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Appraisal of Water Quality Measurements for Canal and Tube Well Water Systems for Agriculture Irrigation in Rechna Doab, Pakistan

Mubarra Noreen, Isma Younes*

Department of Geography, University of the Punjab, Lahore, Pakistan

*Email:Mubarranoreen09@yahoo.com

Abstract: The present study was an attempt to assess the surface and ground water quality for irrigation suitability in Rechna Doab. Irrigation water quality at canals and tube well water were analyzed by physicochemical parameters including pH, Electric Conductivity (EC), important cations such as Calcium (Ca^{2+}) Magnesium (Mg^{2+}), Potassium (K^{+}), Sodium (Na^{+}), important anions such as Chloride (Cl^{-}), Bicarbonate (HCO_3^{-}), Sulphate (SO_4^{2-}), three heavy metals including Zinc (Zn), Nickel (Ni) and Copper (Cu). Twelve water samples were collected from the main canals (Lower Gogera canal, Jhang branch canal and Rakh branch canal) while fifty water samples were collected from the tube wells. Statistically, data were analyzed by generating correlation coefficients. Canal water quality parameters i.e. Sodium Adsorption Ratio (SAR), Magnesium Adsorption Ratio (MAR), Sodium Percentage (Na %), Kelly Ratio (KR), Soluble Sodium Percentage (SSP), Residual Sodium Bicarbonate (RSBC), Permeability Index (PI) and Potential Salinity (PS) with their mean values 0.16,38.18, 8.03, 0.08, 10.17, 0.08, 28.34 and 0.024 respectively were calculated. Piper and Durov diagrammatic representations provided the suitability of the canal water regarding ionic composition. Results revealed that the status of the canal water was fit for agriculture. On the contrary, the data about Electric Conductivity (EC), Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) of tube well water (with their maximum values 4.80, 29.65 and 13.60, respectively) was exceeding the FAO limits owing of sodium hazards. Thus, the scenario of groundwater is alarming due to unfit status of tube well water regarding irrigation purposes. Out of total 50 water samples of tube wells, 11 samples were found to be fit. While 39 samples were unfit for crop irrigation. Geo-statistical analysis was performed by using Inverse Distance Weighted (IDW) technique created in Arc map.

Keywords: Surface and ground water quality, Physiochemical parameters, Irrigation quality indices.

Introduction

Surface and groundwater are fundamental natural sources beneficial for mankind, agriculture growth and for ecosystem performance. The quality deteriorating regarding these sources is a problem in all over the world owing to improper protection measures (Dhayachandhran and Jothilakshmi, 2020). The overexploitation of tube well water owing to the untenable agricultural progress is a common dilemma in irrigation sites. Almost about 90% of international cultivated areas have supported both types of irrigation sources (Hashemy Shahdany et al., 2018). In Colorado, canal system distributions have created for crop irrigation because irrigation canals can be valuable and aquatic habitat, especially in regions with severely degraded streams (Carlson et al., 2019). Lebanon is facing declining in canal and tube well water sources with improper water structures (Alcon et al., 2019). In southern region of Italy, a concept Grey Water Footprint (GWF) has been introduced for impact of groundwater contamination on crops. This idea used as an indicator in the agriculturally land use managements (Serio et al., 2018). A 2nd National Water Resource survey conducted in China in 2015. According to this survey, it was found that the quality of the surface water in the whole country was somehow polluted while, the ground water quality is deteriorating and the level of pollution was about 60% (Zhang et al., 2015). In Tamil Nadu, tube well water quality assessed by physicochemical parameters and it found unfit by WHO standards (Arulnangai et al., 2021; Divahar et al., 2020).

In Pakistan, Indus River system provided 180 billion cubic meters (bcm), out of this 128 (bcm) is going to distribute in the form of irrigation systems. The second irrigation source is groundwater (Tube wells) which consisted of 50-60 (bcm) usage of water on yearly basis (Basharat, 2019). For the purpose to control over the water problems in cultivation areas, the government of Pakistan has initiated the installations of 10,000 groundwater point sources (Tube wells) in various regions. In the Punjab province, about 40% area fulfilled the needs of irrigation by groundwater source (Kazmi et al., 2012). Globally, Pakistan is the fourth largest groundwater user country (Riaz et al., 2018).

Agriculture in the Punjab province of Pakistan is benefited from one of the largest canal irrigation systems in the world. The Rechna Doab region (approximately 2.97 million ha) is located in the Indus basin irrigation system of Pakistan (Ahmad et al., 2005; Cain et al., 2007). The significance of irrigation water is more in Pakistan because of the agrarian based economy. The gap between demand and supply of water has increased (Luan et al., 2018). Cultivation of crops in different seasons required water and this need is fulfilled by both irrigation sources surface and ground water (He et al., 2016; Parvaiz et al., 2020).

The aquifers of studied area found to be heterogeneous and unconfined which were formed by sediment deposition thickness of more than 300m. The sediments were transported from Himalayan mountain by the rivers. Though, aquifer sediments are porous with high

permeability of water in the study area, aquifer comprised of 65 to 75 percent sand beds and remaining consisted of silt and clay. Recharge of aquifers occurs usually from rivers, rainfall, canals, and irrigation water sources while, discharge includes usage of tube well water for irrigation purposes either it creates salinity issues (Hassan et al., 2013; Parvaiz et al., 2020; Shakoor et al., 2017).

There are lots of naturally occurring salts in irrigation water salts have great impact on soil, soil structures its permeability and on growth of the granary crops (Ali et al., 2009). Water from surface and ground water sources contained substantial quantity of contaminated solvents that are alarming for crops. Currently, groundwater usage has been increased. Moreover, Punjab and Sindh provinces (27% and 73% area wise) have unfit irrigation status (Muhammad Arshad and Shakoor, 2017). In the light of above-mentioned canal and tube well water systems research work was planned to evaluate the quality of the irrigation water for agriculture sector.

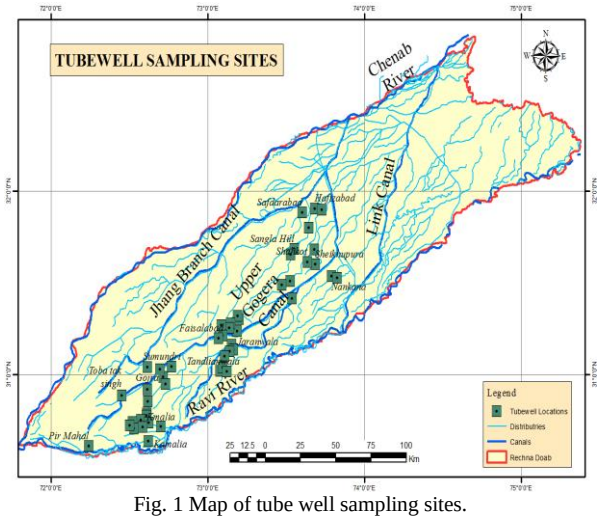

Fig. 1 Map of tube well sampling sites.

The Rechna Doab consisted of 2.98 million hectares and about 2.3 million hectares is cropland. The area lies between the 71º–48/ to 75º–20/ E and 30º–31/ to 32º–51/ N (Mohd Arshad et al., 2009).The Soil Survey of Pakistan has identified four different landforms on the basis of the morphology, soil development and on relative elevations. These landforms are bar uplands, Active flood plains, Flood plains and Kirana Hills. Geologically, the area composed of overlying Pre-Cambrian metamorphic rocks or igneous rocks in the basement (Anjum et al., 2016; Jehangir et al., 2002). The soil of the area is light loam soil which is best for crop growing. The climate is sub-humid in the northeast to semi-arid in the southwest. On high altitudes the rainfall goes above 89 cm annually but in the southwest it declined to about 20 cm annually close to the meeting of the Ravi and Chenab rivers. The lowest temperature which is recorded in winter is 3 to 7 °C and the maximum temperature recorded in summer is 49 °C (Parvaiz et al., 2020). The Lower Chenab Canal (LCC) East Circle area limits the east of the Ravi River and it consists of Lower Gugera, Upper Gugera, Burala and Mian Ali Branch Canals and a large system of branches and watercourses. The circle has 0.803 and 0.622 million hectares of area. This circle covers Faisalabad, Toba Tek Singh, Hafizabad and Sheikhupura districts (Jehangir et al., 2002).

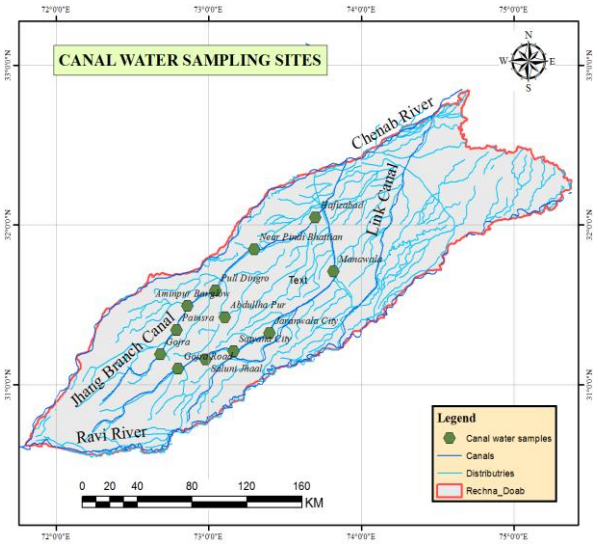

Fig. 2 Map of canal water sampling sites.

Materials and Methods

This study is based on primary data collection. Data about the irrigation water quality of lower Chenab canal east circle canals were assessed. Samples were collected from three main canals of Rechna twelve Doab by linear random sampling technique. Total canal water samples were collected at various sampling sites as shown in (Fig. 2). Assessment quality of the canal water pH, EC, Ca+Mg, K, Na, SO_4, Cl and HCO_3 were quantified by chemical analysis. Moreover, physiochemical parameters i.e pH recorded by pH meter, EC values were recorded by conductivity meter, Ca+Mg, HCO_3, SO_4 and Cl were measured by titration method K and Na determined by flame photometry while three heavy metals Copper, Zinc and Nickel were detected by wet digestion method by using AAS (Malek et al., 2019). Statistically, data analyzed by correlation matrix. Ground water quality was evaluated by three main quality indices (EC, SAR and RSC).

The samples collected from different tube wells of the area from there reclamation division of (LCC) east canal circle, canal division Lower Gogera, Upper Gugara and Burala Divisions which covers the tehsils including Hafizabad, Shahkot, Sheikhupura, Safdarabad, Jaranwala, Nankana, Sangla Hill, Faisalabad, Sumundri, Tandlianwala, Toba Tak Singh, Gojra, Kamalia and Pir Mahal of the study area as shown in (Fig. 1). Random sampling technique was used for 50 sample collections. Maps were created in Arc Map. The IDW interpolation technique was applied on water quality variables which showed the spatial distributions of physiochemical parameters in tube well and canal water samples (Noreen et al., 2017).

Table 1. Ground water irrigation system in the study area.

Sr. No	District	EC	SAR	RSC	Status	Sr. No	District	EC	SAR	RSC	Status
1	Hafizabad	0.97	4.98	5.30	Unfit	26	Faisalabad	2.40	12.42	5.70	Unfit
2	Hafizabad	0.77	3.69	2.58	Unfit	27	Faisalabad	1.30	5.02	3.52	Unfit
3	Hafizabad	1.50	6.51	5.70	Unfit	28	Faisalabad	2.90	7.77	10.20	Unfit
4	Sheikhupura	1.50	5.48	5.10	Unfit	29	Faisalabad	3.20	12.68	5.70	Unfit
5	Sheikhupura	1.30	10.58	6.00	Unfit	30	Faisalabad	3.00	7.51	4.50	Unfit
6	Nankana	1.60	9.90	6.00	Unfit	31	Faisalabad	3.10	10.41	5.70	Unfit
7	Sheikhupura	0.71	5.10	4.30	Unfit	32	Faisalabad	4.30	13.10	4.50	Unfit
8	Sheikhupura	1.20	4.34	3.10	Unfit	33	Faisalabad	3.90	15.32	4.90	Unfit
9	Nankana	1.70	7.49	3.30	Unfit	34	Toba Tek Singh	4.20	13.44	5.70	Unfit
10	Nankana	2.90	15.22	5.20	Unfit	35	Toba Tek Singh	2.70	17.82	10.00	Unfit
11	Faisalabad	2.10	9.49	3.40	Unfit	36	Toba Tek Singh	2.70	9.13	4.50	Unfit
12	Faisalabad	2.00	7.27	5.40	Unfit	37	Toba Tek Singh	1.60	6.57	4.30	Unfit
13	Faisalabad	2.81	8.90	6.50	Unfit	38	Toba Tek Singh	2.00	5.82	4.50	Unfit
14	Nankana	2.80	7.00	8.00	Unfit	39	Toba Tek Singh	3.70	29.65	13.60	Unfit
15	Nankana	1.10	4.92	3.40	Unfit	40	Toba Tek Singh	4.80	6.40	5.70	Unfit
16	Faisalabad	2.10	15.34	10.90	Unfit	41	Toba Tek Singh	4.40	9.45	6.80	Unfit
17	Faisalabad	1.80	6.61	5.10	Unfit	42	Toba Tek Singh	1.42	5.08	0.60	Fit
18	Faisalabad	0.80	0.65	0.60	Fit	43	Toba Tek Singh	1.20	5.52	2.40	Fit
19	Faisalabad	2.80	17.46	10.30	Unfit	44	Toba Tek Singh	0.85	1.97	4.50	Fit
20	Faisalabad	3.30	21.69	11.60	Unfit	45	Toba Tek Singh	1.20	6.41	4.50	Unfit
21	Faisalabad	2.50	14.12	4.70	Unfit	46	Toba Tek Singh	0.48	0.64	6.80	Fit
22	Faisalabad	1.10	3.76	2.50	Fit	47	Toba Tek Singh	1.00	3.56	1.00	Fit
23	Faisalabad	1.90	15.56	6.50	Unfit	48	Toba Tek Singh	1.00	2.98	1.00	Fit
24	Faisalabad	0.74	1.52	0.20	Fit	49	Toba Tek Singh	0.31	0.08	3.40	Fit
25	Faisalabad	2.10	9.92	6.40	Unfit	50	Toba Tek Singh	0.10	2.57	0.20	Fit

Results and Discussion

Physicochemical characteristics of canal water

The data assessed by using the equations of the quality indices and by following the suitability criteria. Results showed that salt concentrations and the ionic compositions were found within the range. Data revealed that the pH values obtained from 7.35 to 7.72 which shows the basic nature of canal water. The values of EC showed range of data from 0.50 to 0.58 dS/m. Although, the spatial distribution of the ionic composition of the canal water represents the range of cations Ca+Mg (4.33 to 5.06 mg/L), Na (0.33 to 0.76 mg/L), K (0.06 to 0.11mg/L), anions HCO_3 (3.84 to 4.44mg/L), Cl (0.37 to 0.57mg/L) and SO_4 (0.62 to 1.2 mg/L). Heavy metals which were quantified from the surface water Cu in the range of 0.07 to 0.11, Zn in the range of 0.04 to 0.13 and Ni with the limit of 0.02 to 0.07 in (mg/L). Although, heavy metals found to be within permissible limits by FAO (Aftab et al., 2011; Mussarat et al., 2007). SAR data showed that the canal water data ranged from 0.09 to 0.18 and their mean is 0.16. These values found within suitability range criteria of SAR which is <10 (Al-Hadithi *et al.*, 2019; Muhammad Arshad and Shakoor, 2017; Joshi *et al.*, 2009). MAR was introduced by Szaboles and Barab (1964) for quality of irrigation water classifications. By this classification, more than 50% magnesium value has a negative impact on crop (Al-Ruwaih and Shafiullah, 2017; Joshi *et al.*, 2009). The value of MAR varies from 22.36% to 46.82% with the mean value of 38.18%. It showed that these MAR values were less than 50 so, the obtained results were within the limits. Doneen's method(Al-Ruwaih and Shafiullah, 2017) is usually used for sodium percentage measurements. More sodium concentrations, decreases the crop growth and also affect the soils penetration ability. Data showed that the Na% from the range of 5.05% to 10.68 % with mean value of 8.03. This data fulfill the criteria of <20 so, according to the results it showed that canal water are excellent (Al-Hadithi et al., 2019; Etteieb et al., 2017; Joshi et al., 2009). Results about SSP found that data were in the range of 6.05meq/l to 13.87meq/l with mean value of 10.17. Its values were <50 so according to this parameter the canal water found to be good and were within the prescribed limits. Kelly's ratio with >1 are unfit for cultivation of crops (Nagaraju et al., 2014). Data about the KR were obtained in the range of 0.05 meq/l to 0.11 meq/l by mean value of 0.08. Results showed that its values found to be <1 so, it's good. Doneen has introduced a criterion for evaluating the fitness of water based on permeability index. Data values for PI ranged 25.71 meq/l to 31.37 meq/l and here, the mean value was 28.34. By follow the Doneen's classification, our calculated data showed the values within the range of 20 to 40. Results indicated that the range of data about RSBC obtained from -0.07 to -0.09 meq/l with mean value of 0.08. These values indicated that these were under the limit value (<1.25) so, by this, the RSBC was found to be under limit considerations.

Physicochemical Characteristics of Tube well water

The most significant parameters calculated for tube well irrigation water suitability levels were sodium content

which were measured by EC, RSC and SAR. Although, these were quantified for tube well water assessments. Tube well water contained sodium quantity abundantly and poses a sodium hazard. Water contained high sodium ratios and more absorption to the soil particles leads to the disintegration of soil structure because it reduces the permeability. Maximum sodium absorption causes toxicity in granary crops causing marginally leaf burning (Riaz et al., 2018). Sodium risk is estimated by (SAR) in the irrigation water. The criteria for EC values showed that <1.0 considered fit, from 1.0 to 1.25 considered marginally fit while >1.25 considered unfit and SAR values showed that <6 considered fit, from 6-10 considered marginally fit while >10 considered unfit regarding irrigation purposes (Masood *et al.*, 2016). Eaton (1950) gave the concept of RSC. By the U.S. Salinity Laboratory, the values of residual sodium carbonate <1.25 meq/l is fit while, >2.5 meq/l is considered to be unfit for irrigation purposes (Joshi et al., 2009; Lubna et al., 2014). The minimum and maximum values about EC, SAR and RSC values found from Hafizabad 0.77 to 1.50 (dS/m), 3.69 to 6.51 and 2.58 to 5.70 (meq/l) respectively. Similarly, other districts showed values that from Sheikhupura from EC values from 0.71 to 1.50, SAR values from 4.34 to 10.58 and RSC values from 3.10 to 6.00 found, from Nankana EC values from 0.63 to 2.90, SAR values from 7.49 to 15.22 and RSC from 3.30 to 8.00 found, from Faisalabad EC values 0.74 to 4.30, SAR values from 0.65 to 21.69 and RSC values from 0.20 to 11.60 found and from Toba Tek Singh EC values 0.10 to 4.80, SAR values from 0.08 to 29.65 and RSC values from 0.20 to 13.60 found and according to their values tube well water status are given in (table 1). Data revealed that the EC values ranged from 0.10 to 4.80 dS/m, so, SAR values ranged from 0.08 to 29.65 and RSC values found from 0.20 to 13.60 (meq/l). The highest EC, SAR and RSC values were found from Toba Tak Singh which was (4.80 ds/m, 29.65 and 13.60 meq/l) respectively. Obtained values revealed that these parameters were found to be in higher values rather than their permissible levels so the tube well water quality considered unfit for irrigation source which is not ignorable issue.

Diagrammatic Representation

The hydrochemistry of surface water samples represented by Piper and Durov diagrams. The ionic compositions of samples are expressed in % concentrations in milliequivalents per liter (meq/l).

Piper Diagram

It is a graphic method for representing the water chemistry. The ionic composition of surface water plotted by Piper diagram, (Figure 3) data showed the similarities, dissimilarities and provided information about data type. By this diagram data classification indicated that all samples were in the Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, SO_4^{2-} orders (Figure 3). The cations (Alkali elements) (Na^+ and K^+) exceeded alkaline nature (Ca^{2+} + Mg^{2+}) while the strong acidic anions (Cl^- + $SO4^{2-}$) exceeded the weak acidic nature in the solution. The Ca-Mg-Cl type of canal water was found (Al-Ruwaih and Shafiullah, 2017; Rasouli *et al.*, 2012).

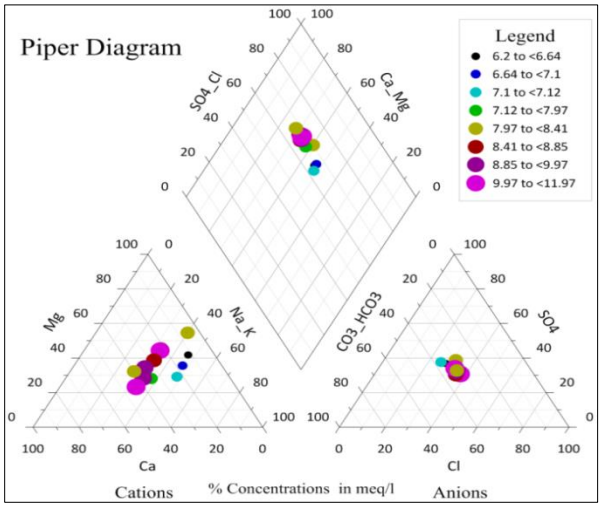

Fig. 3 Ionic composition of canal water by Piper diagram in % conc. in meq/l.

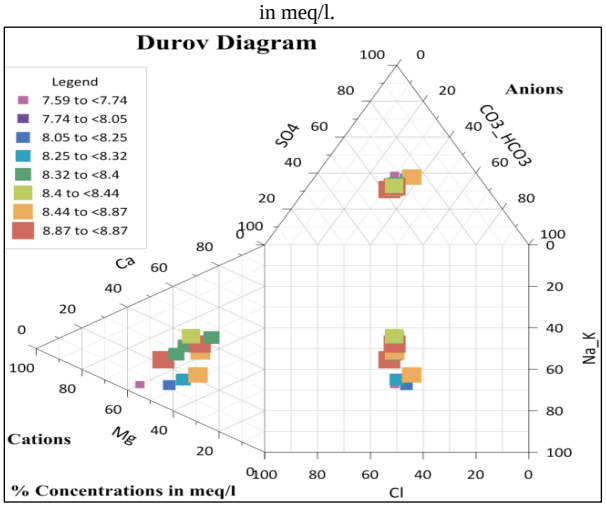

Fig. 4 Ionic composition of canal water by Durov diagram in % conc. in meq/l.

Durov Diagram

This diagram showed the ionic water data of canal water samples from the 12 geographic locations. By this diagram, the ionic compositions were in the range of 7.59<7.74 to 8.87<8.87 (Figure 4). Results showed that the canal water dominated by the alkaline water of leading cations of Ca, Mg, Na and K along with leading anions of HCO_3, Cl and SO_4.

Bore Depths, Aquifer Sedimentation and EC

This scatter plot (Figure 5) shows that EC values have relation with depths. Data revealed that tube well water quality showed fluctuations with respect to the bore depths. The minimum and maximum bore depths were 40 and 350 feet recorded which indicated that sand as dominant aquifer sediment in the area. EC values found more towards the sampling sites have the bore depths of 100 feet to 200 feet while increasing bore depths the EC values decline. Geologically, the area consisted of sand, silt and clay subsurface depositions that from top to 150

feet there was found sand prominent sediment, from 150 to 300 feet depths indicated fine sand, clay and silt sediments while from 300 feet to 900 feet there might have admixtures of sand, silt and clay with alternatively beds (Muhammad Arshad et al., 2007; Khalid et al., 2019).

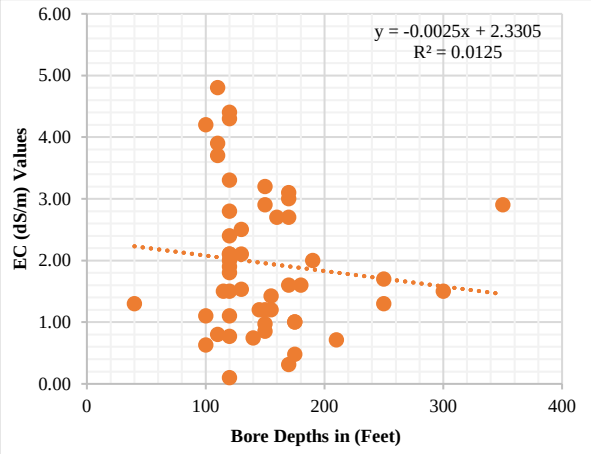

Fig. 5 Scatter plot showing correlation between bore depth and EC

Conclusion

The surface and ground water quality was assessed by physiochemical and geo-statistical analysis and results found that the surface water found to be fit for irrigation of the crops although, Ni, Cu and Zn were detected but found within FAO limits and the ionic composition of canal water found to be good by measured quality indices. On the other hand, the quality of ground water found to be unfit from the study area. Out of total 50 ground water samples 11 samples were found fit while 39 samples were unfit because of more EC, SAR and RSC calculated values. Moreover, high sodium hazard was identified in the study area at ground water levels which is the alarming situation.

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