Archives of Agriculture and Environmental Science 5(4): 554-562 (2020)
https://doi.org/10.26832/24566632.2020.0504019

e-ISSN: 2456-6632

This content is available online at AESA

Archives of Agriculture and Environmental Science

Journal homepage: journals.aesacademy.org/index.php/aaes

ORIGINAL RESEARCH ARTICLE

Suitability of groundwater quality for irrigation in and around the main Gadilam river basin on the east coast of southern India

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ARTICLE HISTORY

Received: 14 September 2020
Revised received: 18 December 2020
Accepted: 21 December 2020

Keywords

Groundwater
Irrigation water quality
Main Gadilam River basin
South India

ABSTRACT

The main intent of this study was to investigate the condition of groundwater quality for irrigation purposes in and around the main Gadilam river basin, the east coast of southern India. A total of fifty groundwater samples were collected and analyzed for various parameters such as electrical conductivity (EC), pH, TDS, major cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) and anions (SO_4^{2-}, Cl^-, HCO_3^-, and NO_3^-). Irrigation water quality parameters like the sodium absorption ratio (SAR), residual sodium carbonate (RSC), percentage sodium (%Na), magnesium hazard (MH), permeability index (PI), and Kelly ratio (KR) were computed to assess the irrigation water quality of groundwater. Furthermore, graphical representation diagrams such as USSL, Wilcox, and Doneen have been prepared for irrigation water quality. From the computation of SAR, Na%, RSC, PI, and KR values, it was found that 100% of groundwater samples were found to be suitable for irrigation purposes. Besides, USSL and Doneen diagrams show that the samples are safe for irrigation usage. The Wilcox diagram in the classification of electrical conductivity reveals that most samples fall into the good to permissible class (78%), in doubtful to unsuitable class (20%), and 2% of samples are unsuitable. Magnesium hazards of 82% of the groundwater samples are suitable for irrigation, while the remaining 18% of the samples exceeded the limit and found to be unsuitable for irrigation purposes. The study concludes that higher percentages of groundwater samples were suitable for irrigation purposes in the study area, and the concentration of magnesium influenced groundwater at a few locations.

Citation of this article: Ravi, R., Aravindan S., Shankar, K. and Balamurugan, P. (2020). Suitability of groundwater quality for irrigation in and around the main Gadilam river basin on the east coast of southern India. *Archives of Agriculture and Environmental Science*, 5(4): 554-562, https://dx.doi.org/10.26832/24566632.2020.0504019

INTRODUCTION

Water is crucial to life in the world, and knowledge of hydrochemistry is essential in evaluating the quality of water to understand its appropriateness for a variety of requirements. Groundwater is the most valuable natural resource for human health, ecosystems, and socio-economic growth (Umamageswari *et al.*, 2019). The existence of groundwater is beneficial for a variety of uses (Balamurugan *et al.*, 2020c). Agricultural production could be a key source of economic value, as well as a backbone of the Indian economy. Approximately 70% of India's population is engaged in agricultural activities, either explicitly or implicitly, to provide sustenance (Rawat *et al.*, 2018). It is everyone's responsibility to protect and increase agricultural production to sustain the country's rapidly growing population. Farmers are prone to water pollution, especially in developing countries where rapid industrialization is taking place. Historically, because of its accessibility and cost-effectiveness, farmers rely on surface water irrigation, which is likely to deteriorate due to industrial discharge, resulting in declining crop production and increased food insecurity. This puts enormous pressure on policymakers who intend to promote a sound strategy for sustainable resource development.

Groundwater suitability for irrigation purposes is based on the evaluation of the geochemical aspects of groundwater as each groundwater system has a diverse chemical composition, and its change is premised on several parameters such as temperature, mineral dissolution, rock-water interaction, soil-water interaction, time-interaction, and anthropogenic factors (Shankar *et al.*, 2010). The quality of irrigation water is defined as total dissolved solids, major cations, and anions. In general, these cations and anions include Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, and HCO_3^{-}. The suitability of water for irrigation is being determined in several ways, including the degree of acidity or alkalinity (pH), Electrical Conductivity, Residual Sodium Carbonate (RSC), Sodium Adsorption Ratio (SAR), and Permeability index (PI). The surplus of these ions causes salinity issues, sodicity, and permeability in the soil root system and inhibits plant growth and yield. The quality of water for agriculture refers to the quantity and class of salts present. It is mainly used for irrigation and domestic activities in arid and semi-arid regions where surface water is scarce (Venkateswaran *et al.*, 2012). Besides, nearly 1.5 billion people worldwide depend on groundwater for residential and irrigation purposes (Bian *et al.*, 2018). India is one of the largest countries in the world to extract maximum groundwater for agricultural (89 %), domestic (9 %), and industrial (2 %) purposes (Margat and Van Der Gun, 2013). In the past two decades, inadequate rainfall, climatic changes, global warming, and contamination of surface water sources due to waste disposal from industries are the major reason for the deterioration of groundwater quality in the arid and semi-arid region of India and all over the world (Solangi *et al.*, 2019). Since the 20th century, groundwater availability has decreased in terms of quality and quantity as a result of industrial and population growth, agricultural development, inadequate sanitation, highly increasing urbanization, and anthropogenic activities (Javed and Ullah, 2017; Palanisamy *et al.*, 2020; Aravinthasamy *et al.*, 2020).

Agriculture is a major income source for the rural-based people on the east coast of South India (Shankar *et al.*, 2011, 2011c). Highly contaminated groundwater utilized for irrigation uses causes severe effects on soil structure and crop yield (Adimalla, 2019). The use of polluted water affects the permeability problem, high salinity, and reduces the naturally available minerals in soil (Ravindra *et al.*, 2019). Several research studies on the assessment of groundwater suitability for domestic and agricultural purposes have been conducted in different parts of the world (Aravindan *et al.*, 2008; 2010; 2011; Aravindan and Shankar, 2011; Shankar *et al.*, 2011a, 2011b; Amiri *et al.*, 2015; Wagh *et al.*, 2018; Ahada and Suthar, 2018; Kavitha *et al.*, 2019a, 2019b; Marghade *et al.*, 2019; Balamurugan *et al.*, 2020a, 2020b; Soujanya *et al.*, 2020). However, concerns about groundwater quality are becoming more challenging with regard to the Gadilam river basin, which has an impact of molasses and Khansari disposal by the Nellikuppam sugar mill, which is part of the study area and whose impact on the major ion is dealt with in this research. Current research has become inevitable in addressing its suitability for irrigation purposes in this rural agrarian geo-environment of the basin.

The main problems of water quality associated with agriculture worldwide are salinization, nitrogen degradation, and fertilizer pollution. Irrigation water quality refers to the types and quantities of salts present in water and their influences on crop yields. Groundwater in the basin was primarily due to over-exploitation, lack of precipitation and environmental destruction, remediation of scarcity, and groundwater deterioration. It might pose significant threats to human beings, domestic animals, and agricultural production. Appropriate appraisal of the quality of groundwater is beneficial in order to enhance agricultural and domestic planning. Consequently, the objective of the present investigation must be to identify the quality of groundwater for irrigation purposes in and around the main Gadilam river basin on the east coast of southern India, using different irrigation water quality parameters.

MATERIALS AND METHODS

Description of study area

The study area under investigation is located in and around the main Gadilam river basin on the east coast of southern India, lies between 11°37'43"N and 11°49'47"N and 79°20'45"E and 79° 47'23"E, situated in the middle of Villupuram and Cuddalore district of Tamil Nadu with an area of 663.65 km^2 of this basin (Figure 1).

The southern and northern boundary of the basin is the rivers Vellar and Ponnaiyar, and the Bay of Bengal in the east. The topography of the basin is flat and slopes towards the south to east. The average annual rainfall in the basin is about 1,635 mm. The mean temperature of the area is approximately 28.6°C. The overall climate of the area is warm and dry. Agriculture is the people's primary occupation, with 45 percent of the population engaged in it. Paddy is the main crop cultivated in the area. The subsurface water supply of this basin is mainly used for agricultural purposes, as most people in this study area depend on agricultural income.

Collection of samples and analysis

The groundwater samples were collected from 50 bore wells during the pre-monsoon (PRM) season (June 2018), which are used for domestic and agricultural purposes. The data collection process involved using GPS to collect location and elevation data. Standard pretreatment procedures (APHA, 2012) for sampling and analysis were followed. Before sampling, the wells were pumped for 5–10 minutes to reduce the pipe water stored in the well and ensure sampling of the primary groundwater. Samples were collected in 500 ml high-density linear polyethylene bottles rinsed with 10% HNO_3 acid solution followed by distilled water 2-3 times to prevent contamination. The collected water sample bottles were then sealed and numbered and brought to the laboratory for analysis and adequately stored at 4°C prior to analysis. Measurements for pH, EC, and

TDS were determined in the field using a handheld Multi-Parameter (PCS-Test 35) while concentrations of chemical components such as major cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) and anions (SO_4^{2-}, Cl^{-}, HCO_3^{-}, and NO_3^{-}) analyzed in groundwater samples were determined in the laboratory. Analysis of major cations, Ca^{2+} and Mg^{2+}, were conducted by titrimetric method, Na^{+} and K^{+} by flame photometer CL-378 (Elico Ltd), major anions SO_4^{2-}, and NO_3^{-} by spectrophotometer SL-27 (Elico Ltd and Cl^{-} and HCO_3^{-} by titrimetric method. Samples were analyzed in duplicate for quality assurance and quality control (QA/QC). The accuracy of the analytical results checked with Ionic Balance Error (IBE%) was calculated using Equation 1 using all major ion data measured in milliequivalents per liter (meq/L). The IBE values were recorded within the acceptance limit of ±5%.

$$\mathrm{IBE}(\%) = \frac{\sum Cations - \sum Anions}{\sum Cations + \sum Anions} \times 100 \quad (1)$$

Irrigation water quality parameters

In order to evaluate the irrigation aptness of groundwater for irrigation purposes, the sodium absorption ratio (SAR), residual sodium carbonate (RSC), percentage sodium (%Na), magnesium hazard (MH), permeability index (PI), and Kelly ratio (KR) were calculated using the following equations (Eqs. 2-7).

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

$$\mathrm{RSC} = (HCO_3^{-} + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \quad (3)$$

$$\%\mathrm{Na} = \frac{(Na^{+} + K^{+}) \times 100}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \quad (4)$$

$$\mathrm{MH} = \frac{Mg^{2+} \times 100}{Ca^{2+} + Mg^{2+}} \quad (5)$$

$$\mathrm{PI} = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Ca^{2+} + Mg^{2+} + Na^{+}} \quad (6)$$

$$\mathrm{KR} = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \quad (7)$$

Statistical analysis

Microsoft Excel 2010 was used for statistical analysis of analytical data obtained after laboratory analysis. Major ions and irrigation parameters ranges, mean, and standard deviations were computed by utilizing excel.

RESULTS AND DISCUSSION

Hydro geochemistry of the river basin

The descriptive statistical summary of the different physico-chemical parameters in groundwater, as well as the limits of drinking water standards BIS (2012) and WHO (2011), are presented in Table 1. The pH values ranged from 6.9 to 9.09, with an average value of 7.66, indicating slightly acidic to nearly alkaline groundwater in the basin. The Electrical conductivity (EC) ranges from 973 to 3403 μS/cm with a mean of 1721.5 μS/cm. The TDS values in groundwater varied from 681 to 2392 mg/L, with an average of 1205.25 mg/L indicated that slightly brackish water. Ca^{2+} and Mg^{2+} ranges from 54.11 to 296.96 and 9.2 to 87.44 mg/L, with average values of 110.72 and 38.83mg/L, respectively. Na^{+} and K^{+} ranges from 11.46 to 165.87 mg/L and 6.36 to 35.84 mg/L, with mean values of 67.14 and 11.42 mg/L, respectively. HCO_3^{-} concentration ranges between 68.24 and 455.37 mg/L with an average of 240.13 mg/L. The minimum and maximum of SO_4^{2-} concentration is 0.42 and 97.69 mg/L with an average value of 13.26 mg/L. Cl^{-} concentration varies from 130.44 to 682.43 mg/L with a mean of 276.8 mg/L. The NO_3^{-} content in groundwater of the study area ranges from 9.96 to 93.51 mg/L with an average of 34.79 mg/L.

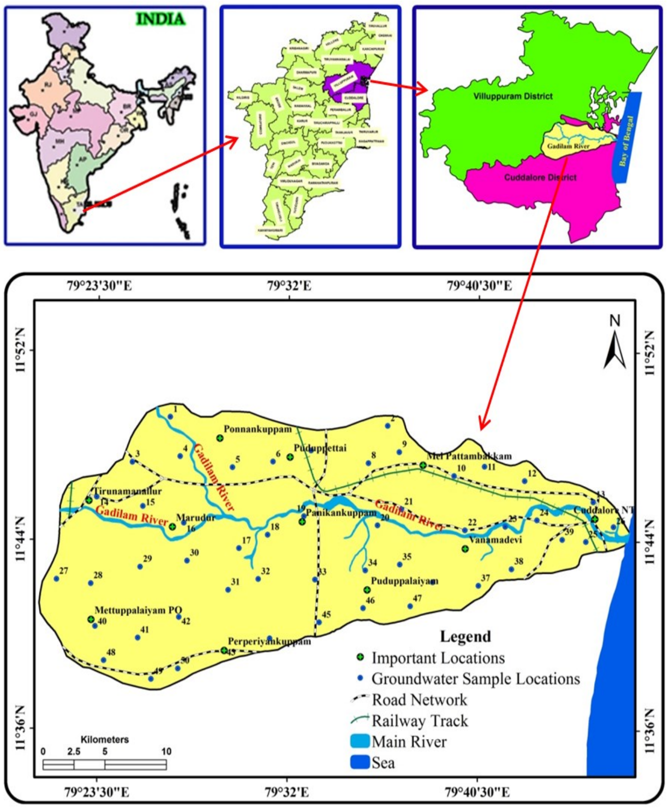

Figure 1. *Location and samples sites in the Gadilam River basin.*

Appraisal of groundwater quality appropriateness for agricultural practices

Groundwater is a major source of irrigation for agricultural activities in the basin during the dry period, with a limited supply of surface water. Agriculture requires good water quality for the production of high-quality crops, which can be supplied from groundwater. Different irrigation water quality parameters such as SAR, %Na, RSC, PI, and KR were calculated, and graphic representation models such as Wilcox, Doneen, and USSL have also been prepared. The groundwater samples are categorized according to its irrigation usage and the statistical summary of the results is presented in Table 2.

Table 1. Statistical summary of the physicochemical parameters in groundwater.

Parameter	Minimum	Maximum	Mean	Standard Deviation	BIS, 2012	WHO, 2011		% samples > exceed limit (%)
						Most desirable	Not permissible	
pH	6.9	9.09	7.66	0.51	6.5-8.5	6.5 to 8.5	<6.5 and >8.5	8
EC (µS/cm)	973	3403	1721.5	574.43	-	<1500	>1500	60
TDS (mg/L)	681	2392	1205.25	402.70	500	<500	>1500	16
Ca^{2+} (mg/L)	54.11	296.96	110.72	43.04	75	<75	>200	2
Mg^{2+} (mg/L)	9.2	87.44	38.83	17.33	30	<50	>150	24
Na^{+} (mg/L)	11.46	165.87	67.14	35.75	200	<200	>200	0
K^{+} (mg/L)	6.36	35.84	11.42	4.71	12	<10	>10	60
Cl^{-} (mg/L)	130.44	682.43	276.8	126.32	250	<200	>600	2
SO_4^{2-} (mg/L)	0.42	97.69	13.26	18.88	250	<400	>400	0
HCO_3^{2-} (mg/L)	68.24	455.37	240.13	80.26	-	<300	>600	18
NO_3^{-} (mg/L)	9.96	93.51	34.79	20.59	45	<45	>45	26

Table 2. Statistical summary and classification of computed groundwater quality parameters for irrigation purposes.

Irrigation indices parameters	Minimum	Maximum	Average	Range	Water class	Pre-monsoon	
						No. of samples	% of samples
EC (µS/cm)	973	3403	1721.5	<250	Low saline	0	0
				250-750	Medium saline	0	0
				750-2250	High saline	44	88
				>2250	Very high saline	6	12
TDS (mg/L)	681	2392	1205.25	< 450	Excellent	0	0
				450 – 750	Good	17	34
				750 – 2000	Permissible	33	66
				> 2000	Unsuitable	0	0
SAR (Richards, 1954) (meq/L)	0.26	2.98	1.39	0-10	Excellent	50	100
				10-18	Good	0	0
				18-26	Doubtful	0	0
				>26	Unfit	0	0
Na (%) (Wilcox, 1955)	8.57	48.94	26.21	<20	Excellent	11	22
				20-40	Good	35	70
				40-60	Moderate	4	8
				60-80	Doubtful	0	0
				>80	Unfit	0	0
RSC (Richards, 1954) (meq/L)	-11.61	-0.66	-4.86	<1.25	Good	50	100
				1.25-2.5	Doubtful	0	0
				>2.5	Unfit	0	0
MH (meq/L)	13.05	53.05	36.68	<50	Suitable	41	82
				>50	Unsuitable	9	18
PI (Doneen, 1964) (%)	23.69	68.33	41.85	>75	Class-I	0	0
				25-75	Class-II	49	98
				<25	Class-III	1	2
KR (Kelly, 1963) (meq/L)	0.07	0.90	0.34	<1	Suitable	50	100
				>1	Unsuitable	0	0

Electrical conductivity (EC) and total dissolved solids (TDS)

Electrical conductivity (EC) is an utmost main parameter to assess groundwater aptness for both ingestion and irrigation practices (Panneerselvam *et al.*, 2020a). EC is a good measurement of salinity hazard to crops when using groundwater for irrigation. EC is one of the parameters that decide the aptness of water for irrigational purposes as it determines the presence of salt content in water (Ayers and Westcott, 1985; Todd, 1959). In addition, Handa (1969) classification was performed in the basin and revealed that 88% of the sample's locations were high salinity, 12% of the samples were very high salinity (Table 2). About 6 sample locations are highly affected due to the action of anthropogenic and geochemical processes predominant for the excess concentration of EC in the basin. The total dissolved solids (TDS) also categorize the irrigational water as no saline (< 450 mg/L) is preferred for irrigation, slight to moderate saline (450–2000 mg/L), and severe saline (> 2000 mg/l) is unsuitable for agricultural purposes (FAO, 2006). Based on TDS values, about 94% of these groundwater samples are in the "slight to moderate" category, and 6% of the samples represent the "severe saline" category for irrigation purposes (Table 2).

Sodium absorption ratio (SAR)

SAR is used to measure the alkali/sodium level to determine the harmful level of crops (Wagh *et al.*, 2016). Na^{+} replaces the exchangeable Ca^{2+} and Mg^{2+} ions; the high Na^{+} content of irrigation water changes the soil characteristics and reduces the crop yield (Esmeray *et al.*, 2020). The computed SAR values of the study area range between 0.26 and 2.98 meq/l with an average value of 1.39 meq/l (Table 2). According to Richards, 1954 classification, the value of SAR is less than 10 is excellent, 10 to 18 is good, 18 to 26 is doubtful, and greater than 26 is unsuitable for irrigation uses. Based on the classification, all groundwater samples are excellent for irrigation purposes in the basin (Figure 2a). Besides, the US salinity laboratory diagram helps identify the salinity influence of groundwater in the agriculture field.

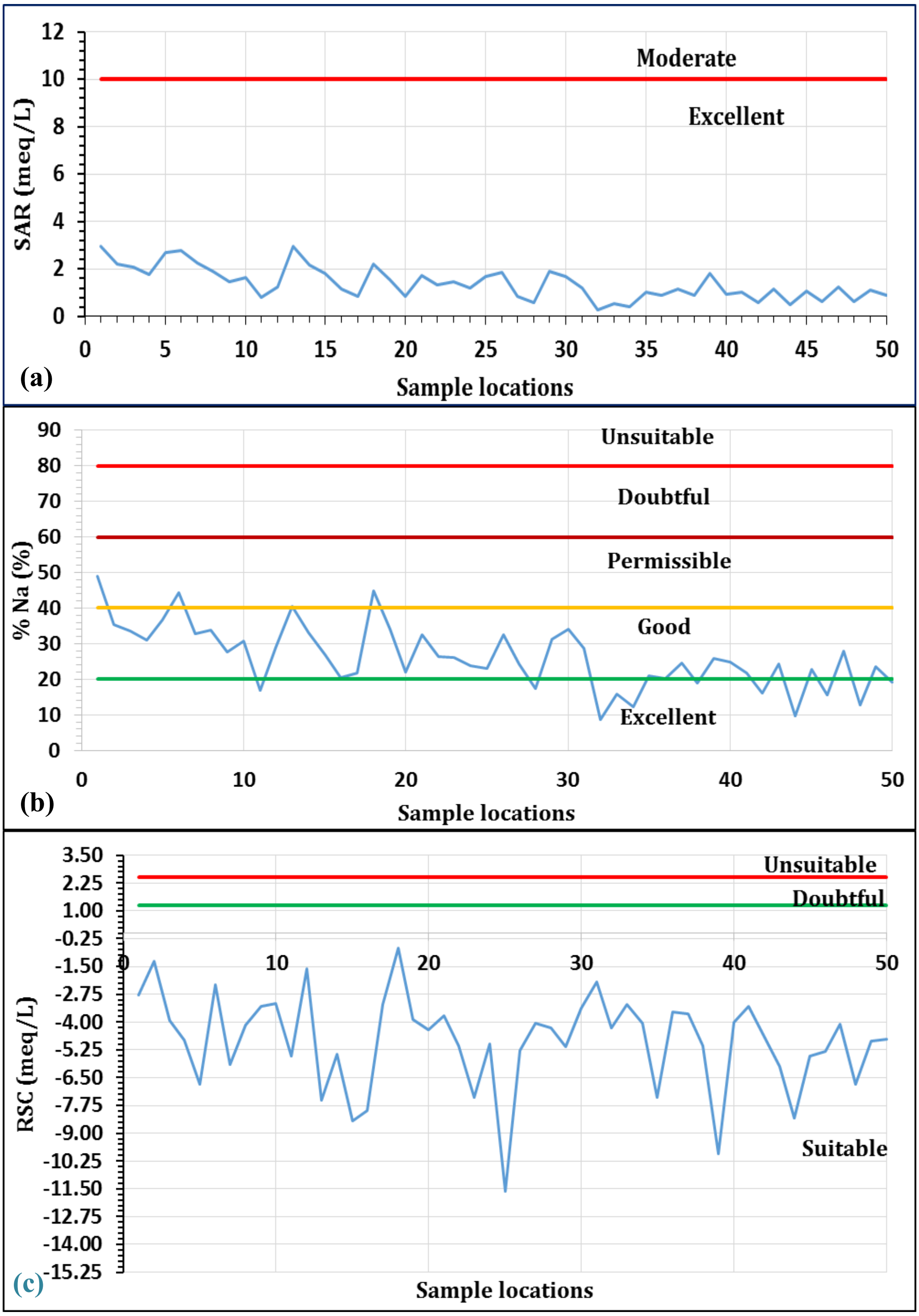

Figure 2. *SAR (a), %Na (b), RSC (c) of the groundwater for irrigation.*

USSL diagram reveals that most groundwater samples fall under the C3-S1 class (n=42, 84% of samples) majority of the groundwater has high salinity with low sodium hazard category, which is good for irrigation (Figure 3). The least sample numbers fall in the C4-S1 category (n=8, 16 of samples), indicating very high salinity with low sodium concentration. It indicates that the basin is suitable for irrigation in almost all soil and crop types.

Percentage of sodium (% Na)

Excessive amounts of EC and Na+ content in agricultural water may also decrease osmotic gradient and reduce the ingestion of nutrients from the soil by plants (Saleh *et al.*, 1999). In the basin, %Na ranged from 8.57% to 48.94%, with an average of 26.21% (Table 2). Based on the %Na, groundwater classified into five classes is 0 to 20% is excellent, 20 to 40% is good, 40 to 60% is permissible, 60 to 80% is doubtful, and more than 80% is unsuitable for irrigation purposes (Kawo and Karuppannan, 2018). It is observed that 22% of samples were classified as excellent and good for irrigation, followed by 70% of samples, and 8% of samples were classified as good and moderate for irrigation (Table 2, Figure 2b). According to (Wilcox, 1955) the diagram in the classification of electrical conductivity reveals that the majority of samples fall in the good to permissible class (78%), in doubtful to unsuitable class (20%), and 2% of samples unsuitable (Figure 4).

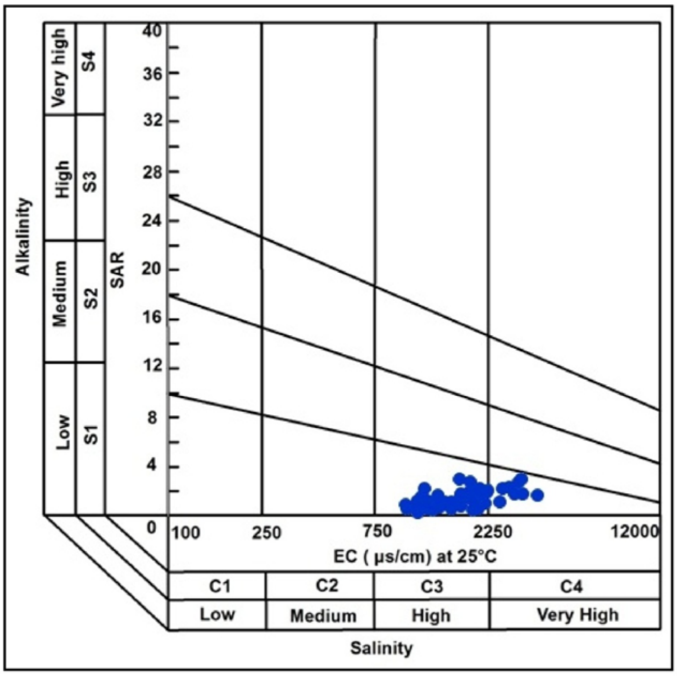

Figure 3. *USSL diagram showing the suitability of groundwater for irrigation.*

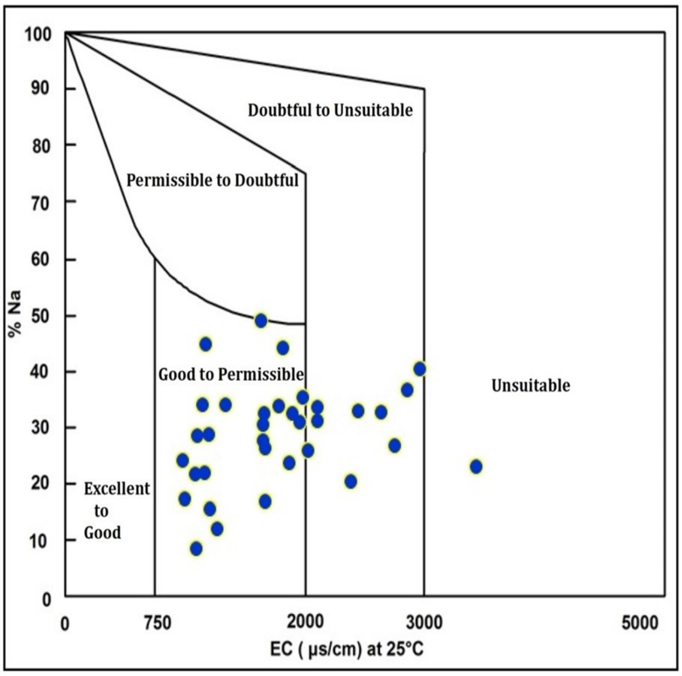

Figure 4. *Wilcox diagram showing the relation between SAR and electrical conductivity.*

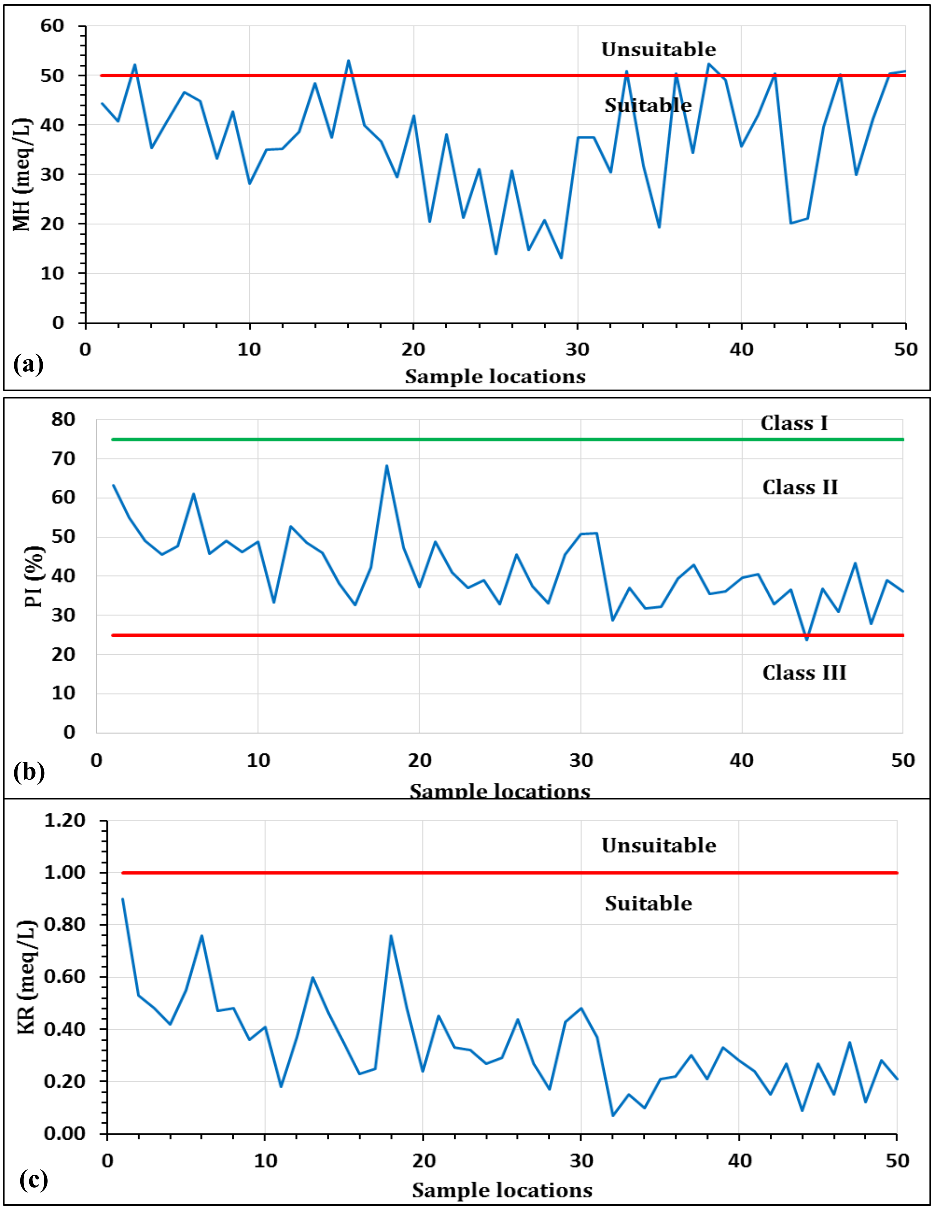

Figure 5. *MH (a), PI (b), and KR (c) of the groundwater for irrigation.*

Residual sodium carbonate (RSC)

The elevated concentration of carbonate and bicarbonate is due to the soil's alkaline nature, which is unfavourable for agricultural use (Jalal *et al.*, 2012). The RSC classifies the water into three classes: less than 1.25meq/L is safe, 1.25 meq/L to 2.5 meq/L is moderately suitable, and more than 2.5 meq/L is unsafe irrigation (Shankar and Kawo, 2019). The value of RSC ranged from -11.61 to -0.66, with an average of -4.86 (Table 4). In the basin, all the samples (100%) fall in the safe for irrigation (Figure 2c).

Magnesium Hazards (MH)

Magnesium hazard is an essential parameter to appraise the irrigation water quality. In the basin, MH ranges from 13.05 to 53.05 %, with an average of 36.68 % (Table 2). If the magnesium hazard surpasses 50 %, then the water is hazardous to agriculture and unsuitable for irrigation, and less than 50 % is suitable for irrigation. Based on the MH, 82% of groundwater samples are found suitable for irrigation, while the remaining 18% of the samples exceeded the limit and found unsuitable for irrigation purposes (Figure 5a).

Permeability Index (PI)

PI is also a vital parameter for the assessment of groundwater fitness for agricultural purposes. It shows the relationship between major cations and bicarbonate in hydrochemistry (Panneerselvam *et al.*, 2020b). According to Doneen (1964), using the Permeability Index (PI), the irrigation water quality is classified into three different classes; more than 75% of the maximum permeability is Class I, suitable for irrigation, 25-75% of the maximum permeability is Class II, slightly suitable, and 25% of the maximum permeability is Class III, not suitable for irrigation. The PI ranges from 23.69 to 68.33%, with an average of 41.85% (Table 2). Based on the Doneen classification, around 66% of the groundwater samples fall within the Class I type (33 samples) due to recharge and dilution to make it as best water for agricultural activity (Figure 5b). About 34% of samples fell in the Class II type of good category (17 samples) were taken to indicate that water has been of good quality suitable for irrigation purposes (Rawat *et al.*, 2018). All the samples fall Class I and II type to indicate their suitability for irrigation purposes (Figure 6).

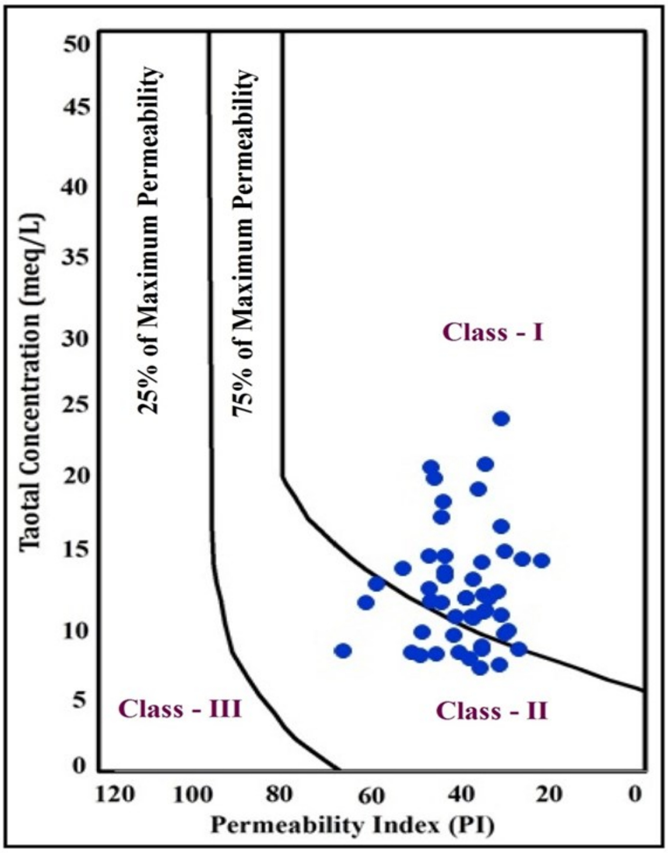

Figure 6. *Doneen's diagram showing the various classes of groundwater for irrigation.*

Kelly's ratio

The concentration of sodium calculated against calcium and magnesium ion is known as Kelly 1963. It is a significant index parameter to assess the suitability of groundwater for irrigation uses. The value of KR, less than one is suitable for irrigation and greater than one is unsuitable for irrigation purposes (Panneerselvam *et al.* 2020a). In the basin, the KR ranged from 0.07 to 0.90, with an average of 0.34 (Table 2). Based on KR, 100% of the groundwater samples are suitable for irrigation purposes (Figure 5c).

Conclusion

In the present study, the assessment of groundwater quality for irrigation purposes in and around the main Gadilam river basin was assessed in accordance with the proposed standard guidelines. The following conclusions are drawn from the study.

- Groundwater is predominantly slightly acidic to nearly alkaline in nature. The EC values show a high salinity in 88 % of samples and very high salinity in 12 % of samples. TDS values, about 94% of these groundwater samples are in the slight to moderate category, and 6% of the samples represent the severe saline category for irrigation purposes.
- Based on the SAR classification, all groundwater samples are excellent for irrigation purposes in the basin. In addition, the USSL diagram reveals that most of the groundwater samples fall under the C3-S1 class, and the C4-S1 category has high salinity with low sodium hazard and very high salinity with low sodium concentration. It indicates that the basin is suitable for irrigation in almost all soil and crop types.
- The %Na is 100% of samples classified as excellent and moderate for irrigation purposes. The Wilcox diagram in the classification of electrical conductivity reveals that most samples fall in the good to permissible class (78%), in doubtful to unsuitable class (20%), and 2% of samples are unsuitable.

- The magnesium hazards of 82% of the groundwater samples are found suitable for irrigation, while the remaining 18% of the samples exceeded the limit and hence found unsuitable for irrigation purposes.
- Doneen's diagram prepared based on PI, and the total concentration of ions in groundwater indicates that Class I and Class II type are suitable for irrigation purposes. The assessment of groundwater suitability for irrigation purposes using RSC, PI, and KR shows that 100% of groundwater samples in the basin is suitable for irrigation use.

Conflict of interest

The authors declare there are no conflicts of interest.

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