



Development of irrigation water quality index incorporating information entropy

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Received: 4 August 2018 / Accepted: 2 March 2019 / Published online: 11 March 2019
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Abstract

The present study demonstrates the efficacy of information entropy for the development of water quality index (WQI) for irrigation purpose and its application on Bharalu River. Water quality for irrigation suitability was assessed by using derived parameters such as permeability index (PI), Kelly's ratio (KR), magnesium adsorption ratio (MgR), sodium adsorption ratio (SAR), soluble sodium percentage (SSP), and residual sodium carbonate (RSC) using annual data from April'2008 to April'2013 and April'2016, April'2017 over a period of 8 years. Values obtained in the study varied from 1.85 to 39.35% for SSP, 0.08 to 1.37 for SAR, 31.7–60.0% for MgR, 0.0–5.45 for RSC, 0.33–2.36% for PI, and 0.01–0.52 for KR. The derived parameters values indicate that water of Bharalu River is suitable for irrigation except April'2008 and April'2011. United States Salinity Laboratory (USSL) and Wilcox diagrams were used for categorizing of water quality. USSL and Wilcox diagrams categorized the water samples as S1-C2 and S1-C3, and 'Excellent to Good' and 'Good to Permissible' respectively, which suggest River Bharalu's irrigation suitability. Entropy weighted irrigation water quality index (EIWQI) has been proposed and applied on Bharalu River data for assessing its suitability and variability for irrigation. EIWQI was found to be less than 1 for all the years except April'2011, which showed its appropriateness for irrigation. This study can be of great help for policymakers and researchers to effectively manage water resources.

Keywords Bharalu River · Information entropy · Irrigation · Water quality

1 Introduction

Effective and viable management of water resources is necessary for ensuring sustainable development. Sustainable development is not possible without freshwater of adequate quantity and quality (Kundzewicz 1997). Presently, rampant urbanization, settlement, and resettlement of communities aided with rapid industrialization has not only stained the quality of water

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sources but also created water scarcity in the different regions (Islam 2012). Conservation and protection of the water sources through comprehensive and precise assessments has thus garnered global consideration (Wu and Tan 2012). Such assessments and implementation of restoration policies necessitate continuous monitoring. However, such monitoring programs generate enormous data-sets consisting of numerous water quality parameters. These datasets, then become extremely difficult to analyse and interpret (Isken et al. 2008). This necessitates their integration into simpler numerical scores which can be interpreted by trained experts as well as local public and policymakers. Water-quality indices (WQIs) helps us in this regard by converting the large datasets generated from the monitoring programs into single value describing the water quality. Water quality index (WQI) integrates several parameters and describes water quality by a single numeric score. Horton (1965) proposed the first modern WQI, which initiated numerous studies in this field (Abbasi and Abbasi 2012, Abtahi et al. 2015; Bouguerne et al. 2017). Recently, many modifications have been considered in the WQI concept by various researchers (Bhargava and Saxena 1990; Dwivedi et al. 1997). Hameed et al. (2017) applied artificial intelligence techniques for WQI prediction, while Najafzadeh et al. (2018) predicted water quality parameters using evolutionary computing based formulation.

To the best of authors' knowledge, Misaghi et al. (2017) introduced the first systematic WQI for irrigation purposes based on NSF-WQI. Water quality parameters were amended to account for parameters suitable for irrigation, and a weighting chart was generated as per FAO 29 guidelines. Water quality for irrigation varies from region to region and depends on several factors, such as, plant characteristics, soil quality, climatic and local conditions, which requires the development of a region-specific WQI.

The present study proposed an entropy weighted WQI for irrigation purpose which is based on information entropy and "Indian Standards guidelines for the quality of irrigation water" developed by Bureau of Indian Standards (BIS). Entropy weighted WQIs are an enhancement over conventional WQIs [based on Delphi method, analytical hierarchy process (AHP) and expert survey method] which are based weights assigned to parameters based of personal judgments and expert opinion (Amiri et al. 2014; Fagbote et al. 2014). Such opinions and judgments often lead to valuable loss of facts about the water quality of an area or region. Furthermore, such methods are often time-consuming exercise as well as tedious (Abbasi and Abbasi 2012). Information entropy quantifies the uncertainty or randomness in the data-sets. Information entropy has been successfully applied in various disciplines of science and engineering which includes biology, genetics, chemistry, physics and quantum mechanics, statistical mechanics, thermodynamics, electronics and communication engineering, hydrology, hydraulics, reliability analysis, reservoir engineering and transportation engineering (Singh 2014). Information entropy helps in extracting the amount of information by measuring the equality, diversity, flexibility, complexity, interactivity, and redundancy of the random datasets (Singh 2013). In the present study, water quality of Bharalu River (Assam, India) was analysed and assessed based on the annual datasets for its suitability for irrigation using the proposed entropy weighted WQI for spatiotemporal variability.

2 Materials and methods

2.1 Study area

Bharalu River originates from the foothills of Khasi Hills (Meghalaya, India), and is the south bank tributary of Brahmaputra River (Fig. 1). The catchment area of Bharalu is approximately 120 km² and it drains about 10.94 km² area of Guwahati city. It enters Guwahati through the south-east corner and is considered one of the most adulterated rivers of Assam as it receives both domestic and industrial wastes directly through several drains during its course of flow. Rapid urbanization near its catchment in recent years has deteriorated the quality of water to a large extent due to unabated encroachment and dumping of garbage into it. When Bharalu

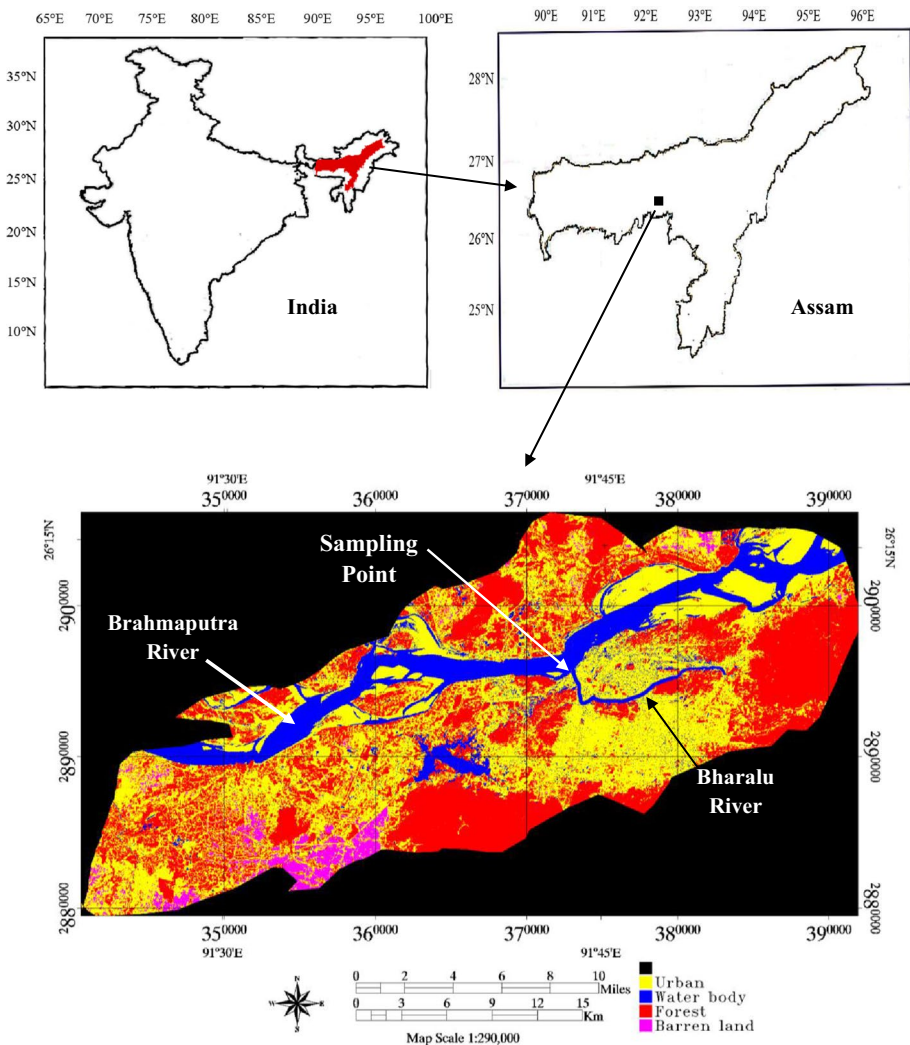


Fig. 1 Study area and land use/land cover of Guwahati

meets Brahmaputra River at Bharalumukh, all the wastes and pollutants get discharged to Brahmaputra River, thereby, polluting it to a great extent. The water of Bharalu River can, therefore, serve as an alternative for irrigation to compensate for water shortages of other water sources. However, existing risks must be comprehended.

2.2 Data and sample collection

The study was carried out at Bharalumukh before the confluence point of Bharalu and Brahmaputra river. Water quality data from April'2008 to April'2013, was acquired from the Pollution Control Board (PCB), Guwahati (Assam). Data for April'2014–2015 was not available with PCB. In addition, samples were collected triplicate in April'2016 and April'2017 in one-litre plastic bottles. All water samples have been analysed in the laboratory as per guidelines laid down in APHA (2012) (Table 1).

2.3 Irrigation water quality parameters

PI, MgR, KR, SAR, SSP, and RSC were employed for the assessment of water quality (Thapa et al. 2017). Formulae for calculation of each term are represented in Eqs. 1–6:

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Na^+ + Ca^{2+} + Mg^{2+}} \times 100 \quad (\text{Doneen 1964}) \quad (1)$$

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \quad (\text{Kelly 1963}) \quad (2)$$

$$MgR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \quad (\text{Raghunath 1987}) \quad (3)$$

$$SAR = \frac{Na^+}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}} \quad (\text{Richards 1954}) \quad (4)$$

Table 1 Water quality parameters associated with their units, abbreviations and analytical methods used in this study

Parameters	Unit	Abbr	Analytical methods
Temperature	°C	T	Thermometer
pH	–	pH	pH-meter
Dissolved oxygen	mg/L	DO	DO meter
Electrical conductivity	µS/cm	EC	Electrometric
Sodium	mg/L	Na ⁺	Flame photometer
Potassium	Mg/L	K ⁺	Flame photometer
Calcium	mg/L	Ca ⁺	Flame photometer
Magnesium	mg/L	Mg ²⁺	Atomic absorption spectroscopy

$$SSP = \frac{Na^+ + K^+}{Na^+ + K^+ + Ca^{2+} + Mg^{2+}} \times 100 \quad (\text{Todd 1980}) \quad (5)$$

$$RSC = [HCO_3^- + CO_3^{2-}] - [Ca^{2+} + Mg^{2+}] \quad (\text{Raghunath 1987}) \quad (6)$$

The concentration of all parameters used in Eqs. (1)–(6) are in meq/L.

2.4 Entropy weighted irrigation water quality index (EIWQI)

EIWQI was developed in four steps. The first step involved the water quality parameters selection, which is one of the most important tasks for researchers to develop WQI. It becomes very difficult to select a few essential parameters among a significant number, representative of the overall water quality for the particular use. For the present study, 4 parameters namely EC, SAR, RSC, and Boron were selected based on the guidelines laid down in BIS (IS 11624 2009). Classification of EC, SAR, RSC, and Boron given by BIS are shown in Table 2. The second step was the formulation of sub-index, for which, a scale of 0–100 has been used. Using 0–100 scale and BIS classification, best-fit curves (Fig. 2) were drawn and their equations were used to transfer all four selected parameters into a single scale.

Equations of sub-indices of all parameters (*j*) are given below:

$$SI(EC) = 0.0167EC \quad (7a)$$

$$SI(SAR) = 0.0167SAR \quad (7b)$$

$$SI(RSC) = 0.0167RSC \quad (7c)$$

$$SI(B) = 0.0167C_B \quad (7d)$$

where C_B is the concentration of Boron in mg/L, EC is in $\mu\text{S}/\text{cm}$, SAR in $\sqrt{\text{meq}/\text{L}}$ and RSC in meq/L.

The third step was the assignment of weight to all the selected parameters. Most common methods include Delphi approach, analytical hierarchical process (AHP), and Entropy weight. Delphi and AHP are monotonous, time-consuming and based on personal judgments and expert opinion which leads to loss of valuable information. Entropy weight is a scientific approach and also incorporates the variability of water quality parameters. Calculation of entropy weights is represented by the following steps:

Table 2 Classification of irrigation water quality parameters (IS 11624 1986)

Sr. no.	Class	Range of EC	Range of SAR	Range of RSC	Range of boron
i	Low	0–1500	0–10	0–1.5	0–1
ii	Medium	1500–3000	10–18	1.5–3	1–2
iii	High	3000–6000	18–26	3–6	2–4
iv	Very high	Above 6000	Above 26	Above 6	Above 4

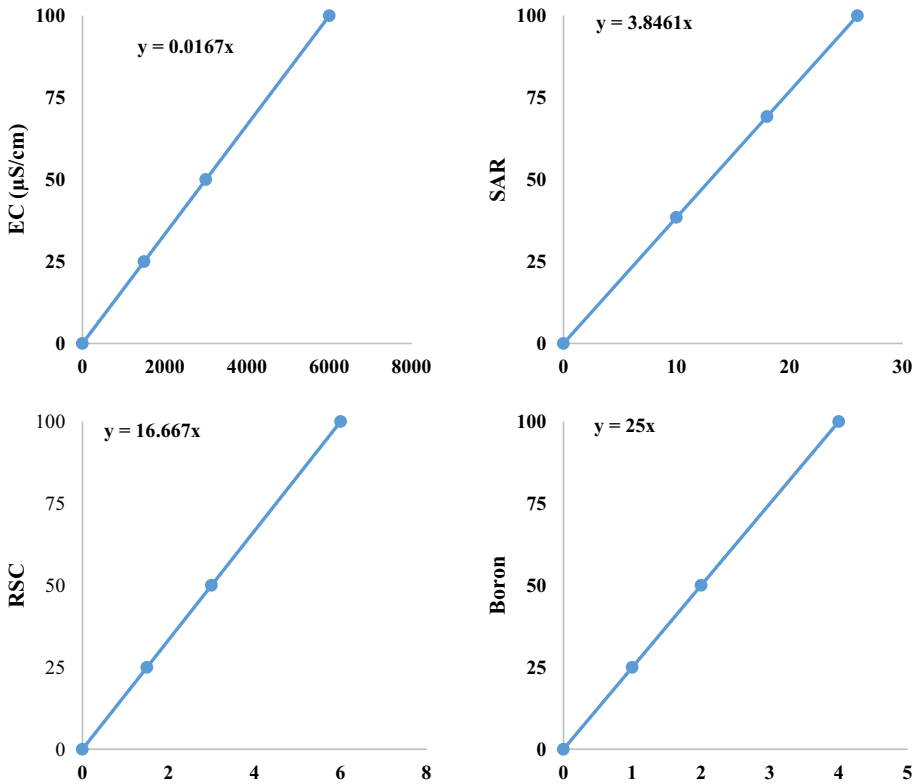


Fig. 2 Sub-index graphs

Step 1 Normalization of data:

$$v_{ij} = \frac{a_{ij}}{a_{1j} + \dots + a_{mj}}; \quad \forall j \in \{1, \dots, c\} \tag{8}$$

where ‘ a_{ij} ’ is the concentration of j th parameter at i th sampling period, ‘ c ’ represents the total number of parameters and ‘ m ’, the total number of sampling periods. For spatial water quality variations, ‘ i ’ will represent the sampling location and ‘ m ’, the total number of sampling locations.

Step 2 Calculation of Information entropy (E):

$$E_j = -\frac{1}{\ln m} \sum_{i=1}^m v_{ij} \ln v_{ij}; \quad \forall j \in \{1, \dots, c\} \tag{9}$$

Step 3 Determination of weight (w) of each selected water quality parameter:

$$w_j = \frac{d_j}{d_1 + \dots + d_c} \tag{10}$$

where, $d_j = 1 - E_j$.

After calculation of entropy weight of parameters, it was multiplied with sub-indices and finally entropy weighted sub-indices was added to obtain the EIWQI

$$\text{EIWQI} = \sum_{j=1}^n w_j \times \text{SI}_j \quad (11)$$

Classification of EIWQI is given in Table 3.

3 Results and discussion

3.1 General water chemistry

Temporal variation of water samples during the period April'2008 to April'2013, April'2016 and 2017 are shown in Fig. 3. Temperature and pH are considered to be essential parameters while assessing water quality because they influence other physicochemical and biological parameters. During the monitoring period temperature was in the range of 24.5–28.3 °C and pH varied from 6.9 to 7.4. EC of the river varied from 319 to 827 $\mu\text{S}/\text{cm}$, which is considered suitable for irrigation (IS 11624 1986). EC is an important parameter in determining the suitability of water for irrigational use. EC is majorly affected by the concentration of dissolved solids, primarily in the form of salts. Salts present in water adversely affect the crop yield, as they increase the salinity of the soil thereby rendering it unsuitable for irrigation (Ayers and Westcot 1985). On the other hand, water with low EC (low salt concentration) is preferable for irrigation but should not be free of the soluble salts. Salt-free water creates permeability problem in soil and dreadfully affects its fertility.

The cations were observed in the order of $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$. Ca^{2+} concentration ranged from 18 to 168 mg/L, Mg^{2+} varied from 5.01 to 108 mg/L, Na^+ varied from 4.5 to 50.5 mg/L and K^+ varied from 2.0 to 18.4 mg/L. High concentration of Na^+ lowers the soil permeability resulting in infiltration problem as an exchangeable fraction of Na^+ replaces Ca^{2+} and Mg^{2+} , hence causing dispersion in the soil (Ayers and Westcot 1985). Boron is an essential component for the growth of plants at low concentrations, however, leads to toxicity at higher concentrations (Ayers and Westcot 1985). Concentration of Boron in Bharalu river ranged between 0.1 and 0.5 mg/L, indicating its suitability for irrigation.

Soils containing a large portion of Na^+ with SO_4^{2-} and Cl^- as the predominant anions are termed as saline soils. Saline soils severely limit the choice of crops and harshly affect germination and yields of crops. It is, therefore important to evaluate irrigation water quality linked with soils to be irrigated (Domenico and Schwartz 1990). SSP and SAR are used to calculate the possibility of Na^+ hazard to soils. An elevated buildup of

Table 3 Classification of EIWQI

Sr. no.	Class	Range of EIWQI
i	Very good	0–25
ii	Good	25–50
iii	Average	50–75
iv	Poor	Above 75

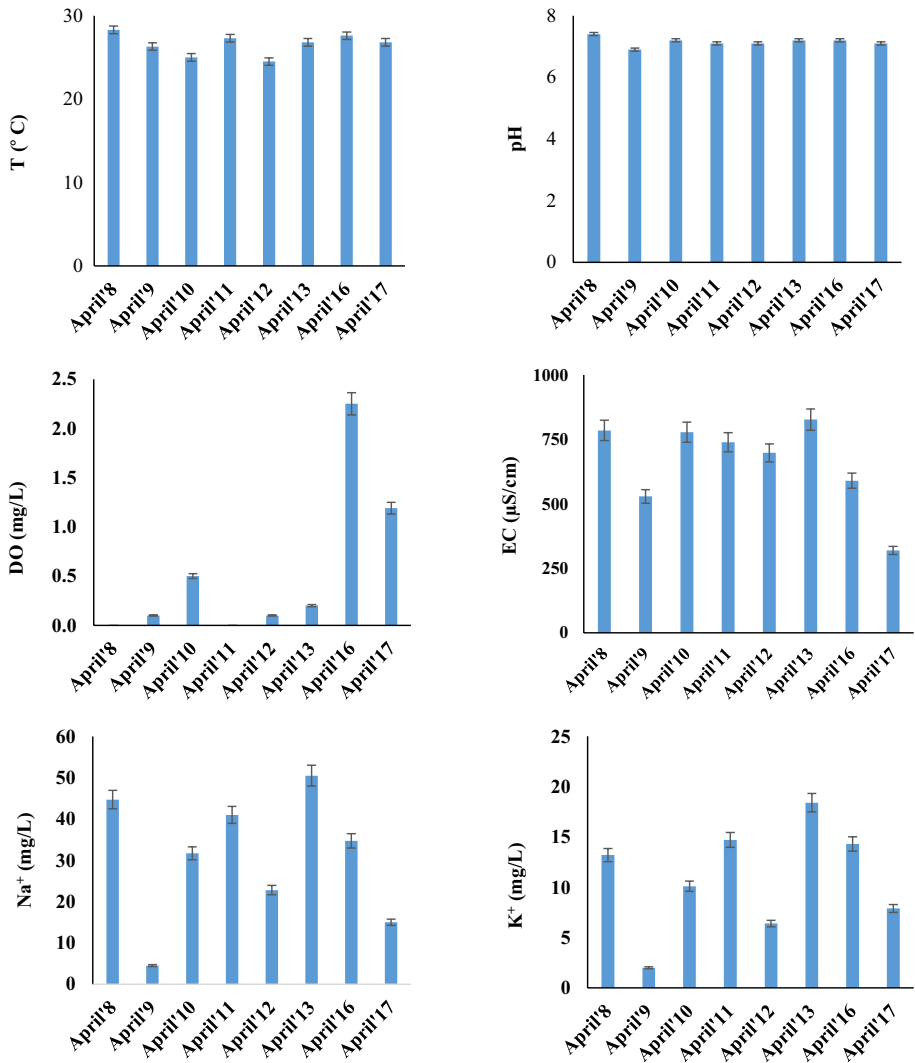


Fig. 3 Temporal variation of water quality parameters

Na⁺ in water causes a breakdown in the soil's physical properties (Ayers and Westcot 1985). SSP is categorized into two classes: 0–50 (Permissible zone) and ≥ 50 (Non-permissible zone) (Todd 1980). The values obtained in the study varied from 1.85 to 39.35% for SSP and 0.08 to 1.37 for SAR indicating irrigation suitability. Ca⁺ and Mg⁺ generally do not behave equally in the soil system and Mg⁺ degrades the structure of soil especially in the presence of Na⁺ dominated waters (Paliwal 1972). An excessive amount of Mg²⁺ in irrigation water leads to toxicity for plants as a result of reduced availability of K⁺ in the soil. MgR values less than 50% is considered safe and irrigation suitable (Khodapanah et al. 2009). MgR values varied from 31.7 to 60.0% which indicates suitability for irrigation use except for the year April'2008 (60%). PI evaluates

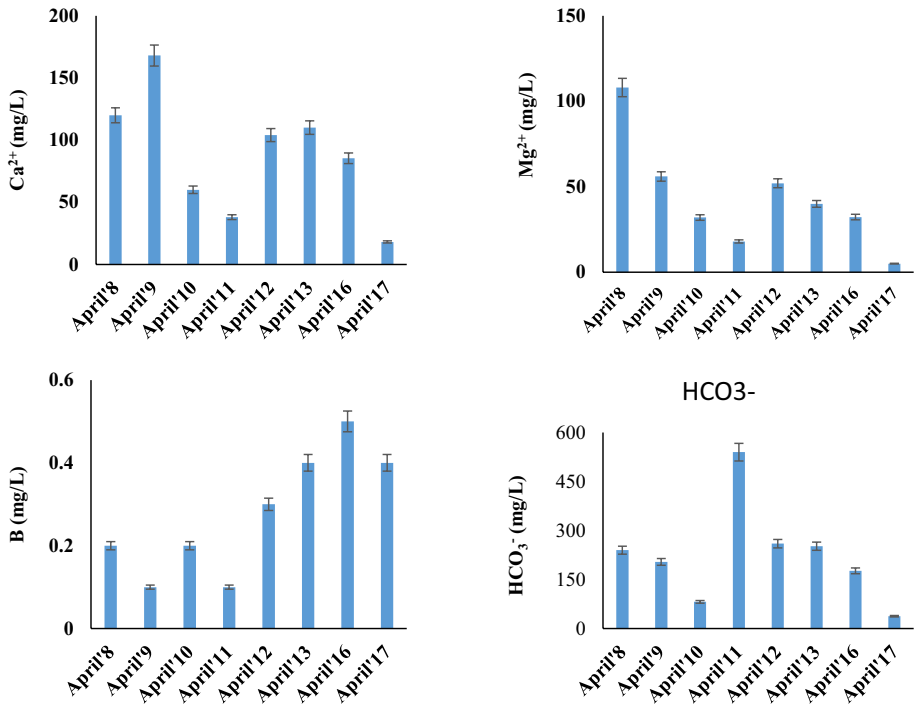


Fig. 3 (continued)

the effects of persistent use of irrigation water containing high amounts of Na^+ , Ca^{2+} , Mg^{2+} , and HCO_3^- on the permeability of soil (Ramesh and Elango 2012). $\text{PI} \geq 80\%$ indicates unsuitability of water for irrigation. The study found all the samples to be irrigation suitable. KR helps in determining the total exchangeable Na^+ ratio. $\text{KR} > 1$ denotes the water to be 'unsuitable' to use. Higher KR values indicate excessive concentrations of Na^+ and hence, the risk of impermeable soils. KR of all water samples was in the range of 0.01–0.52, thus indicating water to be irrigation suitable. Excessive concentrations of carbonate and bicarbonate also contribute to hazardous consequences in soils and plants, which is generally measured in terms of RSC. RSC affects the suitability of irrigation water because higher concentrations of HCO_3^- tends to precipitate Ca^{2+} and Mg^{2+} . Consequently, the relative fraction of Na^+ is increased in the form of NaHCO_3 (Thakur et al. 2016). The water with RSC value high have high pH and land irrigated using such waters turns infertile due to deposition of NaHCO_3 as can be seen from the black colour of soil (Eaton 1950). Samples analysed were observed to be classified in 'Low RSC' category as per IS: 11624-1986 except April 2011 (5.45 meq/L), which were observed to be zero (Table 4).

3.2 U.S. Salinity Laboratory (USSL) and Wilcox diagram

There is a significant relationship between SAR of irrigation water and extent of sodium absorption by soil. High presence of Na^+ salts in soils affects its physical condition texture of soil makes it tough to plough (Nagarajan et al. 2010). Detailed

Table 4 Variation of irrigation water quality suitability parameters

	April'08	April'09	April'10	April'11	April'12	April'13	April'16	April'17
PI	2.06	0.33	1.54	2.36	1.19	2.38	1.71	1.05
Kelly's ratio	0.13	0.01	0.24	0.52	0.10	0.25	0.22	0.50
Mg ratio	60.00	35.71	47.06	44.12	45.45	37.74	38.59	31.69
Na %	13.20	1.85	22.42	38.84	10.81	23.19	21.25	39.35
RSC	0	0	0	5.45	0	0	0	0
SAR	0.71	0.08	0.82	1.37	0.45	1.04	0.81	0.80

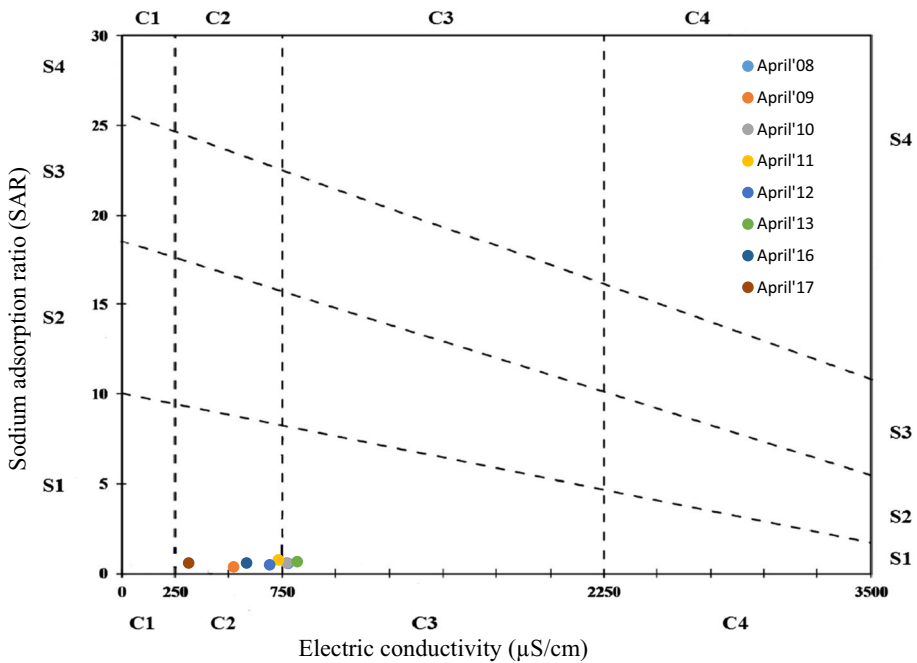


Fig. 4 USSL diagram

information on the analysis in respect of SAR is obtained from the USSL diagram (USSL 1954). The USSL diagram categorizes irrigation water quality, through a plot between SAR and EC (Fig. 4). All the samples were observed to fall in S1-C2 (low sodium and medium salinity) category, except for those in April 2010 and 2013 (S1-C3: low sodium and high salinity), which indicates irrigation use suitability of the sampling location. Wilcox diagrams is another graphical approach to determine the irrigation water suitability. It utilizes a scatter plot of EC versus SSP (Fig. 5). It was

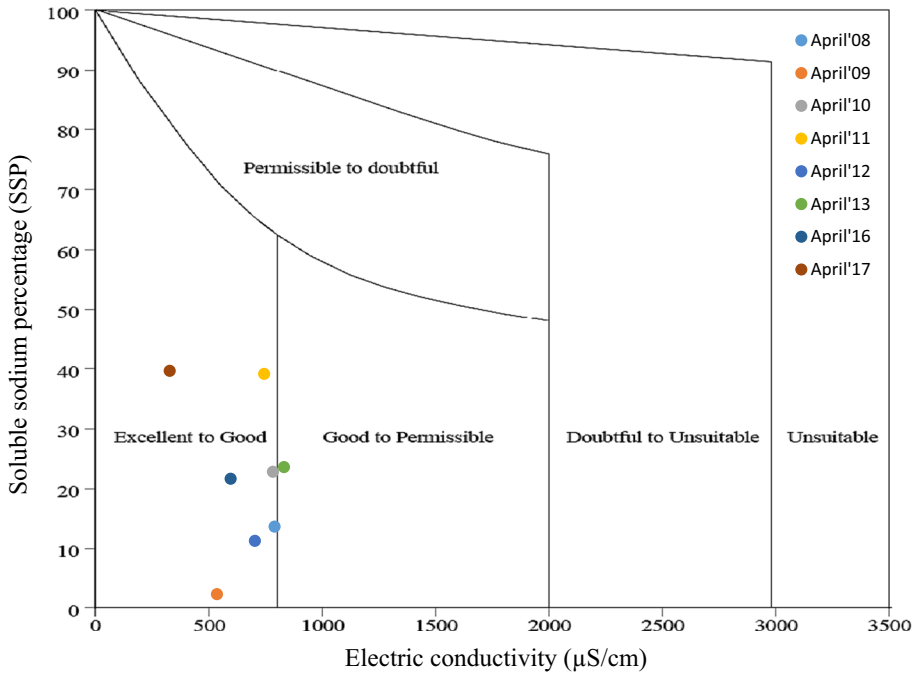


Fig. 5 Wilcox diagram (Wilcox 1955)

observed that all the samples, except for those in April' 2013 (Good to Permissible zone) were in Excellent to Good Zone indicating its viability for irrigation.

3.3 Entropy weighted irrigation water quality index (EIWQI)

Entropy weight of water quality parameters determines its impacts on the water quality. Parameters with the lowest entropy value and highest entropy weight have maximum impact on overall quality (Islam et al. 2017). It was observed that RSC has maximum entropy value and hence the maximum effect on the quality. Entropy weight of the parameters were in order $RSC > SAR > B > EC$. Results of EIWQI are shown in Table 5.

Table 5 Temporal variation of EIWQI

Year	EIWQI
April'08	0.62
April'09	0.28
April' 10	0.64
April' 11	79.92
April' 12	0.68
April' 13	0.98
April' 16	1.02
April' 17	0.81

EIWQI varied from 0.28 (very good) to 79.92 (poor). Results showed that water quality of Bharalu river is suitable (category: very good) of irrigation purpose except in April'2011. In April'2011 water quality index was categorized as "Poor". Reason for being in the poor category is the high value of RSC (5.45) and maximum entropy weight. Entropy weight enhances WQI by decreasing the relative error determined by ignoring the artificial weights (Amiri et al. 2014). EIWQI is an improvement over the conventional methods adopted for characterization and suitability of water for irrigation. It is a scientific way of assessing the water quality by incorporating all important parameters and assigning weight according to their variability. EIWQI is not region specific and is applicable anywhere because of its unique way of assigning weight based on the observed data-sets.

4 Conclusion

In this study, water quality of the Bharalu River was assessed for its irrigation suitability. Important conclusions from the study were drawn as follows:

- Various derived parameters (PI, KR, MgR, SAR, SSP, RSC) were calculated. Values obtained indicated that the river is suitable for irrigation except April'2008 and April'2011.
- USSL diagram categorised water quality as 'low sodium and medium salinity' (S1-C2) and 'low sodium and high salinity' (S1-C3) and Wilcox diagram, showed water quality to be in 'Excellent to Good Zone' and 'Good to Permissible Zone'.
- To evaluate water quality variability, entropy weighted irrigation water quality index (EIWQI) has been proposed, based on which RSC was observed as the most influencing parameter due to its highest entropy weight. EIWQI classified the water quality for the most part of the monitoring period as 'Very Good' except April'2011.

This paper deals with the physiochemical aspect of surface water suitability of Bharalu River but heavy metal analysis to understand the toxic effect of the water can be further investigated. This study can be of immense help to policymakers for effective and efficient management of water resources. The present study will also help researchers working in the field of water quality monitoring and assessment.

Acknowledgements Authors appreciatively accept the support from Pollution Control Board, Guwahati (Assam). Board has provided the previous year's data (April'2008–April'2013) for the study.

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