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Assessment and Conservation of Groundwater Quality: A Challenge for Agriculture

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Authors' contributions

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ABSTRACT

Quality of irrigation water is one of the key factors which have either direct or indirect impact on plant growth, soil and water management practices and plant yield. This work aims at the assessment of groundwater quality for irrigation, impact of different chemical parameters on plant yield and agriculture and water management practices needed in adverse irrigation water conditions. This study was conducted in semi-arid area where salinity and alkalinity are considered the main threats to the sustainable irrigation agriculture. Various sources of groundwater, within an area of 36 km^2, lying in the north-east of the Lakki Marwat district Pakistan, were surveyed and thirty representative samples were collected for the chemical analyses. The data from the chemical analyses of these water samples was compared with the standard values suggested by WAPDA, FAO and USDA Handbook 60. The electrical conductivity values indicate that the groundwater existing in the project area is slightly saline and the pH values find it slightly alkaline. The overall study reveals that none of the water samples has an adverse impact on the yield of barley, sorghum and wheat while 7% and 17% of this water respectively reduce the yield of corn and onion by 50%. Besides, 7% of this water reduces the yield of alfalfa by 25%. The study concludes that the management practices such as deep ploughing, provision of adequate drainage and crop rotation can improve the use of such water.

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1. INTRODUCTION

Groundwater represents all the water present in the soil voids and fissures within geological formations, which come from natural precipitation either directly by infiltration or indirectly from rivers and so. So its quality depends on the quality of recharged water, atmospheric precipitation, inland surface water and subsurface geochemical processes [1-2]. The physical, chemical and biological parameters of groundwater determine its suitability for the intended purpose.

Knowledge of the irrigation water quality and of the nature of soil problems allows steps to be taken for the best use of these resources in order to draw maximum benefits. The quality of irrigation water with respect to total soluble salts, sodium hazard and other elements toxic to crops should be taken in consideration. These together and environmental data and soil information help in identifying what crops can be grown and how much yield is expected. Applied during irrigation, water and its soluble components can undergo numerous chemical reactions when percolates through the soil profile. Many of these chemical reactions are qualitatively understood. Many reactions take place including ion-exchange involving the inorganic and organic colloidal complex of the soil when irrigation water moves through an arid or semi-arid soil profile. As a consequence, soil properties will be modified and affected. Irrigation with water containing high amounts of sodium and soluble salts can create saline-sodic soil conditions which interfere with plant growth if there is not enough calcium available to prevent the formation of sodic condition. Chemical amendments have been used widely for improvement and reclamation of sodic and saline-sodic soils as well as for improving the quality of irrigation water.

1.1 Irrigation Water Quality – Major Concern for Sustainable Agriculture

It is highly recommended to conduct a periodic assessment of groundwater quality for irrigation purposes in order to eradicate the severe problems of salinity, sodicity and specific ions that lead to deterioration of crop production and agriculture in the country. In fresh groundwater areas, excessive pumping by private tube wells leads to mining of the aquifer [3] and redistribution of the groundwater quality [4-5]. The quality of groundwater is area specific and generally ranges from fresh with Total Dissolved Solids (TDS) less than 1000 mg/L near the major rivers to highly saline with salinity exceeding 3000 mg/L TDS. Recharge to the brackish groundwater zone created serious quality concerns for the disposal of the saline effluents despite creating a top layer of potable water for the concerned population [6]. This problem was mainly due to the approach followed for drainage of area under the SCARPs in brackish groundwater zone, where saline groundwater (SGW) was pumped from deeper depths [7].

Exploration of groundwater, which is presently occurring in many areas, will cause intrusion of saline groundwater into the fresh groundwater areas. In addition, seepage of water from farmland will add dissolved fertilizers, pesticides and insecticides to groundwater. This will further increase pollution of groundwater and deteriorate its quality. The use of polluted groundwater for irrigated agriculture may adversely affect production potential of irrigated lands due to aggravation of the problem of salinity, sodicity and specific ion effects on crops and plants. It is essential to minimize groundwater pollution to improve its quality to a maximum possible limit by regulating groundwater extraction and/or increasing the recharge in areas where mining of groundwater is taking place.

The use of poor quality water causes problems of salinity, permeability and toxicity. High salt concentration in soil may clog the soil pores, coat the land surface and reduce water penetration and aeration. The preponderance of sodium in water disturbs the structure of soil and thereby making it unfit for cultivation of various food and fiber crops. Likewise, the concentration of chloride, carbonate and bicarbonate in irrigation water beyond optimum levels are toxic to the growing plants. The effect of brackish water on soils and crops is governed by climate, land and water management practices, type of soil, crop varieties to be grown and clay mineralogy of soil. Therefore, fixing limits of salts is a difficult task. If strict standards are fixed, a vast reservoir of groundwater is eliminated and if liberal standards are fixed, potential hazard may operate to affect the soil as well as crop health. Various soil and cropping problems are developed as the total salt content increases, and special management practices may be required to maintain acceptable crop yield.

1.2 Case Study of Pakistan

Irrigation water is a key factor for successful crop production; unfortunately, there is a severe shortage of good quality water to meet the crop requirement. To augment the inadequate water supply, the use of poor quality groundwater is left as the only option but its continuous use adds salts to the soil and is hazardous. The use of groundwater for irrigation has become a requirement, as canal water is not available in sufficient quantity. Out of the total 4.94 Mha-m of groundwater reservoirs in Indus plains, only 25 percent is fit for irrigation and another 25 percent is marginally fit. Thus 50 percent groundwater if used blindly can be a serious threat to crops and soil [8].

The economy of Pakistan is basically agrarian, and is a dominant sector in the Pakistan’s economy. It constitutes about 23 percent of the gross national product, directly accounts for about 70 percent of the export earnings and employs more than 50 percent of its civilian labor force. Agricultural sector is important to meet the food demand of growing population enforcing the foreign exchange resources through the export of farm produce, to provide raw materials for expanding the industries especially the textile and sugar and also other small and medium scale industries and to employ a much larger proportion of the rural population. Agriculture is therefore, a leading sector and backbone of the economy. However, the agriculture production is not adequate to meet the basic food requirements of increasing population, and thus the problem of food supply is becoming acute day by day. This situation has been further aggravated due to the potential hazard of salinity making irrigation water unsuitable for irrigation, thus reducing agricultural produce.

In Pakistan, the natural precipitation is not sufficient to meet the crop requirement and the soil-water balance is always in deficit range. Supplying water through artificial means to supplement the natural precipitation must make up this deficiency. However, Pakistan is blessed with extensive groundwater resource which has been evolved due to direct recharge from natural precipitation, river flow, and the continued seepage from the conveyance system of canals, distributaries, watercourses and application losses in the irrigated lands during the last 65 years. The vast and readily manageable groundwater aquifer underlying the Indus plains and co-existing with the canal system is an asset for Pakistan’s water resources system. In fact, the aquifers provide the ultimate water storage reservoir system for Pakistan, with useable volume far in excess of all existing and potential surface reservoirs free from sedimentation and large evaporation losses and usually located close to the area of use [9]. Recent estimates of the availability and use of groundwater of an acceptable quality indicate that this resource has been heavily overexploited affecting both the quality and quantity of the groundwater [10]. Since most of the easily exploitable surface water resources have already been tapped, the future demand of water for agriculture, human survival and nature will have to be met largely through water conservation and further exploitation of already over mined groundwater resources.

1.3 Study Area

Fig. 1 showing District Lakki Marwat extends over an area of 3164 km^2, a semi-arid region with an annual rainfall of about 268.7 mm. An area of 36 km^2, lying in the north-east of the district, is the main focus of this study. The project area is about 9 km long and 4 km wide. It consists of hill torrents on one side and the River Kurrum on the other side. The main crops are wheat, gram, maize, sugarcane and vegetable. Fruits include dates, melons and watermelons etc. The land is irrigated by Marwat Canal from Baran Dam and Kachkot Canal from River Kurram. Tube wells and lift irrigation systems also irrigate small portion of the land. Timely rain is the only hope for the farmers.

Fig. 1. Map of Pakistan showing the location of study area in the country

The geology of area comprises of a thick blanket of alluvial plain, containing unconsolidated, quaternary deposits, silt, gravels and sand. This plain is bounded by an assemblage of the sandstone, clay and carbonates. The foothills are dominantly composed of loose boulders of the sandstone, variable in shapes and sizes. These are detached from the higher ranges by the diurnal change of temperature and transported to the plains by the streams. The talus is of variable size and shape and is dominantly sand and erinaceous in composition.

Climate of the study area is semi-arid which necessitates irrigation to undertake agricultural pursuits. Natural surface water resources are rare while fresh groundwater is available in limited pockets with limited potentials. Water used for irrigation varies greatly in quality depending upon the type and quantity of dissolved salts. The suitability of water for irrigation is determined not only by the total amount of salt present but also by the kinds of salt. Various soils and cropping problems develop as the total salt increases, and special management practices may be required to maintain acceptable crop yield.

Keeping in view the above problem, the objectives of study were to:

1. Evaluate the impacts of existing water quality on crop yield
2. Evaluate the quality of irrigation water with respect to total soluble salts, sodium hazard and other elements toxic to crops and
3. Determine the impact of various chemical parameters on crop yield and groundwater use for agriculture

2. METHODOLOGY

The research activity involved site selection, water sampling, chemical analysis in laboratory, and comparison of the results with the standards. This study was conducted from December 2007 to December 2008 in which water quality of different wells for irrigation was analyzed for salinity/sodicity, taken from various locations of the project area. Various parameters like electrical conductivity (ECw), pH, SAR and RSC are investigated and analyzed in the light of a number of different criteria developed by various researchers. ECw of irrigation water measures total salinity. pH is an important characteristic of water which tells whether it is acidic, neutral or alkaline. The relative activity of sodium ion in the exchange reaction with soil is expressed in terms of a ratio known as sodium adsorption ratio (SAR). It is an important parameter for determining the suitability of irrigation water, because it is a measure of alkali/sodium hazard for crops. SAR can be estimated by the formula (all ions are expressed in epm). The total effect of sodium with respect to calcium plus magnesium is called Sodium Adsorption Ratio (SAR), which is used for measuring the sodium hazard of water given by the formula below.

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

To predict the tendency of calcium carbonate to precipitate from high bicarbonate water, Residual Sodium Carbonate (RSC) is used. ECw, RSC and SAR results of water samples are compared with WAPDA local Standards [11] Table 1 and also with Wilcox's graphic (USSL diagram, 1954) in Fig. 2. The various ions like cations (Na^{+}, Ca^{++}, Mg^{++}, K^{+}) and anions (CO_3^{--}, HCO_3^{-}, Cl^{-}, SO_4^{--}) have specific effects on crops and are generally analyzed to check water salinity problems. The anions and cations concentrations in water samples are compared with the classification of Ayers and Westcott [12] as given in Table 2.

Table 1. Irrigation water classification (WAPDA, 1974)

Class of water	EC_W (dS/m)	RSC (mmol/L)	SAR $(mmol/L)^{0.5}$
Useable	0-1.5	0-2.5	0- 10
Marginal	1.5-2.7	2.5-5.0	10-18
Hazardous	>2.7	>5.0	>18

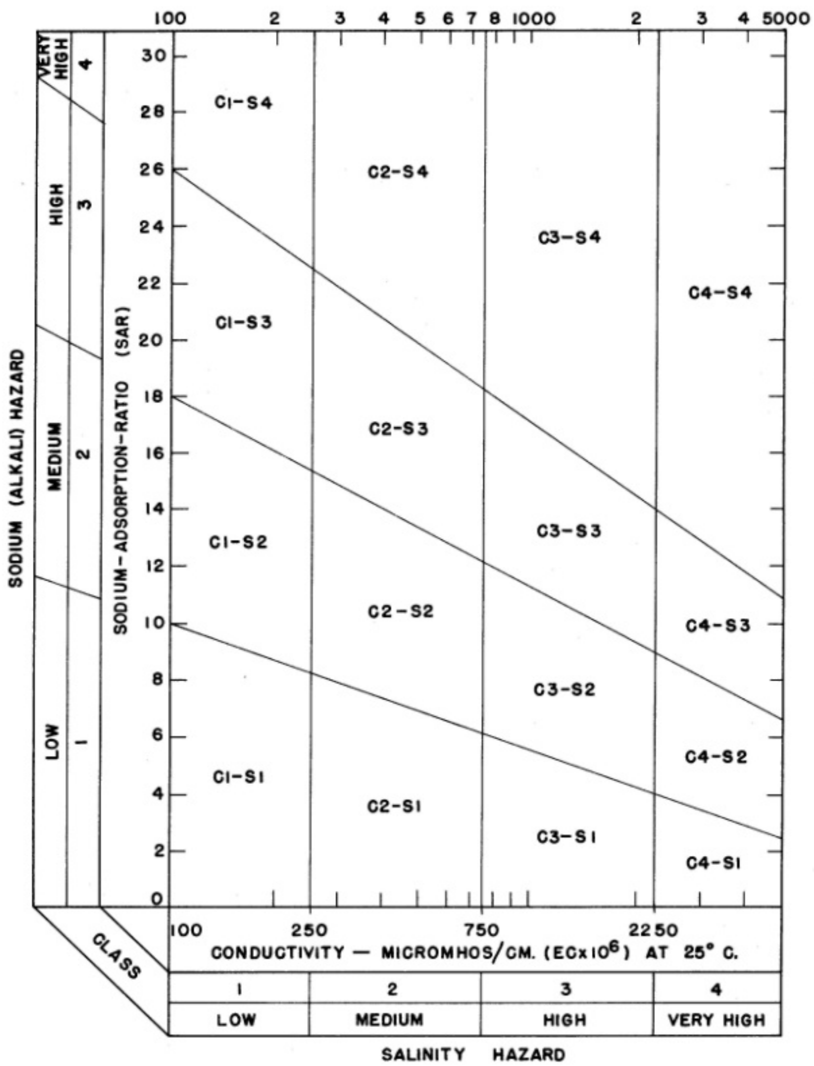

Fig. 2. Wilcox's graphic (USSL diagram, 1954) Diagram for classification of irrigation waters

Table 2. Common irrigation water quality parameters and its range (Ayers and Westcot, 1985)

Water parameters	Symbol	Units	Usual range in irrigation water
Electrical Conductivity	EC_w	dS/m	0-03
Total Dissolved solids	TDS	mg/L	0-2000
Cations			
Calcium	Ca^{++}	meq/L	0-20
Magnesium	Mg^{++}	meq/L	0-05
Sodium	Na^{+}	meq/L	0-40
Potassium	K^{+}	meq/L	0-0.05
Anions			
Carbonate	CO_3^{--}	meq/L	0-01
Bicarbonate	HCO_3^{-}	meq/L	0-10
Chloride	Cl^{-}	meq/L	0-30
Sulfate	SO_4^{--}	meq/L	0-20
Nutrients			
Nitrate-Nitrogen	$NO_3^{-}n$	meg/L	0-10
Ammonium-Nitrogen	NH_4-N	meg/L	0-05
Phosphate- Phosphorous	PO_4-P	meg/L	0-05
Miscellaneous			
Boron	B	meq/L	0-02
Acidity/Basicity	pH	1-14	6.0-8.5
Sodium Adsorption Ratio	SAR	(meq/L)0.5	0-15

2.1 Site Selection and Water Sampling

The primary objective of irrigation is to provide a crop with adequate and timely amounts of water, thus avoiding yield loss caused by extended periods of water stress during stages of crop growth that are sensitive to water shortages. However, during repeated irrigations, the salts in the irrigation water can accumulate in the soil, reducing water available to the crop and hastening the onset of a water shortage. Understanding how this occurs will help suggest ways to counter the effect and reduce the probability of a loss in yield. The mentioned site has been selected due to the major agricultural activity of the region takes place here. Due to considerable decrease in the yield from the land, this study was launched to explore the reasons. The study region belongs to the Upper Ganges Aquifer with one of the largest groundwater footprints of 26.1±7.5 x (10^6 km^2).

There are two major crops grown in the area; Rabi crops or Rabi harvest refers to agricultural crops sown in winter and harvested in the spring. The water that has percolated in the ground during the rains is main source of water for these crops. Rabi crops require irrigation. On the other hand, Kharif crop refers to the planting, cultivation and harvesting of any domesticated plant sown in the rainy (monsoon) season on the Asian subcontinent. Such crops are planted for autumn harvest and may also be called the summer or monsoon crop in Pakistan.

The detail of agricultural activity (cropping pattern) and land utilization in the selected site is shown in Tables 3 and 4 respectively.

Table 3. Acreage and Production of Major Crops

Crops	Area in Hectares			Production in Tones		
	Irrigated	Un irrigated	Total	Irrigated	Un irrigated	Total
Kharif Crops						
Maize	5,504	95	5,599	8,691	57	8,748
Rice	125	---	125	191	---	191
Jowar	467	187	654	306	106	412
Bajra	27	45	72	17	25	42
Sugarcane	494	---	494	18,900	---	18,900
Rabi Crops						
Wheat	23,214	58,929	82,143	43,428	36,966	80,394
Gram	1,303	45,443	46,746	698	15,511	16,209
Barley	114	129	243	72	34	106

Table 4. Land use pattern of District Lakki Marwat

Land Use status	Area (ha)	Percent Area
Total area	629,980	-
Cultivated area	180,350	28.63
Net sown area	145,561	23.11
Current fallow	34,789	5.52
Un-cultivated area	134,640	21.37
Waste area	43,293	6.87
Not available for cultivation	91,347	14.50

The project area was surveyed and thirty water samples were collected randomly for analysis from different tube wells of the project area, using plastic bottles of one-liter size. Each bottle was rinsed with distilled water and then filled with the sample water after running the pump for 5 to 10 minutes. Two or three drops of toluene were added to each bottle for inactivating micro-organisms in the bottle, thus filled bottles were confined with stoppers, labeled and brought to laboratory for analysis.

The project area has been demarcated in the Fig. 3 and Table 5 gives the locations in the project area from where groundwater samples were collected.

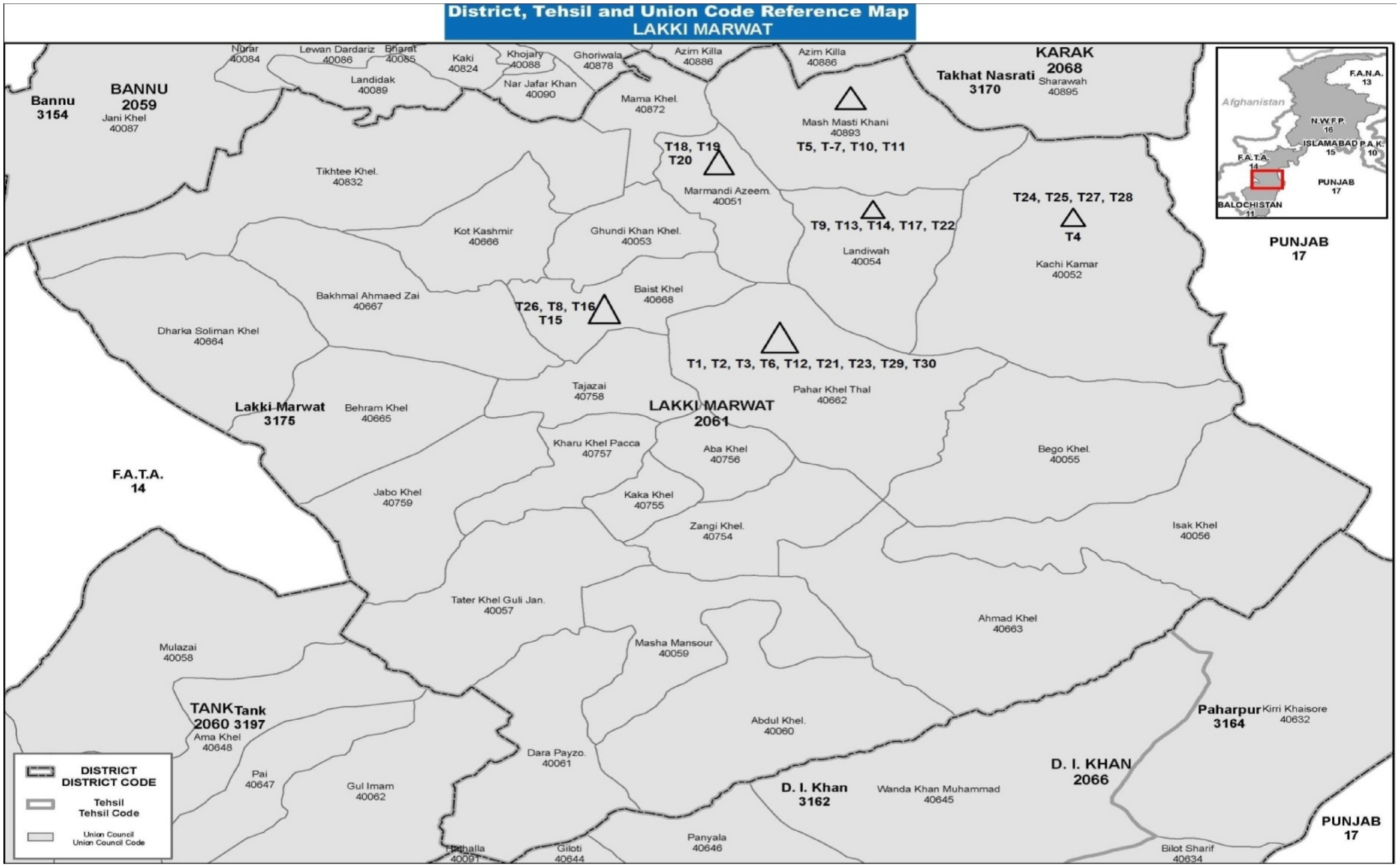

Fig. 3. Location of wells identified by triangular legends

Table 5. Location and source of groundwater samples in project area

Well No	Location	Well No	Location
T1	PaindaMichenKhel	T16	GanguNariva
T2	Mir Azam MichanKhel	T17	Landiwah
T3	SarkatiMichanKhel	T18	Wanda Fatah Khan
T4	KechiQamar	T19	Samandi
T5	Wanda Atshi	T20	Wanda Mush
T6	Wanda Langer Khel	T21	ShamoniKhattak
T7	Wanda Langer Khel	T22	Landiwah
T8	Wanda Langer Khel	T23	Wanda Aurangzab
T9	Landiwah	T24	Hakim Topa
T10	Wanda Kara (Hakim)	T25	Wanda Gulapha
T11	Wanda Gulzari	T26	PurdilBeguKhel
T12	Wanda ShahabKhel	T27	ChokiJandShumali
T13	Landiwah	T28	Wanda Gulapha
T14	Landiwah	T29	TalaChokiJand
T15	GanguNarvia	T30	Wanda Alam Shah Khel

2.2 Chemical Analyses

Various sources of groundwater, within an area of 36 km^2, were surveyed and thirty representative samples were collected for the chemical analyses. The concentration of various ions such as Na^+ (sodium), Ca^{++} (calcium), Mg^{++} (magnesium), K^+ (potassium), CO_3^{--} (carbonate), HCO_3^{--} (bicarbonate), Cl^- (chloride) and SO_4^{--} (sulfate) in the collected groundwater samples was determined. Table 6 gives the methods used for determining parameters. The data collected from the chemical analyses of these water samples was compared with the standard values suggested by WAPDA (Water and Power Development Authority), Food and Agriculture Organization (FAO), and United States Department of Agriculture (USDA) Handbook 60. These water samples were then categorized based on USDA Handbook60 given in Table 11.

Table 6. Types of methods used during analysis

Parameter/Units	Method	Parameter/Units	Method
Electrical Conductivity/ dS/m	EC-meter	**pH**	Electrometric
Sodium (mg/l)	Flame Photometer	**Chloride (mg/l)**	Titration
Potassium (mg/l)	Paqualab photometer	**Carbonate (mg/l)**	Titration
Magnesium (mg/l)	Atomic absorption spectro- photometer	**Bicarbonate (mg/l)**	Titration
Calcium (mg/l)	Atomic absorption spectro- photometer	**Sulfate (mg/l)**	Paqualab photometer

3. RESULTS AND DISCUSSION

Table 7 gives the results obtained from the chemical analyses and table 8 gives the statistical interpretation of these parameters in the form of standard deviation and coefficient of variation. The comparison of results with the FAO and WAPDA guidelines is presented in the Table 8.

Table 7. ECw, pH, soluble cations and anions, SAR, RSC of groundwater

Sample No	EC (ds/m)	PH at 20°C	Soluble Cation (meq/L)				SAR	Soluble Anion (meq/L)				RSC(meq/L)
			Na^{++}	Ca^{++}	Mg^{++}	K^{+}		CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}	
T1	0.49	7.20	6.74	24	10.20	0.32	2.49	0.00	4.45	3.21	1.02	-7.99
T2	0.65	7.30	8.00	6.94	12.02	0.04	22	0.27	5.83	4.89	1.50	-12.86
T3	0.58	7.40	6.26	4.35	9.22	0.14	2.09	0.00	4.09	4.59	1.08	-9.48
T4	0.50	7.10	4.84	2.66	8.72	0.20	1.83	0.20	3.50	1.58	1.54	-7.68
T5	0.81	7.00	4.35	2.56	11.19	0.57	1.52	0.15	4.48	5.92	4.05	-9.12
T6	1.12	7.20	7.50	4.17	9.71	0.32	2.50	0.00	4.62	6.03	7.91	-9.26
T7	0.27	7.30	8.26	4.81	7.08	0.31	2.86	0.33	3.37	0.68	0.59	-8.19
T8	2.90	7.50	28.33	15.80	23.37	0.11	5.40	0.33	16.81	20.90	9.57	-22.03
T9	0.86	7.30	5.08	1.27	2.39	0.51	3.24	0.00	4.21	4.95	2.08	0.55
T10	1.24	7.50	4.15	1.84	1.64	0.38	2.54	0.21	4.33	25	7.27	1.06
T11	1.72	7.50	5.02	2.15	2.16	0.02	2.79	0.12	3.25	2.92	1.80	-0.94
T12	0.70	7.20	4.12	1.72	1.20	0.64	2.70	0.11	4.51	2.08	1.12	1.70
T13	0.96	7.50	3.28	1.96	1.44	0.71	2.00	0.11	3.75	4.81	2.41	0.46
T14	1.90	7.30	2.65	1.68	3.21	0.02	1.46	0.17	5.53	4.56	4.95	0.81
T15	1.60	7.00	3.45	2.38	2.61	0.45	1.80	0.12	4.15	12.53	1.06	-0.72
T16	1.56	7.60	5.97	2.40	4.23	0.04	2.81	0.20	5.27	1.24	4.24	-1.16
T17	0.70	7.40	3.37	1.56	1.20	0.44	29	0.00	2.83	4.00	1.76	0.07
T18	1.86	8.00	21	1.83	2.17	0.38	1.29	0.00	3.06	13.94	2.50	-0.94
T19	0.80	7.30	25	1.47	1.80	0.32	1.46	0.21	2.91	3.45	1.28	-0.15
T20	0.98	7.10	3.21	1.12	1.92	0.03	23	0.00	3.78	2.43	3.64	0.74
T21	0.74	7.20	4.00	1.39	2.78	0.51	2.40	0.14	3.91	1.20	1.03	-0.12
T22	1.85	7.00	4.17	3.70	3.35	0.54	1.80	0.00	4.72	1.90	3.84	-2.33
T23	1.00	7.40	4.67	2.97	5.01	0.10	2.00	0.20	4.33	1.44	2.43	-3.45
T24	2.80	7.40	10.25	8.55	16.88	0.21	2.49	0.27	4.17	4.59	12.82	-20.99
T25	0.54	7.10	2.15	1.47	1.57	0.03	1.43	0.00	3.81	3.42	0.52	0.77
T26	1.20	7.40	6.28	4.32	2.86	0.55	2.62	0.12	2.53	1.33	3.57	-4.53
T27	1.20	7.10	4.33	2.87	4.55	0.45	1.91	0.00	4.83	2.66	2.87	-2.59
T28	1.70	7.00	3.20	1.19	1.83	0.45	21	0.11	3.85	4.92	6.23	0.94
T29	1.10	7.10	4.21	1.87	1.12	0.02	2.70	0.17	3.06	2.58	2.00	0.24
T30	1.30	7.20	6.21	2.94	2.74	0.25	2.99	0.00	3.25	2.43	4.87	-2.43
Avg	1.19	7.29	5.62	3.21	5.34	0.30	2.34	0.12	4.44	4.45	3.39	-3.99
SD	0.64	0.22	4.71	2.92	5.28	0.21	0.77	0.11	2.47	4.28	2.90	6.23
CV	54	3	84	91	99	70	33	91	56	96	86	-156

Table 8. Statistical measures of parameters

Parameter (Units)	Avg.	Standard Deviation	Coefficient of variation (%)	Min	Max	Standards	
						FAO	WAPDA
pH	7.29	0.22	3	7.00	8.00	6-8.50	Nil
ECw (ds/m)	1.19	0.64	54	0.27	2.9	0-3.00	0-2.70
SAR $(meq/L)^{0.5}$	2.34	0.77	33	1.29	5.40	0-15	0-18
RSC (meq/L)	-3.99	6.23	-156	-22.03	1.70	0-05	0-05
Na^+ (meq/L)	5.62	4.71	84	2.15	28.33	0-40	Nil
Ca^{++} (meq/L)	3.21	2.92	91	1.12	15.80	0-20	Nil
Mg^{++} (meq/L)	5.34	5.28	99	1.12	23.37	0-05	Nil
K^+ (meq/L)	0.30	0.21	70	0.02	0.71	0-0.05	Nil
CO_3^{--} (meq/L)	0.12	0.11	91	0	0.33	0-01	Nil
HCO_3^-(meq/L)	4.44	2.47	56	2.53	16.81	0-10	Nil
Cl^- (meq/L)	4.45	4.28	96	0.68	20.90	0-30	Nil
SO_4^{--} (meq/L)	3.39	2.90	86	0.52	12.82	0-20	Nil

3.1 Electrical Conductivity (EC_w)

The most influential water quality guideline on crop productivity is the water salinity hazard as measured by electrical conductivity (ECw). The primary effect of high ECw water on crop productivity is the inability of the plant to compete with ions in the soil solution for water (physiological drought). The higher the ECw, the less water is available to plants, even though the soil may appear wet. Because plants can only transpire “pure” water, useable plant water in the soil solution decreases dramatically as ECw increases. According to WAPDA [11] Table 5, ECw values ranged from 0.27 to 2.90 dS/m; 70% of the water samples had ECw values below 1.5 dS/m, 23.3% were in the range of 1.5 to 2.7 dS/m and 6.7% had values greater than 2.7 dS/m. The average ECw value shows that groundwater had low salt concentration. The results by Hussain et al., [13] indicated that salinity level of soil was reduced considerably or remain unchanged with the application of water having ECw up to 0.75 dS/m, however, increased in other cases when ECw values of water were from 2 to 3 dS/m. Two water samples T8 and T24 are showing the maximum ECw values due to the presence of huge amount of salts. Water with an ECw of 1.15 dS/m contains approximately 907 kg of salt for every 1234 m^3 of water.

Table 9 shows the influence on crop tolerance and yield potential by irrigation water salinity and Table 10 gives the percent reduction in yield of various crops due to adverse values of ECw. It is clear from Table 9 that forage crops are more resistant to salinity, followed by field crops.

Table 9. Crop tolerance and yield potential of selected crops as influenced by irrigation water salinity (Ayers and Westcot, 1985)

Field Crops	100% EC_w	90% EC_w	75% EC_w	50% EC_w	0% EC_w
Barley	5.3	6.7	8.7	12	19
Sorghum	4.5	5.0	5.6	6.7	8.7
Wheat	4.0	4.9	6.3	8.7	13
Soyabean	3.3	3.7	4.2	5.0	6.7
Cowpea	3.3	3.8	4.7	6.0	8.8
Groundnut	2.1	2.4	2.7	3.3	4.4
Rice	2.0	2.6	3.4	4.8	7.6
Corn	1.0	1.7	2.5	3.9	6.7
Forage Crops					
Alfalfa	1.3	2	3.6	5.9	10
Barley hay	4.0	4.9	6.4	8.7	13
Clover	1.0	2	3.9	6.8	13

Table 10. The effect of ECw on the percent reduction of yield of various crops

Crops	No of Samples	ECw (ds/m)	% Reduction in Crop Yield
Barley	30	<5.30	0
Sorghum	30	<4.50	0
Wheat	30	<4.00	0
Corn	16	<1.10	0
	8	>1.10-1.70	10
	4	>1.70-2.50	25
	2	>2.50-3.90	50
Onion	10	<0.8	0
	9	>0.8-1.20	10
	6	>1.20-1.80	25
	5	>1.80-2.90	50
Alfalfa	21	<1.30	0
	7	>1.30-20	10
	2	>20-3.60	25

3.2 pH of Groundwater

pH values ranging from 7.00 to 8.00 indicated that the water samples were slightly alkaline in nature but the alkalinity levels were low enough to induce sodicity problem in the soil. Shainberg and Oster [14] reported that the pH of irrigation water is not an accepted criterion of water quality because it tends to be buffered by the soil and most crops can tolerate a wide pH range, however, some crops can grow better in a specific pH range.

3.3 Ions Concentration

Out of the total water samples, 100% came within the usual range of sodium i.e. 0 to 40 meq/L (Table 7). Babcock et al. [15] concluded that irrigation water containing sodium salts increase the amount of soluble salts and sodium in the soil. Alawi [16] during his PhD work at University of Arizona found that using water containing high amounts of soluble salts and sodium for irrigation can create saline-sodic soil condition which interferes with plant growth if enough calcium is not available in the soil or water to prevent the formation of sodic condition. As it is clear from the results, the sample T8 exhibits the maximum amount of Na i.e. 28.33 meq/L thus causing to create saline-sodic condition due to absence of enough calcium as the occurrence of Mg ions in higher proportions than Ca ions increases the adverse effects due to sodicity [17]. For T8, the Mg is in higher proportion than Ca, thus the higher amount of Na in water is a source of creating saline-sodic condition. The usual range of calcium in irrigation water is 0-20 meq/L while our irrigation water samples ranged from 1.12-15.80 meq/L. The proportion of calcium to other exchangeable cations (Mg^{++}, K^{+}, Na^{+}) generally exceeds 80% in arid and semiarid soils. Soils with high calcium concentration have, in general, a good infiltration rate and a good structure. Calcium plays an important part in maintaining cells integrity, membrane permeability, pollen germinations, and growth. Ayers and Westcott [12] found that frequent irrigation maintain a lower sodium adsorption ratio since dilution favors the absorption of calcium and magnesium over sodium. In this way losses of calcium due to precipitation are minimized. The usual range of magnesium in irrigation water is 0-05 meq/L. 33% of the total water samples had higher values than usual range. For the case of Tubewells T8 and T24, Mg is present in higher proportion than Ca i.e. for T8, Mg is 23.37 meq/L and Ca is 15.80 meq/L and similarly, for T24, Mg is 16.88 and Ca is 8.55. This gives a clear indication of sodicity oriented adverse impact. According to the classification of Ayers and Westcott [12] Table 10, 23% of the total water samples came within usual range of potassium while 77% irrigation water samples were above the usual range of 0-0.05 meq/L. Shalhevet [18] conducted an experiment on the use of saline water for irrigation purpose and came to the conclusion that most crops were more sensitive to the effect of salinity during the seedling stages and that the crop response to nitrogen and potassium fertilizers was not affected by saline condition. So, 77% of irrigation water samples with excess of potassium were posing a serious threat to the crops in the seedling stages.

As per results, 100% of the water samples came within the usual acceptable range of carbonate in irrigation water 0-1 meq/L. Gupta [17] concluded that the presence of carbonate ions is least desirable in irrigation water because they tend to eliminate Ca ions from the water and cause strong alkalization in the irrigated soils, while bicarbonate precipitates Ca ions only partly. The usual acceptable range of bicarbonate in irrigation water is 0-10 meq/L (Table 7). While our irrigation water samples ranged from 2.53 to 16.81 meq/L. 3.33% of the total water samples had higher values than the usual range. The chloride content of our water samples ranged from 0.68-20.90 meq/L. The 100% water samples came under the usual range of Chloride. Kelly [19] found that if the chloride concentration of irrigation water exceeds 5.0 meq/L, the leaves of orange trees commonly showed burning along their margins. Sulfate concentration ranged from 0.52 to 12.82 meq/L. Modaihsh et al. [20] reported that irrigation with sulfate rich water affects the pH and EC_w and improves the availability of nutrients in soil.

3.4 Sodium Adsorption Ratio (SAR) of Groundwater

The SAR of water samples ranged from 1.29 to 5.40 $(meq/L)^{0.5}$. While comparing with WAPDA [11] Table 1, 100% of the water samples had SAR below 10 and met the requirement. The analytical data plotted on the U.S Salinity Laboratory Diagram in Fig 2 illustrates that most of the groundwater samples fall in the field of C_3S_1 and C_2S_1 indicating high to medium salinity and low to medium sodium water type which can be suitable for irrigation purposes.

3.5 Residual Sodium Carbonate (RSC) of Groundwater

RSC values of groundwater ranged from -22.03 to 1.70 meq/L. 67% samples had RSC values less than zero and 33% had values between 0-2.5 meq/L. Hussain et al., [21] reported that RSC in irrigation water has hazardous effect on soil conditions. The infiltration rate is decreased because of the alkali conditions produced in the soil. With water having values RSC closer to 5 meq/L, the hazardous effect is not significant.

3.6 Overall Water Quality Evaluation on the Basis of EC_w, SAR and RSC

Based on EC_w, 70% of water sample were useable; 23.3% marginal and 6.7% were hazardous. While based on SAR and RSC, 100% of water sample were useable. According to the USSL diagram 1954, the water samples have been categorized into USDA groups based on their SAR and EC_wvalues presented in Table 11 below.

Table 11. Water Samples classified based on USDA Handbook60

Water Samples	USDA Classification	SAR	EC_w
30%	C_2S_1	1.43 to 2.86	0.27 to 0.74 ds/m
63.3%	C_3S_1	1.29 to 3.24	0.80 to 1.90 ds/m
6.7%	C_4S_1	2.49 to 5.40	2.80 to 2.90 ds/m

4. CONCLUSION

The electrical conductivity values indicate that the groundwater existing in the project area is slightly saline and the pH values find it slightly alkaline. Salinity and alkalinity are major and ever present threats to the permanence of irrigation agriculture in arid and semi-arid regions. Quality of irrigation water is one of the most important factors which influence directly or indirectly soil and water management practices, plant growth and plant yields [16]. Based on ECw limits, 70% water samples were useable; 23.3% marginal and 6.7% were hazardous. Based on ECw result, 100% of water samples had no effect on barley, wheat and sorghum crop production. The average SAR value of groundwater was 2.34 $(meq/L)^{0.5}$. The SAR of groundwater indicates that it is in the safe limits. Based on SAR limits, 100% of water samples were in useable limits. The RSC value found to be -3.99 meq/L shows that the contraction of carbonate and bicarbonate was low which cannot cause calcium and magnesium to precipitate in the soil. Based on the RSC limits, 100% water samples were useable. The concentrations of Cl- and $SO4^{--}$ in groundwater were in safe ranges. The overall study reveals that none of the water samples has an adverse impact on the yield of barley, sorghum and wheat while 7% and 17% of this water respectively reduce the yield of corn and onion by 50%. Besides, 7% of this water reduces the yield of alfalfa by 25%.

Water from all the tube wells except that from tube well no. T8 and T24 could be used for irrigation without any fear of salinity build up. Water samples from tube well no. T8 and T24 had higher salinity/sodicity problem. The soil should be amended with gypsum before the use of water from these wells for agriculture. Gypsum reduces the soil pH because it helps in replacing the Ca for the Na on the exchange complex and subsequent leaching of the Na out of the soil. When sodium dominates over calcium content, the soil aggregates are unstable and the soil easily loses its structure and hydraulic conductivity is reduced. The soils are dense and hard; they have a low permeability, less water holding capacity, and poor aeration. Root development, water availability, and nutrient uptake are disturbed in these types of soils. Regular/periodic monitoring of groundwater quality is highly recommended to ensure safe irrigation water for sustainable agriculture. The respective organizations and government bodies should monitor the groundwater quality on a periodic basis at least once a year, before its usage for irrigation. All types of crop should be grown in the area without any fear of salinity/sodicity problems. Land leveling and smoothing practice should be adopted for the uniform distribution of water. Proper drainage system, deep ploughing and proper crop rotation will ensure the use of water. Crop rotation is the highly recommended treatment for the study region as it also mitigates the build-up of pathogens and pests that often occurs when one species is continuously cropped, and can also improve soil structure and fertility by alternating deep-rooted and shallow-rooted plants. Properly managed legumes in rotation can increase crop income by providing a legume forage or grain crop, or improving wheat yields after a legume green manure. Legumes improve soil health, especially compared to fallow, by adding nitrogen and organic matter and reducing potential erosion and leaching loss. Fallowing contributes to increased salinity and wastes soil nitrogen and water while legumes may reduce the energy footprint of cropping systems by reducing the need for nitrogen fertilizer, and improve the stability and health of agro-ecosystems.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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