Article

Assessment of Drinking Water Quality and Associated Socio-Economic Impacts in Arid Mountainous Regions

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Abstract: We investigated the quality of drinking water and its possible effects on human health in the Dera Ghazi Khan (D. G. Khan) district of Pakistan. Samples were collected from three tehsils of the D. G. Khan district, namely D. G. Khan, Kot Chutta, and Taunsa. A total of 50 samples ($n = 50$) were collected from the study area using standard procedures. The pH of the water samples ranged from 6.52–8.75, EC 0.31–9.78 dS m^{-1}, and TDS 105–985 mg L^{-1}. The bacterial analysis showed that 9 out of 50 samples (18%) contained pathogenic *E. coli* bacterial. The results showed that the pH and EC values of some sampling sites exceeded the WHO guidelines for drinking water. It was observed that the pH of only 1 sample, and the EC of 18 samples in D. G. Khan—5 in Kot Chutta and 16 in Tehsil Taunsa—exceeded the WHO guidelines. In terms of *E. coli* presence and related diseases (hepatitis A, B, and C), we collected data, which were screened and belonged to the sampling sites, from 1378 patients receiving treatment related to hepatitis A, B, and C. It was revealed that 530 patients belonged to the D. G. Khan site, followed by Taunsa (460), and Kot Chutta (388). Based on the results, it was concluded that the quality of drinking water samples generally was good, except for 6% of the samples, assessed using (SAR) and Kelly's ratio (KR), and 9 sites were positive for *E. coli*.

Keywords: drinking water; ecotoxicology; fecal contamination; health risks; hepatitis

1. Introduction

Water is a universal solvent that dissolves different chemicals and contaminants [1,2]. In numerous parts of the world, fresh water is considered as limited resource, which will become scarce due to increased resource consumption, climate change, and population increase [3]. According to an estimate, 1.1 billion people globally consume polluted water, either intentionally or accidently. Drinking water can be associated directly or indirectly with public health because of the low or high concentration of numerous contaminants [4,5]. In Pakistan, groundwater contamination through industrial and municipal effluents is of great human health concern. The consumption of polluted water, particularly water contaminated with animal and human feces, has been reported as a cause of many infectious diseases in humans, i.e., different forms of hepatitis. Hepatitis is mainly caused due to the presence of different bacteria, such as *E. coli* and *Coliform* genera. These genera include both fecal (specifically present in the intestines and feces of warm-blooded animals) and non-fecal origins. *E. Coli* bacteria belong to the group of fecal coliforms, are harmless, but few strains of *E. Coli* causes severe diseases [6]. It is evident in many studies that many

physical, chemical, and especially biological drinking water quality parameters in Pakistan exceed the WHO limits [7–9].

In Pakistan, millions of people use groundwater for domestic purpose [10], and waterborne diseases are largely produced by slum residents or residential areas with no or improper water supplies or sanitation infrastructure. Along with hepatitis, diarrhea is also the primary cause of death for infants and children in the country, and every fifth resident suffers from illness and disease triggered by fecal-polluted water [11,12]. In recent years, the interest in water quality has grown dramatically, as water quality measures have a significant impact on human health [13]. Poor quality drinking water causes diarrhea [14,15], hepatitis [16], dental caries [17], infant anemia [18], decreased intelligence in childhood, and a decline in brain function and growth [19]. These disease are more prevalent in developing countries such as Pakistan.

In defining precautionary measures to prevent different waterborne ailments, the public consciousness plays a significant role regarding drinking water quality. In Pakistan, 40–60% of the people living in rural as well as urban areas lack access to safe drinking water [20]. The main points of drinking water contamination are seepage from stagnant water and sewage drains, as well as the leakage of septic tanks. Surface water may also be contaminated with harmful contaminants and pathogenic bacteria [21]. It is documented that only 56% of the total population in Pakistan has access to clean drinking water [11]. According to statistics, clean water is out of the reach of 70% of the rural population in Pakistan [22]. Contaminated potable water triggers disease outbreaks. Many diseases illnesses, such as diarrhea, vomiting, gastroenteritis, dysentery, and kidney problems have been reported in the districts of Thatta, Badin, and Thar in southern Sindh, Pakistan, due to drinking polluted water [23]. Chemical pollution is one of the key issues affecting the surface water by leakage, pipeline leaks, and cross-contamination between aquifers that can pass along the pollutants inside them [24–26]. The degree of bacterial pollution in drinking water is closely related to both seasonal patterns and regional variations [27].

Water resource management has become a hot topic in this era as a result of industrialization and high population growth rates. The former has an impact on water quality, whereas the latter reduces it in order to meet the demand for drinking water. Therefore, the need to regularly check surface water quality is becoming increasingly important in order to protect people from chronic illnesses. The different types of water quality indices, i.e., Kelly's ratio and water quality index, which assesses the magnesium hazard and the percentage of sodium in the water, give information about the water quality for human use [9]. The current study was carried out to evaluate the drinking water quality of various sources of potable water in the D. G. Khan district and to correlate the water quality with associated waterborne diseases in humans.

2. Materials and Methods

Study area: Dera Gazi Khan is the 19th largest city in the Punjab Province of Pakistan and is located at 70.38° E and 30.03° N. It is the headquarters and administrative center of the D. G. Khan district and division, respectively. It has three tehsils, namely D. G. Khan, Taunsa, and Kot Chutta (Figure 1). This district has a dry climate, with an annual precipitation of 104 mm. The winter is mild, with an average temperature of 4 °C, and summer is very hot, with an average high temperature of 42 °C. The study was performed to assess the quality of the water in this district. Drinking water samples were collected from the three tehsils of the D. G. Khan district during the summer season, when rainfall is less. The sampling sites of the D. G. Khan, Kot Chutta, and Taunsa tehsils are presented in Figure 1.
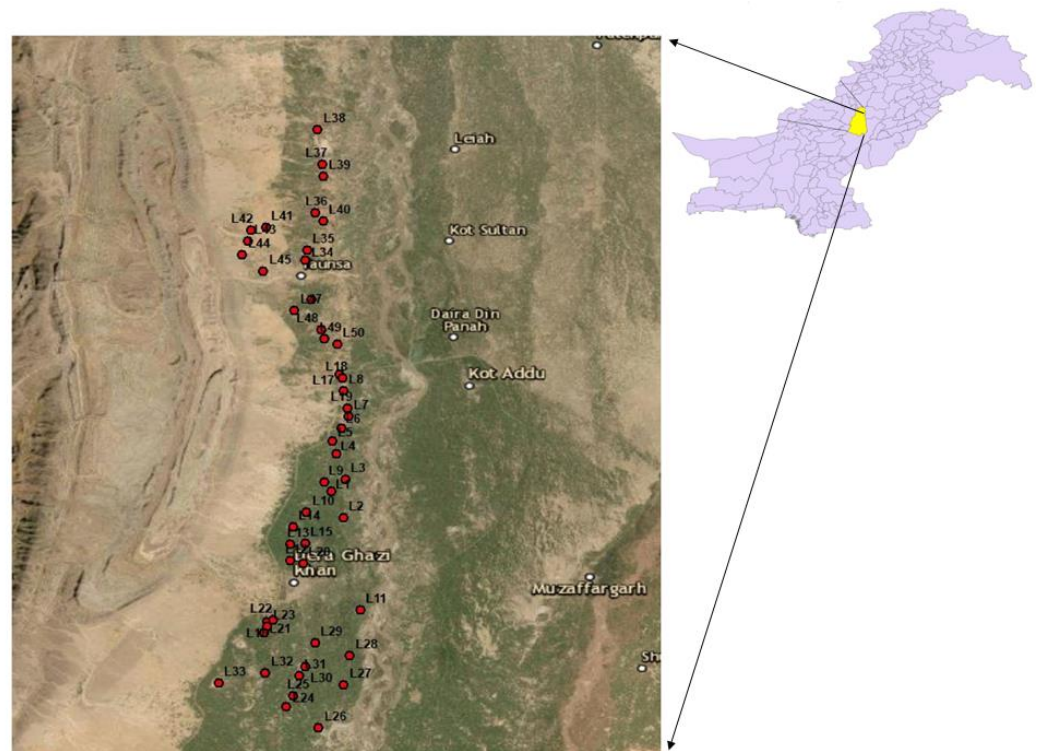
Figure 1. Base map showing the sampling locations.

Sample collection, quality assurance, and preservation: Water samples were collected from selected sites in the D. G. Khan district, and their quality and safety parameters were examined. All the samples of drinking water were collected in sterilized bottles of 250 mL capacity. The tap was properly cleaned with a muslin cloth to remove any kind of dust on the tap. Afterwards, the tap was opened for one to two minutes to flush out the water already present in the pipes. Gloves were used to collect the sample, and the tap was sterilized with a spirit lamp to avoid any type of contamination. In the next step, the tap was again opened and allowed water was allowed to flow for a time before the sample was collected. All the bottles were labeled with tags containing sample codes, as shown in Table 1. The bottles containing water samples were kept in at 4 °C a cooler containing ice cubes and were transferred to the laboratory within 24 h. The charge balance error (CBE) was computed to check the reliability of each sample (Equation (1)). The samples with a CBE < ±5% were consider for further analyses.

$$Charge\ balance\ eror\ (CBE) = \frac{Sum\ of\ cations - Sum\ of\ anions}{Sum\ of\ cations + Sum\ of\ anions} \cdots \tag{1}$$

where ionic concentrations were recorded in me L^{-1}.

Chemical parameters: The collected water samples were analyzed according to the standard methods for evaluating pH, EC, and TDS. The pH was recorded using an electronic digital pH meter (Hanna HI-83141) by calibration using buffer solutions of pH 4 and 7. The TDS and EC were measured using a multipurpose meter (Lovibond SensoDirect con200) after calibration using 0.01 M potassium chloride solution at 25 °C [28].

Cation and anionic analysis: Carbonates (CO_3^{2-}), bicarbonates (HCO_3^{-}), chlorides (Cl^{-}), hardness ($Ca^{2+} + Mg^{2+}$), and sulphates (SO_4^{2-}) were analyzed using standard procedures listed in the American Public Health Association manual [28].

Table 1. Coding of the sampling areas under study.

Symbol	Area Name	Symbol	Area Name
L1	Jattewala	L26	Taunsa City
L2	Pir Adil	L27	Basti Sonra
L3	Shah Sadar Din	L28	Naari Janubi
L4	Darri Dholay Wali	L29	Retra
L5	Kala Kaloni	L30	Tibbi Qaisrani
L6	Kala City	L31	Bulani
L7	Basti Azeem	L32	Dauna
L8	Shadan Lund	L33	Chah Sher Bahadur
L9	Pull Sheikhani	L34	Kot Qaisrani
L10	Kot Mubarak	L35	Basti Buzdar
L11	Samina Sadaat	L36	Koro
L12	Kot Haibat	L37	Mangrotha
L13	Chabri Bala	L38	Basti Bohar
L14	Yaroo Khosa	L39	Basti Gadi
L15	Jhok Yar Shah	L40	Chauki Wala
L16	Mana Ahmadani	L41	Javed Abad
L17	Notak Mahmid	L42	Basti Pir
L18	Sheero Jadeed	L43	Basti Pir-1
L19	Jhok Utra	L44	Ahmadani
L20	Ghausa Abad	L45	Bhatti Wala
L21	Aali Wala	L46	Sahi Wala
L22	Kot Chutta City	L47	Basti Mandhrani
L23	Basti Malana	L48	Basti Tararo
L24	Adaa Haider Abad	L49	Samandri
L25	Chooti Zareen	L50	Basti Darishak

Water quality Indices: Water quality indices were assessed using Equation (2).

$$\mathrm{Wi} = \sum_{n=1}^{n} \mathrm{Wi} \tag{2}$$

where:

n = number of parameters.

The quality rating scale was calculated using:

$$\mathrm{Qi} = \left(\frac{\mathrm{Ci}}{\mathrm{Si}}\right) \times 100$$

The comparison was performed using:

$$\mathrm{SIi} = \mathrm{Wi} - \mathrm{qi}$$

$$\text{Water quality index (WQI)} = \sum \mathrm{SIi}$$

Kelly's ratio was calculated using following formula:

$$\text{Kelly's ratio (KR)} = \frac{\mathrm{Na}^+}{\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}} \tag{3}$$

Microbiological analysis: The Institute of Microbiology at the University of Agriculture Faisalabad (UAF) assisted in performing all the microbiological analyses. The multiple tube fermentation method was employed to analyze *E. coli* in the water samples [29]. A set of tubes containing MacConkey broth (10 mL) were inoculated with 10 mL of collected water samples and placed in an incubator that adjusted the temperature at $37 \pm 1\,^{\circ}\mathrm{C}$ for 24 h. These tubes were examined for gas production in the form of effervescence after 24 h. Formation of gas signifies the presence of bacterial species in the sample. For the

confirmatory test, tubes having bacterial species were re-incubated with 10 mL of tryptone water at $44 \pm 1\,^{\circ}$C temperature for 24 h. A red film was formed upon the addition of 2 drops of Kovacs reagent (Oxide), confirming the presence of *E. coli*

Data collection regarding public health: Data regarding public health impacts due to consumption of microbially contaminated water was collected from the inventory/directory of the Punjab Hepatitis Control Program, DHQ Teaching Hospital, D. G. Khan, being run by the government of Pakistan in the study area. Data for patients diagnosed with hepatitis A, B, and C and who had received medical treatment in the last year was collected (Supplementary Table S1).

Sampling preservation and quality assurance: Standard sampling protocols was carefully followed in collecting the samples. The levels of pH, EC, and TDS were determined on the spot using portable meters. For anionic analysis, samples were shipped to the laboratory and stored at $4\,^{\circ}$C in darkness under dry conditions.

Data Analysis: The data was analyzed to obtain summary statistics and a correlation matrix between the studied parameters using XLSTAT v2018 and Origin 2018b v9.5.1.

3. Results

The Piper classification, based on the cationic and anionic composition of the samples, was used to evaluate the quality (chemical-based) of the groundwater. The Piper chart shows the hydrogeochemical composition of all the water samples analyzed in this study (Figure 2). The results revealed that almost all of the water samples were categorized in the sodium chloride and sodium bicarbonate class, due to the dominance of chloride, bicarbonate, and sodium in the waters samples tested. The classes of all three study areas were nearly same due to the fact that mountainous regions have excessive primary sources of minerals, such as Ca^+, $CO_3{}^-$, Na^+, and other forms of minerals which are contained in the rocks.

Physicochemical parameters:

The pH shows acid-base equilibrium and measures the hydrogen (H^+) ions activity in the water samples. The allowable pH limits in drinking water are 6.5–8.5, according to WHO recommendations. Mean pH values in the water samples were found to be 7.35 ± 0.27, 6.92 ± 0.20, and 7.28 ± 0.46 in Kot Chutta, Taunsa, and D. G. Khan, respectively, as shown in Table 2. The highest and lowest values of pH were found to be 8.75 ± 0.12 and 6.58 ± 0.07 in groundwater samples collected from L11 and L25, respectively. The pH values of all the water samples were found within the allowable limits of WHO for drinking water (6.5–8.5), except for one sample of L11, in which the pH was found to be 8.75.

Electrical conductivity is the ability of water to pass an electric current through it. It is dependent on the concentration of positively and negatively charged inorganic dissolved ions. In the study areas, the mean values of EC in the groundwater samples were found to be 1.24 ± 0.64, 1.79 ± 0.64, and 2.21 ± 2.13 dS m^{-1} in Kot Chutta, Taunsa and D. G. Khan, respectively (Table 2). In the groundwater samples, the highest value of EC 9.78 ± 2.18 dS m^{-1} was found in L10. Other areas such as L10, L9, L13, and L14 also showed higher values of EC which exceeded the WHO safe limit of 1 dS m^{-1}.

The total dissolved solids reflect the quantity of the dissolved inorganic materials in the water, such as bicarbonates, carbonates, phosphates, chlorides, calcium, sodium, magnesium, and other ions. For various purposes, such as drinking, irrigation, washing, recreation, etc., TDS is an important property for water suitability. The mean values of TDS were 371.1 ± 128.30, 611.47 ± 184.40, and 476.88 ± 223.92 mg L^{-1} (Table 2). The highest value of TDS (985 ± 112 mg L^{-1}) was found in L13, and the lowest (105 mg L^{-1}) was found in L6. All the samples analyzed for TDS remained within the WHO permissible limits (Table 2).
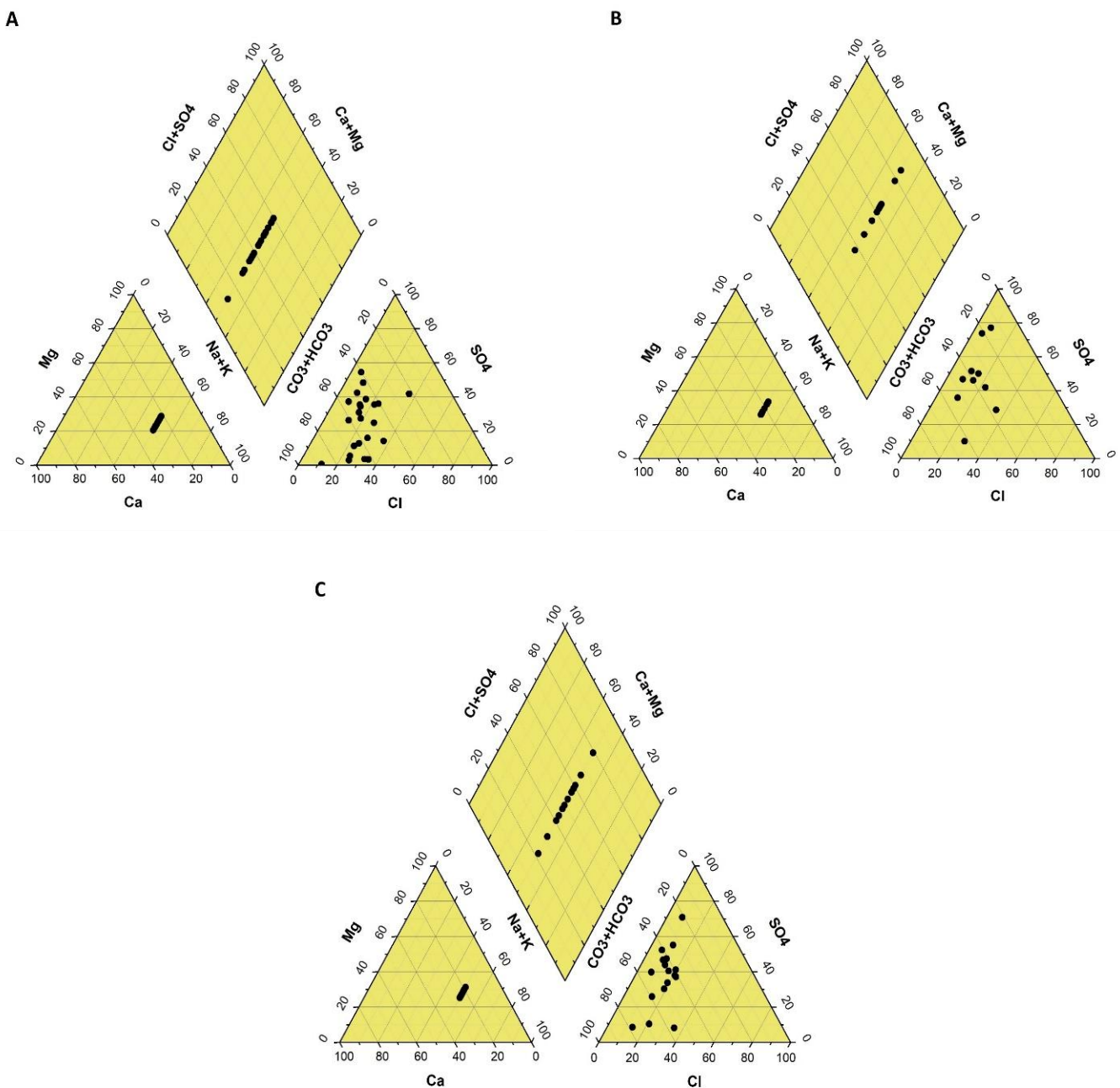
Figure 2. Classification of water type based upon cation and anion concentration (mg L^{-1}) in the drinking water of D. G. Khan (**A**), Taunsa (**B**), and Kot Chutta (**C**).

The concentration of HCO_3^- in water reveals the alkalinity of the water samples. High alkalinity indicates a high buffering capacity for water (resistant to pH changes). The mean concentration of HCO_3^- in drinking water samples was recorded as 200 ± 75.56, 150 ± 47.21, and 186 ± 82.45 mg L^{-1} in Kot Chutta, Taunsa, and D. G. Khan tehsils, respectively (Table 2). The highest value of HCO_3^- was 459 mg L^{-1} found in L3, which is within the permissible limit of WHO (500 mg L^{-1}). The minimum HCO_3^- concentrations (22.36 ± 1.19 mg L^{-1}) were found in L25. The concentration of HCO_3^- in all the collected water samples were within the permissible limit of WHO (500 mg L^{-1}) for drinking water.

Table 2. Summary statistics for the chemical properties of the water samples from the studied area.

Parameters/Units	WHO Limits	Mean	Maximum	Minimum	S.D
Tehsil Kot Chutta					
pH	6.5–8.5	7.35	7.53	6.58	0.278
EC (dS m^{-1})	1	1.24	2.00	0.47	0.485
TDS (mg L^{-1})	500	371	646	209	128.3
Cl$^-$ (mg L^{-1})	250	84.34	145.83	36.16	41.64
HCO$_3^-$ (mg L^{-1})	500	200.48	278.56	22.36	75.56
Ca^{2+} (mg L^{-1})	200	18.53	28.55	10.34	5.641
Mg^{2+} (mg L^{-1})	150	21.08	27.00	14.00	4.119
SO$_4^{2-}$ (mg L^{-1})	250	197.7	432	24	14.32
Tehsil Taunsa					
pH	6.5–8.5	6.92	7.24	6.52	0.200
EC (dS m^{-1})	1	1.79	3.45	0.31	0.646
TDS (mg L^{-1})	500	611	985	348	184.92
Cl$^-$ (mg L^{-1})	250	47.14	77	15.16	17.24
HCO$_3^-$ (mg L^{-1})	500	150.46	237.9	38.63	47.21
Ca^{2+} (mg L^{-1})	200	32.89	63.44	18.55	13.57
Mg^{2+} (mg L^{-1})	150	36.78	56.00	22.55	9.645
SO$_4^{2-}$ (mg L^{-1})	250	131	256	24	5.754
Tehsil and District D. G. Khan					
pH	6.5–8.5	7.28	8.75	6.52	0.462
EC (dS m^{-1})	1	2.21	9.78	0.31	2.131
TDS (mg L^{-1})	500	476	985	105	223.4
Cl$^-$ (mg L^{-1})	250	67.53	156.33	15.16	40.74
HCO$_3^-$ (mg L^{-1})	500	186.15	459.33	22.36	82.45
Ca^{2+} (mg L^{-1})	200	25.35	63.44	10.34	12.33
Mg^{2+} (mg L^{-1})	150	28.02	70	10.22	14.21
SO$_4^{2-}$ (mg L^{-1})	250	111	324	2	31.65

Chloride is one of the most frequently found anions in tap water. It usually combines various salts, including calcium, magnesium, or sodium, e.g., sodium chloride (NaCl) is formed when sodium (Na) and chloride (Cl) are combined to create hard water. The mean concentrations of Cl$^-$ in the water samples was 84.34 ± 41.64, 47.14 ± 17.24, and 67.53 ± 40.74 mg L^{-1} in Kot Chutta, Taunsa, and D. G. Khan, respectively (Table 2). The highest concentration of Cl$^-$ was 156.33 ± 3.02 mg L^{-1} found in L13, and the lowest levels of 15.16 ± 7.71 mg L^{-1} were found in L19 and L33, which were within the permissible limits according to WHO standards (250 mg L^{-1}).

The mean concentration of Ca^{2+} in the collected drinking water samples were found to be 18.53 ± 5.64, 32.89 ± 13.57, and 25.35 ± 12.33 mg L^{-1} in the Kot Chutta, Taunsa, and D. G. Khan tehsils, respectively (Table 2). The maximum concentration of Ca^{2+} (63.44 ± 2.32 mg L^{-1}) in the drinking water samples was found in L28, and the minimum (10.34 ± 2.52 mg L^{-1}) was found in L17. All the Ca^{2+} concentrations were found within the recommended limit of WHO standards (200 mg L^{-1}) for drinking water.

The mean concentration of magnesium in the drinking water samples were 21.08 ± 4.11, 36.78 ± 9.64, and 28.02 ± 14.21 mg L^{-1} in the Kot Chutta, Taunsa, and D. G. Khan tehsils, respectively (Table 2). The maximum value of Mg^{2+} concentration was 70 ± 5.92 mg L^{-1}, found in L28, and lowest (10.22 ± 7.97 mg L^{-1}) was found in L35.

The mean concentration of sulfates in the drinking water samples were 111 ± 14.25, 131 ± 5.75, and 197 ± 31.65 mg L^{-1} in the D. G. Khan, Taunsa, and Kot Chutta tehsils, respectively (Table 2). The maximum value of SO$_4^{2-}$ concentration was 436 ± 7.72 mg L^{-1} in L46 (Kot Chutta), and the lowest (2 ± 4.59 mg L^{-1}) was found in L19 (D. G. Khan), which compared to WHO limit of 250 mg L^{-1}.

Water quality indices

Water Quality Index (WQI): The water quality index was classified according to the criteria described as, i.e., excellent 0–25, good 26–50, poor 51–75, very poor 76–100, and unfit for drinking >100. The results show that all the samples collected fell within the range of excellent and good quality water (Table 3).

Table 3. Summary of different water quality and hazard indices for the samples collected in the study areas.

Areas	Samples	Kelly's Ratio	Mg$^+$ Hazard	% Age Na$^+$	Drinking Water Quality Index		SAR
Tehsil and district Dera Ghazi Khan	L1	1.892	46.267	66.525	28.289	Excellent	14.297
	L2	0.061	46.854	10.397	31.960	Excellent	0.760
	L3	0.491	45.536	38.634	25.068	Excellent	3.347
	L4	0.533	45.323	41.048	48.711	Excellent	4.572
	L5	0.048	50.305	12.244	44.022	Excellent	0.537
	L6	0.188	44.265	24.052	36.854	Excellent	1.531
	L7	0.017	45.917	8.5343	33.977	Excellent	0.153
	L8	0.189	41.085	24.906	41.361	Excellent	1.700
	L9	2.073	48.162	73.937	67.866	Good	13.508
	L10	2.636	43.939	76.916	75.776	Good	19.484
	L11	0.048	45.464	10.292	70.597	Good	0.415
	L12	0.642	44.125	42.851	59.315	Good	5.056
	L13	0.520	52.195	38.274	83.571	Good	8.292
	L14	0.258	44.109	34.277	91.760	Good	2.692
	L15	0.011	50.386	7.546	53.194	Good	0.085
	L26	0.218	51.659	20.652	13.573	Excellent	2.192
	L44	0.014	55.075	12.144	32.314	Excellent	0.161
	L45	0.023	54.968	17.610	40.017	Excellent	0.228
	L46	0.408	64.263	34.864	17.105	Excellent	3.283
	L47	0.265	66.863	26.079	10.345	Excellent	2.677
	L48	0.347	63.906	30.590	11.211	Excellent	3.230
	L49	0.071	54.953	10.811	9.6582	Excellent	0.791
	L50	0.198	58.866	19.901	17.474	Excellent	2.198
Taunsa	L27	0.150	53.427	17.760	12.770	Excellent	1.550
	L28	0.158	52.980	21.766	22.884	Excellent	1.594
	L29	0.149	52.458	15.297	24.555	Excellent	2.448
	L30	0.116	52.419	16.870	7.175	Excellent	1.247
	L31	0.218	54.866	21.414	11.115	Excellent	1.985
	L32	0.076	57.317	11.197	23.804	Excellent	0.781
	L33	0.010	59.509	6.299	14.324	Excellent	0.104
	L34	0.054	54.377	9.808	26.673	Excellent	0.807
	L35	0.185	59.563	22.073	27.596	Excellent	2.277
	L36	0.257	57.306	25.902	31.737	Excellent	3.046
	L37	0.117	53.048	17.101	39.929	Excellent	1.816
	L38	0.135	50.824	20.620	44.183	Excellent	1.803
	L39	0.103	52.230	20.528	31.977	Excellent	1.113
	L40	0.180	62.671	17.825	26.732	Excellent	1.901
	L41	0.140	56.614	21.097	35.030	Excellent	1.677
	L42	0.088	53.416	18.746	32.611	Excellent	0.938
	L43	0.193	52.087	21.285	35.069	Excellent	2.636
Kot-Chutta	L16	0.225	50.723	30.171	55.102	Good	2.326
	L17	0.231	52.585	33.973	50.463	Good	2.041
	L18	0.213	56.089	31.645	36.385	Excellent	1.601
	L19	0.168	51.976	24.411	44.618	Excellent	1.834
	L20	0.410	57.518	33.930	26.900	Excellent	2.866
	L21	0.331	57.663	36.706	48.358	Excellent	2.820
	L22	0.372	54.752	38.012	52.443	Good	3.557
	L23	0.488	51.546	36.294	27.332	Excellent	4.192
	L24	0.477	56.915	41.750	45.519	Excellent	4.147
	L25	0.022	56.704	11.841	31.652	Excellent	0.211

Sodium adsorption ratio (SAR): The value of SAR ranging from 0–10 is commonly used to denote water which is safe for drinking purposes. Using this value, we can calculate the relative proportions of Na^+ to Ca^{2+} + Mg^{2+}. The maximum SAR of 19.48 was found in L10, while a minimum of 0.08 was observed for L15.

Kelly's ratio (KR): Kelly's ratio is a measure of Na^+ in the water. Water with less than 1 Kelly's ratio is consider suitable, whereas a value greater than 1 points to high Na^+ in the water. The maximum Kelly's ratio was found in L10 (2.63), while L33 showed the minimum value of 0.0108.

Percentage sodium (%Na^+): The occurrence of high concentrations of Na^+ in the water are commonly linked with saline soil formation. In the sampling areas, the minimum of 6.29% Na was found in L33 and the maximum of 76.91 in L10.

Magnesium hazard (MH): It is another type of water quality index which evaluates the extent of destruction of soil structure due to Mg^{2+} in irrigational water as high Mg^{2+} in water reduced the infiltration capacity of soil. In our study, 41.08 MH was found in L8, while 66.86 was found in L47.

Pathogenic *E. coli* in drinking water: There are many species of bacteria which are pathogenic to humans and negatively affects drinking water quality. Water samples (n = 50) collected from different locations were subjected for microbial analysis. The results showed that 9 (18% samples) out of 50 water samples were contaminated with *E. coli* It means that these water samples are not fit for drinking purposes. Samples which were *E. coli* positive belonged to L2, L6, L8, and L11 in D. G. Khan; and L16, L17, L19, L22, and L23 in Kot Chutta, while *E. coli* was not detected from Taunsa (Table 4). WHO has recommended that there should not be the presence of E. coli in drinking water to be safe from water borne diseases like diarrhea and hepatitis.

Table 4. Summary of pathogenic E. coli in drinking water samples (n = 50) in D.G. Khan District.

Sample ID	*E. coli* Test	No. of Patients	Sample ID	*E. coli* Test	No. of Patients
L1	-	31	L26	-	00
L2	+	64	L27	-	18
L3	-	23	L28	-	38
L4	-	33	L29	-	23
L5	-	37	L30	-	49
L6	+	51	L31	-	19
L7	-	30	L32	-	54
L8	+	53	L33	-	24
L9	-	09	L34	-	23
L10	-	23	L35	-	07
L11	+	44	L36	-	09
L12	-	02	L37	-	02
L13	-	17	L38	-	48
L14	-	00	L39	-	37
L15	-	00	L40	-	36
L16	+	69	L41	-	16
L17	+	68	L42	-	38
L18	-	23	L43	-	19
L19	+	54	L44	-	11
L20	-	31	L45	-	12
L21	-	19	L46	-	32
L22	+	48	L47	-	00
L23	+	37	L48	-	16
L24	-	27	L49	-	21
L25	-	12	L50	-	21

Impacts of microbial water contamination on local's health: The results of the microbiological testing of drinking water samples depicted that the groundwater in 9 areas, i.e., L2, L6, and L11 in D. G. Khan and L16, L17, L19, L22, and L23 in Kot Chutta were polluted

with *E. coli.* From the study area, data from a total of 1378 patients was retrieved from the hospital. We collected data of the patients who were living in the sites from where we collected samples so that exact figures regarding the human health impacts of pathogenic *E. coli* could be assessed. Of the 1378 patients, 530, 388, and 460 patients were from the D. G. Khan, Kot Chutta, and Taunsa tehsils, respectively. Supplementary Table S1 shows the overall summary of the demographic and human health impacts in the form of hepatitis (A, B, C).

4. Discussion

Descriptive statistics such as mean, minimum, and maximum value, standard deviation, and standard error of water quality parameters were computed and compared with the WHO drinking water guidelines [30] (Table 3). The water samples showed slightly higher salts concentrations (EC and TDS), with EC value of 1.24, 1.79, and 2.21 dS m^{-1} in three respective areas, while TDS = 611 mg L^{-1} in Taunsa. The EC value in 25% of the samples surpassed the WHO safe limit value for drinking water, and elevated levels can disturb the mucous membrane in humans [31]. All the other parameters under study were found to be within the limits prescribed by WHO (Table 3). Chloride is a significant major anion which is present in drinking and groundwater and which arises from geogenic and anthropogenic sources, such as rocks weathering [32], soil erosion [33], deposition from the atmosphere [34], the use of fertilizers, and industrial and municipal effluents [35]. The mean Cl$^-$ concentration (84.34, 47.14, and 67.53 mg L^{-1}, in the respective areas) was detected as below the recommended (250 mg L^{-1}) WHO guideline. Higher levels of Cl$^-$ ions in drinking water are not dangerous to humans, but these results shows the extent of presence of the salts [36]. The mean values of HCO$_3$$^-$ were found to be 200, 150, and 186 mg L^{-1} in the Kot Chutta, Tehsil Taunsa, and D.G Khan regions, which were well below the WHO guideline (500 mg L^{-1}), as shown in Table 3. Again, HCO$_3$$^-$ levels do not pose any significant health risks to humans [37,38]. However, their over concentration decreases the water quality. The EC levels and the dominance of anions were in the order of EC > Cl$^-$ > HCO$_3$$^-$. The average concentrations of Ca^{2+} and Mg^{2+} in all areas were found within the range prescribed by WHO (Table 3). Both Ca^{2+} and Mg^{2+} are important nutrients and are required for the proper functioning of the human body. These minerals originate from the dissolution of carbonate (CO^{3-}) minerals and dolomite rocks [39,40]. Sodium and K$^+$ generally originate from dissolution of clay minerals and the evaporation of silicates [41]. The order of abundance of Ca^{2+}, Mg^{2+}, Na$^+$, and K$^+$ was recorded as Ca^{2+} > Mg^{2+} > Na$^+$ > K$^+$. Anthropogenic activities, such as agriculture and the industry, in close proximity to streams, rivers, and canals, can severely contaminate water, and this problem is exacerbated in highly populated areas, particularly in unplanned urban cities. The concentration of physicochemical parameters compared with WHO guidelines are presented in Table 3 of the present study.

Data generated from the studied parameters was subjected to calculation of the water quality indices, i.e., SAR, RSC, Kelly's ratio (KR), percentage of sodium (%Na$^+$), and magnesium hazard (MH) [42]. The increased RSC values were due to the surrounding anthropogenic activities, which supplied contaminants and resulted in higher RSC and KR values [9]. Water having RSC value < 1.25, 1.25–2.5 and >2.5 mmolc L^{-1} is categorized as good, doubtful, and unfit for human consumption, respectively [9]. Just two locations, L25 and L33, were found to have an RSC value ≤ 1.25 mmolc L^{-1}, i.e., −7.48 and −22.31. Residential areas near the sampling site and leakage of municipal sewage water might be the reason for high RSC and KR values in the samples [43]. The SAR is the relative proportion of Na$^+$ over Ca^{2+} + Mg^{2+} and is computed for its use as a WQI calculation. A maximum value of SAR of 19.48 was found in L10, and the minimum of 0.085 was found in L15. Drinking water is consider excellent when its SAR value is in the range of 0–10. Except for three samples (L1, L9 and L10), all the rest of the samples fall in the safe range. Possibly, municipalities and sewage water delivered Na$^+$ and CO$_3$$^{2-}$ to the groundwater, as well as the drinking water [44].

Correlation between chemical properties and water quality indices: The interrelationship between the studied parameters and their relationships between the secondary parameters were calculated (Table 5). There was a significant relationship between the physicochemical properties and the secondary parameters. The Na had a strong relationship with Mg (R^2 = 0.080), Cl had strong relation (R^2 = 0.029) with SO_4, Ca had strong relation (R^2 = 0.020) with HCO_3, SO_4 (R^2 = 0.088), and Mg (R^2 = 0.040). Secondary parameters, i.e., TDS, had a strong relationship with MgH (R^2 = 0.039) and WQI (R^2 = 0.009), as seen in Table 5.

Table 5. Pearson's correlation coefficient among chemical properties and water quality indices.

	pH	EC	TDS	Cl	HCO₃	Ca	Mg	Na	K	SO₄	KR	SAR	RSC	MgH	%Na	WQI
pH	1															
EC	0.169	1														
TDS	−0.111	−0.136	1													
Cl	0.119	0.562	−0.289	1												
HCO₃	0.147	0.447	−0.140	0.619	1											
Ca	−0.119	0.051	0.898	−0.086	**−0.020 ***	1										
Mg	−0.346	−0.054	0.863	−0.117	−0.154	0.922	1									
Na	0.145	0.916	**−0.088 ***	0.584	0.440	0.101	0.037	1								
K	0.081	0.519	0.100	0.344	0.107	0.189	0.104	0.511	1							
SO₄	−0.088	0.185	−0.079	**0.029 ***	0.156	**−0.088 ***	**−0.04 ***	0.177	−0.078	1						
KR	0.114	0.852	−0.448	0.531	0.449	−0.29	−0.35	0.846	0.453	0.170	1					
SAR	0.128	0.902	−0.336	0.567	0.461	−0.161	−0.230	0.933	0.486	0.174	0.980	1				
RSC	0.208	0.417	−0.393	0.606	0.956	−0.305	−0.432	0.388	0.056	0.163	0.514	0.487	1			
MgH	−0.590	−0.354	**0.039 ***	−0.114	−0.387	−0.069	0.303	−0.224	−0.204	0.099	−0.301	−0.281	−0.399	1		
%Na	0.203	0.767	−0.485	0.595	0.499	−0.351	−0.413	0.808	0.516	0.160	0.906	0.906	0.578	−0.255	1	
WQI	0.695	0.500	**0.009 ***	0.271	0.164	0.092	−0.118	0.445	0.685	−0.119	0.357	0.398	0.159	−0.541	0.432	1

*: Figures in bold show significant correlation, $p < 0.05$.

Microbiological pollution of the water samples: the pollution of drinking water through the existence of antibiotic resistant bacteria, i.e., *E. coli*, increases the risks to human health. It can cause life threatening diseases, including different types of hepatitis, which affect the human liver and its capacity for detoxification and blood production [45]. In the present study, we assessed the drinking water quality, along with the prevalence of *E. coli*, in the drinking water of the D. G. Khan region. The existence of coliform and *E. coli* in water samples collected from Peshawar, Pakistan [46], and Bangladesh [47] were also reported previously. The detection of *E. coli* in water samples is an indication of fecal pollution and the possible existence of pathogenic microbes [18], and the use of such water sources for drinking water should be avoided [47,48]. In the study site, the influx of fecal pollution may have been due to rainfall, as the feces of domestic animals and contaminated soils are easily washed into rivers by rain, leading to an increase in *E. coli* contamination. In the dry season, less rainfall in the study area may reduce the dilution effect of contaminated water, causing a higher level of organic pollution. Except for pH, EC, and *E. coli*, the physicochemical parameters of all the collected samples met the WHO standards for drinking water. *E. coli* is commonly present in the gastrointestinal tracts of humans, and its presence in external environments is an indication of fecal contamination [49]. This niche specificity justifies its use as an indicator of fecal contamination in the environment, where it can persist and grow. The survival of *E. coli* bacteria in the water is largely dependent on its physicochemical properties [50]. The entry of *E. coli* into the drinking and groundwater is also due to the leakage from sewage drains and sewage water pipes [11,51,52]. From the collected samples, 9 (18%) of the total (n = 50) samples were contaminated with *E. coli*, which could pose serious human health hazards, such as diarrhea, impaired growth in children, hepatitis, and other stomach-related issues [53,54].

5. Conclusions

After the physicochemical analysis, it was concluded that only pH and EC of the collected samples from some areas exceeding WHO's acceptable limits for drinking water. From the total collected samples (n = 50), only 4% (1 sample) in the D. G. Khan area exceeded pH range, while 78% of samples in D. G. Khan, 50% of samples in Kot Chutta, and 94% of samples in Tehsil Taunsa exceeded the WHO limits for pH (6.5–8.5). Based on the water quality indices, 6% of the water samples exceeded the SAR and KR values. In

terms of bacteriological parameters, a total of 18% (17% in D. G. Khan and 50% of samples in Kot Chutta) of collected drinking water samples showed positive results for pathogenic *E. coli* bacteria. The ratio of hepatitis patients was noted high, as data from the hospitals showed that there are 1378 total hepatitis patients in the three study areas. All of the patient data was from a single year (2021, when study was performed, and the data was also collected only for the same year), and the patients were infected with either hepatitis A, B, or C. Based on the results, it was concluded that the quality of the groundwater is not fit for drinking purposes, and the natives living in these areas should use filtered water instead of groundwater because of its contamination and possible human health risks, such as hepatitis.

As this study is a first attempt to highlight the water-related disease problems in the study area, we only focus on the water quality of a specific season (summer) and the associated health risks by collecting 1 year of health data from the hospital. Thus, more precise and accurate studies could be conducted by taking seasonal variability into account and using site-wide patient data for more accurate results.

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