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Evaluation of Household Drinking Water Quality in Al-Ahsa City, Saudi Arabia

Abdullah I. Al-Zarah
National Center for Water Technology (NCWT), King Abdulaziz City for Science and Technology (KACST), P.O. Box 6086, Riyadh 11442, Kingdom of Saudi Arabia

ABSTRACT

Provision of safe drinking water is a worldwide issue especially in arid and semi arid countries of the world where freshwater supply is limited. As such, Saudi Arabia is facing an acute problem of safe drinking water to the community. A field study was carried to evaluate household drinking water quality in Al-Ahsa city, Saudi Arabia. Water quality parameters such as pH and total dissolved solids were higher than the permissible limits for drinking water according to Gulf Cooperation Council (GCC) standards. The water quality did not meet the recommended acceptability ranges of drinking water for pH, turbidity, TOTAL DISSOLVED SOLIDS (TDS), hardness, Na, Cl and SO_4 as prescribed by World Health Organization (WHO). The concentration of trace elements in water samples was within the acceptable limits recommended by WHO and GCC. The dominated water type was Na-Ca-Cl-SO_4 and classified as very hard water. The microbiological contamination was more prevalent than the chemical contamination. Out of 199 total water samples, 58% (117 samples) tested positive for total bacteria but about 8% (9 out of 117 samples) tested positive for Fecal coliform, while one sample tested positive for *E. coli* bacteria. In conclusion, all the available drinking water should be examined for microbiological contamination regularly and create awareness among the community members for proper maintenance and cleaning of water storage facilities.

Key words: Household water quality, Al-Ahsa city, trace elements, heavy metals, total bacteria, Fecal coliform, *E. coli*, water storage

INTRODUCTION

According to a survey, around 1.1 billion people in the world have no access to safe drinking water supplies and 2.6 billion people lack adequate sanitation (WHO/UNICEF, 2004). The consumption of unsafe drinking water is the cause of 2.2 million diarrheal disease deaths annually comprising mostly the children (WHO/UNICEF, 2000). A vast majority of diarrhoeal disease in the world (88%) was attributed to unsafe drinking water, sanitation and hygiene (WHO, 2003). Potable water is that water delivered to the consumer that can be used safely for drinking, cooking and washing (DeZuane, 1997). Besides, contamination of drinking water can be at the water source such as water wells, treatment facilities, distribution networks and water tankers and at houses.

Microbiological contamination of water between the source and point-of-use is widespread and significant (Wright *et al.*, 2004). The main sources of microbiological contamination are from human and animal waste, leakage from sewage networks, land disposal of raw sewage effluent without treatment, seepage from septic tanks and pit latrines, improper handling and storage of water at home (WHO, 2010).

Previously, many studies were conducted on the quality of groundwater used for drinking propose and household water quality in the Kingdom of Saudi Arabia or in specific regions of the Kingdom (Mee, 1983; MAW, 1984; Rihan *et al*., 1986; Bazhair and Alkaff, 1989; Faruq *et al*., 1996; Al-Saleh, 1996; Abdel Magid, 1997; Alabdula'aly, 1997a, b; Alabdula'aly *et al*., 2011).

Sadiq and Hussain (1997) reviewed the drinking water quality in Saudi Arabia. They reported that majority of groundwater aquifers, especially in the central and eastern parts, are highly saline and the water requires desalting to become fit for human consumption. The corrosion of utility pipes and leaching of chemicals from PVC pipes could elevate metal concentrations in drinking waters supplied to consumers (Alam and Sadiq, 1989). El-Rehaili and Misbahuddin (1995) reported that houses with galvanized iron plumbing contained higher concentration of iron, copper, chromium, lead, zinc and cadmium in drinking water than those houses with PVC or copper plumbing. They also observed that 34, 23 and 3% of water samples contained Fe, Cu and Pb contents above the maximum permissible limits, respectively.

However, the main concern of consumer is to make sure that the water received is safe and meets the established water quality standards. Previously, free flowing springs were the basis for existence of Al-Ahsa Oasis. Early records on number, location, water quality, water temperature, purity and discharge date back to 1941 and 1951 (Vidal, 1951). Due to urban, rural, industrial and agricultural expansion, the groundwater level decreased significantly. Presently, once free flowing springs have been replaced by wells to fulfill the increasing demand of water for various uses. Also, desalinated water is pumped from the Arabian Gulf to meet the growing demand for water but is mixed with groundwater to improve its quality and quantity.

Therefore, the main objective of this paper is to evaluate household drinking water quality in Al-Ahsa City, Saudi Arabia.

MATERIALS AND METHODS

The study was carried in Al-Ahsa city, Eastern Province, Kingdom of Saudi Arabia. A total of 199 water samples were collected from underground reservoirs, over-head water tanks, municipal water supply network, water tankers and in some locations from wells supplying water to houses from different areas in the city of Al-Ahsa. The following criteria were considered for selecting the study area in the city:

- Areas without sewage system and the houses depending on cesspool system for wastewater disposal
- Areas with a sewage system and the houses are connected to the public swage system
- Public places like mosques and schools

Majority of the houses in Al-Ahsa city depend on underground water storage, because there is no regular water supply by the municipal water supply network. To study the quality of water and to investigate the sources of contamination, water samples were collected and classified as follows:

- The 41 water samples were collected directly from the outlet of municipal water supply network before entering the underground or upper water storage tanks. This was done to collect information on quality of water before entering the houses and eliminate the effect of storage facility on water quality. The collection of limited number of water samples was due to limited accesses to water supply line in some houses. However, in majority of the houses, the water supply line was connected directly to the underground water storage tanks. while in many cases, it was not possible to open the underground storage tank or the manhole cover

- The 158 water samples were collected from the tap water in houses and public facilities (schools and mosques) from water coolers used for drinking. Also, the water storage facilities were inspected thoroughly during sampling for any defect or any obvious source of contamination

During the field work, two drinking wells (one well in the city of Al-Hofuf and the other in a village called Bani Maán) were sampled for analyzing major cations and trace elements.

It was noticed during investigation that many residents of Al-Ahsa city do not use the water supplied by Municipal Corporation for drinking but use it only for cooking and cleaning purposes. Because, they suspicious about the quality of the water which may be contaminated at the source, during transportation or during storage in the houses. However, for drinking purposes, they depend on water supplied by water tankers from different companies which use Reverse Osmosis (RO) technology for water treatment. Some people use water treatment devices under the sink to improve water quality.

Physical water quality parameters such as temperature, Electric Conductivity (EC), pH, Dissolved Oxygen (DO) and turbidity were measured at the time of sample collection. The water samples were stored in an ice chest and then transported to the analytical laboratory of National Center for Water Technology (NCWT), King ABdulaziz City for Science and Technology (KACST) for analysis. The validity of laboratory results was checked by the cations and anion balance on equivalent basis. Furthermore, 19 water samples were collected as duplicate from the same places for quality control.

Simultaneously, water samples were also collected for microbiological analysis, stored in an ice chest and brought to the laboratory for bacterial analysis. The water sampling locations are given in Fig. 1.

Water analysis: The standard analytical procedures described in APHA (1992) were followed for analysis of water samples. Temperature, electrical conductivity (EC), pH and dissolved oxygen (DO) were measured in the field using the portable instrument Thermo Scientific Orion 5-Star Plus. Turbidity was measured using HACH Turbidity Meter (Model 2100P).

Different anions (Cl, SO_4 NO_3 and PO_4) and cations (Na, K, Ca and Mg) were determined by ion chromatography (Dionex Ion Chromatograph models DX 300 and DX 500). The carbonates (CO_3) and bicarbonates (HCO_3) were determined by titration method according to procedures given in USDA (1954).

Traces elements were determined by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) (Optima 2000 DV Perkin Elmer) equipped with an ultrasonic nebulizer model Cetec U 5000 AT.

The microbial quality of water samples was assessed using IDEXX Colilert® as qualitative method showing the presence or absence of coliforms and *Escherichia coli* (*E. coli*).

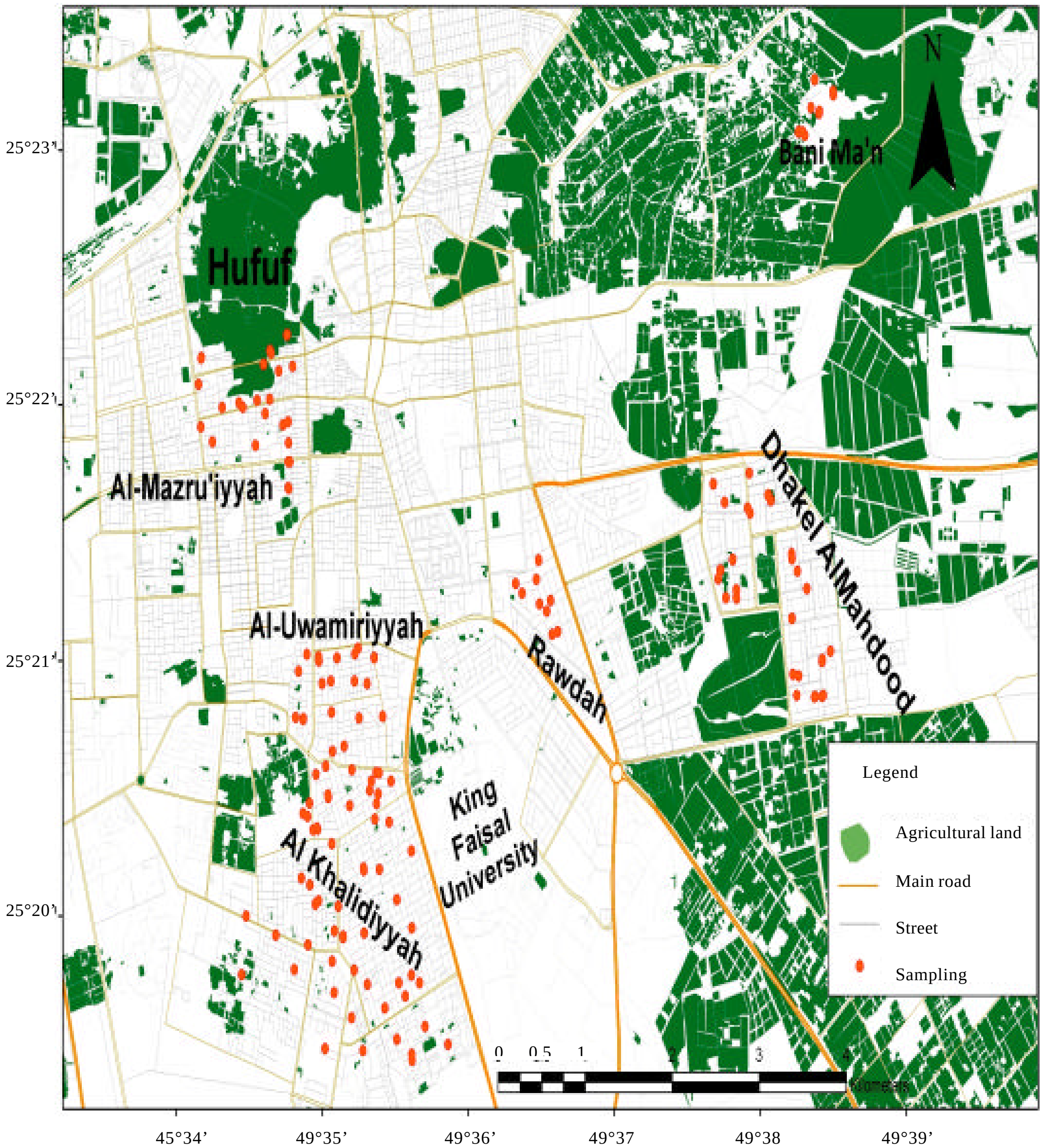

Fig. 1: Location map of drinking water samples in Al-Ahsa city

RESULTS AND DISCUSSION

Water chemistry of the two wells is shown in Table 1 which was considered as an example of groundwater quality for drinking water supply. The TDS (mg L^{-1}) ranged between 1248 and 3230 in Bani Maan and Hofuf well water, respectively. The total water salinity was considerably higher in Hofuf well as compared to the Bani Maan well. The nitrate (NO_3) contents (mg L^{-1}) were 24.9 and 43 in Bani Maan and Hofuf well water, respectively. The NO_3 contents were higher than the WHO permissible limits of 30 mg L^{-1} for drinking in Hofuf well water. The chemistry of groundwater in Al-hasa area was studied by Al-Zarah (2008). He investigated 101 wells and found that the order of abundance for cations was Na>Ca>Mg, while that of anions was $Cl>SO_4>HCO_3$. The groundwater in the study area was classified as very hard water.

Table 1: Physical and chemical parameters of sampled wells used for supplying drinking water

Parameter	Unit	Conc.	
		Bani maán well	Hofuf well
pH		7.93	8.10
Turbidity	NTU	1.95	0.86
Electrical conductivity	$\mu S\ cm^{-1}$	2173	5660
Dissolved oxygen	$mg\ L^{-1}$	7.10	6.36
TDS	$mg\ L^{-1}$	1248	3230
Hardness	$mg\ L^{-1}$ as $CaCO_3$	533	287
Total alkalinity	$mg\ L^{-1}$	149	327
HCO_3	$mg\ L^{-1}$	182	350
Ca	$mg\ L^{-1}$	159	344
Mg	$mg\ L^{-1}$	33	101
Na	$mg\ L^{-1}$	219	627
K	$mg\ L^{-1}$	8.3	24
Cl	$mg\ L^{-1}$	340	1097
SO_4	$mg\ L^{-1}$	353	760
NO_3 as NO_3	$mg\ L^{-1}$	24.9	43
F	$mg\ L^{-1}$	0.44	1.05
SiO_2	$mg\ L^{-1}$	13.8	52.7
B	$mg\ L^{-1}$	213	328
Al	$\mu g\ L^{-1}$	ND	ND
As	$\mu g\ L^{-1}$	ND	ND
Ba	$\mu g\ L^{-1}$	12.2	57.6
Be	$\mu g\ L^{-1}$	ND	ND
Cd	$\mu g\ L^{-1}$	ND	ND
Co	$\mu g\ L^{-1}$	ND	ND
Cr	$\mu g\ L^{-1}$	11.3	19.3
Cu	$\mu g\ L^{-1}$	ND	12.2
Fe	$\mu g\ L^{-1}$	142	326
Hg	$\mu g\ L^{-1}$	ND	ND
Mn	$\mu g\ L^{-1}$	0	4.8
Mo	$\mu g\ L^{-1}$	ND	ND
Ni	$\mu g\ L^{-1}$	ND	ND
Se	$\mu g\ L^{-1}$	0	3.8
Sr	$\mu g\ L^{-1}$	209	327
Pb	$\mu g\ L^{-1}$	ND	2.6
V	$\mu g\ L^{-1}$	ND	ND
Zn	$\mu g\ L^{-1}$	33	184

Maximum, minimum, average and standard deviation for different water quality parameters from water supply lines and household tap waters are presented in Table 2 and 3. The mean values of TDS, chloride (Cl), nitrate (NO_3), iron (Fe) and zinc (Zn) were 725.1, 231.2, 11.5, 73.4 and 58 mg L^{-1}, respectively in water samples collected from water supply network to houses in the city. Whereas, mean values of TDS, chloride (Cl), nitrate (NO_3), iron (Fe) and zinc (Zn) were 708, 226.4, 10.4, 50.4 and 66.6 mg L^{-1}, respectively in water samples collected from tap water of each house in the city. On percent basis, 85.4% (water supply network) and 79.1% (tap water) water samples exceeded the limits of hardness according to WHO (2011) permissible limits. Similarly, 31.7% (water

Table 2: Supply line water quality compared to GCC and WHO guidelines

Parameter	Unit	Conc. Minimum	Maximum	Average	SD	Maximum contaminant limits GCC standard	Guidelines for drinking water quality WHO (2011)	No. of samples exceeding the maximum contaminant limits GCC	WHO	Percentage of samples exceeding the limits GCC	WHO
pH		7.12	8.94	7.9	0.31	6.5-8.5	*	1	-	2.4	-
Turbidity	NTU	0.23	4.3	1.2	0.97	*	*	-	-	-	-
Electrical conductivity	µS cm^{-1}	447	2161	1202	407	*	*	-	-	-	-
Dissolved oxygen	mg L^{-1}	2.39	8.62	6.8	1.04	*	*	-	-	-	-
TDS	mg L^{-1}	261	1684	725.1	278.1	1000	*	5	0	12.2	0
Hardness	mg L^{-1} as $CaCO_3$	138	576	309.6	100.5	*	*	-	-	-	-
Total alkalinity	mg L^{-1}	57	190	115.2	36.9	*	*	-	-	-	-
HCO_3	mg L^{-1}	69	232	140.4	45	*	*	-	-	-	-
Ca	mg L^{-1}	34.2	158	83.8	30.5	*	*	-	-	-	-
Mg	mg L^{-1}	12.7	46.2	24.3	6.32	*	*	-	-	-	-
Na	mg L^{-1}	35.6	382	132.2	64.7	*	*	-	-	-	-
K	mg L^{-1}	3.1	11.2	6.75	1.76	*	*	-	-	-	-
Cl	mg L^{-1}	74.2	642	231.2	114.4	*	*	-	-	-	-
SO_4	mg L^{-1}	44.7	348	145.8	59.62	*	*	-	-	-	-
NO_3 as NO_3	mg L^{-1}	3.8	25.2	11.5	7.1	50	50	0	0	0	0
F	mg L^{-1}	0.28	0.91	0.44	0.156	1.5	1.5	0	0	0	0
SiO_2	mg L^{-1}	7.8	15.2	12.9	1.5	*	*	-	-	-	-
Boron	mg L^{-1}	0.17	0.30	0.23	0.03	0.5	2.4	0	0	0	0
Al	µg L^{-1}	ND	ND	ND	ND	*	*	-	-	-	-
As	µg L^{-1}	ND	ND	ND	ND	10	10	-	-	-	-
Ba	µg L^{-1}	10.1	14.8	12.0	1.11	700	700	0	0	0	0
Be	µg L^{-1}	ND	ND	ND	ND	*	*	-	-	-	-
Cd	µg L^{-1}	ND	ND	ND	ND	3	3	-	-	-	-
Co	µg L^{-1}	ND	ND	ND	ND	*	*0	-	-	-	-
Cr	µg L^{-1}	ND	ND	ND	ND	50	50	-	-	-	-
Cu	µg L^{-1}	ND	ND	ND	ND	1000	2000	-	-	-	-
Fe	µg L^{-1}	22.7	136	73.4	45.6	*	*	-	-	-	-
Hg	µg L^{-1}	ND	ND	ND	ND	1	6	-	-	-	-
Mn	µg L^{-1}	0	8	0.22	1.26	400	*	-	-	-	-

Table 2: Continue

Parameter	Unit	Conc.				Maximum contaminant limits	Guidelines for drinking water quality	No. of samples exceeding the maximum contaminant limits		Percentage of samples exceeding the limits	
		Minimum	Maximum	Average	SD	GCC standard	WHO (2011)	GCC	WHO	GCC	WHO
Mo	μg L^{-1}	ND	ND	ND	ND	*	*	-	-	-	-
Ni	μg L^{-1}	ND	ND	ND	ND	70	70	-	-	-	-
Se	μg L^{-1}	0	2.3	0.8	0.74	10	40	0	0	0	0
Sr	μg L^{-1}	197	321	251	40	*	*	-	-	-	-
Pb	μg L^{-1}	ND	ND	ND	ND	10	10	-	-	-	-
V	μg L^{-1}	ND	ND	ND	ND	*	*	-	-	-	-
Zn	μg L^{-1}	0	126	58	28.6	*	*	-	-	-	-

*: No guideline, ND: Not detectable

Table 3: Household tap water quality compared to GCC and WHO guidelines

		Conc.				Maximum contaminant limits	Guidelines for drinking water quality	No. of samples exceeding the maximum contaminant limits		Percentage of samples exceeding the limits	
Parameter	Unit	Minimum	Maximum	Average	SD	GCC standard	WHO (2011)	GCC	WHO	GCC	WHO
pH		6.36	9.13	8.1	0.36	6.5-8.5	*	12	-	7.6	-
Turbidity	NTU	0.1	5.7	0.97	0.84	*	*	-	-	-	-
Electrical conductivity	$\mu S\ cm^{-1}$	70	2400	1200	570	*	*	-	-	-	-
1.	Dissolved oxygen	$mg\ L^{-1}$	4.3	10.1	7.0	0.8	*	*	-	-	- -
TDS	$mg\ L^{-1}$	56	1254	708	333.7	1000	*	22	-	14	-
Hardness	$mg\ L^{-1}$ as $CaCO_3$	17	544	296	135.1	*	*	-	-	-	-
Total alkalinity	$mg\ L^{-1}$	10	233	96.8	45.3	*	*	-	-	-	-
HCO_3	$mg\ L^{-1}$	12	284	118	55.3	*	*	-	-	-	-
Ca	$mg\ L^{-1}$	4.5	164	81.3	39.5	*	*	-	-	-	-
Mg	$mg\ L^{-1}$	1.4	41	22.6	9.5	*	*	-	-	-	-
Na	$mg\ L^{-1}$	9.7	259	130.2	66.4	*	*	-	-	-	-
K	$mg\ L^{-1}$	1.1	9.7	5.8	2.2	*	*	-	-	-	-
Cl	$mg\ L^{-1}$	13.8	488	226.4	117	*	*	-	-	-	-
SO_4	$mg\ L^{-1}$	7.7	358	152.1	84.1	*	*	-	-	-	-
NO_3 as NO_3	$mg\ L^{-1}$	1.1	28.7	10.4	6.7	50	50	0	0	0	0
F	$mg\ L^{-1}$	0.21	1.4	0.52	0.2	1.5	1.5	0	0	0	0
SiO_2	$mg\ L^{-1}$	0.8	16.2	11.8	4.1	*	*	-	-	-	-
Boron	$mg\ L^{-1}$	0	0.4	0.24	0.12	0.5	2.4	0	0	0	0
Al	$\mu g\ L^{-1}$	ND	ND	ND	ND	*	*	-	-	-	-
As	$\mu g\ L^{-1}$	ND	ND	ND	ND	10	10	0	0	0	0
Ba	$\mu g\ L^{-1}$	0	15.6	10.6	4.5	700	700	0	0	0	0
Be	$\mu g\ L^{-1}$	ND	ND	ND	ND	*	*	-	-	-	-
Cd	$\mu g\ L^{-1}$	ND	ND	ND	ND	3	3	0	0	0	0
Co	$\mu g\ L^{-1}$	ND	ND	ND	ND	*	*	-	-	-	-
Cr	$\mu g\ L^{-1}$	0	19.2	12.2	4.1	50	50	0	0	0	0
Cu	$\mu g\ L^{-1}$	ND	ND	ND	ND	1000	2000	0	0	0	0
Fe	$\mu g\ L^{-1}$	0	154	50.4	47.6	*	*	-	-	-	-
Hg	$\mu g\ L^{-1}$	ND	ND	ND	ND	1	6	0	0	0	0
Mn	$\mu g\ L^{-1}$	0	29	0.37	3.3	400	*	0	-	0	-
Mo	$\mu g\ L^{-1}$	ND	ND	ND	ND	*	*	-	-	-	-

Table 3: Continue

		Conc.				Maximum contaminant limits	Guidelines for drinking water quality	No. of samples exceeding the maximum contaminant limits		Percentage of samples exceeding the limits	
Parameter	Unit	Minimum	Maximum	Average	SD	GCC standard	WHO (2011)	GCC	WHO	GCC	WHO
Ni	$\mu g L^{-1}$	ND	ND	ND	ND	70	70	0	0	0	0
Se	$\mu g L^{-1}$	0	3.1	1.1	0.95	10	40	0	0	0	0
Sr	$\mu g L^{-1}$	102	299	244	58.1	*	*	-	-	-	-
Pb	$\mu g L^{-1}$	ND	ND	ND	ND	10	10	0	0	0	0
V	$\mu g L^{-1}$	ND	ND	ND	ND	*	*	-	-	-	-
Zn	$\mu g L^{-1}$	0	179	66.6	37.1	*	*	-	-	-	-

*: No guideline: ND: Not detectable

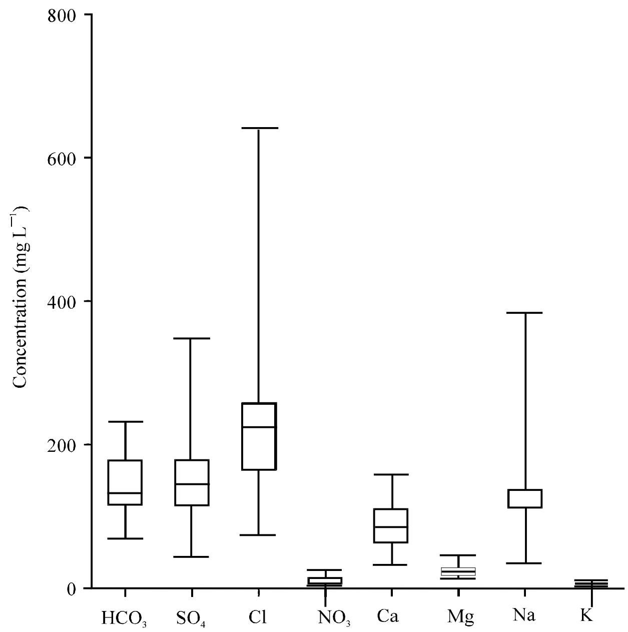

Fig. 2: Concentration of major ions in water supply inlet

supply network) and 51.3% (tap water) water samples exceeded the limits for Cl contents according to WHO (2011) standards. The analytical results were compared with the water quality standards of Gulf Cooperation Countries (GCC) and World Health Organization Standards for evaluation. It was found that all the water quality parameters are within the maximum recommended limits for major cations and trace elements according to WHO (2011). On the other hand, all the water samples exceeded the GCC drinking water quality standard for pH and total dissolved solids (TDS). Out of the total water samples, 6.5% exceeded the GCC standard for pH and 13.6% were above the TDS standards. The study results show that water samples did not meet the recommended acceptable limits established by WHO (2011) for some parameters that may not have any direct health effects but have objectionable taste or odor such as pH, turbidity, TDS, Hardness, Na, Cl and SO_4. However, data in Table 4 presents the number and the percentage of samples that did not meet the WHO maximum acceptable standard for drinking purposes.

Figure 2-5 show the maximum, minimum and average values of cations, anions, trace elements and heavy metals in water samples collected from the drinking water distribution network (inlet) and the household tap waters. The piper diagram (Fig. 6 and 7) showed that the dominated water type is Na-Ca-Cl-SO_4 (114 samples), Na-Ca-Cl-HCO_3-SO_4 (17 samples), Na-Ca-Cl (15 sample), Na-Ca-Mg-Cl-HCO_3 (13 sample) and few samples show the water type as Na-Ca-Mg-Cl-SO_4, Ca-Na-Cl-SO_4, Ca-Na-Mg-Cl-HCO_3-SO_4, Ca-Na-Mg-HCO_3-Cl and Na-Ca-Cl-HCO_3.

Bacterial contamination: Bacteria are present naturally in the environment. Although, the presence of total bacteria are harmless and do not cause diseases but is considered as an indication for the existence of pathogens in water. The presence of Fecal coliform and *E. coli* indicates that water may be contaminated by human and/or animal wastes and may cause water-born illnesses.

Out of 199 water samples collected from different sources, 117 samples (58%) showed Total Bacterial Count (TBC) known as Heterotrophic Plate Count (HPC).The HPC represent bacteria that

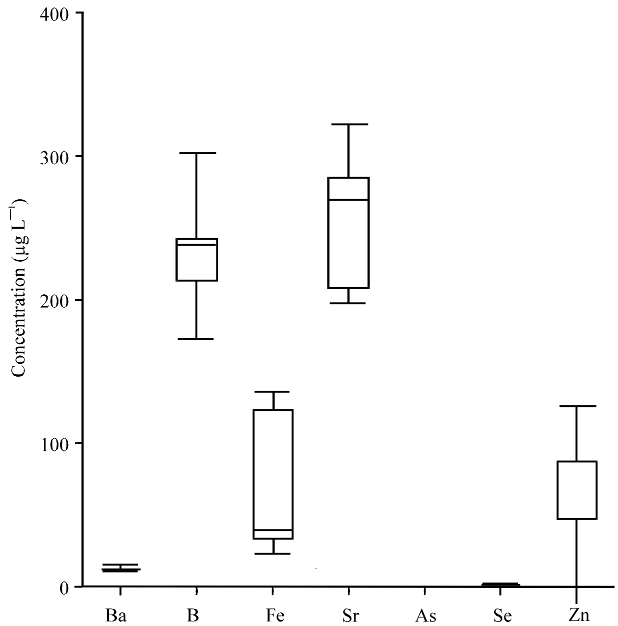

Fig. 3: Concentration of trace elements ions in water supply inlet

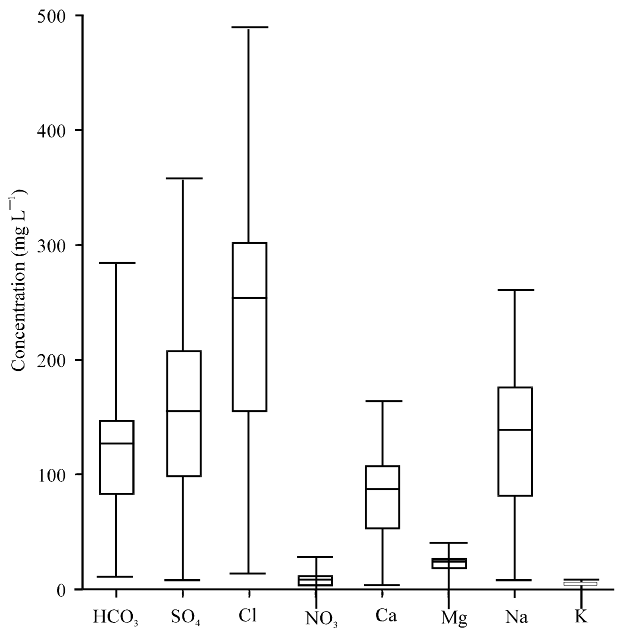

Fig. 4: Concentration of major ions in household tap water

are naturally present in the environment and without any health effects. According to EPA (2012), if the concentration of bacteria in drinking water is low, this means that the water system is maintained properly.

The highest total bacteria counts were found in water samples collected from an area without sewage system. However, one of the two wells sampled during the study, shallow well in area without sewage system, showed 738 total bacteria counts (MPN colonies 100 mL^{-1} water sample) which also showed 7.4 (MPN colonies 100 mL^{-1} water sample) Fecal coliform bacteria.

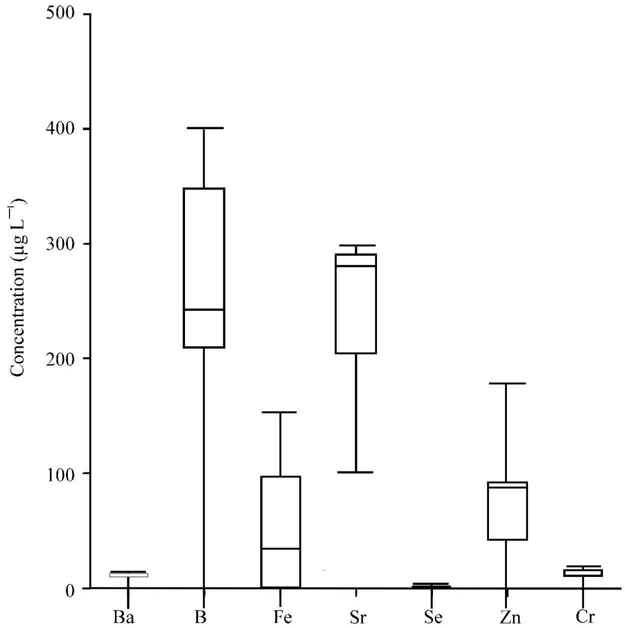

Fig. 5: Concentration of trace elements ions in household tap water

Table 4: No. and percentage of sample exceeding the WHO maximum acceptable concentration limits in water supply inlet and household tap water

Parameter	Unit	WHO maximum acceptability concentration	Water supply in let (total No. of samples 41) #	%	Tap water (total No. of samples 158) #	%
pH		6.5-8.5	1	2.4	12	7.6
Turbidity	NTU	<5	0	-	1	0.6
Electrical Conductivity	$\mu S\ cm^{-1}$	*	-	-	-	-
Dissolved Oxygen	$mg\ L^{-1}$	*	-	-	-	-
TDS	$mg\ L^{-1}$	1000	5	12.2	22	13.9
Hardness	$mg\ L^{-1}$ as $CaCO_3$	200	35	85.4	125	79.1
Total Alkalinity	$mg\ L^{-1}$	*	-	-	-	-
Ca	$mg\ L^{-1}$	*	-	-	-	-
Mg	$mg\ L^{-1}$	*	-	-	-	-
Na	$mg\ L^{-1}$	200	5	12.2	21	13.3
K	$mg\ L^{-1}$	*	-	-	-	-
Cl	$mg\ L^{-1}$	250	13	31.7	81	51.3
SO_4	$mg\ L^{-1}$	250	2	4.9	14	8.9
NO_3 as NO_3	$mg\ L^{-1}$	*	-	-	-	-
F	$mg\ L^{-1}$	*	-	-	-	-
SiO_2	$mg\ L^{-1}$	*	-	-	-	-
Boron	$mg\ L^{-1}$	*	-	-	-	-
Al	$\mu g\ L^{-1}$	100-200	0	0	0	0
As	$\mu g\ L^{-1}$	*	-	-	-	-
Ba	$\mu g\ L^{-1}$	*	-	-	-	-
Be	$\mu g\ L^{-1}$	*	-	-	-	-
Cd	$\mu g\ L^{-1}$	*	-	-	-	-

Table 4: Continue

Parameter	Unit	WHO maximum acceptability concentration	Water supply in let (total No. of samples 41) #	%	Tap water (total No. of samples 158) #	%
Co	µg L^{-1}	*	-	-	-	-
Cr	µg L^{-1}	*	-	-	-	-
Cu	µg L^{-1}	5000	0	0	0	0
Fe	µg L^{-1}	300	0	0	0	0
Hg	µg L^{-1}	*	-	-	-	-
Mn	µg L^{-1}	100	0			
Mo	µg L^{-1}	*	-	-	-	-
Ni	µg L^{-1}	*	-	-	-	-
Se	µg L^{-1}	*	-	-	-	-
Sr	µg L^{-1}	*	-	-	-	-
Pb	µg L^{-1}	*	-	-	-	-
V	µg L^{-1}	*	-	-	-	-
Zn	µg L^{-1}	4000	0	0	0	0

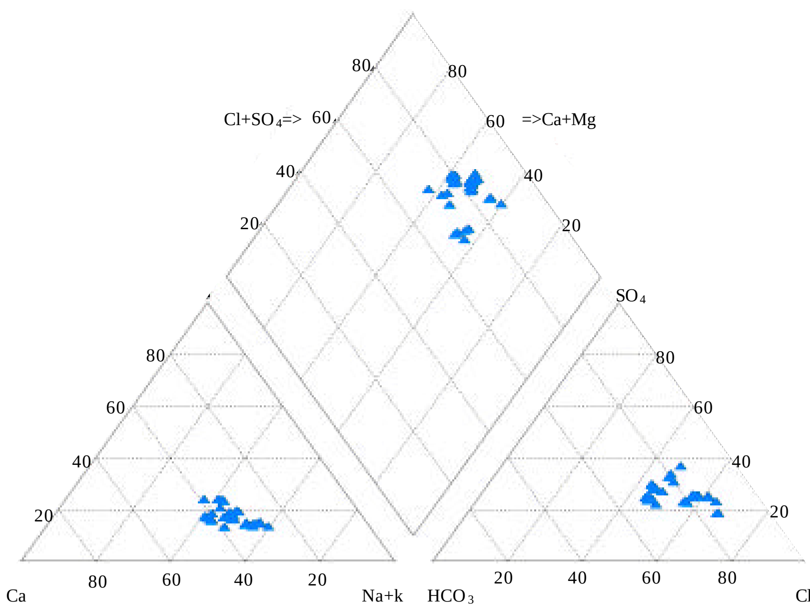

Fig. 6: Piper diagram for samples from water supply inlet

Also, 30 water samples from the water supply inlet (water coming from water authority before entering the houses) showed total bacteria counts, with one showed contamination with fecal coliform bacteria. All these water samples, collected from water coolers installed in different elementary schools and mosques showed the presence of total bacteria. Furthermore, one of the three drinking water distribution tankers showed high total bacteria count and tested positive for Fecal coliform bacteria.

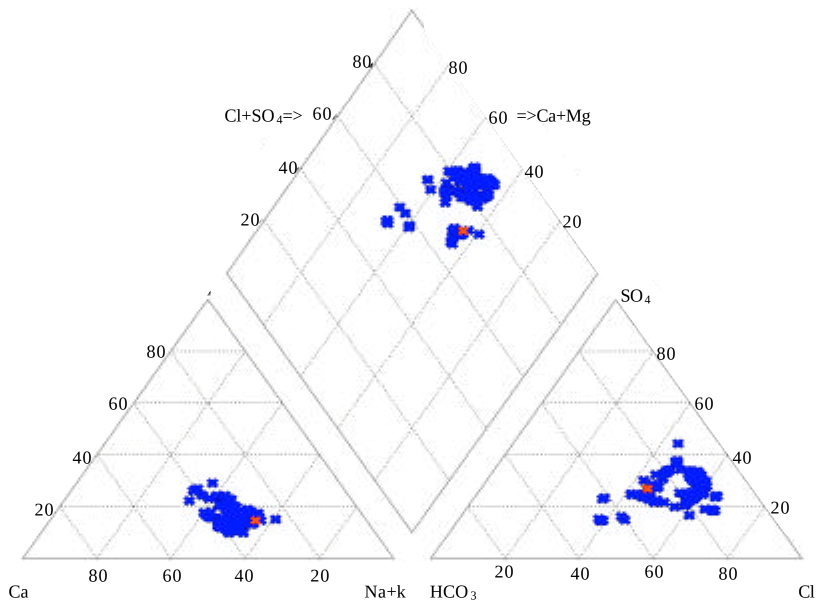

Fig. 7: Piper diagram for tap water

Out of 117 water samples showing Total Bacteria Counts (TBC), only 9 (7.7%) samples tested positive for Fecal coliform, as majority of these samples were from those houses in areas without public swage system. However, only one sample tested positive for *E. coli* bacteria. On the other hand, the EPA Maximum Contaminant Level Goal (MCLG) and the WHO standard for drinking water stated that the *E. coli* or thermotolerant coliform bacteria may not be detectable in 100 ml water sample. Although, coliform bacteria by itself may not cause illness but their presence indicates that the water is vulnerable to contamination and may include other organisms (pathogens) harmful for human health after drinking. The presence of *E. coli* may indicate the presence of disease-causing pathogens, such as bacteria, viruses and parasites. The main source of contamination of household drinking water by total coilform and *E. coli* in this study may be related to improper sewage discharge along with inferior quality household underground water storage facilities.

CONCLUSION

The study showed that microbiological contamination of water is more serious problem than the chemical contamination. The bacterial contamination was observed in those water samples collected from tap-water, public water cooler and the underground water tanks. The main source of bacterial contamination seems to be the unhygienic conditions of the water reservoirs, corrosion of water supply network, leakage of sewage effluent into the damaged water supply network or inferior design and poor condition of household water storage facilities.

Overall, the results showed that all the water samples are within the WHO (2011) standard for all parameters. However, water samples did not meet the recommended acceptable range by the WHO (2011) for pH, turbidity, TDS, Hardness, Na, Cl and SO_4.

Water samples from the water supply network and the household tap water exceeded the GCC standards for pH and total dissolved solids. Among the total water supply line samples (41 samples)

2.4% were higher in pH and 12.2% higher for TDS than the maximum acceptable limits. Out of the total household water samples (158 samples), 7.6% exceeded the GCC standard for the pH and 14% exceeded the maximum acceptable limits for TDS. Majority of household water samples (82%) were classified as very hard water.

Above all, disposal of wastewater using cesspool is a threat to environment and public health and may be a source of contamination to underground water storage. This study emphasized the importance of proper maintenance of water storage facilities at houses which may be a source of microbiological contamination.

Based on the results and observations in this study, chemical disinfectants of water at the point of use is a good alternative for residents in area vulnerable to contamination. This can be achieved by using 6% sodium hypochlorite solution to kill bacterial contamination. In conclusion, the residents should get their water tested for bacterial quality biannually. Also, regular monitoring of drinking water quality in public places (schools and mosques) for bacterial contamination is recommended to avoid human health hazards.

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