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Ionic composition and hazards of poor quality waters for irrigation in southwestern part of Punjab

V. K. VERMA, P. K. SHARMA & R. K. SETIA

Punjab Remote Sensing Centre, Punjab Agricultural University Campus, Ludhiana, Punjab, India

Abstract: *The quality of water is of immense important because poor quality of ground water is not only a limiting factor in crop production but also its constant and indiscriminate use causes secondary salinization. Therefore, a qualitative water quality survey was carried out to diagnose the salinity or sodicity hazards in ground waters in relation to their suitability for irrigation in Faridkot district (Punjab) having two blocks namely Faridkot and Kotkapura. The total concentration of soluble salts in ground waters varied from 0.31-7.53 dS* m^{-1}. *On splitting the analytical data block wise, it was observed that ground waters of Faridkot block pose high salinity hazards than that of Kotkapura block. Among the anions, concentration of* HCO_3^- *varied from 0.5-21.5 me* l^{-1}, *whereas that of* Cl^- *and* SO^{2-}_4 *ranged from 1.00-51.30 and 0.83-48.33 me* l^{-1}, *respectively. The highly saline waters were dominant in* SO_4^{2-} *and* Cl^- *ions rather than* CO_3^{2-} *and* HCO_3^- *ions.* Na^+ *was the dominant cation and its value ranged from 1.74 - 83.93 me* l^{-1}. *The mean sodium adsorption ratio (SAR) of Kotkapura block (17.53 me* $l^{-1})^{0.5}$ *was higher than that of Faridkot block (15.06 me* $l^{-1})^{0.5}$ *indicating more sodicity hazards. The mean residual sodium carbonate (RSC) of ground water indicated that Kotkapura block (4.96 me* l^{-1}) *had more alkalinity hazard than Faridkot block (2.55 me* l^{-1}). *The continuous use of such waters can cause secondary salinization / sodification. At any particular salinity, sodium was always more than other cations and the slope values for* Na^+ *for the district revealed that increase in concentration of* Na^+ *was steeper than other ions. Regression equations were used to predict salinity by using ion concentration as independent variables. Multiple regression analysis indicated that predictability of the relationships between EC and ion concentration improved when Ca+Mg was included along with Na. Among anions, dominance of* SO_4^{2-} *ion was found in under ground waters. Keeping in view the quality of ground water and site specific salinity and sodicity, improved cultural practices including land and water management have been recommended which have direct and positive impacts on the yield of crops.*

Key words: *Ground Water, EC, RSC, and Irrigation*

INTRODUCTION

Irrigation, which is one of the oldest methods of agriculture, also has a long history of different results, favourable and unfavourable. The use of ground water of marginal and poor quality without proper mixing with good waters from canals may degrade the soils, especially at the tail end of the canal system (Mohtadullah, 1997). This practice may also give rise to some apparent and hidden soil problems directly or indirectly associated with tubewell irrigation. Among these, the problem of salinity has been and remains one of the most important (Shainberg and Shelhevet, 1984). Until now, the influence of the geochemical and hydrochemical processes on ground water quality has been underestimated in many places. Although reports on quality parameters for irrigation water are available, the effect of ground water on soil salinity is often left out of consideration.

Soluble salts accumulated in ground waters as a result of geochemical processes pose hazards for irrigation. Excess of sodium ions characterises the water as saline or alkaline depending upon its occurrence in association with chloride/sulphate or carbonate/bicarbonate ions, and accordingly the soils when irrigated with such waters may develop salinity or sodicity problem. Chloride salts are more harmful than sulphate. This is because when both the ions occur in high concentrations, only half of the sulphate contributes to salinity due to the fact that approximately half of the sulphates get precipitated as $CaSO_4$ while the other half remains in soluble form as Na-Mg SO_4 in the soil.

In the State of Punjab, nearly 94 per cent of the net sown area is irrigated, 38 per cent of which depends on surface water received through canals from the rivers of Ravi, Satluj and Beas and the rest (62%) on underground water. With the advent of new technology based on high yielding varieties, the significance of assured water supplies as well as its interaction with fertilizers in increasing agricultural production have resulted in ever increasing exploitation of underground water. Unlike surface waters, ground waters in south western districts namely Mansa, Bathinda, Muktsar, Firozpur and Faridkot contain varying concentrations of soluble salts and their use for irrigation adversely affects agricultural production (Singh *et al.*, 1977; Sood *et al.*, 1998; Patel *et al.*, 2001). In view of this the present study was undertaken to diagnose the hazards of ground waters in relation to their suitability for irrigation in Faridkot district which falls in southwestern part of the Punjab State.

MATERIALS AND METHODS

The study area (Faridkot district having two blocks namely Faridkot and Kotkapura) is a part of Indo-Gangetic alluvial plain located in the semi arid tract of Punjab (Fig. 1). The western Himalayas in the north and the Thar desert in the south and southwest mainly determine the climatic conditions. A systematic survey for assessing the quality of ground waters was conducted in May, 1998. The georeferenced well distributed ground water samples numbering 192 from Faridkot block and 182 from Kotkapura block (374 in the district) were collected from the running tubewells (. 1) and analyzed for various chemical constituents viz., pH, EC (Electrical Conductivity), cations (Na^+, Ca^{2+} + Mg^{2+}, K^+) and anions (CO^{2-}_3, HCO^-_3, Cl^-, SO^{2-}_4) in the same season using the procedures outlined in USDA Handbook No. 60 (Richards, 1954). Residual Sodium Carbonate (RSC) and Sodium Adsorption Ratio (SAR) were calculated using the following standard equations:

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

$SAR = Na^{+}\sqrt{[Ca^{2+} + Mg^{2+}/2]}$

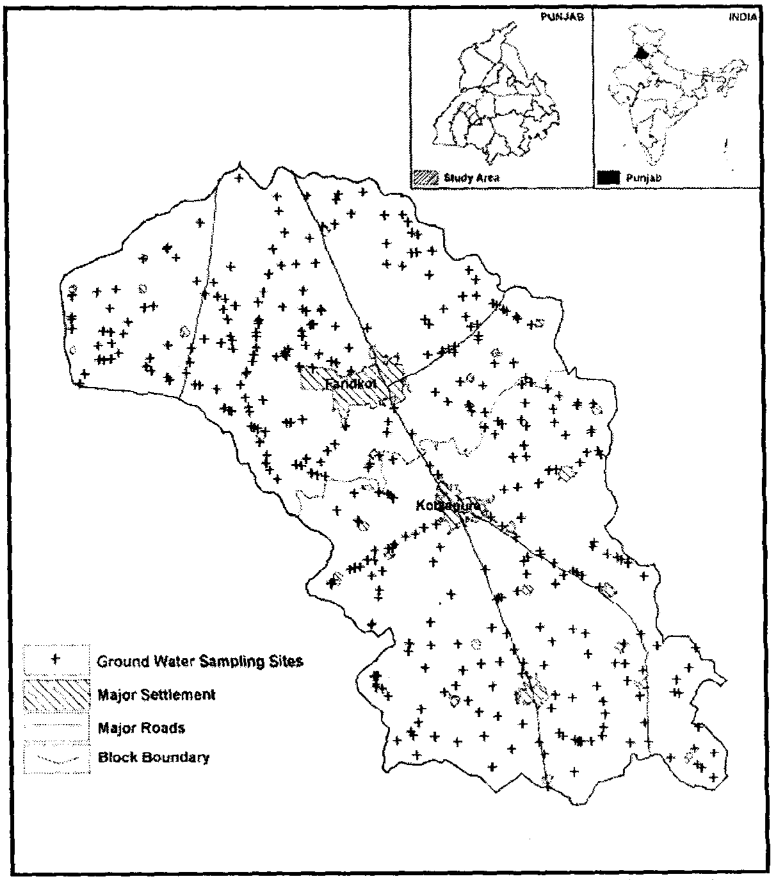


Figure 1. Location of ground water sampling sites in the study area

Adj. SAR was calculated by using formula Adj SAR= SAR $[1+(8.4-pH_c)]$ where Na, Ca and Mg are expressed in meq/l from the water analysis and $pH_c = (pK'_2-pK'_c)+ p(Ca+Mg) + p(Alk)$. The value of $(pK'_2-pK'_c)$ was obtained from using the sum of Ca+Mg+Na in me/l from water analysis data (Ayers ans Westcot, 1976). The suitability of ground water for irrigation was categorized according to the classification used by Singh *et al* (2001).

RESULTS AND DISCUSSION

Chemical Composition of Ground Water

The ground waters of the area are alkaline in reaction (pH >7.0) as pH varied from 7.14 to 9.98. They have varying levels of salinity (0.31 to 7.53 dS m^{-1}), sodium adsorption ratio (1.4 to 70.14 $[me\ l^{-1}]^{1/2}$) and RSC (nil to 16.00 me l^{-1}). The average values of EC, RSC and SAR was 3.01, 3.69 me l^{-1} and 16.23 $[me\ l^{-1}]^{1/2}$ respectively.

Na^+ is the dominant cation and its value ranged from 1.74 - 83.93 me L^{-1} with an average value of 25.7 me l^{-1} (Table 1). Among the anions, concentration of HCO_3^- varied from 0.5 to 21.5 me l^{-1}, whereas that of Cl^- and SO_4^{2-} varied from 1.00 to 51.30 and 0.83 to 48.33 me l^{-1}, respectively. The results showed that highly saline waters are dominant in Cl^- and SO^{2-}_4 ions rather than CO_3^{2-} and HCO_3^- ions (Table 1). The cations and anions in irrigation waters were found in the order of Na^+ > SO_4^{2-} > Cl^- > Ca^{+2} +Mg^{+2} > HCO_3^- > CO_3^{2-} > K^+. As far as distribution of cations and anions in two blocks of Faridkot district is concerned, it was found that the average content of all cations, Cl^- and SO^{2-}_4 was higher in Faridkot block than Kotkapura block but the mean concentration of CO_3^{2-} and HCO_3^- ions was higher in Kotkapura block than Faridkot block. The higher value of SAR, RSC and Adj. SAR in Kotkapura block than Faridkot block may be due to Na^+, CO_3^{2-} HCO_3^- and Ca^{+2} +Mg^{+2} ion concentration was maximum in the former block (Table 1).

Hazards of Ground Waters

The majority of ground waters in the district had high salt content (51.7 %) or high RSC (35.7 %). The continuous use of these waters for irrigation poses following types of hazards and rendered many areas unproductive.

Salinity Hazard

The total concentration of soluble salts in ground waters of Faridkot district varied from 0.31-7.53 dS m^{-1}. The ground waters of Faridkot block had EC values ranged from 0.31 to 7.53 dS m^{-1} with a mean value of 2.21 and that of Kotkapura block ranged from 0.36 to 4.44 dS m^{-1} with a mean value of 1.78. Out of total water samples in the district, 34.8% samples fall under normal water (C1), 51.7 % under low saline water (C2), 9.9 % under medium salinity and the remaining 3.7 % were under high saline water (C4). The majority of ground waters in Faridkot (50.9 %) and Kotkapura block (52.6 %) had salt content falling in the class C2 (Table 2). The waters belonging to class C1 and C2 are suitable for irrigation and that to class C3 and C4 can cause soil salinization, if continuously used over a longer span of time.

As ground water salinity is dependent upon ion concentration, therefore, data were regressed as a function of EC and ion concentration. Both the linear and quadratic regression showed highly significant R^2 values but it was always greater for quadratic than linear regression. Therefore, quadratic functions are presented in Table 3. The rate of change of salt concentration with ion concentration is described by the coefficients 'b' and 'c'. The intercepts of quadratic equations for anions indicated that SO_4^{2-} was the dominant anion among all the anions as evident from maximum 'a' value (Table 4). The maximum rate of change in EC was also found with SO_4^{2-} ion as 'b' and 'c' value was the highest for this anion. At any particular salinity, Na^+ was always more than other cations and 'b' and 'c' values for Na^+ for the district revealed that increase in concentration of Na^+ was steeper than other ions(Table 4). The 'a' value for Na^+ for Faridkot block (a= 9.25) was higher as compared to that of Kotkapura block (a=4.57). In case of anions, the

Table 1. Chemical Characteristics of ground waters of Faridkot district

Chemical Characteristics	Faridkot District				Faridkot Block				Kot Kapura Block			
	Min.	Max.	Mean	S.D.	Min.	Max.	Mean	S.D.	Min.	Max.	Mean	S.D.
pH	7.14	9.98	-	0.36	7.14	9.74	8.57	0.39	8.04	9.98	-	0.29
EC(dS m^{-1})	0.31	7.53	2.01	1.17	0,31	7.53	2.21	1.40	0.36	4.44	1.78	0.79
$Ca^{+2} + Mg^{+2}$	0.90	46.30	6.64	7.08	0.90	46.30	8.68	8.82	1.00	23.20	4.37	3.17
Na^+ (me l^{-1})	1.74	83.93	25.73	14.50	2.20	83.93	27.56	17.35	1.74	49.60	23.69	10.15
K^+(me l^{-1})	0.03	2.82	0.31	0.25	0.03	2.82	0.35	0.32	0.04	1.15	0.25	0.13
CO_3^{-2}(me l^{-1})	0.00	10.00	3.29	1.47	0.00	6.00	2.76	1.27	1.00	10.00	3.88	1.47
HCO_3^-(me l^{-1})	0.50	21.50	4.97	2.52	1.00	21.50	4.95	2.66	0.50	14.00	4.99	2.37
Cl^-(me l^{-1})	1.00	51.30	8.01	8.08	1.00	51.30	10.01	10.09	1.00	28.50	5.77	3.94
SO_4^{2-}(me l^{-1})	0.83	48.33	10.21	9.63	0.83	48.33	12.97	11.24	0.83	31.25	7.15	6.19
RSC (me l^{-1})	0.00	16.00	3.69	3.45	0.00	11.10	2.55	2.87	0.00	16.00	4.96	3.60
SAR (me $l^{-1})^{0.5}$	1.40	70.14	16.23	8.84	1.47	49.55	15.06	9.11	1.40	70.14	17.53	8.37
Adj SAR	2.56	80.20	29.99	18.92	1.00	80.20	29.52	21.68	1.00	69.77	30.34	14.75

Table 2. Salinity (EC), Sodicity (SAR) and Alkalinity hazards (RSC) in ground waters of Faridkot district

Salinity Hazard (ds m^{-1})	% of water samples			Sodicity Hazard Class	% of water samples			Alkalinity hazards class (me / l)	% of water samples		
	FD	FB	KB		FD	FB	KB		FD	FB	KB
(C0) Non saline water (EC <0.2)	0	0	0	(S0) Non sodium water (SAR <5.0)	10.8	15.20	5.84	(A0) Non alkaline water (RSC-ve)	0	0	13.0
(C1) Normal water (EC 0.2-1.5)	34.8	30.4	39.6	(S1) Normal water (SAR 5.0-10.0)	12.3	14.62	9.74	(A1) Normal water (RSC <0)	26.5	38.60	16.2
(C2) Low saline water (EC 1.5-3.0)	51.7	50.9	52.6	(S2) Low sodicity water (SAR 10-20)	48.0	45.61	50.6	(A2) Low alkaline water (RSC <2.5)	18.5	21.05	20.1
(C3) Medium salinity water (EC 3.0-5.0)	9.85	11.7	7.79	(S3) Medium sodicity water (SAR 20-30)	23.7	20.47	27.3	(A3) Medium alkaline water (RSC 2.5- 5.0)	19.4	17.54	43.5
(C4) High salinity water (EC 5.0-10)	3.69	7.0	0	(S4) High sodicity water (SAR >30)	5.23	4.09	6.49	(A4) High alkaline water (RSC 5.0-10.0)	35.7	22.81	7.1

FD- Faridkot District, FB- Faridkot Block, KB- Kotkapura Block

Table 3. ABC Classification of ground waters of Faridkot district

Adjusted SAR Class	% of water samples			EC (dS m^{-1})	% of water samples		
	FD	FB	KB		FD	FB	KB
(S1) Normal water (Adj. SAR 1.0-10.0)	17.23	24.6	9.1	(C1) Normal water (EC <1.5)	34.77	30.4	39.6
(S2) Low sodium water (Adj. SAR 10-20)	12.31	14.0	10.4	(C2) Low salinity water (EC 1.5-3.0)	51.69	50.9	52.6
(S3) Medium sodium water (Adj. SAR 20-30)	22.77	12.9	33.8	(C3) Medium salinity water (EC 3.0-5.0)	9.85	11.7	7.79
(S4) High sodium water (Adj. SAR >30)	47.69	48.5	46.8	(C4) Saline water (EC 5.0-10)	3.69	7.0	0

FD- Faridkot District, FB- Faridkot Block, KB- Kotkapura Block

Table 4. Quadratic functions relating salt concentration to ion concentration

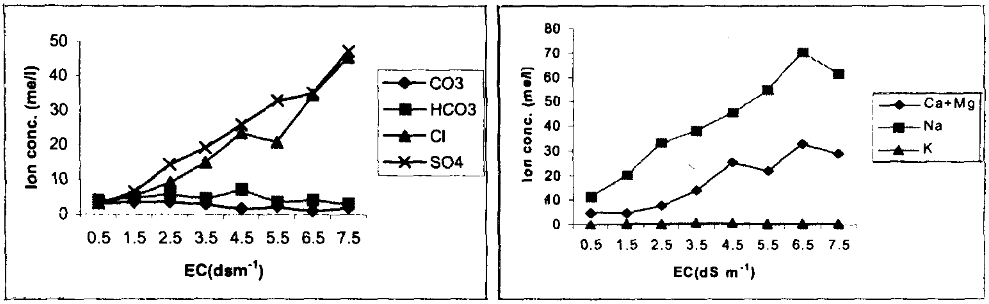
Parameters	a	b	c	a	b	c	a	b	c
	Fardikot District			Faridkot Block			Kotkapura Block		
SO_4^{2-}	5.44	10.88	0.86	5.83	12.4	1.06	1.10	2.58	0.53
Cl^{-1}	2.88	1.05	0.59	2.76	1.95	0.46	3.26	1.03	1.18
HCO_3^-	3.56	1.18	0.17	2.62	1.84	0.24	3.99	1.33	0.35
CO_3^{2-}	3.72	0.29	0.001	3.25	0.31	0.01	2.94	1.25	0.33
Na	6.06	11.0	0.40	4.57	11.9	0.49	9.25	8.41	0.07
Ca+Mg	0.33	3.20	0.15	0.53	4.93	0.07	4.26	1.59	0.82
K	0.02	0.22	0.02	0.01	0.26	0.03	0.11	0.09	0.01

Where, a, b and c are coefficients of quadratic equation $Y = a + bx + cx^2$

concentration of Cl^- and SO_4^{2-} for the district increased with increase in EC value (Fig. 2). The concentration of SO_4^{2-} ion increased linearly with increase in salt concentration in both Faridkot (Fig. 3) and Kotkapura block (Fig 4). On the other hand the concentration of HCO_3 was found to decrease with increase in salinity. These values indicate that most of the ground waters of Faridkot district contains appreciable quantities of Na^+ and SO_4^{2-} ions.

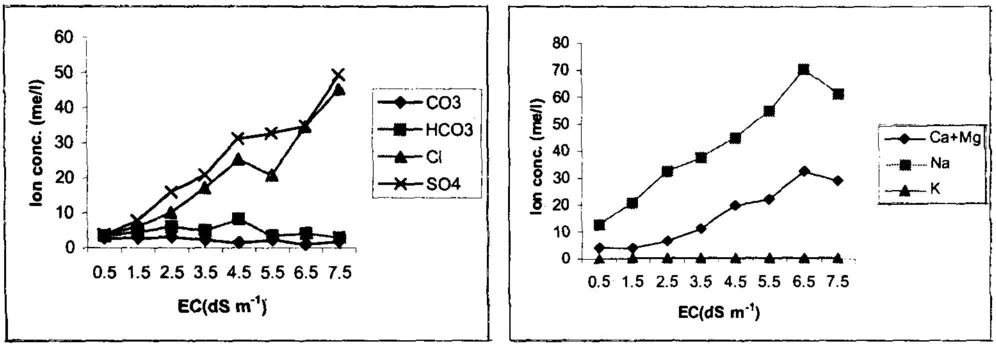
The step wise regression equations were also worked out to find out the relative contribution of cations and anions towards ground water salinity. The coefficient of determination (R^2) value indicated that total variation explained through Na was 54.3 per cent (Table 5). When the contribution of Ca+Mg was included, the R^2 value improved by 7.4 per cent whereas, the contribution of K was only 0.8 per cent. This apparently indicated that Na ion in comparison to other ions was major contributor towards water salinity. Among the anions, Cl^- was the most important variable contributing to EC as 54.5 per cent of the variations could be accounted for by this variable only (Table 5). The inclusion of SO_4^{2-},HCO_3^- and CO_3^{-2} did not significantly improve the R^2 value but change in prediction value

(ΔR^2) value was the highest for SO_4^{2-}. Therefore, Cl^- ion in comparison to other anions was found to be major ion towards ground water salinity.



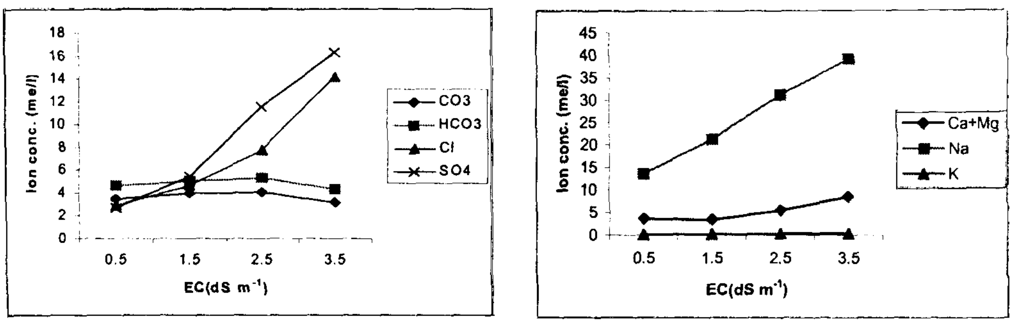
(a) (b)

Figure 2. Mean ionic concentration in relation to EC (Faridkot district)



(a) (b)

Figure 3. Mean ionic concentration in relation to EC (Faridkot block)



(a) (b)

Figure 4. Mean ionic concentration in relation to EC (Kotkapura Block)

Table 5. Relationship between Salinity and ions in irrigation waters of Faridkot district using step wise regression analysis

Regression Equation	R^2
Cations	
Na^+	54.3
$Na^+ + (Ca^{+2} + Mg^{+2})$	61.7
$Na^+ + (Ca^{+2} + Mg^{+2}) + K^+$	62.5
Anions	
SO_4^{2-}	54.5
$SO_4^{2-} + Cl^-$	60.7
$SO_4^{2-} + Cl^- + CO_3^{-2}$	61.1
$SO_4^{2-} + Cl^- + CO_3^{-2} + HCO_3^-$	61.1

Sodicity Hazard

The mean sodium ion concentration in ground water samples of Faridkot district was 25.73 me l^{-1}. The ground water samples from Faridkot block had higher mean sodium concentration (27.56 me l^{-1}) than that of Kotkapura block (23.69 me l^{-1}). The sodium ion concentration is confined mostly in the range of 20 per cent and above of the total cation concentration. Relatively lower sodium per cent have been observed in waters of low salinity where calcium and magnesium together (Ca+Mg) are the dominant cations. In more saline waters, sodium was the major ion. Only 36 per cent of total ground water samples from Faridkot district had sodium below 20 per cent and 13 per cent ground water samples had sodium more than 40 per cent . About 51 per cent ground water samples had sodium between 20-40 per cent of total cation concentration. The SAR of ground water samples from the district varied from 0.14 to 70.14 $(meL^{-1})^{1/2}$ with mean value of 16.23. On splitting the analytical data block wise, it is observed that the mean SAR of Kotkapura block (17.53 me $l^{-1})^{1/2}$ is higher than that of Faridkot block (15.06 me $l^{-1})^{1/2}$. This clearly indicated that the ground waters of Kotkapura block had more sodicity hazard than the Faridkot block. This is also supported by linear increase in Na concentration with increasing salt concentration in ground waters of Kotkapura block (Fig 4), whereas, Na concentration increased with increasing salt concentration upto 7.0 dS m^{-1} in Faridkot block (Fig 3). A decrease in concentration of Na ion with increase in EC after a certain point in Faridkot block was found. This may be due to formation of insoluble complexes after an EC value of 7 dS m^{-1}. The EC value above 7 may be categorised as the utmost severe. The concentration of an ion particularly not dependent on salt concentration but other factors like pH, concentration of other ions also exert a synergistic or antagonistic effect on the availability of that ion.. The another reason for decline in Na concentration with the EC value of more than 7 dS m^{-1} may be due to decrease in the solubilty product of Na with other ions than ionic product (Das, 1997).

According to sodicity hazard classes (Table 2), the water samples were found in the order of low sodium water (S2, 48.0 %) > medium sodium water (S3, 23.7

%) > normal sodium water (S1, 12.3 %) > non sodium water (S0, 10.8 %) > high sodium water (S4, 5.2 %). Therefore, ground waters qualifying for class S0 and S1 are suitable for irrigation.

Alkalinity Hazard

The distribution of carbonate plus bicarbonates in ground waters of Faridkot district revealed that most of the ground water samples (63 per cent) were confined in the carbonate plus bicarbonate range of 5 to 10 per cent. It is also notable that about 22 per cent ground water samples had carbonate plus bicarbonate concentration more than 15 percent of total anions. These bicarbonate rich ground waters will cause precipitation of Ca and Mg in soil.

The data on for calcium plus magnesium showed the reverse trend of distribution of sodium. It was found that that 85 and 9 per cent ground water sample of Faridkot district is confined in the range of < 10 per cent and 10 - 20 per cent concentration regime, respectively. It is interesting to observe that only 6 per cent samples had Ca+Mg concentration > 20 per cent of total cations. The effect of salt concentration on distribution of Ca+Mg in ground water was similar to Na (Fig 2).

The residual sodium carbonate (RSC) of ground water samples from Faridkot district varied from nil to 16.00 me l^{-1}. The mean RSC of ground waters indicated that ground waters from Kotkapura block (4.96 me l^{-1}) had more alkalinity hazard than Faridkot block (2.55 me l^{-1}). Out of total water samples of the district, 26.5 % samples fall under normal water (A1), 18.5 % under low alkaline water (A1), 19.4 % were under medium alkaline water (A3) and 35.7 % were under high alkaline water (A4).

Adj. Sodium Ratio (Adj SAR) of waters ranged from 2.56 to 94.0 with a mean value of 29.9. Out of total water samples, 17.2 % were under normal sodium water (S1), 12.3 % were under low sodium water (S2), 22.8 % under medium sodium water (S2) and 47.7 % were under high sodium water (S4). On splitting the data block wise, it was found that majority of waters of both Faridkot (48.5 %) and Kotkapura block (46.8%) had high sodium water (Table 3).

Discussion

A salinity problem related with water quality occurs if the total concentration of salts is high enough for salts to accumulate in the crop root zone to the extent that yields are affected. The parameters marginally fit waters in terms of salinity could be used for irrigation with some special management practices like the flushing with good quality of water and alternate supply of canal water. However, waters having high electrical conductivity cause salinization. To prevent secondary soil salinization, it is recommended to increase/decrease the depth of bore or change the place of bore to find good quality of water to explore good quality aquifers. Further it is stated that waters having EC between 1.5-3.0 dS m^{-1} can be used for irrigation on most soils with little likelihood development of salinity. The waters with EC value between 3.0-5.0 dS m^{-1} can be used if a moderate leaching occurs.. Waters having EC between 5-10 dS m^{-1} are not suitable for irrigation under normal conditions.

As concerned SAR, water having SAR up to 10 can be used for irrigation on almost all soils with little danger of the development of harmful level of exchangeable sodium. Sodium rich waters causes other related undesirable effects such as soil crusting, poor soil aeration and high incidence of root diseases (Kandiah, 1991). Water with SAR >30 may produce harmful levels of exchangeable sodium in most soils and require special management practices like good drainage, high leaching and organic conditions. Chemical amendments may be required for replacement of exchangeable sodium where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible. The sodic ground waters (RSC 2.5 -7.5 me L^{-1}) can be used safely with recommended gypsum application. However, HCO_3^- containing water may increase the level of exchangeable Na^+ in the soil, even if the concentration of Ca^{2+} and Mg^{2+} ions exceeds that of HCO^-_3 and CO^{2-}_3 (zero RSC waters), because the precipitation of the cations as insoluble carbonates increases the SAR of the soil solution and hence the level of exchangeable Na^+. In the regions, where availability of canal water is less, it is some time necessary to use ground water for irrigation with an SAR which is likely to give sufficiently higher concentration of Na^+ in the soils, concomitantly reducing the permeability of the soil to an unacceptably low level. One of the effective ways of overcoming the sodium hazard of irrigation water is the use of soil and water amendments. Most soil and water amendments supply calcium to the soil water system to counteract the excess sodium. Water amendments are most effective if infiltration problems are caused by a low salinity or high SAR of irrigation water. If water salinity is moderate to high in addition to high SAR, soil applied amendments such as gypsum or sulphur are preferred.

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