



Appraisal of Ground Water Quality of Sindhari and Siwana (Barmer) Rajasthan and its Suitability for Irrigation

Dinesh Sharma¹, Ranjeet Singh^{1*}, RK Jakhar¹, Deshraj Meena¹,
Kishan Damor¹ and RL Meena²

¹Department of Soil Science and Agricultural Chemistry, SKRAU, Bikaner, Rajasthan

²ICAR-CSSRI, Karnal, Haryana

*Corresponding author's E-mail: ranjeetsingh1970@gmail.com

Abstract

Quality of ground water for irrigation is a crucial factor influencing agricultural productivity and environmental sustainability, particularly in arid and semi-arid regions. The chief objective of this study was to characterize the ground water quality of Sindhari and Siwana tehsils of Barmer (Rajasthan). A total of 64 ground water samples were collected and analyzed for various parameters, including pH, EC, cations (Ca^{2+} , Mg^{2+} , Na^+ and K^+) and anions (CO_3^{2-} , HCO_3^- , Cl^- , SO_4^{2-} , nitrate and fluoride). Furthermore, water quality indices like RSC, SAR, Adj. SAR and SSP were calculated using the analytical data. These parameters were evaluated against water quality standards for irrigation to the prevailing crops. Ground water for irrigation in the studied area were good (39.06%), marginally saline (7.81%), high SAR saline (28.13%) and highly alkali (25.0%) types. These results inferred that a substantial portion of samples showed high salinity and sodicity rendering them unsuitable for irrigation without proper management. Hence, sustainable strategies and soil amendments are recommended to mitigate the negative effects of poor-quality ground water for irrigation.

Keywords: Ground water quality, Salinity, Sodicity, Alkalinity, Irrigation suitability

Introduction

Agriculture is a vital sector in India, supporting over 70% of rural households and contributing approximately 17% to the national GDP while employing over 60% of the population (Anon., 2022). In Rajasthan, an agrarian state, around 70% of the population relies on agriculture, which accounts for 22.5% of the state's GDP. Despite a cultivated area of nearly 20 million hectares, only 20% is irrigated due to various constraints (Sharma and Basotia, 2018). The state's arid to sub-humid monsoon climate, characterized by low rainfall, hot winds (Loo) and sandstorms, further challenges agricultural productivity.

Water is essential for life and agriculture, with India being the largest global consumer of ground water, consuming around 230 cubic kilometers annually. Ground water plays a crucial role in Indian agriculture, supporting over 70% of food grain production through irrigation (Gandhi and Namboodiri, 2009). Rajasthan, despite covering

over 10% of India's land area, holds only 1.2% of surface water and 1.7% of ground water reserves (Saikia and Chetry, 2020). Ground water exploitation in the state has surged from 33% in 1984 to 149% in 2023, with only 38 out of 299 blocks remaining in the safe category (Anon., 2024). The quality of irrigation water significantly affects agricultural productivity, particularly in arid and semi-arid regions like Rajasthan, Haryana, Uttar Pradesh, Karnataka, Punjab, and Gujarat, where ground water salinity (EC) and residual sodium carbonate (RSC) levels are high (Manchanda *et al.*, 1989). Saline irrigation water accelerates soil salinization and alkalization, altering soil properties, microbial activity, and nutrient dynamics (Irshad *et al.*, 2005). Globally, 932.2 million hectares are salt-affected, with 76.6 million hectares due to human activities (Shahid *et al.*, 2018). In India, 6.73 million hectares (2.1% of total land) are salt-affected, with Rajasthan contributing 1.18 million hectares (Arora and Sharma, 2017). High evaporation rates in these

regions exacerbate salinity by limiting fresh water availability for salt leaching.

The assessment of water quality for both drinking and irrigation purposes is primarily based on key physicochemical parameters, including major cations (Na^+ , Ca^{2+} , Mg^{2+} , K^+) and anions (Cl^- , SO_4^{2-} , CO_3^{2-} , HCO_3^-). In addition, various water quality indices are commonly employed to evaluate water for irrigation suitability. These indices include electrical conductivity (EC), sodium adsorption ratio (SAR), soluble sodium percentage (SSP), residual sodium carbonate (RSC) and residual alkalinity (RA). These indices are derived from fundamental water quality parameters and serve as critical tools for determining the suitability of water for agricultural applications (Singh *et al.*, 2015; Gautam *et al.*, 2015). The ground water samples were collected with the main objectives (i) to characterize the ground water in study area and (ii) to know the salinity, sodicity, alkalinity and its suitability for irrigation purposes.

Materials and Methods

Study area description

Barmer is the western part of Rajasthan state forming a part of the Thar Desert and located

between $24^{\circ}58'$ to $26^{\circ}32'$ N latitude and $70^{\circ}05'$ to $72^{\circ}52'$ E longitude having total geographical area of 2838700 ha and area under irrigation is 254363 ha. It comprises 14 tehsils, out of these, 2 tehsils located in the southern part of Barmer district *viz.*, Sindhari and Siwana were selected for to fulfill the objectives of the present study. The climate of the study area is extremely arid, characterized by low and erratic rainfall. The mean annual rainfall of the locality is 200-350 mm. The rainfall is mainly received during monsoon season in the month of June to September. The maximum and minimum temperature of the district ranged between 49°C to 1°C and occupies prominent place in the Agro-climatic zone IA (Arid Western Plain Zone) of Rajasthan. The major crops grown in the studied area were pearl millet, cluster bean, mung bean and sesame in *khari*f and cumin, isabgol, mustard and wheat in *rabi* season.

Water sampling and laboratory analysis

A preliminary survey of Sindhari and Siwana tehsils of Barmer district was conducted during the month of March 2022 to select the area and collected 64 water samples from 28 villages of both the tehsils during June 2022 from the tube wells/ open wells, which were used for irrigating the fields (Fig. 1 and Table 1). Collected water samples

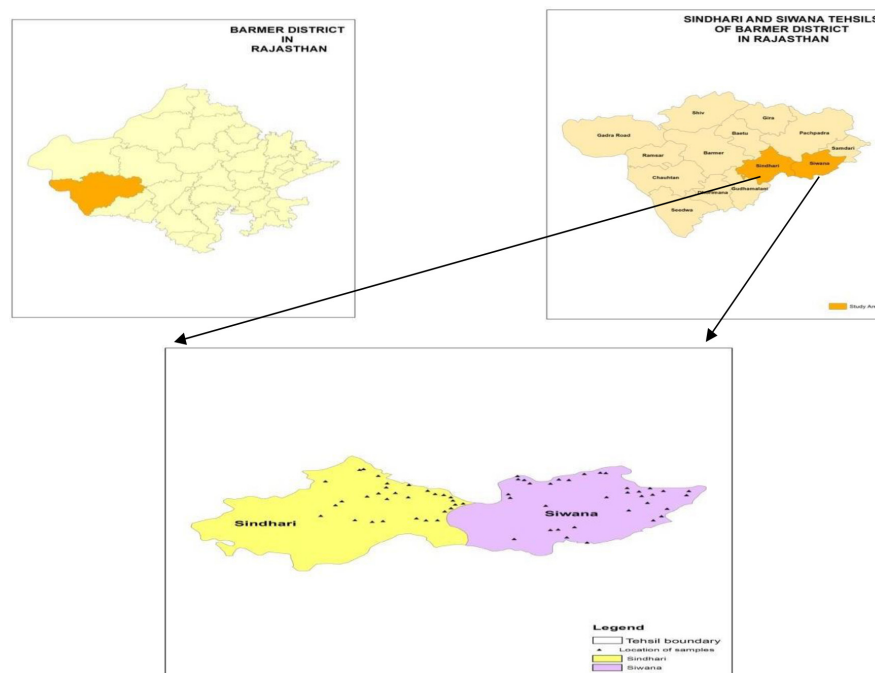


Fig. 1 Location map of Sindhari and Siwana tehsils of Barmer district of Rajasthan showing sample collection sites

Table 1. List of villages of Sindhari and Siwana tehsils of Barmer district of Rajasthan along with their GPS location from where water samples were collected

| Sample No. | Name of Village | GPS location | | Sample No. | Name of Village | GPS location | |
|------------------------|---------------------|--------------|--------------|------------|-----------------------|--------------|--------------|
| | | Latitude | Longitude | | | Latitude | Longitude |
| Sindhari Tehsil | | | | | | | |
| 1 | Panyla | 25° 29' 187" | 71° 51' 973" | 16 | Chado ki dhani | 25° 28' 898" | 72° 01' 740" |
| 2 | Panyla | 25° 29' 256" | 71° 52' 085" | 17 | Chado ki dhani | 25° 28' 955" | 72° 01' 796" |
| 3 | Ramdevra | 25° 29' 972" | 71° 51' 442" | 18 | Chado ki dhani | 25° 28' 970" | 72° 02' 583" |
| 4 | Ramdevra | 25° 30' 115" | 71° 51' 575" | 19 | Chado ki dhani | 25° 29' 264" | 72° 03' 643" |
| 5 | Ramdevra | 25° 30' 480" | 71° 51' 750" | 20 | Kheta ji ki dhani | 25° 30' 156" | 72° 04' 027" |
| 6 | Ramdevra | 25° 30' 808" | 71° 52' 483" | 21 | Kheta ji ki dhani | 25° 30' 115" | 72° 04' 267" |
| 7 | Bhathesaro ki dhani | 25° 30' 901" | 71° 52' 354" | 22 | Juna mithakheda | 25° 30' 313" | 72° 05' 381" |
| 8 | Bhathesaro ki dhani | 25° 31' 044" | 71° 52' 441" | 23 | Juna mithakheda | 25° 30' 306" | 72° 05' 510" |
| 9 | Neemali | 25° 31' 781" | 71° 52' 985" | 24 | Bhavgirijii ka meetha | 25° 31' 119" | 72° 07' 536" |
| 10 | Neemali | 25° 31' 665" | 71° 53' 058" | 25 | Bhavgirijii ka meetha | 25° 31' 390" | 72° 07' 453" |
| 11 | Sindhari | 25° 31' 633" | 71° 56' 304" | 26 | Dhanwa | 25° 31' 601" | 72° 07' 438" |
| 12 | Sindhari | 25° 32' 004" | 71° 55' 835" | 27 | Dhanwa | 25° 31' 698" | 72° 07' 433" |
| 13 | Sindhari | 25° 32' 298" | 71° 55' 051" | 28 | Dhanwa | 25° 32' 015" | 72° 07' 368" |
| 14 | Galanadi | 25° 27' 555" | 72° 00' 601" | 29 | Dakhan | 25° 34' 301" | 72° 07' 874" |
| 15 | Galanadi | 25° 27' 850" | 72° 00' 215" | 30 | Dakhan | 25° 34' 157" | 72° 07' 649" |
| Siwana Tehsil | | | | | | | |
| 1 | Meethora | 25° 33' 966" | 72° 09' 874" | 18 | Jeenpura | 25° 31' 808" | 72° 24' 418" |
| 2 | Meethora | 25° 33' 381" | 72° 09' 057" | 19 | Hemawas | 25° 31' 673" | 72° 23' 503" |
| 3 | Meethora | 25° 33' 625" | 72° 11' 305" | 20 | Hemawas | 25° 31' 669" | 72° 22' 900" |
| 4 | Meethora | 25° 33' 892" | 72° 11' 711" | 21 | Mubari | 25° 31' 689" | 72° 21' 931" |
| 5 | Devpura | 25° 34' 506" | 72° 12' 293" | 22 | Mubari | 25° 31' 689" | 72° 21' 682" |
| 6 | Devpura | 25° 34' 453" | 72° 12' 332" | 23 | Kundal | 25° 31' 516" | 72° 20' 951" |
| 7 | Dharna | 25° 35' 509" | 72° 14' 806" | 24 | Kundal | 25° 31' 460" | 72° 20' 701" |
| 8 | Dharna | 25° 35' 577" | 72° 14' 890" | 25 | Vairo ki nadi | 25° 30' 350" | 72° 19' 021" |
| 9 | Kathari | 25° 31' 559" | 72° 32' 115" | 26 | Vairo ki nadi | 25° 30' 023" | 72° 19' 220" |
| 10 | Kathari | 25° 31' 403" | 72° 32' 300" | 27 | Relo ki dhani | 25° 29' 542" | 72° 17' 562" |
| 11 | Ramaniya | 25° 33' 278" | 72° 33' 279" | 28 | Relo ki dhani | 25° 28' 866" | 72° 17' 301" |
| 12 | Ramaniya | 25° 33' 630" | 72° 28' 979" | 29 | Kakhi | 25° 26' 024" | 72° 16' 488" |
| 13 | Dheera | 25° 33' 009" | 72° 28' 282" | 30 | Kakhi | 25° 26' 860" | 72° 15' 983" |
| 14 | Dheera | 25° 32' 915" | 72° 27' 905" | 31 | Rawat nagar | 25° 27' 019" | 72° 15' 043" |
| 15 | Mangi | 25° 32' 393" | 72° 28' 456" | 32 | Rawat nagar | 25° 27' 045" | 72° 14' 467" |
| 16 | Mangi | 25° 32' 160" | 72° 25' 236" | 33 | Devari | 25° 27' 165" | 72° 13' 468" |
| 17 | Jeenpura | 25° 31' 810" | 72° 24' 650" | 34 | Devari | 25° 26' 218" | 72° 13' 414" |

were stored in clean, rinsed and properly labeled plastic bottles. Few drops of toluene were also added to check the microbial growth. The collected water samples were tested and analyzed by adopting standard method for examination of ground water for irrigation.

Quality assessment of ground water for irrigation

The ground water samples were analyzed for various parameters, including pH, electrical conductivity, cations (Na^+ , Ca^{2+} , Mg^{2+} , K^+), and anions (Cl^- , HCO_3^- , CO_3^{2-} , SO_4^{2-}). The suitability of ground water for irrigation was assessed using

indicators such as electrical conductivity (EC), sodium adsorption ratio (SAR), adjusted sodium adsorption ratio (adj. SAR), residual sodium carbonate (RSC) and soluble sodium percentage (SSP).

Electrical conductivity: Amount of total soluble salts in a sample is generally expressed in terms of the sample's electrical conductivity. It is measured with the help of an electrical conductivity meter. The electrical conductivity of ground water for irrigation in study area ranged between 5.18 to 36.40 with an average value of 11.54 dS m^{-1} and 0.20 to 9.44 with the mean value

of 1.75 dS m⁻¹ in Sindhari and Siwana tehsils, respectively.

Sodium adsorption ratio (SAR): The sodium adsorption ratio is commonly used to evaluate the potential accumulation of sodium in soil, particularly due to the repeated application of sodic water. This accumulation can negatively impact soil structure by displacing calcium and magnesium, which are essential for maintaining soil permeability and water movement (Bhat *et al.*, 2016). Richard (1954) proposed a classification system for water based on SAR values. This parameter is crucial for assessing soil alkalinity and potential alkali hazards associated with using ground water for agricultural purposes (Srivastva and Ramanathan, 2008). SAR is determined using a specific formula:

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}}}$$

Where, all ions are in milliequivalents per liter (me L⁻¹)

Residual sodium carbonate (RSC): Richard has also determined the hazardous effect of carbonate and bicarbonates on water quality (Srivastva and Ramanathan, 2008) and classified the water for irrigation purposes in terms of residual sodium carbonate (RSC). The RSC calculated with the help of formula:

$$\text{RSC (me L}^{-1}\text{)} = (\text{CO}_3^{2-} + \text{HCO}_3^-) - (\text{Ca}^{2+} + \text{Mg}^{2+})$$

Where, all ionic concentrations are expressed in terms of milliequivalents per liter (me L⁻¹).

Soluble sodium percentage (SSP): SSP is used to assess salinity levels by comparing Na⁺ concentration with Ca²⁺ and Mg²⁺. An elevated sodium level relative to calcium and magnesium can lead to toxic conditions, causing leaf burn and plant tissue damage (Bhat *et al.*, 2016). SSP is calculated with the help of formula:

$$\text{SSP} = \frac{\text{Na}^+}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{K}^+ + \text{Na}^+} \times 100$$

Results and Discussion

The results (Table 2) revealed that the pH values were ranged between 7.01 to 7.90 (neutral to

alkaline) with an average value of 7.55 and 7.03 to 8.66 with the mean value of 7.59, in ground water for irrigation of Sindhari and Siwana tehsils of Barmer district, respectively. The maximum (7.59) and minimum (7.55) mean pH values were observed in water of Siwana and Sindhari tehsils, respectively. Alkaline water may contain high concentration of carbonates and bicarbonates which can cause calcium and magnesium to precipitate from the soil which can affect plant growth. These results are in close conformity with the results of Choudhary *et al.* (2022). The electrical conductivity varied from 5.18 to 36.40 with an average value of 11.54 dS m⁻¹ in Sindhari and 0.20 to 9.44 with the mean value of 1.75 dS m⁻¹ in Siwana tehsil. It is apparent from the results that most of the water samples showed very high EC in Sindhari tehsil and low to high EC in Siwana tehsil. This is mainly due to the presence of neutral salts of chloride and sulphate in ground water. Similar results were also reported by Chanwla *et al.* (2023).

The tehsil wise cations Ca, Mg, Na and K of irrigation water varied from 5.29 to 38.27, 11.09 to 77.10, 33.56 to 247.32 and 0.09 to 0.82 me L⁻¹ with the mean value of 12.23, 24.82, 77.61 and 0.35 me L⁻¹ in Sindhari tehsil and 0.12 to 9.02, 0.40 to 17.45, 1.35 to 67.41 and 0.01 to 0.25 with an average values of 1.81, 3.99, 11.49 and 0.09 me L⁻¹ in Siwana tehsil, respectively. Similar results were also observed by Dhaka *et al.* (2022).

It is evident from the data (Table 2) that the anions CO₃²⁻, HCO₃⁻, Cl⁻ and SO₄²⁻ in these irrigation water varied from 2.50 to 30.96, 15.84 to 107.39, 26.36 to 187.37 and 5.27 to 37.79 with an average values of 7.01, 34.47, 61.99 and 11.58 me L⁻¹ in Sindhari tehsil and 0.05 to 4.00, 0.53 to 28.80, 1.09 to 51.54 and 0.21 to 9.76 with the mean values of 0.76, 5.34, 9.56 and 1.74 me L⁻¹ in Siwana tehsil, respectively. Chloride was recorded as dominant anion in ground water for irrigation of study area followed by bicarbonate, sulphate and carbonate. The results of present study were in closed conformity with the findings of Bali *et al.* (2015).

The data depicted in table 2 clearly indicated that the SAR values of ground water for irrigation of Sindhari and Siwana tehsils of Barmer district

Table 2. Characteristic of ground water for irrigation of Sindhari and Siwana tehsils of Barmer district of Rajasthan

| Characteristics | Tehsils | |
|-----------------------------------------------------|-----------------------|---------------------|
| | Sindhari (30)* | Siwana (34)* |
| pH | 7.01-7.90 (7.55)** | 7.03-8.66 (7.59) |
| EC (dS m ⁻¹) | 5.18-36.40 (11.54) | 0.20-9.44 (1.75) |
| Na ⁺ (me L ⁻¹) | 33.56- 247.32 (77.61) | 1.35- 67.41 (11.49) |
| K ⁺ (me L ⁻¹) | 0.09-0.82 (0.35) | 0.01-0.25 (0.09) |
| Ca ²⁺ (me L ⁻¹) | 5.29-38.27 (12.23) | 0.12-9.02 (1.81) |
| Mg ²⁺ (me L ⁻¹) | 11.09-77.10 (24.82) | 0.40-17.45 (3.99) |
| CO ₃ ²⁻ (me L ⁻¹) | 2.50-30.96 (7.01) | 0.05-4.00 (0.76) |
| HCO ₃ ⁻ (me L ⁻¹) | 15.84-107.39 (34.47) | 0.53 -28.80 (5.34) |
| Cl ⁻ (me L ⁻¹) | 26.36-187.37 (61.99) | 1.09 -51.54 (9.56) |
| SO ₄ ²⁻ (me L ⁻¹) | 5.27-37.79 (11.58) | 0.21-9.76 (1.74) |
| SAR | 11.13-32.56 (17.91) | 1.92-18.53 (5.85) |
| RSC (me L ⁻¹) | Nil-24.44 (5.09) | Nil-6.29 (0.73) |
| SSP | 59.93-79.16 (67.78) | 45.62-75.44 (63.87) |
| Adj. SAR | 33.39-143.28 (64.00) | 0.98-63.00 (12.97) |

*Number of water samples taken from study area

**the parentheses values represent average values of the parameters of the samples

of Rajasthan varied from 11.13 to 32.56 with an average value of 17.91 and 1.92 to 18.53 with the mean value of 5.85, respectively. The highest mean value of SAR (17.91) was recorded in ground water for irrigation of Sindhari tehsil and minimum (5.85) in Siwana tehsil, respectively. Due to the dominance of Na⁺ ion over Ca²⁺ and Mg²⁺ ions increase the SAR with increase in pH and EC. The results of the present investigation have been supported by the findings of Choudhary *et al.* (2022).

The data presented in table 2 revealed that RSC values of irrigation water of Sindhari and Siwana tehsils of Barmer district ranged between nil to 24.44 with an average value of 5.09 me L⁻¹ and nil to 6.29 with the mean value of 0.73 me L⁻¹, respectively. The maximum (5.09 me L⁻¹) mean value of RSC were observed in Sindhari tehsil and minimum (0.73 me L⁻¹) in Siwana tehsil. Dhaka *et al.* (2022) have also reported the similar results.

The calculated value of Adj. SAR of ground water for irrigation of Sindhari and Siwana tehsils of Barmer district ranged between 33.39 to 143.28 with the mean values of 64.00 and 0.98 to 63.00 with an average value of 12.97, respectively (Table 2). The maximum (64.00) and minimum (12.97) average value of Adj. SAR were noted in Sindhari tehsil, respectively. These results of the present

investigation were in accordance with findings of Chanwla *et al.* (2023).

Soluble sodium percentage of ground water for irrigation of Sindhari and Siwana tehsils of Barmer district varied from 59.93 to 79.16 with an average value of 67.78 and 45.62 to 75.44 with mean value of 63.87, respectively (Table 2). The main reason for high SSP in ground water was due to their sodium dominating character. In higher salinity range, sodium is associated mainly with chloride and sulphate, whereas, in low to medium salinity water, it is associated with carbonate and bicarbonate. Similar results were also reported by Bali *et al.* (2015).

According to Gupta (1986) standards, the ground water for irrigation of Sindhari and Siwana tehsils of Barmer district were classified into five each of salinity, sodicity and alkalinity classes (Fig. 2). It is apparent from the Fig. 2 data that with respect to salinity classes, 39.07 per cent water samples fell under C₁ (Normal water) class, 6.25 per cent under C₂ (Low salinity water) class, 3.12 per cent under C₃ (Medium salinity water) class, 25.00 per cent under C₄ (High salinity water) class and remaining 26.56 per cent under C₅ (Very high salinity water) class. Similarly, with respect to sodicity, about 31.26 per cent water samples fell under S₀ (Non sodic water) class, 15.62 per

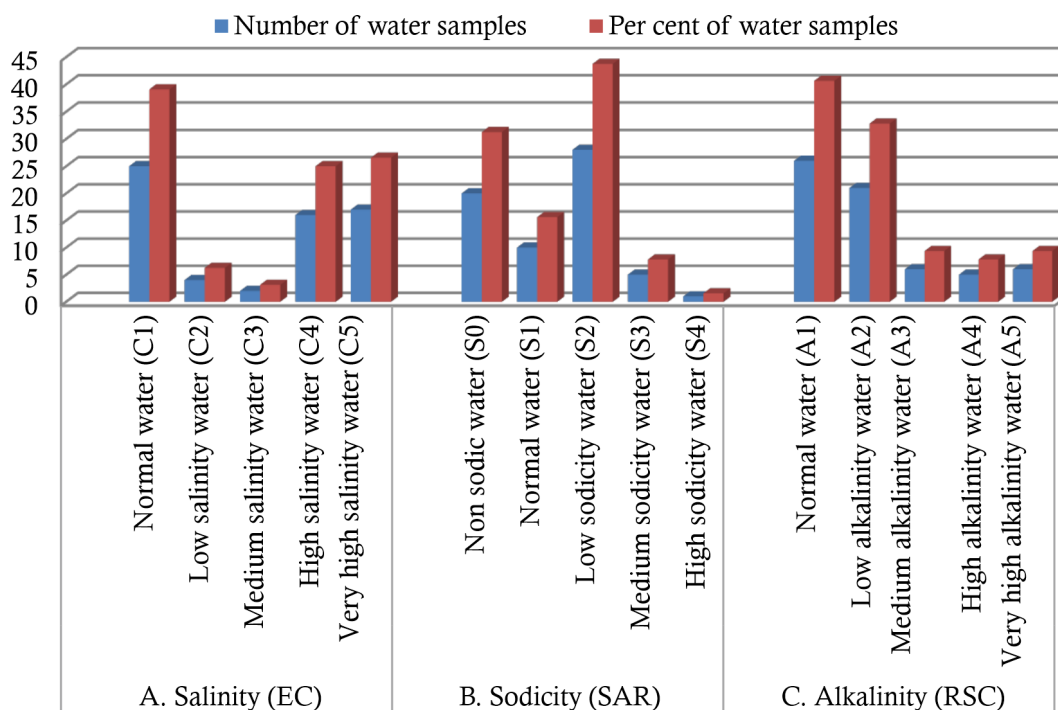


Fig. 2. Distribution of ground water for irrigation of Sindhari and Siwana tehsils of Barmer district of Rajasthan on the basis of salinity (EC), sodicity (SAR) and alkalinity (RSC)

cent under S_1 (Normal water) class, 43.75 per cent in S_2 (Low sodicity water) class, 7.81 per cent in S_3 (Medium sodicity water) class and remaining 1.56 per cent in S_4 (High sodicity water) class.

Further, as per alkalinity hazard, about 40.64 per cent water samples fell under A_1 (Normal water) class, 32.81 per cent under A_2 (Low alkalinity water) class, 9.37 per cent under A_3 (Medium alkalinity water) class, 7.81 per cent under A_4 (High alkalinity water) class and rest 9.37 per cent under A_5 (Very high alkalinity water) class. Thus, around 30 to 50 per cent water samples

may create some problems in successful management of irrigated agriculture in study area.

Further, the ground water for irrigation of Sindhari and Siwana tehsils of Barmer district were classified on the basis of EC, SAR and RSC into four classes. Data (Table 3 and Fig. 3) indicated that 39.06, 7.81, 28.13 and 25.00 per cent water samples fell under good, marginally saline, high SAR saline and highly alkali categories, respectively (Gupta *et al.*, 1994).

Pearson's correlation matrix: The Pearson correlation matrix (Table 4) is used to recognize

Table 3. Classification of ground water for irrigation of Sindhari and Siwana tehsils of Barmer district of Rajasthan on the basis of EC, SAR and RSC

| S. No. | Water quality classes | Per cent of water samples | Name of villages |
|--------|-----------------------|---------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. | Good | 39.06 | Dharna, Ramaniya, Dheera Manji, Jeenpura, Hemawas, Mubari, Kundal, Vairo ki nadi Relo ki dhani, Kakhi, Rawat nagar, Devvari |
| 2. | Marginally saline | 7.81 | Meethora, Devpura, Dharna |
| 3. | High SAR saline | 28.13 | Payla, Galanadi, Chado ki dhani, Bhavgiriji ka meetha, Ramdevra, Bhathe saro ki dhani, Kheta ji ki dhani, Dhanwa, Dhaka, Neemali, Sindhari, Kathari |
| 4. | Highly alkali | 25.00 | Ramdevra, Chado ki dhani, Neemali, Dhanwa, Dhaka, Galanadi, Juna Mithakheda, Sindhari, Kheta ji ki dhani, Kathari, Devpura, Meethora |

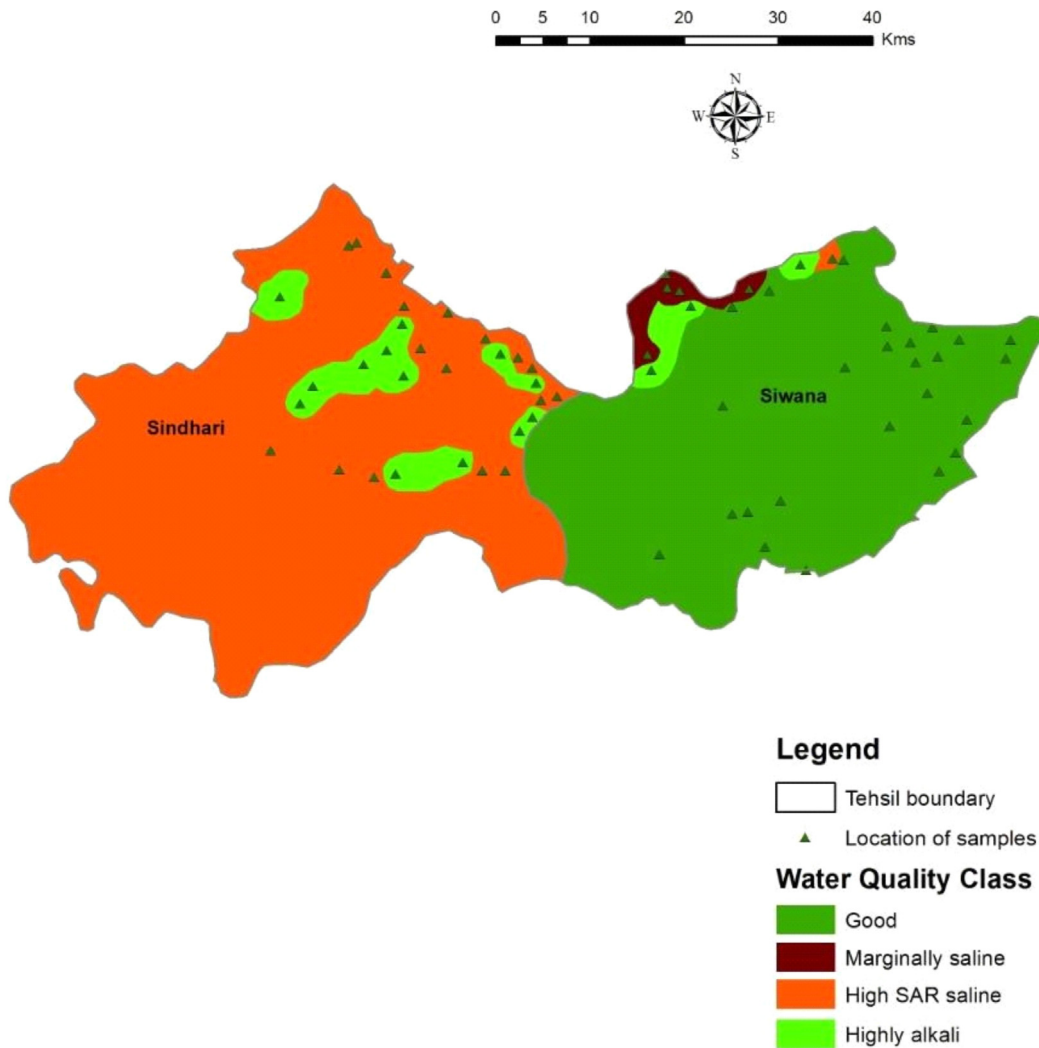


Fig. 3. Map showing quality of ground water for irrigation

Table 4. Correlation matrix among the chemical constituents of the ground water of Sindhari and Siwana tehsils of Barmer district of Rajasthan

| Variables | pH | EC | RSC | SAR | SSP | Adj. SAR |
|-----------|--------|----------|---------|---------|---------|----------|
| pH | 1.00 | | | | | |
| EC | -0.135 | 1.00 | | | | |
| RSC | -0.065 | 0.521 ** | 1.00 | | | |
| SAR | -0.053 | 0.899** | 0.711** | 1.00 | | |
| SSP | -0.081 | 0.224 | 0.574** | 0.502** | 1.00 | |
| Adj. SAR | -0.076 | 0.953** | 0.663** | 0.988** | 0.399** | 1.00 |

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

the relationship between different variables of ground water for irrigation.

pH

pH showed non-significant and negative association with all variables studied viz. EC

(-0.135), SSP (-0.081), Adj. SAR (-0.076), RSC (-0.065) and SAR (-0.053).

EC

The present study unveiled that electrical conductivity of ground water had a significant

positive correlation with Adj. SAR (0.953**), SAR (0.899**) and RSC (0.521**). Furthermore, a positive yet statistically non-significant correlation was observed with SSP (0.224).

RSC

The variables *viz.* SAR (0.711**), Adj. SAR (0.663**), SSP (0.574**) and EC (0.521**), showed a positive and significant association with RSC of ground water for irrigation of studied area.

SAR

The study revealed that trait SAR of ground water for irrigation of Sindhari and Siwana tehsils of Barmer district of Rajasthan had a positive and significant relationship with Adj. SAR (0.988**), EC (0.899**), RSC (0.711**) and SSP (0.502**).

SSP

The data revealed that trait SSP had a positive and significant association with RSC (0.574**), SAR (0.502**) and Adj. SAR (0.399**). Furthermore, a positive yet statistically non-significant correlation was observed with EC (0.224).

Adj. SAR

The traits SAR (0.988**), EC (0.953**), RSC (0.663**) and SSP (0.399**) showed a positive and significant association with Adj. SAR of ground water for irrigation of studied area.

Management strategies for appropriate use of available water resources for irrigation purpose

There are a number of ways to improve water quality, with regard to salinity and sodicity hazards, prior to use for irrigation purposes (Table 5).

Saline water

To maintain the plant root zone moist, light and frequent irrigation should be used. Leaching of salts below the root zone level through making of field bunding and ponding rain water to leach out the salts /or irrigation with mixing with good quality water (GQW) or alternate use of saline and good quality water would be most useful. Salt

tolerant crops and cultivars should be planted. At least once in every three years add organic manures like FYM, Compost, green manuring crop like, dhaincha/sunhemp etc. for sustain soil health and crop yield. Micronutrient application particularly zinc and iron, because soils are zinc and iron poor due to their alkaline character. The saline water quality can be improved if an alternate source of good quality water is available. Good and saline water should be used for irrigating the specific crop by 1:1 or 1:2 or 2:1 ratio by mixing and/or alternate/ cyclic mode with salt-tolerant crops and their varieties. Ground water must be used judiciously (as life- saving/ supplementary) only by mixing with rain water/ good quality water or alternately with good quality water / rain water to sustain crop yield and to avoid further deterioration in soil health. Implementation of silvo pastoral system including stubble mulching, strip cropping, field bunding, raise beneficial trees such as khejri and shisham.

Sodic water

To maintain the plant root zone moist, light and frequent irrigation should be used. Use poor quality water in conjunction with canal water if possible. Sprinkler and drip irrigation may be more effective in reducing sodicity hazards and scarcity of water. At least once in every three years add organic manures like FYM, Compost, green manuring crop like, dhaincha/sunhemp etc. for sustain soil health and crop yield. Micronutrient application particularly zinc and iron, because soils are zinc and iron poor due to their alkaline character. Implementation of silvo pastoral system including stubble mulching, strip cropping, field bunding, raise beneficial trees such as khejri and shisham. Water sodicity and alkalinity can be mitigated through the judicious use of calcium-containing amendments such as gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). The quantity of gypsum needed for adding to irrigation water depends upon the quality of water (RSC and SAR levels) and the quantity of water required for irrigation during the growing season of the crop. Beyond the threshold limit of sodic ground water, medium to very high sodic level of ground water necessitates the adoption of sodic tolerant crop and their varieties, with the addition of gypsum (gypsum-

Table 5. Remedial measures for using saline, sodic and alkali ground water for irrigation

| Hazard | Class and level | Mitigation/Remedial measures |
|-----------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Salinity (EC) | C ₁ : <0.25 dS m ⁻¹ (Excellent) | Can be used for most soil for most crops |
| | C ₂ : 0.25-0.75 dS m ⁻¹ (Good) | Can be used with moderate leaching with moderate salt-tolerant crops and their varieties |
| | C ₃ : 0.75-2.25 dS m ⁻¹ (Fair) | Cannot be used where drainage is restricted, salt-tolerant crops can be grown with careful irrigation (mixing/or alternate use of good quality water), good drainage, and leaching is required |
| | C ₄ : 2.25-5.0 dS m ⁻¹ (Poor) | Unsuitable for irrigation, except for some highly salt-resistant crops, excellent drainage, frequent leaching, and intensive management (mixing/or alternate use of good quality water) required |
| | C ₅ : >5.0 dS m ⁻¹ (Extreme) | Not suitable for irrigation in general |
| Sodicity (SAR) | S ₁ : <10 (Low) | Sodium sensitive crops can be used cautiously |
| | S ₂ : 10-18 (Medium) | Sodium hazard likely in fine textures soil, can be used on soils having high permeability, amendments (such as gypsum) and leaching is required |
| | S ₃ : 18-26 (High) | Generally unsuitable for continuous use may be used with special management practices viz. field bunding for ponding of rainwater and subsequent leaching of salt, sodic tolerant crops and their varieties can be taken with low-cost drainage facility, using requisite gypsum amendments, addition of organic matter and green manuring like daincha/sunhemp etc. |
| | S ₄ : >26 (Very high) | Generally unsuitable for use except with highly irrigation management with special management practices should be taken viz. field bunding for ponding of rainwater and subsequent leaching of salt, sodic tolerant crops and their varieties can be taken with low-cost drainage facility using requisite gypsum amendments, addition of organic matter and green manuring like daincha/sunhemp etc. |
| Alkalinity (RSC) | A ₀ : Negative RSC (Non-alkali) | Can be used for irrigation on almost all soils for all crops for indefinitely long periods without any problem |
| | A ₁ : 0 RSC(Good) | Can be used for irrigation on almost all soils for all crops even those are sensitive to carbonates or bicarbonates |
| | A ₂ : < 2.50 me L-1(Low alkali) | Can be used for irrigation on almost all soils for all crops |
| | A ₃ : 2.50 - 5.00 me L-1(Medium alkali) | Can be used for irrigation on almost all soils with little danger of the development of harmful levels of alkali conditions for growing all crops except sensitive to carbonates or bicarbonates |
| | A ₄ : 5.00-10.00 me L-1(High alkali) | Can be used for irrigation on soils provided with good drainage such that leaching fraction is not <0.3 for growing semi tolerant and tolerant crops to sodium. EC should be <3 dSm ⁻¹ and SAR should be <10 |
| A ₅ : >10 me L-1(Very high alkali) | These water are directly not suitable for irrigation but may be use in conjunction with low alkalinity water or with the use of amendments | |

bed) in requisite quantity using sodic water with appropriate low-cost drainage facility in sodic soils would be beneficial for sustainable soil health as well as crop yield. After the arrival of good monsoon rains and minimal temperature pearl millet (MH-419 and RHB-90) can be grown and minimum supplement irrigation should be given in kharif season and barley (RD-2035) and mustard (Varuna, CS-58, CS-60) crops can be cultivated in rabi season. Periodic monitoring of salt in soil is necessary.

Conclusion

The dominance of major cations were in the order of Na⁺ > Mg²⁺ > Ca²⁺ > K⁺ and the anions were in order of Cl⁻ > HCO₃⁻ > SO₄²⁻ > CO₃²⁻. The chemical composition of ground water for irrigation was characterized by the Na-Cl water type. It was observed that 39.06% samples were of good quality, 7.81% marginally saline, 28.13% high SAR saline and 25.00% highly alkali in nature and it inferred that 53.13% waters were found high

SAR saline to highly alkali types. The continuous use of these high SAR salines and highly alkali types of water may lead to formation of sodic soils.

Acknowledgements

We are thankful to Indian Council of Agricultural Research (ICAR), New Delhi for providing grant under AICRP on Management of Salt Affected Soils and Use of Saline Water in Agriculture at Agricultural Research Station, SKRAU, Bikaner for completion of this study.

References

- Anonymous (2024) Central Ground Water Board Report, 2024. GoI, New Delhi.
- Anonymous (2022) Annual Report 2021–22. Ministry of Agriculture and Farmers Welfare, Government of India.
- Arora S and Sharma V (2017) Reclamation and management of salt-affected soils for safeguarding agricultural productivity. *Journal of Safe Agriculture* **1**: 1–10.
- Bali B, Kumawat BL, Singh A and Chopra R (2015) Evaluation of ground water in Sriganganagar district of Rajasthan. *The Ecoscan* **9**(1& 2): 133-136.
- Bhat MA, Grewal MS, Rajpaul R, Wani SA and Dar EA (2016) Assessment of ground water quality for irrigation purposes using chemical indices. *Indian Journal of Ecology* **43**: 574-579.
- Chanwla C, Ranjeet Singh and Yadav RK (2023) Delineating the underground water quality for irrigation and its influences on the soil properties of Bali and Desuri tehsils of Pali district, Rajasthan. *Annals of Agricultural Research New Series* **44**(3): 370-378.
- Chaudhary V and Kumar SS (2018) Assessment of ground water quality for drinking and irrigation purposes in arid areas of Rajasthan. *Indian Journal of Applied Water Science* **8**: 218.
- Choudhary K, Sharma Y and Singh R (2022) Delineate the quality of underground water for irrigation of north-western part of Pali district of Rajasthan. *Annals of Agricultural Research New Series* **43**(3): 248- 254.
- Dhaka S, Singh R, Chanwla C, Serawat A and Sharma RK (2022) Characterization and quality assessment of ground waters of Marwar Junction and Rani tehsils of Pali, Rajasthan. *Journal of Soil Salinity and Water Quality* **14**(1): 28-32.
- Gandhi VP and Namboodiri NV (2009) Ground water irrigation in India: gains, costs and risks. *Indian Institute of Management, Ahmedabad, India*.
- Gautam SK, Maharana C, Sharma D, Singh AK, Tripathi JK and Singh SK (2015) Evaluation of ground water quality in the Chotanagpur Plateau region of the Subarnarekha River Basin, Jharkhand State, India. *Sustainability of Water Quality and Ecology* **6**: 57-74.
- Gupta IC (1986) Quality of irrigation water-recent criteria and classification. *Current Agriculture* **10**: 1-42.
- Gupta RK, Singh NT and Sethi M (1994). Ground water quality for irrigation in hand book no. 60. Oxford and IBH Pub. Co., New Delhi.
- Irshad M, Honna T, Yamamoto S, Eneji AE, Yamasaki N (2005) Nitrogen mineralization under saline conditions. *Communications in Soil Science and Plant Analysis* **36**: 1681–1689.
- Manchanda HR, Gupta IC and Jain BL (1989) Use of poor-quality waters. In Reviews of research on Sandy Soils in India. *International Symposium on Managing Sandy Soils, CAZRI, Jadhpur, India* 362-383.
- Richards LA (1954) Diagnosis and improvement of saline and alkali soils. *Agricultural Handbook* 60, USDA and IBH publishing Co. Ltd., New Delhi, India, pp. 99.
- Saikia P and Chetry N (2020) Study of fluctuations in the ground water level in Rajasthan: A spatio-temporal approach. *International Journal of Engineering Research and Technology* **9**(7): 1188-1192.
- Shahid SA, Zaman M and Heng L (2018) Soil salinity: historical perspectives and a world overview of the problem, in *Guideline for Salinity Assessment, Mitigation and Adaptation using Nuclear and Related Techniques*. Springer 43–53.
- Sharma P and Basotia N (2018) Impact on agricultural economy of state. *Journal of Modern Management and Entrepreneurship* **8**(1): 101-106.
- Singh SK, Srivastav PK, Singh D, Han D, Gautam SK and Pande AC (2015) Modeling ground water quality over a humid subtropical region using numerical indices, earth observation datasets and X ray diffraction techniques: A case study of Allahabad district India. *Environmental Geochemical Health* **37**(1): 157-180.
- Srivastava SK and Ramanathan AL (2008) Geochemical assessment of ground water quality in vicinity of Bhalswa landfill, Delhi, India, using graphical and multivariate statistical methods. *Environmental Geology* **53**: 1509-1528.