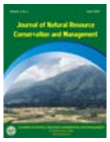
Journal of Natural Resource Conservation and Management
Vol. 1, No. 2, pp 96-103, 2020
doi: 10.51396/ANRCM.1.2.2020.96-103



Secondary salinization risks associated with irrigation water from borewell, lift and canal in the typical black soils of Southern India

H.S. Ashwin[1], M.V. Rekha[2], B.V. Champa[2], A.S. Alur[1], M.S. Nagaraja[2] and A.K. Bhardwaj[1,3,*]

[1]*College of Horticulture, University of Horticultural Sciences, Bagalkot-587103, Karnataka, India*
[2]*University of Agricultural and Horticultural Sciences, Shivamogga-577204, Karnataka, India*
[3]*ICAR-Central Soil Salinity Research Institute, Karnal-132001, Haryana, India*
Corresponding author email: ak.bhardwaj@icar.gov.in, ajaykbhardwaj@gmail.com

Received : August 11, 2020
Revised : November 6, 2020
Accepted : November 10, 2020
Published : December 23, 2020

ABSTRACT

An extensive soil survey was conducted to characterize black soils of Bagalkot district, Karnataka, India, for salinity development aspects when irrigated with waters from various sources. The quality of irrigation waters as well as chemical properties of soils under irrigation with waters from different sources (borewell, lift, canal and combinations) varied widely compared to non-irrigated soils. Though there were no significant differences in soil physical properties, the pH of soils under irrigation ranged from slightly alkaline to high alkalinity. Electrical conductivity (ECe) as well as cationic and anionic composition differed significantly among soils. In general, the concentration of ions in soils were observed in the order of lift = lift + borewell > borewell = canal + borewell > dryland soils. The cations in soil-water extracts were found in the order of $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ while, the anions were in the order of $Cl^- > HCO^{3-} > SO_4^{2-} > CO_3^{2-}$. Correlations showed that the soil pH was significantly correlated with CO_3^{2-} and HCO_3^- contents. The ECe exhibited positive and high significant correlations with all studied ions except CO_3^{2-} (negatively significant) and HCO_3^- (non-significant). Correlation values of cations were found in the order $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ while for anions were in the order $Cl^- > SO_4^{2-} > CO_3^{2-} > HCO_3^-$. No significant changes in soil pH were evident, though there was significant increase in soil ECe mostly because of higher chloride and sulphate salts of sodium, calcium and magnesium added via irrigation water. Increased risk of secondary salinization is likely in the black soils irrigated with lift waters followed by borewell waters until suitable measures like using canal water more frequently and adequately to meet leaching requirement are taken.

Keywords: Black soils, Characterization, Chemical properties, Irrigation water, Salinity.

INTRODUCTION

Soils of northern Karnataka are mostly derived from easily weatherable sedimentary rocks such as limestone and gypsum. The arid climatic conditions, with high temperature and low rainfall, prevailing in this region encourage salt accumulation through soil surface evaporation processes. The alluvial deposits of black soils with high clay content are also characterized by high capillarity and therefore prone to salt accumulation. Thus, the black soils of northern Karnataka have naturally evolved to have higher amounts of salts compared to southern Karnataka soils. However, these salts got redistributed in the area with the introduction of canal irrigation network. Redistribution of salts due to irrigation or seepage is a common phenomenon in canal commands (Bhardwaj *et al.*, 2019). Use of salt rich groundwater through borewell to meet crop water requirement during summer has also altered salt balance in this region. The excess water used in crop production ultimately finds its way to natural surface streams as the impervious parent material lies just beneath the shallow to medium depth soils. The water drains existing along the streams are also known to have excess soluble salts especially after the rainy season. Use of such drain waters for irrigation further adds salts and makes the soil more saline. Ultimately, large tracts of northern Karnataka have turned less productive and unfit for crop production in many extreme cases due to use of such salt laden waters.

The farmers of the region also use both surface and subsurface waters for irrigation. The use of canal water is only prevalent after the release of water in canals. In the areas where there is no canal network, the farmers use stream water through lift irrigation. Use of borewell water has been observed in the dryland areas as well as in canal and lift irrigated areas. Thus, three categories of irrigation water namely, canal water, stream water (via lift irrigation), and borewell water is prevalent in the area. Usually, better quality water is applied whenever available and the poor quality irrigation water is applied whenever good quality water is not available or insufficient. Alternate use of different quality of water does not offset the problems like low infiltration rate caused by high SAR irrigation waters (Minhas *et al.,* 2021). Alternate use of waters with high and low SAR can have serious secondary problems like dispersion and clogging of soil pores, surface crusting and sealing etc. when low SAR waters are used after high SAR waters. In such cases application of amendments before use of good quality water is advised but rarely used by farmers.

The exact characteristics of these black soils irrigated with waters from lift, borewell and canal are not well known. Therefore the current study was undertaken to characterize soils of Bagalkot district in Northern Karnataka irrigated with waters from different sources to understand the salinization patterns in terms of sodicity and salinity development, and to devise appropriate steps for minimizing secondary salinization risks.

MATERIALS AND METHODS

Study Area

The study was carried out in the Bilagi and Bagalkot talukas of Bagalkot district, Karnataka (Fig. 1). The study area falls under hot arid climate with mean temperature of 32.6 °C and rainfall of 517 mm, and falls at an altitude of 620-660 mean sea level. Soil maps generated by National Bureau of Soil Survey and land Use Planning (NBSS&LUP) at 1:1,00,000 scale, and toposheets generated by Survey of India (1:50,000 scale) covering Bilagi and Bagalkot talukas were used for the surveys. The entire black soil region of the study area was traversed and divided into smaller grids of 2.25 X 2.25 km^2. Based on the dominant cropping system in each grid, the exact soil sampling points was determined and marked on the toposheets. Later, the exact locations of the sampling points in each of these grids were identified during field survey and were marked using global positioning system (Garmin, USA).

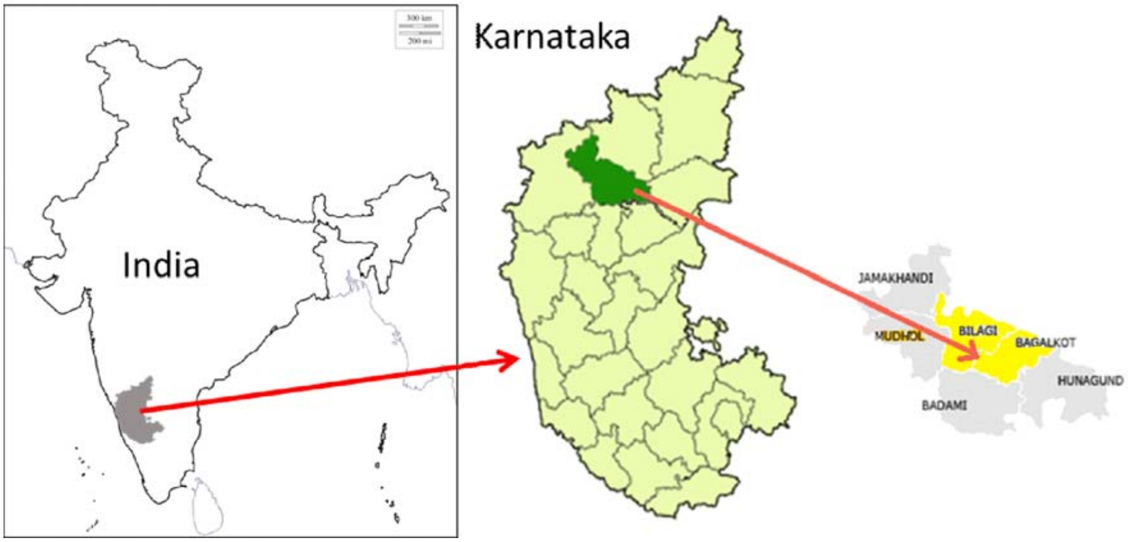


Figure 1. Location of the study area

Soil Sampling and Analysis

At every marked point three surface soil samples (0-15 cm) were randomly collected at a distance of 5 m and made into one composite representative sample of that site. The details of crops grown during last 5 years, drainage conditions, soil colour, topography etc. were also entered into the data sheets. The collected soil samples were air dried, sieved (2 mm) and stored for the laboratory analysis. Processed soil samples were analysed for soil salinity parameters, pH and electrical conductivity (ECe) by multimeter, and water soluble ions (1:2 soil:water suspension) (Sarma *et al.*, 1987). Ca^{+2} and Mg^{+2} were determined by Versenate titration, K^+ and Na^+ by flame photometer, CO_3^{-2} and HCO_3^- by acid titration, Cl^- by silver nitrate titration, and SO_4^{-2} by turbidometry.

Data Analysis

The data was analyzed for spread among different sources of irrigation water. The data obtained was subjected to statistical tests using ANOVA: single factor and descriptive statistical analysis. The statistical analysis of all parameters was done using SAS (2009; SAS Inc., Cary, NC, USA). The separation of means was subjected to Tukey's honestly significant difference test (Steel and Torrie, 1960). Correlation analysis was conducted to identify relationships between the measured parameters. All tests were performed at 0.05 significance level.

RESULTS

Lift irrigation waters recorded highest pH and EC followed by borewell waters and canal water (Fig. 2). Both life and borewell waters had almost double SAR compared canal waters. Canal water had highest RSC followed by borewell and lift, all waters being negative due to excess of Ca and Mg salts. The ECe of soils ranged from 0.98 dS m^{-1} in dryland soils to 6.10 dS m^{-1} in lift irrigation categories (Fig. 3). Nearly half of the soil samples were found safe with ECe of < 2 dS m^{-1} while, 42.1 per cent of soil samples were moderately saline (2 to 4 dS m^{-1}) and only 10.3 per cent samples were found to be saline (> 4 dS m^{-1}) in nature. The dryland soils without irrigation recorded least soluble salt content (1.49 ± 0.09 dS m^{-1}), ranging between 0.98 and 2.64 dS m^{-1}. The magnitude of soil salinity (ECe) increased significantly in the order: dryland < borewell < canal plus borewell < lift plus borewell < lift irrigation.

The amount of water extractable total cations in all the sampled soils ranged from 16.72 to 52.12 meq L^{-1} (Fig. 4). The soils irrigated with lifted waters, with or without conjunctive use of borewell waters, recorded significantly higher amounts of cations (35.89 ± 2.40 meq L^{-1} and 34.42 ± 3.70 meq L^{-1}, respectively). Moderate amounts of cations were observed in soils irrigated with borewell waters (24.18 ± 1.26 meq L^{-1}), and canal plus borewell irrigation (29.51 ± 2.11 meq L^{-1}) while, dryland soils recorded least (14.87 ± 0.97 meq L^{-1}). The amount

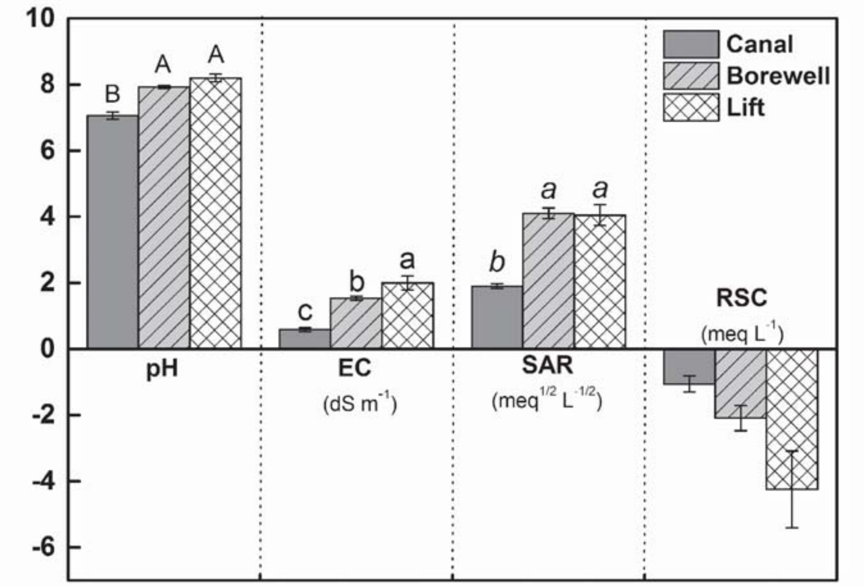


Figure 2. Characteristics of irrigation waters from different sources. Error bars represent ± 1 SD. For a parameter, bar with same letters are not significantly different at p ≤ 0.05

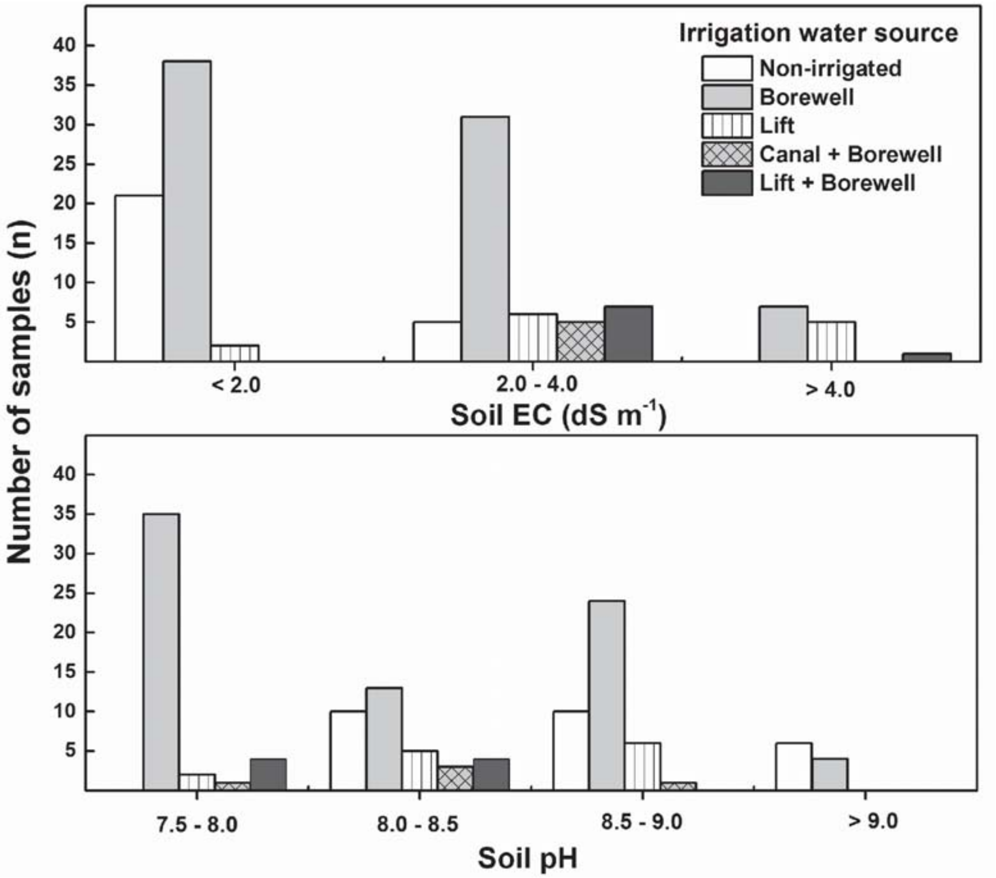


Figure 3. The spread of soil ECe and pH among the sites irrigated with waters from different sources

of total cations in soil-water extracts varied significantly in the order - dryland < borewell < canal plus borewell < lift plus borewell = lift irrigation land categories. In terms of individual cations, it was found in the order: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$, across all irrigation land categories. Among water extractable cations, Na^+ was dominant in all soils, and it ranged from 2.50 meq L^{-1} in borewell irrigated soils to 33.00 meq L^{-1} in lift irrigated soils. Among different land categories, dryland soils least sodium content (6.76 ± 0.55 meq L^{-1}). However, its concentration increased by 1.5 to 3.0 times with use of irrigation waters. Calcium was the second dominant cation and it ranged from 2.20 to 18.10 meq/l. The Ca^{2+} in soil-water extract was lowest in dryland categories (5.02 ± 0.30 meq L^{-1}) and highest in lift irrigated (9.95 ± 0.78 meq L^{-1}) and lift + borewell irrigated (9.35 ± 2.07 meq L^{-1}) land categories. Similar to sodium and calcium ions, the magnesium and potassium ions were least in dry land soils with respective mean values of 2.59 ± 0.16 meq L^{-1} and 0.48 ± 0.05 meq L^{-1}. Land categories belonging to lift irrigation (with or without borewell) and borewell irrigations recorded significantly higher amounts of both Mg^{2+} and K^+ in soil water extracts.

The amount of total anions ranged from 6.47 to 61.27 meq L^{-1}. Dryland soils had the least amount of anions (15.11 ± 0.98 meq L^{-1}) while, lift irrigated (with or without borewell) land categories recorded significantly higher amounts of anions (36.15 ± 2.70 meq L^{-1} in lift irrigated soils; 34.99 ± 3.85 meq L^{-1} in lift + borewell water irrigated soils). The concentration of total anions in soil water extracts varied significantly in the order: dryland < borewell < canal plus borewell < lift = lift plus borewell land categories. Among irrigated land categories, the individual anions were found in the order: $Cl^- > HCO^{3-} > SO_4^{2-} > CO_3^{2-}$. In dryland soils, HCO_3^- was found dominant cation while, SO_4^{-2} was the lowest. Amount of Cl^- in soil-water extract was the lowest in dryland categories (3.01 ± 0.63 meq L^{-1}) and it increased by 4.0 to 5.0 times with irrigations. The mean values ranged from 12.02 ± 0.71 meq L^{-1} in borewell irrigated areas to 20.46 ± 2.68 meq L^{-1} in

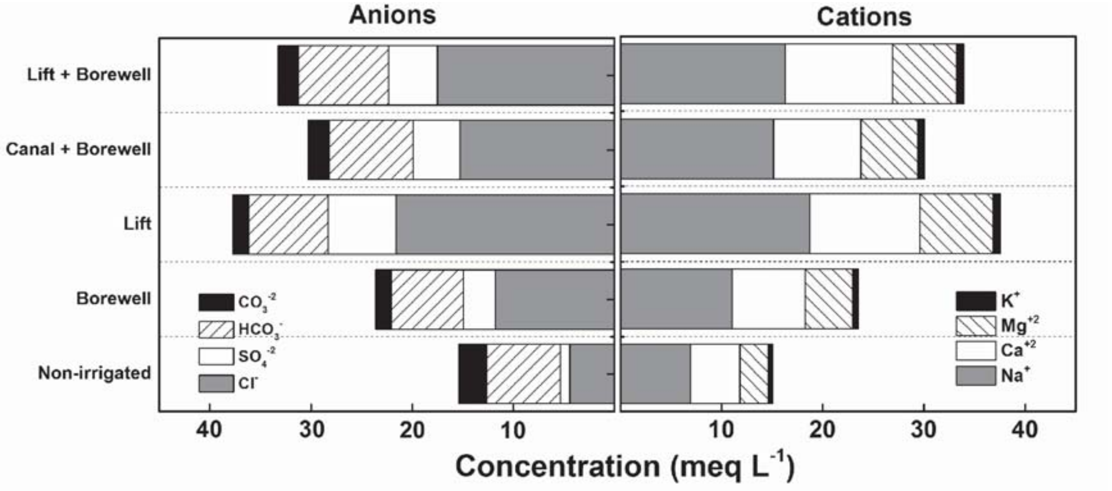


Figure 4. Anionic and cationic composition of soils irrigated with waters from different sources

lift irrigated areas. Water extractable SO_4^{2-} ions among irrigated and dryland soils varied significantly and its concentration ranged from 0.12 to 6.50 meq L^{-1}. However, least SO_4^{2-} content was observed in dryland soils compared to all other irrigated soils. The SO_4^{2-} content in soils varied significantly in the order - dryland < borewell = canal plus borewell < lift plus borewell = lift irrigation land categories. The concentrations of both HCO_3^- and CO_3^{-2} remained on par among all soils belonging to different irrigation land categories. The HCO_3^- contents in soil water extract ranged from 0.56 to 12.8 meq L^{-1}. Similarly, the amount of CO_3^{-2} ranged from traces to 6.10 meq L^{-1}.

While there was no significant difference in the average soil pH values for different irrigation water uses but there was significant change in the ECe of soils with lift and borewell waters, and even after blending/ alternate use. (Table 1). Correlation coefficients were calculated for all the parameters to understand their relationships and the respective coefficient are presented in Table 2. The soil pH was significantly correlated with CO_3^{2-} and HCO_3^- contents. The ECe exhibited positive and high significant correlation values with all most all the ions studied except CO_3^{2-} (negatively significant) and HCO_3^- (non-significant). For cations, it was found in the order - $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ while, for anions it was found in the order $Cl^- > SO_4^{2-} > CO_3^{2-} > HCO_3^-$.

Consequent of the irrigation from these sources of irrigation water, there was a significant change in the sodium adsorption ratio (SAR) of the soils. Most SAR was noted in the lift irrigated soils followed by borewell and mixed waters (canal water + borewell water, lift + borewell water).

DISCUSSION

The black soils of Bagalkot district exists as surface deposits over lime based parent rocks. Thus, the salts also might have been contributed from such

Table 1. Effects of irrigation water application from different sources on soil pH and ECe (saturation paste electrical conductivity). Means followed by same alphabets were not significantly different at p<0.05.

	pH		ECe (dS m^{-1})	
	Range	Mean	Range	Mean
Dry land (no irrigation) (n = 26)	8.23 to 9.26	8.68 ± 0.07[a]	0.98 to 2.64	1.49 ± 0.09[a]
Borewell Irrigation (n = 76)	7.54 to 9.28	8.44 ± 0.05[b]	1.08 to 4.51	2.09 ± 0.09[b]
Lift Irrigation (n = 13)	7.65 to 8.88	8.33 ± 0.10[bc]	2.13 to 6.10	3.65 ± 0.33[c]
Canal + Borewell Irrigation (n = 5)	7.82 to 8.60	8.22 ± 0.23[c]	2.12 to 3.10	2.47 ± 0.21[d]
Lift + Borewell Irrigation (n = 8)	7.60 to 8.98	8.37 ± 0.18[bc]	2.12 to 4.16	3.01 ± 0.21[e]
	Calculated F-value = 5.01		Calculated F-value = 17.10	
	CD (0.05)= 0.19		CD at (0.05)= 0.35	

Table 2. Correlation between measured soil parameters

	pH	ECe	Ca^{2+}	Mg^{2+}	K^+	Na^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	SAR	RSC
pH	1.00											
ECe	0.35**	1.00										
Ca^{2+}	0.41**	0.96**	1.00									
Mg^{2+}	0.39**	0.95**	0.98**	1.00								
K^+	0.04	0.30**	0.25**	0.24*	1.00							
Na^+	0.28**	0.96**	0.85**	0.84**	0.27**	1.00						
CO_3^{2-}	0.90**	0.39**	0.43**	0.41**	0.06	0.34**	1.00					
HCO_3^-	0.63**	0.53**	0.56**	0.54**	0.09	0.47**	0.69**	1.00				
Cl^-	-0.06	0.87**	0.79**	0.80**	0.30**	0.86**	-0.06	0.08	1.00			
SO_4^{2-}	0.17*	0.77**	0.76**	0.75**	0.18*	0.73**	0.20*	0.27**	0.69**	1.00		
SAR	0.05	0.65**	0.43**	0.42**	0.17*	0.82**	0.14	0.27**	0.63**	0.46**	1.00	
RSC	0.36**	-0.53**	-0.54**	-0.55**	-0.19*	-0.47**	0.43**	0.34**	-0.84**	-0.56**	-0.23*	1.00

* Correlation is significant at $p \leq 0.05$. ** Correlation is significant at $p \leq 0.01$

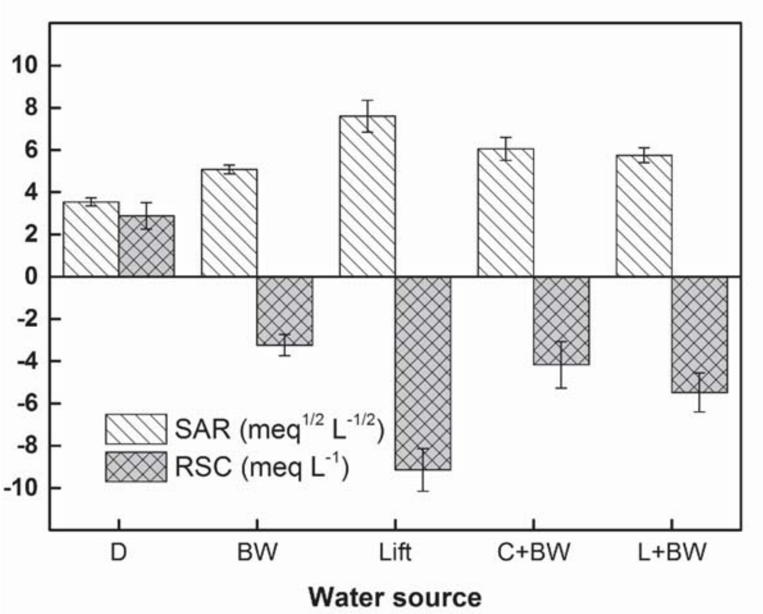


Figure 5. Sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) composition of soils irrigated with waters from different sources. Error bars represent ± 1 SD

easily weatherable parent materials (Doddamani, 1994). Higher ECe values in irrigated areas compared to drylands could be attributed to addition of salts by irrigation water (Paliwal and Maliwal, 1971; Bhardwaj *et al.*, 2008, Edgar *et al.*, 2012) and redistribution of salts through water movement within the landscape (Bhadrapur and Seshagiri Rao, 1979 and Kadu *et al*, 2009). Higher salinity was seen in lift irrigated land categories (both with / without borewell water) existing along natural drainage lines (streams). Higher salt content in stream drained water and its over use for sugarcane might have resulted in higher salt accumulation. Natural movement of percolating water from upper to lower regions also might have contributed for additional salts (Kadu *et al.*, 2009). Moreover, salt accumulation is likely to be more likely in clayey soils (Kijine *et al.*, 1998).

Varied levels of total or individual cations in soils may be attributed to addition and redistribution of salts (ions) by irrigation water (Bhadrapur and Seshagiri Rao, 1979, Edgar *et al.*, 2012). Occurrence of mobilized salts and their differential solubilities also might have contributed for cationic variations (Chabbra, 1996). Thus, higher solubility and easy transport of sodium salts along with percolating water may alter cationic balances in soils (Levy and Feighonbaum, 1977; Kuri and Rao, 1979; Costa *et* *al*., 1991). Higher amounts of sodium (40-50 per cent) in soils compared to other cations also confirm above observations. Relatively higher amounts of calcium in these soils may be attributed to contributions from lime based parent material (Doddamani *et al*., 1994).

Among different land categories, the amount of total anions in soil-water extracts was almost very similar to that of cations. Variations in anionic concentrations in soils of different land use categories could be attributed to quantity and quality of water used for irrigation (Kuri and Rao, 1979; Bhardwaj *et al*., 2019), and the mobilized salts and their solubility also determine the type of ions/ salts present (Costa *et al*., 1991; Bhardwaj *et al*., 2007). Higher amounts of chlorides in soils with irrigation may be attributed to transportation and accumulation of Cl^- due to its high solubility. These salts get easily carried by water and get accumulated in soil over time as water gets removed by transpiration and evaporation process (Agarwal and Rammoorthy, 1970). In some soil samples, chloride was observed even at toxic levels. Low occurrence of CO_3^{-2} in irrigated soils may be due to its precipitation after its interaction with Ca^{2+} ions.

Increase in ECe could be attributed to higher concentrations of all cations and anions in soils and the –ve correlation coefficient of CO_3^{2-} with ECe could be attributed to its precipitation with Ca^{2+} ions (Agarwal and Rammoorthy, 1970). Sodium ions in soil water extract were found positively and significantly correlated with Cl^- and SO_4^{2-} anions. This clearly suggests that the soils are getting enriched with sodium salts in the form of its sulphate and chloride. Increase in concentrations of chloride and sulphate salts of sodium with saline water irrigations or irrigation in saline soils are reported by others (Bhadrapur and Seshagiri Rao, 1979; Edgar *et al*., 2012).

CONCLUSION

The study highlighted the possible secondary salinization risks associated with the irrigation waters from three common sources in the black soils of Karnataka. Of all the sources, the lift waters present the highest risk of salinity development in soil, followed by the borewell waters. Use of canal waters, whenever available, or mixing when the supply is limited can reduce the risk. Presence of significant amounts of chlorides and sulphates point to the need for such urgent measures as frequent use of canal water or rain water harvesting to leach out the built up salt in the soil profile before significant damage is done to soils and crop productivity.

ACKNOWLEDGEMENT

The financial support for this work was provided by the University of Horticultural Sciences, Bagalkot and the Indian Council of Agricultural Research, New Delhi, as part of their regular support for student research on area specific researchable issues.

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