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Assessment of drinking water quality of Tehsil Alipur, Pakistan

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ABSTRACT

Poor quality of drinking water is one of the major threats to human health. Several potential sources such as toxic chemicals, minerals, effluent outfalls from industrial facilities, waste treatment plants, and run-off from agricultural land can contaminate drinking water. To ensure the accessibility of uncontaminated and safe drinking water, its quality should be managed and monitored carefully on a regular basis. A research study was conducted to evaluate the quality of drinking water in tehsil Alipur of district Muzaffargarh, Pakistan. Water samples were collected from different sources such as tube well, hand pump, injector pump, and water supply line from 27 different locations during 2007. The samples were examined for physical, chemical, and bacteriological contamination. Five physical parameters (pH, turbidity, hardness, total dissolved solids, and conductivity) and chemical parameters including sodium, calcium, magnesium, potassium, chloride, nitrate, sulfate, and bicarbonate were tested for each sample and values were compared with the standards set by WHO. The results revealed that physical and chemical parameters for majority of the samples were inside the acceptable limits of WHO for drinking water. However, the study of microbial quality of water showed that, about half of the samples were bacteriologically contaminated and thus unfit for human consumption.

Keywords: Alipur; Contaminants; Water quality; WHO

1. Introduction

Water is a life-sustaining drink for all living organisms. An adequate supply of safe drinking water is of crucial importance for the health of humans all over the world. The safe drinking water must be free from all hazardous materials and contaminants, which may negatively influence human beings. Such materials include toxic chemicals, minerals, and pathogenic micro-organisms. The presence of these contaminants in drinking water causes a widespread of diseases such as diarrhea, typhoid, nausea, gastroenteritis, and

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intestinal worms. A severe load of these contaminants may also lead to death [1]. Thus, safety and monitoring quality of drinking water are of vital importance.

In developing countries, one of the major issues is access to good quality water in sufficient quantity. A significant portion of the population suffers from health problems, which are associated either with the absence of safe drinking water or with microbial contamination of water [2]. Waterborne diseases are cause for 3.4 million human deaths and majority of them are children [3].

In Pakistan, water situation is extremely precarious. Rapid population growth, urbanization, and continued industrial development have resulted in an increased rate of water scarcity and pollution. After the independence of Pakistan in 1947, water availability per capita has decreased from 5,600 m^3 to less than 1,500 m^3 today [4]. Among the available water resources, a large proportion is used for irrigation and other agricultural needs. Only a little portion, about 10%, is left for drinking and other household purposes. Estimates indicate that around 40−55 millions Pakistanis; i.e. every third person, uses contaminated water for drinking [5]. Scarcity and rising demands of water resources for multiple uses have negatively impacted the quality of water. Decline in water quality is mostly caused by the discharge of untreated sewage, wastes from industrial premises including heavy metals and toxic chemicals, municipal wastes and runoff from agricultural land into natural water bodies like rivers, canals, etc. Mixing of these contaminants with ground water resources then causes a widespread of water-related diseases. Diarrhea is one of the most dangerous waterborne diseases in Pakistan and is responsible for the vast majority of deaths in infants and children [3]. According to reports, more than 3 million Pakistanis suffer from waterborne diseases each year, out of which about 0.1 million die [6,7].

Groundwater is a primary source of water supplies in many cities of Pakistan and is being used through tube wells, hand pumps, and motor pumps. Water from these sources is not safe to drink due to manipulation of many external factors as discussed above. Moreover, old and rusty water supply lines and damaged sewerage lines are also significant sources of water pollution. Therefore, drinking water quality should be treated carefully before making it available to public sector. Unfortunately, water and sanitation is an ignored sector in Pakistan. Insufficient water treatment measures, absence of a legal framework for drinking water quality monitoring and public unawareness about water quality issues [8] have led to worsen the situation [9]. Subsequently, Pakistan's water quality ranked 80th in the world [10] and a majority of the population is facing health-related issues. It is a dire need of the hour to consider this issue seriously and take proper steps at both public and government levels to recognize and prevent water contamination problems.

The present study has been designed to investigate the drinking water quality of Alipur, which is one of the tehsils of district Muzaffargarh in South Punjab, Pakistan. International guidelines or national standards are normally used as a basis to judge the drinking-water quality. The most important of these are the guidelines set by WHO which are revised on a regular basis [11]. The physical, chemical, and bacterial parameters of the study area were compared with the guidelines set by Pakistan Standards and Quality Control Authority [12] and the WHO standards.

2. Materials and methods

2.1. Study area

Alipur is one of the tehsils (subdivisions) of Muzaffargarh district in the Punjab province of Pakistan. It is located in the southern part of the district 90 km from Muzaffargarh. Its geographical coordinates are 29°22′48′′N, 70°54′36′′E and it is situated at an altitude of 102 m. Alipur covers an area of 1,391 km^2, has a total population of approximately 513,000, and is administratively subdivided into 14 union councils [13].

2.2. Sample collection

Drinking water samples were gathered from diverse water sources such as house water supply by Water and Sanitation Agency, injector pumps, hand pumps, and tube wells from 27 different localities of Alipur (see Fig. 1). Water is being extracted from more multiple aquifers depending upon the depth of water source. A complete detail of all the sampling locations and sources is given in Table 1. From each sampling point, water samples for physical and chemical analyses were collected in polyethylene (PET) bottles of 1 L capacity. Before taking the water samples, bottles were thoroughly washed several times, first with distilled water and then with sample water. For bacteriological analysis, samples were stored in 1/2 L sterilized PET bottles. The collection and preservation of samples were collected as per standard methods for water quality testing [14].

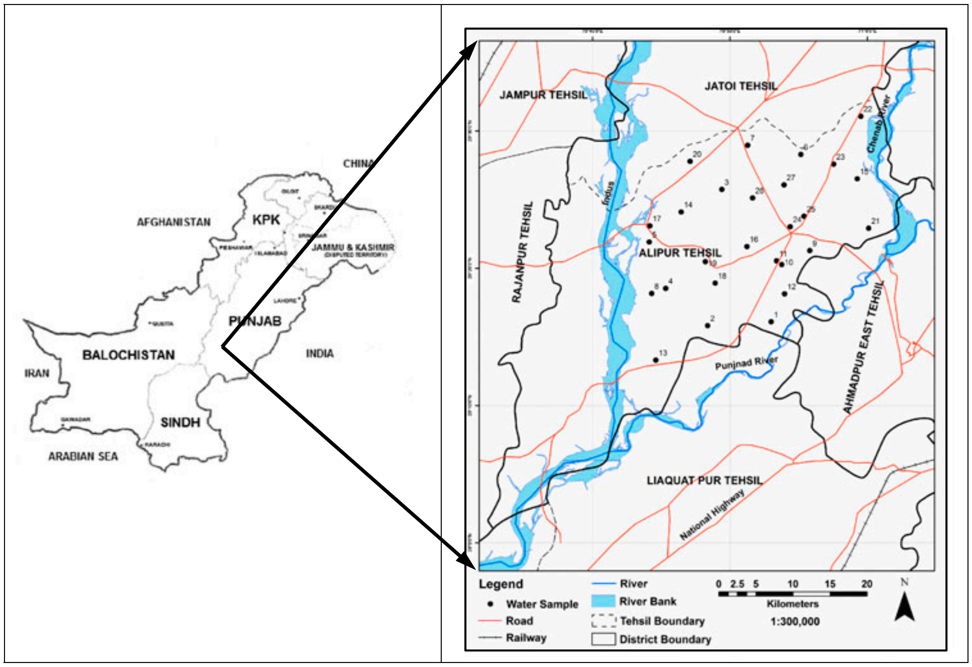

Fig. 1. Map of study area in Alipur showing sample locations.

2.3. Analytical procedure

The water samples were analyzed for physical, chemical, and bacteriological contamination. The basic physical and esthetic parameters, such as color, odor, taste, temperature, pH, turbidity, total dissolved solids, and electrical conductivity were measured/noticed on site. The pH was analyzed using a portable pH meter (Hanna 210), turbidity by using turbidimeter (Hanna HI93703), total dissolved solids using TDS meter, and EC by using conductivity meter (Jenway 4,320). Hardness was estimated by titration method. For chemical parameters, flame photometer (DV710 W) and spectrophotometer (Optizen 2,120) were used as main instruments. Nitrate (NO_3^-) and sulfate (SO_4^{2-}) ions were determined using spectrophotometer. Flame photometer was used for the determination of sodium (Na) and potassium (K) in the samples. Calcium (Ca), magnesium (Mg), chloride (Cl^-), and bicarbonate (HCo_3) concentrations in the water samples were analyzed using titration method. To check the microbiological quality of the water, MPN (Most Probable Method) method was adopted.

3. Results and discussion

The detailed analytical results including physical, bacteriological, and chemical parameters are presented in Tables 2–4. Table 2 summarizes esthetic parameters such as color, odor, taste and temperature of water samples collected from different locations. The presence or absence of bacteriological quality parameters and physical parameters including pH, turbidity, hardness, total dissolved solids, and conductivity are given in Table 3. Chemical parameters (Na, Ca, Mg, K, Cl^-, SO_4^{2-}, NO_3^-, and HCO_3) are summarized in Table 4.

3.1. Color, odor, taste, and temperature

The analytical data indicate that all water samples were found colorless, tasteless, and odorless. The temperature values varied from 39.6 ℃ to 41.1 ℃. WHO and PSQCA provide no guideline for drinking water's temperature. However, it has been proposed that water temperature should be below 15 ℃ since warm temperatures are the major cause for the growth of micro-organisms [15].

3.2. pH

The pH level of drinking water indicates whether water is acidic or basic. The pH is measured on a scale that runs from a value of 0 (very acidic) to a value of 14 (very basic), with 7 being neutral. According to WHO's standards, an appropriate range of pH for drinking water is 6.5–8.5. Water with a

Table 1
Details of sampling locations and sources

Sample no.	Latitude	Longitude	Altitude (m)	Date of survey	Population	Source
01	70.883193	29.268354	90.5	11/06/2007	5,000	Hand pump
02	70.806218	29.263646	93.6	11/06/2007	4,000	Hand pump
03	70.823370	29.428953	102	10/06/2007	14,000	Hand pump
04	70.755291	29.308852	98.5	10/06/2007	10,000	Hand pump
05	70.735477	29.365192	94	10/06/2007	3,000	Injector pump
06	70.919246	29.471554	103.4	10/06/2007	6,000	Hand pump
07	70.854645	29.482598	90.3	10/06/2007	7,000	Injector pump
08	70.738352	29.302601	81.8	10/06/2007	6,000	Hand pump
09	70.930001	29.354722	74	07/06/2007	5,000	Injector pump
10	70.896111	29.337778	73	07/06/2007	2000	Injector pump
11	70.889722	29.342222	91.5	08/06/2007	3,000	Injector pump
12	70.899444	29.302222	83.8	08/06/2007	5,000	Injector pump
13	70.743449	29.221843	93	11/06/2007	15,000	Injector pump
14	70.774092	29.401648	94	11/06/2007	3,500	Hand pump
15	70.987628	29.441942	100	09/06/2007	10,000	Injector pump
16	70.853889	29.359722	99.1	11/06/2007	4,000	Injector pump
17	70.736142	29.384758	94	11/06/2007	3,000	Hand pump
18	70.815344	29.315241	99.1	11/06/2007	1,500	Hand pump
19	70.803427	29.341281	92	09/06/2007	5,000	Injector pump
20	70.784909	29.462997	93.3	09/06/2007	5,000	Hand pump
21	71.001480	29.381933	95	09/06/2007	20,000	Water supply
22	70.991916	29.517737	93.3	09/06/2007	8,000	Hand pump
23	70.958889	29.459722	100	11/06/2007	6,000	Hand pump
24	70.906389	29.383611	88.7	07/06/2007	10,000	Tubewell
25	70.923056	29.396389	98.8	07/06/2007	10,000	Injector pump
26	70.860676	29.418625	97.3	12/06/2007	12,000	Injector pump
27	70.898823	29.434539	100.3	12/06/2007	3,000	Injector pump

Table 2
Basic parameters, color, odor, taste and temperature of water samples

Sample no.	Color	Odor	Taste	Temp. ℃	Sample no.	Color	Odor	Taste	Temp. ℃
1	Colorless	Odorless	Unobjectionable	39.6	15	Colorless	Odorless	Unobjectionable	40.2
2	Colorless	Odorless	Unobjectionable	39.8	16	Colorless	Odorless	Saline	40.2
3	Colorless	Odorless	Unobjectionable	41	17	Colorless	Odorless	Unobjectionable	40.3
4	Colorless	Odorless	Unobjectionable	41	18	Colorless	Odorless	Unobjectionable	40.5
5	Colorless	Odorless	Unobjectionable	40.4	19	Colorless	Odorless	Unobjectionable	40.4
6	Colorless	Odorless	Unobjectionable	40.4	20	Colorless	Odorless	Unobjectionable	40.6
7	Colorless	Odorless	Unobjectionable	40.4	21	Colorless	Odorless	Unobjectionable	40.4
8	Colorless	Odorless	Unobjectionable	40.4	22	Colorless	Odorless	Unobjectionable	40.6
9	Colorless	Odorless	Unobjectionable	40.7	23	Colorless	Odorless	Unobjectionable	40.8
10	Colorless	Odorless	Unobjectionable	40.7	24	Colorless	Odorless	Unobjectionable	39.8
11	Colorless	Odorless	Unobjectionable	40.5	25	Colorless	Odorless	Unobjectionable	39.8
12	Colorless	Odorless	Unobjectionable	40.4	26	Colorless	Odorless	Unobjectionable	40.7
13	Colorless	Odorless	Unobjectionable	40.2	27	Colorless	Odorless	Unobjectionable	41.1
14	Colorless	Odorless	Unobjectionable	40.2					

pH < 6.5 can be acidic, naturally soft, and corrosive. Acidic water can damage metal pipes, thereby releasing toxic metals such as copper, lead, zinc etc. It may result in esthetic problems, such as a metallic or sour taste and can also cause stain in clothes. Water with a pH > 8.5 indicates that there is a high level of

Table 3
Physical and bacteriological quality parameters of drinking water samples

Sample no.	pH	Turbidity (NTU)	Hardness (mg/l)	TDS (mg/l)	Conductivity (μS/cm)	Total coliform	Fecal coliform
1	7.1	0.55	240	758	1,264	Absent	Absent
2	8	0.09	420	1,312	2,187	Present	Absent
3	7.3	0.09	240	346	540	Present	Present
4	7.3	0.11	165	223	349	Present	Present
5	7.4	0.00	280	415	756	Absent	Absent
6	7.4	0.18	360	654	1,022	Present	Present
7	7.3	0.09	310	608	950	Present	Present
8	7.3	0.25	290	480	750	Absent	Absent
9	7.4	0.23	250	476	744	Present	Present
10	7.3	0.24	380	1,137	1,777	Present	Present
11	7.4	0.21	360	531	830	Present	Present
12	7.3	0.29	240	621	971	Absent	Absent
13	7.3	0.30	350	772	1,207	Present	Present
14	7.6	0.51	170	295	461	Present	Present
15	7.6	0.00	315	1,119	1,749	Present	Present
16	8	1.04	990	3,289	5,140	Absent	Absent
17	7.5	0.07	270	319	580	Absent	Absent
18	7.3	0.08	270	319	580	Absent	Absent
19	7	1.00	360	708	1,107	Absent	Absent
20	7.2	0.09	250	429	671	Present	Present
21	7.6	0.05	290	488	888	Absent	Absent
22	6.8	0.06	530	912	1,520	Absent	Absent
23	5.3	0.08	460	1,086	1810	Present	Present
24	7.5	0.09	220	536	975	Absent	Absent
25	7.2	0.07	380	777	1,295	Absent	Absent
26	7.4	0.08	220	484	757	Present	Absent
27	7.5	0.01	180	226	353	Absent	Absent

alkalinity and the water is hard. Hard water has a bitter taste and may result in the formation of scale deposits on dishes, utensils, and in plumbing [16,17]. Fig. 2 shows a comparison of the pH values of the water samples taken from 27 different locations in Alipur with the standards set by WHO. The pH values detected in the samples ranged between 5.3–8.0. The highest pH value (8.0) was found in the samples collected from Sample No. 2 and Sample No. 16, whereas the lowest pH value (5.3) was recorded in Sample No. 23. The pH values in all the samples, except one (pH 5.3), are inside the acceptable limits described by WHO.

3.3. Turbidity

Turbidity is the assessment of cloudiness of a liquid. It is considered as a good measure of the quality of drinking water. Turbidity makes water cloudy or opaque. It is caused by suspended impurities that obstruct with the transparency of the water. These impurities may include silt, clay, soluble colored organic compounds, finely divided organic and inorganic matter, algae and other micro-organisms. Among typical sources of turbidity in water are: waste discharge, urban run-off, algae growth, and sediments from erosion. Higher turbidity level in drinking water is esthetically unpleasing and may also affect human health. Turbidity can provide shelter and food for pathogens and may result in the growth of disease-causing micro-organisms such as viruses, parasites, and bacteria [18]. Interference of turbidity particles with water disinfectants gives rise to substantial chlorine demand for disinfection purposes.

Turbidity was measured in Nephelometric Turbidity Units (NTU) through focusing a light beam on water samples. According to WHO guidelines, turbidity of drinking water should not be more than 5 NTU [11,19] and ideally it should be below 1 NTU for effective disinfection [20]. In the present analysis, the turbidity levels at all the sampling sites are inside the acceptable limits for drinking water (see Fig. 3).

Table 4
Chemical quality parameters of drinking water samples

Sample no.	Sodium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Nitrate (mg/L)	Bicarbonate (mg/L)
1	172	44	32	16	106	115	6.02	400
2	304	84	51	10	156	372	0.01	550
3	30	60	21	3	35	47	0.01	265
4	24	50	9	1.7	35	46.4	0.02	150
5	35	56	34	2	25	69	0.01	330
6	83	68	46	4	46	137	0.01	405
7	76	64	36	4	64	171	0.02	290
8	66	48	41	4	28	153	0.01	290
9	84	40	36	2	42	140	0.02	250
10	254	72	48	11	198	272	0.16	470
11	46	80	38	8	35	109	0.02	380
12	127	60	21	4.4	50	142	0.02	315
13	120	66	44	4	85	200	0.02	360
14	32	28	24	2	28	55.1	0.01	200
15	276	64	37	8	163	304	0.01	420
16	696	186	127	10	815	1,030	6.3	415
17	20	38	43	2	28	36	7.02	215
18	20	38	43	2	28	36	8.02	210
19	102	64	48	8	89	156	0.01	350
20	62	48	31	2	42	101	0.01	270
21	66	54	38	3	74	103	0.04	250
22	120	104	65	14	149	142	7.5	460
23	198	125	33	14	135	242	7.5	460
24	104	60	17	8	50	160	0.01	240
25	120	92	36	8	64	170	9.02	380
26	94	60	17	7	42	145	7.6	280
27	12	32	24	2	21	45	0.02	180

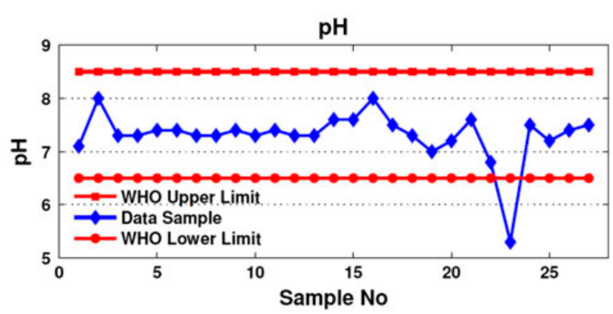

Fig. 2. Comparison of pH level of water samples with WHO standards.

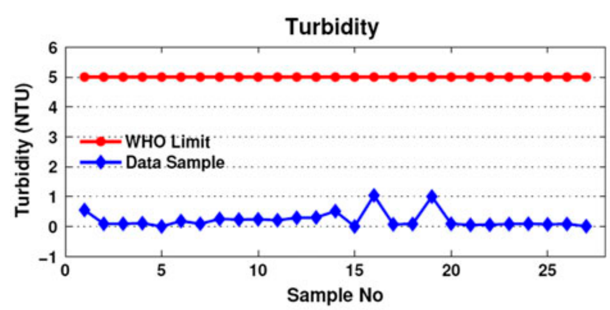

Fig. 3. Comparison of turbidity level of water samples with WHO standards.

3.4. Hardness

The dissolved minerals having a positive electrical charge cause hardness in drinking water. The most common ions are: calcium and magnesium, although other ions e.g. iron, zinc, and manganese may also contribute [21]. Hardness is usually reported on the concentration level of calcium carbonate ($CaCo_3$). The principal natural sources are: metallic ions from seepage, sedimentary rocks, and run-off from soils. Hardness in drinking water does not have any negative effect on human health [22]. At higher concentrations, however, hardness produces soap scum on bath tubs and showers, reduces lathering of soaps and causes scaling of electric heating elements and boilers. The

WHO's recommended value for hardness is 500 mg/L as $CaCo_3$ [11,23,24]. Hardness in water samples collected from Alipur varied from 165 to 990 mg/L. The majority of the samples were within the WHO permissible limits. Only two samples, one taken from Sample No. 16 and the other from Sample No. 22 have hardness more than 500 mg/L (Fig. 4).

3.5. Total dissolved solids

Total dissolved solids (TDS) are estimation of the combined content of all inorganic salts and organic matter dissolved in water. Common inorganic salts include sodium, calcium, potassium, and magnesium cations (ions that carry a positive charge) and chlorides, sulfates, nitrates, carbonates, and bicarbonates, which are all anions (ions carrying a negative charge) [25]. TDS in drinking water originates from a number of natural and unnatural sources such as agricultural and residential run-off, industrial wastewater, sewage, and chemicals used in the water treatment process. An increased TDS concentration results in an undesirable taste, which can be salty or bitter, and it can cause excessive scaling in supply pipes, heaters, and boilers [26]. Water having extremely low concentrations of TDS may cause undesirable flat taste. There is no health-based guideline available on for TDS of drinking water [3]. WHO recommends TDS value to be lower than 1,000 mg/L. Fig. 5 shows the concentration of TDS obtained at different sampling points of the study area. Five of the samples exceeded the WHO recommended TDS value. Statistically highest TDS value (3,289 mg/L) was found in Sample No 16.

3.6. Electrical conductivity

Electrical conductivity (EC) is a quantification of the capacity of a liquid to conduct an electric current. Pure water is a bad conductor of electricity. Water shows significant conductivity when inorganic dissolved solids such as sodium, calcium, magnesium, and aluminum cations, or chloride, nitrate, sulfate, an phosphate anions are present. Measuring the conductivity of the water indirectly indicates the amount of TDS in the water. As the level of TDS rises, conductivity will also increase [27]. Conductivity is also affected by water temperature: the higher the temperature, the higher the conductivity, and therefore it is common to report conductivity at a reference temperature of 25 ℃. Discharges to water can change the conductivity depending upon the nature of discharge. For example, an oil spill would lower the conductivity, as oil is a poor conductor of electric current. One the other hand a failing sewage system would increase the conductivity due to the existence of phosphates, chlorides, and nitrates [27]. Conductivity is measured in microsiemens per centimeter (μS/cm). There is no health-based guideline for conductivity. However, as drinking water usually has to meet a standard of 1,000 mg/L TDS, then by using the relation,

$$\text{TDS (mg/L)} = 0.5 \times 1{,}000 \times \text{EC(mS/cm)}$$

the standard for conductivity can be roughly estimated to be 2000 μS/cm. Fig. 6 shows a comparison of conductivity values for all the samples under study. Conductivity of the water samples ranged from 349 to 5,140 μS/cm, with the maximum value for the Sample No. 16. Except two, all other water samples have conductivity measurements below 2,000 μS/cm.

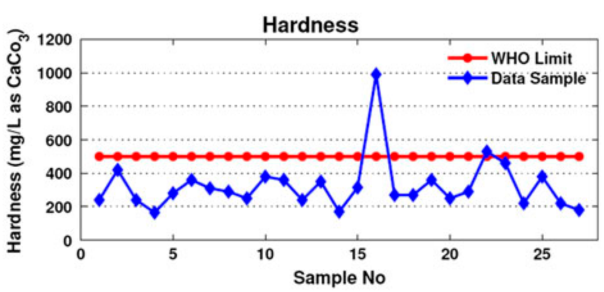

Fig. 4. Comparison of hardness level of water samples with WHO standards.

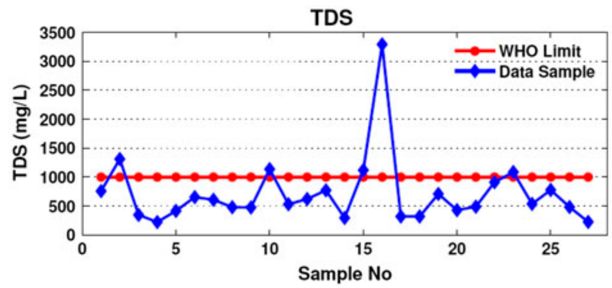

Fig. 5. Comparison of TDS level of water samples with WHO standards.

3.7. Microbial quality of water

One of the most important water quality tests is the determination of bacterial quality of drinking water. The presence of bacterial contaminants, such as total coliform and fecal coliform in drinking water represent an acute health risk. The total coliform group is a large collection of different kinds of bacteria and is commonly found in the environment e.g. in soil or vegetation, and in human or animal wastes.

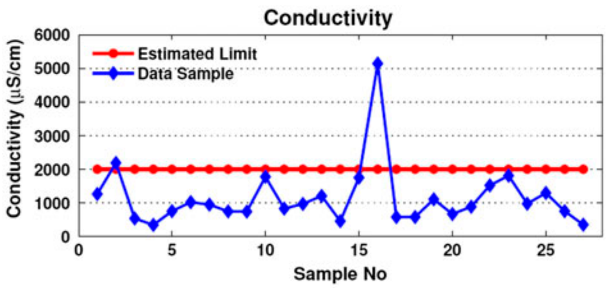

Fig. 6. Comparison of conductivity level of water samples.

Fecal coliforms form a subgroup of total coliforms. They are considered to be present specifically in the feces of human beings and other warm-blooded animals. The presence of fecal coliforms in drinking water indicates recent fecal contamination and their presence warns of the possible presence of disease-causing pathogens. Untreated sewage, storm water run-off, effluent from septic systems and infiltration of domestic or wild animal fecal substance can cause high levels of total and fecal coliform bacteria to appear in a water body. Drinking water contaminated with such micro-organisms can cause diseases, such as diarrhea, nausea, cholera, and typhoid and can even lead to death [28]. These effects may be more severe for infants, children, and people with immune deficiencies [18]. According to WHO, total, and fecal coliform must not be detectable per 100 ml water sample. Fourteen out of twenty-seven samples, which are one half of the total samples, were bacteriologically contaminated with total coliform bacteria. Twelve out of these fourteen samples were also tested positive for fecal coliform. Rafique et al. (2013) also reported nine out of thirty water samples contaminated with fecal coliform in tehsil Jampur of Pakistan [29]. The drinking water from these bacteriologically contaminated areas is unfit for human consumption without proper treatment including boiling of water [30].

3.8. Sodium

Sodium is an essential mineral used for normal functioning of the body including maintenance of body fluids, nerve impulse transmission, and muscle contraction and relaxation [31,32]. Drinking water contributes a small percentage (less than 10%) of a person's overall daily sodium intake. Sodium in drinking water is not generally considered harmful for people in good health. However, for people on sodium-restricted diets, or those suffering from hypertension, cardiovascular or heart disease or with kidney problem, the recommended limit is 20 mg/L. The most common sources of sodium in drinking water are natural erosion of salt deposits, water treatment chemicals, improper sewage treatments, and ion-exchange water softening units. There is no health-based guideline proposed by WHO. However, the suggested limit is 200 mg/L, as sodium level greater than this limit may affect the taste of drinking water. Fig. 7 shows that in four water samples of the study area, the sodium level exceeds the permissible limits. The highest sodium level was found in Sample No. 16, which was collected from injector pump.

3.9. Calcium

Calcium is one of the most abundant element by mass in the human body. Majority of calcium is stored in bones and teeth and it serves as an essential component for the preservation of human skeleton. It is also partially responsible for muscle contraction, blood clotting, and nerve transmission. Insufficient intakes of calcium could result in increased risks of osteoporosis (a disease in which bones become extremely porous), hypertension and stroke, coronary artery disease, and insulin resistance. Calcium occurs in water naturally. Leaching process of rocks may increase the calcium content in water. Higher Calcium concentration may cause hardness in water [33]. Drinking hard water may assist in strengthening bones and teeth. However, high concentration of calcium may adversely affect the absorption of other essential minerals in the body. No health-based guideline regarding calcium concentration in drinking water is set by WHO. However, PSQCA limits the calcium in drinking water to 100 mg/L. A comparison of calcium concentration of water samples is shown in Fig. 8. Three of the water samples (Sample Nos. 16, 22, and 23) did not confirm the PSQCA standards for calcium. In all other samples, calcium level was below 100 mg/L.

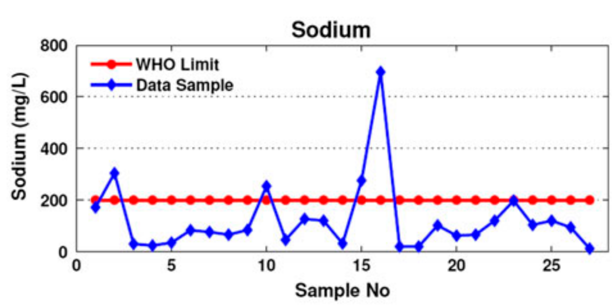

Fig. 7. Comparison of Na level of water samples with WHO standards.

3.10. Magnesium

Magnesium is also one of the most abundant element by mass in the human body. It is indispensable for good human health. About 60% of the total body's magnesium is present in the bones and 40% is present in muscles and other tissues. Magnesium helps developing a healthy immune system. It is also involved in energy metabolism and protein synthesis [34,35]. The percentage of magnesium in drinking water varies depending on the geographical region. Industrial discharge and rainwater falling on rocks can also increase the level of magnesium in groundwater sources and thus makes water hard. Drinking water containing very high level of magnesium can cause vomiting, diarrhea, muscle weakness, and breathlessness. WHO does not propose any health based guideline for magnesium. However, PSQCA sets the standard value for magnesium in drinking water to 50 mg/L. Magnesium detected in water samples ranged from 9 to 127 mg/L (see Fig. 9). Most of the samples, except three, were within the permissible limits of magnesium set by PSQCA. Water Sample No. 16 collected from injector pump showed highest level of magnesium.

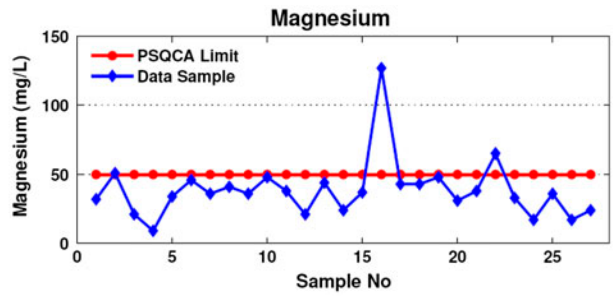

Fig. 9. Comparison of Mg level of water samples with PSQCA standards.

3.11. Potassium

Potassium is an essential body mineral and is a powerful element in improving health. It plays an important role in muscle control, metabolism, blood pressure, and nerve functions. The sources of potassium in drinking water include leaching of fertilizers, erosion of potassium-bearing minerals, and water treatment systems such as ion exchanges (water softeners) that use potassium chloride. Adverse health effects due to increased potassium consumption from drinking water are unlikely to occur in healthy people [36]. However, elevated level of potassium can reveal worsening of groundwater quality and may lead towards the identification of health threatening contamination. There is no health-based guideline for potassium level set by WHO. The PSQCA standard value for potassium in drinking water is 10 mg/L. Four samples of the study area were found to have potassium level higher than 10 mg/L (see Fig. 10). All other samples have lower value as prescribed by PSQCA.

3.12. Chloride

Chloride is common in nature, generally as a salt in the form of sodium chloride (NaCl). Chloride (Cl^-) occurs naturally in groundwater through the leaching of various rocks and soil and the dissolution of salt deposits. Higher level of chloride in water, however, comes from human sources such as industrial wastes, fertilizers, leachates from garbage dumps, sewage contamination, and water softeners. Chloride is required for good health as it keeps the proper balance of body fluids. There are no known health effects associated with chloride. However, at elevated levels, the sodium associated with chloride may be a concern to people on sodium-restricted diet and those suffering from heart disease [37]. WHO recommended limit for chloride is 250 mg/L. Drinking water having Cl^- more

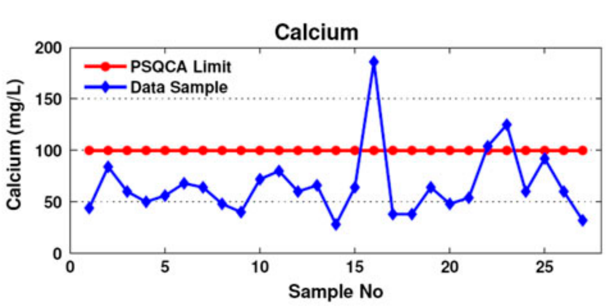

Fig. 8. Comparison of Ca level of water samples with PSQCA standards.

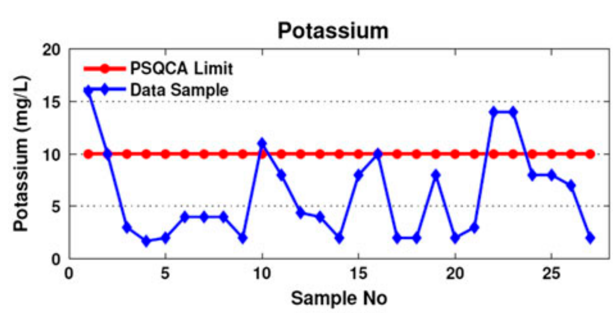

Fig. 10. Comparison of K level of water samples with PSQCA standards.

than 250 mg/L can produce noticeable taste and may cause corrosion of some metals in supply pipes, pumps, and fixtures. Fig. 11 shows the chloride concentration in water samples collected from the study area. The results indicate that chloride was detected in high amounts in only one sample taken from inject pump (Sample No. 16). In all other samples, the chloride level is below the guidelines provided by WHO and hence are considered safe to drink with respect to chloride.

3.13. Sulfate

Sulfate minerals occur naturally in many soils and rocks formation. As water moves through these, therefore, some of the sulfates dissolve into groundwater. Among minerals those containing sulfate are: sodium sulfate (Glauber's salt), calcium sulfate (gypsum), and magnesium sulfate (Epsom salt). Industrial discharge and deposition from burning of fossil fuels are other important factors in raising the level of sulfates in drinking water. At higher concentrations, sulfates give water a bitter or stringent taste and can increase corrosion of plumbing and well materials. Elevated levels of sulfate cause dehydration and diarrhea to the people who drink such water occasionally [38–41]. Based largely on taste considerations, PSQCA recommends but does not require an upper limit of 250 mg/L of sulfate in drinking water. In four of the total samples, sulfate concentration exceeded the allowable limit set by PSQCA. The highest value of sulfate was observed in Sample No. 16 (Fig. 12).

3.14. Nitrate

Nitrate is a naturally occurring inorganic compound made from nitrogen and oxygen and is found in soil, water, and plants. Nitrate can reach groundwater as a result of agricultural activity, from decomposition of plants and leaching of animal manure. Improperly treated septic and sewage discharges can also contribute to increased level of nitrate contamination in groundwater. Nitrate in water does not alter its taste, color, and odor. Chemical analysis is required to detect nitrate. WHO and PSQCA set nitrate value of 10 mg/L value in drinking water. Nitrate values at or above this level are dangerous to pregnant women and can pose a serious health risk to infants under six months old. In infants, the primary health concern regarding high nitrate concentration is the formation of a condition called methemoglobinemia and is also

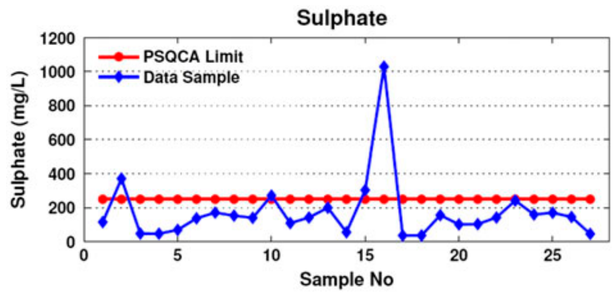

Fig. 12. Comparison of sulfate level of water samples with PSQCA standards.

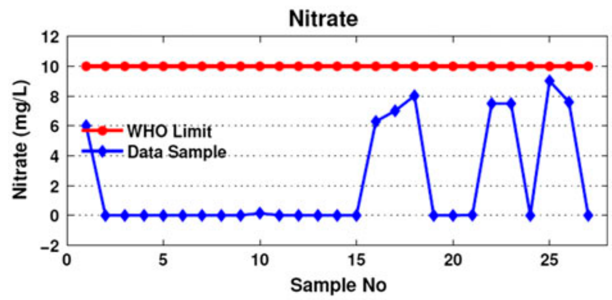

Fig. 13. Comparison of nitrate level of water samples with WHO standards.

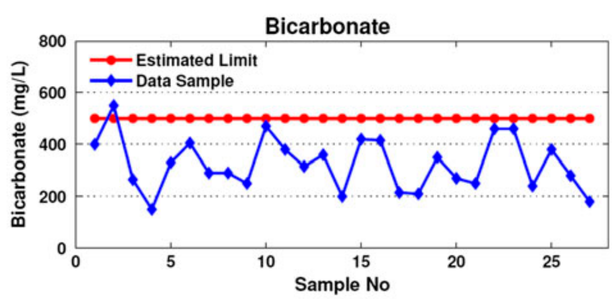

Fig. 14. Comparison of level of bicarbonates in water samples.

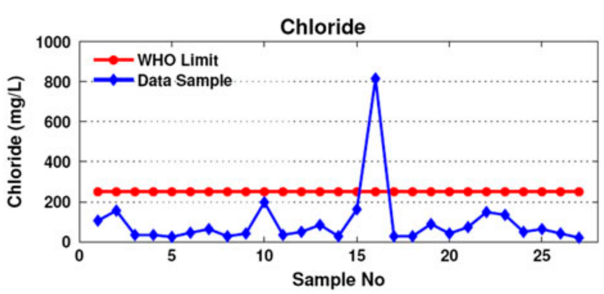

Fig. 11. Comparison of chloride level of water samples with WHO standards.

named as blue-baby syndrome. The immature digestive system of infants can readily convert nitrate (NO_3^-) to nitrite (NO_2^-). Nitrite is absorbed in the blood and the hemoglobin is converted into methemoglobin, which is unable to carry oxygen, and thus the affected baby suffers from oxygen deficiency. Sever methemoglobinemia can result in brain damage and may lead to death [42]. Simple treatment practices such as boiling, disinfection, and water softeners cannot clean nitrates from water. To reduce the levels, it is better to identify and then eliminate the source of nitrate contamination. The research results of the studied area revealed that nitrate levels of all the water samples are under the safe limits (Fig. 13).

3.15. Bicarbonate

Bicarbonate (HCO_3) ions are the main constituent that contribute to alkalinity of water and are naturally present in almost all water supplies. HCO_3 levels in drinking water are also deviated by weathering of rocks. Bicarbonates are vital for withholding of body's internal acid-base balance and serve much in the digestive system. High concentration of bicarbonates does not pose any health risk. Therefore no guidelines related to HCO_3 in drinking water are available. Commonly, 500 mg/L is reckoned as secure limit. Excessive bicarbonates contribute to the production of scale in water heaters and kettles. Fig. 14 shows a comparison of HCO_3 level of the water samples. The HCO_3 values ranged from 150 to 550 mg/L. All the samples, except one, have HCO_3 values lower than 500 mg/L.

6. Conclusions and recommendations

The research results revealed that physical and chemical parameters in the majority of the samples collected from Alipur were roughly inside the acceptable restrictions set by WHO and PSQCA for drinking water. However, in Sample No. 16, several quality parameters such as, hardness, TDS, conductivity, sodium, calcium, magnesium, chloride, and sulfate were significantly higher than the standard values for drinking-water quality and therefore the water from this location is not suitable for drinking purposes. The results from the study of microbial quality of water samples are rather alarming and signify that the quality of water is critical in perspective of bacteriological contamination. About half of the samples were heavily loaded with microbial contaminants such as total coliform and fecal coliform, and the water from these regions is unfit for drinking. There are few water purification plants installed in the study area. Water is being treated through rapid sand (multimedia) filter, granular activated carbon filter, and/or UV sterilizer. The treatment plants are installed at very few places and are not properly maintained. People fetch treated water in bottles for drinking. However, due to lack of information and ignorance, most people drink untreated raw water. Furthermore, no treatment plant is installed at water sampling locations. It is concluded that, there is a need for the implementation of efficient water treatment system especially for microbial quality before it reaches the consumer.

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