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Groundwater Contamination Study of Faisalabad and Sargodha Metropolitan Cities

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Abstract

The groundwater is one of the most important sources for fulfilling daily needs. Groundwater for drinking purposes is the biggest source in Pakistan, but due to population explosion, the rapid development of industrialization, deforestation, urbanization and unplanned housing schemes on agricultural lands are the major reasons for groundwater contamination and deterioration. The work emphasized evaluating the physicochemical characteristics of the groundwater of the two cities of Punjab, Faisalabad and Sargodha for drinking purposes. Overall thirty samples were collected in triplicate, fifteen from each city, Faisalabad and Sargodha, respectively. Physicochemical parameters, trace elements and microbiological analysis were conducted. The results revealed that the quantities of Magnesium (Mg), Calcium (Ca), Sodium (Na), Chloride (Cl^-), and Total Dissolved Solids (TDS) were significantly higher than the permissible limits of WHO in the majority of the samples from Sargodha, while TDS, Total Hardness (TH), were higher in most samples of Faisalabad. The studied trace elements Aluminum (Al), Chromium (Cr), Arsenic (As), Manganese (Mn), Iron (Fe), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Selenium (Se), Cadmium (Cd), and Lead (Pb) were found under safe limits of WHO except Cr, Cd, Se and Mn in Sargodha city and in Faisalabad Se and Cd were found to be crossing WHO levels in few locations. The samples from Faisalabad were found microbiologically unsafe as compared to Sargodha. Principal component analysis (PCA) revealed that the area's most dominant anion was chloride. Many processes are involved in changing water chemistry, and the water quality was controlled by rock water interaction and evaporation procedures. The study concluded that the area's water was brackish; due to this, the water was found unsuitable for drinking purposes. Therefore, the supply of safe water and water treatment plant installations are highly recommended in these areas.

Keywords: Groundwater, Industrial Wastewater, Physicochemical, Pollution, Urbanization, Water Quality.

Introduction

Clean water is a basic human need and should be free from chemicals & microbes. Pakistan is blessed by nature with adequate surface and groundwater resources, including rivers, lakes and groundwater in the country [1]. The water is a vital part of our every field of life [2]. Safe and hygienic water is important for life as well as for the sustainable development of a nation [3]. However, over 844 million humans living on the Earth have no availability of clean water for drinking [4]. Faisalabad city is one of the largest industrial estates and 3rd with a population of 3,203,846, while Sargodha is the 12th largest city with 659,862 population in Pakistan. The groundwater is the major source for drinking purposes in Pakistan, but due to rapid explosion in population, development of industrialization, deforestation, and unplanned housing schemes on agricultural lands are the major reasons for groundwater contamination and deterioration. Water contamination is key to diarrhea disease, with around 2.5 million causalities yearly, otherside polluted water is responsible for 5 million deaths in developing countries [5,6]. Substandard or low-quality drinking water is responsible for 30% and 40% of disease and deaths in Pakistan, while contaminated water affecting 1/5 of the population with diseases [7, 8]. In Sargodha city, around 38% of 96% groundwater was found unfit, with a major role of turbidity, TDS, fluoride, Fe, Pb and microorganism [9]. In Faisalabad, the major sources of drinking water are ground and surface water, 92% and 8%, respectively; while only twenty four percent samples were found fit for drinking purpose. The key contaminants found were turbidity, hardness, TDS, chloride, As, Fe, and microorganisms [9, 10]. The groundwater level of Faisalabad city is gradually decreasing due to the demand of the public and industries [11]. The water table has dropped upto ten meters in some parts of the city [12]. While the groundwater quality of Sargodha city is not much suitable for drinking purposes [13, 14]. In Pakistan, the maximum number of populations have no reach to clean and healthy drinking water and merely 40-60% of people have a good water supply [15]. Water pollution is the main issue for human health all over the globe [16]. Natural water bodies receiving pollution load without treatment are critically depleted of dissolve oxygen levels, disturbing the natural balance of aquatic eco-system while being contaminated with a variety of toxic wastes containing heavy metals (such as As, Cd, Cr etc.) [17]. According to the Pakistan Council of Research in Water Resources, the human community is increasing very speedily. Fresh water is becoming limited because of poor water management, lack of awareness and professionalism. Shortage of freshwater due to overpopulation and industrialization leads to water pollution issues globally. Groundwater is the single drinking source for most global communities [18]. Major contaminants found in water come from natural and anthropogenic sources [19]. In Pakistan, the unsustainable use and regular extraction of water for drinking and farming disturb water quality [19, 20]. Therefore, the groundwater status of Sargodha and Faisalabad districts, Punjab, Pakistan, was evaluated to know the concentration of different physicochemical parameters and the water's suitability for drinking purposes. The main reason behind the shortage and pollution of water, a resource is the wastage of water, unequal distribution, poor drainage system, and contaminated water supply system is responsible for less access to clean water in cities [21]. Due to the huge quantity of industrial sectors and almost running without proper treatment plants, Faisalabad is considered one of the most polluted groundwater in the country [22]. The people’s perception of rural areas in a tehsil Samundri, district Faisalabad, was that the water quality of different sources, that is, hand and electric pumps were poor [23, 24]. The physicochemical analysis of different samples collected from urban areas of Faisalabad showed that the overall groundwater used for drinking in urban areas of Faisalabad was intensively polluted with sewerage water [25]. Pakistan has the largest irrigation system, but due to a poor water distribution system and excess use of fertilizers and pesticides, country is facing around 50% losses and is equally responsible for low groundwater quality. Due to the increasing population of

Faisalabad, contaminated water is the most alarming problem. In 1999, the requirement of Faisalabad city was around 64.7 million gallons of drinking water supply to meet the needs; nearly 03 million gallons of this water came from domestic pumps that come out from subsoil water and tube well [26]. The huge quantity of salt is also the biggest issue of Pakistan's groundwater; the use of salt water for irrigation, dissolution of salts, and intrusion of seawater are also key responsible for the deterioration of the groundwater quality [21,27]. The current work is persistent with the assessment of the drinking water quality assessment of Faisalabad and Sargodha cities in prevailing climate changes.

Materials and Methods

Reagents and Instrumentation

A.R grade chemicals were used in the preparation of reagents and standards. The chemicals used were Sodium salt of EDTA, Silver nitrate, Sulfuric acid, Ammonium chloride, Sodium hydroxide, Sodium chloride, Potassium chloride, pH buffer, Eriochrome indicator, Calcone indicator, Potassium chromate, Bromocresol green etc. All necessary precautions were taken while sampling, transportation, and storage [28]. Trace metals Al, Cr, As, Mn, Fe, Co, Ni, Cu, Zn, Se, Cd, and Pb were analyzed by Inductively Coupled Plasma Mass Spectrometer (ICP-MS) Agilent 7800 ICP-MS, while microbiological tests were conducted by following standard procedures. Analysis was carried out for various water quality parameters in triplicate. Physicochemical analysis was performed for each sample in triplicate, and the average values were recorded. The temperature, pH, and electrical conductivity (EC) of all collected water samples were measured by a digital pH meter (JENWAY-3510) and EC meter (HACH HQ 14D), respectively. Chloride, Ca and Mg (titrimetric method), Na and K were measured on Flame Photometer (AFP−100, Sedico), and total dissolved solid (TDS) and total suspended solids (TSS) were measured gravimetrically after recommended filtration. All the analytical estimations were performed within 48 h of sampling [17].

Study Area

The two cities, Faisalabad and Sargodha of Punjab province of Pakistan, were selected for this study.

Sampling

Total of thirty groundwater samples (Fig 1 & 2), fifteen from different locations of each city, were obtained from (Sargodha city: New satellite town, Ali town, Jamia Masjid Bilal Bypass Faisalabad road, Shell petrol pump Bypass Faisalabad road, Chak # 50, Chak # 47, Government institute of commerce for women chak # 47, Murad colony, Farooq colony, University road, Kilyari town, Jafria colony chowk, Usmania colony, old civil line, Essa nagar, Civil hospital. Faisalabad city: Nishtabad, Manawala, Jameel Abad, WAPDA city, Manawala, Haji Abad, Allied Hospital, Samanabad, Azamabad, Iqbal Stadium, Bus Station, Civic centre, Madina town, Saifabad, Sandhu town) bore wells and community tube wells in pre-cleaned 1.5L polyethylene screw capped container in triplicate. Groundwater samples were collected from the aquifers of Faisalabad City at a depth of 31 to 40 feet; while the aquifers of Sargodha City were at a depth of 50 to 60 feet. Overall, more than a hundred samples were collected. But thirty were a representative average of 3 to 4 replicates per location. For metal determination, the samples were acidified with nitric acid. The samples for microbiology were collected in sterilized bottles. All samples were preserved and transported in the ice box and immediately analyzed.

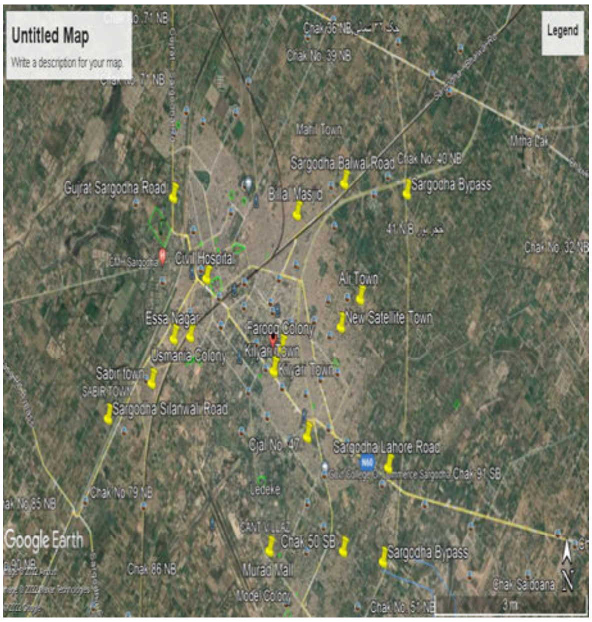

Figure 1. **Sample Location Map of Sargodha City.**

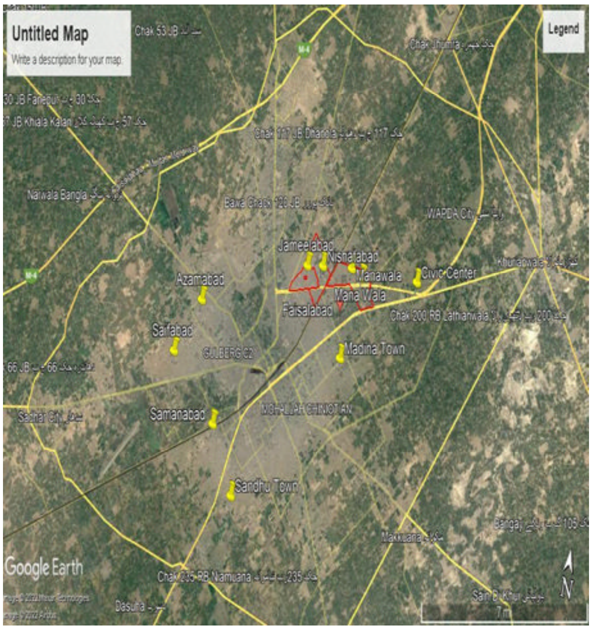

Figure 2. **Sample Location Map of Faisalabad City.**

ICP Analytical Conditions

Agilent inductively coupled plasma mass Spectrometer 7800 ICP-MS with HMI for Aerosol Dilution was used for analysis. Analytical conditions are shown in Table 1.

Table 1. **ICP-MS operating parameters.**

Parameter	Value
RF power (W)	1600
Sampling depth (mm)	10
Carrier Gas (L/min)	0.68
Dilution gas (L/min)	0.27
Helium Cell gas (ml/min)	5.0
Energy discrimination (V)	5.0
ISIS 3 loop size (μL)	300

Sample Preparation

A water sample (100 mL) was placed in a pre-cleaned beaker, to which high purity nitric acid (1 mL) was added. The beaker was heated for approximately two hours on a hot plate covered with a watch glass at a temperature just below boiling. After leaving it to cool to room temperature, it was transferred to a volumetric flask, made up to 50 mL with ultrapure water, and used for analysis. For elements present in high concentration, dilution test solutions were prepared by diluting 10-fold with 1% nitric acid solution. The calibration curve samples were prepared by diluting and mixing appropriate amounts of mixed standard solution and single element standard solution (1000 mg/L) from Merck.

Microbiological Analysis

E. coli, Thermo tolerant coliform and total coliform bacteria were evaluated by using standard methods. Briefly, media was poured into clean Petri dishes; 100 mL of the drinking water was separated through a membrane filter using vacuum filtration assembly. Membrane filters were placed in clean Petri dishes and incubated at 35 °C for 24 h. After 24 h, visible colonies of coliform bacteria turned pink or dark red with a lustrous shine. Triplicate samples were used for each sample.

Statistical Analysis

Statistical calculations were performed using the computer program Minitab (Version 13.2) and Excel.

Results and Discussion

Physico-chemical analyses of both cities are presented in Table 2. The results were compared with the World Health Organization (WHO) recommended levels, showing that the pH was within the WHO recommended levels in all water samples from Faisalabad and Sargodha. The analytical findings of water samples of Faisalabad suggest that TDS and EC of Sample Nos. 7, 8, 9, 10 and 15 from Faisalabad were within the control limits of WHO standards. Whereas, TDS in all samples of Sargodha city was beyond the set limits of WHO. The results were found consistent with the previous studies indicating that the chemical analysis of underground water of Faisalabad city from areas along Narwala and Sargodha road were inadequate for drinking. High levels of TDS are objectionable to consumers owing to excessive scaling in water pipes, heaters, boilers and household appliances [29]. The transition in TDS and EC values in Faisalabad suggests the non-uniform quality of the ground-water [30]. According to the TDS levels, all the water was brackish (TDS greater than 1,000 mg/L), apart from a small number of samples, which were freshwaters (TDS less than 1,000 mg/L) [31]. Chloride concentrations were also higher than the WHO levels except for a few samples.

Table 2. **Physicochemical Analysis of Groundwater Samples of Sargodha and Faisalabad city.**

City	Parameters	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9	S 10	S 11	S 12	S 13	S 14	S 15
Sargodha	TDS	4931	4931	7806	2296	9643	4066	2068	3058	8813	2072	7289	3619	1984	2270	2709
Faisalabad		2727	1221	1632	2306	1587	1548	774	589	1009	403	1218	3182	1956	2823	650
Sargodha	TSS	96	96	48	46	168	106	46	22	160	12	132	30	16	54	58
Faisalabad		8	6	4	10	2	4	0	0	2	0	4	26	14	28	0
Sargodha	Total Hardness as $CaCO_3$	1662	1662	1463	842	1186	2194	1042	953	2793	665	2903	1740	1163	1197	886
Faisalabad		443	787	399	432	299	321	354	465	990	379	654	621	562	432	366
Sargodha	Alkalinity as $CaCO_3$	653	653	749	576	845	557	691	672	480	653	634	653	634	557	422
Faisalabad		440	509	490	758	557	451	298	461	518	307	499	691	595	662	211
Sargodha	Chloride	2729	2729	727	1142	4526	1752	776	1362	4877	874	4162	1606	898	1079	1113
Faisalabad		190	46	149	381	105	125	44	56	64	17	71	290	161	225	198
Sargodha	Calcium	301	301	168	177	106	266	186	195	328	133	319	319	160	2216	151
Faisalabad		53	75	49	53	58	93	27	67	100	98	133	71	84	71	62
Sargodha	Magnesium	218	218	250	96	221	367	138	112	473	80	505	23	184	154	122
Faisalabad		75	144	67	72	37	21	61	72	40	35	77	61	77	61	3
Sargodha	Sodium	60	3520	2570	750	3230	498	28	42	2900	30	3550	44	47	26	35
Faisalabad		643	30	20	25	780	40	29	12	25	4	40	31	28	40	5
Sargodha	Potassium	19	19	18	53	53	16	12	11	50	6	27	14	9	31	44
Faisalabad		61	41	7	10	28	8	7	5	13	2	7	14	11	15	3
Sargodha	Carbonate	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Faisalabad		Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Sargodha	Bicarbonate	535	535	614	472	693	457	567	551	394	535	520	535	520	457	346
Faisalabad		361	417	401	622	457	370	244	378	425	252	409	567	488	543	173
Sargodha	Sulphate	12	124	98	78	197	10	6	8	208	4	168	12	16	8	6
Faisalabad		14	6	7	9	10	8	7	8	6	4	7	6	5	7	10

The concentrations of all cations were almost above the WHO levels, except Na. In all water samples, the cations order was Ca>Mg>Na>K. The finding of heavy and trace metals have been presented in Table 3, observing the presence of heavy metals in Sargodha city. The Al concentration was found between the ranges of 0.28-0.56. However, the permissible limit of Al is 0.2 mg/L, hence all samples were found unfit for drinking water purpose. A huge variation was found in Cr, in sample-8, which was 16.580 mg/L, while other results for Cr were 0.01-0.13, the permissible limit for the parameter is 0.05 mg/L, and hence only one sample was beyond the permissible limit. The highest result of Mn was found in all samples between 0.02-12.09 mg/L, while the permissible limit is 0.04 mg/L. The results ranges for Fe were 0.25-0.4 mg/L. There are no cobalt guidelines, and results were found within the ranges of 0.01-0.6. The results of Ni, Cu, Zn, Se, Cd, and Pb were 0.02-0.21, 0.02-0.1, 0.5-3.56, 0.02-0.29, 0.01-0.7, and 0.01-0.02, respectively. While the results of heavy metals in groundwater samples of Faisalabad were within the ranges of 0.32-0.81, 0.01-0.13, 0.02-0.58, 0.01-0.08, 0.27-0.42, 0.01-0.06, 0.01-0.37, 0.02-0.37, 0.24-0.84, 0.02-0.76, for Al, Cr, As, Mg, Fe, Co, Ni, Cu, Zn, and Se, respectively.

***Table 3*. Trace Element Analysis of Water Samples of Sargodha and Faisalabad city.**

City	Parameters	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9	S 10	S 11	S 12	S 13	S 14	S 15
Sargodha	Aluminum	0.510	0.470	0.500	0.400	0.440	0.480	0.560	0.410	0.300	0.280	0.350	0.340	0.330	0.370	0.390
Faisalabad		0.480	0.420	0.750	0.750	0.800	0.610	0.500	0.530	0.430	0.390	0.320	0.520	0.640	0.580	0.810
Sargodha	Chromium	0.010	0.020	0.010	0.010	0.010	0.030	0.020	16.580	0.090	0.010	0.010	0.010	0.010	0.130	0.050
Faisalabad		0.110	0.060	0.060	0.050	0.130	0.040	0.010	0.040	0.020	0.020	0.020	0.020	0.020	0.010	0.010
Sargodha	Arsenic	0.020	0.010	0.020	0.020	0.010	0.020	0.020	0.010	0.020	0.030	0.010	0.010	0.010	0.010	0.020
Faisalabad		0.040	0.020	0.080	0.050	0.050	0.020	0.050	0.070	0.020	0.020	0.020	0.580	0.020	0.050	0.050
Sargodha	Manganese	4.330	12.090	5.880	0.410	2.640	0.400	0.110	0.020	0.020	1.740	6.650	1.030	0.070	4.350	0.800
Faisalabad		0.080	0.030	0.020	0.020	0.030	0.020	0.020	0.010	0.020	0.010	0.010	0.020	0.020	0.010	0.020
Sargodha	Iron	0.400	0.370	0.370	0.310	0.330	0.360	0.410	0.290	0.280	0.250	0.320	0.350	0.330	0.320	0.290
Faisalabad		0.390	0.280	0.330	0.380	0.390	0.420	0.270	0.270	0.330	0.310	0.320	0.310	0.350	0.420	0.330
Sargodha	Cobalt	0.020	0.030	0.020	0.010	0.010	0.060	0.010	0.010	0.000	0.020	0.020	0.010	0.330	0.020	0.010
Faisalabad		0.010	0.000	0.010	0.010	0.010	0.010	0.010	0.030	0.010	0.010	0.010	0.060	0.020	0.010	0.010
Sargodha	Nickel	0.170	0.070	0.160	0.170	0.090	0.050	0.020	0.040	0.020	0.200	0.210	0.080	0.080	0.030	0.080
Faisalabad		0.030	0.010	0.320	0.080	0.030	0.060	0.010	0.010	0.010	0.100	0.020	0.090	0.080	0.020	0.370
Sargodha	Copper	0.040	0.120	0.050	0.040	0.030	0.040	0.030	0.030	0.020	0.040	0.040	0.080	4.630	0.030	0.030
Faisalabad		0.030	0.020	0.100	0.070	0.050	0.040	0.040	0.050	0.030	0.020	0.020	0.240	0.120	0.050	0.030
Sargodha	Zinc	1.960	1.300	6.060	2.510	0.500	1.060	0.930	1.360	1.390	3.560	2.540	6.200	0.010	1.450	0.850
Faisalabad		0.580	0.400	0.480	0.360	0.840	0.620	0.560	0.520	0.630	0.410	0.420	0.420	0.430	0.240	0.260
Sargodha	Selenium	0.080	0.030	0.080	0.030	0.020	0.100	0.080	0.100	0.280	0.180	0.080	0.060	0.030	0.010	0.290
Faisalabad		0.110	0.060	0.080	0.080	0.110	0.040	0.030	0.420	0.050	0.050	0.050	0.760	0.060	0.020	0.030
Sargodha	Cadmium	0.020	0.020	0.010	0.010	0.010	0.010	0.020	0.010	0.010	0.060	0.040	0.010	0.010	0.010	0.070
Faisalabad		0.040	0.010	0.020	0.010	0.010	0.010	0.010	0.020	0.040	0.010	0.010	0.080	0.070	0.010	0.010
Sargodha	Lead	0.010	0.020	0.010	0.010	0.010	0.010	0.010	0.010	0.000	0.010	0.010	0.010	0.010	0.010	0.010
Faisalabad		0.010	0.000	0.020	0.010	0.110	0.010	0.010	0.010	0.020	0.010	0.010	0.030	0.030	0.010	0.010

While all samples from both cities were found microbiologically unfit for drinking purposes. In the same type of study, 90% of samples from the area of Samundri Faisalabad were higher than the WHO limits [32] due to higher results of EC and TDS in Faisalabad. The outcomes of the microbiological analysis are shown in Table 4. Total plate count was not detected in all the samples of both cities, whereas faecal and total count was observed in all the samples. In a study, the groundwater from Sargodha was reported unsafe due to high TDS, Na and microbiologically [33]. Samples 3, 7 and 12 from Faisalabad were found to be highly polluted with faecal colonies suggesting that these water reservoirs are highly polluted by sewage water [34]. Collectively, a pollution load of approximately 300 and 260 tons of BOD/day from Faisalabad's residential, commercial and industrial sectors is added to Chenab and Ravi rivers, respectively [35].

Correlation Coefficient

The correlation matrix was studied to understand the associations among the studied water variables at a 0.05 significance value in Table 5 [36]. TDS possesses a strong correlation with Cl^-, Mg and K, while a negative correlation existed with pH and EC. Among the other parameters, a good correlation of Cl^- was observed with K, Mg, TH and TA. The Na shows no important correlation with Cl^-, suggesting that halite dissolution may not be the main process affecting the water quality. Mg was found in a strong correlation with TH and TSS, Cl^- and K, representing the identical origin and/ or same hydro-geochemical behavior during different reactions [37].

***Table 4*. Microbiological Analysis of Water Samples of Sargodha and Faisalabad city.**

City	Parameters	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9	S 10	S 11	S 12	S 13	S 14	S 15
Sargodha	TPC	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Faisalabad		Nil	Nil	Nil	Nil	Nil	Nil	Nil	0	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Sargodha	T. Coliforms	<2	<2	<2	<2	<2	<2	Nil	<2	<2	<2	<2	<2	<2	<2	<2
Faisalabad		<2	<2	23	<2	<2	<2	2	<2	<2	<2	<2	7	<2	<2	<2
Sargodha	F. Coliforms	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Faisalabad		<2	<2	1.000	<2	<2	<2	2.000	<2	<2	<2	<2	8.000	<2	<2	<2
Sargodha	E.*coli*	-ve	-ve	-ve	-ve	-ve	-ve	<2	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve
Faisalabad		-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve

***Table 5*. Correlation among various variables of groundwater samples (n=30).**

Variables	pH	EC	TDS	Cl	TA	Na	K	Ca	Mg	TH	TSS
pH	1										
EC	-0.092	1									
TDS	-0.241	-0.398	1								
Cl	-0.070	-0.349	0.831	1							
TA	-0.242	-0.407	0.471	0.301	1						
Na	-0.204	-0.315	0.134	0.290	0.079	1					
K	0.070	-0.189	0.433	0.569	0.002	-0.176	1				
Ca	-0.155	-0.171	0.138	0.184	0.019	0.002	0.313	1			
Mg	-0.377	-0.228	0.810	0.744	0.189	0.144	0.453	0.243	1		
TH	-0.470	-0.276	0.794	0.737	0.193	0.224	0.440	0.315	0.933	1	
TSS	-0.244	-0.359	0.902	0.903	0.276	0.189	0.562	0.260	0.869	0.848	1

Bold figures are different from 0 with a significance value alpha = 0.05

Principal Component Analysis (PCA)

From PCA analysis, three factors (F1, F2 and F3) were derived (Table 6), which shows three major Eigen values. F1 was loaded with TDS, Cl^-, Mg, TH, TSS, Ca and K, which shows the dominancy of rock and water contact and weathering of minerals [38]. The high loading of Cl^- was may be from domestic sewage, industrial discharges, and chemical manures [39, 40]. F2 was loaded with Na and TA and shows that natural processes have major involvement, mainly affecting groundwater chemistry. In F3, high loading of EC, Mg and TH was recorded. Three-factor variabilities with different factor loadings recommend the non-uniform hydro-geochemistry of groundwater in the area. Mg occurrence may be due to water-rocks interaction because of its moderate loadings.

***Table 6*. Correlation between variables and factor composition in samples of water.**

	F1	F2	F3
pH	-0.337	-0.379	-0.757
EC	-0.443	-0.349	0.628
TDS	0.919	0.057	-0.089
Cl^-	0.894	-0.069	-0.185
TA	0.384	0.528	-0.270
Na	0.249	0.646	-0.001
K	0.570	-0.620	-0.207
Ca	0.327	-0.274	0.126
Mg	0.905	-0.091	0.235
TH	0.914	-0.021	0.279
TSS	0.959	-0.095	-0.017
Eigen value	5.168	1.448	1.274
Variability (%)	46.982	13.164	11.586
Cumulative %	46.982	60.147	71.733

Gibbs Diagram

Gibbs's diagram [41] illustrated that water chemistry in the investigated area was mainly controlled by evaporation and rock water interaction processes (Fig. 2).

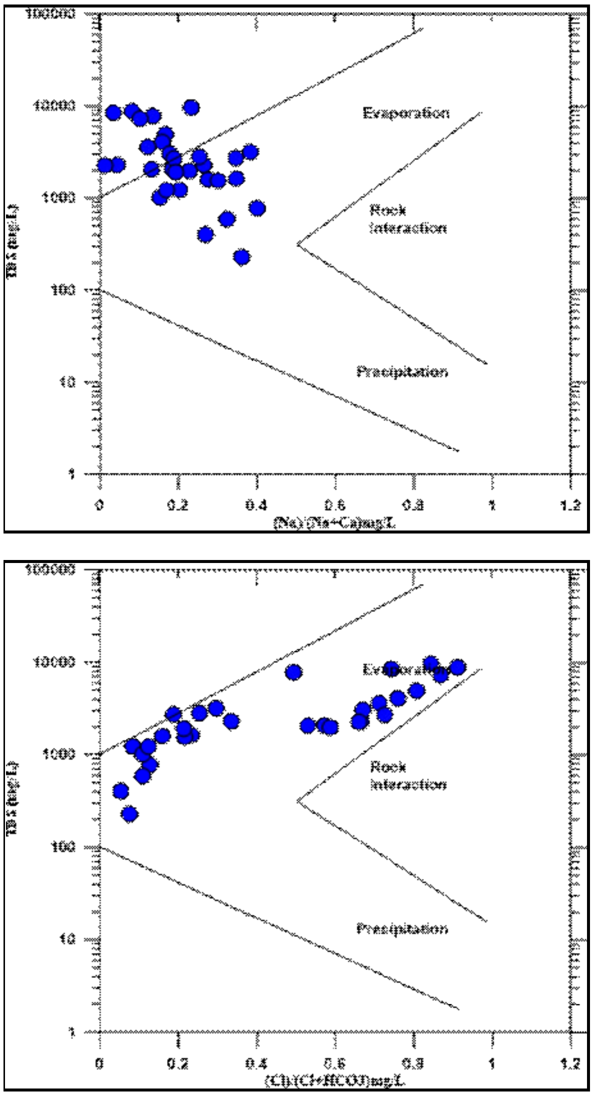

***Figure 3*. Gibbs diagram representing water chemistry in the area**

Conclusions

The rapid increase in population, unplanned growth of industrialization, and unplanned housing schemes on agricultural lands and deforestation are the major reasons for groundwater quality worsening. Suitable cleaning steps should be followed before using groundwater for drinking purposes. The physicochemical results showed that the majority of the parameters were above the WHO limit except pH. Thus, the study concluded that the water was mostly of brackish nature, the heavy metals were almost found within the permissible limit of WHO, while chemically and microbiologically, the samples were found unfit for drinking purposes. From the Principal Component Analysis results, it was also concluded that natural processes were mainly responsible for the non-uniform chemistry of the water, which was mainly controlled by evaporation and rock-water interaction mechanisms. Therefore, the supply of safe and hygienic drinking water and the establishment of water treatment plants are highly recommended to solve the water shortages by using improved and new technologies in irrigation systems. It is concluded that parallel sewage lines and drinking water pipelines are the leading cause of contamination, while the chemical substance is another major source. Discharging chemical substances and effluent into the surface drain, groundwater should be considered a threat to the environment and health. Using cost-effective treatment methods can remove the contaminations, but identification of contamination is essential. While overall, drinking water quality improvement has been observed in Punjab province from 35 to 49% in 2015 and 2020, respectively. As per data, the drinking water in Punjab province has improved, but to achieve sustainable development goals target by 2030, there is a need for more attention and implementation of a safe drinking water policy in Pakistan for achieving the target of sustainable development goals.

Conflict of Interest

The authors declare no conflict of interest.

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