Journal of Experimental Agriculture International

Volume 46, Issue 6, Page 293-302, 2024; Article no.JEAI.116508
ISSN: 2457-0591
(Past name: American Journal of Experimental Agriculture, Past ISSN: 2231-0606)

Survey and Characterization of Ground Water Quality and its Effect on Soil Properties in Malpura Block of Tonk District Rajasthan, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JEAI/2024/v46i62480

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/116508

Original Research Article

Received: 22/02/2024
Accepted: 24/04/2024
Published: 04/05/2024

ABSTRACT

In Malpura block of Tonk district, a survey was conducted to evaluate the quality of the groundwater and determine how it affected the soil qualities. Using a handheld GPS, 60 groundwater samples and 60 soil samples overall were taken at six sites include Lawa(V_1), Borkhandi(V_2), Kadila(V_3),

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Jankipura(V_4), Diggi(V_5) and Nukkad(V_6) in the Malpura block of the Tonk district. The pH, EC, SAR and RSC of ground water ranged from 6.95-8.40, 2.18-3.15(dsm^{-1}), 2.73-10.45 (m mol/L), 1.64-22.3 (meq/L), respectively. The anion contents followed the pattern Cl>SO_4^{2}> HCO_3>NO_3>CO_3^{2} whereas the cations were found to be in the following order: Na^+> Mg^{2+}> Ca^{2+}> K^+. The village of Lawa had the lowest saturation rate (22.84%) and Diggi had the highest saturation percentage (38.34%). The correlation coefficient revealed that electrical conductivity (EC) of soil saturation extract was significantly and positively correlated with EC (0.625), Cl^- (0.200) and Na^+ (0.242) of Groundwater used for irrigation.

Keywords: Water quality; electrical conductivity; saturation percentage; RSC, SAR; soil properties.

1. INTRODUCTION

The quality of irrigation water stands as a crucial factor impacting crop production and soil health. In groundwater assessments, precise laboratory analysis of water quality is indispensable for its optimal utilization. Hydro chemical studies play a pivotal role in determining water suitability for various human purposes like drinking, industrial, and agricultural uses. Given water's proficiency as a solvent, understanding the geochemistry of dissolved constituents and adopting appropriate methods for reporting analytical data becomes imperative. Usually groundwater has base cations (Ca^{2+}, Mg^{2+}, Na^+), bicarbonate and pH in neutral to slightly alkaline range [1]. Quality of water for irrigation is correlated to its impact on soils and crops as well as its management. For agriculture to remain sustainable, effective management of soil and water is crucial. Monitoring soil and water parameters becomes essential in this regard. In arid and semiarid regions, excessive groundwater extraction and declining water quality pose significant threats to crop productivity [2]. The impact of irrigation water on soil infiltration rates depends on the balance between the soil's flocculating effects caused by specific conductance and the dispersion effects of sodium. Soils can tolerate irrigation waters with high *Sodium adsorption ratio* SAR values if specific conductance values are also high. However, besides water quality, other factors such as soil type, crop type, crop pattern, precipitation, etc., significantly influence the suitability of water for irrigation. The quality of water is crucial for its suitability in various uses, including irrigation. Maximum yields in agriculture can be achieved when water quality is good and managed appropriately with suitable soil conditions. However, the salt problem in soils arises when irrigation water contains high levels of soluble salts, which accumulate in the root zone as plants absorb water, thereby reducing yields. Severe water scarcity is becoming increasingly prevalent in many parts of the world, especially in arid and semi-arid regions. Despite the poor quality of irrigation water in these areas, its usage persists due to the absence of alternative water sources. Salinity levels in groundwater wells across Rajasthan range from 2.1 to 9.1 dSm^{-1} choudhary et al. [3]. The excessive rise in soil salinity due to irrigation with saline water can either hinder or completely halt plant growth. Apart from osmotic stress, plant productivity suffers from specific ionic toxicities, limited nutrient availability, and imbalanced cation levels within plants. These soils, which are irrigated with poor quality groundwater in arid and semi-arid regions, typically have low organic matter content and consequently lack fertility. Hence, it is crucial to manage irrigation water wisely in these soils, just as vital as their reclamation efforts Chaudhary et al. [4]. The water quality in Malpura is deteriorating primarily due to the excessive use of fertilizers and pesticides. Additionally, on-going development activities and the over exploitation of water resources have exacerbated this issue, impacting both the quality and quantity of available water. Urban development, particularly pavement construction, has led to reduced groundwater recharge and increased withdrawal, further limiting its availability for use [5]. Hence, it is imperative to evaluate the quality of irrigation water to establish effective irrigation plans and anticipate the potential for secondary salinization or sodification in Malpura. Therefore, considering these factors, the current study was conducted.

2. MATERIALS AND METHODS

Area and location Malpura is a block in Tonk district Rajasthan and it is located at *latitude: 26° 16' 48.00" N longitude: 75° 22' 48.00" E*. It has an average elevation of 132 metres (401 feet). Distance from Jaipur 90 km, Malpura is also known for Avikanagar – 4 km from Malpura. It is known for the Central Sheep and Wool Research Institute (CSWRI) the total geography area of malpura block is 3164.46 hectares. Tonk district is situated in agro-climatic zone 3-A.

2.1 Soil and Climate

Most of the soil of malpura block is sandy, sandy loam type and the climate specifically the semi-arid eastern plain zone the climate of malpura is different from typical semi-arid Rajasthan and is more sub-humid climate [6]. The area does remain dry for almost part of the year and humidity increases only during the monsoon months. Summers are hot and during the peak summer months of May-June the temperature soars to more than 45°C. In winter months that stretch from November to February the mean temperature is low, around 22 °C but the lowest temperatures dip to around 4-5°C. Rainfall is moderate as the average annual rainfall in this district is about 508 mm and rains are received during the monsoon months of July to September.

2.2 Collection of Water Samples

Sixty representative irrigation water samples were collected in 500 ml nerrow neck plastic water sampling bottles during the pre-monsoon period (April- may) in the year 2021 from 6 different villages of Malpura block. These villages include Lawa(V_1), Borkhandi(V_2), Kadila(V_3), Jankipura(V_4), Diggi(V_5) and Nukkad(V_6). The samples were analyzed for different water quality parameters. To prevent microbial growth, 2-3 drops of toluene were added to the water samples and brought to the laboratory for further analysis.

2.3 Analysis of Water Samples

According Table 1, these methods were used to check the irrigation groundwater quality In the laboratory, the water quality analysis was carried out following standard methods outlined in the APHA (American Public Health Association) guidelines from 1992. The specific parameters analyzed were as follows:

1. **pH**: The pH level of each water sample was determined using a pH meter, which measures the acidity or alkalinity of the water.
2. **Electrical Conductivity (EC):** An EC meter was used to measure the electrical conductivity of the water samples. This measurement provides an indication of the concentration of dissolved salts or ions, which influences the water's salinity.
3. **Chlorides**: The concentration of chlorides in the water samples was estimated using Mohr's titration method with the assistance of 0.02N silver nitrate and potassium chromate indicator.
4. **Carbonates and Bicarbonates**: The content of carbonates and bicarbonates in the water samples was determined through the simple acidimetric titration method described by Richards in [7]
5. **Water-Soluble Sodium and Potassium**: A flame photometer was employed to measure the levels of water-soluble sodium and potassium in the water samples.
6. **Total Ca^{2+} + Mg^{2+}**: The total concentration of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions was determined using a complexometric titration method that involved the use of ethylene diamine tetra acetic acid (EDTA).
7. **$SO4^{-2}$:** The turbidimetric method for the analysis of sulfate in irrigation water.

2.4 Characterization of Irrigation Water

A) ***Sodium adsorption ratio (SAR)***: SAR, which measures the alkali/sodium hazard level to the crops, is the sodium toxicity indicator expressed in mmol L^{-l}.

$$\text{SAR } (\text{mmol}^{-1})^{1/2} = \frac{Na^{+}}{\sqrt{\frac{Ca^{+2}+Mg^{+2}}{2}}}$$

B) ***Residual sodium carbonate (RSC)*:** Water containing carbonate plus bicarbonate concentration greater than the calcium plus magnesium concentration referred to as “Residual Sodium Carbonate” and calculated as (Raghunath1987).

$$\text{RSC (me L}^{-1}) = (CO3^{2-} + HCO3^{-}) - (Ca^{2+} + Mg^{2+})$$

C) ***Soluble sodium percentage (SSP)*** (Wilcox, 1955)

$$SSP\ (meq\ l^{-1}) = \frac{Na\times 100}{Ca + Mg + Na}$$

D) ***Permeability index (PI)*:** Permeability index was calculated using the following formula:

$$PI(meq\ l^{-1}) = \frac{Na+\sqrt{HCO3}}{Ca + Mg + Na}\times 100$$

E) ***Kelly's ratio (KR)*:** Kelly's ratio of unity as given by Kelly (1963) of the samples was calculated by using the following formulae:

$$KR(meq\ l^{-1}) = \frac{Na^{+}}{Ca^{+2} + Mg^{+2}}$$

Table 1. Methods to be used for checking of irrigation groundwater quality

S. No.	Experiment	Method	Reference
1.	EC	With the help of EC meter as per method (4b) USDA Hand book No. 60	Richards [7]
2.	pH	pH meter	Richards [7]
3.	$Ca^{2+} + Mg^{2+}$	With standard EDTA solution as per method No. 7 USDA, Hand book No. 60	Richards [7]
4.	Na^{+}	With the help of flame photometer as per method (10a) USDA, Hand book No. 60.	Richards [7]
5.	$CO3^{2-}$ + $HCO3^{-}$	With standard H_2SO_4 as per method 12, USDA, Hand book No. 60.	Richards [7]
6.	Cl^{-}	With standard $AgNO_3$ as per method No. 13, USDA Hand Book No. 60	Richards [7]
7.	SAR	SAR = Na+ / [(Ca^{2+} + Mg^{2+})/2]0.5 Where soluble cations are in me/L	Richards [7]
8.	RSC	($CO3^{2-}$ + HCO3-) – (Ca^{2+} + $Mg^{2+)}$ Where $CO3^{2-}$ + $HCO3^{-}$, Ca^{2+} and Mg^{+} are in me/ L	Richards [7]
9.	$SO4^{-2}$	Turbidimetric method	Richards [7]

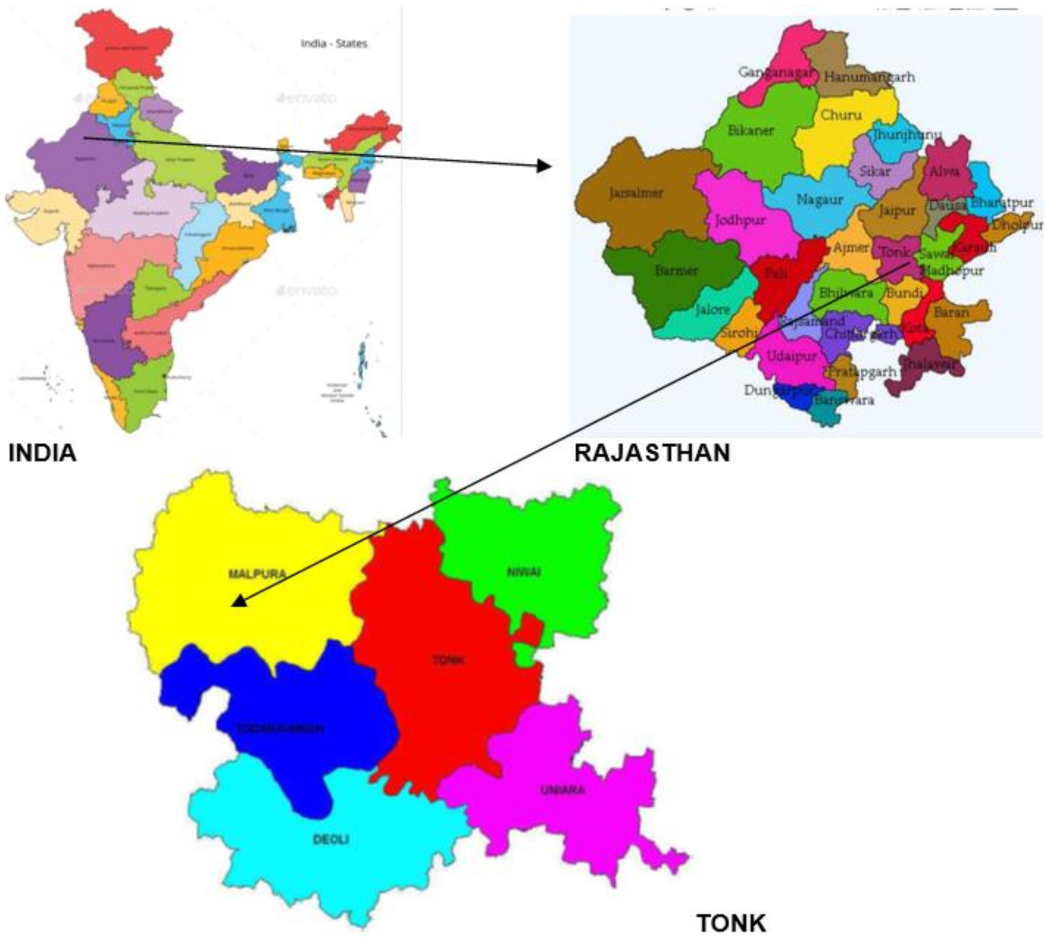

Fig. 1. Location Map of the study area [6]

2.5 Determination of Soil Properties

Soil samples were collected from 0-15 cm depth of fields with the help of auger depending upon the results of ground water quality for fulfilling the purpose of determination of impact of groundwater quality on various soil properties. Soil samples were collected from same field from where groundwater samples of different categories were collected. A total of 6 sites were selected, 10 from each category of water quality for sampling of soil samples in Malpura Block on the basis of results of water quality analysis. Soil samples were analyzed for EC (1:2), pH (1:2), $CaCO_3$, saturation percentage as per standard procedures. For preparation of soil saturation paste, 2 mm sieved soil sample was taken in a beaker and distilled water added to it while stirring with spatula. This method of preparation of soil saturation paste was explained by US Salinity Laboratory Staff, 1954. Then saturation extract collected from soil saturation paste was used for analysis of various soil properties such as, EC (1:2), soluble cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (CO_3^{2-}, HCO_3^{-} $Cl^{–}$, SO_4^{2-}) as per standard procedures as described for water analysis [7] Statistical methods.

2.6 Statistical Methods

Karl Pearson method of correlation was used for computation of correlation coefficient among various parameters of groundwater and soil extracts [9]

3. RESULTS AND DISCUSSION

3.1 Quality of Irrigation Water

The values of different water quality parameters were depicted in Table 2. The result of analysis of ground water samples of malpura block showed that pH, EC, SAR and RSC ranged from 6.95-8.40, 2.18-3.15(dsm^{-1}), 2.73-10.45 (m mol/L), 1.64-22.3 (meq/L), respectively. The lowest value of pH (6.95), EC (2.18dS m-1) and SAR 2.73 (m mol/L), found in village Diggi, Lawa, Kadila, respectively while the highest value of pH (8.40), EC (3.15 dS m$^{-1)}$ and SAR 10.45(m mol/L) found in village Jankipura, Jankipura, Nukkad. According to the pH value, water of Malpura block can be classified as slightly acidic to alkaline in nature. Higher value of pH could be due to high concentration of ions such as Sodium and bicarbonates. Bicarbonates produce hydroxyl ion which is reason for increase or decrease in pH value. Mukesh [10], Deshmukh [11], The cations were found to be in the order of Na^{+}> Mg^{2+}> Ca^{2+}> K^{+} and ranged from 7.78 to 13.98 meq l^{-1}, 2.15 to 16.70 meq l^{-1}, 3 to 7.25 meq l^{-1}, 0.08 to 1.2 meq l^{-1} respectively while anions followed in order of Cl-> SO4^{-2}-> HCO3-> NO^{-}3->CO3^{2-} and varied from 6.1 to 43.18 meq l^{-1}, 1.2 to 3.72 meq l$^{-1,}$ 8.60 to 24.89 meq l$^{-1,}$ 0.21 to 0.80 meq l^{-1}, 2 to 14 meq l^{-1} respectively. Sodium was recorded as governing cation among all the cations (Ca2+, Mg2+, Na+, K+) examined. The high concentration of sodium in groundwater is primarily due to the solubility of sodium compounds and their presence in aqueous solutions, as well as the exchange of cations in groundwater minerals. Additionally, the leaching of salts from surface soil by irrigation or rainwater could contribute to the dominance of Na+ and Cl- ions in groundwater. In the study, it was observed that the concentration of all cations analyzed increased with the electrical conductivity (EC) value in the area, except for potassium, which remained relatively stable. Notably, the increase in sodium and magnesium concentration was much more significant compared to other anions. These findings align with previous research by Shahid et al. [12] and Rathi et al. [13]. The presence of magnesium in groundwater may be attributed to ion exchange processes with minerals in the surrounding soils and rocks. However, the concentration of potassium and carbonates was found to be very low or negligible.

3.2 AICRP (1989) Classification of Groundwater Quality of Gurugram block

The water samples were classified based on the criteria given by All India Coordinated Research Project (AICRP) on “Management of Salt Affected Soils and Use of Saline Water in Agriculture” (1989) in which water quality has been grouped into three categories such as good, saline and alkali. This classification is based upon EC, SAR and RSC Parameters. Based on the limits of various parameters, two poor quality water classes have been further classified each into 3 subclasses. The data pertaining to classification of groundwater quality as per AICRP (1989) criteria according to which 7 groundwater samples were recorded under good (A) category, 3 under saline (B), 19 under marginally saline (B1) category, 6 under saline (B2) category, 12 under high SAR saline (B3) category, 4 under marginally alkali (C1) category, 3 under alkaline condition and 6 under high alkali (C3) category is presented in Table 4. Fig. 3

represents the distribution percentage of water samples and spatial variability of groundwater quality in different water quality categories of Malpura block.

Table 2. Irrigation water quality classification criteria (AICRP on Management of Soil Affected Soils and Use of Saline Water in Agriculture, 1989*)

Sr. No.	Quality of water	Class	Quality parameters		
			EC (dS m^{-1})	SAR (mmol $l^{-1})^{1/2}$	RSC (mel^{-1})
1.	Good	A	<2	<10	<2.5
2.	Saline	B	-	-	-
	Marginally saline	B_1	2-4	<10	<2.5
	Saline	B_2	>4	<10	<2.5
	High SAR saline	B_3	>4	>10	<2.5
3.	Alkali water	C	-	-	-
	Marginally alkali	C_1	<2	<10	2.5-4
	Alkali	C_2	<2	<10	>4
	Highly alkali	C_3	variable	>10	>4

**Tiwari and Sharma [8]*

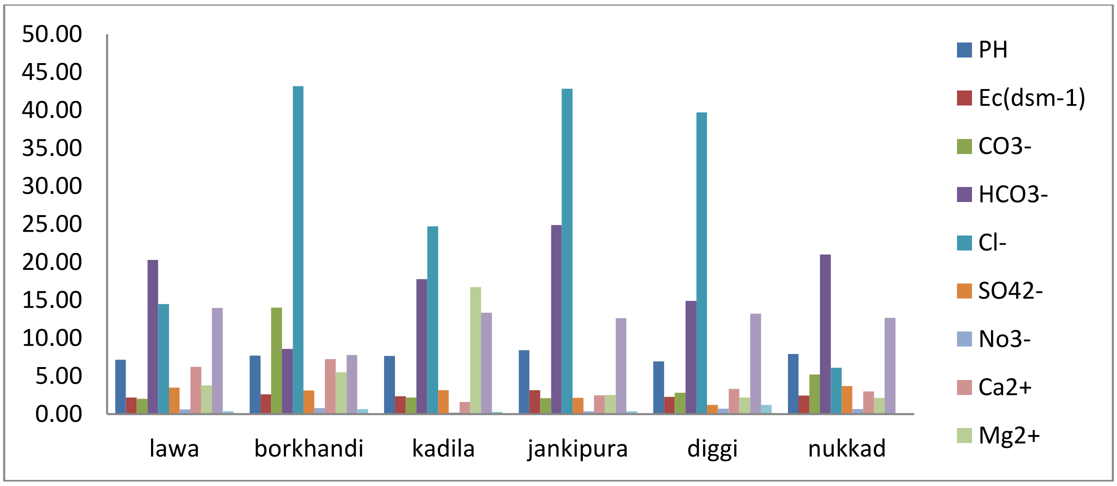

Fig. 2. Chemical composition of Groundwater water

Table 3. Chemical composition of Groundwater water used for irrigation in different villages of Malpura block

Properties	lawa	Borkhandi	kadila	Jankipura	Diggi	Nukkad
PH	7.15	7.70	7.65	8.4	6.95	7.9
Ec(dsm^{-1})	2.18	2.60	2.35	3.15	2.25	2.44
$CO3^-$	2.00	14.00	2.20	2.1	2.8	5.2
$HCO3^-$	20.30	8.60	17.75	24.89	14.9	21.01
Cl^-	14.50	43.18	24.73	42.82	39.7	6.1
$SO4^{2-}$	3.48	3.10	3.15	2.15	1.2	3.72
No_3^-	0.63	0.80	0.21	0.39	0.7	0.67
Ca^{2+}	6.22	7.25	1.61	2.46	3.3	3
Mg^{2+}	3.79	5.50	16.70	2.51	2.2	2.15
Na^+	13.98	7.78	13.35	12.62	13.2	12.68
K^+ (meq/L)	0.39	0.65	0.30	0.38	1.2	0.08
SAR (m mol/L)	7.05	8.90	2.73	6.61	3.05	10.45
RSC (meq/L)	12.29	9.85	1.64	22.03	12.22	21.06
SSP(meq/L)	51.15	26.29	64.80	76.55	74.62	75.67
KR (meq/L)	5.76	6.43	31.05	9.30	8.16	11.03
Pi(%)	70.36	42.22	85.17	108.43	95.50	102.86

Table 4. AICRP (1989) classification of groundwater quality of Malpura block

Sr. No.	Quality of water	Class	Number of sample	Percentage
1.	Good	A	7	11.7
2	Saline	B	3	5
	Marginally saline	B_1	19	31.7
	Saline	B_2	6	10
	High SAR saline	B_3	12	20
3	Alkali water	C	-	-
	Marginally alkali	C_1	4	6.7
	Alkali	C_2	3	5
	Highly alkali	C_3	6	10

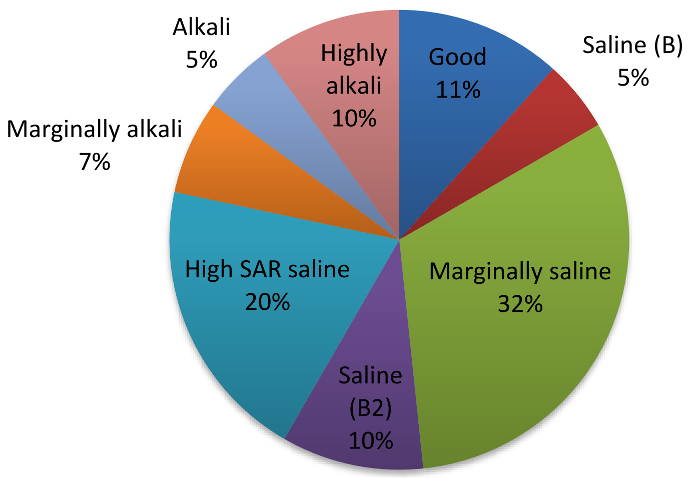

Fig. 3. Water quality distribution as per AICRP (1989)

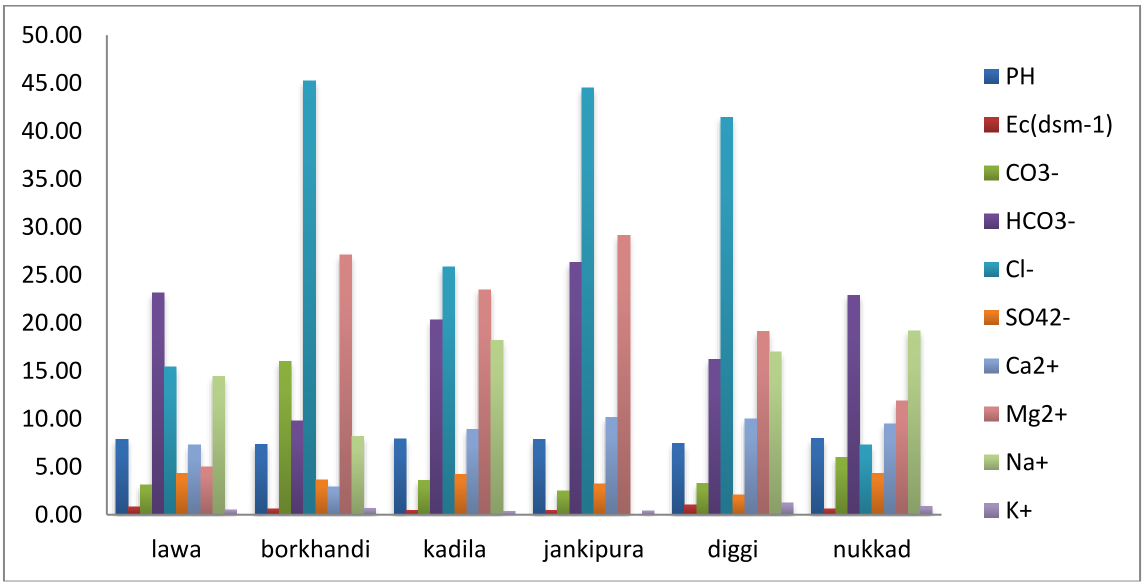

Fig. 4. Effect of ground water quality on soil properties

3.3 Chemical Properties of Soil

The data related to chemical properties of soil were illustrated in Table 5. In the Malpura block village of jankipura (0.93 dS m^{-1}), where water of good quality (A) category was used for irrigation, the mean lowest EC of saturation extract was found. The village of Diggi (3.04 dS m^{-1}) in Malpura block, where high SAR saline (B3) category water was used for irrigation, had the mean highest EC of saturation extract. Village Borkhandi and Nukkad had the mean lowest and mean highest pH readings, respectively, of 7.35 and 8.3. The sodium content was found range from from 8.16 to 19.20, lowest sodium content was found in Borkhandi while highest was found in Nukkad village. The village of Lawa had the lowest saturation rate (22.84%) and Diggi had the highest saturation percentage (38.34%). Average accumulation of cations and anions was found to be in the following order: $Na^{+}>Ca^{2+}>Mg^{2+}>K^{+}$ and $Cl^{-}> HCO_3^{-}> SO_4^{2-}>CO_3^{2-}$ respectively.

3.4 Statistical Analysis of different Water Quality Parameters and Soil Saturation Extract of Malpura Block

The correlation coefficient revealed that electrical conductivity (EC) of soil saturation extract was significantly and positively correlated with EC (0.625), Cl^{-} (0.200) and Na^{+} (0.242) of Groundwater used for irrigation. Similarly, Cl^{-} and Na^{+} of soil saturation extract were significantly and positively correlated with EC (0.514), Cl^{-} (0.786) and EC (0.130), Na^{+} (0.832) of groundwater used for irrigation, respectively. The data pertaining to correlation coefficient between groundwater and soil parameters of Malpura block is presented in Table 6.

3.5 Impact of Ground Water on Soil Properties

The pH of soil showed irregular trend with different villages. It followed decreasing trend in some of the villages whereas in some of the

Table 5. Effect of ground water quality on soil properties of different villages of Malpura block

Property	lawa	borkhandi	kadila	jankipura	diggi	nukkad
PH	7.85	7.35	7.90	7.85	7.45	8.3
Ec(dsm^{-1})	0.81	0.60	0.48	0.47	3.04	0.61
$CO3^{-}$	3.1	16	3.6	2.5	3.3	6
$HCO3^{-}$	23.12	9.80	20.34	26.30	16.2	22.9
Cl^{-}	15.42	45.23	25.83	44.50	41.45	7.30
$SO4^{2-}$	4.32	3.63	4.20	3.24	2.10	4.30
Ca^{2+}	7.28	2.91	8.90	10.14	10.01	9.50
Mg^{2+}	5.00	27.10	23.47	29.15	19.15	11.86
Na^{+}	14.43	8.16	18.20	16..23	16.98	19.20
K^{+}(meq/L)	0.54	0.70	0.35	0.43	1.3	0.90
saturation %	22.84	30.32	34.57	28.32	38.34	29.55
$CaCo_3^{-}$ (%)	0.52	1.00	1.50	1.73	1.88	2.63

Table 6. Correlation coefficient between ground water and soil parameters of Malpura block

	ECiw	EC (Soil)	PH (water)	PH (Soil)	Cl^{-} (water)	Cl^{-} (Soil)	Na^{+}(water)	Na^{+} (soil)
ECiw	1							
EC (Soil)	0.625**	1						
PH (water)	0.880	-0.868	1					
PH (Soil)	0.072	-0.461	0.390	1				
Cl^{-}(water)	0.513	0.200**	0.122*	-0.700	1			
Cl^{-}(Soil)	0.514**	0.021	0.123	-0.706	o.786**	1		
Na^{+}(water)	0.298	0.242**	-0.232	0.681	-0.490	-0.499	1	
Na^{+} (soil)	0.130**	0.007	0.059	0.709	-0.505*	-0.509	0.832**	1

***Correlation is significant at p= 0.01 level of significance*
**Correlation is significant at p= 0.05 level of significance*

villages, it increased with increase in soil profile depth. Reason behind highest value of pH in 0-15 cm soil depth was precipitation of calcium and magnesium carbonates in course of evaporation process due to presence of HCO3- ions along with exchangeable and soluble sodium. So, an indication of sodicity and salinity development was given by high value of pH of soil saturation extract. Vijaykant [14] and Rathi et al. [13] observed similar results.

Due to increase in sodium and clay content, increase in pH with depth in soil profile was observed whereas decrease in pH value with soil depth might be due to release of hydrogen ion under influence of soluble cation present in applied irrigation water. Similar results were confirmed by Gandhi et al. [15] and Tikkoo et al. [16]. In the majority of the villages in the Malpura block, the saturation percentage of the soil profile had a strange relationship to the depth of the soil profile. Similar findings were also reported by choudhary et al. [6]. Calcium carbonate content where found was due to dissolution and leaching of carbonate and bicarbonate in coarse textured soil and CO_2 evolution due to high temperature resulted in calcium carbonate content at these sites [17,18].

The surface layer of soil tends to accumulate the maximum concentration of cations and anions, which then decreases with depth. This phenomenon could be attributed to the capillary action of water, causing the movement of these ions towards the surface layer. The high concentration of ions in the surface layer may be a result of sampling before the monsoon season and evaporation due to the high temperatures experienced during the summer months. Additionally, an increase in electrical conductivity (EC) at lower depths in some areas may lead to higher concentrations of certain ions further down in the soil profile More et al. [19]

4. CONCLUSIONS

The findings showed that a significant portion of the Malpura block had poor-quality water, with the majority being saline rather than alkali. Therefore, it's crucial to develop specialized management strategies considering climatic conditions, soil texture, and the types of crops to be cultivated. This approach is necessary to ensure the efficient use of poor-quality groundwater for sustainable crop production without compromising soil quality.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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