Research Article

Evaluation of Ground Water Quality for Irrigation Purposes and Effect On Crop Yields: A GIS Based Study of Bahawalpur

Umair Riaz*[1], Zafar Abbas[1], Qamar uz Zaman[2], Muhammad Mubashir[1], Mahwish Jabeen[2], Syed Ali Zulqadar[1], Zeenat Javeed[1], Saeed-ur-Rehman[1], Muhammad Ashraf[1] and Muhammad Javid Qamar[1]

[1]Soil and Water Testing Laboratory for Research, Bahawalpur-63100, Pakistan; [2]Department of Environmental Sciences, TheUniversity of Lahore-Lahore, Pakistan.

Abstract | Sampling and analysis of ground water of Bahawalpur Tehsil, Pakistan, has been made to evaluate its suitability for irrigation use. Water samples from different areas of the tehsil were collected and analysed for various physic-chemical properties like pH, electrical conductivity (EC), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), calcium (Ca^{++}), magnesium (Mg^{++}), sulfates (SO_4^-), carbonates (CO_3^-), bicarbonates (HCO_3^-), sodium (Na^+), and chloride(Cl^-). Results showed that 52.78% samples were unfit and 34.37% samples were considered as fit for irrigation. The interesting thing is that about 12.85% sample lies in the category of marginal fit waters for irrigation purposes after comparison with the standard values used for irrigation water for agricultural crops. The values of EC, SAR, and RSC were ranged from 0.031 to 15.39 dS m^{-1}, 0.02 to 52.66, and 0 to 43.3 me L^{-1}, respectively. Overall, in southwest areas the majority of water samples were found to be fit for irrigation while in northwest area majority of the water samples fall under unfit range. The SO_4 ranges from 89 to 1435 mg L^{-1}. The highest value of SO_4 was observed in the samples collected from Chak 13/BC, Chak 23/BC, Chak 12/BC and Cantt Area. The highest cotton and wheat yield on average basis was recorded in union council Goth Gani as compared to all areas while lowest cotton yield was observed in union council Mari Sheikh Sajra. In the light of above findings it is inevitable to treat the ground water with gypsum stones, dilution with canal water and growing of salt tolerant crops. It is necessary to manage the soil structure on sustainable basis for obtaining optimum crop yield.

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***Correspondence** | Umair Riaz, Soil and Water Testing Laboratory for Research, Bahawalpur-63100, Pakistan; **Email:** umairbwp3@gmail.com
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Introduction

The water is the fundamental constituent of about all the customs of life and it is chiefly achieved through two sources, i.e. surface water which includes streams, canals as well as fresh water lakes, rivers, etc. and ground water like borehole water and well water (Hasan, 2017). Because of its distinctive characteristics (i.e. bonding of hydrogen and polarity), and is capable to dissolve suspend, soak and adsorb on various matrix. Therefore, overall in nature the availability of pure water is impossible, as it receive the contaminants from its surroundings and from the human beings, insects, animals and from the other anthropogenic sources (Kosemani and Oyelami, 2017). The groundwater is one of the major sources of drinking water in Pakistan. Further, it is major source of water for agriculture and industrial purposes. Tremendous increase in the population of human beings, uncontrolled urbanization, inconsistent abstraction strategies and improper disposal of solid and liquid wastes and lack of implementation of laws regarding solid waste disposals had deteriorated the quality of groundwater in Pakistan (Rasool, 2017). Pakistan is the fourth largest user of groundwater among all countries (after India, USA and China). The agriculture sector is the largest consumer of ground water within the Pakistan, and provides water for approximately one-half of the total crop water requirements (Qureshi et al., 2008).

The quality of irrigation water adjacent to major cities of Pakistan, like Lahore, Multan, Faisalabad, Peshawar, Bahawalpur and Sheikhupura is declining because of improper disposal of municipal waste water and injudicious use of insecticides and pesticides and other agricultural inputs i.e fertilizers (Bhutta et al., 2002). The literature reported a substantial growth in the number of private tube-wells installed in Pakistan since 1960s (PWP, 2001; GOP, 2000; Qureshi et al., 2008, 2010). There were around 20,000 private tube-wells in the country in 1960; currently this figure crossed one million tube-wells, which are largely being used for irrigation (Yu et al., 2013). Tube wells are concentrated in the Punjab Province, which accounts for 93% of all private tube-wells in Pakistan. The ratio of groundwater recharge to discharge is 0.8 and as aresult prompt decline in the water tables has been stated in many parts of the country (Planning and Development Board, 2007; Qureshi et al., 2010). The quality of irrigation water directly affects the crops in terms of biomass production and yield losses (Yang et al., 2014). Very deep attention is required regarding the quality of irrigation water and all feasible long-term impacts of unfit/brackish water on agricultural crops. Therefore, the understanding regarding the quality of irrigation water is crucial for sustainable crop production.

Material and Methods

Description of the area under study

The spatial domain of the area under study was district Bahawalpur which is located in the southern Punjab (Pakistan). The area under study covers about 50 km from the east to the west and 47 km from the north to the south comprising about an area of 2372 km^2. The minimum daily temperature of the air was 24.5 °C and the maximum temperature was 52 °C in summer. While in winter the lowest air temperature was 10.9 °C and highest was 20.3 °C. The Bahawalpur division falls under the semi-arid region. Most of the area is under the cultivation of agricultural crops. The major cropping system being followed in this region is cotton-wheat cropping system. Only one river (Sutlej) is situated in this area and has no water all the year. In many parts of the study area there is a problems of water salinity due to which the farming community is facing problem of low crop yield (Figure 1).

Water sampling

The water samples were collected from the running tube wells with great precautions. The following observations were recorded: The depth of the tube well, pipe diameter, area being irrigated, the name of the farmer, address of the farmer and agricultural area owned by the farmer and GPS (Geographical Positioning System) location of the area, prevailing cropping pattern, and sampling date. The precautionary measures adopted were: sample quantity was about 0.5 liter to 1.0 liter. The samples were collected in clean plastic bottles. The sampling bottles were rinsed thrice with the same water being sampled. Prior to sampling, the tube well was run about half an hour. The samples were taken from the tube well outlets and no sample was collated from the reservoir. The bottles were closed with the lids and labeled accurately.

Chemical analysis

The collected water samples were analyzed at Soil and Water Testing Laboratory for Research, Bahawalpur for EC, pH, Ca^{++} + Mg^{++}, Na^{+}, CO_3^{-}, HCO_3^{-} and Cl^{-} (Table 1). Then the sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) were calculated by using the formulas given by (Richards, 1954). Based on the values of EC, SAR, RSC, the water samples were classified by using international standards.

SAR was calculated by the following formula:

$$SAR = Na^{+}/[(Ca^{2+} + Mg^{2+})/2]^{1/2}$$

(Cations concentration = mmol$_c$ L^{-1})

$$RSC\ (me\ L^{-1}) = (CO_3^{2-} + HCO_3^{-}) - (Ca^{++} + Mg^{++})$$

Where the concentrations are expressed in milliequivalents per liter (me L^{-1}) (Richards, 1954).

GIS mapping

ArcGIS 10.3 was used to display the spatial distribution of fit, unfit and marginally fit water samples according to EC and ground water quality in the study area.

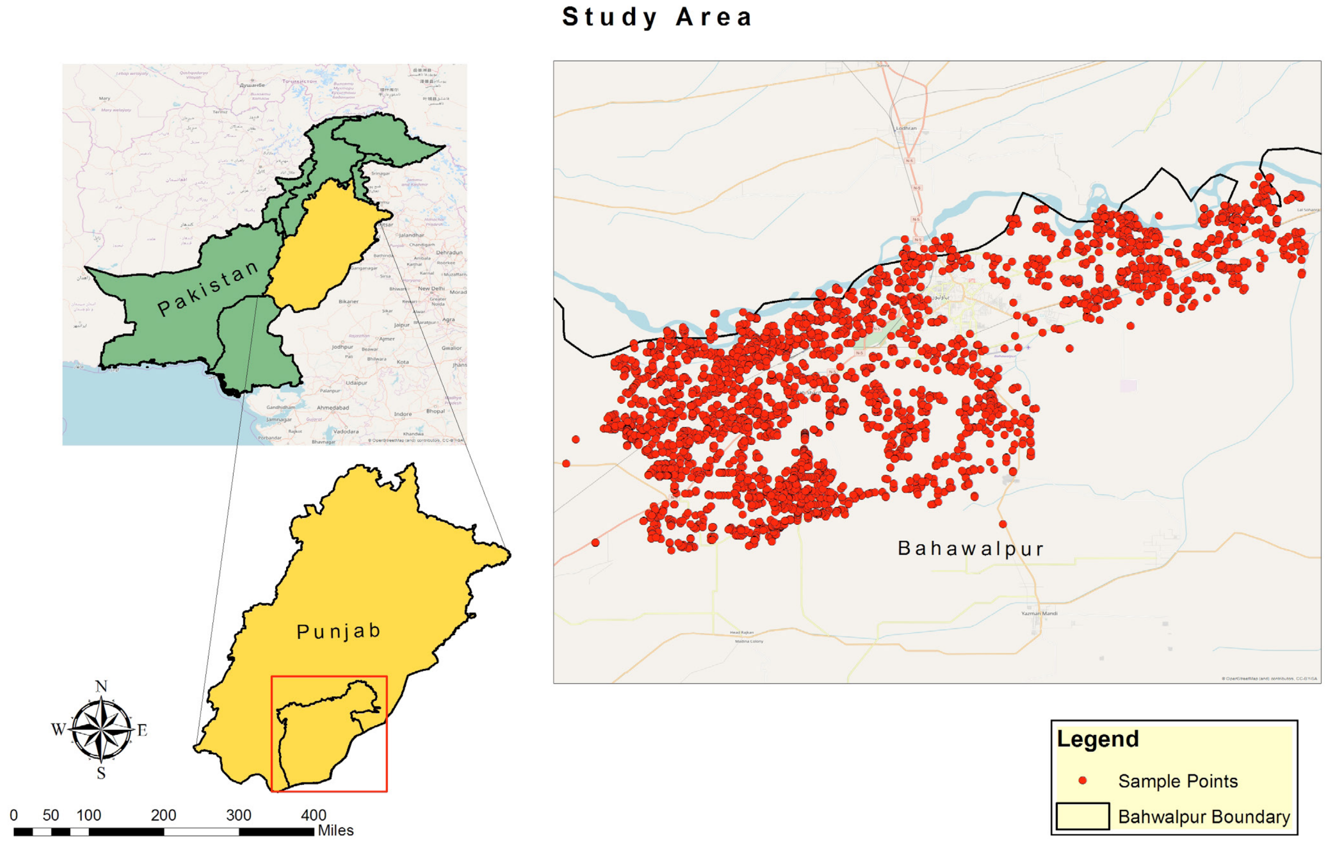

Figure 1: *Study area and water sampling positions*

Statistical analysis

The data was subjected to statistical analysis. The descriptive statistcs was applied for mean, standard deviation and percentage following the procedure described by (Steel et al., 1997).

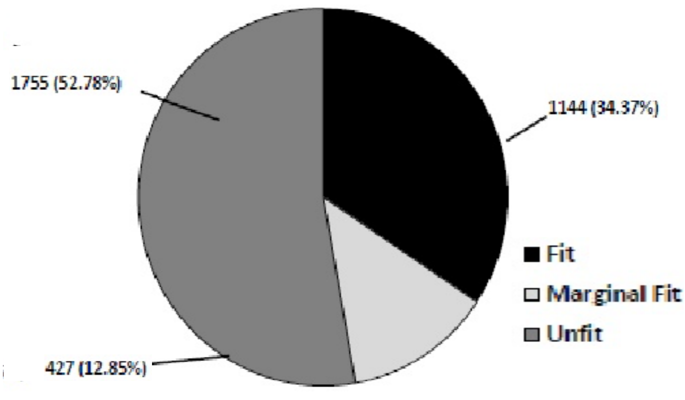

Figure 2: *Irrigation Water Quality of Tehsil Bahawalpur*

Results

Data in Figure 2 depicts the salinity levels of waters pumped out from various tube wells in Tehsil Bahawalpur. The overall data showed that 52.78% samples were unfit and 34.37% samples were considered as fit for irrigation. The interesting thing is that about 12.85% sample lies in the category of marginally fit waters for irrigation purposes according to the standards laid down by Malik et al. (1984) which are presently being followed in Punjab by the Department of Agriculture (Table 2).

Quality parameters of tube-well waters

Electrical conductivity (dSm^{-1}) status: The status of samples with respect to their EC has been shown in Figure 3. The values of EC were ranged from 0.031 to 15.39dSm^{-1}. Overall, about 24% water samples were within safe limits (<1.00 dSm^{-1}) whereas, 34% samples were unfit (>1.25 dSm^{-1}) and 12% were marginally fit (1.00-1.250 dSm^{-1}) for irrigation.

Sodium Adsorption Ratio (SAR) status: In the present study, the SAR ranged from 0.02 to 52.66. The water samples categorization on SAR (Sodium Adsorption Ratio) basis showed that SAR of about 65 % water samples was within safe limits (<6) whereas, 21% samples were unfit (>10) and 14% were marginally fit (6-10) for irrigation. The SAR of all water samples ranged from 0.02 to 52.66.

Residual Sodium Carbonates (RSC) status: The RSC ranged from 0 - 43.3me L^{-1}. About 18% water samples were within safe limits (<1.25 me L^{-1}). Only 7% were unfit (>2.50 me L^{-1}) and 7% were marginally fit (1.25-2.50 me L^{-1}) due to higher RSC.

Table 1: *Analysis techniques with references*

Parameters	Technique	Instrument make and model	Reference
pH	pH-metery	pH 200 Sensodirect	Richards (1954)
Electrical Conductivity	Conductivity meter	CON200 Sensodirect, Lovibond	Richards (1954)
Na and K	Flame photometry	PFP-7, Jenway	Richards (1954)
Ca, Mg, CO_3, Cl and HCO_3	Titrimetric method	-	APHA (2000)

Table 2: *Criteria for irrigation water quality*

Parameters	Fit	Marginally fit	Unfit
EC (μScm^{-1})	<1000	1000 – 1250	> 1250
RSC (me L^{-1})	<1.25	1.25 – 2.25	> 2.25
SAR (mmol L^{-1})½	<6	6 – 10	>10

Malik et al., (1984)

Sulfates (SO_4), pH and alkalinity: Water containing more than 1000 mg L^{-1} sulfates are toxic for plant growth and development (Ghoraba et al., 2013). In the present study, the SO_4 ranges from 89 to 1435 mg L^{-1}. The highest values of SO_4 was observed in samples taken from Chak 13/BC,Chak 23/BC,Chak 12/BC and Cantt Area. The water samples from the reporting areas having pH range from 6.61 to 8.29.

Union Council wise quality of water: Bahawalpur Tehsil is located in southern part of the Punjab under arid climate with dry weather most of the year. The reasons of unfit water samples due to EC, SAR, RSC and their cumulative affect with respect to Union Council is given in Table 3. In majority areas high EC was responsible for the unfitness of samples for crop irrigation. The Union Councils like Chak 4/BC, Chak 24/BC, KhanuWali, Sama Satta, Hakra, Mari Shikhh, JindooMisson, Goth Mehrab and Khanqah Sharif having unfit water for irrigation purposes due to the cumulative effect of EC, SAR and RSC while in union councils like Dera Izzat, Chak 12/BC and GindooMisson having unfit waters only due to SAR and RSC.

Effect of irrigation water on wheat and cotton yield

The highest cotton yield was recorded in union council Goth Gani (3343±166 Kg ha^{-1}), followed by Kanqah Sharif (3243±176 Kg ha^{-1}). This is because of the reason that most of the water samples from those

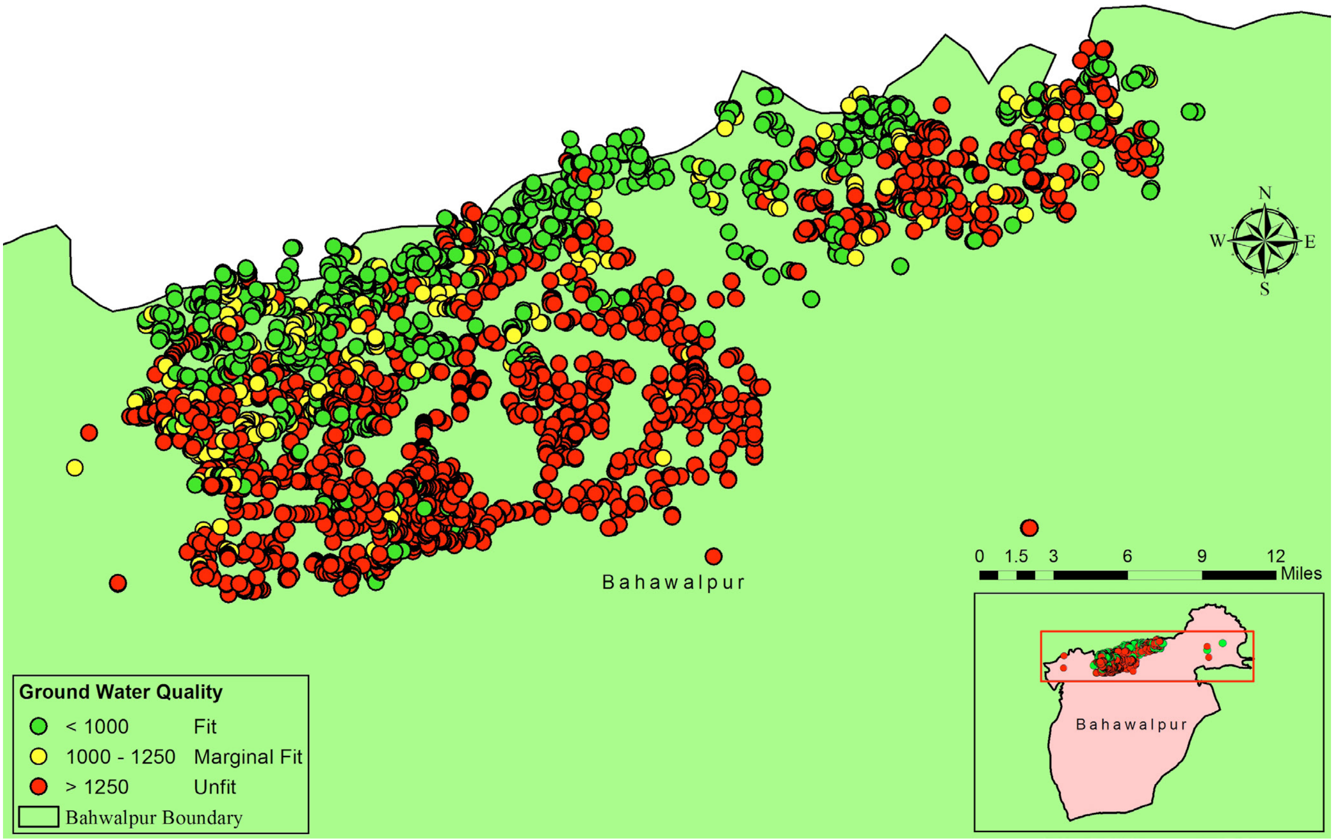

Figure 3: *R.M. Status of Electrical conductivity of ground water in Tehsil Bahawalpur*

areas were fit for irrigation (Table 3). The lowest cotton yield was observed in union council Mari Sheikh Sajra (1698±121 Kg ha^{-1}) due to the high EC of tube well waters in that area. Similarly, maximum wheat yield was found in union council Goth Gani (4621±178 Kg ha^{-1}), followed by Kanqah Sharif (4326±165 Kg ha^{-1}).

Table 3: *Union council wise categorization of unfit water samples*

Union Council	Unfit due to				
	EC	RSC	EC+ RSC	SAR+ RSC	EC+ SAR +RSC
DeraMasti	Unfit	-	-	-	-
Sahalan	Unfit	-	-	-	-
U/C No. 16	Unfit	-	-	-	-
Jhangi Wala	Unfit	-	-	-	-
DeraBakha	Unfit	-	-	-	-
DeraIzzat	-	-	-	Unfit	-
Cantt Area	Unfit	-	-	-	-
Mouza Raman	Unfit	-	-	-	-
Chak 12/BC	-	-	-	Unfit	-
Chak 4/BC	-	-	-	-	Unfit
Sheikh Shujra	Unfit	-	-	-	-
Chak 24/BC	-	-	-	-	Unfit
KhanuWali (south)	Unfit	-	-	-	-
KhanuWali	-	-	-	-	Unfit
Sanjar	-	-	Unfit	-	-
Raman	-	-	Unfit	-	-
SamaSatta	-	-	-	-	Unfit
37/BC	Unfit	-	-	-	-
Abbas Nagar	-	Unfit	-	-	-
Jalal Abad	Unfit	-	-	-	-
Hakra	-	-	-	-	Unfit
Goth Ganni	Unfit	-	-	-	-
1/BC South	Unfit	-	-	-	-
Mari Shikhh	-	-	-	-	Unfit
Mari Sheikh Sajra	Unfit	-	-	-	-
Mari Ameer Muhammad	Unfit	-	-	-	-
GindooMisson	-	-	-	Unfit	-
JindooMisson	-	-	-	-	Unfit
Goth Mehrab	-	-	-	-	Unfit
Khanqah Sharif	-	-	-	-	Unfit

Table 4: *Average yield of cotton and wheat in different union councils of Tehsil Bahawalpur*

Sr. No.	Union Council	Average cotton yield (Kg ha^{-1})	Average wheat yield (Kg ha^{-1})
1	Dera Masti	2681±102	3623±211
2	Sahalan	2594±210	3516±153
3	U/C No. 16	1980±162	3322±156
4	Jhangi Wala	2384±225	3378±128
5	DeraBakha	2810±209	3905±198
6	DeraIzzat	1997±116	2989±156
7	Cantt Area	2037±234	3416±133
8	Mouza Raman	2884±197	3902±149
9	Chak 12/BC	1931±205	5361±182
10	Chak 4/BC	3068±323	3323±196
11	Sheikh Shujra	2867±246	2978±151
12	Chak 24/BC	1809±218	2687±131
13	KhanuWali (south)	2934±197	3652±157
14	KhanuWali	2715±198	3713±216
15	Sanjar	3218±156	4081±201
16	Raman	2870±184	3983±237
17	SamaSatta	2781±165	3891±139
18	37/BC	1934±109	2832±121
19	Abbas Nagar	2123±125	2965±134
20	Jalal Abad	2712±143	3111±143
21	Hakra	2934±154	3326±165
22	Goth Ganni	3343±166	4621±178
23	1/BC South	1809±121	2890±123
24	Mari Shikhh	1989±109	2654±115
25	Mari Sheikh Sajra	1698±121	2398±109
26	Mari Ameer Muhammad	2754±143	3109±175
27	GindooMisson	2843±154	3343±154
28	JindooMisson	2934±136	3311±165
29	Goth Mehrab	3123±143	3326±212
30	Khanqah Sharif	3243±176	4326±165

(Values are means ± standard deviation, n = 3)

Discussion

Conductivity is defined as the current carrying capacity of water. Water with high salinity is toxic to plants and create salinity hazards (Borecka et al., 2016). Soils with high levels of salinity are called saline soils. High concentrations of salt in the soil can result in a "physiological" drought conditions. That is, even though the field appears to have plenty of moisture, but the plants start wilting because the roots become unable to absorb the water (Isbell, 2016). Water salinity is usually measured by the TDS (total dissolved solids) or through EC (Electrical Conductivity). In present study most of the water of Tehsil Bahawalpur was unfit in due to high electrical conductivity (Figure 3). Sodium Adsorption Ratio couriers the relative movement of sodium (Na^+) ions in the exchange reactions with the soil. This ratio processes the relative concentration of Na^+ to calciumand magnesium (Wang, 2013). When water with high SAR is applied to a soil, the sodium (Na^+) in the water can dislocate the calcium (Ca^{+2}) and magnesium (Mg^{+2}) in the soil. It creates hindrance in developing the stable soil aggregates and in turn result damage to soil structure. This also result decline in the permeability and infiltration of water in the soil with concomitant decrease in crop yield (FAO, 1992; Nouri et al., 2017).

Residual sodium carbonate (RSC) occurs in irrigation water when the carbonate (CO_3) plus bicarbonate (HCO_3) content exceeds the calcium (Ca) plus magnesium (Mg) content of the water (Naseem et al., 2010). The extended use of that water with high RSC for irrigation will lead to an accumulation of Na^+ in the soil. It will result 1) Nonstop toxicity to plants, 2) Surplus soil salinity and sodicity and associated poor plant development, and 3) Where significant amount of silt or clay is available in the soil, loss of soil structure and associated decrease in soil permeability. In this study,water with high RSC was found in many areas (Chak 4/BC, Chak 24/BC, KhanuWali, SamaSatta, Hakra, Mari Shikhh, JindooMisson, Goth Mehrab and Khanqah Sharif) indicating sign of danger in future to the soil structure of these areas which in turn hamper the crop yield in future. Regular use of waters with high RSC (>2.5 me L^{-1}) leads to salt build up and which may hinder the air and water movement by clogging the soil pores (Nishanthiny et al., 2010). Sulfite ions have very strong correlation with Mg. The deposition of sulfide minerals in Southwest areas of Bahawalpur is major reasons for this high concentration (89 to 1435 mg L^{-1}) of sulfate in collected water samples. The pH and alkalinity are valuable characteristics that can greatly manipulate the suitability of water for irrigation purposes. The normal pH ranges for irrigation water is 6.5 to 8.4 (Bauder et al., 2010). The alkalinity is imparted due to CO_3 and HCO_3 ions in the ground water. More concentration of HCO_3 get combine with Ca and Mg and will precipitate as carbonates when the soil solution concentrates in drying condition. The application of water with high EC directly affects the crop yields. Kumar et al. (2017) reported obvious decrease of about 53% in grain yield of wheat due to saline water irrigation.

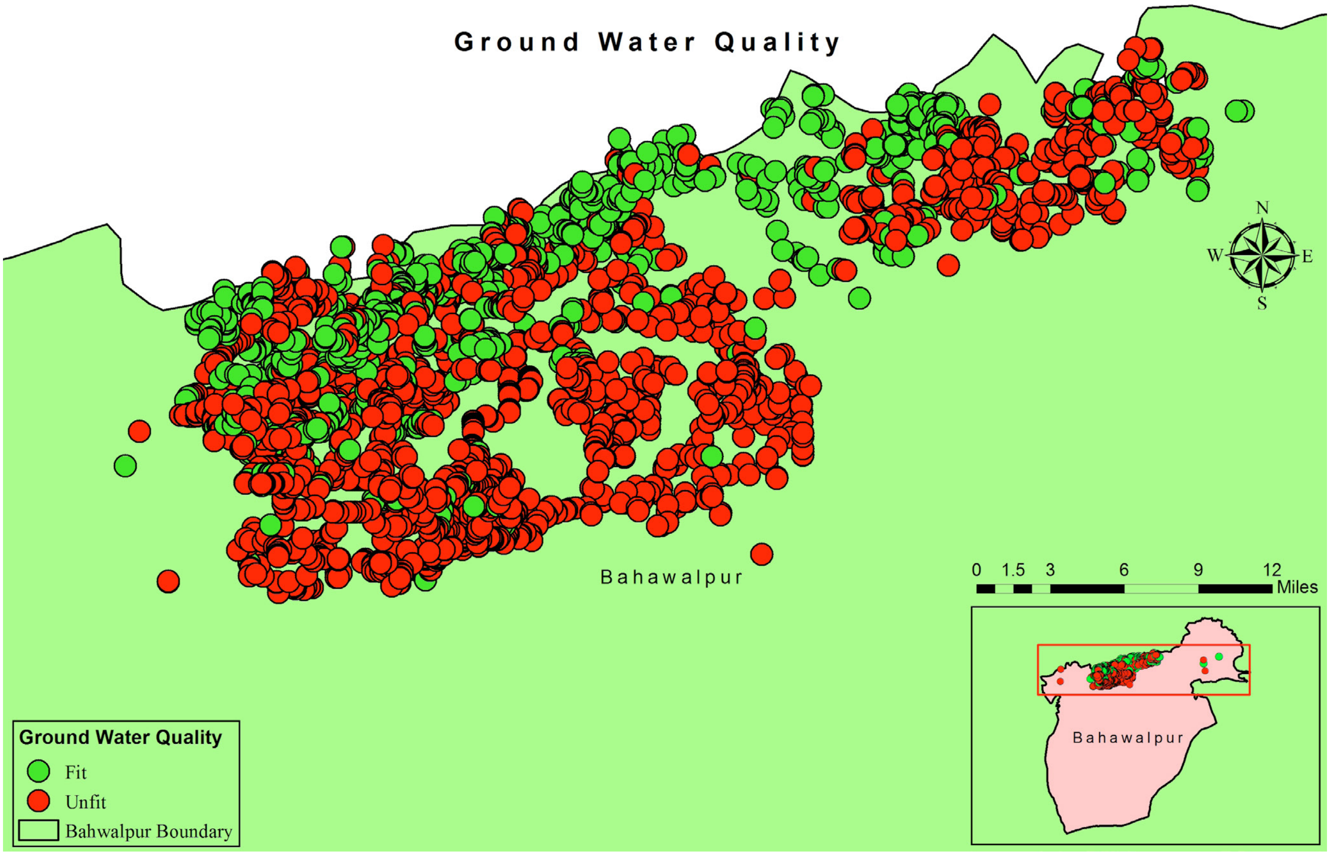

Figure 4: *Ground water quality status of irrigation water with respect to sampling points*

So our results are in line with their results (Table 4). In this case study, maximum wheat grain yield was found in union council Goth Gani (4621±178 Kg ha^{-1}), followed by Kanqah Sharif (4326±165 Kg ha^{-1}). While the lowest yield of cotton was observed in Mari Sheikh Sajra (2398±109 Kg ha^{-1}) which was due to elevated EC of the water as shown in data (Figure 4). As high concentration of soluble salts damaged the roots of the cotton plants which in turn hampered nutrient uptake by the plant with concomitant decrease in cotton yield. Anjum et al. (2005) also observed decline in cotton yield due to saline irrigation water.

Conclusion

The present study showed that the tube well water of large areas was unfit due to EC, SAR and RSC. During the survey of areas it has been witnessed that too much pumping, lack of consciousness and volume of stakeholders, lack of regulatory framework and spatial/temporal uncertainty in surface water due to climatic changes (droughts and floods) are the major challenges.

Recommendations

Good quality canal water, if available, is necessary for irrigation along with tube-well water to dilute its level of SAR. Other option for amelioration of water with excessive SAR is through lining of watercourses with gypsum stones. Management options for improving the water with high RSC include dilution with canal water and neutralization of carbonate and bicarbonates with the application of acids such as sulfuric acid or acid former such as elemental sulfur. Amendments such as gypsum, press mud and manure can be applied to reduce the ill effects of ground water on soil. Growing of salt tolerant crops is also necessary to combat the impact of inferior/unfit irrigation water.

Authors' Contribution

Umair Riaz: Overall research idea, write-up and management of the article.
Zafar Abbas: Data entry and statistical analysis.
Qamar uz Zaman and Mahwish Jabeen: GIS Mapping
Syed Ali Zulqadar: Introduction and chemical Analysis
Zeenat Javeed: References and Analysis
Saeed-ur-Rehman, Muhammad Mubashir and Muhammad Javid Qamar: Sample collection and Analysis
Muhammad Ashraf: Methodology, Provide funding

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