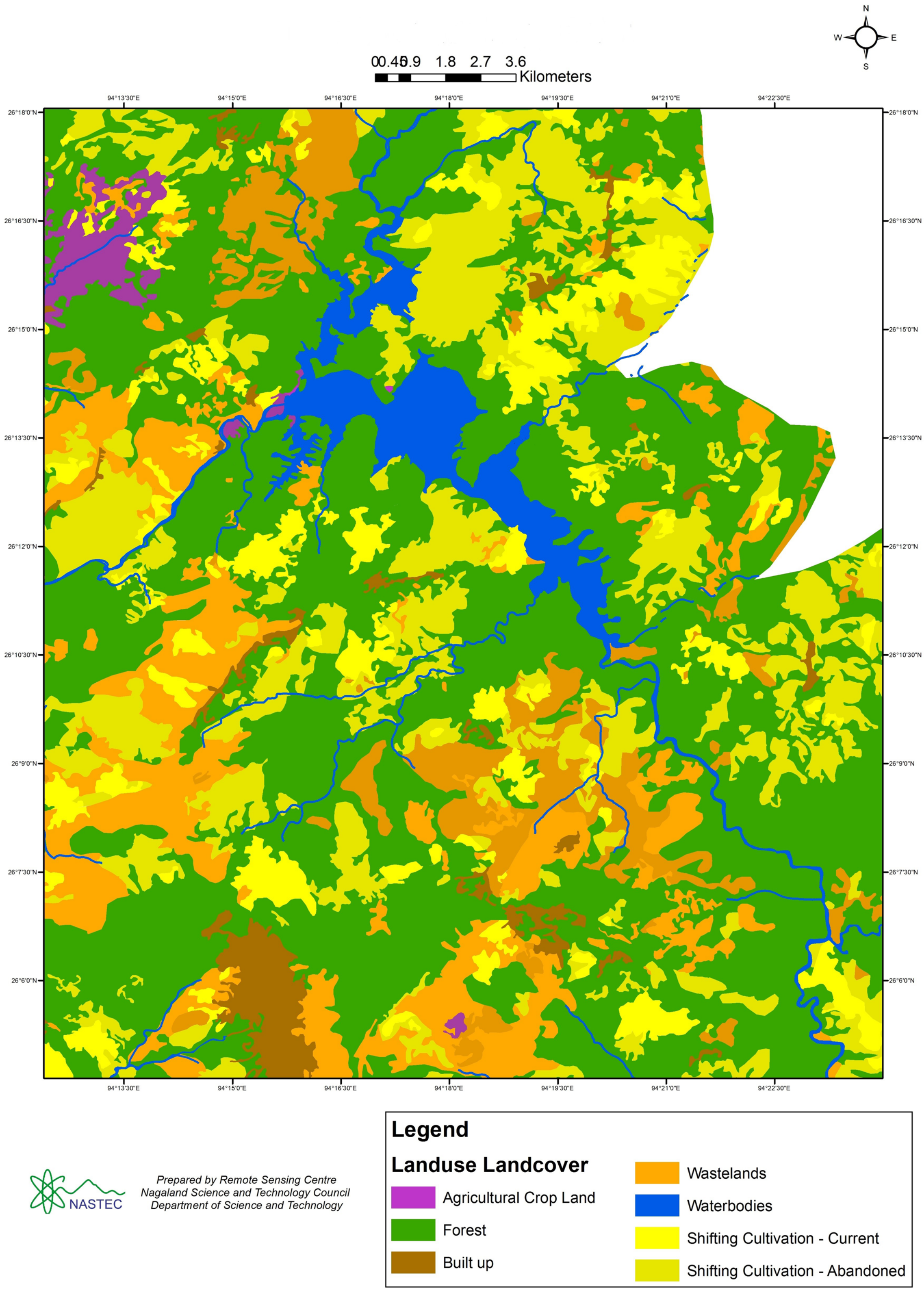

Fig. 1 Map showing the landuse/landcover (LULC) of the study area

to May 2017 for a period of 1 year. The months were later categorized into three different seasons, namely pre-monsoon (PRM), monsoon (MON) and post-monsoon (POM) for interpretation of data. Figure 2 shows the sampling location

Table 1 Characteristic features of the sampling station, their coordinates and elevation along Doyang River

Sl. no	Sampling station	Station code	Characteristics of sampling station	Coordinates	Elevation (msl)
1.	Station 1	S 1	Upstream forested area inhabited by some residential families and ongoing construction site of highway bridge (NH 2).	26°07.298′ N 094°23.099′ E	348 m
2.	Station 2	S 2	Midstream forested area located around the vicinity of hydroelectric dam along the river.	26°13.331′ N 094°18.747′ E	314 m
3.	Station 3	S 3	Jhum cultivate site located around the vicinity of hydroelectric dam along the river	26°14.542′ N 094°17.529′ E	335 m
4.	Station 4	S 4	Teak plantation site located around the vicinity of hydroelectric dam along the river	26°14.214′ N 094°16.933′ E	332 m
5.	Station 5	S 5	Point of dam construction site inhabited by some residential families.	26°13.811′ N 094°15.779′ E	325 m
6.	Station 6	S 6	Residential site along the downstream of the river	26°13.752′ N 094°15.068′ E	266 m
7.	Station 7	S 7	Abandoned Jhum site along the downstream of the river	26°13.078′ N 094°14.661′ E	257 m
8.	Station 8	S 8	Downstream forested area with different landuse like Jhumming and teak plantation (monoculture)	26°12.622′ N 094°14.211′ E	243 m

selected along the river for the study of WQI. Water samples were collected from the first 20 cm of the water column using a bottom-weighted polyethylene flask, previously washed in the laboratory with lapoline, 10% HCl and then with a water sample from each spot. In this study, twelve physicochemical parameters of water were selected, namely pH, electrical conductivity (EC), total dissolved solids (TDS), total alkalinity (TA), total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^{-}), nitrate (NO_3^{-}), sulfate (SO_4^{2-}), dissolved oxygen (DO) and biological oxygen demand (BOD) for generating the overall WQI of Doyang River. Parameters like pH and TDS were measured on the spot with the help of pen-type digital pH and TDS meter. Conductivity was analyzed with the help of a digital conductivity meter in the laboratory. Total alkalinity, total hardness, calcium, magnesium and chloride were analyzed by the titration method. For the measure of dissolved oxygen, fixatives were added on the spot and analyzed thereafter using Winkler's method. Separate samples for BOD were also collected, incubated in the dark at 20 °C for 5 days and analyzed thereafter. Parameters like nitrate and sulfate were analyzed using the double-beam UV–visible spectrophotometer. All the parameters were analyzed using standard methods as prescribed by Trivedy and Goel (1986) and APHA (2005). Finally, the WQI was calculated by employing the Weighted Arithmetic Index method developed by Brown et al. (1970) which is given in the following equation:

$$\mathrm{WQI} = \sum Q_i W_i / \sum W_i$$

The quality rating scale (Q_i) for each parameter was calculated by using the expression:

$$Q_i = 100\left[\left(V_i - V_o / S_i - V_o\right)\right]$$

where V_i = concentration of ith parameter in the water sample analyzed.

V_o = ideal value of parameter in pure water, i.e., $V_o = 0$ (except pH 7.0 and DO = 14.6 mg/l), S_i = recommended standard value of ith parameter.

The unit weight (W_i) for each water quality parameter is calculated by using the following formula:

$$W_i = K / S_i$$

where K = proportionality constant calculated by using the equation

$$K = \frac{1}{\sum (1/S_i)}$$

The WQI range, its status and possible usage (Brown et al. 1972) are presented in Table 2.

Results and discussion

Water quality parameters

The values of water quality parameters obtained from all the sampling stations in three different seasons are presented in Table 3. The pH is a measure of the acidic or alkaline condition of water and serves as an important indicator of water quality and determines the suitability of water for various purposes. The experimental water bodies recorded approximately neutral or slightly alkaline in nature (Bouslah

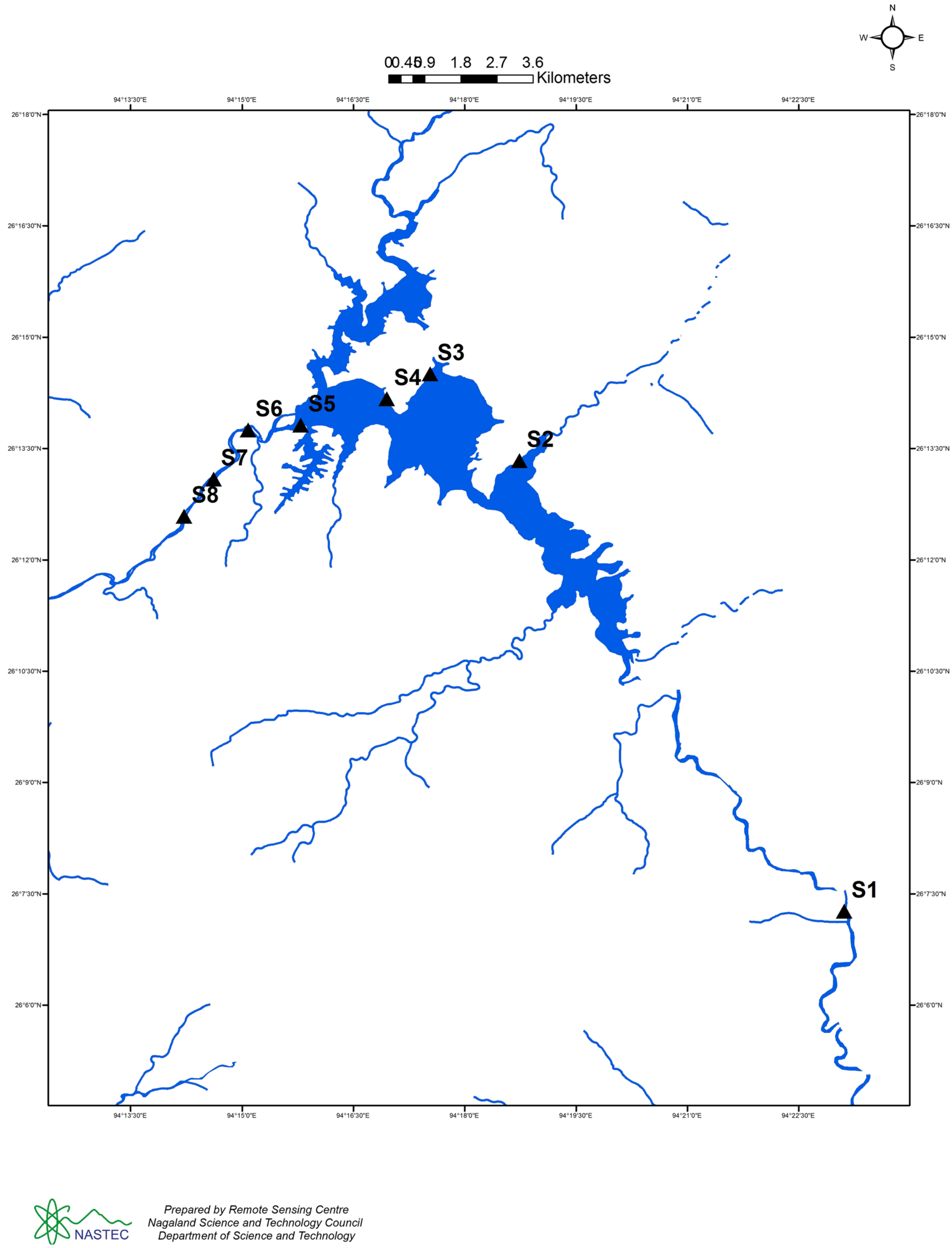

Fig. 2 Map indicating the sampling stations located along Doyang River

et al. 2017). The mean values of pH from all the sampling stations during PRM, MON and POM were found to be 8.09 ± 0.08, 7.84 ± 0.06 and 6.93 ± 0.06. In natural water, the common range of pH falls within 6–8 (Thakre et al. 2010); a similar range of values has also been observed of the current study as well. Electrical conductivity (EC) is an indirect measure of total dissolved salts. The presence of these salts greatly affects the taste and acceptance of the

Table 2 Water Quality Index (WQI) range, status and possible usage of water sample (Brown et al. 1972)

WQI range	Water quality status (WQS)	Probable usage
0–25	Excellent water quality	Drinking, irrigation and industrial purpose
26–50	Good water quality	Drinking, irrigation and industrial purpose
51–75	Poor water quality	Irrigation and industrial purpose
76–100	Very poor water quality	For irrigation purpose
Above 100	Unsuitable for drinking purpose	Proper treatment required for any kind of usage

Table 3 Seasonal mean value, range and statistical variation of water quality parameters of Doyang River

Parameters	Pre-monsoon (PRM)		Monsoon (MON)		Post-monsoon (POM)	
	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD
pH	7.86–8.21	8.09 ± 0.08	7.41–8.29	7.84 ± 0.06	6.75–7.14	6.93 ± 0.06
EC	171.32–271.49	188.67 ± 0.40	144.03–171.23	151.50 ± 0.24	139.42–214.74	155.05 ± 0.28
TDS	84–134.42	93.95 ± 0.62	64–80.09	70.35 ± 0.46	70.84–111.50	79.17 ± 0.45
T H	74.92–111.33	82.39 ± 0.89	67.17–79.34	72.52 ± 0.80	63.50–97.50	70.25 ± 0.81
T A	104.17–141.25	111.05 ± 1.62	77.50–100.84	82.87 ± 1.67	87.09–131.67	96.36 ± 1.71
Ca^{2+}	15.36–23.11	16.79 ± 0.37	11.09–16.10	12.99 ± 0.33	12.43–22.45	14.42 ± 0.38
Mg^{2+}	8.89–13.03	9.90 ± 0.22	8.66–10.88	9.72 ± 0.21	7.80–10.13	8.35 ± 0.20
Cl^-	16.69–24.61	19.07 ± 0.64	14.55–17.51	16.41 ± 0.61	18.46–22.72	20.01 ± 0.68
NO_3^-	0.56–0.81	0.65 ± 0.01	0.49–0.71	0.64 ± 0.02	0.63–0.84	0.72 ± 0.02
SO_4^{2-}	15.45–21.63	16.66 ± 0.06	12.42–16.94	14.60 ± 0.04	10.72–18.05	12.17 ± 0.05
DO	10.02–11.38	10.56 ± 0.15	7.75–10.61	9.12 ± 0.14	8.26–9.68	9.03 ± 0.11
BOD	0.88–2.96	1.68 ± 0.08	1.22–3.34	2.18 ± 0.09	1.72–3.02	2.29 ± 0.08

All the parameters are in milligrams per liter except for pH and EC (µS/cm)

water as potable to the users (Pradeep 1998). Observed mean EC of Doyang River was found to be 188.67 ± 0.40 µS/cm during PRM, 151.50 ± 0.24 µS/cm during the MON and 155.05 ± 0.28 µS/cm in the POM. Season wise a maximum range of 171.32–271.49 µS/cm was observed in PRM across the different stations (Yogendra and Puttaiah 2008). Total dissolved solids (TDS) measure the dissolved particle present in the water sample and indicate the general nature of water quality or salinity. The values recorded were all under the desirable limits of 500 mg/l (BIS) with a maximum in PRM season (93.95 ± 0.62 mg/l). The MON season observed the least mean values of 70.35 ± 0.46 mg/l. Total alkalinity (TA) recorded the highest average value of 111.05 mg/l during the PRM ranging between 104.17 and 141.25 mg/l. However, there was a significant decrease in TA in the monsoon with the mean value of 82.87 ± 1.67 mg/l. This may be attributed to the influx of fresh water into the river system causing dilution (Chatterjee and Raziuddin 2002). In natural water, total hardness (TH) is contributed mainly by dissolved calcium and magnesium ions (Ikomi and Emuh 2000), with all other divalent cations contributing to its concentration. The majority of its source is contributed by the surrounding rocks of the water bodies. The maximum mean concentration of calcium observed was 16.79 ± 0.37 mg/l in PRM with values ranging from 15.36 to 23.11 mg/l. The increase in temperature, low level of water and other domestic waste may have contributed toward its higher concentration (Devi et al. 2015) during the PRM. Magnesium in natural water may be attributed to chemistry of the geological composition of the river bedrock. A mean value of 9.90 ± 0.21 mg/l, 9.72 ± 0.21 mg/l and 8.35 ± 0.20 mg/l was recorded during the PRM, MON and POM, respectively. No significant variation was observed in all the three seasons studied. Total hardness (TH) did not show much variation in their concentration in all three seasons. The mean values observed during the PRM, MON and POM seasons were 82.39 ± 0.89 mg/l, 72.52 ± 0.80 mg/l and 70.25 ± 0.81 mg/l, respectively, and generally fall under the category of moderately hard water (Bora and Goswami 2017). Chloride occurs naturally in all types of water; however, its main contributing sources are runoff of inorganic fertilizers from agricultural fields, sewage discharge, etc. The chloride content of the sample was found to be well within the permissible levels of 250 mg/l. Its highest concentration was recorded during the POM (average value of 20.01 ± 0.68 mg/l) and least (average concentration of 16.41 mg/l) during the MON. Nitrate is found in surface waters as a result of sewage, fertilizer runoff from agricultural land, etc. Excess of nitrate can cause eutrophication

(WHO 1998) resulting in the death of aquatic animals and serious health hazards. The highest recorded mean value of nitrate was found to be 0.72 ± 0.02 mg/l during the POM. However, in the present study, the concentration of nitrate recorded relatively low with values ranging from 0.49 to 0.84 mg/l (Ewaid 2017). Sulfate naturally occurs in surface water as a result of weathering of igneous and sedimentary rock. Other sources may be leachate from abandoned mines, air deposition from the combustion of fossil fuels and industrial wastewater. The mean concentration of sulfate recorded during the study period was 16.66 ± 0.06 mg/l, 14.60 ± 0.04 mg/l and 12.17 ± 0.05 mg/l in PRM, MON and POM, respectively. The PRM recorded the maximum sulfate concentration with values ranging from 15.45 to 21.63 mg/l; nevertheless, all the observed values were within the tolerable limits of 150 mg/l (Yisa and Jimoh 2010). Dissolved oxygen (DO) is the measurement of the amount of oxygen dissolved in water and is a direct indicator of water quality. In a healthy water body that ensures good water quality, DO must be > 4 mg/l (Prasad and Bose 2001). DO along Doyang River was recorded significantly high from all the stations throughout the study period. The highest concentration of DO was observed during the PRM season range from 10.02 to 11.38 mg/l with a mean value of 10.56 ± 0.15 mg/l. The turbulent nature of the water bodies, photosynthesis and a decrease in temperature might have resulted in the increased concentration of DO (Bouslah et al. 2017). Biological oxygen demand (BOD) determines the strength of oxygen to stabilize domestic and industrial waste. A higher value of BOD levels represents a higher level of organic pollution (Patel et al. 1983) indicating higher organic pollution in a water sample. Observed BOD in PRM, MON and POM was 1.68 ± 0.08 mg/l, 2.18 ± 0.09 mg/l and 2.29 ± 0.08 mg/l, respectively. The low level of BOD in the present study indicates less organic matter in the water sample to be oxidized by microorganisms (Singh et al. 2016). All the twelve physicochemical parameters of water analyzed were well within the permissible limits of drinking water given by BIS (2003) and ICMR (1975).

Table 4 Relative weights (W_i) of different parameters and their standards used for WQI determination

Parameters	ICMR/BIS standards (S_i)	Unit weight (W_i)
pH	6.5–8.5	0.192
EC	300	0.005
TDS	500	0.003
T H	300	0.005
T A	120	0.014
Ca^{2+}	75	0.022
Mg^{2+}	30	0.054
Cl^-	250	0.007
NO_3^-	45	0.036
SO_4^{2-}	150	0.011
DO	5	0.326
BOD	5	0.326
$\sum W_i = 1.000$		

Water Quality Index (WQI) calculation

The calculation of WQI using Weighted Arithmetic Index involves the estimation of 'unit weight' assigned to each physicochemical parameter selected. Different units and dimensions of the selected parameters are transformed into

Table 5 Calculation of WQI at station 1 (S 1)

Parameters	Pre-monsoon (PRM)			Monsoon (MON)			Post-monsoon (POM)		
	V_i	Q_i	W_i*Q_i	V_i	Q_i	W_i*Q_i	V_i	Q_i	W_i*Q_i
pH	8.21	80.6667	15.4512	7.74	49.3333	9.4495	7.14	9.3333	1.7877
EC	271.49	90.4967	0.4911	171.23	57.0767	0.3098	214.74	71.5800	0.3885
TDS	134.42	26.8840	0.0875	80.09	16.0180	0.0522	111.5	22.3000	0.0726
T H	111.33	37.1100	0.2014	76	25.3333	0.1375	97.5	32.5000	0.1764
T A	141.25	117.7083	1.5970	100.84	84.0333	1.1401	131.67	109.7250	1.4887
Ca^{2+}	23.11	30.8133	0.6689	16.1	21.4667	0.4660	22.45	29.9333	0.6498
Mg^{2+}	13.03	43.4333	2.3572	8.66	28.8667	1.5666	10.13	33.7667	1.8325
Cl^-	24.61	9.8440	0.0641	17.43	6.9720	0.0454	22.72	9.0880	0.0592
NO_3^-	0.81	1.8000	0.0651	0.71	1.5778	0.0571	0.84	1.8667	0.0675
SO_4^{2-}	21.63	14.4200	0.1565	16.03	10.6867	0.1160	18.05	12.0333	0.1306
DO	10.39	43.8542	14.2800	9.33	54.8958	17.8755	9.68	51.2500	16.6883
BOD	1.91	38.2000	12.4389	1.66	33.2000	10.8108	2.4	48.0000	15.6300
	$\sum W_iQ_i = 47.8591$			$\sum W_iQ_i = 42.0264$			$\sum W_iQ_i = 38.9719$		
	WQI = 47.86			WQI = 42.03			WQI = 38.97		

Table 6 Calculation of WQI at station 2 (S 2)

Parameters	Pre-monsoon (PRM)			Monsoon (MON)			Post-monsoon (POM)		
	V_i	Q_i	W_i*Q_i	V_i	Q_i	W_i*Q_i	V_i	Q_i	W_i*Q_i
pH	7.86	57.3333	10.9819	7.83	55.3333	10.5988	7.12	8.0000	1.5324
EC	194.26	64.7533	0.3514	148.37	49.4567	0.2684	145.71	48.5700	0.2636
TDS	97.92	19.5840	0.0638	69	13.8000	0.0449	74.67	14.9340	0.0486
T H	86.33	28.7767	0.1562	72.34	24.1133	0.1309	66.17	22.0567	0.1197
T A	110.42	92.0167	1.2485	78.75	65.6250	0.8904	89.17	74.3083	1.0082
Ca^{2+}	17.17	22.8933	0.4970	12.69	16.9200	0.3673	13.63	18.1733	0.3945
Mg^{2+}	10.52	35.0667	1.9031	9.99	33.3000	1.8072	7.8	26.0000	1.4110
Cl^-	19.88	7.9520	0.0518	17.51	7.0040	0.0456	18.58	7.4320	0.0484
NO_3^-	0.61	1.3556	0.0490	0.73	1.6222	0.0587	0.79	1.7556	0.0635
SO_4^{2-}	16.94	11.2933	0.1226	13.53	9.0200	0.0979	11.27	7.5133	0.0816
DO	10.05	47.3958	15.4333	9.78	50.2083	16.3491	8.79	60.5208	19.7071
BOD	2.96	59.2000	19.2770	3.24	64.8000	21.1005	3.02	60.4000	19.6678
	$\sum W_iQ_i = 50.1355$			$\sum W_iQ_i = 51.7598$			$\sum W_iQ_i = 44.3464$		
	WQI = 50.14			WQI = 51.76			WQI = 44.35		

Table 7 Calculation of WQI at station 3 (S 3)

Parameters	Pre-monsoon (PRM)			Monsoon (MON)			Post-monsoon (POM)		
	V_i	Q_i	W_i*Q_i	V_i	Q_i	W_i*Q_i	V_i	Q_i	W_i*Q_i
pH	8.1	73.3333	14.0466	8.11	74.0000	14.1743	6.87	−8.6667	−1.6601
EC	176.53	58.8433	0.3193	153.01	51.0033	0.2768	143.97	47.9900	0.2604
TDS	89.25	17.8500	0.0581	70.42	14.0840	0.0459	72	14.4000	0.0469
T H	79	26.3333	0.1429	71.17	23.7233	0.1287	65.17	21.7233	0.1179
T A	107.59	89.6583	1.2165	77.5	64.5833	0.8762	92.92	77.4333	1.0506
Ca^{2+}	15.98	21.3067	0.4625	12.52	16.6933	0.3624	13.03	17.3733	0.3771
Mg^{2+}	9.5	31.6667	1.7186	9.66	32.2000	1.7475	7.92	26.4000	1.4328
Cl^-	18.68	7.4720	0.0487	15.98	6.3920	0.0416	18.46	7.3840	0.0481
NO_3^-	0.59	1.3111	0.0474	0.59	1.3111	0.0474	0.7	1.5556	0.0563
SO_4^{2-}	15.98	10.6533	0.1156	12.92	8.6133	0.0935	10.89	7.2600	0.0788
DO	10.09	46.9792	15.2976	9.38	54.3750	17.7059	8.79	60.5208	19.7071
BOD	2.07	41.4000	13.4809	2.84	56.8000	18.4955	2.18	43.6000	14.1973
	$\sum W_iQ_i = 46.9548$			$\sum W_iQ_i = 53.9958$			$\sum W_iQ_i = 35.7132$		
	WQI = 46.95			WQI = 53.10			WQI = 35.71		

a common scale using the assigning units. Table 4 shows the drinking water quality standards and the unit weights assigned to each parameter used for the calculation of WQI. Considering the significance of water quality assessment and their impact on the value of WQI, a maximum weightage of 0.366 is assigned to both DO and BOD. Tables 5, 6, 7, 8, 9, 10, 11 and 12 depict the values observed for the selected physicochemical parameters from the eight sampling stations during each season and their corresponding WQI values. pH, DO and BOD were found to be the most significant parameters in the WQI scores worked out.

The overall values of WQI of the water samples from all the eight sampling stations for each season are presented in Table 13. WQI were observed to have a positive relationship with the seasonal changes. Maximum WQI values were recorded during MON from all the eight stations followed by PRM and POM. A similar finding has also been reported by researchers like Singh and Kamal (2014), Bora and Goswami (2017) in their studies of assessment of surface water quality status. An average value of WQI for all the stations during PRM, MON and POM was 42.95, 47.13 and 36.66, respectively, as presented in Table 14. This result indicates that the quality of the water samples from all the stations falls under the class of good water samples ($25 < WQI < 50$) suitable for drinking, irrigation and industrial purpose (Fig. 3). Ranges of WQI values from all the eight stations

Table 8 Calculation of WQI at station 4 (S 4)

Parameters	Pre-monsoon (PRM)			Monsoon (MON)			Post-monsoon (POM)		
	V_i	Q_i	W_i*Q_i	V_i	Q_i	W_i*Q_i	V_i	Q_i	W_i*Q_i
pH	8.08	72.0000	13.7912	8.29	86.0000	16.4728	6.86	− 9.3333	− 1.7877
EC	175.91	58.6367	0.3182	144.03	48.0100	0.2606	140.23	46.7433	0.2537
TDS	86.75	17.3500	0.0565	67	13.4000	0.0436	71.5	14.3000	0.0466
T H	77.67	25.8900	0.1405	70.33	23.4433	0.1272	63.5	21.1667	0.1149
T A	107.5	89.5833	1.2154	83.75	69.7917	0.9469	87.09	72.5750	0.9847
Ca^{2+}	15.57	20.7600	0.4507	11.09	14.7867	0.3210	12.43	16.5733	0.3598
Mg^{2+}	9.54	31.8000	1.7258	10.08	33.6000	1.8235	7.92	26.4000	1.4328
Cl^-	19.41	7.7640	0.0506	14.55	5.8200	0.0379	19.17	7.6680	0.0499
NO_3^-	0.56	1.2444	0.0450	0.49	1.0889	0.0394	0.63	1.4000	0.0507
SO_4^{2-}	15.66	10.4400	0.1133	12.8	8.5333	0.0926	10.75	7.1667	0.0778
DO	10.2	45.8333	14.9245	10.61	41.5625	13.5338	8.64	62.0833	20.2159
BOD	1.38	27.6000	8.9873	3.34	66.8000	21.7518	1.72	34.4000	11.2015
	$\sum W_iQ_i = 41.8190$			$\sum W_iQ_i = 55.4512$			$\sum W_iQ_i = 33.0004$		
	WQI = 41.82			WQI = 55.45			WQI = 33.00		

Table 9 Calculation of WQI at station 5 (S 5)

Parameters	Pre-monsoon (PRM)			Monsoon (MON)			Post-monsoon (POM)		
	V_i	Q_i	W_i*Q_i	V_i	Q_i	W_i*Q_i	V_i	Q_i	W_i*Q_i
pH	8.13	75.3333	14.4297	8.22	81.3333	15.5789	6.85	− 10.0000	− 1.9154
EC	171.32	57.1067	0.3099	134.28	44.7600	0.2429	139.42	46.4733	0.2522
TDS	86.42	17.2840	0.0563	64	12.8000	0.0417	70.84	14.1680	0.0461
T H	76.67	25.5567	0.1387	67.17	22.3900	0.1215	63.84	21.2800	0.1155
T A	104.17	86.8083	1.1778	79.59	66.3250	0.8999	87.92	73.2667	0.9941
Ca^{2+}	15.7	20.9333	0.4544	11.15	14.8667	0.3227	12.49	16.6533	0.3615
Mg^{2+}	9.3	31.0000	1.6824	9.58	31.9333	1.7331	7.88	26.2667	1.4255
Cl^-	18.23	7.2920	0.0475	16.8	6.7200	0.0438	18.7	7.4800	0.0487
NO_3^-	0.66	1.4667	0.0531	0.6	1.3333	0.0482	0.63	1.4000	0.0507
SO_4^{2-}	15.56	10.3733	0.1126	12.42	8.2800	0.0899	10.72	7.1467	0.0776
DO	10.02	47.7083	15.5350	10.12	46.6667	15.1959	8.26	66.0417	21.5048
BOD	1.39	27.8000	9.0524	2.63	52.6000	17.1279	1.78	35.6000	11.5923
	$\sum W_iQ_i = 43.0498$			$\sum W_iQ_i = 51.4463$			$\sum W_iQ_i = 34.5535$		
	WQI = 43.05			WQI = 51.45			WQI = 34.55		

during PRM, MON and POM were: 35.89 (S 6)–50.14 (S 2), 40.77 (S 7)–55.45 (S 4) and 33.00 (S 4)–44.35 (S 2), respectively (Table 13). In all the stations, both PRM and POM showed good water quality status. However, MON showed poor water quality status at stations 2, 3, 4 and 5 located around the vicinity of the hydroelectric dam.

The WQI value showed a mixed pattern of changes in all the seasons (Fig. 4). WQI of the upstream stations from 1 to 5 is higher than the downstream stations, i.e., 6–8 showing the decrease in pollution level while moving downstream of the river. Such observation was also made by Bora and Goswami (2017) in their studies of water quality assessment of Kolong River, Assam, where the water samples showed a decreasing pollution trend further downstream. Workers like Ewaid (2017) have observed better water quality status in upstream than downstream due to a decrease in water and accumulation of contaminants along the downstream of the river. However, the above case is not the same in the present study. This could be due to the absorption of contaminants by healthy riparian vegetation that is present along the downstream of the river. Despite witnessing several landuse practices along the riparian zones, there also observed abundant growth of riparian vegetation that might have positively mitigated in controlling pollution of the river. Workers like Othman et al. (2012) and Naubi et al. (2016) have

Table 10 Calculation of WQI at station 6 (S 6)

Parameters	Pre-monsoon (PRM)			Monsoon (MON)			Post-monsoon (POM)		
	V_i	Q_i	W_i*Q_i	V_i	Q_i	W_i*Q_i	V_i	Q_i	W_i*Q_i
pH	8.17	78.0000	14.9405	7.56	37.3333	7.1510	6.75	− 16.6667	− 3.1924
EC	172.77	57.5900	0.3125	153.76	51.2533	0.2782	154.56	51.5200	0.2796
TDS	84	16.8000	0.0547	70.31	14.0620	0.0458	78.25	15.6500	0.0510
T H	77	25.6667	0.1393	68.67	22.8900	0.1242	68.67	22.8900	0.1242
T A	107.5	89.5833	1.2154	77.92	64.9333	0.8810	91.25	76.0417	1.0317
Ca^{2+}	15.36	20.4800	0.4446	13.23	17.6400	0.3829	13.5	18.0000	0.3908
Mg^{2+}	9.44	31.4667	1.7077	8.73	29.1000	1.5793	8.53	28.4333	1.5431
Cl^-	17.28	6.9120	0.0450	15.74	6.2960	0.0410	19.76	7.9040	0.0515
NO_3^-	0.72	1.6000	0.0579	0.83	1.8444	0.0667	0.71	1.5778	0.0571
SO_4^{2-}	16.03	10.6867	0.1160	16.94	11.2933	0.1226	12.04	8.0267	0.0871
DO	11.32	34.1667	11.1255	7.85	70.3125	22.8955	9.24	55.8333	18.1808
BOD	0.88	17.6000	5.7310	1.22	24.4000	7.9453	2.67	53.4000	17.3884
	$\sum W_iQ_i=35.8902$			$\sum W_iQ_i=41.5135$			$\sum W_iQ_i=35.9928$		
	WQI = 35.89			WQI = 41.51			WQI = 35.99		

Table 11 Calculation of WQI at station 7 (S 7)

Parameters	Pre-monsoon (PRM)			Monsoon (MON)			Post-monsoon (POM)		
	V_i	Q_i	W_i*Q_i	V_i	Q_i	W_i*Q_i	V_i	Q_i	W_i*Q_i
pH	8.06	70.6667	13.5358	7.41	27.3333	5.2355	6.99	− 0.6667	− 0.1277
EC	173.43	57.8100	0.3137	154.14	51.3800	0.2788	151.09	50.3633	0.2733
TDS	87.17	17.4340	0.0568	70.83	14.1660	0.0461	77.58	15.5160	0.0505
T H	74.92	24.9733	0.1355	79.34	26.4467	0.1435	67.67	22.5567	0.1224
T A	104.58	87.1500	1.1824	81.25	67.7083	0.9186	92.5	77.0833	1.0458
Ca^{2+}	15.5	20.6667	0.4486	13.76	18.3467	0.3983	13.63	18.1733	0.3945
Mg^{2+}	8.97	29.9000	1.6227	10.88	36.2667	1.9682	8.24	27.4667	1.4906
Cl^-	16.69	6.6760	0.0435	16.21	6.4840	0.0422	20.95	8.3800	0.0546
NO_3^-	0.63	1.4000	0.0507	0.6	1.3333	0.0482	0.76	1.6889	0.0611
SO_4^{2-}	16.02	10.6800	0.1159	16.25	10.8333	0.1176	11.86	7.9067	0.0858
DO	10.99	37.6042	12.2449	7.75	71.3542	23.2347	9.4	54.1667	17.6380
BOD	1.29	25.8000	8.4011	1.28	25.6000	8.3360	2.2	44.0000	14.3275
	$\sum W_iQ_i=38.1517$			$\sum W_iQ_i=40.7680$			$\sum W_iQ_i=35.4166$		
	WQI = 38.15			WQI = 40.77			WQI = 35.42		

shown encouraging results in the improvement of water quality due to proper management policy and remedial measures. Stations 2–5 experience an abrupt rise in pollution level as all these stations are located near the vicinity of the hydroelectric dam. The stagnant condition of water bodies due to the presence of hydroelectric dam and different landuse activities around these stations could have contributed to the deteriorating condition of water quality. Particularly at station 1, runoff of bridge construction materials (concrete, asphalt, etc.) from the ongoing construction of national highway bridge (NH-02) across the river and cutting down of riparian hill slope for the same have contributed to the increased concentration of many of the water quality parameters analyzed. The presence of some residential homes in the adjoining areas of station 1 has also played a vital role in influencing the physicochemical parameters of water. Different landuse activities located in the upstream of the river like Jhumming (S3), residential area (S1 and S5) and monoculture like teak plantation (S4) have imposed a serious threat to water quality deterioration. Besides, burning of forest annually for shifting cultivation, felling and logging of

Table 12 Calculation of WQI at station 8 (S 8)

Parameters	Pre-monsoon (PRM)			Monsoon (MON)			Post-monsoon (POM)		
	V_i	Q_i	W_i*Q_i	V_i	Q_i	W_i*Q_i	V_i	Q_i	W_i*Q_i
pH	8.14	76.0000	14.5574	7.57	38.0000	7.2787	6.89	−7.3333	−1.4047
EC	173.64	57.8800	0.3141	153.16	51.0533	0.2771	150.65	50.2167	0.2725
TDS	85.67	17.1340	0.0558	71.17	14.2340	0.0463	77	15.4000	0.0501
T H	76.17	25.3900	0.1378	75.17	25.0567	0.1360	69.5	23.1667	0.1257
T A	105.42	87.8500	1.1919	83.34	69.4500	0.9423	98.34	81.9500	1.1119
Ca^{2+}	15.9	21.2000	0.4602	13.36	17.8133	0.3867	14.17	18.8933	0.4101
Mg^{2+}	8.89	29.6333	1.6082	10.15	33.8333	1.8362	8.36	27.8667	1.5123
Cl^-	17.75	7.1000	0.0462	17.04	6.8160	0.0444	21.77	8.7080	0.0567
NO_3^-	0.62	1.3778	0.0498	0.57	1.2667	0.0458	0.69	1.5333	0.0555
SO_4^{2-}	15.45	10.3000	0.1118	15.9	10.6000	0.1151	11.79	7.8600	0.0853
DO	11.38	33.5417	10.9220	8.14	67.2917	21.9119	9.4	54.1667	17.6380
BOD	1.58	31.6000	10.2898	1.22	24.4000	7.9453	2.36	47.2000	15.3695
	$\sum W_iQ_i=39.7451$			$\sum W_iQ_i=40.9656$			$\sum W_iQ_i=35.2832$		
	WQI = 39.75			WQI = 40.97			WQI = 35.28		

Table 13 Summary of WQI of Doyang River along with its water quality status (WQS)

Sampling station	Pre-monsoon (PRM)		Monsoon (MON)		Post-monsoon (POM)	
	WQI	WQS	WQI	WQS	WQI	WQS
S 1	47.86	Good	42.03	Good	38.97	Good
S 2	50.14	Poor	51.76	Poor	44.35	Good
S 3	46.95	Good	53.10	Poor	35.71	Good
S 4	41.82	Good	55.45	Poor	33.00	Good
S 5	43.05	Good	51.45	Poor	34.55	Good
S 6	35.89	Good	41.51	Good	35.99	Good
S 7	38.15	Good	40.77	Good	35.42	Good
S 8	39.75	Good	40.97	Good	35.28	Good

Table 14 Seasonal WQI of Doyang River with its water quality status (WQI)

Seasons	WQI	WQS
Pre-monsoon	42.95	Good
Monsoon	47.13	Good
Post-monsoon	36.66	Good

trees for timber, picnic spot along the river and fishing activities have also exerted much pressure in influencing the water quality of the river. Anthropogenic activities like sewage disposal by the communities residing in the catchment areas, agricultural runoff and unprotected river sites (Yisa and Jimoh 2010, Bouslah et al. 2017 and Shah and Joshi 2017) have also been contributing agents in the deterioration of water quality.

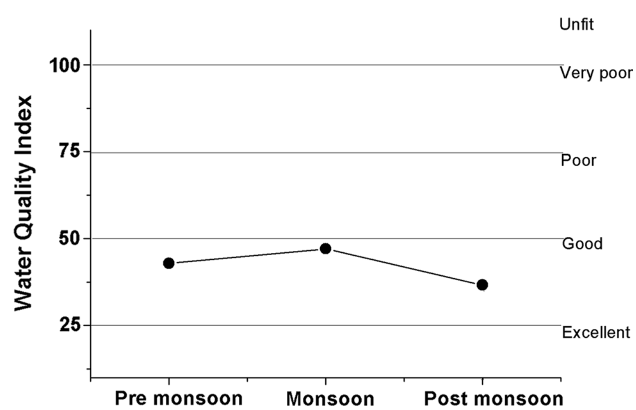

Fig. 3 WQI rating of Doyang River in various seasons

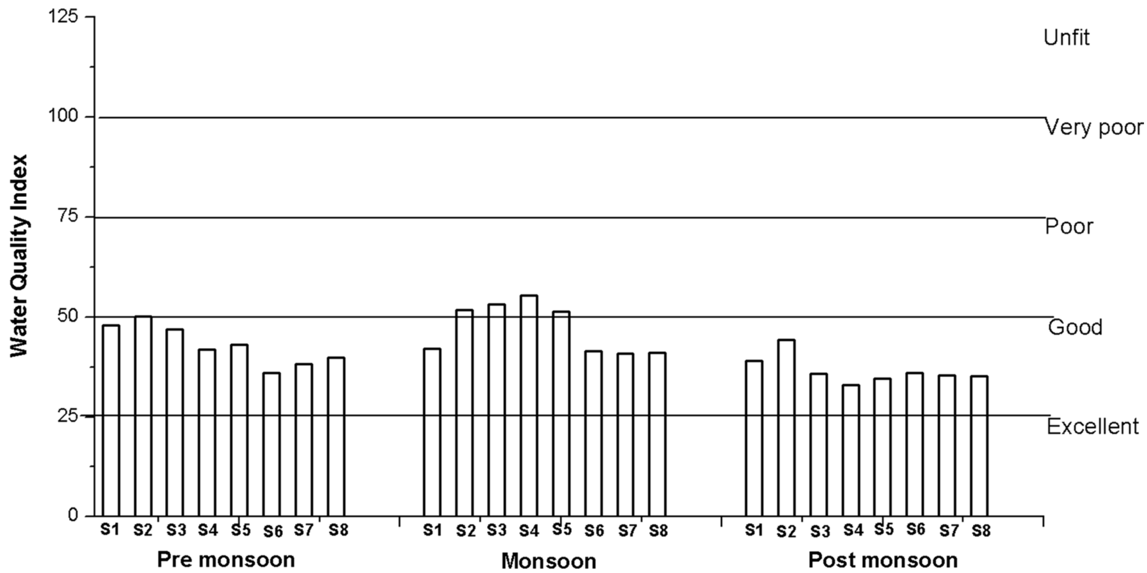

Fig. 4 WQI value of various sampling stations showing a varied pattern of change across seasons

Conclusion

The study provides us with valuable information about the overall water quality status of the Doyang River by calculating the WQI values. As per the observation, recorded WQI values fall in good water quality status during pre- and post-monsoon in all the sampling stations and poor water quality status during monsoon in some of the sampling stations that are located upstream of the river. No considerable changes in WQI were observed throughout the study period except in few sites, where a modest increase in WQI was observed during monsoon. The overall average WQI, however, indicated good water quality status. All the physicochemical parameters of water analyzed were within the permissible limit of drinking water quality, and at present, they do not pose a serious threat for different human usage. In the present study, pH, DO and BOD played a significant role in affecting the WQI of the river. Though in the case of nutrient parameters, no such significant roles were observed. Nevertheless, there are disturbances like Jhum cultivation, extensive teak plantation (monoculture) and increased settlements in the catchment area. Annual burning of the forest for shifting cultivation, logging of trees, eco-tourism, poisoning of rivers and use of explosives for fishing can impose a serious threat to the water quality. These activities, if not controlled, could lead to further deterioration of water quality in the near future. To further improve the water quality, proper management policy must be adopted on disposal of sewage by the communities residing in the catchment areas, agricultural runoff, unmanaged landuse practices and unprotected riparian areas. Special focus on community participation in conservation efforts could be helpful. Remedial measures along the riparian zones could play a positive role in future monitoring and improvement of Doyang River water quality.

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