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Index-based assessment of suitability of water quality for irrigation purpose under Indian conditions

Surjeet Singh · N. C. Ghosh · Suman Gurjar · Gopal Krishan · Sumant Kumar · Preeti Berwal

Abstract Agriculture is a major sector in India which contributes around 14% of country's gross domestic product (GDP). Being an agriculture-based country, good quality of water for irrigation has been a prime requisite. Highly growing population and accelerated industrial development are causing anthropogenic pollution to both surface and groundwater on one side and geogenic contamination like arsenic, fluoride, high dissolved solids, sodicity, and iron in groundwater on other side. As a result, ensuring safe water quality for the irrigation has become a major challenge to both the central and state governments. The present irrigation water quality standards being followed in India have been set by the Central Pollution Control Board (CPCB) and Central Ground Water Board (CGWB) in the year 2000. These standards are solely based on four parameters, namely electrical conductivity, sodium percentage, sodium absorption ratio, and residual sodium carbonate, which are quite subjective and many times are not capable to exactly decide the quality of irrigation water particularly when there are large variations in the source water quality. Therefore, in the present paper, an indices-based approach is presented for categorization of irrigation water quality. These indices are mathematical equations that transform water quality data into a numeric value, which describes the quality of irrigation water. The proposed irrigation water quality index (IWQI), which is based on 12 parameters, classifies the water into five categories, viz. excellent, good, medium, bad, and very bad in the same manner as given by the CPCB and CGWB. In order to give proper rating to various parameters of the index, weights are computed using Saaty's analytic hierarchy process (AHP)-based multiple criteria decision analysis (MCDA) approach. This approach minimizes the subjectivity in assessment of weights and improves understanding of water quality issues by generating an overall index to describe the status of water quality. The proposed index will be beneficial for the water management authorities in ensuring safe water to the stakeholders.

Keywords IWQI · Water quality · Irrigation · Indices · Saaty AHP

Introduction

Water availability for irrigation encompasses both quantity and quality considerations. However, the quality aspects are often ignored. Irrigation water quality can be well accepted based on the experience and judgment which demands for proper monitoring and assessment on the suitability of water for the irrigation purpose. If the quality of irrigation water is good, it will result in the maximum crop yield under normal soil and water management practices. The quality of irrigation water is defined in terms of total dissolved solids, major cations and anions. Broadly, these cations and anions include Ca^{2+}, Mg^{2+}, Na^+, K^+, CO_3^{2-}, and HCO_3^-. Excess

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amount of these ions causes salinity, sodicity, and permeability problems in the soil root zone and hampers plant growth and yield of crops. The quality of water for irrigation depends on the amount and type of salts present. Problems related to soil and plant arise with the application of poor quality of water. Management or reclamation practices then becomes necessary to sustain complete crop growth. Three worldwide most common problems associated with the poor quality of water are increased salinity, reduced permeability, and specific ions (sodium, chloride, and boron) toxicity. However, these problems vary depending on the types of soil, climate, and crops grown. Excess amount of various constituents occurring in irrigation water affects soils and plants in different ways. By application of poor quality of water, dissolved salts accumulate in the root zone and cause difficulty to roots in extracting water from the soil matrix. Because of this reduced water uptake, plants suffer from stunted growth and early wilting. Presence of carbonate and bicarbonate ions in irrigation water affects soil permeability. If the water also contains high sodium contents, it causes permeability hazard (poor drainage) to the soils. The toxicity of irrigation water mainly occurs due to the presence of high sodium, chloride, and boron contents. Complexity of soil water further aggravates with toxicity in combination with soil salinity or permeability. Irrigation water with high sodium contents is very injurious to crops. Sodium taken up with water by plants accumulates in the leaves and is concentrated as water is lost through transpiration. It then causes sodium toxicity as concentration exceeds the tolerance capacity of crops. However, the sodium toxicity is reduced if calcium is present in water. Chloride, present in water, is not adsorbed by soils but passes readily with the soil water and accumulates in the plant leaves similar to the sodium. Toxicity occurs when chloride concentration exceeds the tolerance capacity of crops. In small quantities, boron is required by plants for their metabolic activities. However, at higher concentrations, it accumulates in the leaves and other parts of the plants and causes toxicity. Similarly, nitrogen is also beneficial to the plants in desired quantities but in excess amounts, it affects growth and delays maturity. Sensitive crops may be affected by nitrogen concentration above 5 mg/l. Most other crops are relatively unaffected until nitrogen exceeds 30 mg/l (FAO 1985). Irrigation waters having pH beyond the acceptable range are generally not harmful but may pose problems related to toxicity. Irrigation water quality aspects normally have long-term influence on the soil-plant and soil-water system as it affect crop production and soil and water management.

The irrigation water guidelines proposed by FAO are practical and have been used successfully in general irrigated agriculture for evaluation of the common constituents in surface water, groundwater, drainage water, sewage effluent, and wastewater. The guidelines do not evaluate the effect of unusual or special water constituents sometimes found in wastewater, such as pesticides and organics. In irrigation water evaluation, emphasis is placed on the chemical and physical characteristics of the water and rarely any other factors considered important. As a rule of thumb, irrigation water supplies do not need to be checked for trace elements unless there is some reason to suspect toxicity. In almost all cases where trace elements are at high levels, they are the result of man's activities, particularly wastewater disposal. Any project using wastewater should check for trace elements (FAO 1985).

Main concern in developing an overall quality index has been deciding the proper weights for various parameters considered. Because of this, substantial subjectivity occurs in the selected weights and the overall index always remains under questions. Weights can be derived from experimental judgements of relative importance of factors using analytical hierarchy process (Wu et al. 2017). Therefore, in the proposed work, the weights are optimized using the analytic hierarchy process (AHP) and subjectivity is minimized. Various researchers have developed a number of water quality indices but most of them are for the drinking purpose (Horton 1965; Mc Duffie and Haney 1973; Nemerow and Sumitomo 1970; Brown et al. 1970; Landwehr 1976; Parti et al. 1971; Dinius 1972; Dee et al. 1973; O'Cornor 1972; Deininger and Landwehr 1971; Walski and Parker 1974; Stoner 1978). Singh et al. (2015) have developed overall water quality index by formulating water quality indices based on 16 water quality parameters. These indices are developed for the Indian conditions based on the water quality standards given by Bureau of Indian Standards (BIS 1991). Mostafaei (2014) has evaluated the water quality in the Kashkan River using water quality index. The Canadian Council of Ministers of Environment Water Quality Index (CCME WQI) technique was utilized using measurements from 10 sampling stations during a period of 36 years (1974–2009). The measured data included

cations (Na$^+$, K$^+$, Ca^{2+}, Mg^{2+}), anions (HCO3$^-$, Cl$^-$, SO4^{2-}), pH, and electrical conductivity. Recently, Orozco et al. (2017) have developed a water quality index for an irrigation dam. They concluded that water treatment must be applied before waters from La Vega dam reservoir can be used for irrigation or other purposes. They also recommended that the water quality at La Vega dam is continually monitored for several years in order to confirm the findings of this short-term study. Sutadian et al. (2016) have reviewed a number of water quality indices. They observed that a major factor that influences wider use of a WQI is the support provided by the government and authorities to implement a WQI as the main tool to evaluate the status of rivers.

In water quality monitoring program, data from multiple locations create voluminous information and result in complexity to categorize the quality of water. The present criteria, on the suitability assessment of irrigation water, being followed in India is given by CPCB and CGWB (2000) which is based on electrical conductivity, sodium percentage, sodium absorption ratio, and residual sodium carbonate. Each of these parameters has wide range of variation within a particular class. Many events occur when these parameters classify irrigation water into different suitability classes making it difficult to decide the exact suitability class. In order to overcome such difficulties, an irrigation water quality index (IWQI) is developed in this paper based on the 12 parameters that are generally used for the irrigation purpose under normal conditions as well as under suspected special conditions related to water quality. These parameters include electrical conductivity (EC), sodium percentage (Na%), sodium absorption ratio (SAR), residual sodium carbonate (RSC), pH, chloride, nitrate-nitrogen, boron, arsenic, cadmium, fluoride, and iron. For categorizing the concentration ranges, the standards given by CPCB and CGWB (2000) and FAO (1985) are followed. The proposed IWQI aids in assessing the irrigation water quality by transforming large datasets into a single numerical score, which describes the health of irrigation water resource. In addition, the proposed sub-indices functions also assist the individual parameters about their pollution status. The proposed sub-indices and the overall irrigation water quality index will prove very helpful to the irrigation water managers, field engineers, and decision makers in monitoring, assessment, and control of the irrigation water.

Methodology

The methodology for the development of water quality indices for irrigation is defined in brief as follows:

(i)   Selection of water quality parameters,
(ii) Development of sub-indices function,
(iii) Assignment of parameter weights, and
(iv) Aggregation of sub-indices to generate an overall index.

Selection of water quality parameters

In India, CPCB and CGWB (2000) standards govern the quality of water for the irrigation use. Based on these standards, four parameters, namely electrical conductivity, sodium percentage, sodium absorption ratio, and residual sodium carbonate are considered to control the quality of irrigation water. For all these parameters, a class categorization criterion is used to assess the quality of irrigation water into five classes. These classes include excellent, good, medium, bad, and very bad. The classification criteria are presented in Table 1.

In the present paper, the scope of Table 1 is further extended and a number of governing parameters are enhanced to 12. These parameters have been selected based on natural and anthropogenic pollution, which include EC, Na%, SAR, RSC, pH, chloride, nitrate-nitrogen, boron, arsenic, cadmium, fluoride, and iron. Sub-indices functions are developed for all these parameters.

Development of sub-indices function

Sub-indices functions are the mathematical relations that transform the values of various parameters into indices score. These scores are then converted to a

Table 1 Guidelines for the evaluation of irrigation water quality (CGWB and CPCB 2000)

Water class	Na (%)	EC (μS/cm)	SAR	RSC (meq/l)
Excellent	< 20	< 250	< 10	< 1.25
Good	20–40	250–750	10–18	1.25–2.0
Medium	40–60	750–2250	18–26	2.0–2.5
Bad	60–80	2250–4000	> 26	2.5–3.0
Very bad	> 80	> 4000	> 26	> 3.0

common scale based on their relative importance to affect the irrigation water quality. The sub-indices functions are then developed based on the irrigation quality standards given by CPCB and CGWB (2000) and FAO (1985) and their concentrations to meet in a particular range. For this purpose, mathematical expressions are fitted for each parameter to obtain the sub-index equations as given in Table 2 such that the corresponding variation between the ranges of parameters and indices is uniform to produce reliable estimate of indices.

Parameter weights

Selection of weights of parameters is another most important and toughest job. The parameter, having the most significant influence, is assigned the highest weight and vice-versa. Such weights are assigned based on the judgment of the authors or the past experience. The selection of weights has always been a challenge because of the subjectivity resulting from different expert opinion. Therefore, more emphasis should be given to decide the weight of parameters, which can be optimized using Saaty's AHP approach. Since the quality of water for the irrigation use depends on several inter-related parameters, the assessment of suitable weights is possible using a set of multiple parameters using a multiple criteria decision analysis (MCDA). The MCDA tools are widely considered useful in resolving conflicts related to the decision-making process (Javanbarg et al. 2012). Saaty's AHP (SAHP) is the most commonly used MCDA tool that uses hierarchical structures to represent a problem and then develop priorities for the alternatives based on the judgment of the user (Saaty 1980). The SAHP process involves defining the unstructured problem, developing AHP hierarchy, pair-wise comparison, computation of relative weights, consistency check, and finally, obtaining parameter weights (Lee et al. 2008).

Saaty's AHP

The analytic hierarchy process (AHP) is a multi-criteria decision-making approach that constructs a matrix of pair-wise comparisons between the factors responsible for any process. These factors are scaled from 1 to 9, 1 indicates that the two factors are equally important and 9 indicate that the one factor

Table 2 Development of sub-indices function for various parameters

Parameters	Range of parameters	Sub-index functions
Na %	0–20	$Y = -0.25, X + 100.00$
	20–40	$Y = -1.00, X + 115.00$
	40–60	$Y = -1.25, X + 125.00$
	60–80	
	> 80	
Electrical conductivity	0–250	$Y = -0.02, X + 100.00$
	250–750	$Y = -0.04, X + 105.00$
	750–2250	$Y = -0.02, X + 87.50$
	2250–4000	$Y = -0.01, X + 82.14$
	> 4000	$Y = -0.00417, X + 41.67$
SAR	0–10	$Y = -0.50, X + 100.00$
	10–18	$Y = -2.50, X + 120.00$
	18–26	$Y = -3.13, X + 131.25$
	26–34	
	> 34	
RSC	< 1.25	$Y = -4.00, X + 100.00$
	1.25–2	$Y = -26.67, X + 128.33$
	2–2.5	$Y = -50.00, X + 175.00$
	2.5–3	
	> 3	$Y = -25.00, X + 100.00$
pH	7–8	$Y = -5.00, X + 135.00$
	6.5–7 and 8.0–8.4	$Y = -10.53, X + 163.42$
	6.0–6.5 and 8.4–9.0	$Y = -8.33, X + 125.00$
	5.5–6.0 and 9.0–9.5	$Y = -6.25, X + 84.38$
	5.5 < and > 9.5	0.00
Chloride	0–106.5	$Y = -0.05, X + 100.00$
	106.5–213	$Y = -0.19, X + 115.00$
	213–355	$Y = -0.18, X + 112.50$
	355–532.5	$Y = -0.14, X + 100.00$
	> 532.5	$Y = -0.07, X + 62.50$
Nitrogen ($NO_3^- - N$)	0–4	$Y = -1.25, X + 100.00$
	4–10	$Y = -3.33, X + 108.33$
	10–20	$Y = -2.50, X + 100.00$
	20–30	
	30	
Boron	0–0.5	$Y = -10.00, X + 100.00$
	0.5–1	$Y = -40.00, X + 115.00$
	1–2	$Y = -25.00, X + 100.00$
	2–3	
	> 3	$Y = -12.50, X + 62.50$
Arsenic	0–0.0005	$Y = -10,000.00, X + 100.00$
	0.0005–0.01	$Y = -2105.26, X + 96.05$
	0.01–0.1	$Y = -277.78, X + 77.78$

Table 2 (continued)

Parameters	Range of parameters	Sub-index functions
	0.1–0.2	Y = −250.00, X + 75.00
	> 0.2	Y = −83.33, X + 41.67
Cadmium	0–0.0001	Y = −50,000.00, X + 100.00
	0.0001–0.001	Y = −22,222.22, X + 97.22
	0.001–0.01	Y = −2777.78, X + 77.78
	0.01–0.05	Y = −625.00, X + 56.25
	> 0.05	Y = −500.00, X + 50.00
Fluoride	0–0.5	Y = −10.00, X + 100.00
	0.5–0.7	Y = −100.00, X + 145.00
	0.7–1	Y = −83.33, X + 133.33
	1–2	Y = −25.00, X + 75.00
	> 2	Y = −8.33, X + 41.67
Iron	0–1	Y = −5.00, X + 100.00
	1–2	Y = −20.00, X + 115.00
	2–5	Y = −8.33, X + 91.67
	5–10	Y = −5.00 X + 75.00
	> 10	

Table 3 Saaty's rating scale (Saaty 1980; Majumdar et al. 2004)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective.
3	Moderate importance of one over another	Experience and judgment slightly favor one activity over another.
5	Essential or strong importance	Experience and judgment strongly favor one activity over another.
7	Very strong importance	An activity is strongly favored and its dominance is demonstrated in practice.
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation.
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed.
Reciprocals	If activity p has one of the above numbers assigned to it when compared with activity q, then q has the reciprocal value when compared with p.	

is more important than the other. Reciprocal of 1 to 9 (1/1 and 1/9) shows that one is less important than the other is. Table 3 describes Saaty's rating scale and the allocation of the weights for the identical parameters depend on their relative importance and participatory group of decision makers. In order to fill the comparison matrix, a comparison of each parameter with all other parameters is done. The diagonal elements of the matrix are always unity. If the judgment value in the comparison matrix is to the left side of the diagonal element, then actual judgment value is used to fill the upper triangular matrix. If the judgment value is to the right side of the diagonal element, then reciprocal is used. The lower triangular matrix is filled by taking reciprocal of the upper triangular matrix. The comparison matrix is constructed by deciding the relative importance of each parameter by an expert group of five members from the related research area. In this manner, the whole comparison matrix is prepared. Making use of this comparison matrix, priority vector is computed which is the normalized Eigen vector of the matrix. The priority vectors help to compute the weight for different parameters. In the present work, 12 parameters that govern the irrigation water quality are selected for construction of AHP matrix.

Consistency check

The consistency in subjective judgment of the weight of parameters can be checked by consistency ratio, which is the comparison between consistency index and random consistency index. The consistency ratio (CR) is computed by the following equation:

$$CR = \frac{CI}{RI} \tag{1}$$

where CI is the consistency index and RI is the random consistency index. The consistency index is a measure of consistency that can be estimated using the following equation:

$$CI = \frac{\lambda_{max} - 1}{n - 1} \tag{2}$$

where λ_{max} is the principle Eigen value obtained from the priority matrix and n is the size of the comparison matrix. Saaty (1980) has determined the average

Table 4 Average random consistency index for various sizes of matrix (N)

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49
N	11	12								
RI	1.51	1.54								

random consistency index (RI) on the basis of the sample size. The average random consistency index for various sizes of matrix (N) is given in Table 4.

The RI in combination with λ_{max} can be used for the computation of CI. In the present study, 12 parameters, that influence the irrigation water quality, have been taken into account for the computation of weights using Saaty's AHP-based MCDA support tool. These parameters include EC, Na%, SAR, RSC, pH, chloride, nitrate-nitrogen, boron, arsenic, cadmium, fluoride, and iron.

Computation of weights

In Saaty's AHP-based MCDA tool, a comparison matrix is prepared on the comparison of importance between the water quality variables affecting the decision. The principal Eigen value has been computed which in turn is used to determine the weights and consistency index using Eq. (2). After estimation of consistency index, consistency ratio is determined using Eq. (1). If the consistency ratio is less than 10%, then the computed parameter weights are

consistent and the weights are considered as final. If not so, then alterations are made in the assigned weight factors of the comparison matrix, the weights are computed again, and CR is again checked unless it is found within 10%.

In the present work, Saaty's AHP-based MCDA tool is used to quantify the weights by preparation of comparison matrix. The comparison matrix having relative importance and normalized values are given in Table 5. This comparison matrix is then used to determine normalized principal Eigen vector with the help of approximation technique (Table 6). The principal Eigen value (λ_{max}) and consistency index (CI) are determined as 13.074 and 0.0977, respectively. Since 12 variables are considered in the decision analysis, the random consistency index (RI) comes out to be 1.54. The consistency ratio for the present decisions has been computed as 6.34%, which is less than 10%. Thus, the inconsistency in the decisions is acceptable and the weights obtained are consistent for further use. The weight factors of all the 12 parameters are given in Table 7.

Table 5 Comparison matrix for EHPs in Saaty's analysis

	pH	As	Na%	Fl⁻	RSC	EC	B	SAR	Fe	Cl⁻	NO₃⁻-N	Cd
pH	1	0.125	0.2	0.125	0.333	0.167	0.125	0.2	0.143	0.333	0.333	0.111
As	8	1	5	2	7	4	2	6	3	8	8	0.5
Na%	5	0.2	1	0.333	2	0.5	0.25	2	0.5	3	4	0.167
Fl⁻	8	0.5	3	1	5	2	1	4	2	6	7	0.333
RSC	3	0.143	0.5	0.2	1	0.333	0.167	0.333	0.25	3	3	0.125
EC	6	0.25	2	0.5	3	1	0.333	2	0.5	4	5	0.2
B	8	0.5	4	1	6	3	1	5	2	7	8	0.333
SAR	5	0.167	0.5	0.25	3	0.5	0.2	1	0.333	3	3	0.143
Fe	7	0.333	2	0.5	4	2	0.5	3	1	5	6	0.25
Cl⁻	3	0.125	0.333	0.167	0.333	0.25	0.143	0.333	0.2	1	3	0.125
NO₃⁻–N	3	0.125	0.25	0.143	0.333	0.2	0.125	0.333	0.167	0.333	1	0.125
Cd	9	2	6	3	8	5	3	7	4	8	8	1

Table 6 Computation of final weights for EHPs using Saaty's AHP technique

	pH	As	Na%	Fl⁻	RSC	EC	B	SAR	Fe	Cl⁻	NO₃⁻-N	Cd	Eigen value	Weight
pH	0.015	0.023	0.008	0.014	0.008	0.009	0.014	0.006	0.010	0.007	0.006	0.033	0.840	0.013
As	0.121	0.183	0.202	0.217	0.175	0.211	0.226	0.192	0.213	0.164	0.142	0.147	0.999	0.183
Na%	0.076	0.037	0.040	0.036	0.050	0.026	0.028	0.064	0.035	0.062	0.071	0.049	1.187	0.048
Fl⁻	0.121	0.091	0.121	0.108	0.125	0.106	0.113	0.128	0.142	0.123	0.124	0.098	1.076	0.117
RSC	0.045	0.026	0.020	0.022	0.025	0.018	0.019	0.011	0.018	0.062	0.053	0.037	1.183	0.030
EC	0.091	0.046	0.081	0.054	0.075	0.053	0.038	0.064	0.035	0.082	0.089	0.059	1.210	0.064
B	0.121	0.091	0.161	0.108	0.150	0.158	0.113	0.160	0.142	0.144	0.142	0.098	1.171	0.132
SAR	0.076	0.030	0.020	0.027	0.075	0.026	0.023	0.032	0.024	0.062	0.053	0.042	1.274	0.041
Fe	0.106	0.061	0.081	0.054	0.100	0.106	0.057	0.096	0.071	0.103	0.107	0.073	1.190	0.084
Cl⁻	0.045	0.023	0.013	0.018	0.008	0.013	0.016	0.011	0.014	0.021	0.053	0.037	1.107	0.023
NO₃⁻-N	0.045	0.023	0.010	0.015	0.008	0.011	0.014	0.011	0.012	0.007	0.018	0.037	0.989	0.018
Cd	0.136	0.366	0.242	0.325	0.200	0.264	0.339	0.224	0.284	0.164	0.142	0.293	0.848	0.248

Aggregation of sub-indices—irrigation water quality index

The indices developed above are on individual parameter based. One particular index is developed for each parameter. To compute an overall quality index, the influence of each individual parameter needs to bring on a common single scale. For this purpose, irrigation water quality index (IWQI) can be developed using a weighing scheme. In the present paper, the following weighted average aggregation equation is proposed:

$$IWQI = \frac{\sum\limits_{i=1}^{n} w_i . Y_i}{W} \qquad (3)$$

where W is the sum of all the weights of water quality parameters ($\sum w_i$), w_i is the weight of the ith water

quality parameter, and Y_i is the sub-index value of the ith water quality parameter.

Equation (3) can be used to compute the irrigation water quality index based on the concentration of all individual parameters. The proposed equations, as given in Table 2, have been developed to produce the indices in the range from 0 to 100. On the basis of the index value, the quality of irrigation water can be classified into five categories: very bad (0–25), bad (25–50), medium (50–75), good (75–95), and excellent (95–100). The status of water corresponding to various IWQI values is presented in Table 8. Lower value of the index indicates that some of the water quality parameters are affected either by anthropogenic pollution or by geogenic contamination. Therefore, suitable measures are needed either to protect or to improve the quality of source water. The irrigation water in such case further needs to investigate the causes of quality deterioration and attention for appropriate remedial measures. Thus, the proposed index may be used as a deciding rule in

Table 7 Weights for various water quality parameters

Water quality parameter	Weight factor	Water quality parameter	Weight factor
RSC	0.030	NO₃⁻–Nitrogen	0.018
SAR	0.041	Boron	0.132
Na%	0.048	Arsenic	0.183
EC	0.064	Cadmium	0.248
pH	0.013	Fluoride	0.117
Chloride	0.023	Iron	0.084

Table 8 IWQI and corresponding class and status of water quality

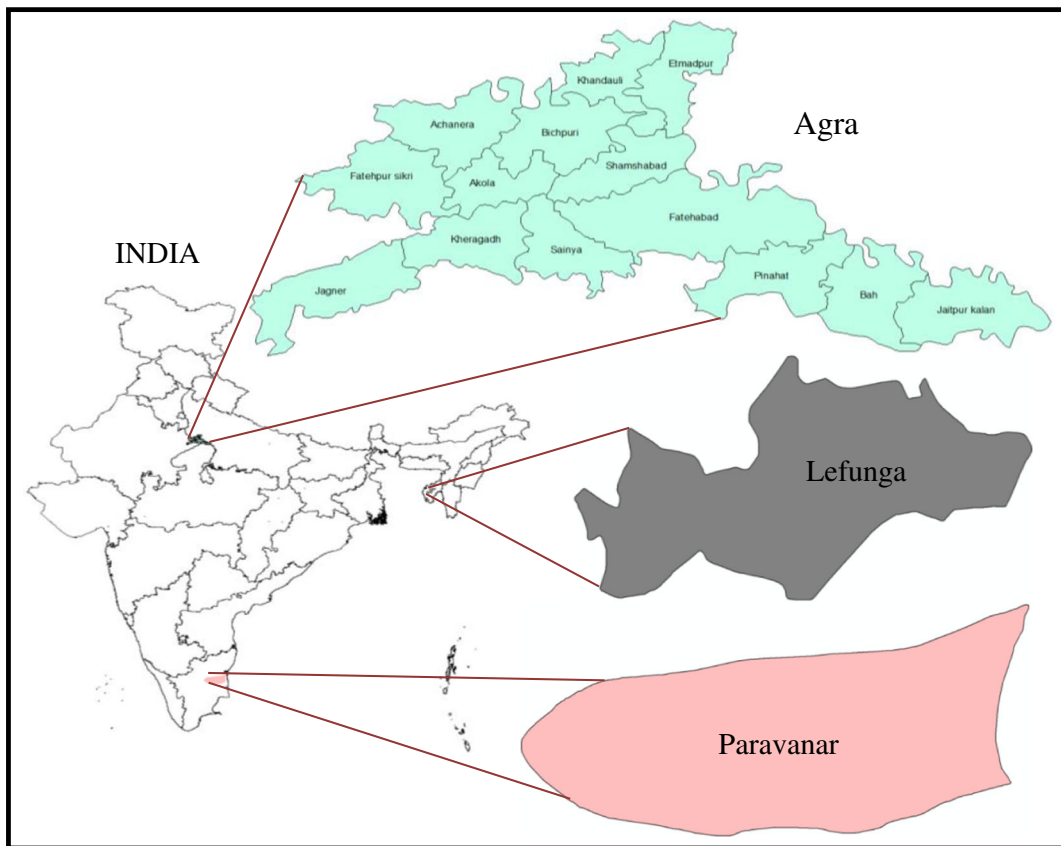| Class	IWQI value	Status of water
Very bad	0–25	Unsuitable
Bad	25–50	Management of water quality needed
Medium	50–75	Can be used depending on soil and crop conditions
Good	75–95	Acceptable
Excellent	95–100	Pristine quality

Fig. 1 Map showing the three locations for the water quality assessment

proper irrigation water management of both surface and groundwater resources.

Results and discussion

The proposed irrigation water quality indices have been applied on the data of three locations in India, namely the Agra district in Uttar Pradesh, Paravanar sub-basin in Cuddalore district of Tamil Nadu, and Lefunga Block in West Tripura district of Tripura state. The individual indices and IWQI are estimated for all these locations, and accordingly, the status of irrigation water is assessed. For this purpose, water quality data have been taken from the published literature (Shankar et al. 2011; Paul et al. 2016) and Ground Water Department, Uttar Pradesh. In order to compute the individual indices and irrigation water quality index (IWQI), a Microsoft Excel 2016-based computer code is developed. This program suggests the quality class and status of water on the basis of the IWQI. The program also highlights the particular

parameters that affect the quality of irrigation water. The applications of the proposed index have been described in the following sections.

Application of index for assessment of irrigation water quality

The map showing Agra district in Uttar Pradesh, Paravanar sub-basin in Cuddalore district of Tamil Nadu, and Lefunga Block in West Tripura district of Tripura state is presented in Fig. 1.

The Agra district falls in the western part of the Uttar Pradesh on the bank of the Yamuna River between 27.11′ to 27.11′ N latitude and 78.0′ to 78.2′ E longitude at an altitude of 169 m above mean sea level. The district is sub-divided into 15 administrative blocks. Major crops grown in the district are wheat, paddy, bajra, mustard, and potato. The geology of Agra district is represented by the Gangetic alluvium which is named as Varanasi Alluvium. This formation has a wide spread and is overlain on the basement formed by the rocks of Super

Fig. 2 Box-Whisker plot for the groundwater quality of Agra district

(Unit of EC is µS/cm and of other parameters is meq/l)
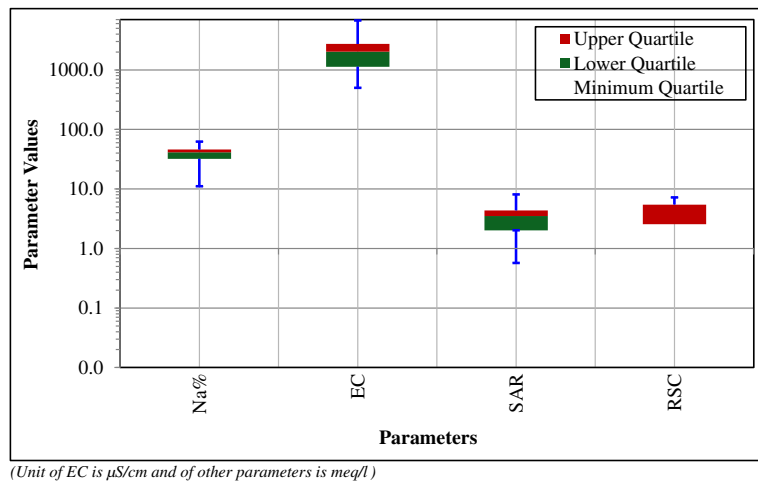
Vindhyan Group of Neoproterozoic age. The soil types are loose, sandy and calcareous, and are characterized by alluvium, which is an admixture of gravel, sand, silt, and clay in various proportions. The district has a continental sub-tropical climate with long hot summers from April to September when temperature reaches up to 45 °C. During summer, dry winds blow in this region. During winter, maximum temperature goes up to 31.7 °C and minimum temperature up to about 4.2 °C. About 670-mm rainfall occurs during rainy season from July to September.

The Paravanar sub-basin falls in the Cuddalore District of Tamil Nadu state. The sub-basin is bounded on the north by the main Gadilam river basin, on the south by the Vellar basin, on the east by Bay of Bengal. Most part of the basin is a flat plain, slopping very gently towards the sea on the

east. The uplands are only on the northwestern border, with the Capper Mound or the Red Plateau running parallel to the sea with an elevation of < 25 m above mean seal level, forming part of red lateritic "Cuddalore Sand Stones" (Shankar et al. 2011). The area has a tropical climate with the lowest and highest temperatures recorded in January and May, respectively. The precipitation mainly depends upon North East monsoon, which is cyclonic in nature and attributed to the development of low pressure in the Indian Ocean and Bay of Bengal. The area receives about 1162-mm annual rainfall. Geologically, the area is underlined by the Tertiary to recent alluvium sediments. The River Paravanar originates from the Cuddalore sandstone of Tertiary age which is composed of mottled argillaceous sandstone (Balasundar 1968). The Cuddalore sandstone

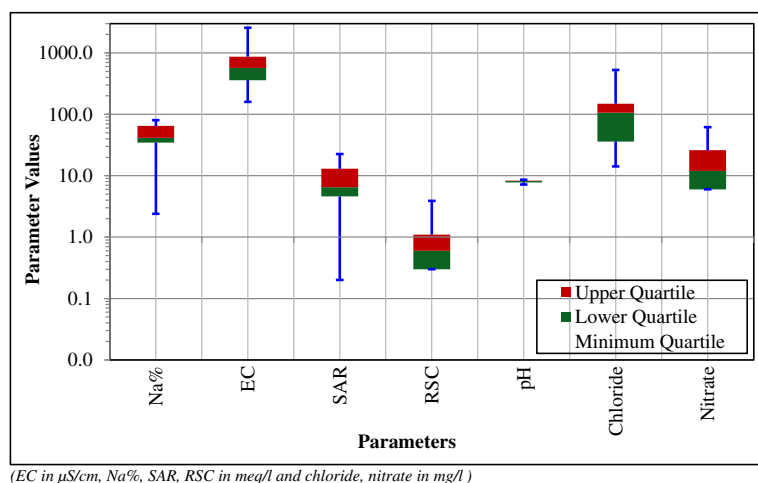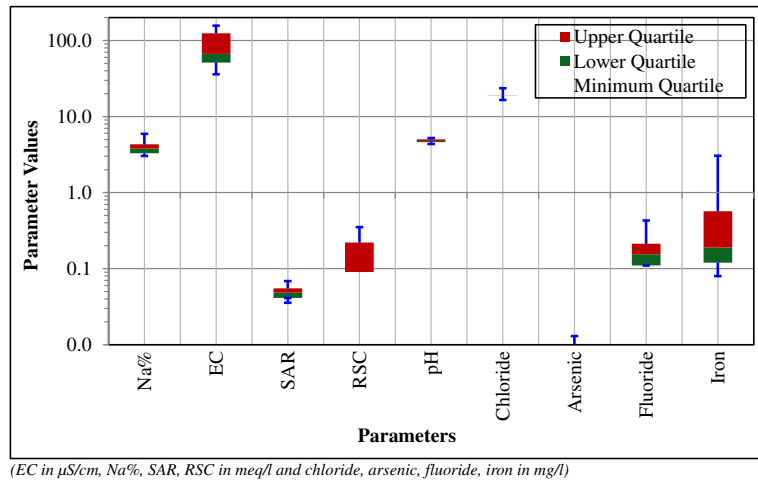**Fig. 3** Box-Whisker plot for the groundwater quality of Cuddalore district

(EC in µS/cm, Na%, SAR, RSC in meq/l and chloride, nitrate in mg/l)

Fig. 4 Box-Whisker plot for the groundwater quality of Lefunga Block, West Tripura

(EC in µS/cm, Na%, SAR, RSC in meq/l and chloride, arsenic, fluoride, iron in mg/l)

occurs at capper plateau south of Cuddalore town and is made up of sandstone, clay, and silt. The lower Cuddalore sandstone is unconsolidated at few places. The sandstones are found intercalated with clay lenses and covered by lateritic formation (Selvaraj and Ramasamy 1998). The major soil types in this basin are inceptisol, entisol, alfisol, and vertisol. The main crop grown in the basin is cashew plantation.

The Lefunga block falls in West Tripura district of Tripura state, which lies between 23° 52 22 to 23° 56 55 N latitude and 91°18 10 to 91°25 49 E longitude. Temperature varies between 10 and 35 °C and the average annual rainfall of the district is 2200 mm. Geologically, the area is composed of Recent Formation (alluvium), Dupitila Series, and Tipam Group. Alluvium deposits of recent or sub-recent rivers comprising silica Ghilatoli formation sand, silt and clay, and vegetation debris, pale yellow to dirty sand, silt clay with organic contents and massive, coarse-grained, gritty poorly cemented sandstone with current bedding. Tipam Group conformably overlies Surma Group and the gradational contact is marked by a ribbed sandstone unit with minor

thin siltstone bands (Paul et al. 2016). Dupitila formation overlies Tipam Group with an angular unconformity. The contact is marked by a thin band of pebble—conglomerate. It comprises white to yellowish, loose, unconsolidated ferruginous sandstone with pink and yellow clay bands. The coarse-grained sandstone contains fragments of quartz, quartzite, muscovite, biotite, and feldspar with profuse lithic fragments. Bedding is indistinct due to massive and unconsolidated nature of sand rock. There are pockets of well-sorted, medium- to coarse-grained quartz, and white clay. Thin lateritic soil capping has been recorded on the top of several mounds composed of the sandstone. Potato, tomato, and *Boro* rice are generally grown during the winter season. Other crops include pineapple, orange, cashew nut, jackfruit, coconut, tea, rubber, and forest plantations.

In order to study the variability in the groundwater data of various parameters, Box-Whisker plot has been presented for each location. The boxplot consists of five sample statistics, i.e., the minimum, the lower quartile, the median, the upper quartile, and the maximum. The box of the plot is a rectangle which encloses the middle half of the sample, with an end at each quartile. The length of the boxplot is the inter-quartile range of the sample. There is a line across the box which is the sample median. Whiskers sprout-out the two ends of the box until they reach the sample minimum and maximum. The crossbar at the far end of each whisker is its length.

The Box-Whisker plot of groundwater quality of the Agra district is shown in Fig. 2. The box plot shows that inter-quartile range (IQR) is very high for the electrical conductivity, which indicates large variation in the EC

Table 9 Statistics of groundwater quality of Agra district

	Na%	EC	SAR	RSC
No. of data, 15				
Min	11.07	500.00	0.57	− 29.99
Max	62.41	6780.00	8.10	0.07
Mean	38.44	2195.00	3.49	− 6.01
90th percentile	52.58	3454.00	6.68	− 0.24

Table 10 Statistics of groundwater quality of Paravanar sub-basin

	Na%	EC	SAR	RSC	pH	Cl⁻	NO₃⁻
No. of data, 17							
Min	2.40	160.00	0.20	− 3.60	7.20	14.18	0.00
Max	80.30	2580.00	22.50	3.90	8.60	527.00	62.00
Mean	45.29	817.06	8.66	0.64	8.07	136.05	18.15
90th percentile	69.64	1986.40	18.38	3.58	8.40	341.60	42.20

values. In general, the whiskers are long-tailed for all the parameters. The Na% and RSC data are left-skewed while EC and RSC are right-skewed. One lower outlier is detected only for RSC (− 29.99 meq/l) and no other outliers are observed in any other parameter. It is also seen that more than 53% of the data are lying above median value for all the parameters.

The Box-Whisker plot of groundwater quality of Paravanar sub-basin is shown in Fig. 3. The box plot shows that IQR is more for the electrical conductivity and chloride. The whiskers are long-tailed for all the parameters. The data for Na%, SAR, and pH are near-normal distributed while for EC, chloride, and nitrate are right-skewed. Two higher outliers are detected for RSC (3.9 and 3.7 mg/l), one lower outlier for EC (160 μS/cm), one lower outlier for chloride (14.18 mg/L), and three lower outliers for RSC (− 3.6, − 2.7, and − 0.8 meq/l). It is also seen that more than 53% of the data are lying above median value. Further, the data for SAR is centered on mean value.

The Box-Whisker plot of groundwater quality of Lefunga block of West Tripura district is shown in Fig. 4. The box plot shows that IQR is very high for the electrical conductivity, which shows wide variation in the data. The whiskers are short-tailed for EC and long-tailed for all other parameters. The data for pH are left-skewed while for rest of the parameters, the data are right-skewed. In total, one lower outlier is detected for

chloride, one higher outlier for iron, and two higher outliers for chloride. For most of the parameters, more than 56% of the data are lying above the median value.

The statistics, which summarize data from sampling using indexes, such as the mean or minimum and maximum variation, draw conclusions from data itself that are subject to random variation (e.g., observational errors, sampling variation). A percentile is a measure in statistics, which indicates the value below which a given percentage of observations fall in a group. For example, the 90th percentile is the value below which only 10% of the observations may be found. Tables 9, 10, 11 present the statistics of groundwater quality of the Agra district, Paravanar sub-basin, and Lefunga block, respectively. It is seen that the electrical conductivity is quite high in the Agra district and varies from 500 to 6780 μS/cm. Five blocks of the district are severely affected by the intrinsic salinity. The water quality of Paravanar sub-basin indicates high concentration levels of Na% and nitrate while other parameters are in normal range. The groundwater quality of Lefunga block specifically has very low pH in the range 4.36 to 5.23 with an average of 4.81, which indicates that the water is highly acidic in nature.

The water quality indices are first estimated parameter-wise and then the IWQI is computed for each location and presented in Table 12. In order to assess the spatial variation of water quality status, the computed IWQI are rasterized for each of the three locations and

Table 11 Statistics of groundwater quality of Lefunga Block, West Tripura

	Na%	EC	SAR	RSC	pH	Cl⁻	Arsenic	Fl⁻	Iron
No. of data, 09									
Min	3.04	35.90	0.04	− 0.62	4.36	16.50	0.01	0.11	0.08
Max	5.91	157.01	0.07	− 0.12	5.23	23.57	0.01	0.43	3.06
Mean	4.12	88.88	0.05	− 0.38	4.81	19.47	0.01	0.20	0.61
90th percentile	5.91	149.23	0.07	− 0.21	5.13	22.31	0.01	0.35	1.16

Table 12 Irrigation water quality indices and IWQI for various locations

	Na%	EC	SAR	RSC	pH	Cl$^-$	NO$_3^-$N	Arsenic	Fl$^-$	Iron	IWQI
Agra, Uttar Pradesh	74.79	54.40	98.26	99.98	–	–	–	–	–	–	81.9
Paravanar sub-basin, Tamil Nadu	66.07	78.83	90.93	81.52	83.13	85.84	91.47	–	–	–	82.5
Lefunga block, West Tripura	98.97	98.22	99.98	100.0	0.00	99.09	–	89.64	98.05	94.89	86.5

are shown in Figs. 5, 6, and 7. It is seen from Fig. 5 that IWQI is low in the western part of the Agra district and high in the eastern and southeast part of the district. This is obvious from the map and it is clearly stated that the groundwater of the eastern and southeast portion of the Agra district is much better quality and suitable for the irrigation use. Figure 6 presents the variation of IWQI in the Parabanar sub-basin of the Tamil Nadu state. It is seen that the IWQI is low in the eastern part of the basin and the water quality is not good. In the western part of the sub-basin, the index value is high and quality of groundwater is better except at three locations, namely Perpriyankuppam, Sathankuppam, and Vadalur. In overall, quality of major portion of the sub-basin is suitable for the irrigation use. The variation of IWQI for the Lefunga block is shown in Fig. 7, which indicates that the IWQI varies from 76.4 to 95.5 for the whole block. It is also seen that the groundwater quality for the irrigation purpose is good at Birmohan Village and Abhicharan Bazar while it is of excellent class at all other locations.

The computed water quality indices and IWQI for all three regions are given in Table 12. It is seen from the table that the EC index for the Agra district is low and falls under the medium category. This is because of the occurrence of high EC values in the district. The water quality of the Paravanar sub-basin is good except the Na% index which is moderate because of the elevated values of sodium. In the case of Lefunga block, the pH index is zero, which is due to the consistent very low pH values in the whole block. However, low pH is not harmful to soil and plants but may pose problems related to toxicity in the long term. Therefore, as per irrigation water guidelines, causes related to low pH need to be investigated and related measures shall be taken for future protection.

In overall, the IWQI values for the Agra district, Paravanar sub-basin, and Lefunga block are found as 81.9, 82.5, and 86.5, respectively. This indicates that the suitability of the groundwater quality of all the three regions fall under the "good" category and the water is acceptable for the irrigation use.
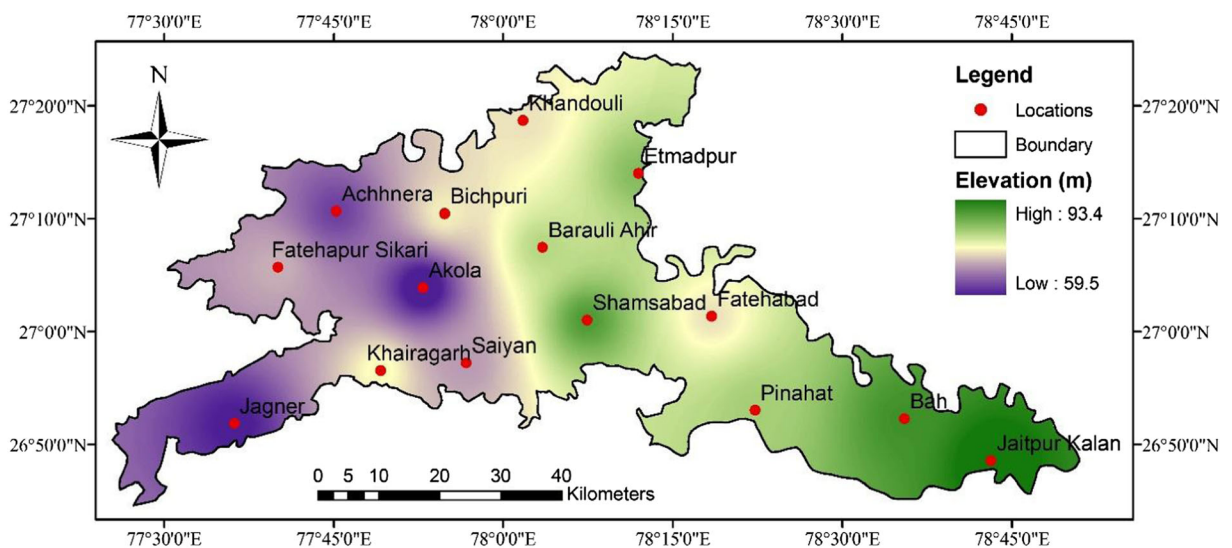

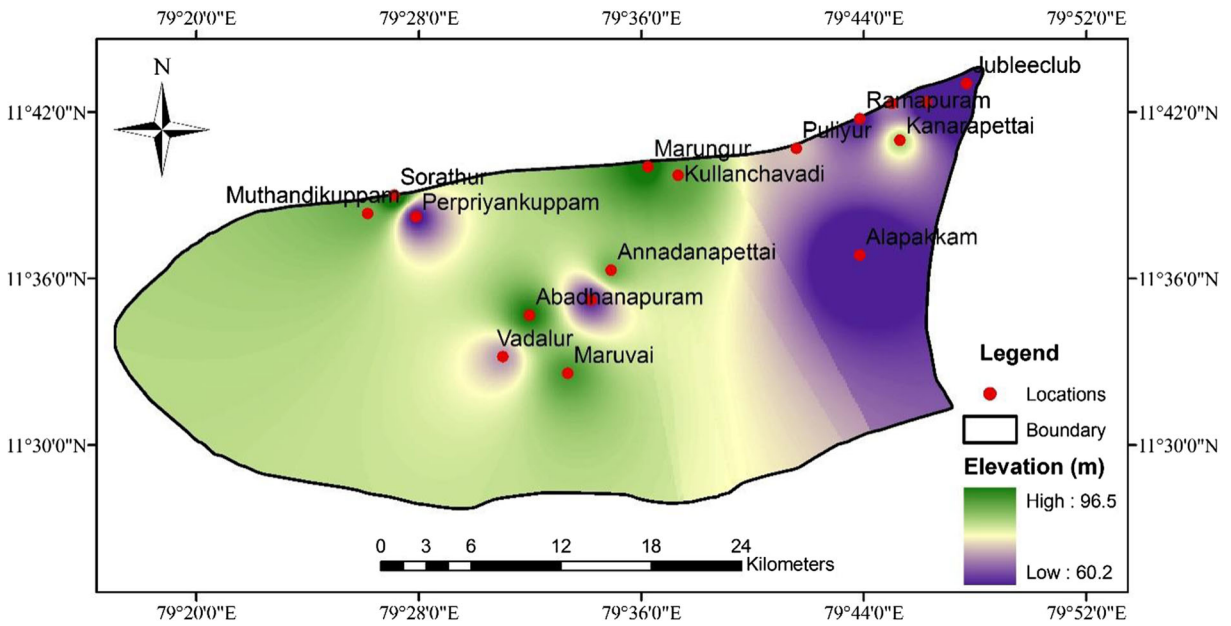**Fig. 5** Variation of irrigation water quality index for the Agra district

Fig. 6 Variation of irrigation water quality index for the Paravanar sub-basin

Conclusions

In the present paper, sub-indices functions and irrigation water quality index (IWQI) are developed to provide an effective means for the assessment of quality of both surface and undergroundwater for the irrigation

purpose. The indices functions are developed based on 12 parameters following the guiding standards fixed by the CPCB and CGWB, India, and the FAO for the irrigation use. In order to minimize the subjectivity in assessment, the weights of the variables have been optimized using the SAHP technique. The application of
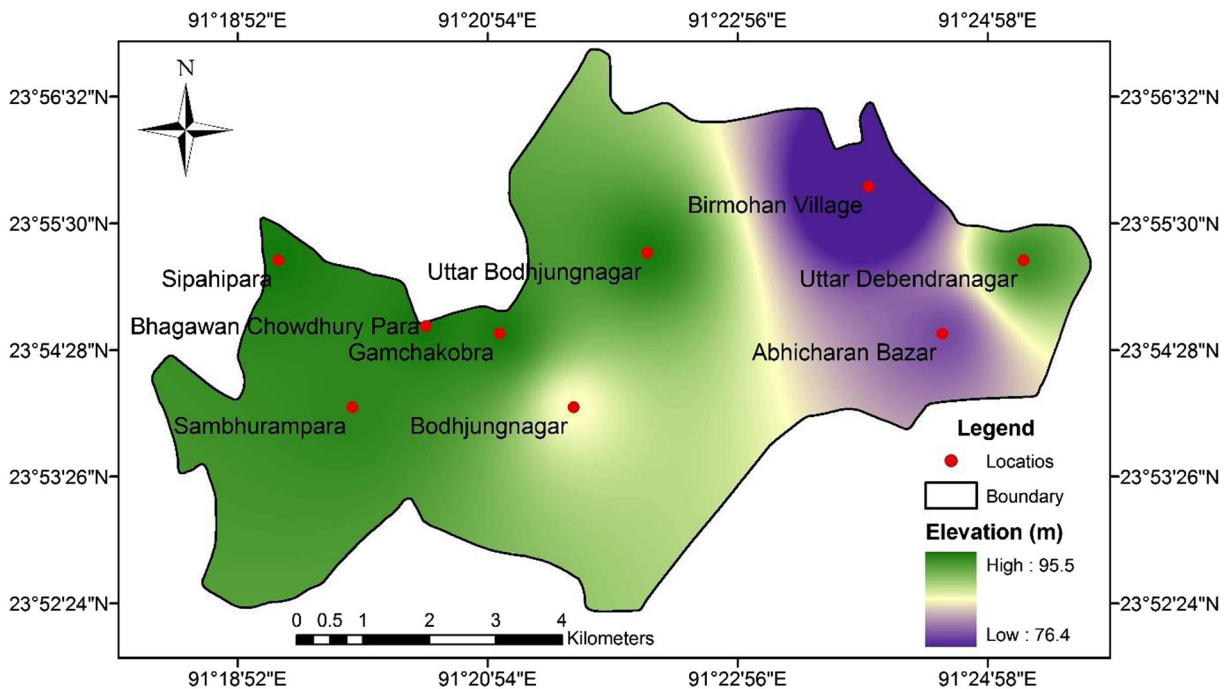

Fig. 7 Variation of irrigation water quality index for the Lefunga Block, West Tripura

the proposed index is illustrated for three locations in India, and accordingly, the status of irrigation water quality is described based on the developed index. The proposed sub-indices and the IWQI will be useful to the irrigation water managers, field engineers, and decision makers in monitoring, assessment, and control of the irrigation water. The web-based online system of the proposed index can serve as a decision support tool for the irrigation water users and stakeholders.

Compliance with ethical standards

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