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Drinking suitability assessment of treated and untreated ground water used in Bahawalpur City of Pakistan

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ABSTRACT

Background: Availability and supply of clean drinking water is essential for healthiness of the people. Bahawalpur is amongst the rapidly growing cities of Pakistan. Underground water table is declining and contamination in water is increasing over time. The city is dependent upon ground water, whereas the availability of safe drinking water is becoming a major challenge for both government and city dwellers.

Objectives: The basic objectives of the study were to provide a precise assessment of the drinking suitability of treated and untreated ground water used in Bahawalpur city and to point out appropriate drinking water areas.

Methods: Drinking water samples were obtained from 26 water filtration plants installed by the government in Bahawalpur City of Punjab Province. At the same time, samples of un-filtered ground water were also collected from the supply sources of filtration plants and houses located nearest to the filtration plants. The collected samples were tested from the labs of Pakistan Council of Research in Water Resources and Public Health Engineering Department.

Results: Results show that assessed parameters of only 7.7% samples of unfiltered ground water fall within permissible limits for drinking and 92.3% samples deviate from WHO standards. Results were compared with the international standards for drinking water suitability set by WHO. Thus, unfiltered ground water of most of the areas of Bahawalpur City is unhealthy and not suitable for drinking. Whilst the assessed parameters of 65.4% of the samples of filtered ground water fall within the permissible limits of WHO and are found suitable to be used for drinking purpose.

Conclusion: This study concluded that the use of untreated ground water in Bahawalpur City is un-healthy. Thus, more filtration plants are required to be installed and properly managed to provide safe drinking water to the masses.

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1. INTRODUCTION

Safe drinking water is one of the most important and basic human needs for healthy life. It is an essential requirement for all customary household uses comprising drinking, meal preparation and individual cleanness (World Health Organization, 2011). About 71% of the earth's surface is covered with water and 97.5% of that constitutes salty oceans. The remaining 2.5% is fresh water, out of which less than 1% of freshwater is useable (PCRWR, 2006). Almost 30% of all fresh water and 97% of liquid fresh water is stored in aquifers which are tapped on every continent and are basic source of drinking water for over 1.5 billion people worldwide (Oskin, 2018; Safe Drinking Water Foundation, 2017). Nearly one-third of Asia's overall drinking

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water supply comes from aquifers. Several important cities of the world like Mexico City, Dhaka, Jakarta, Lima, Bahawalpur etc. rely on aquifers for almost their entire water supply (Safe Drinking Water Foundation, 2017). Globally, water use has increased at a rate twice the rate of population growth over the last century and it is still increasing in all sectors. Clean water supply has always been and continues to be one of the major challenges of civilizations. Ancient civilizations also faced several problems associated with water as a means for their existence (Mays, 2007). Although, water is a life sustaining natural commodity but is scarce in many countries. Some countries are facing physical scarcity where water is physically short like several African, Asian and South American countries, while some countries are facing economic scarcity where due to lack of infrastructure or institutional inefficiency, water resources are not properly managed like Pakistan. In such countries, water scarcity gives birth to the issue of water contamination also.

The effects of climate change are also threatening the water resources. Currently, above two billion people live in countries facing high water stress and their number would continue to increase (World Data Lab, 2020). However, awareness about the worth of water and influence of quality considerations of water on human health is increasing globally and majority of the people are cognizant of the fact that water will be one of the highly critical natural resource in coming times (Arain et al., 2008; Daud et al., 2017; Dixit & Tiwari, 2008). At present, world population has grown to over 7.8 billion (World Population Clock, 2020). Its water demands are also increasing in different sectors like domestic, agriculture, manufacturing, hydro-electricity generation etc. As a consequence, water scarcity and pressure on existing water resources is increasingly damaging the quality of usable water. It seems that supply of safe drinking water could be the biggest problem of the 21st century.

In Pakistan, during the past few decades, water consumption has increased immensely because of rapid increase in population, change in the habits and ways of life, and intensification of vast array of wide-ranging human activities. Over two-third of the country's 207.8 million population depend upon ground water for domestic uses which is deteriorating rapidly together in terms of quantity as well as quality. In arid and semi-arid areas like Bahawalpur, intensive agricultural practices are also threatening the quantity and quality of groundwater resources (Daud et al., 2017; Q. Zhang et al., 2019). For such reasons, the assessment of water quality has attained the status of a critical research issue in different countries (Alobaidy et al., 2010). Many studies, hitherto, have been conducted on its availability, conservation and suitability in various parts of the world. However, in case of Pakistan only a handful studies related to quantity and quality of water have been conducted on national and local level (Daud et al., 2017; Hussain et al., 2016; Khan et al., 2014; Mehmood et al., 2012; Memon et al., 2011; Mohsin et al., 2013; Safdar et al., 2014; Safder & Babar, 2019; Shahid et al., 2015; Zulfiqar et al., 2016). On government level, PCRWR (2006) assessed the quality of ground water in 25 cities of Pakistan including Bahawalpur where due to extreme arid climatic conditions, water demands are comparatively high. Thus, for this area more scientific studies are certainly required to predict the future trends and problems, and to help for the preparation of guidelines for the planning and sustainable management of clean water supply.

Earlier studies indicate that a close relationship exists between human health and ground water pollution (Rahman et al., 2018; Y. Zhang et al., 2018). Whether using it for drinking or for any other domestic purpose, contaminated water can cause diseases and makes the life worse. Contaminated water containing chemical, microbiological or other impurities invisible to naked eye is a direct source of spreading several diseases. Water borne diseases cause enormous encumbrance on people's health specifically in less developed areas like Bahawalpur. Use of unsafe drinking water may cause several diseases like gastro, typhoid, cholera, intestinal worms etc. Many of the contagious diseases in the world over are water borne that transmit because of drinking contaminated water and may result in morbidities and mortalities. In numerous developing countries including Pakistan, deteriorating water quality has caused hepatitis-E (Rab et al., 1997), diarrhoea (Fewtrell et al., 2005; Organization, 2000; Thompson & Khan, 2003; World Health Organization, 2004), dental carries and oral hygiene (Ishaque & Khan, 2001), reduction in brain functioning and intelligence in children (Dillingham & Guerrant, 2004), and anaemia in children (Stephenson et al.,

2000). Some past studies indicate that 68% of the rural inhabitants of Pakistan are drinking poor quality water and nearly 100 million patients of diarrheal diseases are being recorded in hospitals in a year (Tahir et al., 1998; Tahir & Rashid, 1997). Interventions, on the other hand, made for the improvement of drinking water quality, substantially benefit the human health (World Health Organization, 2011). Drinking clean water plays crucial role in preventing diseases. Taking eight glasses of clean water every day can reduce the chances of breast cancer significantly, danger of colon cancer up to 45% and bladder cancer up to 50%. Consumption, over lifetime, of clean drinking water, defined according to WHO recommendations, does not cause any substantial health risk including various sensitivities which might happen among different stages of life. In developed countries, drinking water quality is taken very seriously without any kind of compromises and water quality parameters are analysed to determine its status before supplying to the community (PCRWR, 2006).

Although, treated and untreated surface water is also used for drinking in several areas of Pakistan, but due to the dryness of Sutlej River and low precipitation in study region, people had to be dependent on the ground water for drinking and other uses. Resultantly, the level of underground water table is steadily falling. Rapidly enhancing consumption has increased the speed of ground water depletion and contamination. Each year several mortalities occur because of health issues related to the use of polluted water in Pakistan, including study area. In view of such kind of dangers, Government of Pakistan launched the project, 'Clean Drinking Water for All' in 2004 with the objective to install at least one water filtration plant in each union council (UC) of the country. Under this project, some water filtration plants were also installed in Bahawalpur City. Currently, almost entire population of Bahawalpur City depends upon ground water for household consumption. The ground water obtained through water pumps and turbines is used directly as well as after purification. Filtered water is obtained from filtration plants that have been installed time to time by the government at 32 different locations of the city (Map 2).

Assessment of water quality is essential before using it for numerous envisioned needs. To make decisions about the quality and health of water, contamination levels of various parameters are measured. It is reasonably possible that any water sample will show different levels of impurities of various parameters investigated (Abbasi, 1999). As nature and form of drinking water differ, standards of its purity may also differ to some extent across the regions and countries, for instance unanimously acceptable and universally applicable, however, no single approach regarding water quality standards, until now, exist. It is thus, crucial to note that for framing and implementing standards of water quality, health department and the local government are responsible agencies. This study has been carried out to assess the drinking suitability of treated and untreated ground water used in Bahawalpur City as per the WHO's standards for physical, chemical and microbiological parameters. Furthermore, this study also aims to points out the appropriate drinking water areas.

2. METHODS

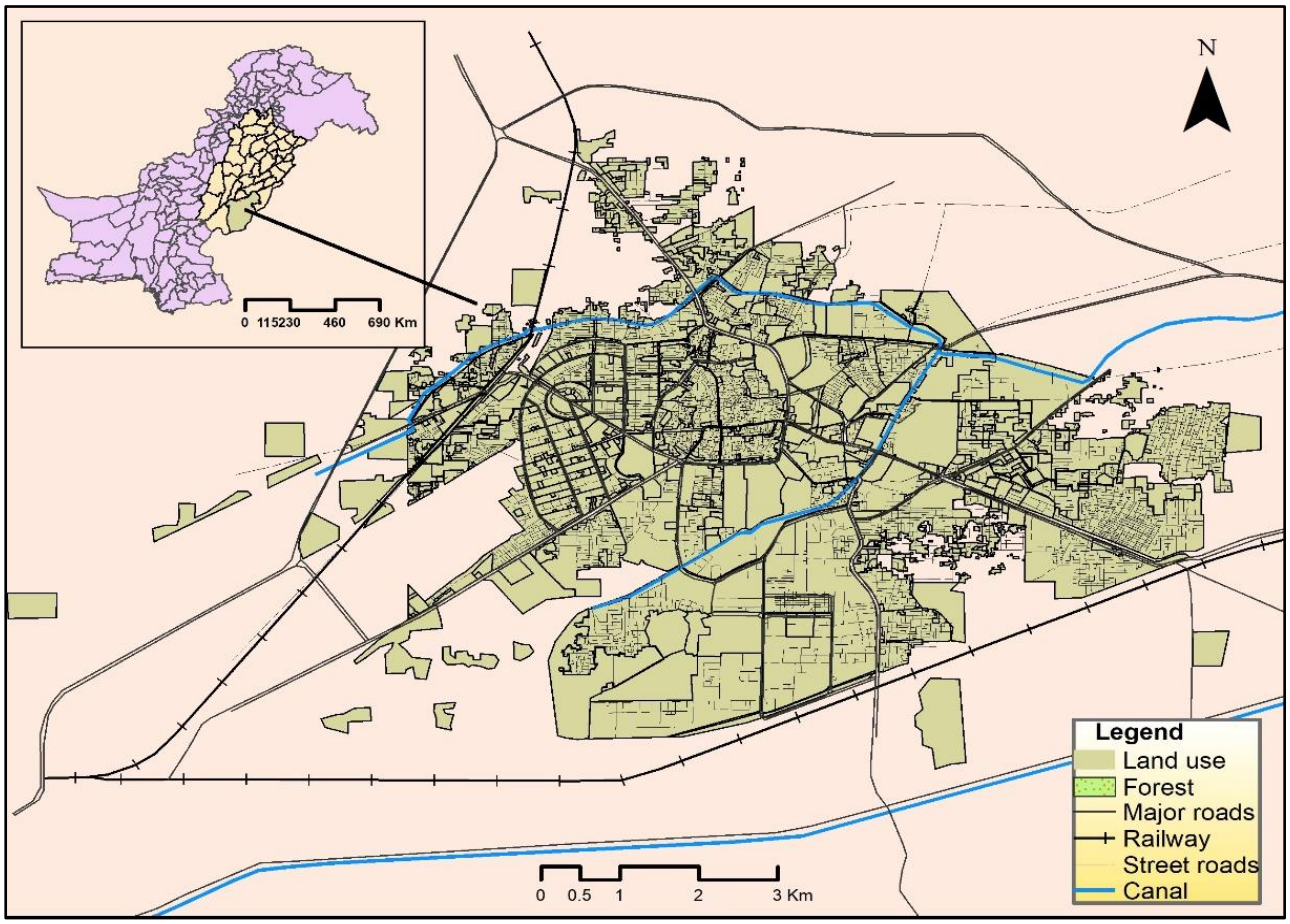
2.1 Study design

Using case study design, the current study has used cross-sectional data.

2.2 Setting

The study area, Bahawalpur City, is located in the southern part of the Punjab province of Pakistan (Map 1). It lies along the south-eastern bank of Sutlej River on northern fringe of the Cholistan desert. The absolute location of city is 71°-41′-1″ East longitude and 29°-23′-44″ North latitude. Covering an area of 237.2 square km, population size of 762,111 persons, and population density of 3213 persons per square km, it is 12th biggest city of Pakistan (Pakistan Bureau of Statistics, 2017). Founded in 1748, Bahawalpur City enjoyed the status of capital of the former princely state while currently it is headquarter of the Bahawalpur District. It is one of the fastest growing cities of Pakistan. In addition to rapid natural growth of urban population, incessantly increasing rural to urban migration has put lot of pressure on its resources.

Although, during the past few years the city has attracted ample attention of the provincial government in terms of development, even then it is still facing several problems including the shortage of safe drinking water.



Map 1 Location of study area (Bahawalpur City) Punjab and Bahawalpur district

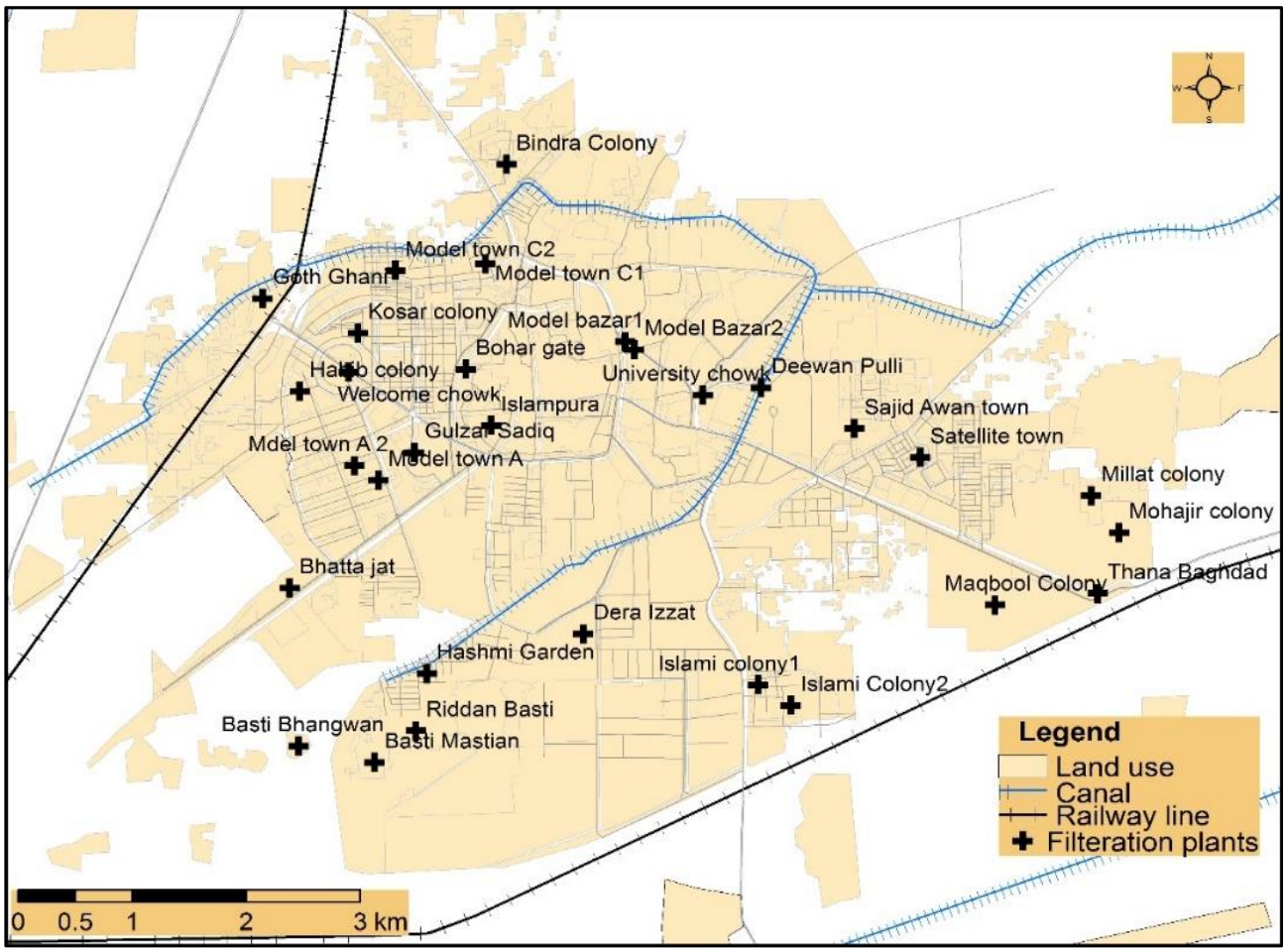
2.3 Data sources and measurement

Map 2 shows the location of filtration plants in the study area. In total, there were 27 functional, 3 non-functional (Maqbool Colony, Basti Deeran and Satellite Town-2), and 2 under construction (Gulzar-e-Sadiq Road and Basti Bhangwan) water filtration plants in Bahawalpur City (including cantonment area) at the time of field survey. However, the samples of water for laboratory test were collected from 26 filtration plants. One functional (Liaquat Road, Model Town-A) which was closed at the time of survey, three non-functional, and two under-construction plants were dropped from the study because they are not currently supplying drinking water. The suitability of the untreated and treated drinking water of different locations of the city was tested (Table 2 & 4). For this purpose, duplicate samples were collected from each location, sample of treated groundwater from filtration plant, and sample of untreated water from the supply source of the treatment plant or from any other water-pump located nearest to the treatment plant.

2.4 Sample design

Sampling and analysis (SAP) plain was prepared according to the lab requirements before the collection of samples. SAP contained sampling locations, types and number of samples, and quality control requirements of the study. According to the instructions of lab staff, all the samples were collected in duplicate in 1,000 ml plastic bottles from most frequently used tap outlets of unfiltered and filtered water separately from 26 locations of the city (Map 2). The tapes were run at least five minutes and the bottles were rinsed three times before filling in with sample water. For the detection of metals, samples were

gathered separately in polyethylene bottles containing 0.2 ml concentrated nitric acid as preservative per 100 ml of sample. All the bottles were carefully screwed with lid and labeled before delivering them to the labs for analysis.



Map 2 Location of groundwater filtration plants in Bahawalpur City

2.5 Data analysis methods

The collected samples were sent forthwith to the PCRWR and PHED laboratories Bahawalpur to analyze the physical, chemical and bacteriological parameters of quality including toxic and trace elements with standard analytical methods. The pH, TDS and EC were analyzed using pH-meter (Jenway 3505, UK) and conductivity-meter (Inolab, Germany). Using phenolphthalein and methyl orange as indicators, alkalinity of water was estimated by titration with strong acid. The concentration of sulfates etc. was determined with the help of spectrophotometric method using reagents. The amounts of chlorides and fluorides were determined by argentometric titration and SPADNS method using colorimeter respectively. Essential minerals such as calcium and magnesium were determined by complexometric titration. The amount of heavy metals was estimated by atomic absorption spectrometer using air acetylene flame for combustion with single element hollow cathode lamp. The presence of coliform bacteria was determined by MacConkey's broth kits (MB-Kits). Occurrence of yellow or yellowish colour established the existence of coliform bacteria while appearance of purple or reddish colour pointed out bacterial absence. Though, direct plate count method was also available, but the coliform colonies were estimated by using membrane filter technique. The results were then compared with the quality standards set by World Health Organization (2011) given in Table 1 to reach the conclusions. The amount/concentration of tested parameters determined the suitability or unsuitability of drinking water samples.

Table 1 WHO standards of physical, chemical and bacteriological parameters for safe drinking water

Sr. No.	Parameter	Measuring Unit	WHO Permissible Limits
1	pH	Numeric Scale (0-14)	6.5-8.5
2	Electrical Conductivity	uS/cm^2	2150 uS/cm^2
3	Turbidity	NTU (Nephelometric Turbidity Units)	5 NTU
4	Alkalinity	ppm	200 ppm
5	Calcium	ppm	75 ppm
6	Magnesium	ppm	150 ppm
7	Hardness	ppm	500 ppm
8	Chlorides	ppm	200 ppm
9	Sulfate	ppm	200 ppm
10	Total Dissolved Solids	ppm	1000 ppm
11	Iron	ppm	0.3 ppm
12	Fluoride	ppm (mg/L)	1.5 ppm (1.5 mg/L)
13	Arsenic	ppb	10 ppb
14	Bacterial Presence	Presence/Absence	Absence
	No. of Colonies	No. per 100 ml	0/100 ml

Source: (World Health Organization, 2011)

3. RESULTS

According to the physical properties, clean and safe drinking water should be transparent, colourless, odourless, and free from suspended impurities and harmful micro-organisms. It should also contain some salts and minerals necessary for human body and some dissolved gasses to add taste. It has been ascertained that several trace elements are vital for human health, but their excessive concentrations in water and ingestion in high amounts, can cause serious health issues (Goldhaber, 2003; Mastoi et al., 2008; World Health Organization, 2004). Such elements include Zn, Cu, Fe, Mn, Cd, Ni and Pb etc.

Physical tests of unfiltered and filtered water samples were conducted to determine whether water is polluted or not. These tests principally include temperature, colour, odour, taste, foaminess (presence of the detergents, soaps etc.), turbidity, electrical conductivity (EC) and total dissolved solids (TDS). Temperature of all collected unfiltered and filtered groundwater samples was found almost 25ºC which is considered as normal. All the samples were found colourless, odourless, tasteless and foamless while turbidity, EC and TDS varied from sample to sample (Table 2 & 4). An interesting and widely accepted notion among the people about the taste and quality of filtration plants' water was noted during the field survey. Majority of the people who use treated water of filtration plants opined that water of Model Bazar filtration plants is relatively better in taste and drinkability, if compared to the filtration plants' water of other locations of the city. Besides lab results, long queues of the people coming from various vicinities of the city to obtain water from Model Bazar filtration plants was another evidence of this view.

3.1 Laboratory assessment of unfiltered drinking water used in the study area

The lab test results of physical, chemical and microbiological/ bacteriological properties of the unfiltered water samples are given in Table 2. The amounts exceeding from WHO permissible limits are shown in bold. According to WHO criteria, unfiltered water was found suitable for drinking at just two locations (7.7% of the total samples) i.e., Hashmi Garden and Kousar Colony, whereas at 24 locations (92.3% of the

total samples) it was unsuitable for drinking, mostly, due to contamination of arsenic and bacteria. The pH value, turbidity, magnesium and sulfates in every sample were found within the acceptable limits. However, other parameters including electrical conductivity, alkalinity, calcium, hardness, chloride, total dissolved

Table 2 Results of chemical and bacteriological analysis of unfiltered groundwater samples

Sample Locality	pH	EC	Tb	Alk	Ca	Mg	Hd	Cl	SO4	TDS	Fe	F	As	Bc/ CC
Dera Izzat	7.49	882	1.02	120	35	75	400	166	71	565	0.00	0.16	**5**	**P/4**
Basti Maseetan	7.66	1265	1.25	150	50	62	410	130	86	810	0.00	0.40	0	**P/3**
Islami Colony-1	8.00	2117	1.11	**210**	**90**	78	**540**	180	70	**1355**	**1.20**	1.13	**55**	**P/5**
Islami Colony-2	8.00	2117	1.11	**210**	**90**	78	**540**	180	70	**1355**	**1.20**	1.13	**55**	**P/5**
Hashmi Garden	7.60	1156	1.02	200	43	100	500	150	80	740	0.00	0.60	0	**-**
Bhatta Jaat	7.35	609	1.09	60	61	28	270	75	40	390	0.00	0.00	0	**P/5**
Muhajir Colony	8.25	**2710**	1.55	**300**	**150**	100	**760**	**280**	160	**1735**	0.00	1.11	10	**P/4**
Millat Colony	7.31	546	1.66	100	23	32	200	80	30	350	0.00	**2.00**	0	-
Thana Baghdad	7.55	937	1.38	170	**105**	35	400	160	90	600	0.00	1.00	0	-
Satellite Town	8.10	**2265**	0.96	**290**	**190**	93	**850**	**280**	120	**1450**	0.00	1.02	0	-
Kousar Colony	7.34	796	1.41	100	40	50	305	110	50	510	**1.03**	0.27	0	-
Sajid Awan Colony	7.30	609	1.20	100	34	36	230	61	50	390	0.00	0.00	**60**	-
Model Town-A (Ghaznvi Road)	7.30	453	1.55	65	23	27	170	80	46	296	0.00	**2.00**	**60**	**P/5**
Islampura	7.21	437	1.00	55	30	18	130	48	29	280	0.00	0.76	**40**	**P/3**
University Chowk	7.29	468	1.21	50	26	25	170	55	30	300	0.00	0.49	**60**	**P/4**
Habib Colony	7.20	390	1.13	50	29	25	175	60	30	250	0.00	0.45	**60**	-
Model Town-A (Rashid Minhas Road)	7.21	375	0.66	49	21	27	160	71	31	240	0.00	**2.00**	**60**	-
Welcome Chowk	7.21	375	1.11	60	29	18	150	55	30	240	**1.10**	0.29	**40**	**P/3**
Bohar Gate	7.23	382	1.88	60	35	20	170	71	20	245	0.00	1.15	**60**	**P/12**
Model Bazar-1	7.20	453	1.76	80	28	27	180	75	30	290	0.00	0.71	**25**	**P/10**
Model Bazar-2	7.20	453	1.76	80	28	27	180	75	30	290	0.00	0.71	**25**	**P/10**
Goth Ghani	7.18	343	1.19	50	30	16	140	46	30	220	0.00	0.15	**70**	-
Model Town-C-1	7.31	625	0.96	160	60	35	340	140	70	400	0.00	0.60	**20**	-
Model Town-C-2	7.31	625	0.96	160	60	35	340	140	70	400.	0.00	0.60	**20**	-
Diwan Wah Pulli	7.35	625	1.26	100	70	33	310	76	49	400.	0.00	**2.20**	0	-
Bindra Colony	7.15	300	1.19	50	17	27	160	48	29	195.	0.00	0.30	**55**	-

Source: Water samples collected by the authors and get tested from PCRWR & Public Health Engineering Department labs Bahawalpur.

Abbreviations: pH=pH-Value, EC=Electrical Conductivity, Tb=Turbidity, Alk=Alkalinity, Ca=Calcium, Mg=Magnesium, Hd=Hardness, Cl=Chloride, SO4=Sulfate, TDS=Total dissolved solids, Fe=Iron, F=Fluoride, As=Arsenic, Bc=Bacteria (P=Present), CC=Colonies of Coliforms per 100 ml of water.

solids, iron and fluoride amounts exceeded from normal limits in different samples. Electrical conductivity of 7.7% and alkalinity of 15.4% samples was found higher than the permissible limits. Excessive amount of

calcium was found in 19.2%, chloride in 7.7%, TDS in 15.4%, iron in 15.4%, and fluoride in 15.4% of the total samples. Arsenic was found in 61.5% and bacteria in 50% of the total samples.

Table 3 Suitability assessment of unfiltered ground water samples for drinking

Sample No.	Locality	Parameters Beyond Permissible Limits as per WHO 2011 Standards	Remarks
1	Dera Izzat	Bacteria	Unsuitable
2	Basti Maseetan	Bacteria	Unsuitable
3	Islami Colony-1	Alk, Ca, Hd, TDS, Fe, As, Bacteria	Unsuitable
4	Islami Colony-2	Alk, Ca, Hd, TDS, Fe, As, Bacteria	Unsuitable
5	Hashmi Garden	-	***Suitable***
6	Bhatta Jaat	Bacteria	Unsuitable
7	Muhajir Colony	EC, Alk, Ca, Hd, Cl, TDS, Bacteria	Unsuitable
8	Millat Colony	F	Unsuitable
9	Thana Baghdad	Ca	Unsuitable
10	Satellite Town	EC, Alk, Ca, Hd, Cl, TDS.	Unsuitable
11	Kousar Colony	-	***Suitable***
12	Sajid Awan Colony	As	Unsuitable
13	Model Town-A (Ghaznvi Road)	F, As, Bacteria	Unsuitable
14	Islampura	As, Bacteria	Unsuitable
15	University Chowk	As, Bacteria	Unsuitable
16	Habib Colony	As	Unsuitable
17	Model Town-A (Rashid Minhas Road)	F, As	Unsuitable
18	Welcome Chowk	Fe, As, Bacteria	Unsuitable
19	Bohar Gate	As, Bacteria	Unsuitable
20	Model Bazar-1	As, Bacteria	Unsuitable
21	Model Bazar-2	As, Bacteria	Unsuitable
22	Goth Ghani	As	Unsuitable
23	Model Town-C-1	As	Unsuitable
24	Model Town-C-2	As	Unsuitable
25	Diwan Wah Pulli	F	Unsuitable
26	Bindra Colony	As	Unsuitable

Source: Water samples collected by the authors and get tested from PCRWR & Public Health Engineering Department laboratories Bahawalpur.

3.2 Laboratory assessment of unfiltered drinking water used in the study area

The laboratory test results of physical, chemical and microbiological/ bacteriological properties of filtered water samples are shown in Table 4. The amounts exceeding from WHO permissible limits are shown in bold. The pH value, electrical conductivity, turbidity, magnesium, sulphates and iron in all the samples were found within the permissible limits. However, other properties including alkalinity, calcium, hardness, chloride, total dissolved solids, and fluoride amounts exceeded from normal limits in few samples. Arsenic

and bacteria were also present in some samples. Results show that according to WHO criteria, filtered water is suitable for drinking at 17 out of 26 locations from which samples were collected and tested in the

Table 4 Results of chemical and bacteriological analysis of filtered groundwater samples

Sample Locality	pH	EC	Tb	Alk	Ca	Mg	Hd	Cl	SO_4	TDS	Fe	F	As	Bc/ CC
Dera Izzat	7.48	876	0.36	140	42	70	380	131	80	561	0	0.16	5	-
Basti Maseetan	7.44	875	0.55	120	40	75	380	155	49	560	0	0.38	0	-
Islami Colony-1	7.16	300	0.40	60	18	21	130	50	40	195	0	0.15	0	-
Islami Colony-2	7.10	312	0.74	60	20	25	150	50	25	200	0	0.21	0	-
Hashmi Garden	7.23	500	0.48	100	50	28	240	90	50	320	0	0.45	0	-
Bhatta Jaat	7.65	1093	0.96	60	40	25	200	55	30	700	0	0.78	0	-
Muhajir Colony	7.96	1656	1.03	**210**	**90**	78	**590**	180	120	**1060**	0	0.60	0	-
Millat Colony	7.23	375	0.76	70	20	22	140	65	30	240	0	**2.00**	0	-
Thana Baghdad	7.31	726	0.33	100	60	37	310	85	50	465	0	0.08	0	-
Satellite Town	7.95	1625	0.55	**210**	**150**	66	**640**	**260**	120	**1040**	0	1.05	0	-
Kousar Colony	7.31	609	0.86	90	35	27	300	86	40	390	0	0.31	0	-
Sajid Awan Colony	7.31	600	1.04	83	22	35	200	71	41	380	0	0.00	**25**	-
Model Town-A (Ghaznvi Road)	7.29	396	0.29	55	24	30	180	61	29	250	0	**2.00**	**60**	**P/6**
Islampura	7.20	343	1.03	60	30	11	110	55	30	220	0	0.31	0	-
University Chok	7.25	476	0.76	80	47	27	220	90	40	305	0	0.40	0	-
Habib Colony	7.24	398	0.39	60	26	35	210	55	30	255	0	0.08	0	-
Model Town-A (Rashid Minhas Road)	7.20	398	0.49	55	18	27	160	61	26	255	0	**2.00**	**60**	-
Welcome Chowk	7.18	359	0.55	40	36	20	170	50	25	230	0	0.35	0	-
Bohar Gate	7.18	385	0.90	70	27	20	160	61	39	250	0	0.29	0	**P/13**
Model Bazar-1	7.22	484	1.01	50	25	27	175	74	40	310	0	0.20	0	-
Model Bazar-2	7.21	437	0.96	60	21	37	200	55	31	280	0	0.83	0	-
Goth Ghani	7.31	656	1.16	90	37	51	300	80	40	420	0	0.35	0	-
Model Town-C-1	7.17	312	1.00	45	45	20	160	55	29	200	0	0.33	**25**	-
Model Town-C-2	7.18	320	0.56	50	25	24	165	60	40	205	0	0.62	**25**	-
Diwan Wah Pulli	7.32	625	0.70	50	48	42	290	71	30	400	0	0.56	0	-
Bindra Colony	7.22	390	1.05	50	24	30	180	49	20	250	0	0.96	0	-

Source: Water samples collected by the authors and get tested from PCRWR & Public Health Engineering Department labs Bahawalpur.

Abbreviations**:** pH=pH-Value, EC=Electrical Conductivity, Tb=Turbidity, Alk=Alkalinity, Ca=Calcium, Mg=Magnesium, Hd=Hardness, Cl=Chloride, SO_4=Sulfate, TDS=Total dissolved solids, Fe=Iron, F=Fluoride, As=Arsenic, Bc=Bacteria (P=Present), CC=Colonies of Coliforms per 100 ml of water.

laboratories, while at 09 locations it is unsuitable for drinking due to contaminations mentioned in bold in Table 4. It was found that 65.4% of the water filtration plants are supplying safe water while 34.6% are supplying unsafe water perhaps because of less care and poor maintenance of water treatment units. The

pH value, electrical conductivity, turbidity, amount of magnesium, sulphates, and iron in all the purified water samples were normal. However, excessive alkalinity was found in 7.7%, calcium in 7.7%, hardness in 7.7%, chloride in 3.8%, TDS in 7.7%, and fluoride in11.5% of the total tested samples. Arsenic was found in 19.2% and bacteria in 7.7% of the total samples.

Table 5 Suitability of filtered groundwater samples for drinking

Sample No.	Locality	Parameters Beyond Permissible Limits as per WHO 2011 Standards	Remarks
1	Dera Izzat	-	Suitable
2	Basti Maseetan	-	Suitable
3	Islami Colony-1	-	Suitable
4	Islami Colony-2	-	Suitable
5	Hashmi Garden	-	Suitable
6	Bhatta Jaat	-	Suitable
7	Muhajir Colony	Alk, Ca, Hd, TDS.	*Unsuitable*
8	Millat Colony	F	*Unsuitable*
9	Thana Baghdad	-	Suitable
10	Satellite Town	Alk, Ca, Hd, Cl, TDS.	*Unsuitable*
11	Kousar Colony	-	Suitable
12	Sajid Awan Colony	As	*Unsuitable*
13	Model Town-A (Ghaznvi Road)	F, As, Bacteria	*Unsuitable*
14	Islampura	-	Suitable
15	University Chowk	-	Suitable
16	Habib Colony	-	Suitable
17	Model Town-A (Rashid Minhas Road)	F, As	*Unsuitable*
18	Welcome Chowk	-	Suitable
19	Bohar Gate	Bacteria	*Unsuitable*
20	Model Bazar-1	-	Suitable
21	Model Bazar-2	-	Suitable
22	Goth Ghani	-	Suitable
23	Model Town-C-1	As	*Unsuitable*
24	Model Town-C-2	As	*Unsuitable*
25	Diwan Wah Pulli	-	Suitable
26	Bindra Colony	-	Suitable

Source: Water samples collected by the authors and get tested from PCRWR & Public Health Engineering Department labs Bahawalpur.

4. DISCUSSION

Availability of and access to safe drinking water is turning to be a major problem for the inhabitants of Bahawalpur City. Ground water is the only source of drinking water in this city. The rate of pumping of water from aquifers is much higher than that of the rate of their recharge. During the field survey, some senior citizens told that underground water-table of Bahawalpur City went down from 35 feet depth in

1988 to 95 feet depth in 2020 indicating a decline of 60 feet just in 32 years at an alarming rate of about 1.9 feet per year. Resultantly, water resources of the area are rapidly dwindling and contaminating. With reduction in quantity, concentration of impurities in water is increasing beyond the WHO permissible limits, thus damaging its quality. Every house in Bahawalpur City is installed with its own water pump to draw ground water which is used for drinking as well as for other domestic purposes mostly without any scientific treatment. The average depth of these water-pumps is 90 to 100 feet. Salts concentration is naturally high almost everywhere in the city because it is located in the region geographically known as Bahawalpur Plains (which is a part of Upper Indus or Punjab Plains) and termed as 'salt sink region' because of having high salt concentrations in soils and water. The analysis of water samples also indicate slightly above normal salts concentration in most of the cases of specifically untreated water.

Quality of water for drinking is determined by its physical (aesthetic), chemical and microbiological properties that vary markedly throughout the world. Most of the physical properties are determined by senses of sight, touch, smell and taste. For example, color, turbidity, floating debris and suspended solids by sight, temperature and foam by touch, odour by smell, and flavor and taste by tongue. Water temperature affects some of its important characteristics like thermal capacity, density, viscosity, specific weight, surface tension, solubility of dissolved gases, specific conductivity and salinity etc. Chemical and biological reaction rates are accelerated with increase in temperature. Water color is a concern of its quality mainly due to aesthetic reason. Colored water gives the look of being risky for drinking, even if it may be impeccably safe for community use. On the other side, color can be indication of the presence of organic materials like humic compounds or algae etc. Taste and odour are human perceptions of water quality. Presence of simple compounds produce salty and sour tastes while presence of complex organic compounds produces sweet and bitter tastes. Many people think that quality of drinking water is determined by its smell, colour and taste. To them, bad smelling, faint colour and brackish taste make the water undrinkable. But these physical properties are not the absolute determinants of water quality. Chemical and microbiological properties are rather more important determinants of water quality. For instance, presence or absence of disease causing organisms cannot be estimated by look, smell or taste of water and only test is the reliable way.

Tested water samples of both untreated water and treated water from 26 locations of the city clearly indicate that use of unfiltered water can be seriously harmful for human health because at most places it does not meet the WHO standards set for safe drinking water. Out of total tested samples of unfiltered water, 92.3% were found polluted and just 7.7% were found safe for drinking. On the other hand 65.4% of the filtered water samples were found safe for drinking and 34.6% were found unsafe mainly due to inadequate and less care of some filtration plants. Surreptitious investigation revealed that the plants supplying unsafe water were not timely and properly maintained otherwise they can also supply safe water. Results reveal that electrical conductivity of 7.7% samples of unfiltered water is excessive whereas in all the samples of filtered water, it was within the desirable limits. Ionic concentration of dissolved solids determines the electrical conductivity of water. It tells the amount of dissolved substances, minerals and chemicals present in the water (Meride & Ayenew, 2016). Higher electrical conductivity indicates the higher concentrations of impurities. Thus, long term drinking of water showing electrical conductivity beyond the WHO permissible limits can cause numerous health problems. Alkalinity of 15.4% samples of unfiltered and 7.7% samples of filtered water has been recorded higher than the WHO recommended limits. Though, slightly alkaline water is considered safe for drinking, but excessive alkalinity may have side effects such as it can lower natural acidity of the stomach necessary to kill the growth of harmful bacteria.

Amount of TDS in 15.4% of unfiltered and 7.7% of filtered water samples is high. Higher TDS value is not necessarily harmful but may cause bitter taste and hardness of water which leads to staining and scale formation. Calcium (Ca) that takes part in several metabolic processes of the body and is one of the basic structural components of bones, teeth and soft tissues has been noted higher in 19.2% samples of unfiltered and 7.7% samples of filtered water. Although, short time consumption of excessive amounts of

calcium do not have any harmful effect on the human body, but its long term intake may cause hypercalcemia, suppression of bone remodeling, calcification in urinary tract and soft tissues like kidneys and arterial walls (Azizullah et al., 2011). Chloride (Cl) which is one of the most important electrolytes in the blood has been recorded higher in 7.7% of unfiltered 3.8% of filtered water samples. It helps in maintaining proper blood volume and blood pressure, and in balancing the amount of fluid inside and outside of body cells. However, higher concentrations of chloride may cause bitter taste of water, hyperchloremia, high blood pressure, kidney problems etc. Fluoride is another important mineral that plays vital role in dental health and in preventing growth of oral bacteria. Its concentration in drinking water depends upon several factors like depth of water source, temperature, pH, TDS, and alkalinity (Mandinic et al., 2010). It is excessive in 15.4% of unfiltered11.5% of filtered water samples. Ingestion of its excessive amounts may cause dental and skeletal fluorosis leading to bone fracture, bone cancer, arthritis, kidney problems and low intelligence quotient (IQ) in children (Mandinic et al., 2010; Pehrsson et al., 2006). Presence of iron (Fe), beyond the permissible limits, in 15.4% of the unfiltered water samples is an alarming sign while its absence in all filtered water samples is a healthy sign for the consumers. Its presence in drinking water may be due to several factors such as the presence of organic matter can increase iron concentration in water. Its occurrence in high concentrations can be indication of arsenic presence also (Van Halem et al., 2010). Drinking such water for long time may cause mutagenicity, nephrotoxicity and renal carcinoma (Al-Saleh, 1996). Presence of arsenic in 61.5% of unfiltered and 19.2% of filtered water samples is a real danger for the users. It is highly hazardous pollutant because it may change its form and difficult to remove from water. On reduction in water it may get converted from As (V) to As (III) which is more dangerous for human health. It is also known for its carcinogenic effects and acute toxicity and is more hazardous for humans than animals (Mehmood et al., 2012). Presence of arsenic in drinking water may cause lung, bladder and kidney cancer and skin problems (Saint-Jacques et al., 2018). Bacterial contamination in 50% of unfiltered and 7.7% of filtered water samples is another danger for the users. Use of such water may cause diarrhea, nausea, cramps, headache and other such problems specifically in children and people with compromised immune system.

All such findings are in line with previous studies conducted on drinking water quality of Bahawalpur city (Khan et al., 2014; Mehmood et al., 2012; Mohsin et al., 2013; Mohsin et al., 2019; Safdar et al., 2014). In sum, the study reveals that ground water at most places of the city is contaminated and unsafe for drinking until and unless treated. Use of unfiltered ground water may cause several health related issues mentioned in the above discussion. Many diseases like diarrhea, abdominal cramps, dysentery, gastritis, hepatitis, typhoid have already been reported to spread in the study area mainly because of drinking contaminated water (Khan et al., 2014). Water filtration plants are also required to be upgraded and maintained properly for continuous supply of safe drinking water.

5. CONCLUSION

After assessing the drinking suitability of treated and untreated ground water used in Bahawalpur City, the study concludes that the inhabitants of this area exclusively rely on the aquifer's water for drinking and other household uses. The analysis of the physical, chemical and microbiological conditions of treated and untreated drinking water samples revealed some alarming facts. Out of 26 unfiltered water samples, 24 deviated from WHO standards set for drinking water. Main contaminants are arsenic, bacteria, iron, calcium, fluorides and TDS. Arsenic, along with other impurities in some cases, showed presence in the ground water of 17 locations. Bacteria, in addition to other impurities, showed presence in the drinking water of 13 locations. Out of 26 filtered water samples, 9 deviated from WHO standards. Along with other impurities, arsenic showed presence in 5, bacteria in 2, fluoride in 2, calcium and TDS in 2 and chloride in one sample. Amongst the unfiltered water samples, only 2 out of 26 qualify and in the filtered water samples, 17 out of 26 qualify for drinking according to the standards set by WHO.

Supply of unsafe drinking water from some filtration plants is an extremely worrying matter because users are unaware of this state of affairs. This is happening because of the lack of skilled operators of filtration units, careless attitude of the handlers, and lack of proper and timely maintenance of filtration plants. The study, thus, concludes that in most of the locations of Bahawalpur City, groundwater is not safe for drinking without filtration. Use of contaminated water may cause many health issues. Therefore, people must be careful in using unfiltered water and they should prefer filtered water for drinking. As city is expanding rapidly, some more water filtration plants are needed to be installed in new colonies and existing plants should be maintained properly. The concerned government departments like Municipal Corporation, Public Health Engineering etc. should also play their part efficiently by providing filtered water facility to every resident of the City. The people who use unfiltered water are advised to boil the water before use specifically during rainy season. Iodine solution, tablets or crystals can also be added according to recommended quantity to make the water safe for drinking. Addition of chlorine and exposure to ultraviolet light can also kill the bacteria in water.

From the facts study revealed, two important lessons can be drawn for the future planning. Firstly, besides water resource conservation, number of water filtration plants must be increased and use of filtered water should be encouraged in the city through public awareness programs. This is essential to keep the people healthy and to save them from the diseases spreading because of consuming contaminated water. Secondly, all the water filtration plants supplying drinking water to the city's inhabitants should be maintained timely and properly and monitored strictly. This can be made possible by keeping serious checks and balances on the concerned departments. Quality of water also needs to be laboratory tested from time to time and there should be no relaxation in this process.

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