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Water Pollution

Sustainable groundwater – a need of sustainable agriculture

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Abstract

Globally, irrigated agriculture is the largest extractor and the most frequent consumer of groundwater resources, with important groundwater-dependent and largely spread agro-economies. 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 yields. This work aims at highlighting the importance of periodic 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. Thirty representative samples were collected for chemical analyses from various sources of groundwater, within an area of 36 km^2, lying in the north-east of the Lakki Marwat district Pakistan. The standard values suggested by WAPDA, FAO and USDA Handbook 60 were used as benchmark for comparison. The electrical conductivity and pH values together classify groundwater as saline-alkaline. It is revealed 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%. This work recommends management practices such as deep ploughing, provision of adequate drainage and crop rotation for improving the use of such water.

Keywords: *Groundwater, Lakki marwat, WAPDA, Salinity, Sodicity, Irrigation.*

1. Introduction

General

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 with environmental data and soil information help identify 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.

Case Study of Pakistan

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

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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 [3]. 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 [4]. 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.

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 [5] and redistribution of the groundwater quality [6-7]. 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 [8]. 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 [9].

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.

Irrigation Water Quality Standards and Classification

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. Scientific research in this direction was accomplished by different researchers as given in the Tables from 1 to 10.

Table 1 Irrigation water classification based on salt concentration (Richards, 1954)

Water Class	EC_w (dS/m)	Suitability for irrigation
Low Salinity Water (Cl)	0.1 -0.25	Suitable for all types of crops and soil. Permissible under normal irrigation practices except in extremely low permeability
Medium Salinity Water (C2)	0.25-0.75	Can be used, if a moderate amount of leaching occurs. Normal salt tolerant plants can be grown without much salinity control.
High Salinity Water (C3)	0.75 -25	Unsuitable for soil with restricted drainage. Only high salt tolerant plants can be grown.
Very high Salinity Water (C4)	>25	Unsuitable for irrigation under ordinary conditions.

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Table 2 Irrigation water classification based on SAR (Richards, 1954)

Water Class	SAR(meq/L)$^{0.5}$	Suitability for irrigation
Low Sodium Water (S1)	<10	Suitable for irrigation on almost all soils with little danger of the development of exchangeable sodium.
Medium Sodium Water (S2)	10-18	Will present an appreciable sodium hazard in fine textured soil. It can be used on coarse textured or
High Sodium Water (S3)	18-26	May produce harmful level of exchangeable the sodium in most soils and require, good management, drainage, leaching and organic matter addition.
Very high Sodium Water (S4)	>26	Unsatisfactory for irrigation purposes.

Table 3 Irrigation water classification based on TDS, SAR, and RSC [23]

Class of Water	TDS (ppm)	SAR (mmol/L)$^{0.5}$	RSC (mmol/L)
Safe	<1000	<5	<1.25
Marginal	1000-2000	5-10	1.25-2.50
Hazardous	>2000	>10	>2.50

Table 4 Irrigation water class based on EC_W [24]

Class of Water	EC_W (dS/m)
Safe	1.5
Marginal	1.5-3.0
Unsafe	>3.0

Table 5 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

Table 6 Irrigation water classification [25]

Class of water	TDS (ppm)	SAR (mmol/L)$^{0.5}$	RSC (mmol/L)
Safe	Upto 1000	Upto 10	Upto 2.50
Marginal	1000- 1500	10-18	2.50-5.0
Hazardous	>1500	>18	>5.0

Table 7 Irrigation water criteria [26]

Class of water	TDS (ppm)	SAR (mmol/L)^{10}	RSC (mmol/L)
Good	a) ^{1}< 1000 b) ^{2} < 750	10 7	2.50 2.50
Marginal	a) 1000-2000 b) 750-1500	10-15 7-12	2.5-5.0 2.50-5.0
Hazardous	a) >2000 b) >1500	>15 >12	>5.0 >5.0

a)^1 Under optimum management condition, b)^2 Under form management condition

Table 8 Irrigation water quality criteria (Department of Agriculture, Punjab)

Class of water	TDS (ppm)	SAR (mmol/L)$^{0.5}$	RSC (mmol/L)
Suitable	< 800	<8	<1.25
Marginal	800-1000	8-10	1.25-2.50
Hazardous	>1000	>10	>2.5

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Table 9 Irrigation water standards (Ayers and Westcot, 1985)

Degree of Restriction on Use	EC_W (dS/m)	TDS (mg/L)
None	<0.7	<450
Slight to moderate	0.7-3.0	450-2000
Severe	>3.0	>2000

Table 10 Common irrigation water quality parameters and its range (Ayers and Westcot, 1985)

Water parameters	Symbol	Units	Usual range in irrigation water
Electrical Conductivity Conductivity	EC_w	dS/m	0-3
Total or dissolved solid	TDS	mg/l	0-2000
Cations			
Calcium	Ca^{++}	meq/l	0-20
Magnesium	Mg^{++}	meq/l	0-5
Sodium	Na^{+}	meq/l	0-40
Potassium	K^{+}	mg/l	0-2
Anions			
Carbonate	CO_3^{--}	meq/l	0-1
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	mg/l	0-10
Ammonium-Nitrogen	NH_4-N	mg/l	0-5
Phosphate- Phosphorous	PO_4-P	mg/l	0-2
Miscellaneous			
Boron	B	mg/l	0-2
Acidity/Basicity	pH	1-14	6.0-8.5
Sodium Adsorption Ratio	SAR	$(meq/L)^{0.5}$	0-15

Study Area

District Lakki Marwat extends over an area of 3164 km^2, a semi-arid region with an annual rainfall of about 268.7 mm. Fig. 1. shows the location and neighborhood of Lakki Marwat district in Pakistan. 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. Some of the land is irrigated by Marwat Canal from Baran Dam and Kachkot Canal from River Kurram. Tube wells and lift irrigation systems irrigate major portion of this land through the use of groundwater. So, groundwater is the main and major source of irrigated agriculture.

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.

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

Study Objectives

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 [10]. 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. 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.

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. conduct chemical analysis of groundwater.
2. obtain information concerning the effects of these chemicals on water quality.
3. find salinity/sodality levels and ion concentration in irrigation water at different locations.
4. evaluate the impacts of existing water quality on crop yield.
5. suggest proper agricultural water management practices, if needed.
6. evaluate the quality of irrigation water with respect to total soluble salts, sodium hazard and other elements toxic to crops.
7. determine impact of various chemical parameters on crop yield and groundwater use for agriculture.
8. determine need for periodic assessment and regular testing of groundwater to identify variation in water quality and suitability with the passage of time.
9. devise water management practices required for sustainable agriculture.

Methodology

The work consisted of 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 based on the problems faced by farmers in these areas. This study was then taken up to help the local farmers. Various parameters like electrical conductivity

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(EC_w), pH, SAR and RSC are investigated and analyzed in the light of a number of different criteria developed by various researchers. EC_w of irrigation water measures total salinity. pH is an important characteristic of water which tells whether it is acidic, neutral or alkaline. 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. To predict the tendency of calcium carbonate to precipitate from high bicarbonate water, residual sodium carbonate (RSC) is used. EC_w, RSC and SAR results of water samples are compared with WAPDA Standards (1974) Table 5 and also with Richard s' classification (1954) given in Table 1 and 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 Westcot [11] as given in Table 10. For the assessment of overall impact of present water quality on crop yield, Ayers and Westcot s' Classification [11] as given in Table 11 has been used.

Table 11 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
Barely	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
Barely hay	4.0	4.9	6.4	8.7	13
Clover	1.0	2	3.9	6.8	13

Site Selection and Water Sampling

The project area was surveyed and thirty water samples were collected, based on the repeated complaints of local farmers from the area of concern that was being irrigated with groundwater, 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. 2 and Table 12 gives the locations in the project area from where groundwater samples were collected.

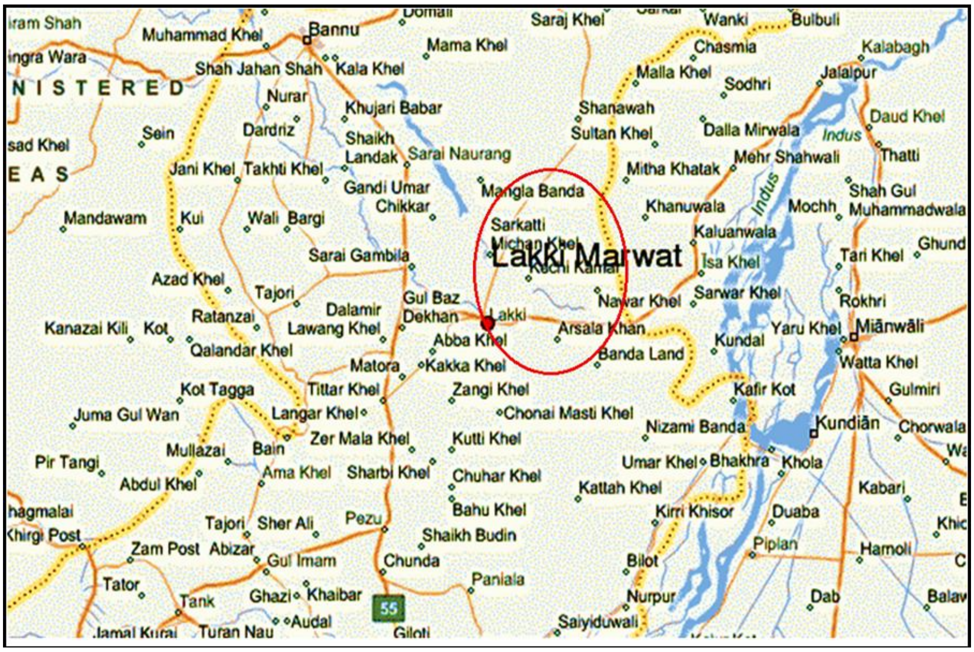

Fig. 2 Map of Lakki Marwat showing study area

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Table 12 Location and source of groundwater samples in project area

WELL NO	LOCATION	WELL NO	LOCATION
T1	Painda Michen Khel	T16	Gangu Nariva
T2	Mir Azam Michan Khel	T17	Landiwah
T3	Sarkati Michan Khel	T18	Wanda Fatah Khan
T4	Kechi Qamar	T19	Samandi
T5	Wanda Atshi	T20	Wanda Mush
T6	Wanda Langer Khel	T21	Shamoni Khattak
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	Purdil Begu Khel
T12	Wanda Shahab Khel	T27	Choki Jand Shumali
T13	Landiwah	T28	Wanda Gulapha
T14	Landiwah	T29	Tala Choki Jand
T15	Gangu Narvia	T30	Wanda Alam Shah Khel

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 keeping in view the fact to cover all the areas of concern. 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 13 gives the methods and equipments 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 18.

Table 13 Types of methods, equipment and chemicals used during analysis

S#	Parameter/Units	Method	Reagent/ Apparatus
1	**Electrical Conductivity/dS/m**	EC-meter	Distilled water Filter paper
2	**pH**	Electrometric	Buffer solution of pH 4.0 and pH 7.0 Distilled water
3	**Sodium (mg/l)**	Flame Photometer	Sodium Chloride , Distilled water
4	**Potassium (mg/l)**	Paqualab photometer	1 Palintest tablet 15 ml Distilled water
5	**Calcium & Magnesium (mg/l)**	Atomic absorption spectro photometer	Lanthanum oxide Distilled water
6	**Chloride (mg/l)**	Titration	Silver Nitrate Standard Solution 0.005 N Graduated Cylinder, 10 ml (2 required) Potassium Chromate Indicator Pipet Filter, Pipet Volumetric, 5.0 ml
7	**Carbonate (mg/l)**	Titration	Phenolphthalein Indicator Solution, 5 g/l Sulfuric acid Standard Solution 0.02 N Burette, Erlenmeyer Flask, Graduated cylinder 300ml
8	**Bicarbonate (mg/l)**	Titration	Sulfuric acid Standard Solution 0.02 N Methyl Orange Indicator Burette, Erlenmeyer Flask, Graduated cylinder 300ml
9	**Sulfate (mg/l)**	Paqualab photometer	Palintest Tablet Distilled water

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Results and Discussion

Table 14 gives the results obtained from the chemical analyses and Table 15 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 15. The interpretation of results has been produced in the form of graphs shown in Figs. 3 to 14.

Table 15 Statistical measures of parameters

Parameter (Units)	Avg.	Standard Deviation	Coefficient of variation (%)		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	0-0.05	0-0.05
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	0-0.05	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	0-0.01	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

Table 14 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

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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

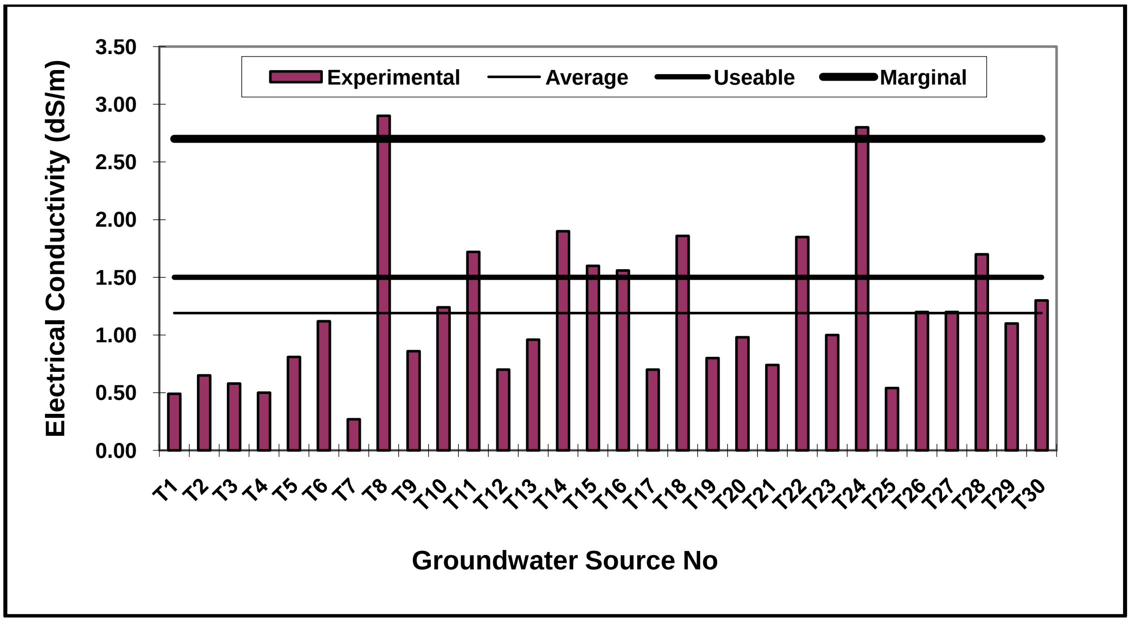

Fig. 3 Electrical Conductivity in Groundwater

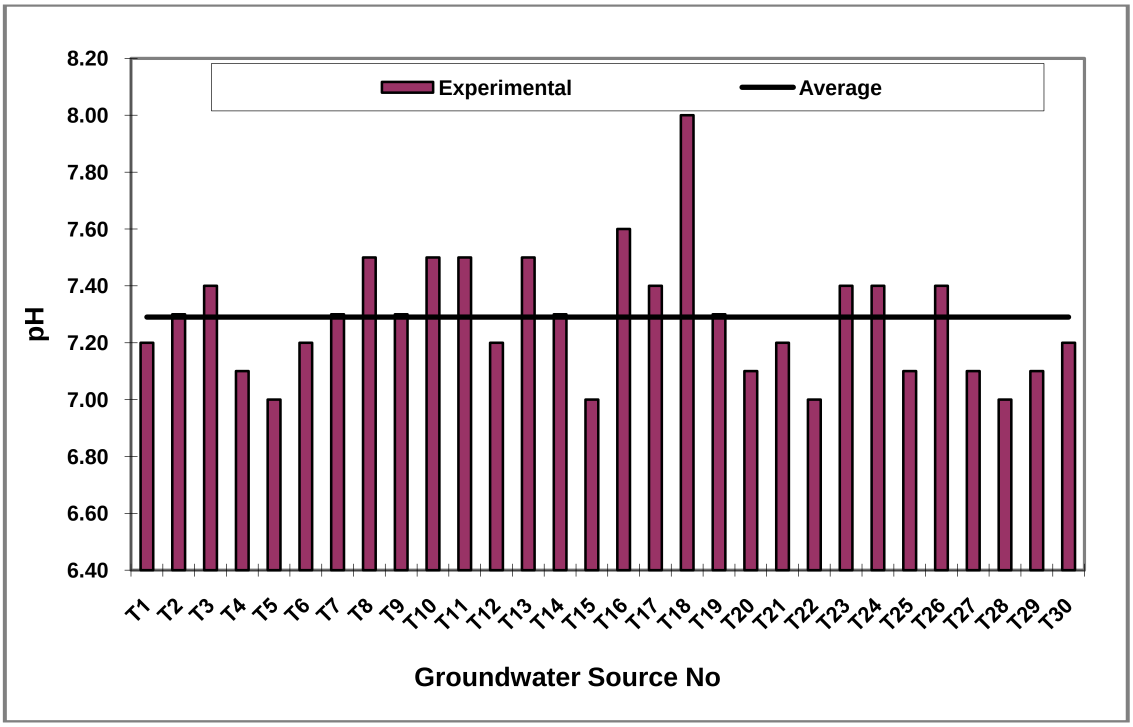

Fig. 4 pH Values of Groundwater

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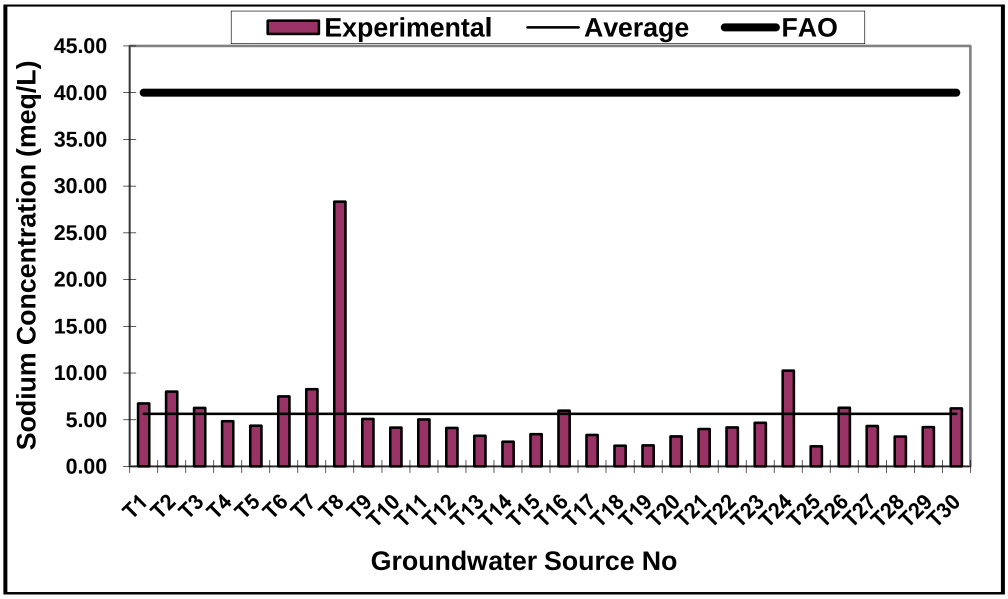

Fig. 5 Sodium Concentration in groundwater

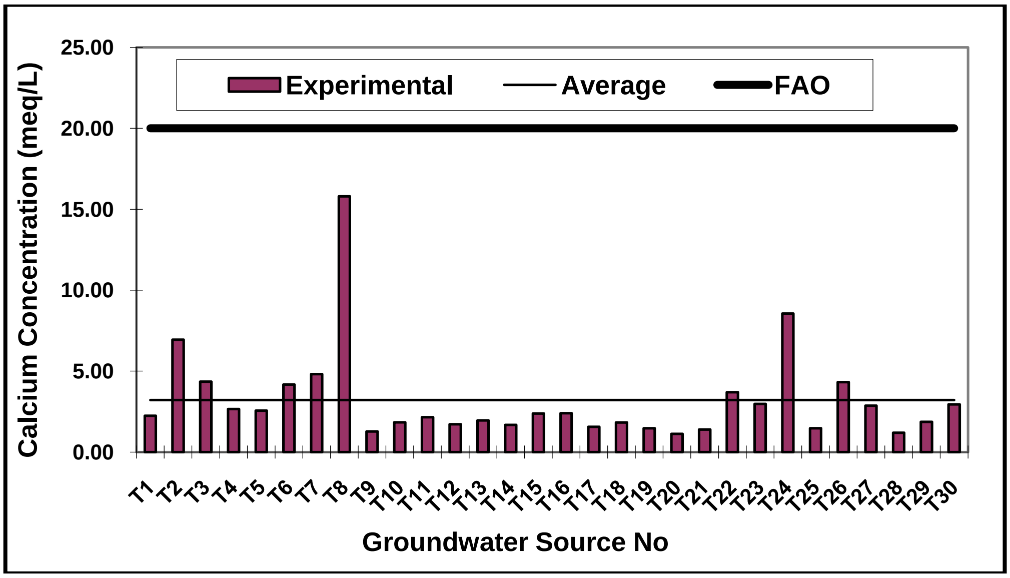

Fig. 6 Calcium Concentration in Groundwater

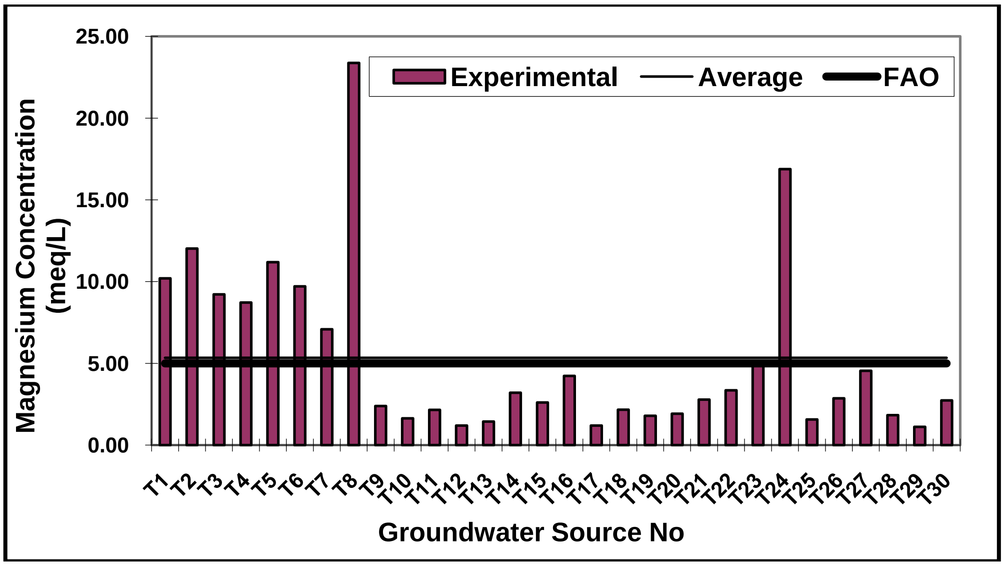

Fig. 7 Magnesium Concentration in Groundwater

[DOI: 10.22068/IJCE.13.3.305]

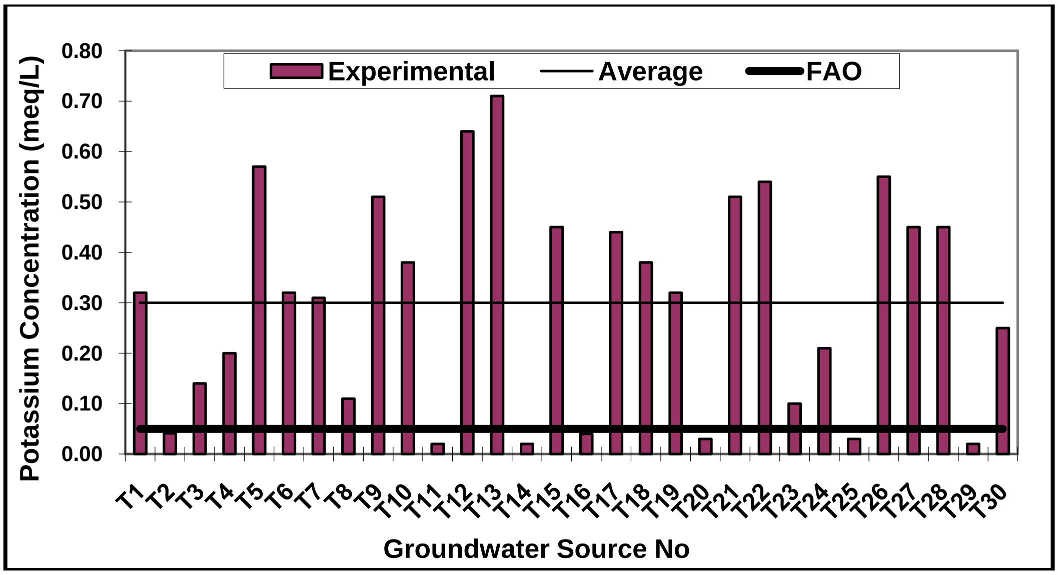

Fig. 8 Potassium Concentration in Groundwater

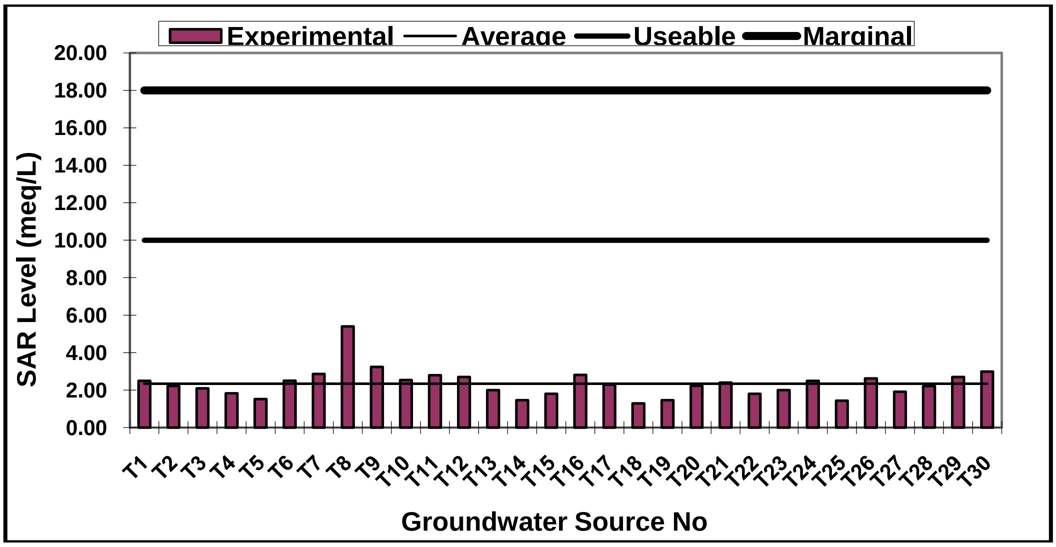

Fig. 9 SAR Level in Groundwater

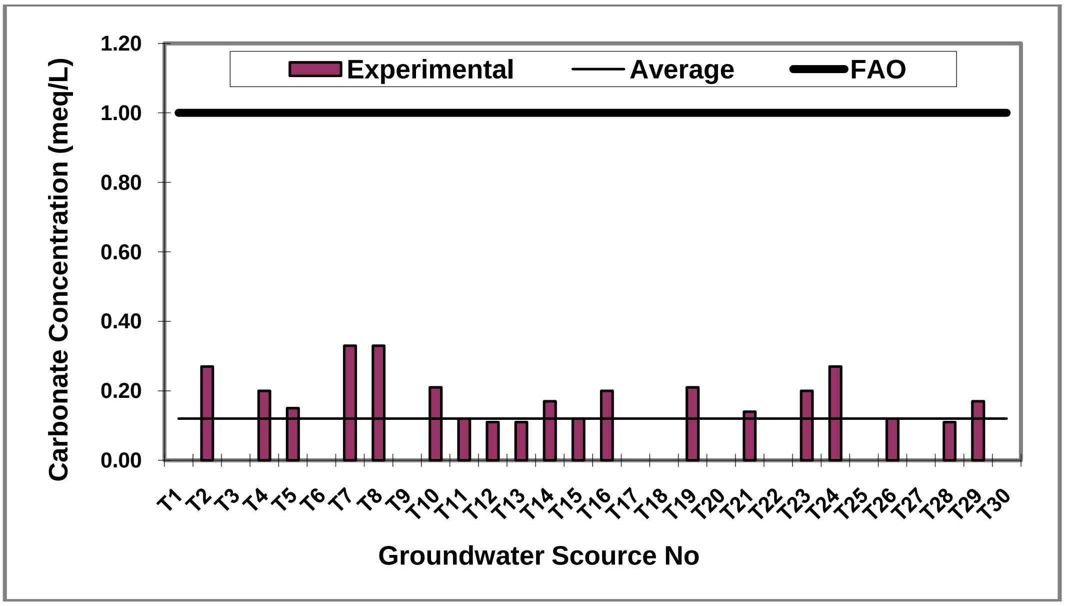

Fig. 10 Carbonate Concentration in Groundwater

[DOI: 10.22068/IJCE.13.3.305]

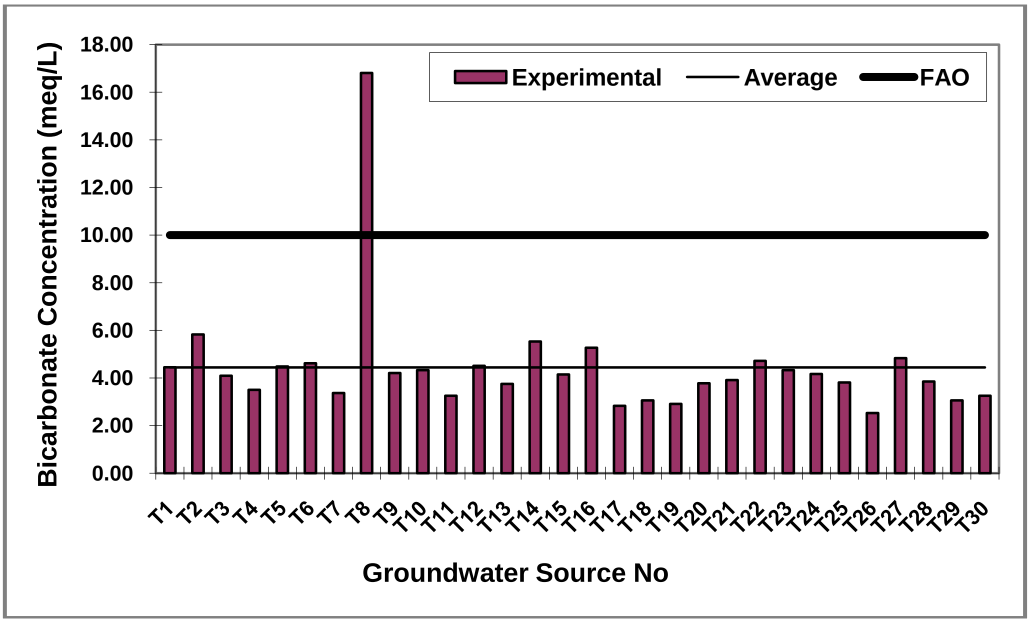

Fig. 11 Bicarbonate Concentration in Groundwater

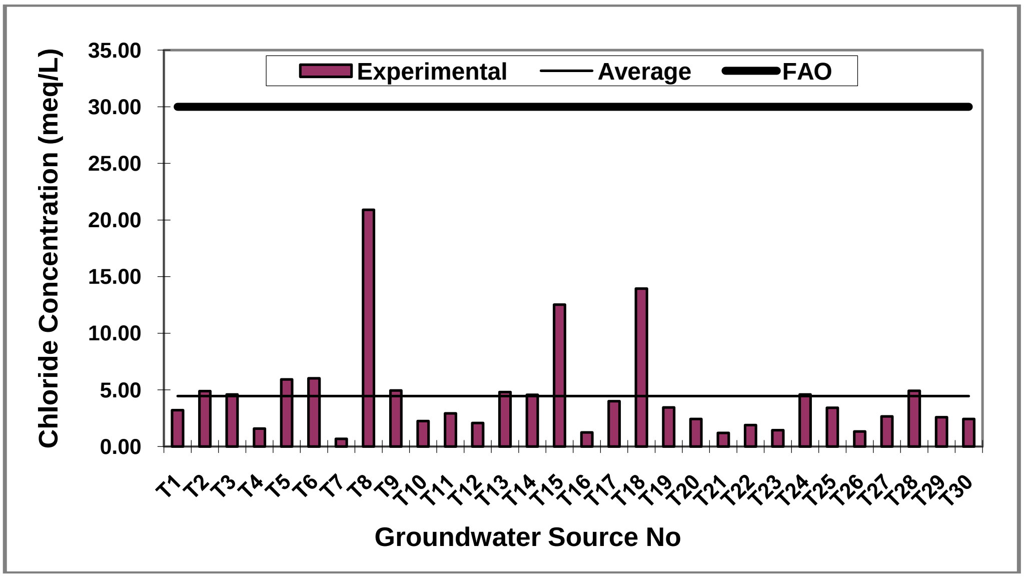

Fig. 12 Chloride Concentration in Groundwater

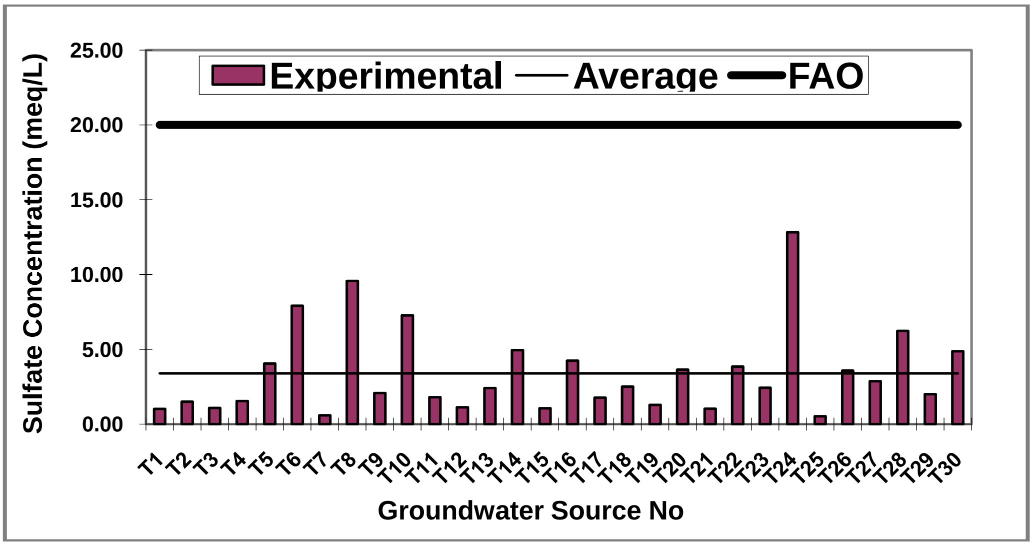

Fig. 13 Sulfate Concentration in Groundwater

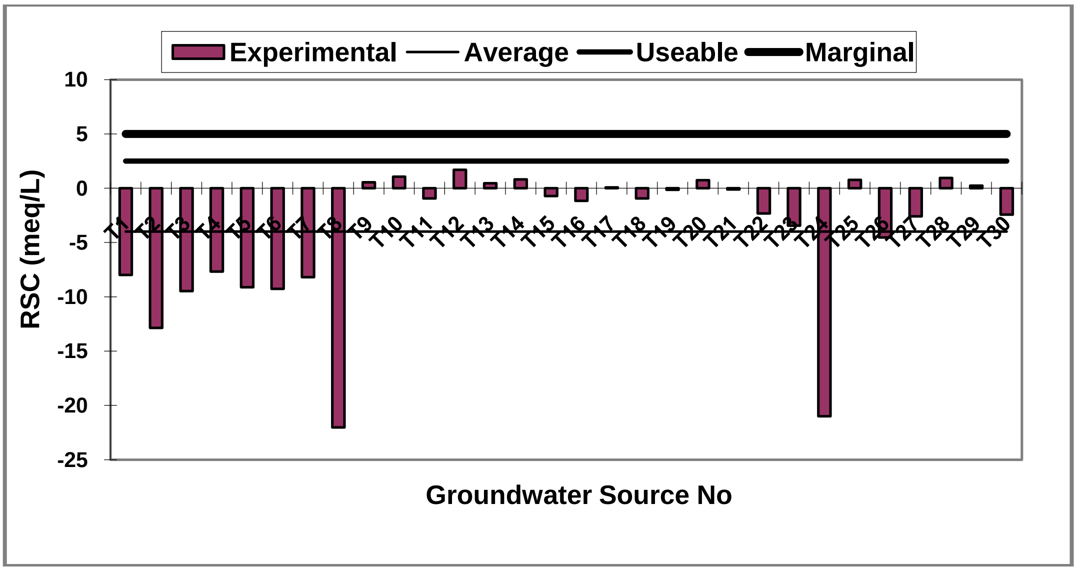

Fig. 14 RSC Level in Groundwater

Electrical Conductivity (ECw)

According to WAPDA [12] Table 5, EC_w values ranged from 0.27 to 2.90 dS/m; 70% of the water samples had EC_w 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 EC_w 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 EC_w up to 0.75 dS/m, however, increased in other cases when EC_w values of water were from 2 to 3 dS/m.

pH of Groundwater

pH values of all the samples 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.

Soluble Cations in Groundwater

The major cations in the groundwater, which were analyzed, include sodium, calcium, magnesium and potassium. An interpretation of experimental values was done according to the classification of Ayers and Westcot [11] given in Table 10.

Sodium Concentration in Groundwater

Out of the total water samples, 100% came within the usual range of sodium i.e. 0 to 40 meq/L. 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.

Calcium Concentration in Groundwater

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.

Magnesium Concentration in Groundwater

The usual range of magnesium in irrigation water is 0-0.05 meq/L. 33% of the total water samples had higher values than usual range. Gupta [17] concluded that the occurrence of Mg ions in higher proportions than Ca ions increases the adverse effects due to sodicity.

Potassium Concentration in Groundwater

According to the classification of Ayers and West cot [11] 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] concluded that most crops were more sensitive to the effect of salinity during the seedling stages and it was observed that the crop response to nitrogen and potassium fertilizers was not affected by saline condition.

Sodium Adsorption Ratio of Groundwater

The SAR of water sample ranged from 1.29 to 5.40 $(meq/L)^{0.5}$. While comparing with WAPDA [12] Table 5, 100% of the water samples had SAR below 10 and met the requirement. But the combined assessment based on all parameters is presented at the end.

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Soluble Anions of Groundwater

The major anions for groundwater, which were analyzed, include carbonate, bicarbonate, chloride and sulfate. An interpretation of experimental values was done according to the classification of Ayers and Westcot [11], Table 10.

Carbonate Concentration in Groundwater

As per result, 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 form the water and cause strong alkalization in the irrigated soils, while bicarbonate precipitates Ca ions only partly.

Bicarbonate Concentration in Groundwater

The usual acceptable range of bicarbonate in irrigation water is 0-10 meq/L (Table 10). 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.

Chloride Concentration in Groundwater

The chloride content of our water samples ranged from 0.68-20.90 meq/L which showed that water samples with chloride content exceeding 5 meq/L do not come 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 in Groundwater

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.

Residual Sodium Carbonate (RSC) of Groundwater

RSC values of groundwater ranged from 1.70 to 22.03meq/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.

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. But based on all the parameters combined, the water samples from tube wells T8 and T24 are not found fit for irrigated agriculture.

Water Quality Evaluation on the Basis of USDA Hand Book 60

According to the classification of Richards [22] Table 1 and Table 2, the water samples have been categorized into USDA groups based on their SAR and EC_w values.

Water Salinity Effects on Various Crops yield

To know the percent reduction in yield due to salinity, Table 11 is used and the interpretation is obtained in tables 16 and 17. The effect of different salinity levels in groundwater on yield to be measured by the EC_w of irrigation water is indicated in Table 11 for field and forage crops. The salinity effects are indicated as the expected percent of yield reduction over different ranges of EC_w. It is clear from Table 11 that forage crops are more resistant to salinity, followed by field crops. Table 18 gives the classification of collected water samples based on USDA Handbook60.

Table 16 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

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Table 17 Reduction in crop yield

Crops	Water Samples	% Reduction in Crop Yield
Barley	100%	0
Sorghum	100%	0
Corn	53.3%	0
	26.7%	10%
	13.3%	25%
	6.7%	50%
Onion	33.3%	0
	30%	10%
	20%	25%
	16.7%	50%
Alfalfa	70%	0
	23.3%	10%
	7%	25%

Table 18 Water Samples classified based on USDA Handbook60

Water Samples	USDA Classification	SAR	EC_w
30%	C2S1	1.43 to 2.86	0.27 to 0.74 ds/m
63.3%	C3S1	1.29 to 3.24	0.80 to 1.90 ds/m
6.7%	C4S1	2.49 to 5.40	2.80 to 2.90 ds/m

Conclusions

The following conclusions are drawn:

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 EC_w limits, 70% water samples were useable; 23.3% marginal and 6.7% were hazardous. Based on EC_w 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 SO_4^{--} 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 water of these wells should be amended with gypsum. 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. The relevant 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. Regular/periodic monitoring of groundwater quality is highly recommended to ensure safe irrigation water for sustainable agriculture.

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