The Research of Medical Science Review
ISSN: 3007-1208 & 3007-1216 Volume 3, Issue 8, 2025

ASSESSMENT OF GROUNDWATER CONTAMINATION AND DRINKING WATER QUALITY IN MULTAN AND BAHAWALPUR, PUNJAB, PAKISTAN

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DOI: https://doi.org/10.5281/zenodo.16948576

Keywords
Ground water, Multan, Bahawalpur, Drinking purpose

Article History
Received on 26 May 2025
Accepted on 08 August 2025
Published on 26 August 2025

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Abstract

Water is the basic necessity for mankind and never been alternate by other liquid. Ground water is important as it is the only natural reservoir accessible to human beings for their domestic, agricultural and industrial uses. Quality of ground water is rapidly degraded for years due to anthropogenic activities combined with less annual precipitation especially in arid areas. Pakistan, being a developing country faces high concentration of pollutants in ground water which badly affect human health. Current work is designed to access the ground water quality for drinking purpose of Multan and Bahawalpur, two major cities in Southern Punjab, Pakistan having annual precipitation less enough not to fulfill basic necessities of inhabitant. In total 25 ground water samples were collected from various selected areas of each city through pumping wells. These water samples were analyzed for electrical conductivity, total dissolved solids, pH, hardness, Ca^{2+}, Mg^{2+}, Na^{2+}, K^{+}, CO_3^{2-}, HCO_3^{-}, Cl^{-}, F^{-}, NO_3^{-}, total coliform, E. coli, arsenic, cadmium and chromium. Water quality index and heavy metal pollution index indicates that ground water quality of various selected areas in both cities were not even meet basic quality standards set by WHO. Water quality index, heavy metal index, physiochemical properties and microbial activity indicates that few ground water samples from Multan and Bahawalpur are contaminated. Furthermore spatial analysis of ground water also paved way towards sustainable management which enhances public satisfaction to the importance of water quality

Introduction:

Water is one of the most important element to sustain life on planet earth. Most of the fresh water resources were kept frozen in ice caps while small portion were present in rivers and lakes on the surface of the earth. A descent amount of fresh water is also locked underground between rocks in the form of aquifers. Underground water is considered to be major portion of fresh water and is used for drinking and domestic purposes (Akintan et al., 2024). Underground water quality is largely dependent on external factors like, rate of discharge, precipitation rate and sub-surface geo-chemical process.

Underground water is the primary source of potable water for community living in urban areas. Ground water is easy to extract out from soil and had higher standard than surface water (Patel et al., 2020). Furthermore, underground

water is also of utter importance when used to fulfill municipal needs (Gronwall and Danert, 2020). Increase in population, urbanization and industrialization needs ground water on daily basis with increasing requirement every year (Gao et al., 2020). Chemistry of ground water aquifer is greatly determined by geochemical process which causes hydrolysis, precipitation of ions, cation exchange capacity in soil sediment-water interaction. As ground water is the daily requirement of the urban community, therefore its quality is crucial for public health. In recent years, ground water of urban areas surrounded by industrial units is greatly polluted due to widespread effect of industries (Krishnamoorthy et al., 2023).

Pakistan a developing country is facing poor ground water quality for decades. Urbanization in developing countries like Pakistan put a positive impact on social development and economy but unplanned urbanization with poor sanitation now become a massive chaos and unable to meet basic human necessities (Sohail et al., 2022). Contaminants from urban areas, industries and agricultural wastage easily made its way into the fresh ground water resources in the country not imposing environmental laws (Amin et al., 2019). Contaminants of chemical, toxic and microbial nature in ground water aquifers made it unfit for human consumption. Importance of ground water on communal life is important to an extinct that even a small imbalance in water quality can cause a major obstacle in health of individual. Renal, skin, central nervous system disorder, circulatory disorder, gastrointestinal disorder, blue baby syndrome and bone damage are few examples related to prolonged consumption of unfit water (Rehman et al., 2018).

Taking into account current work is designed with a purpose to quantify contaminants in ground water of Multan and Bahawalpur City with a strong purpose of water quality indices. For this ground water samples were taken from urban areas of Multan and Bahawalpur to analyze water quality. Five samples from ten different locations of both cities was taken up with an objective to access the level of contamination in drinking water which further provide a reference to researchers for conducting surveys.

Material and methodology:

Study Area:

Multan and Bahawalpur are situated in the southern Punjab of Pakistan. Multan is an ancient city with an area of 3721 km^2 and population of 2.20 million inhabitant located along river Chenab (30.1864° N 71.4886° E) while Bahawalpur city having area of 246 km^2 with 0.90 million population located along river Satluj (29.3544° N 71.6911° E). Climatic condition of both cities varies between arid to semi-arid regions. Ground water aquifer of both cites were never been recharge since both nearest rivers cannot flow for years except for the monsoon season where river flow was considerably high. Precipitation per annum varies between 175 mm and 143 mm which are insufficient to recharge ground water resources. Resident of both cities consume poor quality of ground water long ago thereby access to safe water quality is of great significance.

Ground water sampling:

Fifty underground water samples from ten (five from each city) different locations of Multan and Bahawalpur were pumped out through bore-well before monsoon season between May and June 2024. Sampling points were chosen in a pattern that each sampling point is within the range of 500 meters in a specific coordinate. Bore-well was running for 5 minutes prior to sampling for homogeneity. Temperature, pH and electrical conductivity of the water was recorded with potable instrument at the time of sampling and stored in 1-liter pre-cleaned, sterilized air tight polythene containers for physicochemical and heavy metal analysis. 100 ml water samples were also collected separately to quantify pathogenic microbial colonies in the sample. Depth of bore-well and usage pattern of water was also recorded at the time of sampling. Location of the sampling site was also recorded at the time of sampling through Global Positioning System (GPS).

Table 1 showing coordinates of different locations for water sampling in Multan and Bahawalpur

Multan		Bahawalpur	
Location	Coordinate	Location	Coordinate
Mumtazabad	30.1740° N 71.4762° E	Islamia colony	29.3704° N 71.6952° E
Gillani Mohalla	30.1902° N 71.4708° E	Mohajir colony	29.3820° N 71.7205° E
Shamsabad colony	30.2095° N 71.4851° E	Nishat colony	29.4103° N 71.6834° E
Mohalla Nawazabad	30.2047° N 71.4742° E	Sadiq colony	29.3824° N 71.6598° E
Nawabpur	30.2948° N 71.4678° E	Mohallah Aam Khas	29.3995° N 71.6736° E

Ground water quality assessment:

Collected ground water samples were physic-chemically analyzed in Soil salinity laboratory, The Islamia University of Bahawalpur, Pakistan (29.3981° N 71.6908° E). Temperature of water was determined by mercury thermometer. pH of the water samples was measured by pH meter (model: Mi-150) pre celebrated with potassium chloride solution while conductivity and total dissolved solids (TDS) was measured by electrical conductivity meter (3100C) also pre celebrated with potassium chloride solution. Cations (Na^{2+}, Ca^{2+}, K^{+}) was calculated by using flame photometer (Model: BWB technologies). Anions (CO_3^{-}, HCO_3^{-}, F^{-}, NO_3^{-}, Cl^{-}) was determined by titration. Magnesium was calculated by developing color through spectrophotometer (Model: CE7400S). All physic-chemical parameters were done according to the protocol assessed as per American Public Health Association (Greenberg et al., 2005). Water Quality Index (WQI) was accessed by computing all water parameters from selected locations;

$$\mathrm{UWQI} = \sum_{i=1}^{n} \mathrm{Qi}$$

Heavy metal analysis:

Heavy metal analysis was done according to the method adopted by Akintan et al. (2019). Ground water samples were analyzed for heavy metal from department of chemistry, Government College University Lahore through atomic absorption spectrophotometer (Model: Shimadzu 7000 F). Blank and reference standards were run before the start of analysis to evaluate the accuracy of analytical method. Following formula is used to compute the heavy metal pollution index;

$$\mathrm{HPI} = \frac{\sum_{i=1}^{n} \mathrm{WiQi}}{\sum_{i=1}^{n} \mathrm{Wi}}$$

Microbial analysis:

Microbial analysis was conducted to quantify the coliform and E.*coli* in the water samples. 100 ml water containing microbial concentration was filtered through membrane having mesh size 0.45 µm and subsequently incubate in petri plate on agar media at 37° C for 24-48 hrs. Colonies were counted through colony counter after incubation and expressed as colony per 100 ml of water (Forbes et al., 2007).

Results:

Physical properties of ground water samples:

Figure 1 represent physical properties of ground water collected from various locations of Multan and Bahawalpur City. pH of water samples collected from both Multan and Bahawalpur were well under permissible limit according to WHO guidelines (6.5-8.5). Electrical conductivity of ground water is usually governed by dissolved solids present in it. Almost all ground water samples taken from Multan and Bahawalpur are above the permissible limit according to WHO (400 µS cm^{-1}). Highest EC in Multan was observed in ground water

samples of Mumtazabad (4357 µS cm^{-1}) while in Bahawalpur highest EC was noted in Mohajir colony (3205 µS cm^{-1}). Least of it was observed in Ghillani Mohalla (707 µS cm^{-1}) of Multan and Sadiq colony (1076 µS cm^{-1}) of Bahawalpur. Considering health perspective all ground water samples from Multan and Bahawalpur are unfit to drink due to excess ions in the water.

Water containing total dissolved solids is unfit for human consumption if its concentration is above 400 mg/l. Obtained data from sampling areas of both cities clearly indicates dissolved solids concentration varied between 834 and 4425 mg/l. In Multan, Mumtazabad being a residential area exhibits highest TDS while Mohajir colony in Bahawalpur also exhibit highest TDS. Least TDS was observed in Gillani Mohalla of Multan city and Mohallah Aam Khas of Bahawalpur.

Hardness of water in studied area is also beyond the permissible limits according to the WHO. In Multan city, Nawabpur (690 mg/l) exhibit highest hardness followed by Mumtazabad (570 mg/l) and Gillani Mohalla (450 mg/l) while in Bahwalpur, Mohajir colony (760 mg/l) exhibit highest hardness followed by Isalmia colony (700 mg/l). Water samples from Multan and Bahawalpur also doesn't exhibit any color and taste upon consumption.

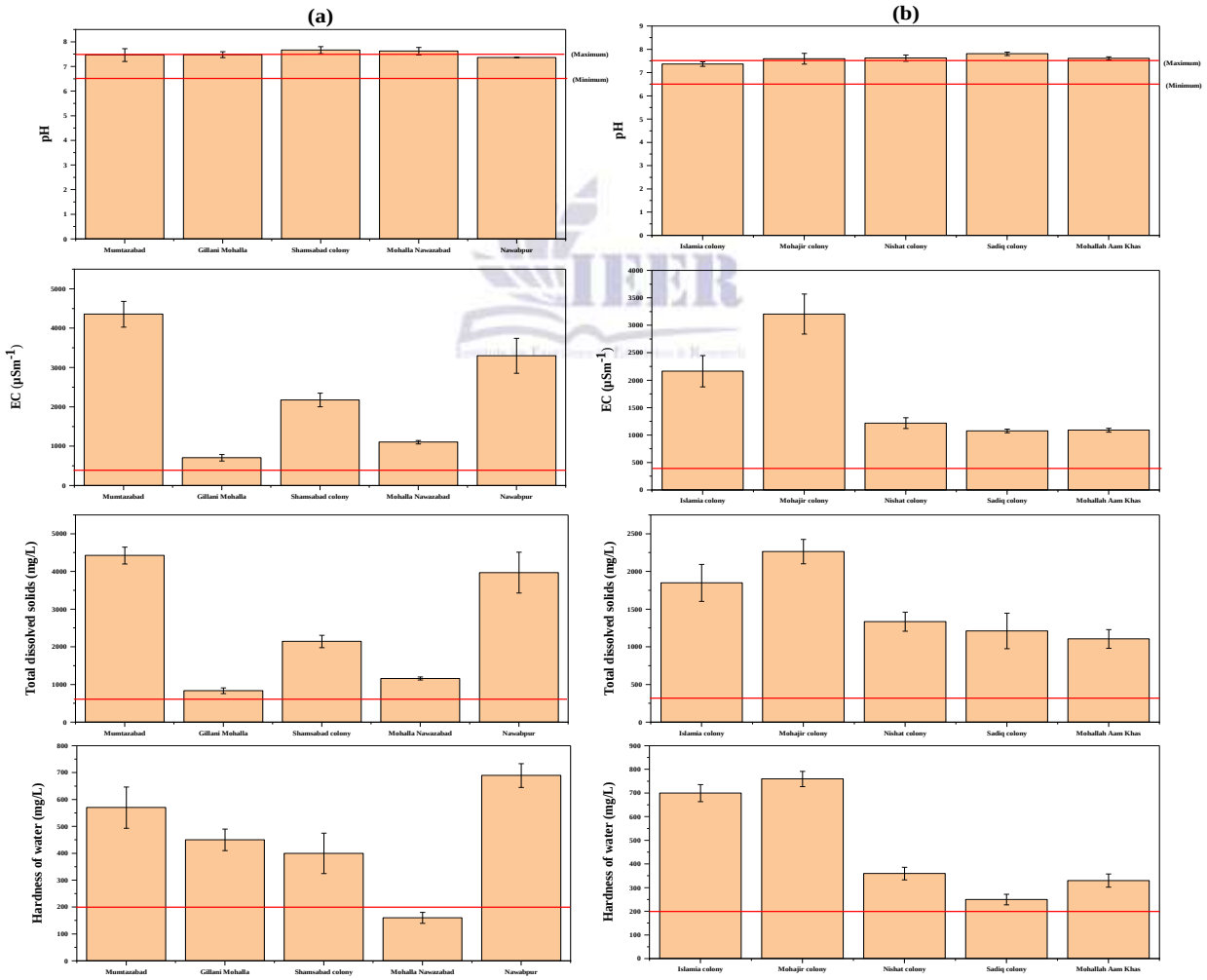


Figure 1 representing physical properties of ground water collected from various locations of (a) Multan and (b) Bahawalpur city. Red line indicates maximum permissible limit in drinking water as per the guidelines of WHO.

Cation's concentration in ground water samples:

Cationic concentration (Calcium, Magnesium, Sodium & Potassium) in ground water samples of Multan and Bahawalpur were under limits according to WHO (Figure 2). Calcium an important element for human physiological activity which enhances bone structure and nerve transmission. Calcium concentration in drinking water doesn't exceed 75 mg/l as per WHO guidelines. Calcium in water samples from different areas of Multan and Bahawalpur were well under the permissible limit. Magnesium present in earth crust is also a vital element for human health. Its concentration in drinking water must not increase by 150 mg/l. The highest concentration of magnesium in ground water samples collected from Multan and Bahawalpur is 26 mg/l which made it favorable for drinking purpose. Sodium, an important element to smooth metabolic activity also found in ground water. It is worth noting that sodium alone is not responsible for presence of salt in the water. Various other factors also involves in making water unfavorable for drinking purpose. Safe limit of sodium in drinking water is must be lower than 200 mg/l. Ground water samples of Multan and Bahawalpur are still far more less then as prescribed by WHO. Potassium is important to regulate human body by maintaining movement of various solutes in the body with the help of blood. Minimum amount of potassium must present in drinking water to fulfill body requirement. However its concentration above 12 mg/l is lethal to body as it creates different disorders. Ground water taken from Multan and Bahawalpur has potassium ranges between 8.0 mg/l and 1.7 mg/l which is quite well for normal bodily functioning.

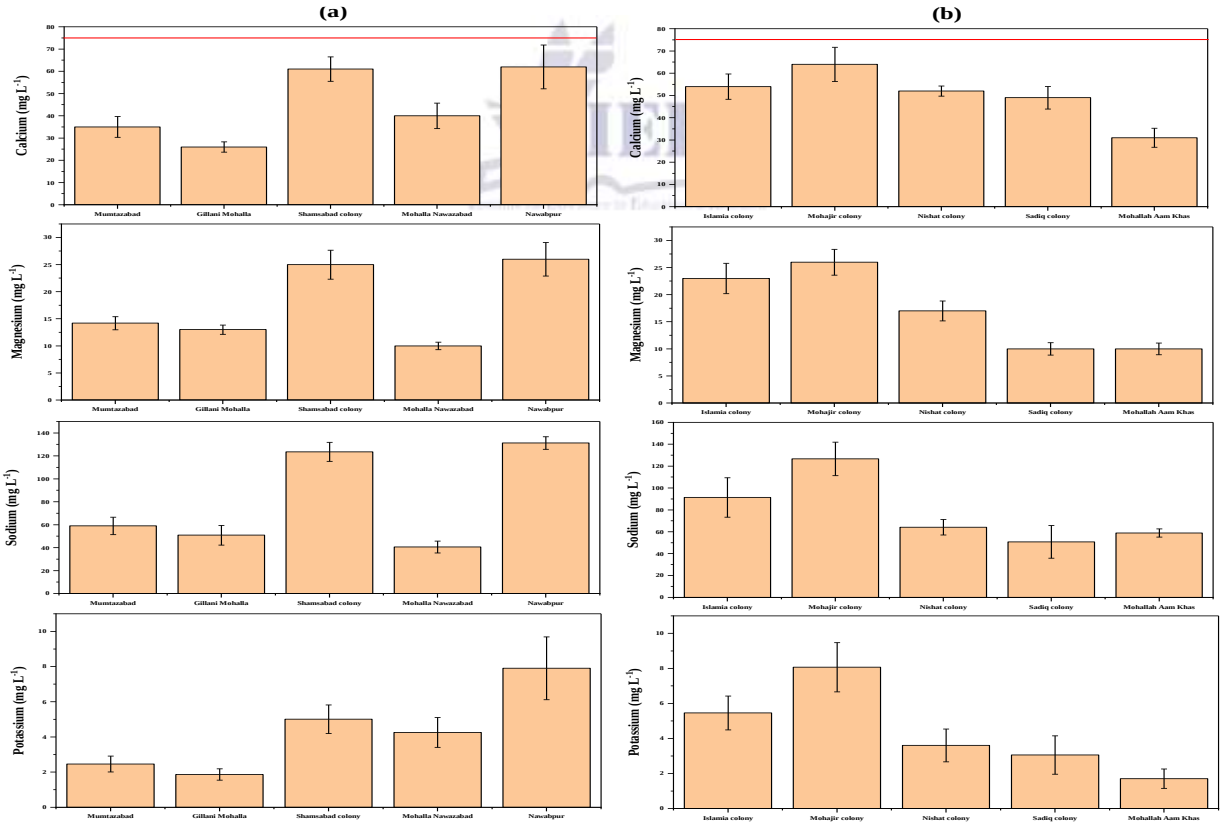


Figure 2 representing cationic concentration (Calcium, Magnesium, Sodium & Potassium) of ground water collected from various locations of (a) Multan and (b) Bahawalpur city. Red line indicates maximum permissible limit of cations in drinking water as per the guidelines of WHO.

Anion's concentration in ground water samples:

Anion concentration (Fluoride, chloride, nitrate, bicarbonates and carbonates) in ground water of Multan and Bahawalpur City is illustrated in the figure 3. Usually anions in ground water collected from various locations are below the limits set by WHO except bicarbonates which is more than acceptable standards according to WHO. Fluoride content in collected ground water samples were well under WHO limits (2 mg/l). Highest fluoride content in water changes its chemistry by altering pH. Water collected from various areas of Bahawalpur experience high content of fluoride compared to Multan but in permissible range according to WHO. Chloride ion is also detected in ground water samples but less than permissible limit according to WHO (250 mg/l). Water samples collected from studied area suggest that water is in safe limits for drinking purpose as not a single water sample exceeds the threshold set by WHO. Nitrate is also an important anion which intruded into ground water mainly by fertilizers, human/animal waste and food preservers. Mainly nitrate more than 10 mg/l in water is not suitable to consume for drinking purpose. Highest recorded nitrate content in ground water of Mohajir colony in Bahawalpur is 1.06 mg/l which is quite low then WHO threshold.

Data regarding bicarbonate concentration in ground water samples were less enough that it could be used for drinking purpose except for the ground water of Mohajir colony which is recorded at 657 mg/l. Carbonates were only detected in the ground water of Multan while in Bahawalpur they were not detected. Carbonate concentration in ground water of Multan is less enough to support water for drinking purpose. Highest noted carbonate concentration in Multan is ground water of Nawabpur (1.02 mg/l).

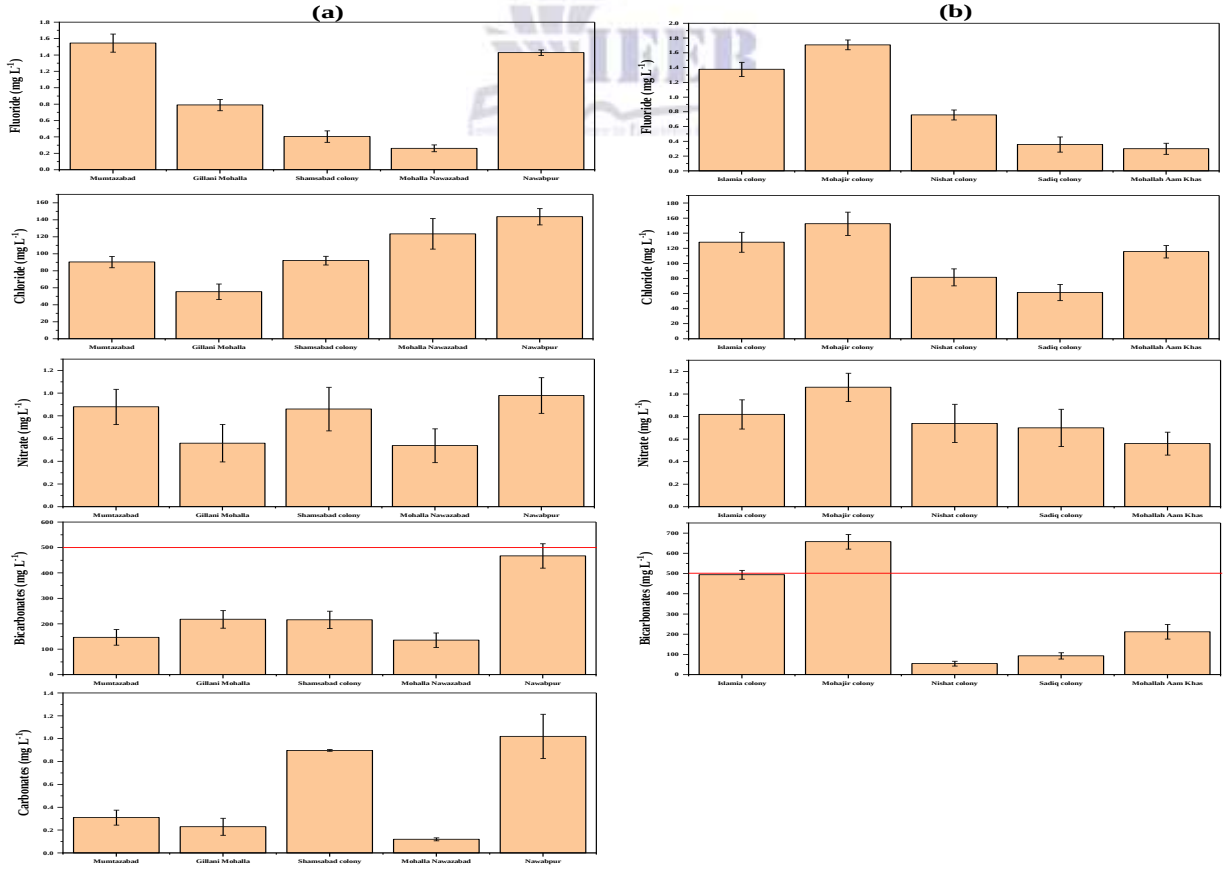


Figure 3 representing anionic concentration (Fluoride, Chloride, Nitrate, Bicarbonates & Carbonates) of ground water collected from various locations of (a) Multan and (b) Bahawalpur city. Red line indicates maximum permissible limit of anions in drinking water as per the guidelines of WHO.

Ground water quality index (WQI):

Ground water quality index of selected areas from Multan and Bahawalpur was computed by using concentration of various parameters. Data reveals that none of the water samples collected from all 50 areas from Multan and Bahawalpur was not fall in the category of EXCELLENT and GOOD. Ground water of Gillani Mohalla and Mohalla Nawazabad were POOR to be used for drinking purpose while water samples taken from Nishat colony, Sadiq colony and Mohallah Aam Khas were also fall in POOR water quality category for drinking. Water of Mumtazabad, Shamsabad colony and Nawabpur were HAZARDOUS enough for drinking perspective. Same was noted in the case of Isalmia colony and Mohajir colony from Bahawalpur were water is also categorized as HAZARDOUS for drinking purpose.

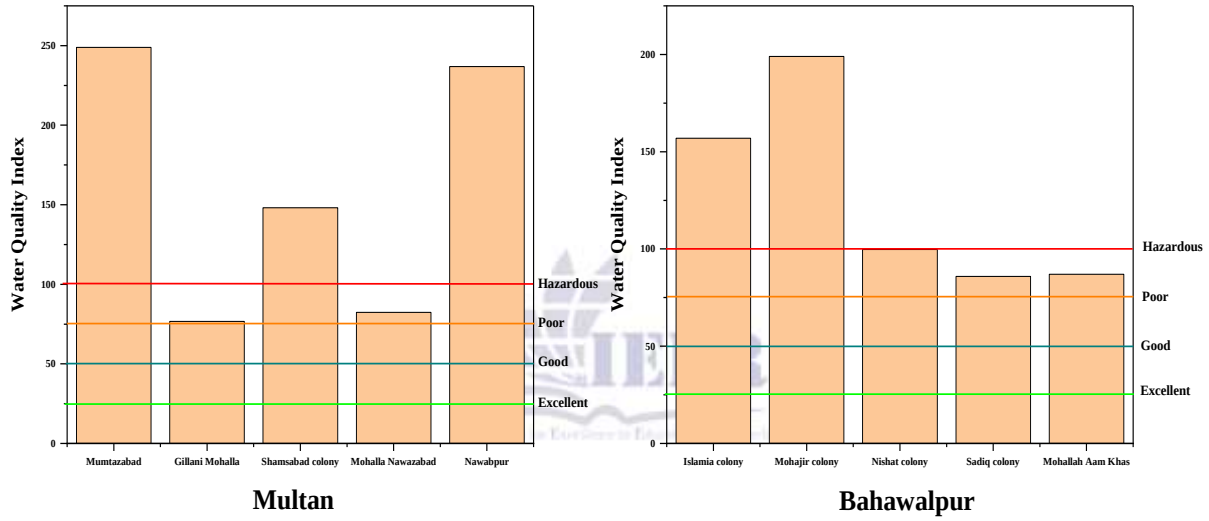


Figure 4: Ground water quality (WQI) of Multan and Bahawalpur

Heavy metal analysis:

Heavy metal analysis was done to find out the concentration of metal present in water. Arsenic and cadmium was detected in the ground water samples of Bahawalpur while chromium with all above mentioned metals was also detected in Multan City. Arseniosis is the major factor of wide spread exposure of arsenic in the water. According to WHO arsenic threshold level in drinking water is 10 µg/l. Water collected from three locations of Multan and one location of Bahawalpur exhibit elevated arsenic level then the threshold level of WHO. Water samples from two localities of Multan and four localities of Bahawalpur were within safe limits for drinking purpose. Cadmium on the other hand is yet another harmful metal which had lethal effect on human health upon consumption even in small quantity. Major portion of cadmium is added into ground water aquifers by anthropogenic activity mainly by pesticide application which percolates down into ground water. Weathering of cadmium containing rocks is another reason for its intrusion into ground water aquifers. Ground water of Shamsabad colony (3.08 µg/l) and Nawabpur (3.05 µg/l) in Multan were designated to be higher than WHO threshold (3 µg/l) while in Bahawalpur all water samples were within the range of WHO and can fit to use for drinking purpose. Chromium is also a harmful metal usually produces from tanning industries and its

minimum consumption causes vomiting, nausea and other mental disorder in human body. According to WHO chromium above 5 µg/l is lethal. Chromium is only detected in the ground water of Multan while no traces were found in ground water samples of Bahawalpur city. Shamsabad colony is the only area in Multan where Cr concentration (5.28 µg/l) is higher than WHO threshold. All other selected areas are below chromium toxicity level according to WHO.

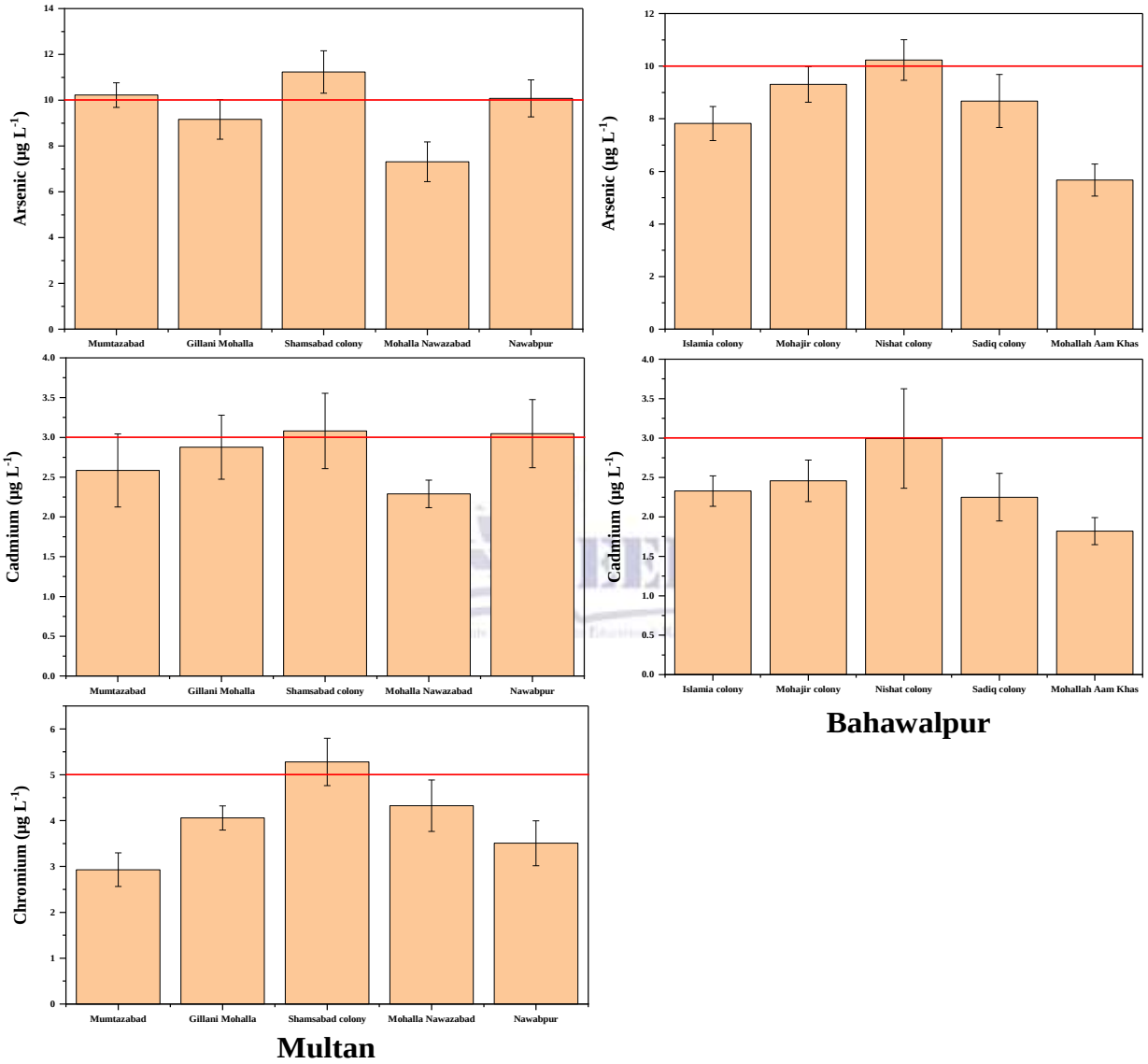


Figure 5: Heavy metal concentration (Arsenic, Cadmium & Chromium) in ground water of Multan and Bahawalpur

Heavy metal Pollution Index (HPI):

Data from heavy metals (Arsenic, cadmium & chromium) was subjected to computation to find out the heavy metal pollution index (HMPI). According to WHO standards water exceeds 100 HPI is unsafe to use for any kind of activity. In Multan, highest HPI was noted in Shamsabad colony (100) followed by Nawabpur (97) and Gillani mohalla (91) while least was observed in Mohalla Nawazabad (72). HPI results in

Bahawalpur indicates that neither sample exceed the minimum threshold level of 100 however Nishat colony (95) exhbit high HPI followed by Mohajir colony (80). Lowest recorded HPI was obtained from area of Mohallah Aam Khas (57).

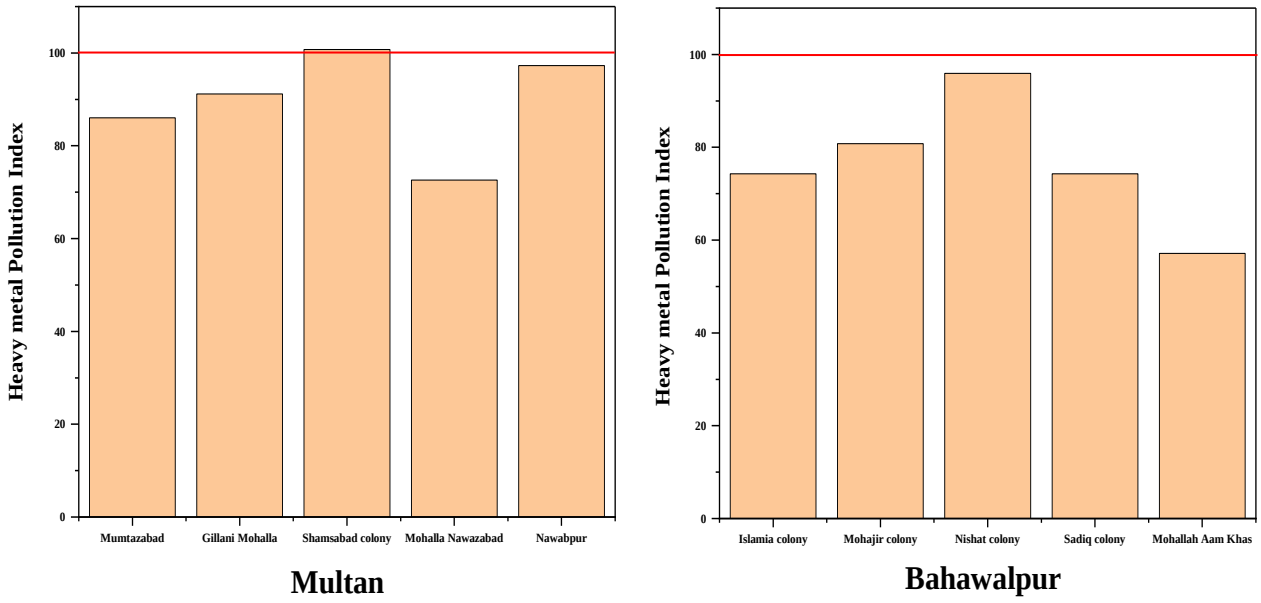


Figure 4: Heavy metal Pollution Index (HPI) of drinking water of Multan and Bahawalpur City

Bacterial activity:

Water containing Total coliform and E. *coli* indicates the presence of pathogenic microbes in water. According to WHO, Colony Forming Unit (CFU) in 100 ml water is not more than 126 CFU while 0 CFU should present in water used for drinking purpose. Pathogenic microbial concentration in the ground water of selected areas in Multan and Bahawalpur varied in numbers. Highest total coliform was detected in the ground water of selected areas of Multan are Gillani Mohalla (), Nawabpur () and Shamsabad colony () while least of it was observed in Mohalla Nawazabad (). Total coliform concentration in the ground water areas of Bahawalpur is Isalmia colony () followed by Sadiq colony () while lowest concentration of total coliform was observed in Nishat colony ().

E. *coli* is also pathogenic bacteria whose concentration must be 0 CFU in drinking water. E. *coli* concentration in ground water of various areas of Multan varied between 73 CFU and 47 CFU. Highest recorded E. *coli* concentration in ground water of Mumtazabad (73 CFU) followed by Shamsabad colony (68 CFU) and Nawabpur (65 CFU) while least recorded E. *coli* was noted in ground water of Mohalla Nawazabad (47 CFU). On the other hand E. *coli* in ground water of Bahawalpur varied between 94 CFU and 40 CFU. Highest recorded E. *coli* was observed in Islamia colony (94 CFU), Nishat colony (80 CFU) and Mohajir colony (74 CFU). Least recorded E. *coli* was observed in Mohallah Aam Khas (40 CFU).

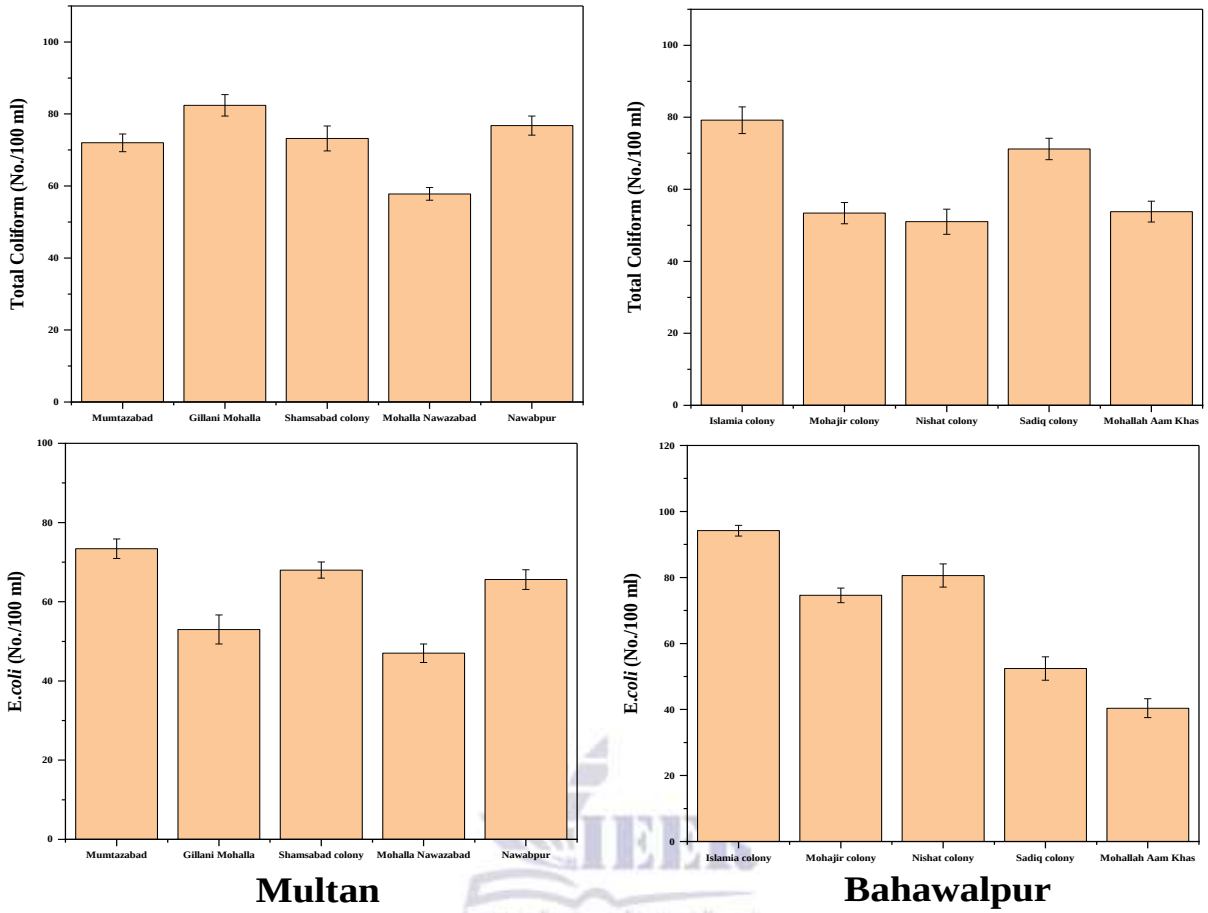


Figure 6: Bacterial activity (Total Coliform & E. *coli*) in ground water of Multan and Bahawalpur

Physicochemical characteristics of water samples collected from various locations of Multan and Bahawalpur, Punjab, Pakistan:

The table demonstrates the physicochemical properties of various locations of Multan and Bahawalpur City. Ground water of various areas of Multan has pH values ranging between 7.66 and 7.37, averaging 7.52 while in Bahawalpur its values are between 7.81 and 7.37 with an average of 7.60. WHO recommends pH of drinking water between 6.5-8.5. Based on the results it can be suggested that ground water of Multan and Bahawalpur is fit for drinking with respect to pH. Electrical conductivity of various locations in Multan lies between 4356.80 $\mu S/cm^{-1}$ and 707.20 $\mu S/cm^{-1}$ with an average of 2328.60 $\mu S/cm^{-1}$ while samples from different locations of Bahawalpur lies within the range of 3205.40 $\mu S/cm^{-1}$ to 1075.80 $\mu S/cm^{-1}$ with an average value of 1751.08 $\mu S/cm^{-1}$. This indicates that ground water in various selected areas of Bahawalpur and Multan has more than higher concentration of salt making it unviable to drink anymore. WHO recommends water having EC lower than 400 $\mu S/cm^{-1}$ is consumable as high salts could cause renal disorders. Dissolved solids in ground water of Multan and Bahawalpur lies in the range of 4425.20-834.20 mg/l and 2265.40-1105.20 mg/l, respectively. This indicates that salt concentration in ground water of all selected areas of Bahawalpur surpasses the threshold and not be used for drinking while salts in ground water of few areas of Multan still below the WHO threshold (1000 mg/l). The mean hardness of water in Multan and Bahawalpur is 454 mg/l and 479.96 mg/l. Since hardness of water is not a danger for human health thus

WHO recommendation for hardness is still undefined however its concentration more than 500 mg/l is unsuitable for any kind of purpose due to taste problems. Sample exceeds the limit referred to have increased hardness level.

Increase in calcium concentration above 100 mg/l also increases hardness of water. Ground water samples of Multan and Bahawalpur are below the range of 100 mg/l and do not have any health based recommendations. Similarly magnesium above 50 mg/l also causes hardness in water but ground water of Multan and Bahawalpur also ranges between 10-26 mg/l. Likewise calcium, magnesium also doesn't have any health related recommendations but create hardness in water when surpasses the threshold. Limiting value for sodium in drinking water was 200 mg/l according to WHO, yet this value is not passed by any of the ground water sample indicating adequate salt concentration in ground water of selected areas of Multan and Bahawalpur. Potassium concentration in ground water ranges between 7.91-1.87 mg/l in Multan while 8.07-1.71 mg/l in Bahawalpur. WHO doesn't limits any number for potassium because of no indication of health related disorders with elevated potassium thus highest value obtained from the area considered to be in safe limits for domestic use.

Carbonates were not found in the ground water of Bahawalpur while its concentration in ground water of Multan ranges between 1.02 t0 0.12 mg/l, averaging 0.52 mg/l. Bicarbonates concentration on the other hand ranges between 467.06 mg/l and 135.62 mg/l in Multan with a mean value of 236.59 mg/l. Bicarbonate concentration in Bahawalpur ranges between 657.42 mg/l and 55.06 mg/l averaging 302.36 mg/l. WHO has no health related guidelines for carbonates and bicarbonates thus measured levels have no regulatory issues. Fluoride content in Multan and Bahawalpur ranges between 1.55-0.26 mg/l and 1.71-0.30 mg/l, respectively. According to WHO recommendations, fluoride content in drinking water must less than 1.5 mg/l. Few samples from both cites exhibit slight increase in fluoride content then recommended value as elevated fluoride may cause dental fluorosis. WHO recommends chloride concentration at 250 mg/l and none of the ground water sample exceeds the permitted level. Nitrate concentration in ground water samples collected from selected areas also well below the WHO permissible limit (50 mg/l) making water NO_3^- free contaminants.

Presence of E. *coli* and total coliform in ground water samples of Multan and Bahawalpur were within the range of 94 and 40 for E. *coli* while total Coliform was within the range of 82 and 51 CFU/100 ml. According to WHO, the concentration of pathogenic microbes (Total coliform and E. coli) must absent from 100 ml of water sample. Presence of these pathogenic microbes in drinking water indicates potential health hazard for human beings.

Arsenic and cadmium concentration in the ground water of both cities varies between 5-11 µg/l for arsenic and 1-3 µg/l for cadmium, respectively. WHO recommends that arsenic above 10 µg/l and cadmium above 3 µg/l is potentially hazardous for human health for long term even consume in small quantity. Both heavy metals persist in human body and causes kidney disorder as well as attack central nervous system which may affect normal body functioning. Chromium is only found in the ground water samples of Multan and made its way into ground water from tanning industry as Cr is the principal metal used in tanneries. Few ground water samples gives elevated figures as recommended by WHO (5 µg/l) which negatively affect human health.

All water samples exceeded WHO permissible criteria are potential threat to local community using water.

Table 2 representing physicochemical properties of ground water collected from different locations of Multan and Bahawalpur City

MUL	pH	EC	TDS	HD	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{-}	HCO_3^{-}	F^{-}	Cl^{-}	NO_3^{-}	T. Coliform	E. *coli*	Ar	Cd	Cr
Maximum	7.66	4356.80	4425.20	689.60	62	26	131.30	7.91	1.02	467.06	1.55	143.70	0.98	82.40	73.40	11.23	3.08	5.28
Minimum	7.37	707.20	834.20	160.40	26	10	40.60	1.87	0.12	135.62	0.26	55.40	0.54	57.80	47	7.31	2.29	2.93
Mean	7.52	2328.60	2507.20	454	44.80	17.64	81.08	4.30	0.52	236.59	0.89	101.02	0.76	72.44	61.40	9.60	2.78	4.02
SD	0.12	1517.53	1625.18	198.82	16.05	7.34	42.92	2.39	0.41	134.30	0.58	33.91	0.20	9.13	10.99	1.48	0.33	0.89
CV	1.62	65.17	64.82	43.79	35.83	41.64	52.93	55.51	80.09	56.77	65.74	33.57	26.36	12.60	17.90	15.38	12.06	22.04
Median	7.48	2175.60	2145	450.20	40	14.20	59	4.26	0.31	215.78	0.79	92.10	0.86	73.20	65.60	10.08	2.88	4.06
Kurtosis	-1.65	-1.64	-2.75	0.56	-2.52	-2.91	-3.06	0.30	-2.86	3.48	-2.78	-0.51	-2.84	2.10	-1.92	1.18	-0.94	0.16
BWP	**pH**	**EC**	**TDS**	**HD**	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{-}	HCO_3^{-}	F^{-}	Cl^{-}	NO_3^{-}	T. Coliform	E. *coli*	Ar	Cd	Cr
Maximum	7.81	3205.40	2265.40	759.60	64	26	126.70	8.07	0	657.42	1.71	152.50	1.06	79.20	94.20	10.23	2.99	0
Minimum	7.37	1075.80	1105.20	250	31	10	50.80	1.71	0	55.06	0.30	61.50	0.56	51	40.40	5.67	1.82	0
Mean	7.60	1751.08	1553.16	479.96	50	17.20	78.40	4.38	0	302.36	0.90	107.82	0.78	61.72	68.44	8.34	2.37	0
SD	0.16	930.29	489.93	232.55	12.02	7.33	31.01	2.46	0	262.68	0.62	36.39	0.18	12.67	21.75	1.73	0.42	0
CV	2.08	53.13	31.54	48.45	24.04	42.60	39.55	56.23	0	86.88	69.24	33.75	23.79	20.53	31.79	20.78	17.85	0
Median	7.61	1218.80	1334.40	360	52	17	64.20	3.61	0	212.34	0.76	115.50	0.74	53.80	74.60	8.68	2.33	0

Kurtosis	2.01	0.31	-1.03	-2.88	2.11	-2.58	0.43	0.18	0	-1.96	-2.24	-1.41	1.38	-2.01	-1.59	0.94	1.50	0
WHO Guidelines (mg L^{-1})	**6.5-8.5**	**400**	**1000**				**200**				**1.5**	**250**	**50**	**0**	**0**	**0.01**	**0.003**	**0.005**

Pearson correlation for ground water samples in selected areas of Multan and Bahawalpur:

Pearson correlation coefficient of ground water samples collected from selected areas of Multan and Bahawalpur indicates correlation among water quality parameters. Single matrix containing value represents correlation coefficient among two parameters ranging between -1 and 1. Value near to 1 is highly positive correlating to other parameter while value near to -1 represents highly negative correlation. Value near to 0 represents less or no correlation among measured water parameters.

In Multan pH is weakly correlated with any of the water indicator except chromium (0.80) due to its anthropogenic appearance in water. Electrical conductivity is strongly correlated with TDS (0.98) due to the presence of dissolved solids in the ground water in large concentration as well as with E. coli which probably associated with it due to addition of sewage water into ground water which might contain different salts. Total dissolved solids in ground water of Multan are highly correlated with fluoride (0.85) and nitrate (0.87) which suggest their existence in water due to ion exchange through pollution. All other water quality parameters were not affecting due to increase in dissolved solids. Hardness of water on the other hand is largely affect due to increase in fluoride content (0.89) and slightly affect by bacterial activity. Geological nature of location also enhances fluoride content in water. Calcium, magnesium, sodium, potassium and carbonates strongly correlate each other indicating major contribution to mineral content in water. Since, total coliform and E. coli intrude into ground water through external source such as sewage water so they do not correlate to any of the water quality parameter except nitrate ion suggesting its occurrence in water through external source. Similarly, arsenic and cadmium correlates weakly with EC and cations indicating its external linkage with waste water percolation or geological activates which largely affect these heavy metals then water quality parameters. Chromium however intermediately correlates with pH suggesting its occurrence in ground water might be due to geochemical as well as anthropogenic activates. Another reason of persistence of heavy metals in ground water is due to elevated level of magnesium (0.85), sodium (0.82) and carbonates (0.82) indicating soil-water interaction in the area.

In Bahawalpur, EC is the strongest factor which correlates with dissolved solids (0.98), hardness of water (0.94), magnesium (0.91), sodium (0.99), potassium (0.96), bicarbonates (0.94), fluoride (0.95) and nitrate (0.93) indicating presence of salts and its effect water quality indicators. Dissolved solids also strongly correlate with hardness of water (0.95), magnesium (0.95), sodium (0.97), potassium (0.98), bicarbonates (0.92), fluoride (0.98) and nitrate ion (0.95) which also indicates salt effect on water quality parameters. It seems that all these values are associated with salts which add into the ground water through weathering of parent rocks altering overall water chemistry. Calcium, sodium, magnesium and potassium are all water quality parameters which govern by external factors. All anions fluoride (0.88), chloride (0.92) and nitrate (0.79) are strongly correlated to bicarbonates due to anion exchange among soil/water interface. Nitrate and fluoride also strongly correlated to each other where increase in one concentration will also increase in the concentration of others. Total coliform and E. *coli* are weakly correlated with chemical properties of water. Microbial contents are weakly correlated with EC () and TDS () and made entry into ground water aquifers through sewage water which

demonstrates that chemical constraints don't ingress into bacterial activity. Arsenic is strongly correlated to cadmium (0.92) in the ground water of Bahawalpur while very weakly correlates with pH (0.19) and EC (0.26) representing local pollution on ground which percolates into ground water and no giving or taking with water quality indicators.

Person correlation matrix indicates that chemical parameters along with potential contaminants which are strongly correlated with water quality parameters. Pearson correlation data is important in analyzing ground water quality, sampling, ranking and planning sustainable water management in two major southern Punjab cities i.e., Multan and Bahawalpur.

Multan	pH	EC	TDS	HD water	Ca^{2+}	Mg^{2+}	Na^{2+}	K^{+}	CO_3^{-}	HCO_3^{-}	F^{-}	Cl^{-}	NO_3^{-}	T. Coliform	E. *coli*	As	Cd	Cr
pH	1.00																	
EC	-0.45	1.00																
TDS	-0.56	**0.98**	1.00															
HD water	-0.82	0.69	0.76	1.00														
Ca^{2+}	0.05	0.31	0.36	0.27	1.00													
Mg^{2+}	-0.17	0.37	0.44	0.58	**0.89**	1.00												
Na^{2+}	-0.16	0.36	0.43	0.55	**0.91**	**0.99**	1.00											
K^{+}	-0.22	0.25	0.36	0.32	**0.89**	0.75	0.79	1.00										
CO_3^{-}	-0.20	0.38	0.45	0.58	**0.91**	**0.99**	**0.99**	0.80	1.00									
HCO_3^{-}	-0.66	0.24	0.39	0.69	0.62	0.74	0.75	0.80	0.77	1.00								
F^{-}	-0.87	0.80	**0.85**	**0.89**	-0.00	0.23	0.20	0.11	0.23	0.44	1.00							
Cl^{-}	-0.19	0.32	0.41	0.10	0.66	0.36	0.42	**0.85**	0.43	0.52	0.13	1.00						
NO_3^{-}	-0.41	0.84	**0.87**	0.78	0.70	0.80	0.80	0.59	0.81	0.59	0.65	0.41	1.00					
T.Coliform	-0.54	0.09	0.14	0.71	-0.04	0.40	0.35	-0.07	0.36	0.47	0.46	-0.48	0.30	1.00				
E. *coli*	-0.27	**0.87**	0.84	0.71	0.40	0.59	0.56	0.17	0.56	0.23	0.65	0.03	**0.89**	0.36	1.00			
As	-0.12	0.55	0.53	0.65	0.50	0.77	0.73	0.20	0.72	0.32	0.39	-0.16	0.79	0.59	**0.87**	1.00		
Cd	-0.25	0.12	0.18	0.62	0.55	**0.85**	0.82	0.41	0.82	0.66	0.21	-0.10	0.57	0.78	0.47	0.79	1.00	
Cr	0.80	-0.62	-0.65	-0.57	0.35	0.23	0.25	0.11	0.21	-0.16	-0.87	-0.13	-0.27	-0.15	-0.29	0.07	0.26	1.00

Table 3 representing Pearson correlation among different measured parameters from different locations of Multan & Bahawalpur

Bahawalpur	pH	EC	TDS	Hardness	Ca^{2+}	Mg^{2+}	Na^{2+}	K^{+}	HCO_3^-	F^-	Cl^-	NO_3^-	T. Coliform	E. *coli*	As	Cd
pH	1.00															
EC	-0.44	1.00														
TDS	-0.49	**0.98**	1.00													
HD water	-0.71	**0.94**	**0.95**	1.00												
Ca^{2+}	-0.17	0.76	0.83	0.68	1.00											
Mg^{2+}	-0.64	**0.91**	**0.95**	**0.95**	0.82	1.00										
Na^{2+}	-0.48	**0.99**	**0.97**	**0.94**	0.73	**0.92**	1.00									
K^{+}	-0.37	**0.96**	**0.98**	**0.90**	**0.89**	**0.93**	**0.95**	1.00								
HCO_3^-	-0.58	**0.94**	**0.92**	**0.95**	0.56	0.83	**0.94**	**0.86**	1.00							
F^-	-0.60	**0.95**	**0.98**	**0.96**	0.83	**0.99**	**0.95**	**0.96**	**0.88**	1.00						
Cl^-	-0.66	0.83	0.78	**0.87**	0.31	0.74	**0.86**	0.69	**0.92**	0.77	1.00					
NO_3^-	-0.25	**0.93**	**0.95**	0.83	**0.93**	**0.89**	**0.92**	**0.99**	0.79	**0.92**	0.60	1.00				
T. Coliform	-0.30	-0.00	0.07	0.15	0.11	0.05	-0.08	0.04	0.13	0.08	-0.12	-0.02	1.00			
E. *coli*	-0.68	0.52	0.64	0.68	0.72	0.81	0.53	0.64	0.43	0.75	0.31	0.60	0.30	1.00		
As	0.19	0.26	0.35	0.15	0.78	0.43	0.26	0.48	-0.02	0.39	-0.20	0.57	-0.14	0.56	1.00	
Cd	-0.01	0.14	0.24	0.12	0.63	0.42	0.16	0.34	-0.12	0.33	-0.19	0.41	-0.23	0.66	**0.92**	1.00

Discussion:

Access to ground water for drinking purpose is of immense importance which directly affects the health of human being. pH of water is essential parameter to evaluate the hydrogen potential in the water as pH range between 6.5-8.5 is good for all kind of activity. Ground water samples collected from Multan and Bahawalpur were within the range but exceed 7 gives idea about their basic property. Moreover, pH also influences various heavy metal co-existences in water which had grave impact on chemistry which upon consumption causes different health related hazard (Dirisu et al., 2016). Electrical conductivity of water describes capacity of water to conduct electric current while TDS is the concentration of dissolved solids, added salts and minerals in the given volume of water. Usually water having high level of TDS also exhibit high EC as dissolved solids are capable of conducting electrical current. Consumption of water having high concentration of TDS will ultimately results into diarrhea, fainting, itching and respiratory problems while long term usage will results to cancer, loss of memory due to denaturing of signaling through central nervous system and renal diseases (Krishnamoorthy et al., 2023). According to Chebet et al (2020), high TDS will cause specific ion toxicity in water which affects human health. Results indicate that all five specific areas from both cities were well above the minimum threshold according to WHO making water unfit to consume. The most prominent reason behind increased TDS is anthropogenic activities coupled with geochemical changes in earth make water unfit for human consumption. Current work also indicates that ground water hardness from selected areas also surpasses the minimum threshold which usually increases by percolating principal components from detergents i.e., calcium and magnesium. Usually fresh water on ground along with sunlight act as a natural barrier to neutralize hardness but same was not happened underground where access to sunlight is not possible. Ground water aquifers in Pakistan were covered by rocks of calcium carbonates which upon weathering also enhance hardness in ground water (Mohsin et al., 2013). Cations like calcium and magnesium is important to public health since human body always needs adequate quantity of both minerals. Rocks of calcite, limestone are primary deposits of both mineral and add into water through weathering. Since both minerals are of immense importance so there maximum intake has no harmful effect on public health (Kozisek, 2020). Our result also suggests that ground water of both cities also have adequate amount of these minerals which is beneficial for human health. Sodium and potassium were also noted in the adequate range for human consumption. Chloride ion is associated with Ca^{2+}, Mg^{2+}, Na^{2+} and K^{+} which create specific ion toxicity. Chlorine is the largely used in the cleaning of water treatment plant which might seeps down to the ground water and become sink for chloride ion however in our case chlorine ion in ground water samples were less enough not to become toxic upon consumption. Inorganic fertilizers containing chloride ion get mix with agricultural wastage and makes way to ground water is another source of chloride ion which contaminate water. Our results also indicates that chlorine ion were still in permissible limit as per WHO (Geilfus, 2019).

Carbonates, bicarbonates, sulfates and nitrate were derived into ground water by natural weathering of parent material. Municipal, industrial and agricultural wastage also add anions in ground water. These anions get mix up with magnesium and calcium degrades water quality thus creating hostile environment (Hasan and Muhammad, 2020). Presence of carbonates and bicarbonates in ground water points towards the occurrence of limestone in the area however area distinguish by high pH content is best suited to bicarbonates as it neutralize pH and made water good enough to drinkable (Murakami et al., 2015). In our study area Mohajir colony only exhibit highest bicarbonate content while carbonates were not found in any of the ground water samples collected from Bahawalpur. Concentration of nitrate is important to infants as it creates blue

baby syndrome. Fluoride concentration is also important to human health as it prevent oral cavity from microbes and germs buildup and its concentration in ground water depends upon TDS, pH, temperature and depth of ground water aquifers (Mandinic et al., 2010).

Ground water quality index (WQI) indicates that 60% ground water samples from Multan and 40% samples from Bahawalpur were hazardous for drinking purpose. 40% samples from Multan and 60% samples from Bahawalpur falls in poor category while no ground water sample falls in good and excellent category. Poor ground water quality index in Multan and Bahawalpur is due to excess of dissolved solids and EC. The second most important reason behind poor water quality is addition of bicarbonates and hardness in ground water due to mix up of chloride in water. It has been understood that ground water qualities of both cities were poor enough that it couldn't be used for domestic purpose any more.

Arsenic, cadmium and chromium were also detected in ground water samples along with other chemicals. Heavy metals in ground water based on concentration are harmful or harmless to biotic factor. Marked increase was noted in the water samples of two areas in Multan while one area in Bahawalpur. Chromium above WHO threshold only found in one area of Multan while it was not detected in the ground water of Bahawalpur. Installation of industrial units nearby urban areas is the primary reason behind addition of heavy metal in ground water. Another reason is the addition of agricultural waste into open wells which directly pollute water resource. It has been reported that consumption of cadmium containing water directly affect central nervous system and might cause other degenerative disorders in human body. Metabolic activity is largely reduced due to Parkinson's diseases (WHO, 2017). Population of southern Punjab is most vulnerable to cadmium toxicity due to high exchange capacity of Cd in soil/water interface due to aridity (Pan et al., 2010). Chromium is the principal component used in tanning industry from where it easily pollutes fresh water resource even present on or below ground. According to Srinivasa Gowd and Govil, (2008) the rocks of granite around ground water doesn't contain chromium as Cr didn't have capability in forming complex. This theory strengthen that Cr intrude into fresh water through foreign pollutant. Chromium is only present in the ground water of Multan where its concentration below WHO limit except for one area. Heavy metal pollution index (HPI) was noted to calculate its concentration in water. A medium to high concentration was noted from densely populated areas to adjoining industrial units which are the source of heavy metals. Results indicate that water is not favorable for drinking purpose due to high concentration of heavy metals (Hartiningsih et al., 2024).

Occurrence of total coliform and E. *coli* in ground water is based on the source of contamination and its characteristics along with its interaction with other pollutants in water. Water samples indicate the presence of microbes which could be due to the addition of municipal waste into water. Total coliform and E. coli were present in the small intestines of cold blooded animals and humans from where it easily moves to soil and percolate down to ground water resource (Odonkor and Ampofo, 2013). Vomiting, headache, nausea, dirreha and stomach pain is common when consuming bacterial contaminated water on large scale for long time without any effective treatment (Adekunle et al., 2020).

Conclusion:

Current work reveals the number of samples showing various parameters that exceeds the WHO threshold in ground water of selected areas of two major cities of Southern Punjab, Pakistan. From overall work it can be concluded that most of the parameters are above permissible limit making water unfit for drinking purpose. During sampling it has been noted that over usage of water resources is common which severely affect water quality in creation areas. Electrical conductivity, TDS, hardness of water, total coliform, E. *coli*, arsenic, cadmium and chromium increases WHO limits

in various ground water samples which confirms infiltration of industrial and municipal waste water into ground water. Furthermore, water quality index indicates that all ground water samples are unfit for drinking as well as domestic purpose. 3 samples out of 5 in Multan are poor enough to be used for drinking purpose, similarly 2 out 5 ground water samples from selected areas of Bahawalpur are also falls in poor category. Heavy metals As, Cd and Cr also surpasses WHO threshold in ground water of various areas which is an alarming situation. It is concluded that continues monitoring by spatial analysis is mandatory for sustainable development of ground water resources.

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