Hydrochemical characteristics and water quality assessment for drinking and agricultural purposes in District Jacobabad, Lower Indus Plain, Pakistan

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Abstract: Undeniably water is of utmost importance while considering basic necessities. This investigation emphasized on the hydrochemical evaluation and drinking water quality assessment in District Jacobabad located in lower Indus plain, Pakistan. Certainly world's largest irrigation system emerged from Indus Basin, which is underlain by well transmissive aquifer resulting in higher water table. Water supply schemes with their water sources from ground water and surface water provide piped water for drinking purpose to the community. Water samples were collected from all the forty eight supply schemes of which thirty two were found nonfunctional. Analytical parameters were compared with World Health Organization (WHO) and Pakistan Water Quality Standards but adversely substantial samples were found nonpotable. Alkalinity, bicarbonate and nitrate met the standard safe limits while values for EC, TDS, hardness, cations and anions exceeded the limits in numerous samples. SPSS and ArcGIS softwares were used for statistical analysis and spatial distribution of parameters. Hydrochemical facies were developed and suitability assessment of water resources was examined for agricultural use. The ground water type was classified as Na-HCO_3 type with high salinity and it required treatment prior to irrigation. The proposed research exhibited the probable drinking water contamination sources and it demanded instant actions to further protect the valuable drinking water resources in District Jacobabad.

Keywords: water quality assessment, water supply schemes, drinking and agriculture, arsenic, ArcGIS, Pakistan
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1 Introduction

Water is critical for human survival. Provision of safe drinking water is the fundamental challenge confronted across globe. 30% of global fresh water resource is contributed by groundwater. Compared to surface water, ground water is nontoxic and immaculate and necessitates minimal treatment[1]. However, natural perturbations have resulted in an unsustainable condition on ground water resource. Drinking water quality evaluation is one of the most significant aspects in groundwater studies. The hydrochemical investigation encompasses quality of water which is adequate for drinking, agricultural and industrial purposes.

Inadequate management of water supply systems explicitly causes the quality of piped drinking water to deteriorate below the adequate levels and leads to severe health risks[2]. Hydrochemical evaluation is used to portray and classify the relevant water-rock interfaces, which are accountable for the poor groundwater quality. Additionally, the chemical parameters of groundwater play a significant role in sorting and evaluating water quality. Water quality issues are more severe in industrialized areas with dense population and shallow ground water level[3]. Undoubtedly, water quality assures sound health of the population. There is a major concern over water pollution in recent times due to leaching of industrial and agricultural pollutants[4]. The geochemical information presents the suitability of ground water for domestic and irrigation purposes. It is important to consider both microbiological and chemical characteristics when ensuring drinking water quality.

District Jacobabad is located in the lower Indus Plain, Sindh Province of Pakistan and Indus Basin aquifer is one of the prime and richest aquifers in terms of ground water resources. Indus aquifer accounts for about 40% of water requirements of Pakistan. With the onset of canal irrigation system in the Indus Basin in the middle of nineteenth century, it has resulted in the disturbance of the natural groundwater equilibrium, thus posing a challenge in the management of this aquifer and related environmental issues[5].

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Environmental issues related to groundwater pose serious concerns for the sustainability of irrigated agriculture in Indus Basin. Several observations wells were setup in 1870 as a remedial measure in the irrigated areas to monitor the environmental hazards of rising water table[6].

For an estimated population of 0.98 million in District Jacobabad, monitoring of drinking water quality has never been conducted. Only limited information was available from two studies carried out in Sindh Province[7] with little focus on District Jacobabad. The greater part of the study area and Indus plain is water logged and highly saline[8] due to the extensive irrigation and rice cultivation in this area; only a little land is free from these two problems.

Up to our knowledge, the study of hydrochemical characteristics and the quality evaluation of water supply schemes are first of its kind for the area. This study was designed to investigate and assess the drinking water quality and the relationship among various parameters along with suitability for drinking and irrigation purposes, in order to understand the spatial distribution of main drinking water parameters. We assume the findings of this study will enhance the understanding and identification of the possible sources of groundwater contamination and will offer a valuable tool for reliable management of drinking water resources.

2 Study area

The study area lies between 68°00' to 69°44' east latitudes and 27°55' to 28°29' north latitudes; it abuts Baluchistan Province in the north, District Shahdad Kot in the west, District Shikarpur and Larkana in the south and District Kashmore in the east. The total area of the District Jacobabad is 2667.98 km^2. Topography varies from 51.8 m to 52.7 m above sea level. Jacobabad is recognized to be the hottest place in South Asia and locates in the subtropical region. The mean minimum and maximum temperatures in the hottest month (June) are 29.38°C and 44.33°C and in the coldest month (January) are 7.68°C and 22.60°C respectively. Jacobabad lies in the arid zone where scarce rainfall occurs. The average annual rainfall is less than 110 mm and is mostly in the monsoon period (July-August). Total population of Jacobabad comprised of 980 296 persons in accordance with the 2010 evaluation.

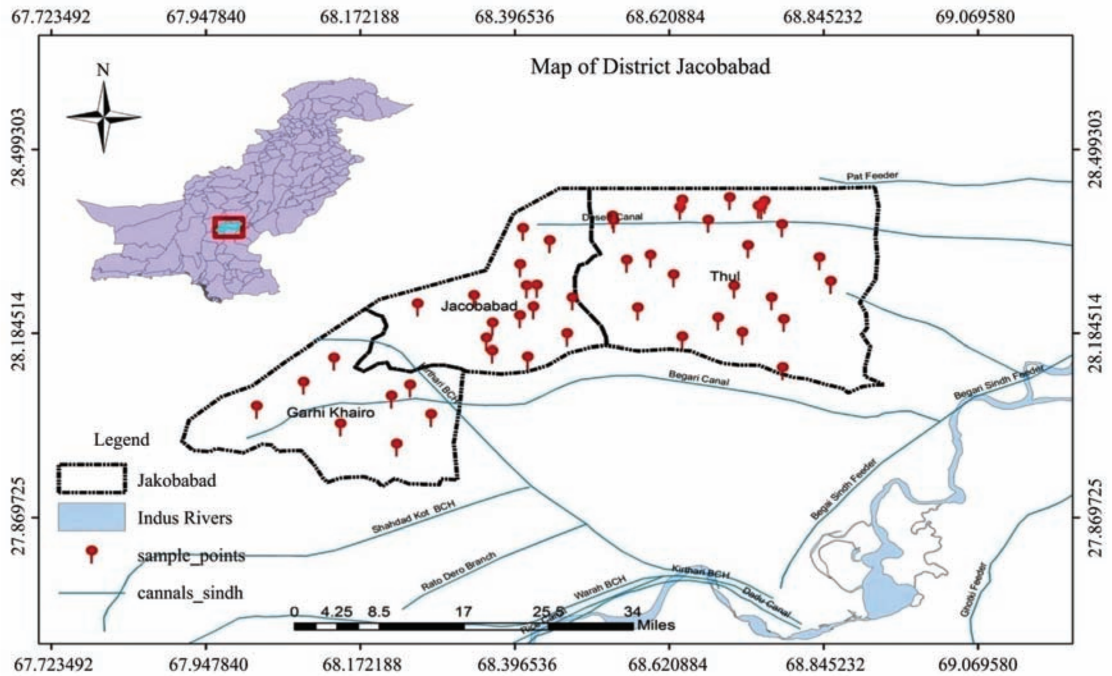

Figure 1 Study area map showing the location of water supply schemes in District Jacobabad

The proposed study area is entirely described via sedimentary rocks. The geology mainly constitutes of Cretaceous and Tertiary formations which are composed of limestone, dolomite, marl, chert, marly limestone, and chalky limestone with chert interaction are found in the investigated area[9].

District Jacobabad has one of the finest canal irrigation systems in the world which is secured by two large dams, one from the adjoining District Sukkur and the other from District Kashmore. The water supply schemes of Jacobabad provide piped water for drinking purpose and are supervised by local government organizations (District governments and County administrations). Map of the study area along with the distribution of water supply schemes in the three counties of District Jacobabad, i.e., Thul, Jacobabad and Ghari Khairo are shown in Figure 1. Canal water originated from River Indus is the most important source of irrigation in Jacobabad. There were two types of supply schemes based upon their source of water, i.e., surface water and ground water, and were analyzed for their physicochemical characteristics.

3 Material and methods

After a detailed survey, 48 water samples were collected from all the water supply schemes distributed in the three counties of District Jacobabad prior to monsoon period, 2013. These included 19 samples from ground water supply schemes and 29 samples from surface water supply schemes. After collection, all the samples were analyzed for physical, chemical and biological parameters following standard protocols.

3.1 Physicochemical analysis

For physicochemical analysis, water samples were collected in polystyrene bottles of 1.5 L and of 0.5 L capacities. The bottles were properly washed and thoroughly rinsed with distilled water several times before collecting the samples. Boric acid and HCl were used as preservatives in the sampling bottles for nitrate, nitrogen and trace elements respectively.

Hydrochemical characteristics including general physicochemical properties (pH, electrical conductivity (EC), total dissolved solids (TDS) and total hardness), major anions, such as chloride (Cl^-), bicarbonate (HCO_3^-) and sulfate (SO_4^{2-}) and major cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and sodium (Na^+) were determined for the water samples. The analysis was carried out in the National Water Quality Laboratory, Pakistan Council of Research in Water Resources (PCRWR). Total arsenic (As) was analyzed in PCRWR water testing laboratory with Merck Arsenic Kit for 0.01-0.5 mg/L. All analyses were performed according to the standard test methods[10].

3.2 Statistical analysis of data

Descriptive statistics including mean values and standard deviations were calculated while regression analysis was performed to observe the association among parameters. The water quality parameters of three counties were compared using one way ANOVA and mean value of each parameter was verified for significant difference. A $p<0.05$ was considered statistically significant. All analyses were performed in SPSS 16.0 for Windows®. Aqua Chem 2010 was used to develop hydrological facies through piper plot to reveal dominant water type and to determine the suitability of ground water for irrigation. ArcGIS 10.1 was used for the determination of spatial distribution of water quality parameters through interpolation techniques.

4 Results and discussion

Water quality of Jacobabad samples were tested with WHO and Pakistan drinking water quality standards (Table 1). The comparison of drinking water quality for ground water (GW) and surface water (SW) supply schemes illustrated that most of the parameters varied greatly and exceeded the drinking water standard concentrations of WHO (Table 1 and Table 2). A potential health risk is associated with these parameters as concentration of maximum samples exceeded the WHO and National Standards of Drinking Water Quality (NSDWQ) Pakistan[11]. Water supply schemes serve about 0.10 million out of total 0.98 million population.

The overall condition of the water supply schemes was shown in Table 3 and it illustrated that 32 of 48 total supply schemes were not functioning due to permanent or temporary out of order with various reasons, e.g., lack of funds and technical issues. A substantial number of people are depending directly on supply schemes for drinking purpose which are susceptible to untreated or polluted water with poor water quality. The pH ranged from 6.3 to 8.3 and only 2% of the samples exceeded WHO standard (Table 1) and mostly alkaline pH prevailed in the study area. Southern Sindh also revealed alkaline pH mostly predominated as found in previous study[7]. 91.66% of the EC samples exceeded the WHO standard limit (Table 1) with the mean value of 1820.3 μS/cm (Table 2). The high EC rise was a direct function of TDS. The mean EC value of surface water samples was slightly higher than the ground water samples which is probably due to the addition of saline water from River Indus. The drinking water had been classified into different classes based on EC value (Table 4) and it showed that 43.75% of the samples were in the permissible category, 45.83% were not permissible while 10.41% were considered hazardous. The high EC of water samples corresponded to the presence of ions (HCO_3^-, SO_4^{2-}, Ca^{2+} and Mg^{2+}) in higher concentrations which resulted from the solubility of rocks and ion exchange process in aquifers. Around 34% of the water samples from District Jacobabad had TDS values greater than the safe limit. The classification of drinking water based on TDS concentration indicated that 20.83% of the water samples were desirable for drinking, 45.83% were permissible for drinking and 31.25% were useful for irrigation (Table 5). The exceeding TDS concentrations in the study area were probably due to the occurrence of high levels of natural minerals in the soil. A detailed look of this problem requires an epidemiologic survey of District Jacobabad to identify health risks associated with excessive TDS in drinking water.

Cl^- concentration varied from 28 mg/L to 1500 mg/L with the mean value of 298.45 mg/L (Table 2). Concentration of Na^+ ranged from 8 mg/L to 759 mg/L with a mean of 94.4 mg/L. In comparison to ground water, high concentrations of Na^+ and Cl^- were observed in the surface water samples. Presence of high concentration of chlorine may be due to its use for disinfection in the supply schemes. High water table and high rate of evaporation in Sindh and Jacobabad cause an increase in the salinity level. Similarly, the use of petrochemical fertilizers/ pesticides and dumping of urban and industrial wastes deteriorate the water quality[7].

Table 1 Comparison of drinking water quality standards

S. #.	Characteristics	PSQCA standards	WHO maximum allowable Standards	Range detected in current study	Number of samples exceeding WHO Standard	Percentage of samples exceeding WHO standard/%
1	pH	5.5-8.5	6.5-8.5	6.3-8.3	1	2.08
2	EC/μS·cm^{-1}	1500	1000	35-7700	44	91.66
3	Turbidity/NTU	25	5	0-120	14	29.16
4	TDS/mg·L^{-1}	1500	1000	151-3860	6	12.5
5	HCO_3^-/mg·L^{-1}	500	350	80-870	7	14.58
6	Cl^-/mg·L^{-1}	600	600	28-1500	5	10.41
7	SO_4^{2-}/mg·L^{-1}	400	250	7-1475	14	29.16
8	Ca^{2+}/mg·L^{-1}	200	75	28-1500	17	35.41
9	Mg^{2+}/mg·L^{-1}	150	150	4-400	8	16.66
10	Na^+/mg·L^{-1}	-	200	8-759	13	27.08
11	Total Hardness/mg·L^{-1}	500	500	110-2500	22	45.83
12	NO_3^-/mg·L^{-1}	10	10	0.07-3.6	0	0
13	Total As/ppb	50	10	0-100	5	10.41

Note: PSQCA is Pakistan Standards and Quality Control Authority.

Table 2 Statistical summary and comparison between water supply schemes originated from GW and SW

Source	EC	pH	Turbidity	TDS	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	Hardness	NO_3^-	Total As
GW													
Minimum	813	6.3	0	406	130	35	31	12	11	10	230	0.07	0
Maximum	3333	8.2	120	1666	470	777	810	132	176	354	960	1.90	50
Mean	1726.2	7.37	9.49	886.4	267.5	289	217.5	68.6	78.89	149.4	500.5	0.76	3.33
SD	705.04	0.41	27.91	342.8	90.61	187.2	209.51	36.01	45.16	104.0	205.5	0.60	11.76
SW													
Minimum	35	6.8	0	151	80	28	7	24	4	8	110	0.10	0
Maximum	7700	8.3	70	3860	870	1500	1475	340	400	759	2500	3.60	100
Mean	1878.7	7.3	6.13	999.1	254.7	304.3	305.1	80.97	94.55	184.6	594.1	0.92	9.83
SD	1570.6	0.35	13.28	787.3	152.7	321.5	344.6	58.33	83.27	189.2	449.7	0.89	21.81
p value (among water sources)	0.7	0.53	0.58	0.57	0.01	0.86	0.34	0.42	0.47	0.47	0.41	0.51	0.25
p value (among tehsils)	0.25	0.58	0.3	0.69	0.002	0.97	0.67	0.78	0.82	0.62	0.84	0.18	0.01
OVERALL													
Mean	1820.3	7.33	7.42	955.94	259.6	298.5	271.6	76.21	88.55	171.2	558.3	0.86	7.34
SD	1300.3	0.37	19.95	650.95	131.4	275.6	300.62	50.87	70.95	161.5	54.73	0.79	18.73
Minimum	35	6.3	0	151	80	28	7	12	4	8	110	0.07	0
Maximum	7700	8.3	120	3860	870	1500	1475	340	400	759	2500	3.60	100
CV%	71.41	5.05	38.54	68.1	50.72	92.32	65	66.7	80.1	94.4	9.8	91.6	40

Note: All values are in mg/L except EC (μS/cm), Turbidity (NTU) and Total As (ppb). p value=0.05.

Table 3 Status of water supply schemes in District Jacobabad[13]

Tehsil	Water supply schemes		Functional schemes			Nonfunctional schemes						
	Total	Surveyed	No.	%	Population served (×1000)	Total		Temporarily closed		Permanently closed		Population of served (×1000)
						No.	%	No.	%	No.	%	
Jacobabad	15	15	6	40	63	9	66	6	78	2	22	32
Garhi Khairo	9	9	1	11	6	8	89	6	75	2	25	25
Thul	24	24	9	37.5	33	15	67	9	60	5	31	183
District total	48	48	16	31	102	32	69	21	71	9	26	240

Table 4 GW classification based on EC

EC/μS•cm^{-1}	Classification	Numbers of samples	Percentage of samples/%
<1500	Permissible	21	43.75
1500-3000	Not permissible	22	45.83
>3000	Hazardous	5	10.41
Total		48	100

Table 5 GW classification based on TDS[12]

TDS/mg·L^{-1}	Classification	Number of Samples	Percentage of Samples/%
<500	Desirable for drinking	10	20.83
500-1000	Permissible for drinking	22	45.83
1000-3000	Useful for irrigation	15	31.25
>3000	Unfit for drinking and irrigation	1	2.08
Total		48	100

Carbonates as per WHO guidelines were absent in all the samples while cations including Mg^{2+}, and $Ca^{2+,}$ Na^+ had values ranged of 4-400, 28-1500 and 8-759 mg/l respectively. It is observed that Ca^{2+}, Mg^{2+} and total hardness in 36%, 17% and 47% of water samples had exceeded the WHO safe limits. The drinking water in the study area was very difficult to be used for drinking purpose as 39 samples were in the very hard category of drinking water (total hardness>300 mg/L). The presence of two important ions Ca^{2+} and Mg^{2+} contributed to hardness. And these two ions are mainly found in the sedimentary rocks especially limestone which are found to be abundant in the study area. The SO_4^{2-} levels were above the safe limit in 14 drinking water samples. All other water samples analyzed contained NO_3^- within permissible range (Table 1). The presence of nitrogen species is a consequence of fertilizer utilization in agriculture and sewage pollution in the lower Indus Plain.

As is the most prevalent heavy metal in the Sindh Province, and in some areas the contamination exceeds 200 μg/L[13]. High concentration of As was found in ground water samples. Previous studies conducted on ground water quality of Sindh also revealed elevated concentration of As in different parts of Sindh Province due to moderate saline and alkaline, and anoxic conditions along with the higher concentration of Fe in the ground water[14]. In District Dadu (Sindh Province), As concentration ranged from 0-500 μg/L while 96 μg/L and 157 μg/L were detected in ground surface water in District Jamshoro[15].

No significant difference was observed among the means of the samples from ground water and surface water except HCO_3^- (Table 2). Similar relationship was observed in water quality among the three counties (Thul, Jacobabad and Ghari Khairo) and no significant difference was observed in the means of parameters in three counties except HCO_3^- and As. So the entire area had similar hydrochemistry and similar water quality, and consumer shared similar experiences in terms of potability but requires extra care for As and HCO_3^- which resulted from the nonfunction of the supply schemes and improper treatment of the piped water[16].

4.1 Behavior of major ions

Narrating the relationship among TDS with cations and anions, a regression analysis was performed. A strong positive correlation of TDS was observed with Na^+ (0.723) which reflected the saline nature of the drinking water. And mild correlations of TDS were observed with Mg^{2+} and Ca^{2+} with correlation values of 0.645 and 0.516 respectively (Figure 2). Similarly a strong positive correlation was observed between TDS and Cl^- (0.767) and mild correlations with SO_4^{2-} and HCO_3^- with R^2 values of 0.596 and 0.351 respectively (Figure 3). Among anions, Cl^- contributed greatly to the salinity of water. It was concluded that the correlation studies of the water quality parameters had major significance in water resources inquiry.

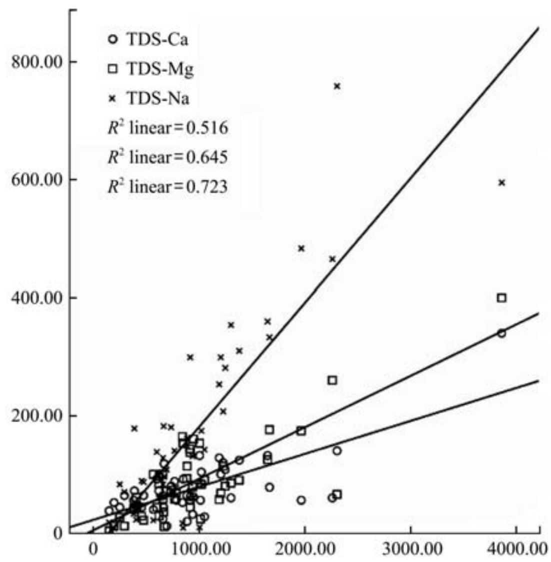

Figure 2 Variation of TDS with cations Ca^{2+}, Mg^{2+} and Na^+

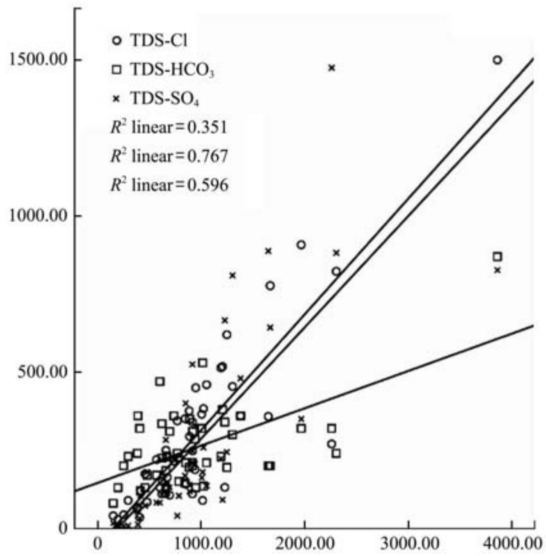

Figure 3 Variation of TDS with anions Cl^-, SO_4^{2-} and HCO_3^-

4.2 Spatial distribution of parameters

GIS based maps were prepared through spatial interpolation for EC, pH, TDS, hardness, As and SO_4^{2-} (Figure 4). The EC value of drinking water samples from Thul County was comparatively higher than the other two counties. Apart from EC, spatial distribution of other water quality parameters illustrated higher concentration in the Thul region. While distribution trend for pH concentrations reflected that water quality in the three counties did not show considerable variance. When mean values were compared, it also has showed a nonsignificance differences in three counties for these water quality parameters. The spatial distribution of As showed a concentration ranging from 0-100 ppb with the highest concentration found in the Ghari Khairo County (Figure 4e). Geochemical processes mainly contribute to the presence of As in ground water. As is the most toxic heavy metals found in the drinking water in the Sindh Province including District Jacobabad. As will affect the health of people with skin problems like hyperkeratosis and pigmentation and cancer depending upon the ingestion level and time period[14].

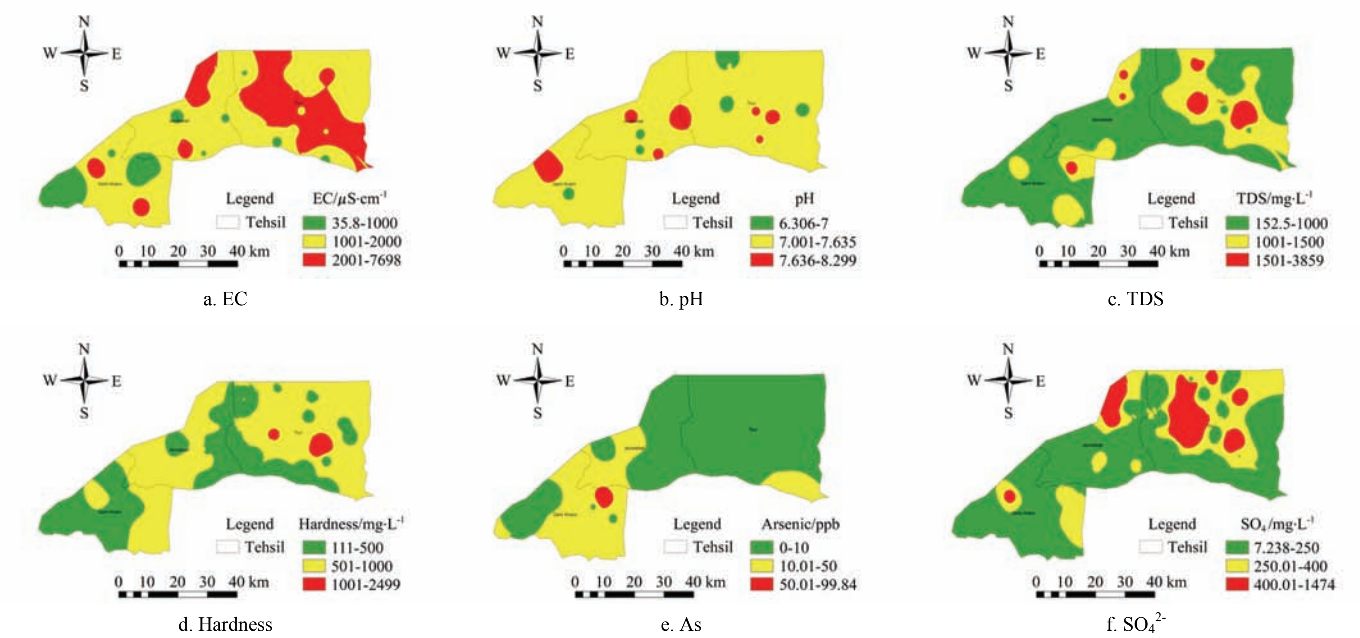

Figure 4 Spatial distribution of parameters

4.3 Major water pollution sources

Admittedly water quality proposed research region exceeded from the standards in basic water quality parameters including EC, TDS, hardness, anions and cations which consequently can have certain health implications. The principle cause of high concentration includes anthropogenic, geogenic factors and nonfunction of the water supply schemes. All the sewages from household and industries are disposed to canal system which ultimately replenishes the ground water. Moreover, due to extensive surface water availability from irrigation network, it reduces ground water utilization which raises the water table due to higher recharge and eventually leads to saline and water logged conditions[17,18]. Geologically, the study area is rich in minerals and sedimentary clay materials which will result in high concentration of hardness. Furthermore, the nonfunction of the water supply schemes along with poor and unhygienic distribution system makes it more susceptible to contamination.

4.4 Hydrochemical facies and water type

Piper plot is capable to show graphical diagram for the classification of water types. In the piper plot prepared for District Jacobabad through Aqua Chem, ground water was divided into six facies based on chemical analysis (Figure 5). The diamond shape in the piper plot showed that majority of the samples accumulated in the upper corner of the plot indicating CaCl as the dominant water type followed by $CaHCO_3$ water type. The remaining samples positioned in the centre of the plot indicating mixed type and confirmed CaMgCl water type while few sample showed NaCl water type in the area. It can be observed in the cations plot (left triangle) that a significant portion of samples exist in the mixed zone and showed predominance of mixture of cations (Ca^{2+}, Mg^{2+} and Na^{+}) while the rest of samples positioned towards Mg^{2+} and Na^{+} plot, so the water can be considered as mixed and $Mg^{2+}$and Na^{+} type. In the anions plot, Cl^{-} and HCO_3^{-} were dominant over SO_4^{2-}. This suggested that ground water was originated mainly from carbonate rocks dissolution and was classified as Na-HCO_3 with high salinity, thus reflected the saline nature of water. Some samples were located in the middle of the triangle showing no dominant anions.

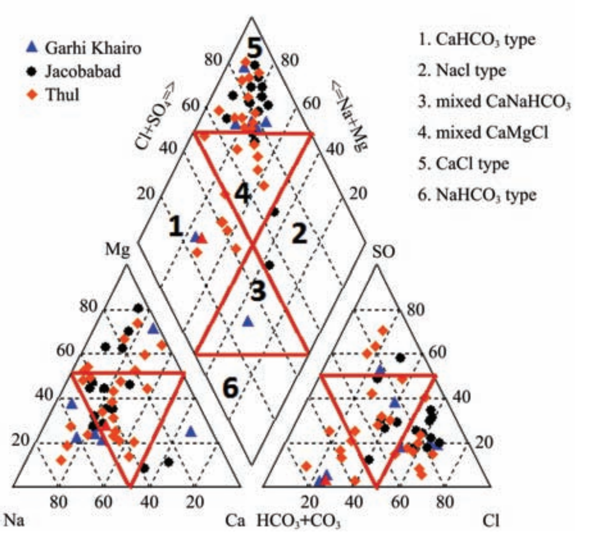

Figure 5 Piper diagram showing ground water types in District Jacobabad

4.5 Water quality assessment for irrigation

Suitability of water for irrigation depends on natural concentration of soluble salts[19]. In this study suitability of ground water for irrigation was evaluated by two basic parameters EC and Sodium Absorption Ratio (SAR), which is the measure of alkalinity hazard. Water salinity can be measured in terms of EC as it reflects the TDS in water. High EC and excessive salinity of water were proved to be detrimental to crops by plummeting the osmotic activity of plants and thus interferes with the absorption of nutrients and water from the soil[20]. High SAR value implies that Mg^{2+} and Ca^{2+} may be replaced in soil by Na^{+} in the irrigation, potentially causing damage to the soil structure. Wilcox diagram [22] classified the suitability of groundwater samples for irrigation. In this diagram, SAR was taken as alkalinity hazard and EC was used as salinity hazard (Figure 6). Salinity hazard were categorized as Low salinity water (C1), Medium salinity water (C2), High salinity water (C3) and Very high salinity water (C4). Meanwhile, alkalinity hazard were categorized as Low sodium water (S1), Medium sodium water (S2), High sodium water (S3) and Very high sodium water (S4). From alkalinity hazard perspective, 77.08% of water was excellent, 20.83% was good while just 2.08% was unsuitable for irrigation purpose (Table 6). While Wilcox diagram showed that 70.83% of water samples were located in C4-S1 category with very high salinity and low sodium hazard. This water type is suitable for plants with high salt tolerance and soil with well drainage system. District Jacobabad has intensive irrigation system with high water table and extensive rice cultivation which restrict the use of such type of water. 20.83% of the samples located in C4-S2 class with very high salinity and medium sodium hazard. This type of water is not recommended for irrigation purpose but can be used after treatment and adopting management practices. It is concluded that 78% of the irrigated land in Sindh Province is underlain by brackish or saline water, which is unsuitable for agriculture use[8]. This showed that water cannot be used for irrigation without drainage and special management strategies need to be adopted for salinity control.

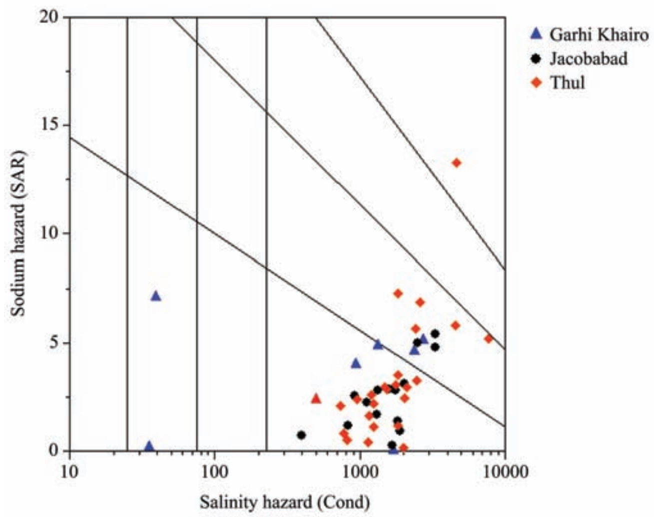

Figure 6 Effect of SAR on overall salinity hazards of water samples in the study area

Table 6 Alkalinity hazard classes of GW (suitability for agriculture)[21]

SAR	Alkalinity hazard	Water class	Total number of samples	Percentage of samples/%
<10	S1	Excellent	37	77.08
10-18	S2	Good	10	20.83
18-26	S3	Doubtful	0	0
>26	S4	Unsuitable	1	2.08

5 Conclusions

The local population of District Jacobabad has diminished drinking water resources to sustain their livelihood explicitly. Among available sources i.e. water supply scheme provided by the local government, 32 out of total 48 schemes were nonfunctional due to lack of funds or technical complications. A substantial proportion of water samples were detected nonpotable according to WHO drinking water quality standards. A nonsignificant relationship was observed among the means of water quality parameters of three counties and sources of water for the supply schemes. Spatial distribution showed comparatively higher distribution of parameters in the Thul County while a higher distribution of As was detected in the Garhi Khairo County. Based on this study, it will be required to address water related diseases and the proper management of water supply schemes will be needed. Regular monitoring of ground water quality should be accomplished; sewer drains should be away from water supply drains to inhibit leaching of waste water into ground water; sufficient filtration plants should be installed by District government to ensure the supply of potable drinking water. Awareness campaign regarding provision of safe water for human health and controlling waterborne diseases should be inaugurated by local municipal administration.

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