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ASSESSING GROUNDWATER QUALITY DYNAMICS UNDER CLIMATE-INDUCED CHANGE BY RAINFALL AND TEMPERATURE PATTERNS: A COMPARATIVE STUDY OF WATER QUALITY SHIFTS OVER PAST DECADE IN MULTAN AND BAHAWALPUR, PUNJAB

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Abstract

Ground water is polluting since long ago. Changing climate with less rainfall and increasing evaporation is crucial to long term water quality in arid regions. To assess hydro-chemical properties of Multan and Bahawalpur, ten years (2014-2024) ground water quality data along with temperature and rainfall was noted. In this study ground water samples were taken from various areas of Multan and Bahawalpur and analyzed for pH, electrical conductivity (EC), total dissolved solids (TDS), calcium (Ca^{2+}), Magnesium (Mg^{2+}), potassium (K^+), sodium (Na^+), bicarbonates (HCO_3^-), sulphate (SO_4^{2-}), chloride (Cl^-), nitrate (NO_3^-), fluoride (F^-), microbial activity (T. coliform & E. coli) and heavy metal (As, Cd, Cr & Fe). Results obtained from analysis suggest that water is enriched with dissolved solids along with increased HCO_3^- and SO_4^{2-} govern by weathering of rocks and anthropogenic activities. Major water type in Multan is Na^{2+}-Ca^+ while in Bahawalpur water type is HCO_3^--SO_4^{2-}. Piper plot also describe mixed water type in Multan and bicarbonate-sulphate type usually predominant by water-rock interaction, evaporation and anthropogenic activities. Heavy metal concentration in ground water samples is directly connected to industrial effluents produces from industries leach down to ground water aquifers. Water Quality Index (WQI) of both cities also indicates hazardous nature of ground water sampled from all sampling sites. Ground water of both cities therefore require strict monitoring with tangible evidence of reducing fertilizers application as well as installation of water purification plants to purify ground water for better public health.

Keywords: Ground water quality, Hydro-chemical properties, Multan, Bahawalpur

Introduction:

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Decrease in ground water quality and quantity is escalating around the globe due to over-exploitation, addition of contaminants and climate change. Many developing Asian countries like China, India, Pakistan, Bangladesh and Sri Lanka are viewing urbanization and industrialization coupled with climate change greatly affect ground water usage pattern (Vivek et al., 2024). In arid to semi-arid regions limited surface water and precipitation leads to over use of ground water for domestic, industrial and irrigation purposes. Over-exploitation of ground water resources in arid to semi-arid regions lack economic development and poses significant challenges to associated factors like education, health and agriculture. Ground water therefore, is of prime importance as it became critical under the influence of climate change (Dao et al., 2024). According to European Environmental Agency 2019, the emission of carbon dioxide into atmosphere has been recorded by 407.58 ppm increasing global temperature by 0.08 ºC per decade.

Ground water is the major component of natural hydrological cycle which receives water from percolation and surface runoffs from rivers, canals and lakes while in the same time it also discharge through evaporation, evapotranspiration and seepage. Climate change greatly affects land use efficiency which leads to improper use of ground water. Extreme weather events due to increasing temperature cause storms, typhoons, flood and drought which affect water quality (Lasagna et al., 2020). A very well established linkage between ground water quality and climate change is not known until yet which affect current water availability and future sustainability. However anthropogenic activities under the influence of climate change may exert pressure by disturbing the hydrological cycle due to land use, less precipitation and characteristics of soil (Andrei et al., 2021). Under such prevailing condition metrological drought is inevitable where ground water exploitation increases with decrease in its recharge by affecting its quality. Role of climate change in recharge of ground water aquifers is crucial for proper management of such useful resource. Added water in aquifers might contain dissolved ions and salts having ability to alter water chemistry. Health related disorders such as hypertension, cardiovascular diseases, skeletal and dental fluorosis were due to high concentration of dissolved ions in ground water (Barbieri et al., 2019).

Aforementioned factors confirmed that ground water quality may alter under changing climate. Current study is therefore a preliminary step towards the change in ground water quality over the

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period of time (2014-2024) in context to climate change in Multan and Bahawalpur, Punjab, Pakistan.

Material and methodology

Study area

Multan (29.3544º N 71.6911º E) and Bahawalpur (29.3544º N 71.6911º E) are two major cities of South Punjab, Pakistan with population of 2.20 million and 0.90 million, respectively. Climatic conditions are arid to semi-arid with mean annual rainfall 175 and 143 mm, respectively. Nearby rivers in both cities were not flown for decades except monsoon season. Ground water is therefore recharge by industrial effluents and sewage water.

Mean temperature, rainfall and ground water quality data

Chemical and physical ion concentration of ground water of Multan and Bahawalpur, Punjab, Pakistan between 2014 and 2024 was provided by Pakistan Council of Research on Water Resources (PCRWR). Mean average temperature and rainfall was available on Open Weather website (https://openweathermap.org/). Metrological data regarding precipitation was also collected by World Weather Online website (https://www.worldweatheronline.com/).

Ground water sampling

Ground water samples were collected from five separate areas (five samples from each location) with different water use pattern, demography, living standards, sanitation and infrastructure. Sampling points were within the range of 500 meters in specific coordinates. Bore-hole pump was running for 5 minutes prior to sampling and collected in pre sterilized 1 liter plastic bottles. pH, EC and TDS were recorded at sampling site and coordinate was noted giving in table 1.

Table 1. Coordinates of different locations for water sampling in Multan and Bahawalpur, Punjab, Pakistan

Multan		**Bahawalpur**	
Location	**Coordinate**	**Location**	**Coordinate**
Ismailabad	30.1297º N 71.3530º E	**Muhajir colony**	29.3820º N 71.7205º E
Samejabad	30.1988º N 71.5375º E	**Sadiq colony**	29.3824º N 71.6598º E
Gulgasht colony	30.2258º N 71.4745º E	**Trust colony**	29.3890º N 71.6790º E
Shah Shams colony	30.1675º N 71.4806º E	**Satellite Town**	29.3908º N 71.7092º E

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Writes colony	30.1991º N 71.4938º E	**Model Town**	29.3930º N 71.6596º E

Water quality assessment, microbial and heavy metal analysis

Ground water samples were collected from both cities to assess the current water contamination level. pH of ground water samples was noted by pH meter (Model: Mi-150) fitted with temperature sensor and calibrated with potassium chloride solution. Concentration of dissolved solids and hardness level was also calculated by using electrical conductivity (Model: 3100C). Cations like Ca^{2+}, Na^{2+} & K^{+} was measured by flame photometer (Model: BWB XP technologies) by adapting specific procedure. Mg^{2+} was calculated by colorimetric method in spectrophotometer (Model: CE7400S). Among anion HCO_3^- was recorded by titrimetric method. NO_3^-, F^- and SO_4^{2-} were noted by running in spectrophotometer at wavelength 229, 570 and 420 nm, respectively. Cl^- was recorded by titrating sample against 0.2N silver nitrate ($AgNO_3$) in potassium chromate (K_2CrO_4) indicator. All physiochemical analysis was done according to the American Public Health Association procedures (Greenberg et al., 2005). Heavy metal (As, Cd, Cr & Fe) concentration in ground water was noted by Atomic Absorption Spectrophotometer (ASS) (Model: Agilent technologies AAS 200, USA). A blank and standard solution was also run along with sample to set a reference for analytical recording. Microbial concentration (T. coliform & E. coli) was noted by filtering water through membrane having size 0.45 µm and incubate for 48 hrs at 37º C. Colony Forming Unit (CFU) were recorded in colony counter (Forbes et al., 2007). Piper plot and Principle Component Analysis (PCA) were used to find out geochemical particulars of ground water.

Water quality index

Water quality index was assessed by computing results into following equation;

$$WQI = \sum_{i=1}^{n} Qi$$

Where; n is the number of samples, i is parameter range and Qi is relative measure of water specific to parameter.

Results

Yearly temperature, rainfall and water data of Multan & Bahawalpur

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Figure 1 indicates yearly temperature and precipitation data in two major cities of South Punjab (Multan & Bahawalpur). Mean annual temperature ranges between 24.1ºC-28.33ºC in Multan while 24.47ºC-27.93ºC in Bahawalpur. Mean precipitation rate in the similar time was also recorded between 158.1-314.7 mm in Multan while 121 and 243.3 mm in Bahawalpur. Overall change in temperature and rainfall pattern between year 2014 and 2024 varies due to changing climate. Table 2 suggests ground water quality of both cities between 2014-2024. Remarkable change in ground water is observed by the passage of time where microbial concentration remains constant and cationic and anionic attributes increases in Multan. Heavy metal (Fe, As, Cr, Cd) also gives varied concentration where increasing trend for Cr and Fe was noted. A similar variation in ground water data of Bahawalpur was observed. Nitrate, fluoride and chromium ions were not detected between years 2014/15/16. However, concentration of cations and anions in the vicinity of Bahawalpur increases by time. EC and TDS is the major factor in the soils of Bahawalpur which also increases by time. Microbial concentration remains constant throughout the decade.

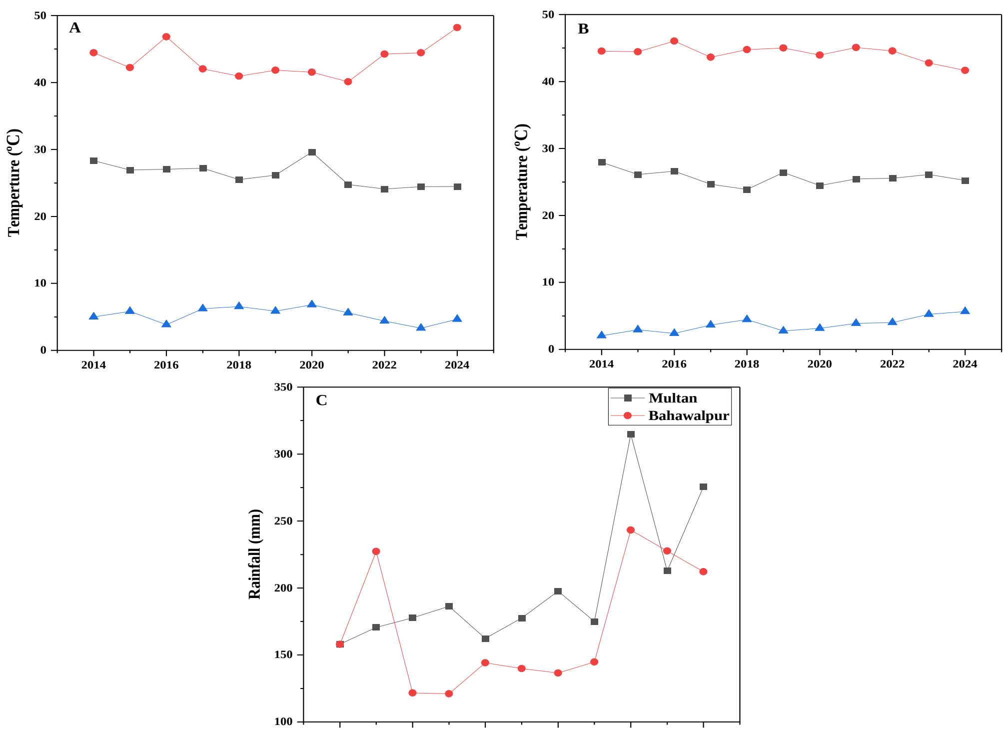

Figure 1. Yearly temperature (a) Multan (b) Bahawalpur and (c) rainfall data. Source:

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Metrological department of Pakistan and weather websites. In A & B red line indicate maximum temperature, blue line is minimum temperature and black line is mean annual temperature.

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Multan	pH	EC (µS cm^{-1})	TDS (mg/L)	Hardness (mg/L)	SO_4^{2-} (mg/L)	F^- (mg/L)	HCO_3^- (mg/L)	Cl^- (mg/L)	NO_3^- (mg/L)	Mg^{2+} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Ca^{2+} (mg/L)	Total Coliform (CFU)*	E. coli (CFU)*	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Fe (mg/L)
2014	7.2	881	987.5	104	89	N.D	322	21.97	N.D	11.5	250	6	40	11	2	0.09	0.03	0.041	0.16

Table 2. Yearly ground water data of Multan, Punjab, Pakistan

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2015	7.32	829	956.3	98.5	94.3	N.D	327.5	21.56	0.032	10.3	247.5	17	67.3	29	14	0.09	0.023	0.044	0.16
2016	7.15	895	1001.5	125	77.4	N.D	384.7	23.42	N.D	9.2	252.3	14.5	27.6	33	10	0.08	0.017	0.026	0.2
2017	7.24	942	1187.7	183	72.1	0.12	397.6	25.24	0.035	15.5	269.7	11.01	33.4	39	12	0.05	0.001	0.048	0.11
2018	7.39	1165	946.7	327.8	97.4	0.27	412	36.3	0.056	26.2	245.2	10.4	87.5	36	11	0.15	0.029	0.083	0.15
2019	7.44	883	1146.5	252.5	94.7	0.31	322	34.2	0.052	13.6	256.3	8.5	63.5	32	16	0.09	0.032	0.075	0.17
2020	7.87	995	1098	222.3	91.2	0.38	316	29.4	0.05	17	263.5	7.9	58.2	26	15	0.08	0.035	0.075	0.27
2021	7.82	1386	1045	259	85.2	0.54	301.5	40	0.03	32.5	250	8.5	55	19	10	0.1	0.041	0.078	0.32
2022	7.48	1450	1141.5	255	77.5	0.93	312	38	0.073	30.56	239.5	9.1	45.5	23	8	0.15	0.032	0.068	0.39
2023	7.92	1329	1200.1	267.5	75.5	1.05	376	44.2	0.95	30.12	276.4	10	42.6	20	19	0.11	0.046	0.077	0.35
2024	7.53	1224	1304.5	258.5	77	1.11	362	34.24	1.04	29.45	265.3	12.01	41.5	22	21	0.09	0.027	0.073	0.42

Source: PCRWR water quality reports, *** CFU** = Colony Forming Unit

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Bahawalpur	pH	EC (µS cm^{-1})	TDS (mg/L)	Hardness (mg/L)	SO_4^{2-} (mg/L)	F^- (mg/L)	HCO_3^- (mg/L)	Cl^- (mg/L)	NO_3^- (mg/L)	Mg^{2+} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Ca^{2+} (mg/L)	Total Coliform (CFU)*	E. coli (CFU)*	As (mg/L)	Cd (mg/L)	Fe (mg/L)
2014	8.03	4630	3295.5	134	69.9	N.D	233.6	121	N.D	11.5	248	21	90	94	80	0.06	N.D	0.34
2015	8.19	5204	3865.5	172	52.5	0.45	235.2	135	N.D	11.2	256	17.5	105	104	73	0.05	N.D	0.39
2016	8.05	3629	2966.1	207	49.4	N.D	299.2	92.4	N.D	12.4	247.8	10.5	101	107	86	0.02	N.D	0.21
2017	7.4	4488	2546	229	52.4	N.D	289.5	90.1	0.002	9.3	268.4	26.3	150	104	90	0.005	0.0002	0.13
2018	7.82	4219	2281.5	289	74.3	0.32	219.4	106	0.01	14.7	232.5	12.6	100	101	87	0.07	0.001	0.3
2019	7.96	4727	2470.4	219.3	66.5	0.37	243.6	128	N.D	15.4	263.1	13.7	60.2	95	81	0.01	0.0014	0.33
2020	8.00	4875	2728.8	289.7	70	0.89	241.7	112	N.D	21.1	259.7	17.1	150	107	89	0.06	0.002	0.42
2021	7.99	4022	3001.5	295	72.6	1.04	261.5	108	0.016	30.5	273.7	14.8	129	100	82	0.072	0.005	0.45
2022	7.67	3856	3023.4	272	66.5	1.01	231	100	0.031	32.9	229.5	11.9	147	103	87	0.065	0.0055	0.49
2023	8.32	3543	3523.8	276.5	62.3	1.05	277	94.5	0.029	35.6	263.5	11.6	148	100	93	0.89	0.0061	0.51
2024	8.21	3255	3789.5	252.5	61.3	1.12	262	72.2	0.12	35.4	255.7	11.8	137	101	89	0.46	0.0058	0.46

Table 3. Yearly ground water data of Bahawalpur, Punjab, Pakistan

Source: PCRWR water quality reports, *** CFU** = Colony Forming Unit

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Physiochemical properties of ground water samples

Physiochemical properties of ground water samples from Multan and Bahawalpur were given in table 4 & 5. pH, EC and TDS are the most basic parameter to identify the usage pattern and quality of ground water as their concentration in drinking water must be 6.5-8.5, <400 µS cm^{-1} and <1000 mg/L according to WHO. Analyzed data exhibit that mean of total ground water samples collected from both cities, pH is in the range of 7.49-7.85 and 7.55-7.75 while EC is in the range of 1556-2751 µS cm^{-1} and 2007-3958 µS cm^{-1} and TDS is 2274-2617 mg/L and 3119-3584 mg/L in Multan and Bahawalpur, respectively. Frequency distribution is so that only 20% sample is in the range of pH 7-7.5 while 80% samples were above pH 7.5 in Multan while 100% samples were above pH 7.5 in Bahawalpur. EC of 40% samples were below 2000 µS cm^{-1} while 60% samples exhibit EC higher than 2000 µS cm^{-1} in Multan. 40% samples of ground water have EC less than 2500 µS cm^{-1} in Bahawalpur while 60% have EC greater than 3000 µS cm^{-1}. TDS on the other hand also gives similar trend where 60% samples were less than 2500 mg/L and 40% where above this concentration in Multan. In Bahawalpur only 20% samples were above 3500 mg/L and 80% samples were less than this concentration. Ground water hardness in both cities was in the range of 352-356 mg/L and 334-709 mg/L. 40% samples from both cities were well above the recommendations of WHO.

Major cation and anion in both cities were well below the recommended concentration except for sulphate and bicarbonates where its concentration in selected areas surpasses the concentration. High concentration of sulphates in some water samples indicates change in the taste of water sample to bitter. High bicarbonate concentration in some water samples from both cities also suggests its unsuitability for drinking purpose. 40% water sample from Multan and 20% samples from Bahawalpur were beyond WHO limitation for SO_4^- concentration. 40% ground water sample from both cities also surpasses maximum HCO_3 concentration according to WHO. In total a mixed concentration of anions and cations was largely distributed over selected study area and not restricted to a specific area.

Total coliform & E.coli in all study areas of both cities were found. Usually, ground water samples collected from various areas of Multan exhibit less microbial concentration then the Bahawalpur. Mean value for Total coliform found in the ground water samples of Multan is only 17 CFU which on the other hand in Bahawalpur increases by 29 CFU. Similar trend was also

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noted in case of E. coli where mean value for ground water samples of Multan city is only 16 CFU which in Bahawalpur is 87 CFU. Addition of sewage water into ground water is the prominent reason which increases by the passage of time.

Heavy metal (As, Cd, Cr & Fe) in ground water samples collected from various locations of both cities also enhances. Since most of the ground water samples from both cities give varied heavy metal concentration therefore its consumption for long time may be lethal to human health. High concentration of heavy metal in different ground water samples is due to the presence of different soil minerals like aluminum and molybdenum into water which increases pH and microbial activity. Among all chromium is not detected in any ground water sample collected from Bahawalpur which might suggest its anthropogenic origin in ground water samples of Multan.

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Sampling Sites	pH	EC (µS cm^{-1})	TDS (mg/L)	Hardness (mg/L)	SO_4^{2-} (mg/L)	F^- (mg/L)	HCO_3^- (mg/L)	Cl^- (mg/L)	NO_3^- (mg/L)	Mg^{2+} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Ca^{2+} (mg/L)	Total Coliform (CFU)*	E. coli (CFU)*	As (µg/L)	Cd (µg/L)	Cr (µg/L)	Fe (µg/L)

Table 4. Physiochemical analysis of ground water of Multan city, Punjab, Pakistan

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Ismailabad	7.60	2555	2394	360.4	78.5	0.88	241.92	160.78	0.81	17	69	6.26	33	20	14	8.69	4.25	4.90	2.96
Samejabad	7.64	1556	2506	502	180.8	0.79	253.08	151.2	0.51	27	67.9	4.47	29	17	19	13.39	5.53	4.17	3.67
Gulgasht colony	7.85	2304	2283	381.6	185.5	0.39	356	135.8	0.83	41	130.2	5.61	42	14	16	17.47	3.97	5.95	1.86
Shah Shams colony	7.66	1615	2274	352.4	312.9	0.73	483.42	107.1	0.45	38	81	6.06	39	20	16	16.51	3.69	5.31	2.53
Writes colony	7.49	2751	2616	566.4	478.9	1.72	580.14	143.7	1.06	32	127.1	9.31	51	17	15	17.68	3.65	4.72	2.21
Maximum	7.85	2751	2616	566.4	378.9	1.72	580.14	160.7	1.06	41	130.2	9.31	51	20	19	17.68	5.53	5.95	3.67
Minimum	7.49	1556	2274	352.4	78.5	0.39	241.92	107.1	0.45	17	67.9	4.47	29	14	14	8.69	3.65	4.17	1.86
Mean	7.65	2156	2415	432.56	227.3	0.90	382.91	139.72	0.73	31	95.04	6.34	38.8	17	16	14.75	4.22	5.01	2.65
Standard Deviation	0.13	544.7	147	96.13	118.7	0.49	147.02	20.43	0.25	9.51	31.13	1.80	8.5	2.51	1.87	3.8	0.77	0.67	0.70

***CFU =** Colony Forming Unit

Table 5. Physiochemical analysis of ground water quality of Bahawalpur city, Punjab, Pakistan

Sampling Sites	**pH**	**EC (µS cm^{-1})**	**TDS (mg/L)**	**HD (mg/L)**	**SO_4^{2-} (mg/L)**	**F^- (mg/L)**	**HCO_3 (mg/L)**	**Cl^- (mg/L)**	**NO_3^- (mg/L)**	**Mg^{2+} (mg/L)**	**Na^+ (mg/L)**	**K^+ (mg/L)**	**Ca^{2+} (mg/L)**	**T. coliform (CFU)**	**E. coli (CFU)**	**As (µg/L)**	**Cd (µg/L)**	**Fe (µg/L)**

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Muhajir colony	7.71	3513	3189	709.2	868.7	1.39	551.1	148.3	0.79	63	146.8	8.46	200	117	95	8.27	3.08	0.67
Sadiq colony	7.76	3957	3584	702	80.35	1.66	682.5	147.3	1.05	62	136.5	12	152	140	83	7.37	3.35	1.33
Trust colony	7.72	3055	3119	412.2	83.06	1.17	238.9	94.7	0.66	49	166.2	8.21	145	103	88	9.65	3.13	1.84
Satellite Town	7.74	2006	3454	367	49.32	0.66	451.9	109.6	0.82	46	130.8	9.66	124	131	86	7.76	2.91	0.66
Model Town	7.55	2143	3341	334.2	171.1	1.48	446.1	156.9	0.7	48	158.9	11.1	117	155	85	9.64	4.1	3.44
Maximum	7.76	3957	3484	709.2	868.8	1.66	682.5	156.9	1.05	63	166.2	12	200	155	95	9.64	4.1	3.44
Minimum	7.55	2006	3119	334.2	49.32	0.66	238.9	94.7	0.66	46	130.8	8.21	117	103	83	7.37	2.91	0.66
Mean	7.70	2935	3337	504.9	250.5	1.27	474.1	131.3	0.8	53	147.8	9.9	147	129	87	8.54	3.31	1.59
Standard Deviation	0.08	849	189.6	185.2	348.5	0.38	162.7	27.4	0.15	8.2	14.83	1.67	32.6	20.13	4.62	1.06	0.47	1.15

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Major water type in ground aquifers of Multan and Bahawalpur

Major water type in selected areas of Multan (Figure 2A) is classified into calcium-magnesium type, sodium-calcium type along with few samples were dominated by bicarbonate-chloride type. Ground water type of collected water samples from different areas of Multan suggest predominance of calcium, magnesium and bicarbonate ions often associated to limestone and carbonate rich rocks. Bicarbonate is the only predominant anion in water samples of Multan while sulphate and chloride ions are less abundant therefore it is mixed fresh water type and may alter by limestone present around aquifers. Major water type in selected areas of Bahawalpur is given in figure 2B. Results suggest that ground water is predominant by sodium-potassium type and sulphate ion. If Mohajir colony shifted more towards sulphate it could indicates presence of gypsum. Difference in rainfall pattern in Bahawalpur also exhibit highest sodium. Change in the taste is due to the increased SO_4^- concentration.

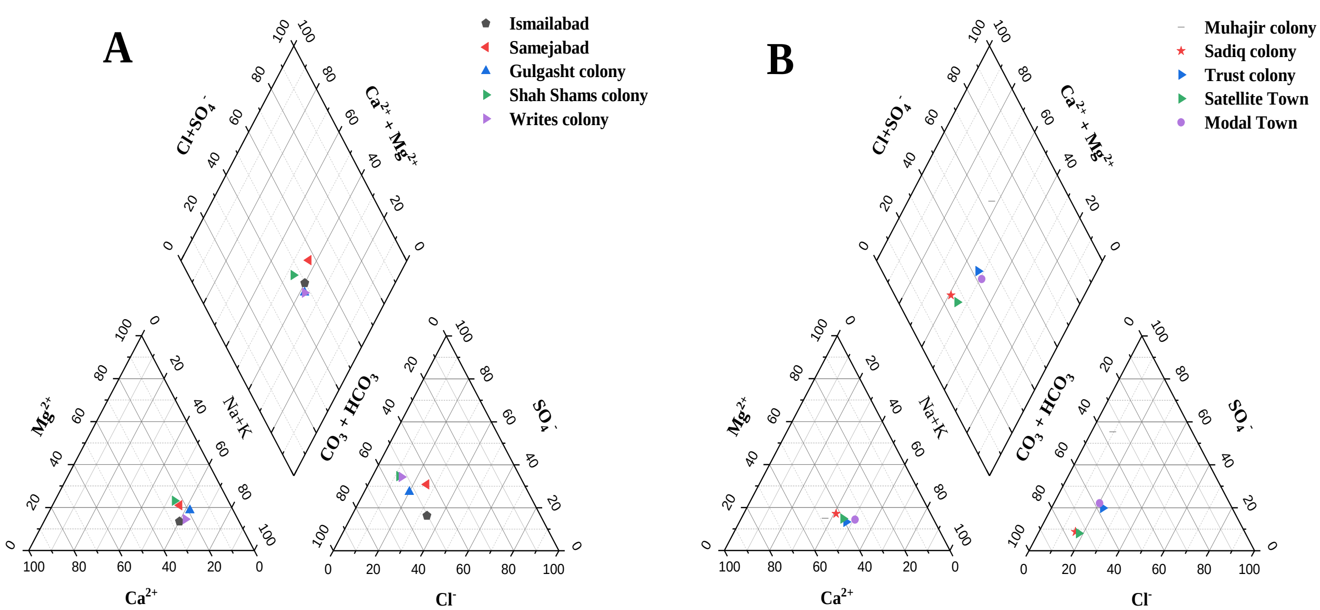

Figure 2. Piper plot representing ground water type in (A) Multan and (B) Bahawalpur city, Punjab, Pakistan

Ground water quality index in Multan and Bahawalpur

Water quality index (WQI) is considered to be the complete set of water quality indices along with heavy metals. WQI is divided into four categories i.e., <25 is excellent, 26-50 is good, 51-75 is poor and >100 is hazardous. WQI of selected sites from Multan and Bahawalpur (Figure 3)

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suggest that all water sample were hazardous and never meant to use for drinking purpose as all samples exceeds hazardous limit.

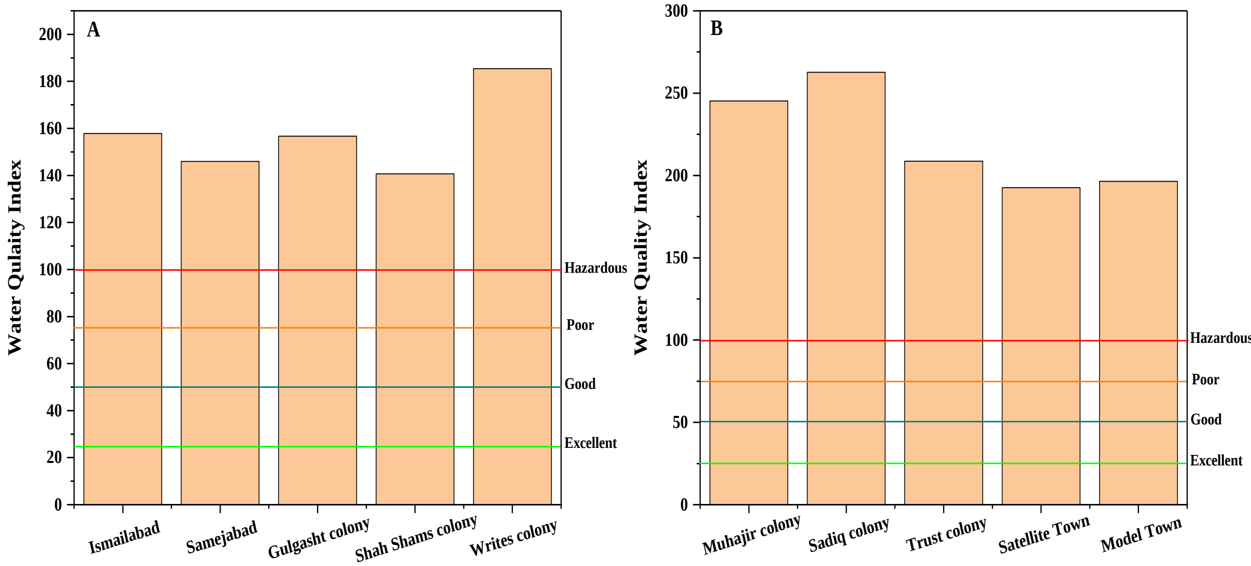

Figure 3. Grou nd water quality index of (A) Multan and (B) Bahawalpur city, Punjab, Pakistan

Principle Component Analysis (PCA)

Principle component analysis was generated between two factors, PC_1 and PC_2 to evaluate the enrichment of physiochemical and heavy metal concentration in ground water of both cities i.e., Multan and Bahawalpur (Figure 4 & 5). In particular PC_1 and PC_2 contribute to 41.62% and 28.98%, respectively in figure 4. The longer positive arrow of TDS, F^- and hardness on score plot indicates presence of salts in ground water of Writes colony. It seems that Samejabad experienced highest Fe and Cd concentration in ground water where Isamialabad has highest Cl^- content. Shah Shams colony has greatest Mg and Cr content in its water. However Gulgasht colony in bottom right quadrant of PC_1, far away from all quality parameters has distinct water type. Similar score plot was also exhibited for ground water samples of Bahawalpur in figure 5. PC_1 is 39.66% while PC_2 is 31.13%. Satellite town having varied concentration lies in center. Model town having highest Fe and Cd lies in the top left quadrant of PC_2 whereas water sample of Sadiq colony is prevalent to various cations, anions and total coliform. Trust colony on the left lower quadrant of PC_1 also indicates presence of main ions along with metal ions either present upper or lower side of both PCs.

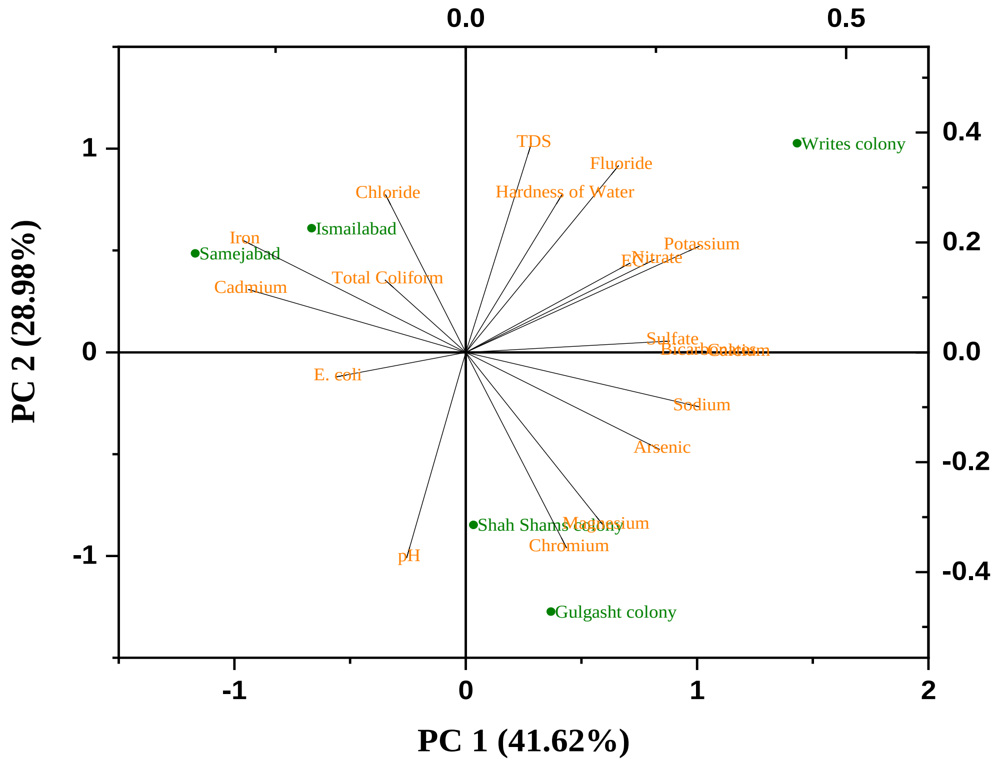

Figure 4. Principle Component Analysis (PCA) for ground water samples collected from various locations of Multan city, Punjab, Pakistan

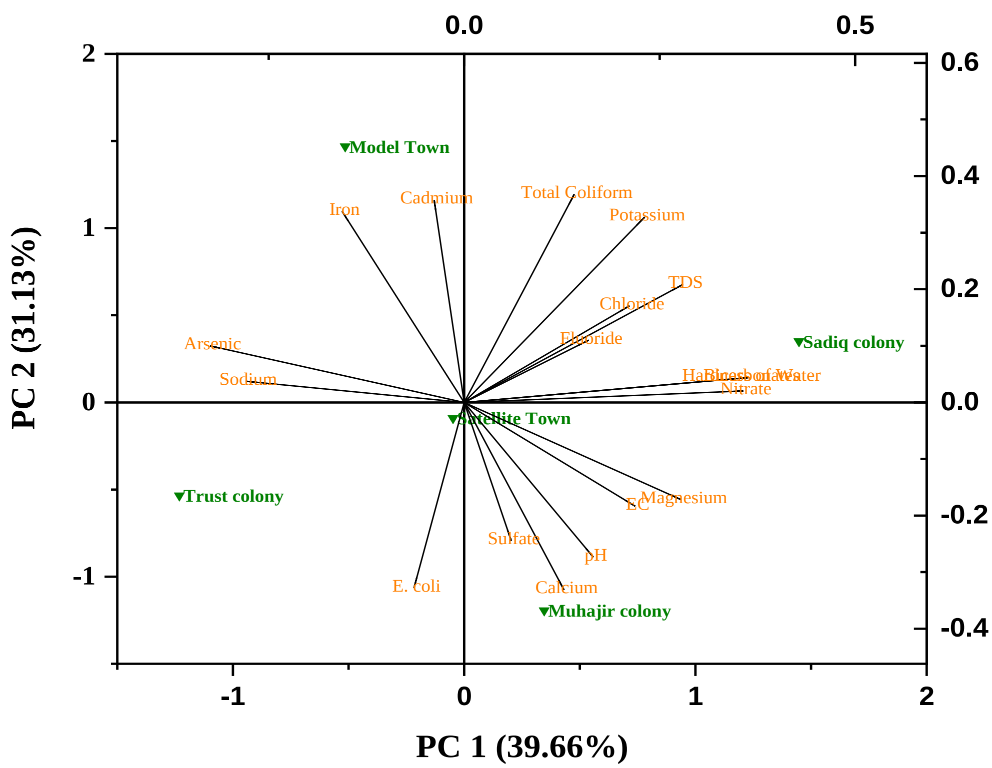

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Figure 5. Principle component analysis (PCA) for ground water samples collected from various locations of Bahawalpur city, Punjab, Pakistan

Discussion

Ground water quality is of great importance to evaluate its physical, chemical and biological properties to ensure its fitness for drinking purpose under changing climate. Ground water temperature largely alters under changing climate as a case study in Switzerland where alluvial ground water aquifers changes their temperature even in rural or non-urban areas which is not impacted by anthropogenic activites (Epting et al., 2021). Current work is not heavily dependent on ground water temperature as area lies in arid to semi-arid region where anthropogenic pattern is change in changing climate which has potential to alter ground water quality. Precipitation rate in study area also varies significantly over decade by shifting monsoon season. Less aquifer recharge with greater runoff also affect ground water resource. Intensive agricultural practices in arid to semi-arid regions might accumulate Cl^- and NO_3 ions in vadose zone (Gurdak et al., 2007). In study area NO_3 ion is not observed in the year 2014-15-16 suggesting possible accumulation of nitrate under prevailing climate change.

pH of water samples from selected areas suggest slightly alkaline having values within the permissible limit for drinking purpose. HCO_3^- is responsible for alkalinity as pH of water is greatly influence by carbonaceous rock weathering. Likewise pH, ground water EC is an important parameter to measure quality of ground water. Major reason behind elevated EC in ground water sample is dissolved solids. Ion exchange between soil minerals and ground water increases TDS, EC and pH (Alam et al., 2021). Ground water hardness also increases due to ground water aquifers are surrounded by $CaCO_3$ containing rocks which upon weathering made its way into water and is responsible for water hardness (Mohsin et al., 2013). Hydro chemical analysis of ground water samples gives major cations like Ca^{2+}, Mg^{2+}, Na^+ and K^+. Ca^{2+} and Na^+ in ground water were added through surface water by soil-water interaction which under changing climate might increase salt concentration within water by added anthropogenic activities as observed in study areas (Table 2 & 3) or by the infiltration of water soluble salts. Weathering of silicate minerals is another reason for addition of Na^+ and Ca^{2+} due to water rock interaction (Ramkumar et al., 2010). K^+ concentration in selected water samples were below permissible limit as observed in table 4 & 5 as it attach on the clay mineral and detach slowly

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(Jehan et al., 2023). Mg^{2+} on the other hand is under permissible limit in all water samples from both cities as well as in yearly obtained data. Anions were also detected in ground water samples. Among all HCO_3^- gives highest value followed by SO_4^{2-}, Cl^-, NO_3^- and F^- as of increasing population and agricultural practices in selective study area (Rasool et al., 2016). Addition of fertilizers and waste from urban areas along with weathering of carbonaceous rocks are the most possible reasons behind elevated HCO_3^- concentration from study area. Results are also reinforced by yearly obtained data from Multan and Bahawalpur. Elevated SO_4^{2-} & Cl^- in study area is due to ground water interaction with surface water altering due to anthropogenic activities like municipal sewage and bio wastage. As study area is arid to semi-arid therefore natural flow directs to South West from North capable to add more SO_4^{2-} & Cl^- in ground water. SO_4^{2-} may cause water to become bitter in taste (Arshad and Umar, 2022). Fluoride ion along with nitrate were found less in Pakistani soil but increase in these content brought about under less rainfall in arid condition where prolonged soil-rock interaction may pollute the ground water aquifers. Under low rainfall evaporation enhances through which $CaCO_3$ moves upward thus facilitate fluoride dissolving in water (Vithanage and Bhattacharya, 2015). Piper plot (Figure 2) is made to explore major water type of both cities, its interaction with external factors like rainfall and evaporation as well as source of contamination. Piper plot describe that weathering of rocks play vital role in ground water alteration which influence by precipitation and dissolution of secondary carbonates associated with low rainfall and increased evaporation in arid climate with low hydrolytic conductivity of water (Su et al., 2020).

100% ground water samples from Bahawalpur and 35% from Multan were enriched with pathogenic microbes. Total coliform were found in abundance indicate presence of illness causing bacteria. E. coli however is present in large intestine excrete out through feces and my cause illness upon consuming pathogenic microbes in water. Bacteriological properties of ground water found in heavily populated areas (Vendrell and Atiles, 2013).

Spatial distribution of heavy metals in ground water samples suggest that among all As gives highest concentration. More heavy metal were recorded in the ground water of Multan then in the Bahawalpur and areas exposed to industrial sites. Accumulation of Fe, Al and Mn in soil helps release in As form rocks. Intensive agricultural practices often associated with fertilizers

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and pesticides made soil and ground water vulnerable to As, Cd, Pb, Cr, Ni and Fe in Punjab, Pakistan (NFDS, 2016).

Score plot for Principle Component Analysis (PCA) evaluate that ground water quality related issues are more in Bahawalpur because of accumulating salts at shallow depth while similar was not happened in ground water of Multan. Water samples from Multan have high heavy metal concentration in certain areas which might have hazardous effect on human health (Mohsin et al., 2013).

Conclusion

In conclusion most of the analyzed ground water samples were unfit to for drinking without any prior treatment. Prominent factor in ground water samples of all studied area suggest enrichment of dissolved solids which overall changes the ground water chemistry. Less rainfall, high temperature and increased evaporation is the major cause of dissolved solids through human activities. Distribution of cations and anions in study area is so that it is predominant by sodium, bicarbonates and sulphates. Hydrochemical study suggests that ground water is largely polluted by weathering of rocks due to rock-water interaction in vedose zone. Piper plot suggest major water type in sampling area is Na^+, SO_4^{2-} and HCO_3^- type. Heavy metal in study area is due to nearby industrial sites with As is major metal to be found in ground water. Intermediate to higher Cd, Cr, and Fe concentration was also observed in ground water samples. Water quality index (WQI) suggests that all ground water samples from Multan and Bahawalpur were hazardous. PCA was performed to find out geochemical behavior of trace elements. Yearly data also supports our result regarding physiochemical properties of ground water however direct link between changing climate and ground water quality is not established. Therefore, this study suggests that ground water treatment was taken prior to human consumption.

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