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Prabhoo Singh
Department of Soil Science,
S.K.N. Agriculture University,
Jobner, Jaipur, Rajasthan, India

KK Sharma
Department of Soil Science,
S.K.N. Agriculture University,
Jobner, Jaipur, Rajasthan, India

Corresponding Author:
Prabhoo Singh
Department of Soil Science,
S.K.N. Agriculture University,
Jobner, Jaipur, Rajasthan, India

Poor quality of underground irrigation water: In western Rajasthan, India

Prabhoo Singh and KK Sharma

Abstract
Groundwater quality depends on the nature of recharging water, precipitation, subsurface and surface water. Groundwater tables are depleting at an accelerated rate and the groundwater quality is rotating substandard due to inflated natural processes and unsuitable artificial activities. In this paper gives imminent into the numerous irrigation water quality measures as well as describes the effects of poor quality groundwater on crop production and soil properties. Poor water quality must be managed carefully in arid and semi arid region. One hundred fifty water samples collected from irrigated area of Nagaur district of Rajasthan and revealed that 0.66 per cent water samples were good water, 1.33 per cent were marginally saline, 16.67 per cent were saline, 18 per cent were high SAR saline, 32 per cent were marginally alkali, 20 per cent were alkali and 11.34 were per cent high alkali categories, respectively. Basic criteria for evaluating water quality for irrigation purposes are described, including water Salinity (EC), Sodium hazards (Sodium adsorption ratio), Salt index, Bicarbonate hazard (Residual Sodium Carbonates (RSC), Boron concentration, Chloride concentration, Soluble sodium percentage, Magnesium hazard and ion toxicity.

Keywords: Irrigation water, salinity, SAR, salt index, RSC, boron concentration, chloride concentration, SSP and magnesium hazard

Introduction
Water quality is critical for the survival of humans, animals, industry and agriculture. Furthermore, the proper management is requisite to meet water quality standards and for ecosystem health (Narasaiah and Rao, 2021) [15]. The agriculture success is highly dependable on the quality of water applied in an agriculture area. Due to the application of poor or hazardous quality water the agriculture land/soil is affected and damages the crop yield in several ways. The accumulation of salts in root zone, limited the availability of water and plant can take up lesser water which resulted in high plant stress and decreased crop yields (Shakoor, 2015) [21]. The quality of water is, thus, an important component with regard to sustainable use of water for irrigated agriculture, especially when salinity development is expected to be a problem in an irrigated agricultural area. The characteristics of water quality have become important in water resources planning and development for drinking, industrial and irrigation purposes (Kumar and Kuriachan 2022) [16]. Water quality is the basic to judge the fitness of water for its proposed application for existing conditions. The current information is required, provided by water quality monitor for optimum development and management of water for its proficient uses (Latha, 2019) [12].

The presence of metals in irrigation water also has adverse effects on crop production. Also, high concentration of salts can change the plant nutrients balance in the soil meanwhile some salts are toxic to certain plants (Shakoor *et al*., 2015; Irfan *et al*., 2014) [21, 9]. Irrigation water quality is defned by the type and concentration of dissolved salts and solids (Etteieb *et al*. 2017) [6]. Irrigation water quality information holds critical importance for understanding the changes in the product quality, and the required modifcations in water management (Ramakrishnaiah *et al*. 2009) [17].

The availability of water for irrigation purposes involves a number of issues such as the quantity and quality of water. However, quality aspects are generally overlooked while considering the quantity of water. Irrigation water quality is generally defned in terms of total dissolved solids, major cations and anions. The three most common issues associated with low water quality around the world are salinity, reduced permeability and increased specifc ion toxicity (Singh *et al*. 2018) [23].

Material and Methods

Experimental Site: The study was carried out in Nagaur district situated in North-Eastern part of Rajasthan state of India located at 26^0 25' 40" & 27^0 40' 35" North latitude and 73^0 10' 22" & 75^0 15' 55" East longitude. Ground water samples and irrigated soil samples from 150 tube wells/open wells were collected randomly from 150 villages of command area of Nagaur district.

Salinity Hazard: The groundwater becomes saline if high salt content is present. The evaluation of salinity hazard is an important parameter of agriculture water as high salt content of irrigation water causes the soil to become saline, and it also adversely affects the salt intake efficiency of the plants. Electrical conductivity (EC) and total dissolved solid (TDS) values are measure of salinity hazard of irrigation water. According to USSL classification, four salinity classes *i.e*. C1, C2, C3 and C4 have been proposed based on EC values expressed as mSm^{-1}.

Sodium Hazard (SH): Sodium hazard is assessing by evaluate soluble sodium percentage and sodium absorption ratio and drawing Wilcox diagram. According to Gholami and Srikantaswamy (2009) [17], the alkali or sodium hazard can be expressed in terms of sodium adsorption ratio. Sodium hazard is the main parameter for assessment of groundwater suitability for irrigation purpose. Sodiumenriched groundwater is unsuitable for irrigation of agricultural lands.

Sodium Adsorption Ratio (SAR): SAR is calculating by the equation given by Raghunath 1987. The concentration of the ions is express in meq L^{-1}.

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

Adjusted SAR: Adj. SAR = SAR (1+8.4-pH_c). (Ayers and Westcot, 1976) [2].

Carbonate and Bicarbonate Hazard (CBH): Carbonate and bicarbonate hazard is assessing by evaluating soluble sodium carbonate.

Residual Sodium Carbonate (RSC): A high value of RSC in irrigation water means an increase in the adsorption of Na^+ in the soil. Water having more 5 RSC has not been recommended for irrigation because of damaging effects on plant growth. Generally any source of water in which RSC is higher than 2.5 is not considered for irrigation purpose, and water <1.25 is recommended as safe for irrigation purpose. A negative value of RSC reveals that concentration of Ca^{2+} and Mg^{2+} is in excess. A positive RSC denotes that Na^+ existences in the soil are possible. RSC calculation is also important in context to calculate the required amount of gypsum or sulfuric acid per acre-foot in irrigation water to neutralize residual carbonates effect. This is evaluating by the following equation of Eaton, 1950.

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

Where CO_3^{2-}, HCO_3^-, Ca^{2+} and Mg^{2+} are in me L^{-1}

Potential salinity: PS is another water quality parameter-based index (Doneen, 1964) [4] for categorization of water for agriculture use. PS <3 $meqL^{-1}$ is an indication of the suitability of water for irrigation.

$$PS = Cl^- + 0.5 \times SO_4^{2-}$$

pH_c: A theoratical calculated pH of irrigation water in contact with lime and in equilibrium with soil CO_2

$$PH_c = (pk_2 - pk_c) + pCa + p\,(alk)$$ (Gupta, 1979) [7].

Where,

($pk_2 - pk_c$): Obtained from using the sum of $Ca^{2+} + Mg^{2+} + Na^+$ in me L^{-1}

pCa: Obtained by using the sum of Ca^{2+} in me L^{-1}

p (alk): Obtained by using the sum of CO_3^{2-} +HCO_3^- in me L^{-1}

Table 1: Classification of irrigation water based on combined evaluation of EC, SAR and RSC (Gupta *et al.* 1994) [8].

	Water quality	EC (dS m^{-1})	SAR	RSC (me L^{-1})
1.	Good	<2	<10	<2.5
2.	Marginally saline	2-4	<10	<2.5
3.	Saline	>4	<10	<2.5
4.	High-SAR saline	>4	>10	<2.5
5.	Marginally alkali	<4	<10	2.5-4
6.	Alkali	<4	<10	>4.0
7.	Highly alkali	Variable	>10	>4.0

Table 2: Guidelines for irrigation water quality established by Food and Agriculture Organization (FAO) (Ayres and westcot, 1976) [2].

	Water constituent	Intensity of problem		
		No problem	Moderate	Severe
1.	pH	6.5-8.5	-	0-5, >8.5
2.	Salinity (dS m^{-1})	<0.75	0.75-3.0	>3.0
3.	Sodium (as adjusted SAR)	<3	3-9	>9
4.	Chloride (me L^{-1})	<4	4-10	>10
5.	Boron (me L^{-1})	<0.75	0.75-2.0	>2.0
6.	HCO_3^- (me L^{-1})	<1.5	1.5-8.5	>8.5

Table 3: Classes of irrigation water based on Quality/Suitability

S. No.	EC	Quality/Suitability
1.	C1=<0-25	Suitable for irrigation
2.	C2=25-75	Suitable for irrigation
3.	C3=75-225	Not suitable
4.	C4=225-500	Not suitable
	SSP	
1.	0-20	Excellent
2.	20-40	Good
3.	40-60	Permissible
4.	60-80	Doubtful
5.	>80	Not suitable
	SAR	
1.	S1=<10	Low
2.	S2=10-18	Medium
3.	S3=18-26	High
4.	S4=>26	Very high
	RSC	
1.	<1.25	Good
2.	1.25-2.50	Doubtful
3.	>2.50	Unsuitable
	Potential Salinity	
1.	<5	Good
2.	5-10	Doubtful
3.	>10	Unsuitable

***Source*:** Richard, 1954

Result and Discussion

Quality of underground irrigation water

SAR of underground irrigation water was recorded from Nagaur district, 8.5 minimum and 22.78 maximum with the average value of 15.05. High sodium concentrations affect soil permeability and have direct effect on total salinity of water. The detection of salinity hazard depends on electrical conductivity measurements. The concept of SAR is used for detection of a probable sodium hazard. Similar results also reported by Almeida *et al*. 2008 [1], Kumar *et al*. 2017 [17], Meena 2017 [13] and More *et al*. 2017 [14].

RSC of underground irrigation water was recorded from Nagaur district, 3.30 (me L^{-1}) maximum and -3.70 (me L^{-1}) minimum with the average value of 0.40 (me L^{-1}). Similar results also reported by Roy *et al*. 2018 [20] and Singh 2017. The Residual sodium carbonate indicates the excess of carbonate and bicarbonate over calcium and magnesium in irrigation water. Generally these types of waters are dominating in HCO_3^- over CO_3^{2-}.

Mg/Ca ratio of underground irrigation water of various tehsils was recorded from 0.57 to 1.83 with the average value of 1.14 in Nagaur, 0.39 to 1.43 with the average value of 0.98 in Jayal, 0.66 to 1.56 with the average value of 1.04 in Didwana, 0.57 to 1.36 with the average value of 0.97 in Ladnu, 0.33 to 1.56 with the average value of 1.00 in Nawa, respectively. In Mg/Ca ratio the effects of excessive magnesium over calcium of the underground irrigation water were taken into consideration. Similar results were also reported by Kumar *et al*. (2016) [10] and Selvakumar *et al*. (2017) [10].

pH_c of underground irrigation water of various tehsils were varied from 7.20 to 8.20 with the average value of 7.55 in Nagaur, 7.10 to 7.80 with the average value of 7.43 in Jayal, 6.90 to 7.90 with the average value of 7.42 in Didwana, 7.20 to 8.10 with the average value of 7.47 in Ladnu, 7.20 to 8.00 with the average value of 7.49 in Nawa, respectively. The pH_c of underground irrigation water refers to a theoretical, calculated value of pH in contact with lime and equilibrium with soil carbon dioxide. These low values of pH_c indicates the tendency to precipitate lime from the applied irrigation water. Similar results were also reported by Wilcox (1966), Ayers and Westcot (1976) [2].

The calculated adjusted sodium adsorption ratio of underground irrigation water of various tehsils was recorded from 10.21 to 44.67 with the average value of 28.06 in Nagaur, 20.65 to 47.60 with the average value of 35.75 in Jayal, 20.01 to 52.47 with the average value of 35.04 in Didwana, 15.89 to 47.57 with the average value of 32.45 in Ladnu, 19.89 to 53.95 with the average value of 35.41 in Nawa, respectively. In adjusted sodium adsorption ratio the effects of excessive sodium of high carbonate or bicarbonate and total salts load of the water were taken into consideration. Similar results were also reported by Verma *et al*. (2016) [25].

Boron of underground irrigation water of various tehsils was varied from 0.20 to 3.20 ppm with the average value of 1.30 ppm in Nagaur, 0.50 to 3.20 ppm with the average value of 1.91 ppm in Jayal, 0.40 to 2.70 ppm with the average value of 1.67 ppm in Didwana, 0.45 to 3.00 ppm with the average value of 1.57 ppm in Ladnu, 0.40 to 3.20 ppm with the average value of 1.63 ppm in Nawa, respectively. Irrigation water containing boron between 0.3 to 0.6 ppm can be used safely, whereas, soils irrigated with water containing 1 to 3 ppm causes toxicity of boron in plants. Similar results were also reported by Yuce, G. and Yasin, D.U. (2012) [26].

Potential salinity of underground irrigation water of various tehsils was recorded from 8.80 to 34.84 me L^{-1} with the average value of 22.88 me L^{-1} in Nagaur, 13.30 to 37.62 me L^{-1} with the average value of 26.94 me L^{-1} in Jayal, 10.04 to 39.83 me L^{-1} with the average value of 24.99 me L^{-1} in Didwana, 10.33 to 38.95 me L^{-1} with the average value of 24.76 me L^{-1} in Ladnu, 13.08 to 42.08 me L^{-1} with the average value of 25.71 me L^{-1} in Nawa, respectively. Doneen (1963) [4] introduced the term "Potential salinity" of underground irrigation water and suggested its determination as given below: Potential salinity = (Cl^- + ½ SO_4^{2-}), all soluble ions are expressed as meL^{-1} and recommended permissible limits as 5 - 20, 3 - 15 and 3 – 7 meL^{-1} as good, medium and low permeability, respectively. The adverse effect due to salinity at 20 dS m^{-1} caused in the presence of chloride is the same as that at 40 dS m^{-1} in the presence of sulphates. This is because when both the ions present in high amount, only half of the sulphate ions contribute to salinity due to the fact that approximately half of the sulphates get precipitated as $CaSO_4$ while the another half remains in soluble form as Na-Mg-SO_4 in the soil. Similar results were also reported by More *et al*. (2017) [14] and Riaz *et al*. (2018) [18].

Table 4: Chemical properties of irrigation water of various tehsils of Nagpur district

Tehsils	SAR	RSC (me L^{-1})	Mg/Ca Ratio	pH_c	Adj. SAR	B (ppm)	Potential salinity (me L^{-1})
			NAGAUR				
Max	22.78	3.70	1.83	8.20	44.67	3.20	34.84
Min	8.50	-3.30	0.57	7.20	10.21	0.20	8.80
Mean	15.05	0.40	1.14	7.55	28.06	1.30	22.88
SD	3.96	1.71	0.32	0.22	8.50	0.78	5.97
			JAYAL				
Max	24.35	6.60	1.43	7.80	47.60	3.20	37.62
Min	10.88	-1.90	0.39	7.10	20.65	0.50	13.30
Mean	18.15	1.40	0.98	7.43	35.75	1.91	26.94
SD	3.10	2.12	0.25	0.18	7.03	0.77	6.42
			DIDWANA				
Max	26.51	6.40	1.56	7.90	52.47	2.70	39.83
Min	9.53	-1.80	0.66	6.90	20.01	0.40	10.04
Mean	17.71	2.00	1.04	7.42	35.04	1.67	24.99
SD	4.19	2.12	0.28	0.19	9.07	0.62	9.00
			LADNU				
Max	23.89	5.90	1.36	8.10	47.57	3.00	38.95
Min	9.21	-2.00	0.57	7.20	15.89	0.45	10.33

Mean	16.77	1.00	0.97	7.47	32.45	1.57	24.76
SD	4.06	1.89	0.21	0.22	8.73	0.64	7.80
NAWA							
Max	28.40	5.80	1.56	8.00	53.95	3.20	42.08
Min	10.35	-1.80	0.33	7.20	19.89	0.40	13.08
Mean	18.50	1.60	1.00	7.49	35.41	1.63	25.71
SD	4.94	2.28	0.27	0.18	9.82	0.75	8.51

Underground irrigation water and their suitability

It is evident from the data (Table 5) that the irrigation water of various tehsils of Nagaur district have been classified into three salinity classes (C-1, C-2 and C-3), three sodicity classes (S-1, S-2 and S-3) and five alkalinity classes (A-0, A-1, A-2, A-3 and A-4) as per standard proposed by Gupta (1986) on the basis of salinity (EC), sodicity (SAR) and alkalinity (RSC), respectively.

It is evident from the data given in table 5 revealed that, on the basis of salinity (EC) 0.66 per cent water samples fall under C-1 (Normal salinity water) class, 39.34 per cent under C-2 (Low salinity water) class and 60 per cent under C-3 (Medium salinity water). On the basis of SAR, 2 per cent water samples were rated as S-1 (Normal water), 74.66 per cent water samples as S-2 (Low sodicity water) class and 23.34 per cent water samples as S-3 (Medium sodicity water) class out of 150 irrigation water samples.

Further, on the basis of RSC, 30 per cent water samples fall under A-0 (Non alkaline water), 2 per cent water samples under A-1 (Normal water) class, 44.66 per cent water samples under A-2 (Low alkalinity water) class, 16 per cent under A-3 (Medium alkalinity water) class and 7.34 per cent under A-4 (high alkalinity water) class out of 150 irrigation water samples. Thus, the majority of water may anticipate some problem in the successful maintenance of irrigated soils of this area.

The irrigation water of these five tehsils of Nagaur district was also classified according to guidelines suggested by Gupta *et al.* (1994) [8]. Data (Table 6) indicated that the irrigation water were classified into seven categories, 0.66 per cent water samples were found good, 1.33 per cent water samples were found marginally saline, 16.67 per cent water samples were found saline, 18 per cent water samples were found high SAR saline, 32 per cent water samples were found marginally alkali, 20 per cent water samples were found alkali and 11.34 per cent water samples were found highly alkali in nature. Most of the irrigation water samples were found marginally alkali category out of 150 irrigation water samples.

Table 5: Classification of irrigation water on the basis of salinity (EC), sodicity (SAR) and alkalinity (RSC) of various tehsils of Nagaur district (Gupta, 1986)

S. No.	Water class	No. of water sample	Percent of water sample	Suitability of irrigation water
A.	**Salinity (EC dS m^{-1})**			
1.	Normal water (C-1)	1	0.66%	Can be used for irrigation almost all crops.
2.	Low salinity water (C-2)	59	39.34%	Can be used for irrigation if a moderate amount of leaching of salts. Most of the crops except sensitive crops (leguminous and horticultural crops) can be grown on all soils accept very heavy textured.
3.	Medium salinity water (C-3)	90	60%	Most of the semi-tolerant and tolerant crop varieties can be grown with management.
	Total	150	100%	-
B.	**Sodicity (SAR)**			
1.	Normal water (S-1)	3	2%	Can be used for irrigation on almost all soils for all crops.
2.	Low sodicity water (S-2)	112	74.66%	Can be used for grow semi-tolerant crops on light to medium textured soils and for tolerant crops on heavy textured soils
3.	Medium sodicity water (S-3)	35	23.34%	Can be used only for crops which are tolerant to sodium with good drainage facilities.
	Total	150	100%	-
C.	**Alkalinity (RSC me L^{-1})**			
1.	Non alkaline water (A-0)	45	30%	Can be used for irrigation on almost all soils.
2.	Normal water (A-1)	3	2%	Can be used for irrigation on almost all soils.
3.	Low alkalinity water (A-2)	67	44.66%	Can be used for irrigation on almost all soils but these waters may create permeability problems in impeded drainage conditions.
4.	Medium alkalinity water (A-3)	24	16%	Can be used for irrigation on almost all soils for all crops except those are specifically sensitive to carbonate and bicarbonate.
5.	High alkalinity water (A-4)	11	7.34%	Unsuitable for irrigation
	Total	150	100%	-

Table 6: Classification of underground irrigation water on the basis of EC, SAR and RSC (Gupta *et al.* 1994) [8].

S. No.	Water quality classes	No. of water samples	Percent of water samples
1.	Good (EC <2 dS m^{-1}, SAR <10 and RSC <2.5 me L^{-1})	1	0.66%
2.	Marginally saline (EC 2-4 dS m^{-1}, SAR <10 and RSC <2.5 me L^{-1})	2	1.33%
3.	Saline (EC >4 dS m^{-1}, SAR <10 and RSC <2.5 me L^{-1})	25	16.67%
4.	High SAR saline (EC >4 dS m^{-1}, SAR >10 and RSC <2.5 me L^{-1})	27	18%
5.	Marginally alkali (EC <4 dS m^{-1}, SAR <10 and RSC 2.5-4.0 me L^{-1})	48	32%
6.	Alkali (EC <4 dS m^{-1}, SAR <10 and RSC >4 me L^{-1})	30	20%
7.	Highly alkali (EC <4 dS m^{-1}, SAR >10 and RSC >4 me L^{-1})	17	11.34%
	Total	150	100%

According to classification given by Food and Agriculture Organization (Ayres and westcot, 1976) [2], 122 water samples have no problem and 28 water samples have severe pH problem. In cash of salinity, 60 samples have moderate problem whereas, 90 samples have severe problem of salinity. In cash of sodium and chloride, all samples have been reported severe problem. In cash boron, 90 samples have no problem, 89 samples have moderate problem whereas, 42 samples have severe problem. In cash of bicarbonate, 143 samples have moderate problem and only 7 samples have severe problem out of 150 irrigation water samples (Table 7).

Table 7: Classification of irrigation water on the basis of Food and Agriculture Organization (Ayres and westcot, 1976) [2].

	Water constituent	Intensity of problem		
		No problem	Moderate	Severe
1.	pH	122	0	28
2.	Salinity (dS m^{-1})	0	60	90
3.	Sodium (as adjusted SAR)	0	0	150
4.	Chloride (me L^{-1})	0	0	150
5.	Boron (me L^{-1})	19	89	42
6.	HCO_3^- (me L^{-1})	0	143	7

Recommendation

Use of poor quality waters requires standard irrigation practices: (1) selection of appropriately salt-tolerant crops; (2) improvements in water management, and in some cases, the adoption of advanced irrigation technology; and (3) maintenance of soil-physical properties to assure soil tilth and adequate soil permeability to meet crop water and leaching requirements (LR). This paper looks at farmers' experiences, research, and computer modeling in these areas, and concludes with a discussion of examples of farm experiences with waters that caused problems with infiltration rates and soil tilth and the practices used to mitigate these problems.

Conclusion

Underground Irrigation water of low standard has lowered agriculture production and deteriorated the soil's infiltration properties. After testing the quality of water from irrigation water sources is needed to suggest a proper management method. This review paper summaries the significance of different water quality parameters to classify the water into separate classes according to individual factors or by combining multiple factors. This paper will assist in better planning for future remediation steps. In addition to remediation measures, regulatory processes, especially in the developing world, are essential to developing. The investigation outcomes are beneficial for researchers and students since they provide a detailed description of the global research practices on irrigation water suitability. Several water quality indices have been established to evaluate water quality so the future emphasis has to be on assessing quantity as well as quality to conserve groundwater.

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