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Ground water quality characterization and its correlation with wheat yield

A. Hannan[1*], M. Ahmad[2], A. Niaz[3], L. Ali[4] and T. Waheed[5]
[1]Directorate of Land Reclamation, Irrigation and Power Department, Lahore
[2]Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad
[3]Soil Chemistry Section, Ayub Agriculture Research Institute, Faisalabad
[4]Adaptive Research Centre, Vehari
[5]Engro Fertilizer Limited

Abstract

*Tube well water quality is the major contributing factor towards the low yield of crops in Pakistan, as it is not fit for irrigation in most of the areas. This is a survey study in which100 water samples collected from farmer's tube wells were evaluated for their quality characteristics. The data depicted the average values of EC_{iw}, SAR_{iw} and RSC_{iw} corresponding to 1.93 ± 0.67 dS m^{-1}, 12.2 ± 65.00 (mmol $L^{-1})^{0.5}$ and 3.6±1.96 mmol L^{-1}, respectively. The range values noted for different water quality indications were $0.78 \geq EC_{iw} < 3.12$ dS m^{-1}, $2.57 \geq SAR_{iw} \geq 23.98$ (mmole $L^{-1})^{0.5}$ and $0.10 \geq RSC_{iw} < 7.10$ mmole L^{-1}. Within the conventional water quality indicators a significant correlation was found between SAR_{iw} and EC_{iw} (r=0.84**) showing that SAR_{iw} is a function of total salinity in irrigation water. However, RSC_{iw} and EC_{iw} were not significantly correlated (r=0.32). The significant correlation coefficients showed an increase in SAR and EC of soil with the use of irrigation water of high EC_{iw} and SAR. The wheat yield harvested from the fields irrigated with tube well water was found to be more affected by the sodicity compared with salinity of water, each having corresponding values of $2.08 \geq SAR < 22.38$ (mmole$^{-1})^{0.5}$ and $1.03 \geq ECe \leq 4.31$dS m^{-1}. A statistically justified model (R^2=0.934) $Y = 8317[EC_e]^{0.177}[EC_{iw}]^{0.883} / [SAR_{iw}]^{0.396}[SAR_s]^{0.416}[RSC_{iw}]^{0.382}$ was developed to predict wheat yield trend under a given set of soil and water characteristics. It was concluded that subsoil water of the region is of poor quality and should not be exploited by the farmers through private tube wells. Its injudicious use would salinize or sodicate the soils.*

Keywords: Soil, groundwater, correlation, modeling, wheat yield

Introduction

Importance of good quality surface irrigation water for agricultural sustainability can not be over emphasized. Unluckily, in Pakistan, surface water supplies are not adequate to support a fully developed agriculture. Forced by the canal water shortage, farmers have started exploiting groundwater resource to supplement the canal water (Javaid *et al*., 1998a).

According to an estimate about 44 million acre foot of ground water is being exploited for supplementing canal supplies (Mohtadullah *et al*., 1993). Unfortunately, about 50-60 % of discharge of existing wells is brackish in nature (Ashfaq *et al*., 2009) that requires interventions for sustainable land use. According to another estimate, 25 percent of tube well discharge in the Punjab province is useable, while 25% and 50% is marginal and unfit, respectively, for irrigation (Malik *et al*., 1984; Ashfaq *et al*., 2009). The quality of available ground water in most of the villages in Lahore district is not suitable for sustainable crop production and soil health (Ali *et al*., 2009). Similary, 48 percent of the water samples in Gujrat (Zahid *et al*., 2003) and 20 percent in Rawalpindi (Rizwan *et al*., 2003) were unfit for irrigation.

For sustainable crop production without damaging soil properties, the quality of groundwater is the main concern of the day. The injudicious use of poor quality groundwater increases salinity and sodicity problems because of its residual alkalinity (Javaid and Younis, 1998), high sulphate content (Javaid and Ali, 1999) and increased Na/Ca ratios (Ghafoor *et al*., 1997). Different water quality indicators with highly unfit range induce soil dispersion (Girdhar and Yadav, 1982; Khan, 1975) and subsequently decrease the crop yield (Nadeem *et al*., 2006; Ahmed *et al*., 2008).

For the mineral contents of irrigation water applied as same field conditions it was found that there was decrease in yield with the increase in the electrical conductivity of irrigation water (EC_{iw}). At low EC_{iw} (up to 1.5 dS m^{-1}) the yields of most crops were not affected (Ashfaq *et al*., 2009). In case of wheat, water having EC_{iw} of 3 to 3.5 dS m^{-1} caused about 10% reduction in yield (Hussain and Nishat, 1963). Effect of salinity on crop growth however, depends on type of salinity, specific ion-effect and many other

*Email: maqshoof@gmail.com

related factors (Richards, 1954; Parida and Das, 2005). Literature also supports that wheat yield is affected when EC_e is > 6 dS m^{-1} as root zone salinity (Ayers and Westcot, 1985). It is also reported that wheat crop in contrast to rice is resistant to salinity but sensitive to sodicity (Ahmed and Chaudhry, 1997).

With the above scenario in view, this study was conducted to develop a relationship between soil characteristics, brackishness of groundwater and wheat yield in Lalian unit in district Jhang.

Table 1: Soil and groundwater saline characteristics along with yield range

Particular	EC_{iw} (dS m^{-1})	EC_e (dS m^{-1})	SAR_{iw} (mmol $L^{-1})^{0.5}$	SARs (mmol $L^{-1})^{0.5}$	RSC_{iw} ($mmole_c$ L^{-1})	Wheat yield (kg ha^{-1})
Minimum	0.78	1.03	2.57	2.08	0.1	1140
Maximum	3.12	4.31	23.98	22.38	7.1	3797
Average	1.93±0.67	2.34±0.95	12.26±5.90	11.49±3.30	3.6±1.96	2342±884
CV (%)	34.9	40.59	48.20	28.73	54.5	37.8

Materials and Methods

The area of Lalian unit in District Jhang was selected for conducting this survey study. One hundred private tube wells were bench marked and water samples were collected in one liter bottles after operating the tubewells for half an hour. The depth of tube wells ranged from 80 to 110 ft. The average depth of ground water table in the area was from 14-38 ft. The water samples were analyzed for major cations (Ca^{+2}, Mg^{+2}, Na^{+}) and anions (CO_3^{-2}, HCO_3^- Cl^-, SO_4^{-2}) which were determined according to the procedures described by Richards (1954). The EC_{iw} was determined by EC meter. The residual sodium carbonate (RSC) and sodium adsorption ration (SAR) were computed by using the formulae:

$RSC = (CO_3^{-2} + CO_3^{-}) – (Ca^{+2} + Mg^{+2})$
$SAR = Na^{+} / (Ca^{+2} + Mg^{+2})^{0.5}$ (concentration in $mmol_c L^{-1}$)

One hundred soil samples were also collected at random from the selected wheat fields under going irrigation with the tube well water in the whole unit of Lalian. The soil samples (1 kg) were taken from 0-15 cm depth with an auger after the harvest of wheat crop. The grid density of the samples was 1 km x 1 km. The wheat yield ha^{-1} was recorded. A multiple regression model was developed to establish the relationship between crop yield and different soil and water quality indicators. The correlation between different water quality indicators was also worked out (Steel and Torrie, 1980).

Results and Discussion

(A) Characteristics of the groundwater

(i) Electrical conductivity (EC)

Data presented in Table 1 indicate that electrical conductivity of groundwater ranged from 0.78 to 3.12 dS m^{-1} with an average value of 1.93±0.67 dS m^{-1}. The coefficient of variation was 34.9 %. The data grouped into frequency classes (Table 2) indicate that relatively more water samples had an EC range of 1.01 to 1.50 with relative frequency of 27.59%. Only 3.45 % water samples had EC between 3.0 and 3.5 dS m^{-1}.

Table 2: Percent frequency distribution of different water quality characteristics

Estimate	Class interval	Frequency distribution
EC	<1.00	6.89
(dS m^{-1})	1.01-1.50	27.59
	1.51-2.00	20.69
	2.01-2.50	20.69
	2.51-3.00	20.68
	3.01-3.50	3.45
SAR	<6.0	13.79
(mmole $L^{-1})^{0.5}$	6.01-10.0	27.59
	10.01-14.0	20.69
	14.01-18.0	24.15
	18.01-22.0	6.89
	22.01-26.00	6.89
RSC	<1.25	6.89
($mmole_c$ $L^{-1})^{0.5}$	1.26-2.50	24.15
	2.51-3.75	27.59
	3.76-5.00	10.34
	5.01-6.25	20.69
	6.26-7.50	10.34

(ii) Sodium adsorption ration (SAR)

The sodium adsorption ratio (SAR) exhibited a great variation (C.V = 48.2 %) in the range of 2.57 to 23.98 with an average value of 12.26±5.90 (mmol $L^{-1})^{0.5}$ in Table 1. Data grouped into frequency classes (Table 2) indicate that 13.79 % water samples had SAR less than 6.0. Maximum frequency distribution was noted (27.59 %) in the SAR range of 6-10 (mmole $L^{-1})^{0.5}$, while 58.62 % water samples had SAR between 10 and 26 (mmole $L^{-1})^{0.5}$.

(iii) Residual sodium carbonate (RSC)

The residual sodium carbonate (RSC) values ranged from 0.1 to 7.1 $mmole_c\ L^{-1}$ with an average value of 3.6±1.96 mmol L^{-1} (Table 1). The highest coefficient of variation (54.5 %) among the water quality indicator was noted in case of RSC. The relative frequency distribution (Table 2) indicates that only 6.89 % water samples had RSC less than 1.25 $mmole_c\ L^{-1}$. Relatively, more water samples (27.59 %) were found in the RSC range of 2.51 to 375 $mmole_c\ L^{-1}$. Only 10.34 % water samples had RSC between 6.26 and 7.5 $mmole_c\ L^{-1}$.

Comparison among EC, SAR and RSC indicates that maximum number of water samples was unfit for irrigation. About 79 % water samples collected were found unfit on the basis of individual or combined water quality parameters. About 55.17 % water samples (Table 3) had all the EC, SAR and RSC values above the permissible level fixed at 1.5 dS m^{-1}, 10 $(mmol\ L^{-1})^{0.5}$ and 2.25 $mmole_c\ L^{-1}$, respectively.

Table 3: Distribution of 79 unfit water samples out of 100 total samples on the basis of different water quality indicators (individual or combined)

Water quality indicator	%
SAR basis	-
RSC basis	13.79
EC basis	3.45
EC-SAR basis	3.45
SAR-RSC basis	-
EC-RSC basis	3.45
EC-SAR-RSC basis	55.17

The literature supports that the use of water with high EC or SAR may lower down the farm income by deteriorating the soils undergoing irrigation with such waters (Parida and Das, 2005). However, the extent of soil deterioration depends upon soil type and management practices.

(iv) Interaction within water quality parameters

The relationship between different water quality parameters was worked out through regression and correlation analyses of the data (Table 4). It was noted that SAR_{iw} and EC_{iw} significantly correlated with each other (r = 0.84^{**}). The same was noted for RSC_{iw}-SAR_{iw} relationship (r = 0.82^{**}). However, a non significant correlation was found between RSC and EC parameter (r = 0.32^{ns}). It shows that SAR is a function of salinity i.e. the SAR together with total salt concentration (EC) may be used as an index to indicate salinity/sodicity hazard.

Table 4: Some statistical functions for different groundwater characteristics

Regression equation	Correlation coefficient
Water	
SAR = -1.996+7.387 (EC)	0.84**
RSC = 0.582+1.560 (EC)	0.32ns
RSC = 0.381+0.262(SAR)	0.82**
Soil	
EC_e = -0.371-1.02 EC_{iw}	0.68**
SAR_s = 6.092+0.440 SAR_{iw}	0.74**
SAR_s = 6.67=1.340 RSC_{iw}	0.75**

** = significant at P=0.01, ns = non-significant

B) Soil and brackish water relations

The EC_e of soil ranged from 1.03 to 4.31 dS m^{-1} (Table 1) with average EC_e value of 2.34±0.95 dS m^{-1}. A wide variation (40.59 %) in ECe of soil samples was noted. Similarly, the minimum and maximum SAR values corresponding to 2.08 and 22.38 $(mmol\ L^{-1})^{0.5}$ were noted with an average magnitude of 11.94±3.30 $(mmol\ L^{-1})^{0.5}$. Coefficient of variation was 28.73% showing a small variation in case of SAR compared to EC_e of the fields samples.

A highly significant correlation was found between soil and water characteristics (Table 4) showing the effect of brackish water on soil salinization/ sodification. The regression analysis of the data (Table 4) showed a substantial increase in SAR of the soil with the increase in each SAR and RSC of the irrigation water. An increase of 0.440 and 1.340 per unit increase in SAR_{iw} and RSC_{iw} was worked out. It shows that RSC_{iw} has relatively more detrimental affect on soil as compared to SAR of irrigation water. However, the degree of sodicity build-up in soils depends upon farmer’s management practices. Similarly, ECe of the soil gave a good correlation with EC_{iw} (r = 0.68**). That high SAR_{iw} certainly creates sodicity front in soil. The unscientific use of groundwater charged with bicarbonate and sodium contents resulted in the alkalization of certain soils of Pakistan (Bhatti, 1986). Under average management practices, the SAR of soil increases significantly in direct proportion to SAR_{iw} (Khandelwal and Pal, 1993) and is more harmful for soils as well as for crops than water with higher salinity (Haider *et al*., 1973).

C) Crop yield prediction in relation to soil and water characteristics

The effect of different soil and water characteristics on wheat crop was assessed. It was noted that the wheat yield ranged from 1140 to 3797 kg ha^{-1} with an average value of 2342±884 kg ha^{-1} against EC_e, SAR_s, SAR_{iw} and RSC_{iw} ranges corresponding to 1.03-4.31 dS m^{-1}, 2.08-22.38, 0.78-

3.12 dS m^{-1}, 2.57-23.98 and 0.1-7.1 $mmole_c\ L^{-1}$ (Table 1). Based on the data coded in a multiple regression equation, it was noticed that wheat crop was not affected by salinity. The small differences in wheat yield at various EC levels were due to the reason that wheat germination is little affected by saline water upto 4.5 dS m^{-1} (Francois *et al*., 1986). Similarly, Hussain (1963) pointed out that irrigation water up to 5.0 dS m^{-1} did not reduce the yield in case of wheat. It was noted that it is the sodicity of soil or water which actually affects the wheat crop. It is also reported that higher SAR_{iw} is more harmful than the total salinity of water (Ali *et al*., 1981).

It is fact that crop yield is affected by a number of soil, water and environmental factors. All these different factors exert integrated effect on crop yield. It is not possible to define the critical limits of EC_{iw}, SAR_{iw} and RSC_{iw} because the effect of different qualities of water on soil health and crop yield is governed more by the type of soil, climate and soil and water management practices than the chemistry of irrigation water (Ali *et al*., 1981; Singh *et al*., 1992). However, to predict crop yield trend, a multi-dimensional model is developed which covers the soil and water characteristics. The model developed is statistically justified (R^2 = 0.934**) and can be used effectively to predict wheat yield trend in the region under study. The empirical model used is given as under:

$$Y = \frac{8317[EC_e]^{0.177}[EC_{iw}]^{0.883}}{[SAR_{iw}]^{0.396}[SAR_s]^{0.416}[RSC_{iw}]^{0.382}}$$

Table 5: Soil and water quality characteristics in relation to wheat yield (selected samples for model verification)

Sample No.	EC_e (dS m^{-1})	SAR_s $(mmol\ L^{-1})^{0.5}$	EC_{iw} (dS m^{-1})	SAR_{iw} $(mmol\ L^{-1})^{0.5}$	RSC $(mmole_c\ L^{-1})$	Wheat yield (kg ha^{-1})
W_6	2.81	10.23	2.50	15.14	5.13	1511
W_{11}	3.09	11.22	2.51	15.85	5.37	1380
W_{29}	4.07	16.59	2.95	22.38	6.76	1202
W_{40}	3.31	13.49	2.50	16.59	5.62	1258
W_{59}	3.09	12.02	2.51	16.22	5.50	1566
W_{62}	1.31	3.16	1.25	2.95	1.70	3368
W_{64}	2.19	6.61	2.18	13.18	3.89	1905
W_{76}	1.82	3.98	1.41	4.05	2.18	3019
W_{87}	2.64	8.70	2.29	14.45	4.05	1641
W_{94}	1.26	2.09	0.79	2.57	0.80	3766

The data depicted via Figure1 show that a very close relationship exists between actual and the predicted values. To assess the compatibility, the selected data values on soil, water and crop yield are given in Table 5, which are coded as W_6, W_{11}, W_{29} etc. in the Figure 1. Soil and water composition can be fitted in the model for tentative yield prediction under a given set of soil and water characteristics. Need, however, be felt to model irrigation delta, soil and crop management practice etc.

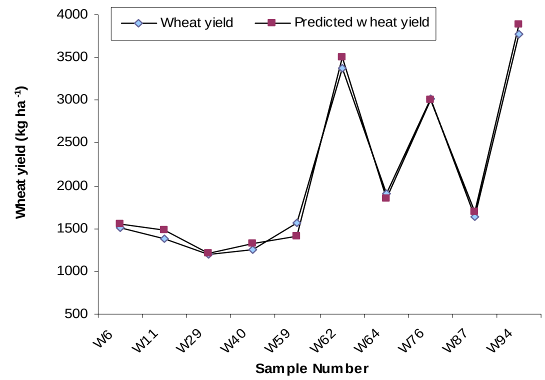

Figure 1: Relationship between actual and predicted wheat yield (kg ha^{-1})

Conclusion

As a strong relationship exists between the soil and water characteristics, and wheat yield, so it is concluded from the study that the multi-dimensional models should be developed to appraise crop yield under a given set of soil and water characteristics, keeping in view the water delta and soil texture in addition to soil and crop water management practices opted by farmers. Also, injudicious ground water exploitation by the farmers themselves would develop salinity/sodicity in the soil, hence reducing the crop yield.

References

Ahmed, C.N. and M.R. Chaudhry. 1997. Review of research on reclamation of salt affected soils in Pakistan. IWASRI Publication No. 175, Lahore, 131p.

Ahmed, S., J. Mohyuddin, S.M. Siddiqui and M.N. Bhutta. 2008. Use of brackish drainage effluent for agriculture in lower Indus basin. *Pakistan Journal of Water Resources* 12(2): 25-32.

Ali, M.S., S. Mahmood, M.N. Chaudhary and M. Sadiq. 2009. Irrigation quality of ground water of twenty villages in Lahore district. *Soil & Environment* 28(1): 17-23

Ali, T., G. Haider and M.A.R. Farooqi. 1981. Effect of tube well waters of different salinities on growth of sugarcane crop and soil properties. p. 164-177. *In:* Proceedings, Workshop on Membrane Biophysics and Salt Tolerance in Plants. March 11-21, 1978. Faisalabad.

Ashfaq, M., G. Griffith and I. Hussain. 2009. Economics of Water Resources in Pakistan, Pak TM printers, Lahore, Pakistan. 230p.

Ayers, R. and D.W. Westcot. 1985. Water Quality for Agriculture. Review 1. FAO, Irrigation and Drainage Paper 29. Rome, Italy, 174p.

Bhatti, H.M. 1986. Management of irrigation water qualities for crop production. Final technical report of PL-480 Project, AARI., Faisalabad.

Francois, L.E., E.V. Maas, T.J. Donovan and V.L. Youngs. 1986. Effect of salinity on grain yield and quality, vegetative growth and germination of semi dwarf and durum wheat. *Agronomy Journal* 78: 1053-1058.

Ghafoor, A., M.R. Chaudhry, M. Qadir, G. Murtaza and H.R. Ahmad. 1997. Use of drainage water for crops on normal and salt-affected soils without disturbing biosphere equilibrium. IWASRI, Publication No. 176, Lahore, Pakistan.

Girdhar, I.K. and J.S.P. Yadav. 1982. Effect of different Ca:Mg ratios and electrolyte concentration in irrigation water on the nutrient content of wheat crop. *Plant Science* 65: 63-70.

Haider, G., T. Ali and M.A.R. Farooqi. 1973. Effect of tube well water of different salinities on soil conditions and crop growth. MREP Publication No. 25, Manao Reclamation Experimental Project, Bhalwal.

Hussain, M. 1963. Research on reclamation of water logged and salt tolerance of crops. Directorate of Land Reclamation Research Publication No. 11: 103, Lahore.

Hussain, M. and H.A. Nishat. 1963. Review of reclamation activities and methods, and suggested measures for water logging and salinity control. p. 179-202. *In:* Proceedings of Symposium on Water-logging and Salinity in West Pakistan. Engineering Congress, Lahore.

Javaid, M.A. and M. Younis. 1998. Residual Alkalinity: A prospect in water quality. *Science International* 10: 425-428.

Javaid, M.A., C.K. Ali, J.I. Anjum and T.R. Khan. 1998a. Soil characteristics and wheat yield in the irrigation command of Gajer Gola distributory. *Pakistan Journal of Soil Science* 14:43-49.

Javaid, M.A. and C.K. Ali. 1999. Soil sodification as a function of high sulphate irrigation water application. PCRWR Proceedings on Water Resources: Achievements and Issues on 20th Century. June 28-30, 1990. Islamabad.

Khan, M. 1975. The effect of Mg on classification of alkali soils. p. 390-395. *In:* Proceedings International Conference Water logging and Salinity. October 13-17, 1975. Lahore.

Khandelwal, R.B. and P. Pal. 1993. Effect of salinity, sodicity and boron of irrigation water on the properties of different soils and yield of wheat. *Journal of Indian Society of Soil Science* 39:537-541.

Malik, D.M., M.A. Khan and B. Ahmad. 1984. Gypsum and fertilizer use efficiency of crops under different irrigation system in Punjab. Presented in Seminar on Optimizing Crop Production through Management of Soil Resources. May 12-13, 1984. Lahore. 27p.

Mohtadullah, K., C.A.U. Rehman and C.M. Munir. 1993. Water for the 21st Century. p. 1-29. IUCN- The World conservation union. Environmental and Urban Affairs Division, Government of Pakistan, Islamabad.

Nadeem, S.M., Z.A. Zahir, M. Naveed, M. Arshad and S.M. Shahzad. 2006. Variation in growth and ion uptake of maize due to inoculation with plant growth promoting rhizobacteria under salt stress. *Soil & Environment* 25(2): 78-84.

Parida, A.K. and A.B. Das. 2005. Salt tolerance and salinity effects on plants: A review. *Ecotoxicology and Environmental Safety* 60: 324-349.

Richard, L.A. (ed.). 1954. Diagnosis and Improvement of Saline and Alkali Soils. USDA Handbook No. 60, Washington, D. C., USA.

Rizwan, K., T. Mahmood, Z. Abbas, M. Dilshad and M.I. Lone. 2003. Ground water quality for irrigation in Rawalpindi district. *Pakistan Journal of Soil Scien*ce 22(1): 43-47.

Singh, R.B., P.S. Minhas, C.P.S. Chaulian and R.K. Gupta. 1992. Effect of high salinity and SAR waters on salinization, sodification and yields of pearl millet and wheat. *Agricultural Water Management* 21: 15-25.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and Procedures of Statistics. (2nd Ed). McGraw Hill Book Co. Inc., N. Y., USA.

Zahid, P., S.S.H. Kazmi and K.H. Gill. 2003. Characterization of irrigation quality of ground water in Gujrat District. *Pakistan Journal of Soil Science* 22(1): 48-54.