



Assessing the suitability of water for irrigation using major physical parameters and ion chemistry: a study of the Churni River, India

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Abstract

The aim of the present work is to evaluate the suitability of Churni River water for irrigation based on major physical and chemical parameters of 83 water samples collected during February 2011–December 2017 (one in every month) at two stations: Majdia and Ranaghat. The physical parameters measured are electrical conductivity (EC) (204–697 $\mu\text{S}/\text{cm}$ for Majdia and 182–731 $\mu\text{S}/\text{cm}$ for Ranaghat) and total dissolved solids (TDS) (40–526 mg/L for Majdia and 84–496 mg/L for Ranaghat). Besides, ion chemistry of four cations (concentration order: $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$) and four anions ($\text{HCO}_3^- > \text{CO}_3^{2-} > \text{Cl}^- > \text{SO}_4^{2-}$) depicts good ionic combination (ion balance error within 10%) and suitability of water for irrigation as indicated by the lower value of sodicity hazard (sodium absorption ratio (SAR) of 0.07–0.52 for Majdia and 0.05–0.52 for Ranaghat), alkalinity hazard (residual sodium carbonate of 2–10 for Majdia and 2–13 for Ranaghat) and permeability hazard (permeability index of 39–74 for Majdia and 40–139 for Ranaghat). Similarly, the compound ranking method locates the water samples of both the stations at 1.57 on a 1–3 scale when 1, 2 and 3 indicate good, permissible and unsuitable, respectively. Finally, ANOVA shows no significant difference in water quality except SAR between the upstream (Majdia) and downstream (Ranaghat) areas of the river.

Keywords Electrical conductivity · Total dissolved solids · Sodicity hazard · Alkalinity hazard · Permeability hazard · Churni River water

Introduction

Physicochemical analysis of water is essential to determine the quality of water in every sector. Analyses are conducted on water sampled from aquiferous layers (Kumar et al. 2014; Ali Moasheri et al. 2012; Singh and Kumar 2015), surface water (Kumarasamy et al. 2013; Disli 2017; Shakir et al. 2017) and wastewater (Baig Asadullah et al. 2018) because water from different sources is used for multiple purposes. The river is an important source of surface water used for potable water, irrigation, manufacturing industries, etc. Sustainable agricultural return largely depends on improved performance of an irrigation system which is evaluated by analysing the quality of water delivered. However, sustainability in agricultural return depends not only

on improved irrigation systems but also on crop yields and market prices of inputs and outputs. Many scholastic works have identified the suitability of river water for irrigation (Kumarasamy et al. 2013; Disli 2017; Costa and Aparicio 2015; Huong et al. 2008; Fulazzaky 2010; Khan et al. 2005; Rao et al. 2015; Shakir et al. 2017). As the river gets polluted from different sources, identification of that sources and their proper management is a major challenge. Besides, compositional proportions of different physicochemical properties may induce water pollution. Therefore, measuring the concentration of each parameter and finding out the principal factors of water pollution are essential to evaluate its suitability for irrigation. For this purpose, some indices such as sodicity hazard [sodium absorption ratio (SAR) and percent sodium or (% Na)], alkalinity hazard (residual sodium carbonate (RSC)) and permeability hazard (permeability index (PI)) have widely been used (Piper 1944; Eaton 1950; Richards 1954; Todd 1959; Gibbs 1970; Ravikumar et al. 2015; Reddy 2013; Sadick et al. 2017; Satyanarayana et al. 2016; Smith et al. 2014; Wilcox 1955). A good share of global agricultural products comes from irrigated lands. In India, ~63.25 million ha is the net area under irrigated land where principal sources of irrigation are tube wells and other wells (62%), canals (26%),

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tanks (3%) and other sources (9%) (Directorate of Economics and Statistics 2018). Regarding canal irrigation, most of the canals are taken off from perennial rivers. The alluvial plains in India having perennial rivers and excessive groundwater storage are the areas of the highest percentage of irrigation. One of the high-intensity irrigation areas of India is the Gangetic Plain where, apart from groundwater, river water plays a significant role to boost up the agricultural production. But, water, both the groundwater and surface water, is of concern because in the Gangetic Plain, rivers and groundwater are getting polluted. So, in this regard, it is important to monitor the quality of the river to receive pollution-free water. In the context of Bengal Delta, rivers are deteriorating at a faster rate since the sixteenth century (Majumdar 1941; Parua 2010; Rudra 2010, 2011, 2014). Like the decay of Bhagirathi-Hooghly River (Guchhait et al. 2016; Islam and Guchhait 2018), many other rivers in the Bengal Delta such as Bhirab-Jalangi and Mathabhanga-Churni are still facing heavy siltation at their source and are separated from the Ganga River throughout the year except monsoon period (Chapman and Rudra 2015). Consequently, velocity has become too feeble to carry suspended load and therefore has allowed a greater part of sediment to deposit on its bed. Thus, the channels have become choked and finally turned into decayed rivers. This phenomenon is natural and caused by continuous south-eastward swing of the Ganga-Padma River as a result of neo-tectonic movements (Allison 1998; Allison and Kepple 2001; Goodberd 2003; Kuehl et al. 1997; Islam and Guchhait 2017a). Besides, some scholars have addressed few anthropogenic activities like the release of urban industrial wastewater, runoff from agriculture, urbanisation and rapid land use and land cover change as potential factors affecting the chemical composition of river water (Das 2015). Similarly, some have paid attention to water pollution and its effects on aquatic ecology and fish community structure (Das and Chakrabarty 2007; Das 2015) of the Churni River. Based on the available literature, it can be mentioned that assessing the suitability of river water for irrigation is explored by a few scholars in general and for river Churni in particular. Keeping this gap in mind, this paper would address the following objectives:

- i. To analyse the physicochemical properties of water for assessing its suitability for irrigation, and
- ii. To find out the variations in the suitability of water between the upstream and downstream segments.

Study area

Three rivers, the Bhagirathi, the Jalangi and the Mathabhanga in Nadia District of West Bengal playing an important role in influencing local geomorphology, geohydrology, climate, soil, land use and socioeconomic spectrum, are known as ‘Nadia

Rivers’ (Majumder 1978). River Churni has been selected for study which is the extended part of the Mathabhanga River. The Mathabhanga originates from the Padma River in Bangladesh (24° 03′ 19″ N and 88° 24′ 21″ E) and is bifurcated into two channels: the Ichhamati and the Churni near Majdia (23° 40′ N, 88° 70′ E) in Nadia District. The Churni runs through Shibnivas, Hanskhali, Birmagar, Aranghata and Ranaghat and finally falls into the Hooghly River near Chakdah (23° 13′ N, 88° 50′ E). It flows for ~56 km. Two stations, Majdia (upstream) and Ranaghat (downstream), have been selected as water sample locations for analysing the suitability of water quality for irrigation (Fig. 1). Geographically, the area is a featureless monotonous deltaic plain with an imperceptible gentle slope (Islam and Guchhait 2017b). The climate of this area is characterised by tropical monsoon recording an average annual temperature of about 27 °C and average precipitation of about 1353 mm. The precipitation regime in this climate portrays that rainfall is concentrated only in 3 months (July–September), triggering a significant change in upland discharge from agricultural fields increasing total dissolved solids (TDS) and electrical conductivity (EC). The area (four community development blocks of Nadia District: Krishnaganj, Hanskhali, Ranaghat-I and Ranaghat-II) is densely populated with the rural (80%) and urban (20%) people (Directorate of Census Operation 2011). The economy of the area is dependent mostly on agriculture. Most of the agricultural tracts are irrigated by the water lifted from the Churni River. Thus, the government has installed many irrigation pumps on the Churni River (Fig. 2).

Database and methods

Database

We observed 83 water samples (one in every month) during February 2011–December 2017 at two stations: Majdia and Ranaghat. The tests on water quality were done by Kankinara Laboratory under West Bengal Pollution Control Board. For assessing the suitability of water for irrigation, we have simultaneously taken two physical parameters (EC and TDS) though they are similar in measuring the salinity level of water. However, TDS analysis measures salinity intrusion more effectively than EC (Khaki et al. 2015). Thus, in our present study, in order to segregate the level of salinity intrusion in the tidal stretch from the non-tidal stretch of the Churni River, we have applied TDS analysis. Besides, TDS and EC are not linearly correlated and hence the derivative measures may not represent the reality because, with a slight change in temperature, the constant in the TDS-EC equation ($TDS = k EC$ (in 25 °C)) often changes (Rusydi 2018). In the present context, the EC data used are taken as temperature compensating. Thus, to detect the minute difference in water quality for

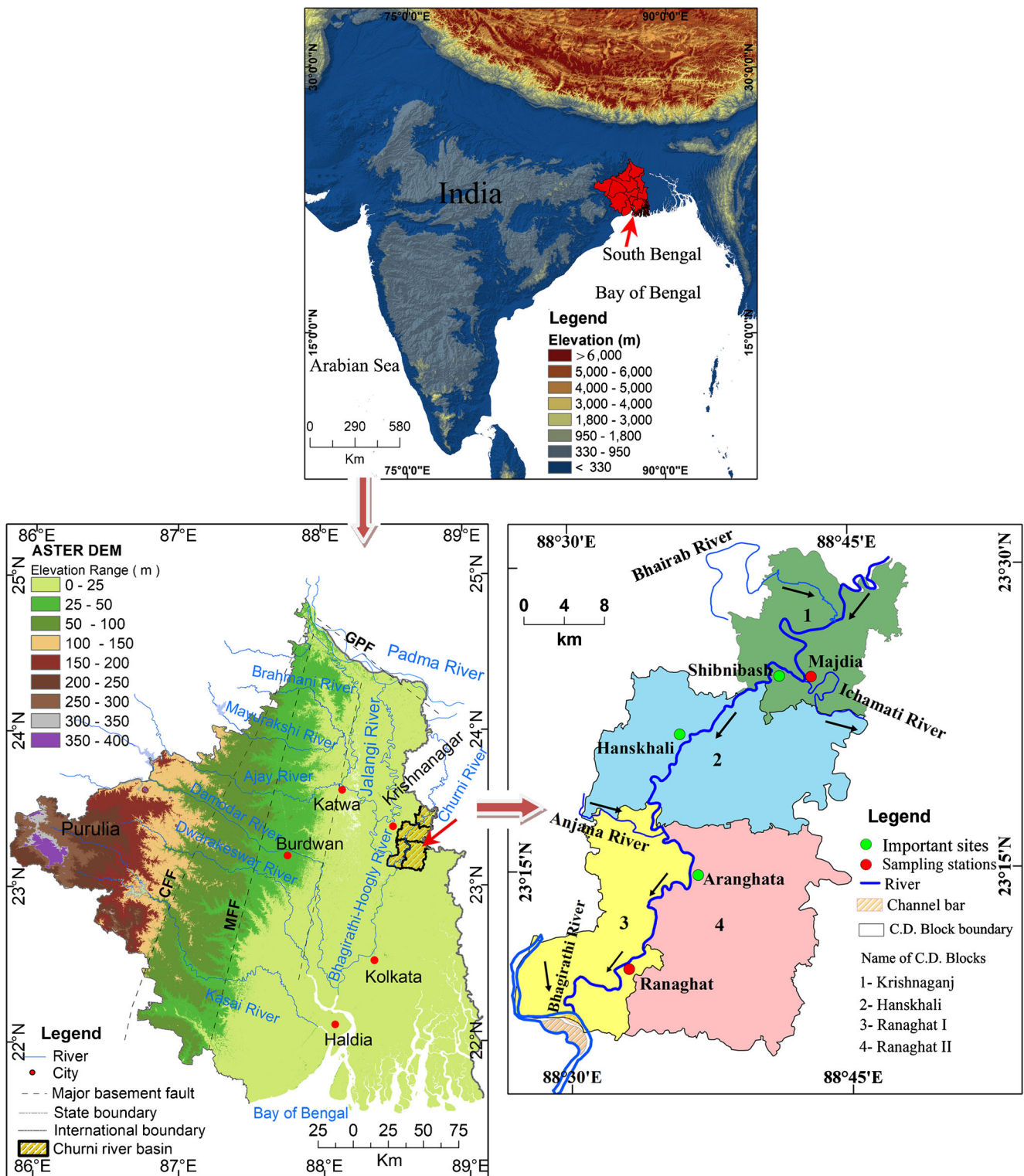


Fig. 1 Location of the study area

irrigation, simultaneous use of EC and TDS is justified. Besides, ion chemistry has been measured with reference to four cations [calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium

(Na^+) and potassium (K^+)] and four anions [bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), chloride (Cl^-) and sulphate (SO_4^{2-})].

Fig. 2 **a** Irrigation pump installed by the government on the Churni River. **b** Cultivation of crops beside the river (field survey in 2018)



Methods

Chemical classification of water

Using the AquaChem 2014.2 software, hydrochemical classification of the water samples of the Churni River has precisely been done through developing a piper trilinear diagram. Testing of ionic balance of the water sample is vital while analysing the physicochemical quality of water. In principle of electroneutrality, the concentration or sum of the positive ions (cations) must be equal to the sum of the negative ions (anions) (Nag and Das 2014). So, ion balancing is one of the most important validation tests for surface water and groundwater quality analysis. For calculation of ion balance, the concentration of each ion in water samples is measured in mEq/l. The most commonly used formula for ion balance is as follows (Nag and Das 2014):

$$\% \text{Ion balance error} = \frac{\Sigma \text{cations} - \Sigma \text{anions}}{\Sigma \text{cations} + \Sigma \text{anions}} \times 100 \quad (1)$$

In good water quality, both the groundwater and surface water, % of ion balance should be within the range of + 10% to – 10%. If the value of a particular sample exceeds the range, the analysis does not pass the validation check.

Measurement of the suitability of water for irrigation

The suitability of the Churni River for irrigation has been assessed using three types of hazards: sodicity, alkaline and permeability hazard. Different types of indices have been employed for measuring each hazard as follows:

- i. Sodicity hazard: Sodicity implies the amount of dissolved sodium present in water. Irrigation water having a high concentration of sodium brings about hazard deforming soil physical structure and making plant growth difficult. The physical processes directed by the high concentration of sodium are soil dispersion and clay platelet and aggregate swelling (Sarah 2004). The degree of force that binds clay particles together becomes feeble at the presence of the large amount of sodium ions in the pore space. Therefore, clay particles swell which leads to soil dispersion. Consequently, soil pores are plugged by clay particles resulting in poor soil permeability. More particularly, the three main types of clay (montmorillonite, illite and kaolinite) have their different sodium ion holding capacity. Montmorillonite clay having high sodium holding

Table 1 EC and TDS at Majdia and Ranaghat

Year	Electrical conductivity (μS/cm)		Total dissolved solids (mg/L)	
	Majdia	Ranaghat	Majdia	Ranaghat
2011	457	396	339	298
2012	493	469	352	315
2013	438	483	304	326
2014	543	563	366	382
2015	533	539	299	328
2016	555	558	331	319
2017	554	563	368	332
Average	510	510	337	329
SD	48	63	28	26
CV	9	12	8	8

Computed by the authors (2018)

capacity is considerably more prone to swelling and dispersion than other clays while kaolinite is least prone to swelling and dispersion (DeCarlo and Shokri 2014; Grim 1939). Therefore, sodium hazard is a good measure for assessing the suitability of irrigation water and widely evaluated through SAR and % Na.

- a. SAR: It is a ratio of sodium ion to calcium and magnesium ions which helps in predicting the degree to which irrigation water tends to enter into cation-exchange reaction in soil, and it is expressed as follows (Asadollahfardi et al. 2013):

$$SAR = \frac{Na^+}{\sqrt{\frac{1}{2} (Ca^{2+} + Mg^{2+})}} \tag{2}$$

The significant relationship between SAR values and the extent to which sodium is absorbed by soil has been proved and accepted.

- b. % Na: Sodium in water is generally expressed in two ways: percent sodium and soluble sodium percentage. Apart from creating obstacles for plants' growth directly, it changes the physical and chemical properties of soil. Percent sodium is calculated using the following formula (Singh and Kumar 2015):

$$\%Na = \frac{(Na^+ + K^+) \times 100}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \tag{3}$$

- ii. Alkaline hazard measured by RSC decides the degree of alkaline hazard for soil (Richards 1954). Alkalinity in the most natural surface water is derived from dissolution of carbonate and CO₂ present in the atmosphere. Normally, alkalinity in water is determined by three carbonate species (H₂CO₃, HCO₃⁻ and CO₃²⁻) and their proportion is dependent on pH and temperature. When the concentration of carbonate exceeds the total amount of calcium and magnesium, the quality of water for irrigation deteriorates. In water, if the concentration of carbonate and bicarbonate is too high, there is a tendency for calcium and magnesium to form solid materials (scale) and precipitates as calcium carbonate (CaCO₃) and magnesium carbonate (MgCO₃) as a result of a chemical reaction (Dinka 2016; Silva 2004). Consequently, the relative proportion of sodium in water has a tendency to be increased as sodium bicarbonate. This excess (amount of sodium increased due to precipitation of calcium and magnesium) of sodium is known as residual sodium carbonate and calculated using the following equation (Richards 1954):

$$RSC = CO_3^{2-} + HCO_3^- (Ca^{2+} + Mg^{2+}) \tag{4}$$

Table 2 USDA classification on salinity gradient based on EC and TDS range

Salinity class	Electric conductivity (μS/cm)	Total dissolved solids (mg/l)	Potential injury and necessary management for use as irrigation water
Low	< 250	< 150	Minimum salinity hazard; additional management is optional
Medium	251–750	150–500	Medium salinity hazard; damage to salt sensitive crops may occur; additional management is needed
High	751–2250	500–1500	Damage to crops with low tolerance to salinity may occur; quality water will be used for irrigation
Very high	2250–5000	> 1500	Damage to crops with low tolerance to salinity may occur; management requires salt-tolerant plants, good soil drainage and excess irrigation for leaching

Disli (2017)

Table 3 Descriptive statistics of the cations and anions

Parameters	Majdia				Ranaghat			
	Min (mg/L)	Max (mg/L)	Avg (mg/L)	CV (%)	Min (mg/L)	Max (mg/L)	Avg (mg/L)	CV (%)
Ca ²⁺	27	117	74	37	24	116	72	40
Mg ²⁺	5	30	14	48	6	29	13	44
Na ⁺	3	15	10	32	2	20	11	40
K ⁺	1	9	5	35	0.01	10	4	45
HCO ₃ ⁻	122	504	297	35	127	511	294	36
CO ₃ ²⁻	60	248	146	35	63	253	146	36
Cl ⁻	1.2	93	9	109	4	19	11	35
SO ₄ ²⁻	0.3	16	5	65	0.1	25	6	78

Computed by the authors, 2018

iii. Permeability hazard measured by PI defines the potentiality of water to hinder soil permeability. Permeability of soil is greatly influenced by continuous irrigation with the water having a high concentration of sodium, calcium, magnesium and carbonates assembled in soil (Doneen 1964). It was Doneen who evaluated the suitability of water for irrigation based on permeability index using the following equation (Doneen 1964):

$$PI = \frac{(Na^+ + SQRT HCO_3^-) \times 100}{Ca^{2+} + Mg^{2+} + Na^+} \quad (5)$$

Results

EC and TDS

Electrical conductivity determines the quality of water for both drinking and irrigation purposes because salinity hazard and suitability of water for irrigation are, to a great extent, determined by the concentration of EC. It is the capacity of water to conduct electrical current, and this capacity is directly proportional to the ions and solid particles present in water. The mean EC for both Majdia and Ranaghat is about 510 μ S/cm (Table 1) while slightly higher coefficient of variation (CV) of about 12% has been recorded by Ranaghat compared to Majdia (CV = 9%). Total dissolved solids refer to all organic and inorganic substances present in water. In other words, it is a measure of any minerals, salts, cation and anion dissolved in water. The acceptable range of TDS for irrigation is from 200 to 500 mg/L. If the concentration of TDS is higher than 1500, attention should be paid on the selection of crops and the duration and frequency of irrigation and soil drainage (Table 2). The mean TDS

for Majdia and Ranaghat is about 337 mg/L and 329 mg/L (Table 1), respectively, and CV for both the stations is about 8%.

Ionic chemistry of water

From the chemical analysis, it has been found that the concentration of all cations is in the order of Ca²⁺ > Mg²⁺ > Na⁺ > K⁺ and that of anions is of HCO₃⁻ > CO₃²⁻ > Cl⁻ > SO₄²⁻ at Majdia and Ranaghat (Table 3). Water samples from both the stations reveal neutral to the alkaline type of water (pH ranging from 7.2 to 8.4 at Majdia and from 7 to 8.3 at Ranaghat). The piper diagram depicts that the dominant water facies is Ca²⁺-CO₃²⁻-HCO₃⁻. The cationic triangle indicates Ca²⁺-dominated water while anionic triangle indicates carbonate and bicarbonate-dominated water. Moreover, the diagram shows that all the samples fall in the zones of 1, 3 and 5 (Fig. 3a-c), indicating that alkaline earth (Ca²⁺ + Mg²⁺) exceeds alkalis (Na⁺ + K⁺), weak acids (CO₃²⁻ + HCO₃⁻) exceed strong acids (SO₄²⁻ + Cl⁻) and carbonate hardness (secondary alkalinity) exceeds 50%. The average concentration of the cations and anions is similar in both the measuring stations except relatively higher values for Na⁺, Cl⁻ and SO₄²⁻ at

Fig. 3 Piper trilinear diagram (a Majdia; b Ranaghat) representing hydrochemical classification of the water samples of the Churni River c. Hydro-chemical zones -in zone 1, alkaline earth (Ca²⁺ + Mg²⁺) exceeds alkalis (Na⁺ + K⁺); in zone 2, alkalis exceed alkaline earth; in zone 3, alkalis exceed alkaline earth; in zone 4, strong acids exceed weak acid; in zone 5, carbonate hardness (secondary alkalinity) exceeds 50%; in zone 6, non-carbonate hardness (secondary alkalinity) exceeds 50%; in zone 7, non-carbonate alkali (primary salinity alkalinity) exceeds 50%; in zone 8, carbonate alkali (primary alkalinity) exceeds 50%; in zone 9, no cation-anion pair exceeds 50%

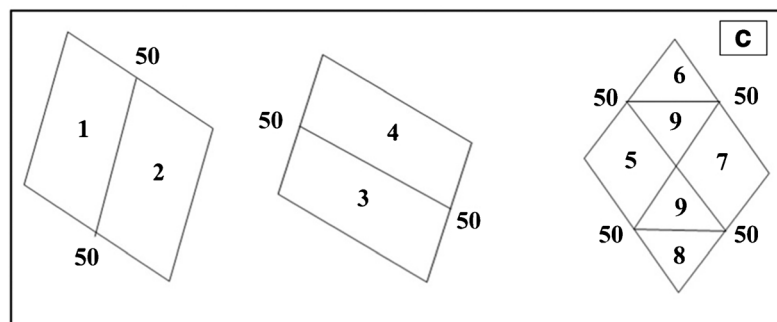
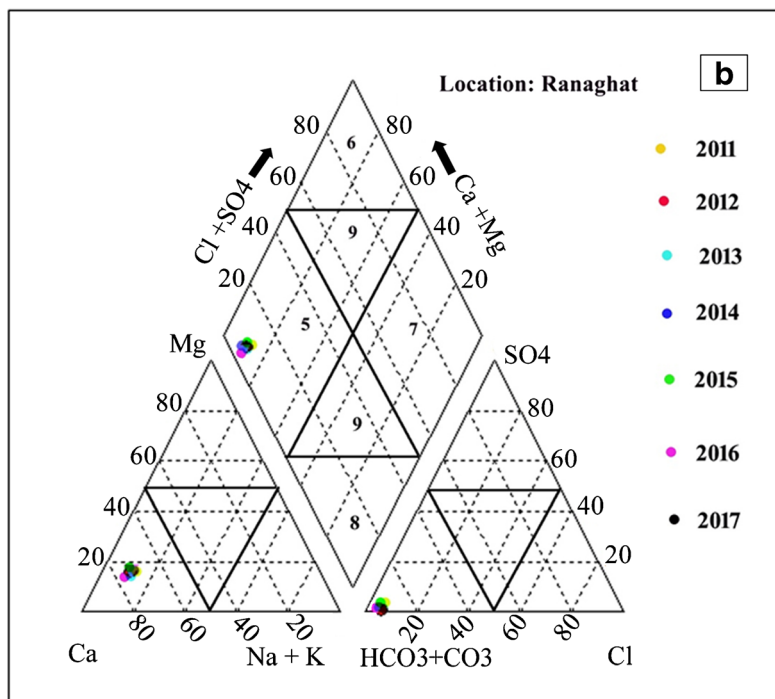
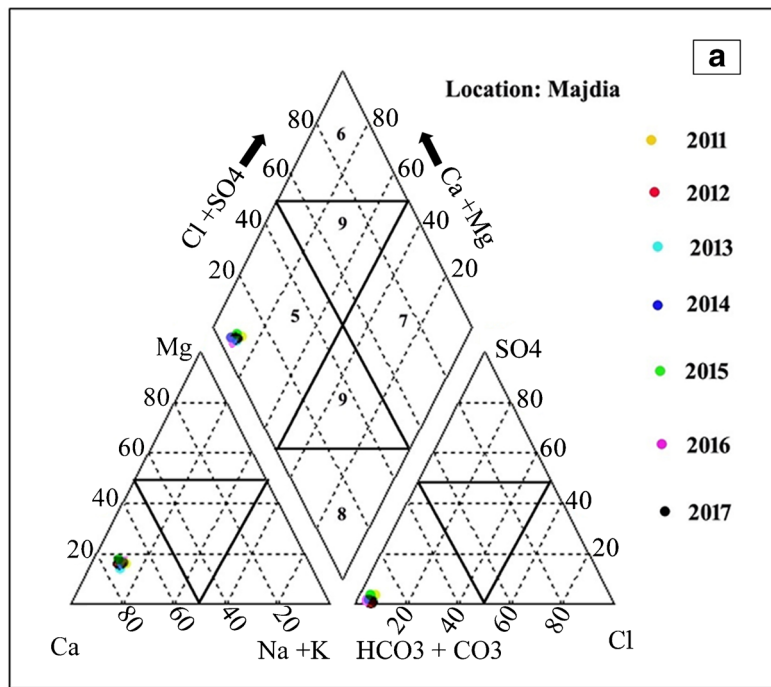


Table 4 Correlation matrix of the ions

	Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Carbonate	Chloride	Sulphate
Calcium	1							
Magnesium	.448** (.406**)	1						
Sodium	.607** (.544**)	.388** (.171)	1					
Potassium	.274* (.2)	.006 (-.166)	.5** (.645**)	1				
Bicarbonate	.943** (.842**)	.676** (.656**)	.601** (.294**)	.214 (-.112)	1			
Carbonate	.943** (.842**)	.676** (.656**)	.601** (.294**)	.214 (-.112)	1** (1**)	1		
Chloride	.267* (.542**)	.312** (.413**)	.354** (.453**)	.1 (.206)	.314** (.492**)	.314** (.492**)	1	
Sulphate	-.472** (-.128)	.0001 (.165)	-.322** (-.176)	-.365** (-.369**)	-.398** (.001)	-.398** (.001)	.042 (.026)	1

Computed by the authors, 2018 (figures within parenthesis indicate Ranaghat), $n = 83$

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed)

Ranaghat (Table 3). The similar results have been observed regarding other descriptive statistics—minimum, maximum and CV (Table 3). To comprehend the association between the anions and cations, a correlation matrix has been derived (Table 4) which depicts that calcium, magnesium, sodium, CO_3^{2-} , HCO_3^- and Cl^- are strongly correlated with the other ions and most correlation is significant at the 0.01 level (2-tailed) at both the stations. But, potassium and sulphate are poorly correlated with the other anions and cations. Except for some minor irregularity, the overall strong and significant relation between the ions may ensure the quality water for irrigation at both the stations. Besides, the ion balancing test also reveals that all the values of water samples are within 10% ion balance errors except the average value -16 found in 2011 at Ranaghat (Fig. 4). The average (based on mod values) and median of ion balance error during 2011–2017 are 2.5 and 1.8 at

Majdia and 4.1 and 1.8 at Ranaghat, respectively, which signify good ionic combination which also ensures the quality of water for irrigation.

Irrigation hazards

Sodicity hazard

The high concentration of sodium in water is not suitable for irrigation because it creates sodium hazard in soil destroying soil aggregates and decreasing soil permeability which jointly triggers hindrance for good agricultural production. Sodium hazard has been quantitatively analysed by SAR and % Na.

- SAR: Higher sodium absorption ratio in water badly affects the soil in such a way that sodium ion tends to be absorbed by clay particles, displacing Ca^{2+}

Fig. 4 Ion balance error (Majdia and Ranaghat)

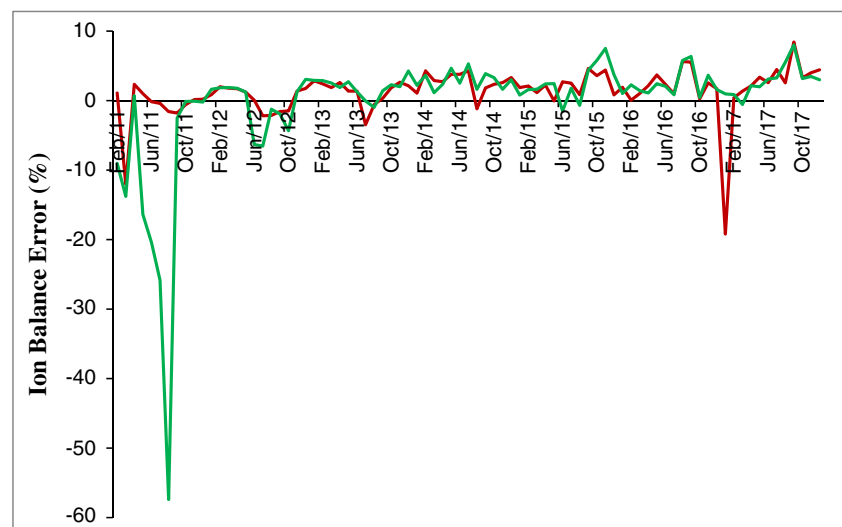
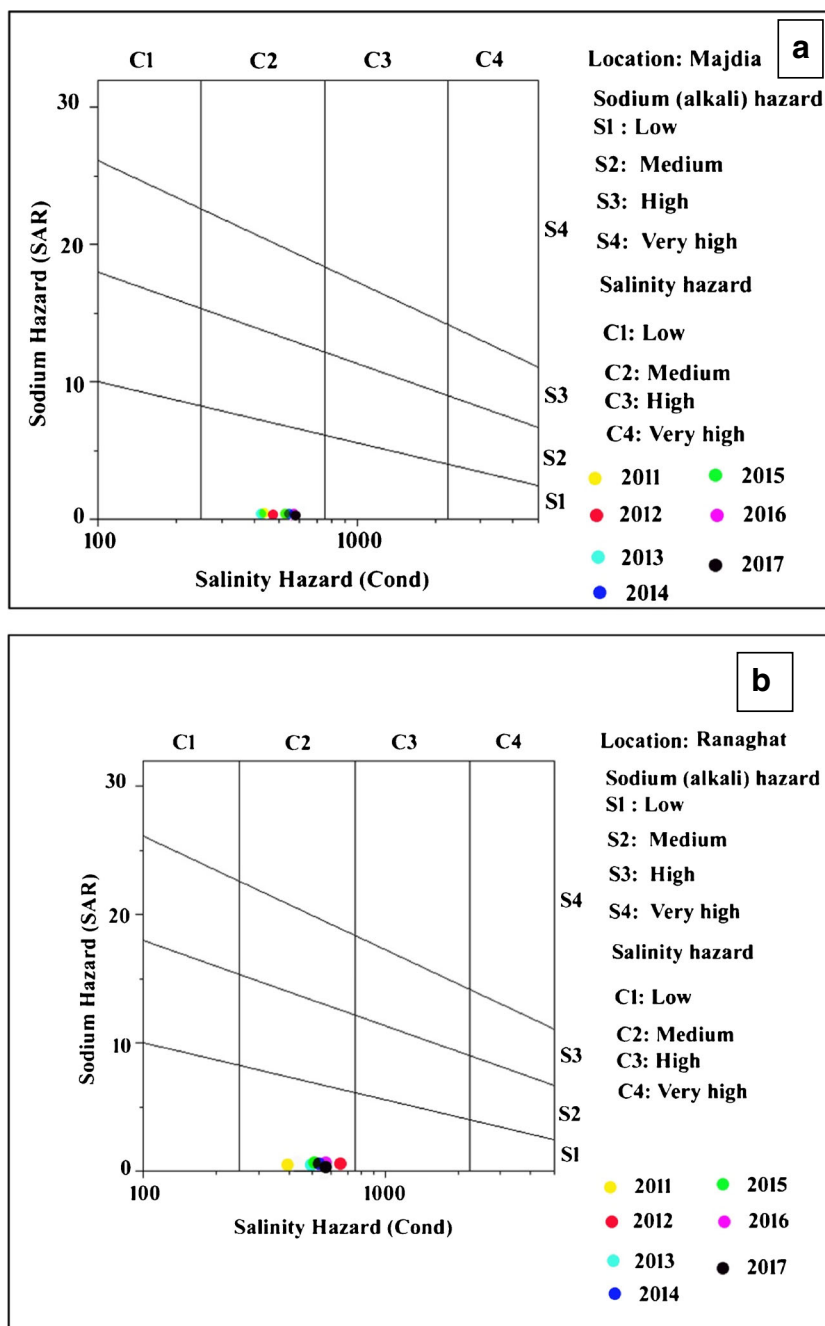


Fig. 5 USSSL classification of the collected water samples from the study area (a Majdia; b Ranaghat)



and Mg^{2+} , resulting in its low permeability and poor soil aeration and soil with poor drainage (Kelly 1951; Ishaku et al. 2011). For measuring the salinity and sodium hazard of irrigation water, Richards (1954) classified the concentration of soluble salt into four classes based on EC and concentration of SAR. Different classes of salinity hazard are low or C1 ($EC < 250 \mu S/cm$), medium or C2 ($EC 250-750 \mu S/cm$), high or C3 ($EC 750-2250 \mu S/cm$) and very high or C4 ($EC > 2250 \mu S/cm$). Similarly, classes of sodium hazard are low or S1

($SAR < 10$), medium or S2 ($SAR 10-18$), high or S3 ($SAR 18-26$) and very high ($SAR > 26$). After plotting all the values of SAR against EC in a U.S. Salinity Laboratory Staff (USSSL) diagram, it has been found that 100% of the samples fall in S1 and C2 classes, indicating that the water is free from sodium hazard but has medium salinity hazard (Fig. 5a, b). In Majdia, the value of EC ranges from 204 to 697 $\mu S/cm$ with the mean value of 517.89 $\mu S/cm$, and in Ranaghat, it ranges from 182 to 731 $\mu S/cm$ with the mean value of 516 $\mu S/cm$.

Fig. 6 Suitability of the Chumi River water for irrigation in the Wilcox diagram (a Majdia; b Ranaghat)

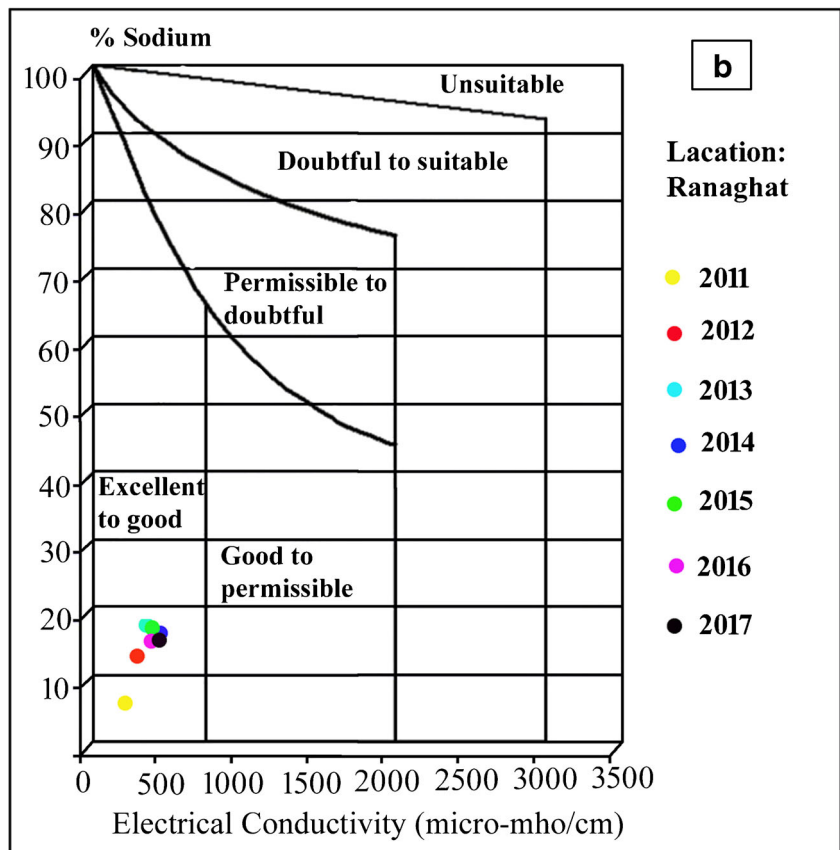
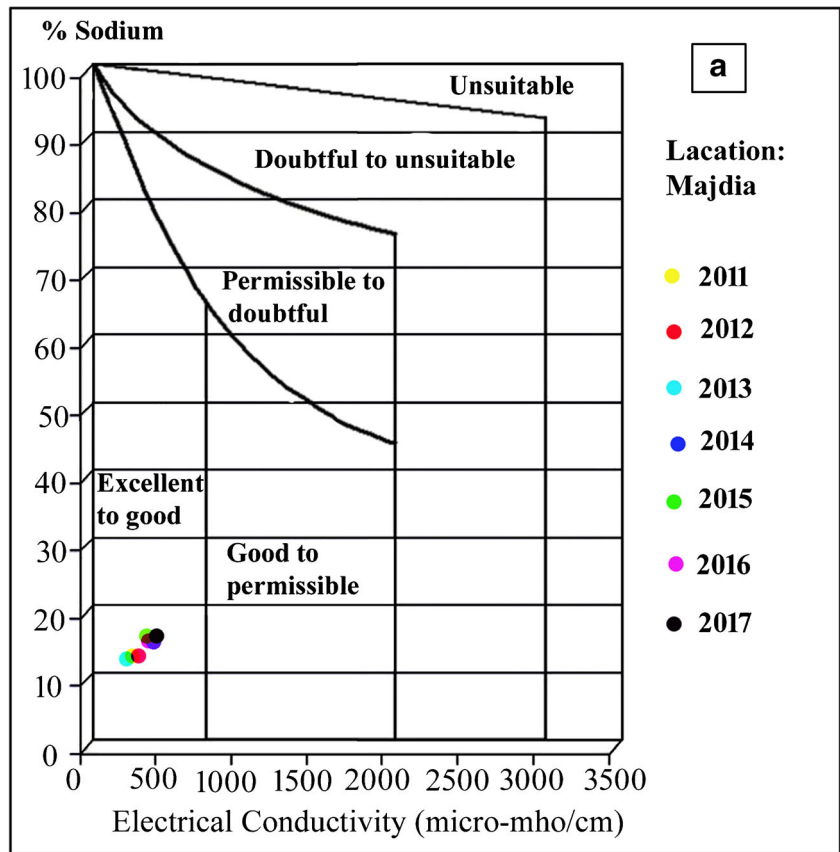


Table 5 Classification of water for irrigation use

Parameters	Range	Water class	Majdia			Ranaghat		
			Range	Mean	CV	Range	Mean	CV
% Na	< 20	Excellent	3–23	11	31	2–23	11	39
	20–40	Good						
	40–60	Permissible						
	60–80	Doubtful						
	> 80	Unsuitable						
SAR	< 10	Excellent	0.1–0.52	0.27	27	0.05–0.52	0.3	36
	10–18	Good						
	18–26	Doubtful						
	> 26	Unsuitable						
RSC	< 1.25	Good	2–10	5	35	2–13	5	41
	1.25–2.50	Doubtful						
	> 2.50	Unsuitable						
PI	< 80	Good	39–73	52	18	39–138	54	25
	80–100	Moderate						
	> 100	Unsuitable						

Computed by the authors, 2018

b. % Na: Percentage of sodium is commonly used for assessing the suitability of water for irrigation. When the concentration of sodium in irrigation water is high, sodium has a tendency to be absorbed by clay particles, displacing calcium and magnesium ions. This process reduces the soil permeability. The values of percent sodium are plotted against the values of electrical conductivity using the Wilcox diagram (Wilcox 1955) which categorises water for irrigation into five classes: excellent (< 20% Na), good (20–30% Na), permissible (40–60% Na), doubtful (60–80% Na) and unsuitable (> 80% Na). From the tested value of the water sample, both the stations come under excellent to good category (Figs. 3b and 6a).

Alkalinity hazard

The water with high residual sodium carbonate has high pH value and, when irrigated with such type of water, can cause infertile soil owing to the deposition of sodium carbonate. As per the USSSL classification, the value of residual sodium carbonate less than 1.25 signifies good quality of water, 1.25–2.50 signifies medium quality of water and more than 2.50 signifies bad quality of water for irrigation. Moreover, the constant use of water which contains the RSC value of more than 2.5 may hinder the movement of air and water in the soil by

clogging the soil pores. In Majdia, the value of RSC ranges from 4.5 in 2013 to 5.6 in 2011 with the mean value of 5, and in Ranaghat, it ranges from 4.5 to 7.5 with the mean value of 5.1 (Table 5). Based on the RSC classification, all the tested samples of Majdia and Ranaghat exceed the range of 2.5 which signifies that the water containing an excess amount of bicarbonate is not suitable for irrigation.

Permeability hazard

Doneen (1964) categorised the values of PI into three classes: values less than 80 (class 1) as good (75% permeability), from 80 to 100 (class 2) as moderate (25–75% permeability) and more than 100 (class 3) as poor (25% of maximum permeability) and as bad quality of water for irrigation. The result shows that at Majdia, the PI value ranges from 39 to 74 with an average value of 52 and, in Ranaghat, the PI value ranges from 40 to 139 with an average value of 55 (Fig. 7a, b; Table 5). Based on the PI values, all the tested samples of Majdia and Ranaghat fall in class 1 which signify that the water is suitable for irrigation.

Suitability of water for irrigation

To assess the suitability of water for irrigation, a compound-ranking method was applied. Ranks have been assigned to seven parameters based on their degree of suitability for irrigation (Table 6). Ranks 1, 2 and 3 represent good, permissible and unsuitable, respectively.

Fig. 7 Classification of the water samples in Doneen's permeability index (a Majdia; b Ranaghat)

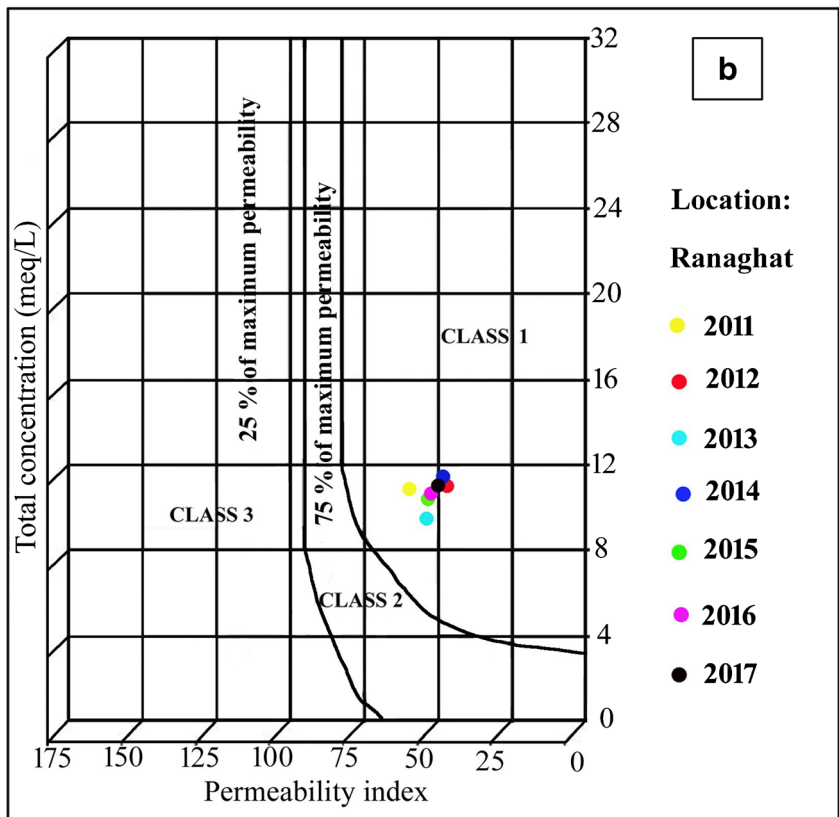
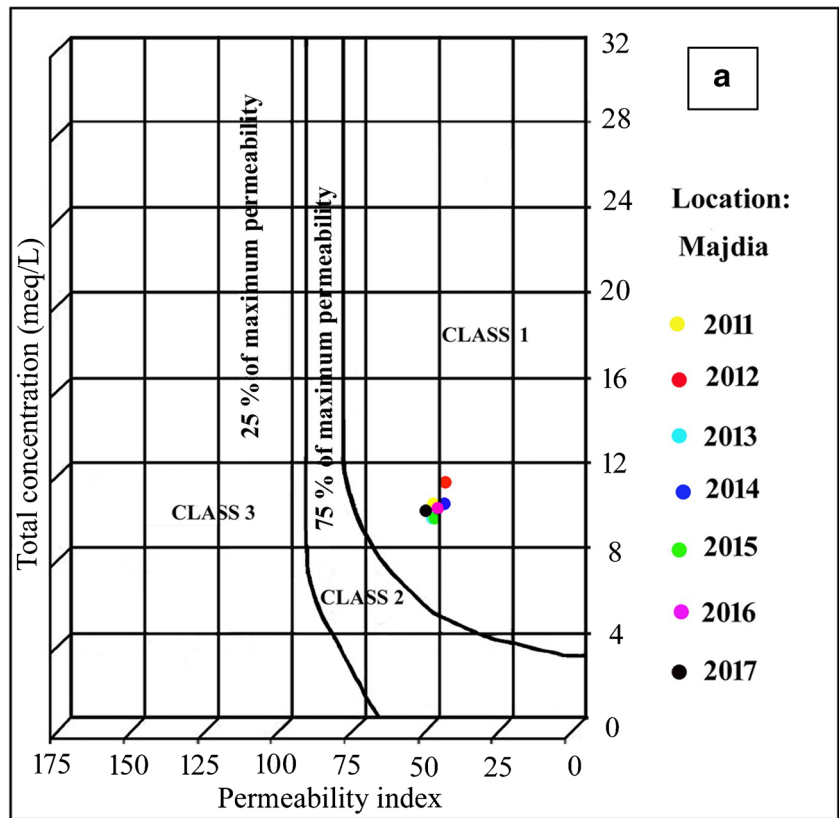


Table 6 Suitability of water based on the compound-ranking method

Suitability category	Rank score	EC ($\mu\text{S}/\text{cm}$)	TDS (mg/L)	Ion balance (%)	SAR	% Na	RSC	PI
Good	1	< 250	< 150	0–10	< 18	< 40	< 1.25	< 80
Permissible	2	250–750	150–500	10–20	18–26	40–80	1.25–2.50	80–100
Unsuitable	3	> 750	> 500	> 20	> 26	> 80	> 2.50	> 100

Based on Disli (2017)

The average composite rank scores for both Majdia and Ranaghat have been found to be 1.57 (Table 7), indicating good to the permissible category of water. But if a sophisticated look is embraced into absolute values of seven hazard parameters (Table 7), it is found that Majdia has registered a higher score regarding three parameters (EC, TDS and PI) showing that the lesser hazard score for Ranaghat makes this station more suitable for irrigation.

Upstream-downstream variation in irrigation water quality

To find out any statistically significant difference between two stations in terms of seven selected variables (EC, TDS, ion balance, SAR, % Na, RAC and PI), separate ANOVA for each variable has been run. The 'F critical' for 162 degrees of freedom at the 0.05 significance level is 3.89 while each computed F value remains well below that range except SAR (Table 8) which portrays that null hypothesis is accepted for every case except SAR. Similarly, the significance value, i.e. P value (Table 8) in case of every parameter except the SAR, exceeds 0.05, signifying that the null hypothesis is accepted. It proves that there is no significant difference between the upstream (Majdia) and downstream (Ranaghat) segments of the river in water quality for irrigation.

Discussions

The ANOVA findings indicate that there is upstream-downstream variation in water quality only in terms of SAR. And, the rest of the parameters have strongly nullified this trend. However, a slight difference though not statistically significant exists in overall water quality between the stations.

Therefore, this work intends to address these variations. First, the value of SAR is more for Ranaghat than Majdia because downstream of the Churni River is a two-way semi-tidal channel having a comparatively more concentration of soluble salts by the saline intrusion. And, it is established that the SAR is linearly correlated with the tidal water intrusion (Shammi et al. 2016). Thus, Ranaghat is revealing more salinity hazard than Majdia. Second, the slight difference vis-à-vis overall water pollution is due to the discharge of effluents from wastewater released by Carew and Company located at Darshana in Bangladesh while manufacturing sugar, wine and chemicals (Das and Chakrabarty 2007). Throughout the year, this company releases its stored wastewater into the river Mathabangha which ultimately finds its way into the river Churni, thereby increasing carbonate hardness and alkalinity. More particularly, the tests depict that in normal situation, the concentrations of carbonate hardness and alkalinity in the river are 321 mg/L and 216 mg/L, respectively, which, during the discharge of industrial effluents from Carew and Company, increase up to 324 mg/L for carbonate hardness and 328 mg/L for alkalinity. As the level of pollution decreases with increasing distance, the effect of wastewater of this industry is found to be minimum for Ranaghat located downstream. Moreover, another potential source of water pollution in the downstream segment is the urban effluents especially from the built-up area of Ranaghat municipality and the agricultural runoff from the on-bed and off-bed intensive agricultural practice. Ozaki et al. (2014) pointed out that the pollution of water is largely controlled by the balance between the volume of toxic effluents and the magnitude of dilution effects by the tidal action. Similarly, many scholastic works established that the overall quality of water is relatively poorer in low tidal stretches of the river and the better quality in high tidal one. However, few scholars strongly established that seawater intrusion is the principal factor for the stagnation of river water by lowering

Table 7 Ranking criteria for suitability assessment of water

Mentoring stations	EC ($\mu\text{S}/\text{cm}$)	TDS (mg/L)	Ion balance (%)	SAR	% Na	RSC	PI	Total score	Average composite score
Majdia	510.4 (2)	337 (2)	2.5* (1)	0.27 (1)	11 (1)	4.8 (3)	47 (1)	(11)	(1.57)
Ranaghat	510.1 (2)	329 (2)	4* (1)	0.3 (1)	13 (1)	5 (3)	45 (1)	(11)	(1.57)

Computed by the authors, 2018 (figures within parentheses indicate the rank score)

*Average of the mod values of the ions

Table 8 ANOVA of different physicochemical parameters

Physicochemical parameters	<i>F</i>	<i>P</i> value	<i>F</i> critical*	Remarks
EC	0.002	0.95	3.89	Null
TDS	0.09	0.75	3.89	Null
Ion balance	1.8	0.17	3.89	Null
SAR	6.38	0.01	3.89	Alternative
% Na	2.38	0.12	3.89	Null
RAC	0.06	0.79	3.89	Null
PI	1.59	0.2	3.89	Null

Computed by the authors, 2018

*For 162 degree of freedom at the 0.05 significance level

the discharge and scaling up the pollution loads at a significant rate (Hosoi et al. 1996; Akther and Ahmed 2019). The Churni River, although receiving little toxic loads from urban effluents because of the less spatial urbanisation (only one municipality, i.e. Ranaghat, having an area of about 8 km²), gets substantial agricultural runoff. However, the tidal flux from the Hooghly River into the downstream part of the Churni triggers a proactive dilution process especially during the high tide and thereby maintaining the overall water pollution lesser at the lower stretch of the river.

Conclusion

The present study reveals that all the samples fall under low sodium hazard (S1) and medium salinity hazard (C2) in the USSL diagram while all samples come under 'excellent to good category' for irrigation to sensitive crops on the Wilcox diagram. As per the RSC, water is not suitable for irrigation due to the high concentration of carbonate ions whereas Doneen's PI values indicate that the river water is free from permeability hazard. River Churni has been facing multiple pressures since long back, and now, the river has become a subject of an international issue as Dasrana sugar mill situated in Bangladesh (a neighbouring country of India) is releasing industrial wastewater into the Churni River. Besides, the lower reach of the river is receiving industrial effluents and urban sewage. Consequently, the water of the entire river has been affected by pollutants, leaving an unhealthy environment for aquatic lives and scaling down the level of well-being of the people depending upon the river. Though no serious issues have been faced using water for irrigation (good composite rank score of 1.57), the water may be harmful if the pollution level continues to be raised. Although there is very slight difference between the hazard scores for irrigation, the ANOVA reveals that there is no significant difference of the physicochemical parameters between the upper (Majdia) and the lower (Ranaghat) stretches of the river.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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