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ORIGINAL ARTICLE

Water quality assessment in terms of water quality index (WQI): case study of the Kolong River, Assam, India

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Abstract The Kolong River of Nagaon district, Assam has been facing serious degradation leading to its current moribund condition due to a drastic human intervention in the form of an embankment put across it near its take-off point from the Brahmaputra River in the year 1964. The blockage of the river flow was adopted as a flood control measure to protect its riparian areas, especially the Nagaon town, from flood hazard. The river, once a blooming distributary of the mighty Brahmaputra, had high navigability and rich riparian biodiversity with a well established agriculturally productive watershed. However, the present status of Kolong River is highly wretched as a consequence of the post-dam effects thus leaving it as stagnant pools of polluted water with negligible socio-economic and ecological value. The Central Pollution Control Board, in one of its report has placed the Kolong River among 275 most polluted rivers of India. Thus, this study is conducted to analyze the seasonal water quality status of the Kolong River in terms of water quality index (WQI). The WQI scores shows very poor to unsuitable quality of water samples in almost all the seven sampling sites along the Kolong River. The water quality is found to be most deteriorated during monsoon season with an average WQI value of 122.47 as compared to pre-monsoon and post-monsoon season having average WQI value of 85.73 and 80.75, respectively. Out of the seven sampling sites, Hatimura site (S1) and Nagaon Town site (S4) are observed to be the most polluted sites.

Keywords Kolong River · Embankment · Post-dam effects · Pollution · Water quality index (WQI)

Introduction

Freshwater sources in the form of rivers are very much essential for the sustenance and well being of a hale and hearty society. Unfortunately, during the last few decades these natural resources are continuously being tainted all around the world for the sake of development and flood hazard mitigation. However, north-east India is blessed enough to have bounty of accessible freshwater sources in the form of various rivers, streams, lakes, swamps, marshes, etc., with the mighty Brahmaputra river along with its numerous tributaries bifurcating the whole area. These rivers are the lifelines of these regions acting like arteries in our body and are supporting the social, ecological, cultural and overall environmental setup. Additionally, these rivers along with their numerous wetlands formed and feed by them also serve as the refuge to diverse organisms and sub-ecosystems.

Natural flow patterns are the heartbeat of a river. Each component of a flow regime—ranging from low flow to seasonal floods play a vital role in shaping a river ecosystem and livelihoods of river-dependent communities. Until recently, rivers of north-eastern region of India were in pristine free-flowing and unpolluted condition. However, during the last few decades in the pursuit to cope up with rest of the world in terms of development, our freshwater resources are continuously being tainted and deteriorated to an inconceivable stage. Out of various negative anthropogenic acts being perpetuated over our rivers those requiring special mention are water pollution from various point and non-point sources, damming (both

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for hydroelectricity generation as well as flood control), over abstraction and human encroachment. Ecosystems and communities dependent on natural flow regime have already experienced the adverse impacts of altered flow regimes due to engineering interventions. In nutshell, dams/embankments have regulated and fragmented the flows of our rivers—often irreplaceably and as a result, our rivers are inching towards their ecological and hydrological death.

Kolong River of Nagaon district in Assam is an appropriate example of such human intervention which is facing the gripe for the past fifty years. The Kolong River which once used to be a prize possession for the people of the state in general and for the people of Nagaon in particular, is presently gasping on its death-bed because of the ruthless and untenable act perpetrated on it in the name of engineering solution to the increasing flood hazard attributed to it in the aftermath of the great Assam earthquake of 1950.

During the years preceding 1964, primarily as a consequence of the great Assam earthquake of 1950 (measuring 8.7 on Richter scale), this region experienced repetition of large floods due mainly to raised bed level of the Brahmaputra through massive aggradation vis-à-vis the bed level of Kolong, leading thereby to its higher flood levels inundating adjoining low-lying areas like Nagaon. Mainly as a response to the increasing food hazard faced by the district administrative headquarter, i.e., the Nagaon town, an ad hoc flood control measure was undertaken by constructing an earthen embankment, known as *Hatimura dyke*, across the river's take-off point near Hatimura in the year 1964. This drastic human intervention has end up in converting the once free flowing river into a string of alternating dry stretches and stagnant pools during the decades that followed (Bora and Goswami 2014). The river in the present scenario with negligible self-purification capacity is facing severe anthropogenic pressure and acts as the receiver of huge amount of point and non-point pollutants. Consequently, the Kolong River is listed among the 275 most polluted rivers of India by the Central Pollution Control Board (CPCB 2015). Furthermore, drastic changes in landuse/landcover (LULC) pattern of the Kolong River basin have been reported by Bora and Goswami (2016). To restore the health of the Kolong River, a sustainable river-restoration plan seeks its exigency. Thus, the overall aim of the present investigation is to finalize the prevailing water quality inventory of the Kolong River based on WQI and then to propose effective measures to revitalize the Kolong River within the milieu of the continued urbanization by restoring it to its natural state, while allowing the river system to continue to support flood management, landscape development and recreational activities.

A water quality index (WQI) helps in understanding the general water quality status of a water source and hence it has been applied for both surface and ground water quality assessment all around the world since the last few decades (Samantray et al. 2009; Sharma and Kansal 2011; Alam and Pathak 2010; Sebastian and Yamakanamardi 2013; Seth et al. 2014; Tyagi et al. 2013; Bhutiani et al. 2014; VishnuRadhan et al. 2015; Yadav et al. 2015; Dash et al. 2015; Krishnan et al. 2016; Kaviarasan et al. 2016). The main purpose of developing a WQI is to transform a complex set of water quality data into lucid and exploitable information by which a layman can know the status of the water source (Akoteyon et al. 2011; Balan et al. 2012). WQI aims at giving a single value to the water quality of a source by translating the list of parameters and their concentrations present in a sample into a single value, which in turn provides an extensive interpretation of the quality of water and its suitability for various purposes like drinking, irrigation, fishing etc. (Abbasi 2002).

Although, water pollution is a chief matter of apprehension in regard to Kolong River, the water quality issue of the river has not yet got its due importance. However, few scientific investigations on water quality assessment of Kolong River (Saikia and Sarma 2011; Barbaruah et al. 2012; Khan and Hazarika 2012; Bora and Goswami 2014, 2015) have been reported. Fluoride geochemistry of Kolong River was discussed elaborately by Saikia and Sarma (2011). They found that the fluoride concentration of groundwater samples collected from Kolong River basin ranged between 0.03 and 5.68 mg/l. Khan and Hazarika (2012) reported that the increased pollution level of Kolong River water is mainly attributed by the discharge of various types of domestic and commercial waste water, sewage and effluent. Moreover, the truncated river flow accompanied with diminished flow velocity has reduced the self-assimilation and self-purification capacity of the Kolong River (Bora and Goswami 2015). Ironically, literature survey revealed the fact that so far no detailed work on WQI has been carried out for Kolong River. Hence, in continuation of our previous work (Bora and Goswami 2014, 2015), the present investigation is carried out to establish the general pollution trend of the river and to determine the aptness of the water for various purposes based on a set of observed water quality parameters. In this context, an attempt has been made to determine the fitness of various water samples collected along Kolong River for different uses, using the 'weighted arithmetic index method' given by Brown et al. (1970).

Study area

This study is conducted in the Kolong River which is an important river of middle Assam. The Kolong River with a total length of about 212 km is a distributary (*Suti* in local language) of the Brahmaputra which branches out from the near Jakhalabandha, about 77 km upstream of Nagaon, and meets it again at Kajalimukh near Guwahati in a joint channel with the Kopili River—a major south bank tributary of Brahmaputra that flows into Kolong near Jagibhakatgaon of Morigaon district (Fig. 1). The river during its course traverses through the plains of Nagaon, Morigaon and Kamrup districts of Assam. During the course from source to mouth the Kolong River is joined by three main tributaries namely Misa, Dizu and Haria.

Materials and methods

Water samples were collected from seven sampling sites viz. Hatimura (S1), Missamukh (S2), Dizumukh (S3), Nagaon town (S4), Hariamukh (S5), Jagibhakatgaon (S6) and Kajalimukh (S7) during pre-monsoon (PRM), monsoon (MON) and post-monsoon (POM) season over a period of three years, i.e., from January 2012 to November 2015. The details of sampling sites are shown in Fig. 2.

Various physico-chemical parameters of the water samples were analyzed by following the standard methods of APHA (2005) and Trivedy and Goel (1986). A set of ten most commonly used water quality parameters namely pH, electrical conductivity (EC), total dissolved solid (TDS), total suspended solid (TSS), chloride, total alkalinity (TA), total hardness (TH), dissolved oxygen (DO), biochemical oxygen demand (BOD) and sulphate which, together, reflect the overall water quality of the Kolong River were selected for generating the water quality index (WQI). Calculation of WQI was carried out by following the 'weighted arithmetic index method' (Brown et al. 1970), using the equation:

$$\mathrm{WQI} = \sum Q_n W_n \Big/ \sum W_n$$

where Q_n is the quality rating of nth water quality parameter, W_n is the unit weight of nth water quality parameter.

The quality rating Q_n is calculated using the equation

$$Q_n = 100\,[(V_n - V_i)/(V_s - V_i)]$$

where V_n is the actual amount of nth parameter present, V_i is the ideal value of the parameter [$V_i = 0$, except for pH ($V_i = 7$) and DO ($V_i = 14.6$ mg/l)], V_s is the standard permissible value for the nth water quality parameter.

Unit weight (W_n) is calculated using the formula

$$W_n = k/V_s$$

where k is the constant of proportionality and it is calculated using the equation

$$k = \left[1 \Big/ \sum 1/V_s = 1, 2, \ldots, n\right].$$

The water quality status (WQS) according to WQI is shown in Table 1.

Results and discussions

For calculating WQI, the prime pre-requisite is the results of various water quality analyses. The statistical summary of the selected water quality parameters at various

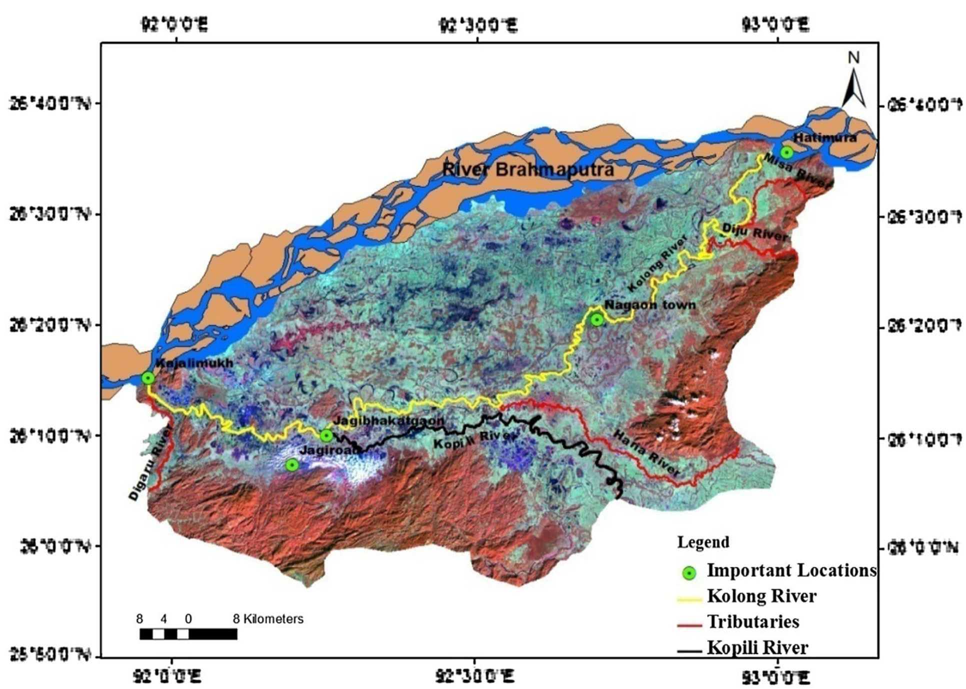

Fig. 1 Map showing the study area

Fig. 2 Map showing sampling sites

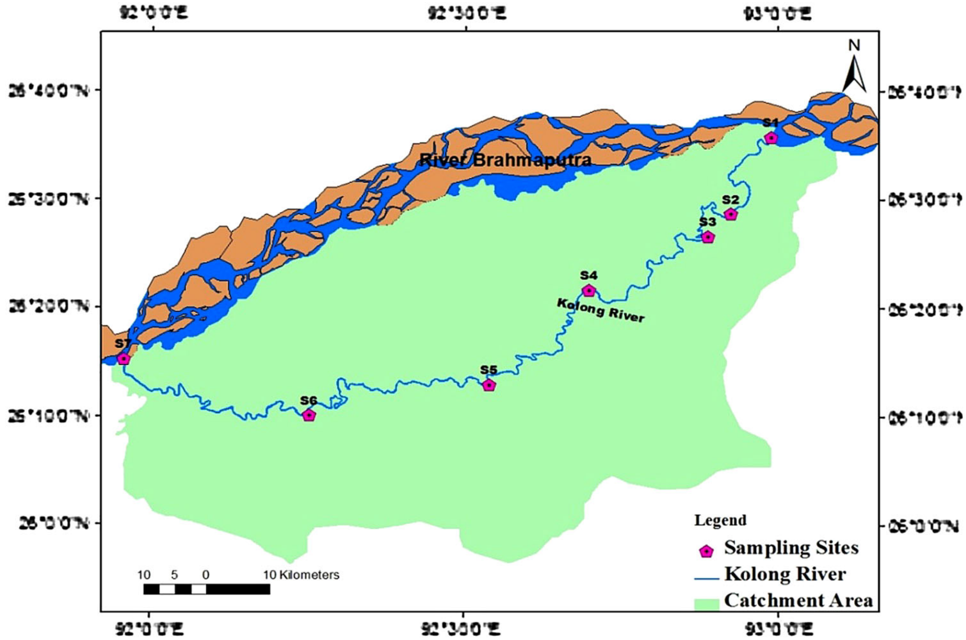

Table 1 WQI range, status and possible usage of the water sample (Brown et al. 1972)

WQI	Water quality status (WQS)	Possible usage
0–25	Excellent	Drinking, irrigation and industrial
26–50	Good	Drinking, irrigation and industrial
51–75	Poor	Irrigation and industrial
76–100	Very poor	Irrigation
Above 100	Unsuitable for drinking and fish culture	Proper treatment required before use

sampling sites of the Kolong River during PRM, MON and POM season is presented in Table 2.

pH generally signifies the degree of acidity or alkalinity of a water sample. The average pH values for PRM, MON and POM season were 7.11 ± 0.52, 6.65 ± 0.06 and 6.57 ± 0.34, respectively. Although the average pH values were within the BIS prescribed limits, however, the minimum pH values during PRM and POM were below the prescribed limit, i.e., 6.5–8.5. Electrical conductivity measures the electric current carrying capacity of a water sample and is directly related to the dissolved ions present in the water. EC was measured using a digital conductivity meter and the results were expressed in microsiemen/centimeter. Observed EC values for the water samples of the Kolong River ranged between 1017–1900 µS/cm (±340), 60–410 µS/cm (±122) and 90–199 µS/cm (±50) during PRM, MON and POM season, respectively, with the values exceeding the ICMR standard of 300 µS/cm at some of the sampling sites during PRM and MON seasons.

TSS and TDS are, respectively, the direct measurement of total suspended and dissolved particles present in a water sample and BIS desirable limit for both the parameters are 500 mg/l. Suspended and dissolved solids are both organic as well as inorganic in nature. The concentration of TSS for the water samples ranged from 65 to 107 mg/l (±13.7) during PRM, from 97.88 to 178.21 mg/l during MON and from 48 to 78 mg/l during POM season, which were well within the BIS desirable limit of 500 mg/l. Similarly, TDS values were also within the desirable limit with mean values of 313.55 mg/l (±44.97), 257.69 mg/l (±32.9) and 153.28 mg/l (±18.66) during PPM, MON and POM season, respectively.

Hardness implies the lather forming capacity of a water sample and the two cations mainly responsible for hardness of water are calcium and magnesium. The observed values of total hardness for the water samples of the Kolong River during PRM, MON and POM season ranged from 52 to 164 mg/l (±41.03), 88 to 288 mg/l (±70.05) and 72 to 296 mg/l (±87.62), respectively, and the values were within the desirable limit of 300 mg/l. Based on the hardness values, Kolong River water generally falls under moderately hard to hard water category.

Chloride is one of the important WQ parameter and is widely distributed in nature in the form of salts of sodium

Table 2 Descriptive statistics for the water quality parameters of the Kolong River

Parameter	Pre-monsoon	Monsoon	Post-monsoon
pH	7.11 ± 0.52 (6.31–7.59)	6.65 ± 0.06 (6.59–6.75)	6.57 ± 0.34 (6.23–7.12)
EC (μS/cm)	1302.3 ± 340 (1017–1900)	170 ± 122 (60–410)	140 ± 50 (90–199)
TDS (mg/l)	313.55 ± 44.97 (250–370)	257.69 ± 32.9 (210.75–299)	153.28 ± 18.66 (122–175)
TSS (mg/l)	81.14 ± 13.7 (65–105)	144.05 ± 27.37 (97.88–178.21)	65.68 ± 16.04 (48–78)
TH (mg/l)	90.86 ± 41.03 (52–164)	140.71 ± 70.5 (88–288)	183.43 ± 87.62 (72–296)
Cl^- (mg/l)	69.12 ± 15.6 (45.44–94.56)	55.6 ± 8.6 (45.44–71)	25.52 ± 5.2 (19.88–34.08)
DO (mg l^{-1})	9.22 ± 4.9 (0–13.77)	2.96 ± 1.07 (0.81–4.05)	7.8 ± 3 (3.4–12.83)
BOD (mg/l)	8.19 ± 3.6 (4.2–13.3)	10.98 ± 3.9 (7.06–17.8)	7.96 ± 3.8 (4.3–15.01)
SO_2^{-4} (mg/l)	12.6 ± 5.4 (6.64–21.64)	15.45 ± 4.9 (9.82–21.9)	13.27 ± 4.35 (7.07–20.74)
TA (mg/l)	210.7 ± 70.5 (125–300)	231.43 ± 96.5 (100–360)	154.14 ± 58.1 (100–255)

Values are expressed in mean ± SD (the values in parentheses denotes the range of each parameter)

(NaCl), potassium (KCl) and calcium ($CaCl_2$). Various sources contributing chloride in water are leaching from various rocks by the process of weathering, surface run-off from inorganic fertilizers dependent agricultural fields, irrigation discharge, animal feeds, etc. The average chloride concentration for the studied water samples during PRM, MON and POM season were 45.44 to 94.56 mg/l (±15.6), 45.44 to 71 mg/l (±8.6) and 19.88 to 34.08 mg/l (±5.2), respectively. The observed chloride concentrations were well within the desirable limit cited by BIS, i.e., 250 mg/l.

Amount of total oxygen dissolved in a water body is termed as dissolved oxygen (DO) and its concentration depend on physical, chemical and biological activities of the water body. Estimation of DO is very much essential in water pollution control. A DO level of 4–6 mg/l is optimum range for a good water quality sustaining aquatic life. Water sample with DO concentration below this optimum range is expected to be polluted. The mean DO values ranged from a minimum of 2.96 mg/l (±1.07) during MON season to a maximum of 9.22 mg/l (±4.9) during PRM season. DO is nil (0 mg/l) at site S1 during PRM, attributed chiefly by the high stagnancy of the water source due to lack of sufficient flow.

The total amount of oxygen required by aerobic microorganisms for complete degradation of organic wastes present in a water body is termed as biochemical oxygen demand (BOD). Thus, BOD is an indicator of organic pollution with higher values indicating higher levels of organic pollution (Patel et al. 1983). BOD values above 5 mg/l are undesirable and the present analysis revealed the mean BOD values as 8.19 mg/l (±3.6), 10.98 mg/l (±3.9) and 7.96 mg/l (±3.8) during PRM, MON and POM season, respectively, with values exceeding the desirable limit. The higher values of BOD emphasized the presence of prominent organic pollution source near the sampling sites.

Occurrence of sulphate in river water is mainly natural in nature contributed chiefly by mineral sources like gypsum, etc. Although in small concentration sulphate is harmless, however, high concentration of sulphate in drinking water may cause various intestinal diseases. Mean sulphate concentration of the water samples under investigation varied from 12.6 mg/l (±5.4) during PRM season to 15.45 mg/l (±4.9) during MON season and the values were within the standard limit of 150 mg/l as per BIS.

Total alkalinity is the capability of an aqueous solution to neutralize an acid. Alkalinity is due to the various carbonate, bicarbonate and hydroxide ions present in water. The mean concentration of alkalinity in water samples was observed to be 210.7 mg/l (±70.5), 231.43 mg/l (±96.5) and 154.14 mg/l (±58.1) during PRM, MON and POM season, respectively. The mean alkalinity values exceeded the BIS prescribed limit of 120 mg/l during all the seasons.

WQI analysis

The first step in calculation of WQI following 'weighted arithmetic index' method involves the estimation of 'unit weight' assigned to each physico-chemical parameter considered for the calculation. By assigning unit-weights, all the concerned parameters of different units and dimensions are transformed to a common scale. Table 3 shows the drinking water quality standards and the unit-weights assigned to each parameter used for calculating the WQI. Maximum weight, i.e., 0.366 is assigned to both DO and BOD, thus suggesting the key significance of these two parameters in water quality assessment and their considerable impact on the index.

Table 3 Relative weights (W_n) of the parameters used for WQI determination

Parameter	ICMR/BIS standard (V_s)	Unit weight (W_n)
pH	6.5–8.5	0.215
Electrical conductivity	300	0.0061
TDS	500	0.00366
TSS	500	0.00366
Total hardness	300	0.0061
Chloride	250	0.00732
DO	5	0.366
BOD	5	0.366
Sulphate	150	0.0122
Total alkalinity	120	0.01525
$\sum W_n = 1.001$		

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

The observed values of the selected physico-chemical parameters in all the sampling sites for each season and the corresponding WQI values are presented in tabular form (Tables 4, 5, 6, 7, 8, 9, 10). Out of the ten parameters considered for this study, DO and BOD were found to be the highest influencing parameters in the WQI scores (Tables 4, 5, 6, 7, 8, 9, 10).

The summary of WQI values of the water samples from all the seven sampling sites for each season are presented in Table 11 given below. The results showed that majority of the water sample fall under very poor ($75 < \text{WQI} < 100$) and unsuitable water category ($\text{WQI} > 100$). Highest WQI values were recorded during monsoon season with values ranging from a low of 88.15 at site S6 to a high of 169.2 at site S1 with an average WQI value of 122.47 ± 30.02 (Table 11). The unsuitability of river water during monsoon season is mainly

Table 4 Calculation of WQI at site S1

Parameter	PRM			MON			POM		
	V_n	Q_n	Q_nW_n	V_n	Q_n	Q_nW_n	V_n	Q_n	Q_nW_n
pH	6.5	−33.33	−6.13	6.64	−24	−4.416	6.23	−51.33	−11.04
EC	1690	563.33	3.43	411	137	0.83	199	66.33	0.404
TDS	250	50	0.1565	230.45	46.09	0.144	122	24.4	0.089
TSS	65	13	0.041	122.5	24.5	0.0767	60	12	0.044
TH	164	54.66	0.28	92	30.66	0.159	140	46.66	0.28
Chloride	76.86	30.74	0.19	53.96	21.58	0.135	34.08	13.632	0.1
DO	0	152.08	47.6	2.43	126.77	39.679	3.4	116.66	42.7
BOD	13.3	266	83.258	17.8	356	130.3	15.01	300.2	109.87
Sulphate	9.915	6.6	0.068	12.03	8.02	0.0834	11.6	7.73	0.1
TA	275	229.16	2.98	220	183.33	2.383	100	83.33	1.27
	$\sum W_nQ_n = 131.87$			$\sum W_nQ_n = 169.37$			$\sum W_nQ_n = 143.82$		
	WQI = 131.74			WQI = 169.2			WQI = 143.67		

Table 5 Calculation of WQI at site S2

Parameter	PRM			MON			POM		
	V_n	Q_n	Q_nW_n	V_n	Q_n	Q_nW_n	V_n	Q_n	Q_nW_n
pH	6.31	−46	−9.89	6.6	−26.66	−5.732	6.26	−49.33	−10.605
EC	1017	339	2.07	169.9	56.63	0.345	130	43.33	0.264
TDS	269	53.8	0.197	250.66	50.132	0.1834	150	30	0.1098
TSS	88	17.6	0.064	160.73	32.146	0.118	78	15.6	0.057
TH	52	17.33	0.1057	100	0.333	0.002	228	0.76	0.0046
Chloride	59.64	23.856	0.1746	53.96	0.2158	0.0016	19.88	7.952	0.0582
DO	5.16	98.3	35.98	3.24	118.33	43.31	6.1	88.54	32.405
BOD	8.4	168	61.488	12.58	251.6	92.08	9.8	196	71.736
Sulphate	12.84	8.56	0.1044	15.1	10.066	0.123	13	8.66	0.1056
TA	275	229.16	3.49	360	300	4.575	100	83.33	1.27
	$\sum W_nQ_n = 93.78$			$\sum W_nQ_n = 135.01$			$\sum W_nQ_n = 95.4$		
	WQI = 93.7			WQI = 134.87			WQI = 95.3		

Table 6 Calculation of WQI at site S3

Parameter	PRM			MON			POM		
	V_n	Q_n	Q_nW_n	V_n	Q_n	Q_nW_n	V_n	Q_n	Q_nW_n
pH	7.25	16.66	3.58	6.75	−16.66	−3.58	6.52	−32	−6.88
EC	1048	349.33	2.13	207	69	0.42	109.3	36.43	0.22
TDS	345	69	0.25	257.97	51.594	0.188	150	30	0.1098
TSS	72	14.4	0.0527	165	33	0.12	56	11.2	0.0409
TH	68	22.66	0.138	129	40	0.244	76	25.33	0.1545
Chloride	62.48	24.992	0.1829	62.48	24.99	0.1829	19.88	7.952	0.0582
DO	11.35	33.85	12.389	3.24	118.33	43.308	8.11	67.6	24.74
BOD	6.31	126.2	46.19	9.1	182	66.612	4.3	86	31.476
Sulphate	6.587	4.39	0.0535	9.82	6.546	0.0798	7.07	4.71	0.0574
TA	175	145.83	2.22	260	216.66	3.3	175	145.83	2.22
	$\sum W_nQ_n = 67.2$			$\sum W_nQ_n = 110.87$			$\sum W_nQ_n = 52.2$		
	WQI = 67.13			WQI = 110.76			WQI = 52.15		

Table 7 Calculation of WQI at site S4

Parameter	PRM			MON			POM		
	V_n	Q_n	Q_nW_n	V_n	Q_n	Q_nW_n	V_n	Q_n	Q_nW_n
pH	7.47	31.33	6.736	6.6	−26.66	−5.732	6.32	−45.33	−9.746
EC	1885	628.33	3.83	191	63.66	0.4	159	53	0.32
TDS	370	74	0.27	300	60	0.22	166	33.22	0.1216
TSS	80	16	0.058	143.87	28.77	0.1053	66.78	13.356	0.0488
TH	128	42.66	0.26	288	96	0.5856	296	98.66	0.602
Chloride	94.56	37.824	0.277	53.96	21.584	0.158	28.4	11.36	0.083
DO	10.54	42.29	15.48	0.81	143.64	52.57	6.08	88.75	32.48
BOD	12.9	258	94.43	13.88	277.6	101.6	9.7	194	71.004
Sulphate	6.64	4.42	0.054	11	7.33	0.0894	10.31	6.87	0.0838
TA	300	250	3.81	340	283.33	4.32	255	187.5	2.86
	$\sum W_nQ_n = 125.2$			$\sum W_nQ_n = 154.32$			$\sum W_nQ_n = 97.86$		
	WQI = 125.07			WQI = 154.16			WQI = 97.76		

attributed by increased surface run-off from the adjacent urban agglomerations and direct discharge from storm water drains along roads adjacent to the river; similar results were also observed by Sebastian and Yamakanamardi (2013) in case of Cauvery River. The WQI analysis unveiled the fact that site S1 and site S4 were the two most polluted sites along the entire reach of the Kolong River. The WQI values of site S1 specified the fact that the water was unsuitable for any use including drinking, fish culture and irrigation during all the sampling season (Table 1). In addition to high domestic sewage disposal and eutrophication of the water body, the append reason behind high pollution level of site S1 is the lack of sufficient flow leading to the stagnancy of the water, which in turn reduced the self-assimilation capacity of the riverine ecosystem. Analogous effects of altered river flow on water quality were also reported in Tunga-Bhadra River by Rehana and Mujumdar (2011). Similarly, site S4, i.e., Nagaon town, the most populated urban agglomeration along Kolong River also witnessed a highly deteriorated water quality mainly contributed by huge demographic as well as socio-economic pressure in the form of river bed encroachment and river water exploitation for various chores. Thus, site S4 acquired very poor to unfit water quality status as indicated by the WQI values ranging

Table 8 Calculation of WQI at site S5

Parameter	PRM			MON			POM		
	V_n	Q_n	Q_nW_n	V_n	Q_n	Q_nW_n	V_n	Q_n	Q_nW_n
pH	7.59	39.33	8.45	6.66	−22.66	−4.89	6.9	−6.66	−1.43
EC	1062	354	2.16	84.6	28.2	0.17	97	32.33	0.2
TDS	350	70	0.256	210.75	42.15	0.154	170	34	0.124
TSS	105	21	0.077	178.21	35.64	0.13	95	19	0.069
TH	88	29.33	0.18	168	56	0.34	240	80	0.488
Chloride	68.16	27.26	0.199	45.44	18.176	0.133	25.26	10.104	0.0739
DO	11.6	31.25	11.437	3.7	113.54	41.55	9.12	57.08	20.89
BOD	4.2	84	30.74	7.5	150	54.9	6.3	126	46.116
Sulphate	15.47	10.31	0.1257	16.4	10.93	0.133	14.4	9.6	0.117
TA	150	125	1.9	200	1.66	0.025	175	148.83	2.73
	$\sum W_nQ_n = 55.52$			$\sum W_nQ_n = 92.64$			$\sum W_nQ_n = 69.4$		
	WQI = 55.46			WQI = 92.55			WQI = 69.33		

Table 9 Calculation of WQI at site S6

Parameter	PRM			MON			POM		
	V_n	Q_n	Q_nW_n	V_n	Q_n	Q_nW_n	V_n	Q_n	Q_nW_n
pH	7.21	14	3.01	6.59	−27.33	−5.876	7.12	8	1.72
EC	1161	387	2.36	69	23	0.14	212.2	70.73	0.43
TDS	290	58	0.212	255	51	0.1866	175	35	0.128
TSS	70	14	0.0512	97.88	19.576	0.0716	48	9.6	0.035
TH	80	26.66	0.1626	120	40	0.244	232	77.33	0.472
Chloride	45.44	18.176	0.133	48.28	19.312	0.141	22.72	9.088	0.0665
DO	13.778	8.56	3.133	4.054	109.85	40.205	12.83	18.437	6.75
BOD	5.34	106.8	44.65	7.06	141.2	51.68	5.1	102	37.33
Sulphate	15.184	10.123	0.1235	21.9	14.6	0.178	15.8	10.53	0.128
TA	125	104.16	1.588	100	83.33	1.271	175	145.83	2.22
	$\sum W_nQ_n = 55.42$			$\sum W_nQ_n = 88.24$			$\sum W_nQ_n = 49.3$		
	WQI = 55.36			WQI = 88.15			WQI = 49.25		

between 97.76 during post-monsoon season to 154.16 during monsoon season (Table 11). Likewise, the fetid water quality at sites S2, S3, S5 and S7 is a result of the pollution contributed by the nearby urban settlements namely Missa town, Amoni, Raha and Chandrapur, respectively. The high WQI scores in all the above sites are contributed mainly by various anthropogenic activities like the inflow of direct sewerage from residential and commercial establishments, lack of proper sanitation system, agricultural run-off, direct disposal of untreated effluents from small scale industries and factories and unabated dumping of solid wastes by the communities residing alongside the river, etc. It is clear from Tables 4, 5, 6, 7, 8, 9 and 10 that BOD and DO were the two deciding parameters exhibiting the maximum influence in WQI calculation. The Kolong River water samples experienced lower DO concentration and higher BOD concentration, thus signifying high organic pollution load.

The WQI values of site S6, i.e., near Jagibhakatgaon, a rural area, was comparatively better among all the studied sites with values ranging from 49.25 during post-monsoon season to 88.15 during monsoon season. The comparatively improved water quality condition at site S6 is mainly because of the dilution of the polluted Kolong River water with less polluted Kopili River water, besides the absence of any major urban agglomeration.

The pollution level as supported by the WQI value showed a mixed pattern of change during all the sampling seasons (Fig. 3). Figure 3 clearly indicates that while

Table 10 Calculation of WQI at site S7

Parameter	PRM			MON			POM		
	V_n	Q_n	Q_nW_n	V_n	Q_n	Q_nW_n	V_n	Q_n	Q_nW_n
pH	7.44	29.33	6.306	6.7	−20	−4.3	6.63	24.66	−5.3
EC	1253	417.66	2.55	60	20	0.122	90	30	0.183
TDS	320.88	64.176	0.235	299	59.8	0.2188	140	28	0.102
TSS	88	17.6	0.064	140.18	28.036	0.1026	56	11.2	0.041
TH	56	18.66	0.1138	88	29.33	0.1789	72	24	0.146
Chloride	76.68	30.67	0.224	71	28.4	0.208	28.4	11.36	0.083
DO	12.16	25.42	9.3	3.24	118.33	43.31	9.12	57.08	20.89
BOD	6.9	138	50.51	9	180	65.88	5.5	110	40.26
Sulphate	21.637	14.42	0.176	21.9	14.6	0.178	20.74	13.83	0.168
TA	175	145.83	2.224	140	116.66	1.779	100	83.3	1.27
	$\sum W_nQ_n = 71.7$			$\sum W_nQ_n = 107.7$			$\sum W_nQ_n = 57.84$		
	WQI = 71.63			WQI = 107.59			WQI = 57.78		

Table 11 Summary of WQI of the Kolong River

Sampling station	PRM		MON		POM	
	WQI	WQS	WQI	WQS	WQI	WQS
S1	131.74	Unsuitable	169.2	Unsuitable	143.67	Unsuitable
S2	93.7	Poor	134.87	Unsuitable	95.3	Very poor
S3	67.13	Poor	110.76	Unsuitable	52.15	Poor
S4	125.07	Unsuitable	154.16	Unsuitable	97.76	Very poor
S5	55.46	Poor	92.55	Very poor	69.33	Poor
S6	55.36	Poor	88.15	Very poor	49.25	***Good***
S7	71.63	Poor	107.59	Unsuitable	57.78	Poor
Average	85.73		122.47		80.75	

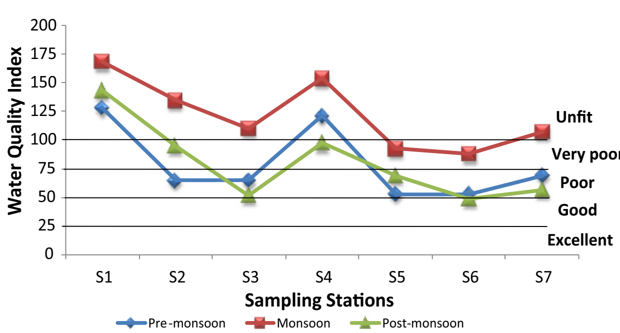

Fig. 3 WQI rating of various sampling sites of Kolong River

moving in the downstream direction, the pollution level gradually decreases from station S1 up to station S3. Whereas station S4 experiences an abrupt raise in pollution level, justified by the demographic as well as commercial pressure at the site. Further downstream, water samples showed a decreasing pollution trend up to site S6. Site S7 again rendered an increased pollution level when compared to its immediate upstream sampling site, i.e., site S6, mainly supported by the fact that site S7 is located near an urban agglomeration dominated by brick knils and a market place. While the fall in graph towards site S6 is supported by the fact that unlike other sampling locations the aforementioned sampling site is located near a rural settlement with no major source of water pollutants as discussed earlier.

In monsoon season, the water qualities of all the sampling sites were found unsuitable except at site S5 and S6 where the water is of very poor quality, as depicted in Fig. 3. During pre-monsoon season, water quality of the sampling sites was found to fall under unsuitable to poor water quality. During post-monsoon season, site S6 experienced marginally good water quality while the rest lied in unsuitable, very poor and poor water quality category (Fig. 3). Interestingly, the WQI scores for site S1 showed unsuitable water quality status during every sampling season mainly because of the lack of sufficient flow in addition to increased organic pollution load, thus reducing the self-purification capacity of the river at the site.

Conclusion

Water quality index is helpful in assessment and management of water quality. The present investigation represents the first of its type undertaken on the Kolong River of Assam. The case study provides valuable insight into the status of overall suitability of the Kolong River water based on WQI values. It highlights the salient features of various important physico-chemical parameters acting upon the general water quality of the river. The season wise variations in the WQI values were examined based on seasonal water quality analysis data of seven sampling sites distributed along the river channel. The baseline data generated in these investigations and their analysis and interpretation will go a long way in improving our understanding and knowledge base about the status of water quality of a socio-economically vital fluvial system, i.e., the Kolong River and the factors affecting the overall quality of its water. The study has both academic value and practical significance. Based on observed WQI results it can be concluded that effective treatment measures are urgently required to augment the river water quality by defining an appropriate water quality management plan which in turn will support any future plan for sustainable river restoration. Water quality of the river needs to be restored by adopting measures like restricting inflows of raw sewerage from residential/commercial establishments, limiting direct discharge from storm water drains into the river and preventing unabated dumping of solid waste by communities residing along the river. Besides, desilting measures to improve the carrying capacity of the river channel needs to be adopted and existing encroachments for settlement and infrastructural development should be removed.

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