

Hydrochemical assessment of surface water and groundwater quality along Uyyakondan channel, south India

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Abstract Groundwater and surface water quality is an important factor that determines its usage for drinking and irrigational use. This study was carried out along a major irrigation water source—Uyyakondan channel in Tiruchirappalli, south India. Fourteen surface water samples along the channel and fifteen groundwater samples close to the surface water sampling locations were collected to determine its suitability for drinking and irrigational purposes. Electrical conductivity, pH and concentrations of calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride, sulphate, fluoride and nitrate were determined in the water samples. The chemical composition of the water samples were compared with the drinking water standards of World Health Organisation and Bureau of Indian Standards. Groundwater from this area was suitable for drinking based on magnesium, sulphate, bicarbonate, fluoride and nitrate, while the concentration of calcium, sodium, potassium and chloride exceeded the maximum permissible limits at few locations. Surface water was within the permissible limits for magnesium, potassium, bicarbonate, sulphate, fluoride and nitrate, while calcium, sodium and chloride exceeded the highest desirable limits. Sodium chloride was the dominant groundwater and surface water type. Irrigation water quality was assessed based on magnesium hazard, residual sodium carbonate, sodium percentage, sodium adsorption ratio, permeability index and salinity hazard. Water was suitable for irrigation based on

magnesium hazard and residual sodium carbonate. Most water samples were doubtful for irrigation use based on sodium percentage and good for irrigation depending on sodium adsorption ratio. Though 60 % of groundwater and 29 % of surface water samples were suitable for drinking based on water quality index, majority of the water samples were not suitable for irrigation. The water quality in this area needs to be monitored regularly and it is crucial to treat the water before consumption.

Keywords Water quality index · Drinking water · Irrigation water · Tiruchirappalli · India

Introduction

Development in various sectors such as agriculture and industry as well as urbanisation and increase in population have enhanced the overall water demand. In many countries, people depend on piped water supplied from reservoirs as well as private wells for their water needs. Quality of the water that is put into use is a critical component that is assessed by its physical, chemical and biological composition. This determines the use of available water for different activities. Permissible limits for various ions to be present in water for drinking use is given by World Health Organisation (WHO 1993), Bureau of Indian Standards (BIS 2012) etc. If chemical ions are present in excess of these limits, they might cause health problems when consumed. Many researches have reported the health impact due to undesirable water quality (Garg et al. 2009; Azizullah et al. 2011; Brindha et al. 2011; Mandour 2012; Dahunsi et al. 2014; Wongsasuluk et al. 2014). Similarly the desirability of water for irrigation use can be determined by sodium percent (Na %), magnesium hazard

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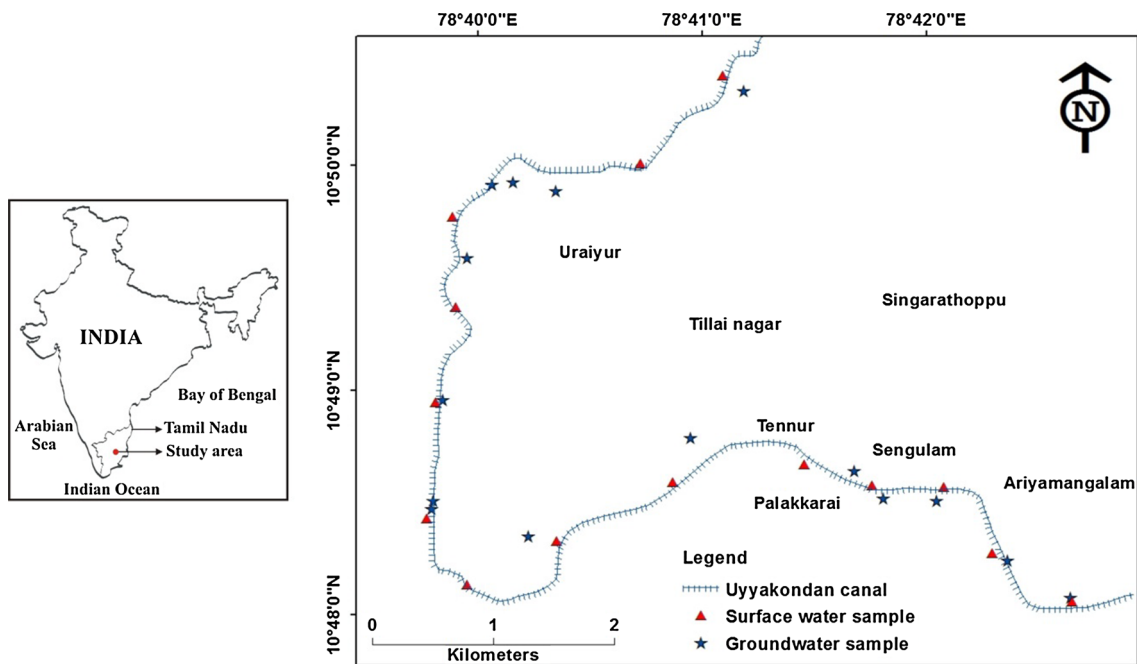


Fig. 1 Location of the study area and sampling locations

(MH), residual sodium carbonate (RSC), sodium adsorption ratio (SAR), permeability index (PI), salinity index etc. Water not complying with these parameters may affect the plant growth. These standards and classification indices have been used widely to ascertain the quality of water for irrigation in various parts of the world by several researchers (Offiong and Edet 1998; Korfali and Jurdi 2007; Mkandawire 2008; Cieszynska et al. 2012). Similar studies have also been carried out in India to determine the suitability of water for drinking and irrigational use (Arumugam and Elangovan 2009; Nagarajan et al. 2010; Brindha and Elango 2011; Jagadeshan and Elango 2012; Ramesh and Elango 2012; Kalpana and Elango 2013; Brindha et al. 2014).

Tiruchirappalli (also known as ‘Trichy’) is located centrally in the state of Tamil Nadu, south India. Uyyakondan, one of the main irrigation channels and a distributary of River Cauvery drains this area (Fig. 1). This channel is at threat due to urban pollution like the disposal of domestic sewage, hospital wastes etc. (Williams 2011; Jeena et al. 2012; Sirajudeen et al. 2013; Ganesan 2014), and the deterioration of water quality in the channel may also affect the groundwater quality. Though several studies have reported on the surface water and the groundwater quality along the River Cauvery (Suresh et al. 2010; Solaraj et al. 2010; Vetrinmurugan et al. 2013), very few studies are available on the quality of water in and around the Uyyakondan channel. Surface water quality analysis of this channel showed that it is much more polluted than its distributary i.e. River Cauvery which is mainly due to

domestic wastes (Jeena et al. 2012). Groundwater quality studied along the channel have shown that the water is not suitable for drinking in many places (Sirajudeen et al. 2013), and the pollution of groundwater is much pronounced in the urban areas than the rural areas (Jameel and Hussain 2011). Though these studies report on the pollution of the Uyyakondan channel and the groundwater in its vicinity, the suitability of groundwater as well as surface water for irrigation practices has not been assessed. It is important to study the suitability of the water in the channel as it is one of the main irrigation water sources and also as it may influence the groundwater quality. This study aims to determine the present status of groundwater and surface water quality along the Uyyakondan channel, Tiruchirappalli, India, and to assess its suitability for domestic and irrigation purposes.

Study area

Tiruchirappalli is the fourth most populated city in the state of Tamil Nadu, India. With a number of industries and agricultural activities, the demand for water is high. River Cauvery and its tributary Kollidam are the two main rivers that drain the city. Apart from this, three channels—Uyyakondan, Koraiyar and Kudamuritti also drain this area. Climate is sub-tropical with no major summer and winter seasons. Temperature ranges between 36 °C and 41 °C from March to May which is the hottest period of the year. Between December and February, the temperature

ranges from 19 to 22 °C (Tiruchirappalli City Municipal Corporation 2013). Average annual rainfall is about 840 mm (CGWB 2008) and most of the monsoon occurs between June and September. Topography is almost flat ranging from 70 to 78 m msl. Drainage pattern is mostly dendritic (CGWB 2008). Geology of this area mainly comprises of charnockites, granite gneisses, granites and alluvium (CGWB 2008). Irrigation sources mainly include the channel, dug wells and bore wells. Major crops include paddy, cereals, fruits and vegetables.

Methodology

Surface water samples were collected along the Uyyakondan channel in 14 locations and groundwater samples were collected adjacent to these locations in 15 locations during January 2014 (Fig. 1). Samples were collected in high density polyethylene bottles of 500 ml capacity. These bottles were pre-cleaned with 1:1 dilute hydrochloric acid and washed with distilled water. Prior to sample collection, the bottles were washed again twice with the sample to be collected. Tube wells were pumped for about 10 min before collecting the groundwater sample. Electrical conductivity (EC) and pH were measured using digital probes that were calibrated prior to the analysis. The bottles were labelled and brought to the laboratory for analysis. Concentration of calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride, sulphate, fluoride and nitrate were determined by standard procedures (APHA 1998). Calcium, magnesium, carbonate, bicarbonate and chloride were determined in the water samples by volumetric titration. Sodium and potassium were determined by flame photometry, while sulphate was analysed using spectrophotometer. Colorimetric analysis was used for determining the concentration of fluoride and

nitrate in the water samples. Ion balance error was calculated to check the accuracy of the analysis which was within ±5 %.

Results and discussion

Minimum, maximum and mean values of pH, EC and concentration of various ions present in groundwater and surface water is given in Table 1. Order of dominance of cations for groundwater and surface water was sodium > calcium > magnesium > potassium. For anions it was chloride > bicarbonate > sulphate > nitrate > fluoride for groundwater and chloride > sulphate > bicarbonate > nitrate > fluoride for surface water. Water type based on the hydrochemistry is often assessed using the trilinear diagram (Piper 1944). A modified form of this trilinear diagram was proposed by Chadha (1999). Eight water types that can be identified from the diagram depend on the relationship between alkaline earths (calcium and magnesium), alkali metals (sodium and potassium), weak acidic anions (carbonate and bicarbonate) and strong acidic anions (chloride and sulphate) which are explained in Chadha (1999). The groundwater and surface water samples of this area were plotted on the graph as cations versus anions expressed in milliequivalent percentage (Fig. 2). Sodium chloride was the dominant groundwater and surface water type in this area where the alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions.

Drinking water quality

Groundwater and surface water samples were compared with the WHO (1993) and BIS (2012) standards to determine its suitability for drinking.

Table 1 Statistical summary of hydrochemical parameters

Parameter	Groundwater			Surface water		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
pH	6.0	7.7	6.9	6.3	7.0	6.6
EC (µS/cm at 25 °C)	630.0	4500.0	1855.3	1200.0	1800.0	1500.0
Calcium (mg/l)	58.0	324.0	135.6	86.0	130.0	102.1
Magnesium (mg/l)	4.0	44.0	21.9	8.0	30.0	20.6
Sodium (mg/l)	180.0	1710.0	653.7	540.0	580.0	557.7
Potassium (mg/l)	2.0	36.0	12.5	6.0	12.0	9.7
Bicarbonate (mg/l)	72.0	324.0	147.6	72.0	126.0	95.6
Chloride (mg/l)	180.0	1260.0	471.9	306.0	504.0	383.3
Sulphate (mg/l)	4.0	342.0	119.1	54.0	144.0	115.3
Fluoride (mg/l)	0.2	0.7	0.5	0.3	0.7	0.5
Nitrate (mg/l)	1.8	13.5	8.7	7.2	9.8	8.3

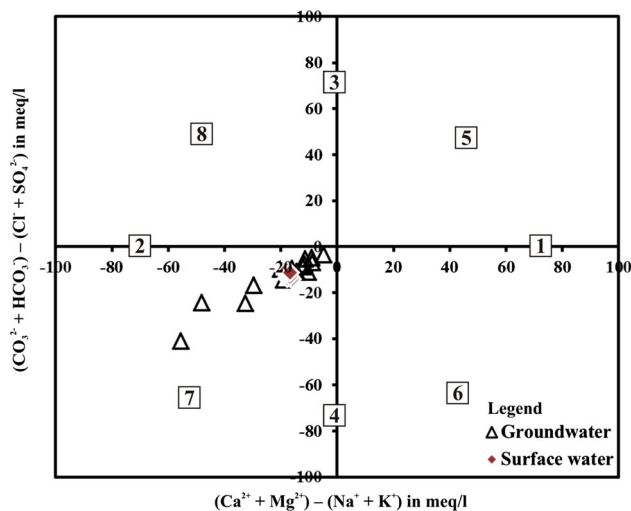


Fig. 2 Groundwater and surface water type

pH

Acidity or basicity of a solution is determined by its pH which for this area ranged from 6 to 7.7 for groundwater and from 6.3 to 7 for surface water (Table 1). The water in this area is slightly acidic to neutral. The desirable limit for pH in drinking water is 6.5 to 8.5 according to BIS (2012) and WHO (1993). None of the groundwater and surface water samples exceeded this limit but three samples of groundwater (20 %) and three samples of surface water (21 %) were below the desirable limit of 6.5 for pH. Acidic waters over a longer time tend to corrode metals used for plumbing of water supply system and increase the heavy metal content in water.

Electrical conductivity

Total ionised constituents of water denoted by EC greatly determine the quality of water for drinking. Groundwater had an average EC of 1855 $\mu\text{S}/\text{cm}$ and surface water had 1500 $\mu\text{S}/\text{cm}$. Water with EC less than 750 $\mu\text{S}/\text{cm}$ is desirable for drinking. Only one groundwater sample falls in this category, while none of the surface water samples were less than 750 $\mu\text{S}/\text{cm}$. EC less than 1500 $\mu\text{S}/\text{cm}$ is permissible for drinking. Six groundwater and eight surface water samples were within the permissible range of 750–1500 $\mu\text{S}/\text{cm}$ (Table 2). EC of the groundwater higher than 3000 $\mu\text{S}/\text{cm}$ was recorded in two locations which is similar to the high values of EC reported by Jameel and Hussain (2011). Higher EC of groundwater depends on the weathering of aquifer material and influence of anthropogenic activities polluting the ground surface. Surface water quality is mainly affected by human activities in this area which may also have an impact on groundwater.

Table 2 Classification of groundwater and surface water for drinking based on EC

EC ($\mu\text{S}/\text{cm}$ at 25 °C)	Classification	Percentage of samples	
		Groundwater	Surface water
<750	Desirable	1	Nil
750–1,500	Permissible	6	8
1,500–3,000	Not permissible	6	6
>3,000	Hazardous	2	Nil

Total dissolved solids

TDS was calculated from EC by the relationship (Lloyd and Heathcote 1985),

$$\text{TDS (mg/l)} = \text{EC } (\mu\text{S}/\text{cm}) \times 0.64 \quad (1)$$

TDS ranged from 378 to 2754 mg/l in groundwater with a mean of 1132 mg/l and from 768 to 1152 mg/l in surface water with a mean of 960 mg/l. Classification of groundwater and surface water based on TDS is given in Table 3. Most of the water was fresh i.e. 60 % of groundwater and 64 % of surface water, while the rest were brackish based on Freeze and Cherry (1979) classification. As per Davis and DeWiest (1966) classification, 60 % of groundwater and 64 % of surface water were permissible for drinking. But all samples were useful for irrigation as the TDS was less than 3000 mg/l (Table 3). High TDS may distort the taste of water and may cause gastrointestinal irritation in human beings (Howard and Bartram 2003).

Total hardness

TH depends on the calcium and magnesium content of water (Sawyer and McCarty 1978) and is calculated by

$$\text{TH (mg/l)} = 2.497\text{Ca}^{2+}(\text{mg/l}) + 4.115\text{Mg}^{2+}(\text{mg/l}) \quad (2)$$

Majority of the groundwater and surface waters in this area were very hard in nature (Table 4). Very hard waters may have adverse health effects like stone formation in kidney, calcification of arteries and other cardiovascular and stomach disorders. TH above 300 mg/l (BIS 2012) is not suitable for drinking and most samples were above this limit. These waters cause scaling in public water supply systems. It also requires more detergent for cleaning and causes yellowing of fabrics.

Cations

Highest desirable level of calcium in drinking water is 75 mg/l and maximum permissible limit is 200 mg/l (BIS

Table 3 Classification of groundwater based on TDS

TDS (mg/l)	Water type/classification	Percentage of samples		Reference
		Groundwater	Surface water	
<1,000	Fresh	9	9	Freeze and Cherry (1979)
1,000–10,000	Brackish	6	5	
10,000–100,000	Saline	Nil	Nil	
>1,00,000	Brine	Nil	Nil	Davis and DeWiest (1966)
<500	Desirable for drinking	1	Nil	
500–1,000	Permissible for drinking	8	9	
1,000–3,000	Useful for irrigation	6	5	
>3,000	Unfit for drinking and irrigation	Nil	Nil	

Table 4 Classification of groundwater based on TH

TH (mg/l)	Water type	Percentage of samples	
		Groundwater	Surface water
<75	Soft	Nil	Nil
75–150	Moderately high	Nil	Nil
150–300	Hard	5	1
>300	Very Hard	10	13

2012). The maximum permissible limit is considered usually in the absence of any other source of water for drinking. Average calcium concentration in groundwater was 136 mg/l and surface water was 102 mg/l. Two groundwater samples were less than the highest desirable limit and three samples were above maximum permissible limit. Calcium content in surface water ranged from 86 to 130 mg/l. Thus, all samples were between the highest desirable limit and the maximum permissible limit for calcium. Magnesium in groundwater and surface water was at a maximum of 44 and 30 mg/l, respectively. All the surface water samples were within the highest desirable limit of 30 mg/l prescribed by BIS (2012). Among the groundwater samples, four samples were greater than 30 mg/l for magnesium. But all groundwater samples were within 100 mg/l which is the maximum permissible limit for magnesium in drinking water according to BIS (2012). High concentration of calcium and magnesium may increase the hardness of water, the effects of which were explained earlier.

Sodium was the dominant cation in groundwater as well as surface water of this area and contributes to the general salt content of water. Concentration of sodium ranged from 180 to 1710 mg/l in groundwater and from 540 to 580 mg/l for surface water (Table 1). Maximum permissible limit for sodium in drinking water is 200 mg/l (WHO 1993). Fourteen groundwater and all surface water samples were exceeding this limit. Thus, the water in this area had high concentrations of sodium in groundwater and surface water which if consumed may have adverse health impacts.

Acute effects are nausea and vomiting, while chronic effects may cause cerebral and pulmonary oedema (Department of National Health and Welfare 1992; Elton et al. 1963). Dahl (1960) put forth the effects of high sodium intake as hypertension, heart and kidney problems. Potassium does not usually have an adverse effect on humans due to consumption. Average concentration of potassium was 13 mg/l in groundwater and 10 mg/l in surface water. Four groundwater samples were exceeding the limit of 12 mg/l prescribed by WHO (1993), while all the surface water samples were within the limit.

Anions

Bicarbonate levels were at a mean of 148 and 96 mg/l for groundwater and surface water, respectively. There exists no clear evidence for health effects due to the presence of bicarbonate. It is suggested that bicarbonate levels less than 200 mg/l is suitable for drinking purpose (Bhardwaj and Singh 2011). High chloride in water usually creates a salty taste and might have a laxative effect (Bhardwaj and Singh 2011). It is also usually associated with corrosion of metal pipes. Highest desirable limit for chloride in drinking water is 250 mg/l (BIS 2012) and maximum permissible limit is 1000 mg/l (BIS 2012). Only three groundwater samples were within the highest desirable limit and one sample was above the maximum permissible limit. All the surface water samples were below 1000 mg/l but none within the desirable limit. Maximum chloride in groundwater and surface water was 1260 and 504 mg/l, respectively. Sulphate concentration in groundwater varied from 4 to 342 mg/l with an average of 119 mg/l. One groundwater sample was above the highest desirable limit of 200 mg/l (BIS 2012), but within the maximum permissible limit of 400 mg/l (BIS 2012). Surface water was at a minimum of 54 mg/l and maximum of 144 mg/l with a mean of 115 mg/l. All surface water samples were within the highest desirable limit i.e. 200 mg/l. High concentration of sulphate may cause respiratory problems (Maiti 1982; Rao 1993) and may have laxative effect on humans.

Essentially fluoride between 0.6 and 1.5 mg/l (WHO 1993) is required for healthy teeth and bones. But intake of fluoride above 1.5 mg/l over prolonged time period may lead to dental and skeletal fluorosis. Though the water samples in this area did not exceed the highest desirable level for fluoride, more samples were below the required limit. A minimum fluoride concentration of 0.6 mg/l is required in drinking water for healthy bones and teeth. Twelve groundwater and eleven surface water samples had fluoride below the desirable limit of 0.6 mg/l. Nitrate was at a maximum of 13.5 mg/l in groundwater and 8.3 mg/l in surface water. Water is safe for drinking with respect to nitrate as the highest desirable limit is 45 mg/l (BIS 2012), and all samples are within this limit. Prolonged exposure to nitrate above 45 mg/l may lead to methemoglobinemia especially in infants.

Drinking water quality index

Water quality index (WQI) is widely used as a tool to determine the suitability of water (Horton 1965). As several parameters determine the water quality, it is difficult to determine the suitability of water by cumulative means. Hence, WQI is used which represents the water quality of a sample as a single value. This makes it easy to classify and know the suitability. Drinking WQI (DWQI) for groundwater was calculated based on pH, EC, calcium, magnesium, sodium, potassium, chloride, sulphate, fluoride and nitrate. Since TDS and TH were already represented by EC, calcium and magnesium from which these parameters were calculated, they were exempted from the DWQI calculation. DWQI was calculated by

$$DWQI = \sum (W_n \times Q_n) \quad (3)$$

W_n = unit weight of the nth parameter

Q_n = quality rating or sub index corresponding to the nth parameter

$$W_n = K/S_n \quad (4)$$

K = proportionality constant which is computed by

$$K = 1 / \sum_{i=1}^n \frac{1}{S_n} \quad (5)$$

$$\sum_{i=1}^n \frac{1}{S_n} = \frac{1}{S_{pH}} + \frac{1}{S_{EC}} + \frac{1}{S_{Ca}} \dots + \frac{1}{S_n} \quad (6)$$

S_n = Standard permissible limit in water for the nth parameter

$$Q_n = 100 \times [V_n - V_i] / [S_n - V_i] \quad (7)$$

where

V_n = measured value of the nth parameter in groundwater at a sampling location

V_i = ideal value of the nth parameter in water (0 for all parameters except for pH = 7).

Weight of each parameter arrived based on Eq. 4 is given in Table 5. DWQI for groundwater varied from 21 to 95 with an average of 54 and surface water varied from 34 to 69 with an average of 52. Classification of water type based on DWQI is given in Table 6. While most of the groundwater samples were good, three groundwater samples were very poor. Majority of the surface water samples were poor (Table 6) for drinking except for four samples of the total fourteen samples. Overall the groundwater of this area was good to moderate except for few locations, and surface water was mostly unsuitable for drinking purpose.

Irrigation water quality

The suitability of water for irrigation also depends on its chemical constituents. As this channel serves as one of the major source for irrigation, it was necessary to analyse its suitability for irrigation. Groundwater has also been used as a source for irrigation by pumping water from bore wells.

Table 5 Weight of each parameter and the highest desirable limit for drinking

Parameter	Unit	Highest desirable limit for drinking	Unit weight (W_n)	Reference
pH	No unit	8.5	0.091	BIS (2012)
EC	$\mu\text{S}/\text{cm}$	1500	0.001	–
Calcium	mg/l	75	0.010	BIS (2012)
Magnesium	mg/l	30	0.026	BIS (2012)
Sodium	mg/l	200	0.004	WHO (1993)
Potassium	mg/l	12	0.065	WHO (1993)
Chloride	mg/l	250	0.003	BIS (2012)
Sulphate	mg/l	150	0.005	BIS (2012)
Fluoride	mg/l	1	0.777	BIS (2012)
Nitrate	mg/l	45	0.017	BIS (2012)

Table 6 Classification based on WQI

WQI level	Water quality	DWQI (Number of samples)		IWQI (Number of samples)	
		Groundwater	Surface water	Groundwater	Surface water
0–25	Excellent	1	Nil	Nil	Nil
26–50	Good	8	4	Nil	Nil
51–75	Poor	3	10	1	Nil
76–100	Very poor	3	Nil	2	Nil
>100	Unsuitable	Nil	Nil	12	14

Table 7 Classification of water for irrigation

Index/classification	Range	Suitability for irrigation	Number of samples	
			Groundwater	Surface water
RSC (meq/l)	<1.25	Safe	15	14
	1.25–2.5	Moderate	Nil	Nil
	>2.5	Unsuitable	Nil	Nil
	<20	Excellent	Nil	Nil
Na %	20–40	Good	Nil	Nil
	40–60	Permissible	Nil	Nil
	60–80	Doubtful	14	12
	>80	Unsuitable	1	2
SAR	<10	Excellent	4	Nil
	10–18	Good	9	14
	18–26	Doubtful	2	Nil
	>26	Unsuitable	Nil	Nil
Salinity hazard (EC in $\mu\text{S}/\text{cm}$)	<250	C1- Excellent or low	Nil	Nil
	250–750	C2- Good or medium	1	Nil
	750–2250	C3- Permissible or high	10	14
	2250–5000	C4- Unsuitable or very high	4	Nil

MH, RSC, Na %, SAR, PI and salinity hazard were used in this study to assess the suitability of water for irrigation.

Magnesium hazard

MH was calculated based on the formula proposed by Szabolcs and Darab (1964) wherein all the concentrations are in meq/l.

$$\text{MH} = \text{Mg}^{2+} / (\text{Ca}^{2+} + \text{Mg}^{2+}) \times 100 \tag{8}$$

The safe limit for MH is 50 above which the water is not suitable for irrigation. All the groundwater and surface water samples were within the safe limit and do not pose threat due to magnesium.

Residual sodium carbonate

Presence of carbonates and bicarbonates in excess than calcium and magnesium is undesirable as they tend to form precipitates and increase soil salinity, thus decreasing its fertility. So, RSC considers the concentrations of calcium, magnesium, carbonate and bicarbonate of water. The

following formula was used to compute the RSC (Eaton 1950) of groundwater and surface water samples where ions are expressed in meq/l.

$$\text{RSC} = (\text{CO}_3^{2-} + \text{HCO}_3^-) - (\text{Ca}^{2+} + \text{Mg}^{2+}) \tag{9}$$

Classification of water based on RSC is given in Table 7. All the water samples were less than 1.25 meq/l which is the safe limit for irrigation.

Sodium percent

Sodium is considered as an important parameter in irrigation water as it decreases the soil fertility. High concentration of sodium has profound effect on plant growth. Na % was calculated by the formula (Wilcox 1955)

$$\text{Na \%} = \frac{(\text{Na}^+ + \text{K}^+) \times 100}{(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+)} \tag{10}$$

where all concentrations are expressed in meq/l. Most samples are doubtful due to the high concentration of sodium in water. Fourteen groundwater and twelve surface water samples has 60 % to 80 % sodium which is harmful

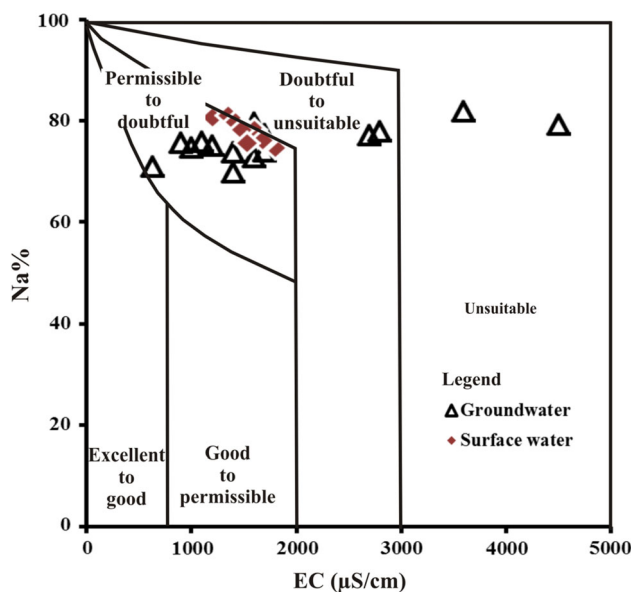


Fig. 3 Suitability of water for irrigation based on EC ($\mu\text{S}/\text{cm}$) and Na %

for the crops. Few samples were unsuitable. Na % plotted against EC to determine the suitability for irrigation is given in Fig. 3. Though few groundwater samples range from doubtful to unsuitable (Fig. 3), most groundwater and all surface water samples are in the permissible to doubtful range.

Sodium adsorption ratio

Sodic hazard of irrigation waters is often determined by SAR which is considered as an important parameter. SAR was given by Richards (1954) as

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}}} \quad (11)$$

where all the concentrations are in meq/l.

Most of the groundwater samples were good except for two samples which were doubtful and all the surface water samples were suitable for irrigation based on SAR (Table 7). Salinity and sodicity hazards can be determined together by the United States Salinity Laboratory (USSL) diagram (Richards 1954). Suitability of water for irrigation classified as four classes based on salinity (C1–C4) and four classes based on sodicity (S1 to S4) is shown in Fig. 4. All the surface water samples fall under C3S3 category. But groundwater samples fall under various categories: C2S1 (7 %); C2S2 (13 %); C3S2 (33 %); C3S3 (20 %) and C4S4 (27 %). Only three groundwater samples were desirable for irrigation, while the rest of the groundwater samples as well as all the surface water samples had high salinity and sodicity.

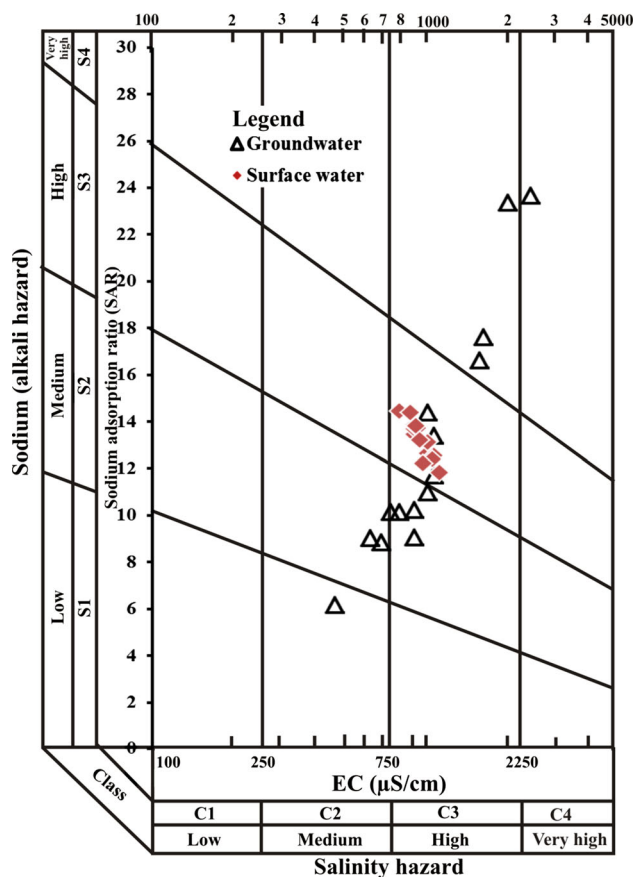


Fig. 4 Suitability of water for irrigation based on salinity and SAR

Permeability index

Sodium is an important chemical constituent in irrigation water that can cause permeability problems when in excess. If carbonates and bicarbonates are in high concentration, they form precipitates along with calcium and magnesium reducing the permeability. Hence, calcium, magnesium, sodium and bicarbonate ions are used to calculate the PI (Doneen 1964) which is given by

$$\text{PI} = \frac{(\text{Na}^+ + \sqrt{\text{HCO}_3^-})}{(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+)} \times 100 \quad (12)$$

where concentrations are in meq/l. According to the classification (Fig. 5), class I and class II water are suitable for irrigation and class III is unsuitable (Doneen 1964). Groundwater as well as surface water were suitable for irrigation based on PI as all samples were in class I.

Salinity hazard

EC which is a representation of the general concentration of soluble ions in water was classified based on the guideline proposed by USSL (Freeze and Cherry 1979).

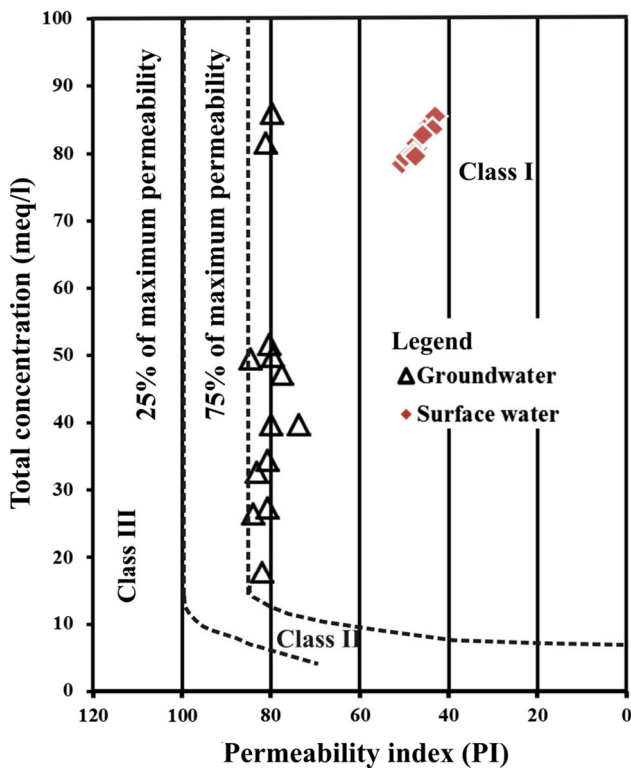


Fig. 5 Suitability of water for irrigation based on PI and total concentration of ions

Classification of water for irrigation suitability based on EC is shown in Table 7. C1 and C2 are considered very good for irrigation and C3 is permissible. Most of the groundwater samples were within C3 salinity class (Fig. 4), while four samples were unsuitable for irrigation. All the surface water samples were permissible to high based on EC.

Irrigation water quality index

Similar to the application of WQI for drinking purpose, it was applied to irrigation purpose. Irrigation water quality index (IWQI) based on the six indices: MH, RSC, Na %, SAR, PI and salinity hazard was calculated from Eqs. 2, 3. Ideal value of the nth parameter in water represented by ‘Vi’ in Eq. 7 was considered as ‘0’ for all indices. The weightage assigned to these indices are given in Table 8, and the classification of the groundwater and surface water samples based on IWQI is given in Table 6. IWQI for groundwater varied between 66 and 604 with a mean of 199 and the minimum, maximum and mean of IWQI for surface water were 140, 222 and 182, respectively. Twelve groundwater samples and all the surface water samples were not suitable for irrigation.

Overall water quality assessment in this area shows that the surface water is polluted in more locations compared to

Table 8 Weight of each parameter and the suitable limit for irrigation

Parameter	Unit	Suitable limit for irrigation	Unit weight (W _n)	Reference
MH	No unit	50.0	0.110	Szabolcs and Darab (1964)
RSC	meq/l	2.5	0.793	Eaton (1950)
Na %	%	60.0	0.040	Wilcox (1955)
SAR	No unit	18.0	0.033	Richard (1954)
EC	μS/cm	2250.0	0.023	Freeze and Cherry (1979)
PI	No unit	85.0	0.001	Doneen (1964)

groundwater (Table 6). The concentration of certain ions was higher in groundwater than in surface water, reasons for which may be more complex than what is discussed in the paper. A more detailed geochemical assessment of the processes that control the groundwater chemistry of this area and a regular spatio-temporal analysis will help to identify the reasons for the presence and variation of various ions in water. It is suggested from this study that the water should be treated before drinking and proper irrigation management practices are required to preserve the soil fertility.

Conclusion

Groundwater and surface water quality was assessed along the Uyyakondan channel in Tiruchirappalli, Tamil Nadu, India, which is one of the major irrigation channels in this region. Major groundwater and surface water type in this area was sodium chloride. 46 % of groundwater and 57 % of surface water had EC less than 1500 μS/cm which is the permissible level for drinking. Most of the water was fresh to brackish based on TDS and very hard based on TH. Magnesium, sulphate, bicarbonate, fluoride and nitrate concentrations in groundwater and surface water were within the prescribed limits for drinking. Calcium, sodium, potassium and chloride exceeded the maximum permissible limits at few locations for groundwater and in surface water, calcium, sodium and chloride exceeded the highest desirable limits. DWQI indicates that mostly groundwater is from good to poor, while most of the surface water is poor for drinking purpose. Suitability of water for irrigation showed that groundwater and surface water are safe for irrigation based on MH and RSC, but few groundwater samples were doubtful depending on SAR. Salinity hazard showed that most of the water was permissible to doubtful for irrigation and sodium was identified as the major ion that hinders the water quality for irrigation in this region.

IWQI indicate that most of the water is unsuitable for irrigation. It is suggested from this study that it is essential to treat the water before using for drinking purpose. Continuous monitoring of groundwater and surface water is also required to preserve this resource from further pollution.

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