

## **OVERVIEW OF THE CHEMICAL CONTENT OF HOUSEHOLD (TAP) DRINKING WATER QUALITY IN THE STATE OF KUWAIT**

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### **ABSTRACT**

The main objectives of this study were to evaluate the chemical content of household drinking water available in the State of Kuwait and to investigate the effect of distribution facilities and seasonal variations on the level of various contaminants. The collected samples were analyzed for water quality parameters, inorganic anions, 25 of the trace and heavy metals, disinfection by-products (DBPs) trihalomethanes (THMs) and haloacetic acids (HAAs), volatile organic compounds (VOCs), and extractable semivolatiles (SVs) including pesticides. All analyses were performed according to approved USEPA methods. It was found that the chemical content in water samples, with the exception of few, are within the acceptable levels of the World Health Organization (WHO) guidelines and are lower than maximum contaminant levels (MCL) established by the United States Environmental Protection Agency (USEPA).

**Keywords:** drinking water, bottled water, Kuwait, trace metals, organic compounds, microbiology.

### **INTRODUCTION**

Water means life – we must have adequate, clean drinking water to sustain life. Given the extensive consumption of drinking water, the question naturally arises about acute and chronic human health effects resulting from the consumption of water containing various chemical and microbiological contaminants. The kinds of these contaminants in drinking water of any type depend on the source of the water and on the treatment process. Epidemiological studies carried out in various countries all over the world have shown an inverse correlation between high levels of minerals and organic contaminants in drinking water and mortality from ischemic heart disease, cardiac arrhythmias, sudden death, liver and kidney damage, and cancer.<sup>(1-14)</sup> There is a correlation between consumption of trihalomethanes (THMs) as disinfection by-products (DBPs) encountered within distribution systems that utilize chlorination and

human bladder and rectal cancer.<sup>(1, 2)</sup> Another common disinfection treatment process utilizing ozone produces other DBPs including aldehydes, ketones, nitriles, and bromate; which are also believed to be cancer-causing agents.<sup>(14)</sup>

The State of Kuwait is located in an arid area characterized by severe weather conditions very low rainfall, and consequently an absence of rivers and lakes. Kuwait has very limited underground water resources with variable quality and insufficient quantity for domestic use. Kuwait obtains potable water through the desalination of seawater. The dual-purpose power and desalination plants are multi-stage flash (MSF) distillation plants producing distilled water which is then blended with 5-10% brackish water, chlorinated and pumped to the distribution system which consists of underground reservoirs at the desalination sites, elevated storage towers, pipelines, and filling stations for road tankers to distribute potable water to areas in the country not supplied by the pipeline network. A literature survey indicates that there is limited published work regarding the quality of household and bottled drinking water in the State of Kuwait.<sup>(15-18)</sup> Al-Fraj et al.<sup>(15)</sup> examined the quality of drinking water in Kuwait from six different sources and stations, in addition to 25 different brands of bottled mineral water for physicochemical properties and minerals. They reported that all water samples tested complied with WHO Guidelines. In another study, Al-Fraj et al.<sup>(16)</sup> reviewed different possible sources of potable drinking water contamination through transport and storage conditions. They mentioned that all materials in direct contact with water contribute strongly to the contamination of drinking water at the point of consumption. Also, Al-Fraj et al.<sup>(18)</sup> surveyed the level of Pb in the water produced during the period from 1992-1995 and reported a mean value of 0.243 µg/L before entering the coolers. Bu-Olayan et al.<sup>(17)</sup> reported a positive correlation between Pb levels in drinking water from commercial water coolers and in fingernails from both males and females.

The objectives of this study were to investigate: 1) the levels of various classes of chemical contaminants in household water in Kuwait, and 2) the effect of distribution facilities and seasonal variations on the level of contaminants.

## **MATERIALS AND METHODS**

Type I of ICP/MS grade, volatiles-free grade, and chromatography grade waters are used for all preparations of reagents and standard solutions. These grades are obtained by using three different Ultra Pure Water Purification Systems (*Millipore, Bedford, MA, USA*); each is specially equipped with the appropriate cartridges and filters. Certified high purity chemicals, individual calibration standards and mixes, and quality control as well as reference materials are obtained from Sigma-Aldrich, Merk, Alfa Aeser, AccuStandard, Supelco, Absolute Standards, Chemservice, and Agilent companies. The media used for microbiological studies were obtained from Oxiod and Defco.

Measured water quality parameters (Temperature, pH, TDS, conductivity, and residual Chlorine) are measured on-site during the process of sampling. The anions fluoride ( $F^-$ ), chloride ( $Cl^-$ ), bromide ( $Br^-$ ), nitrite ( $NO_2^-$ ), nitrate ( $NO_3^-$ ), sulfate ( $SO_4^{2-}$ ), and phosphate ( $PO_4^{3-}$ ); as well as the inorganic disinfection byproducts (DBPs) bromate ( $BrO_3^-$ ), chlorate ( $ClO_3^-$ ), and chlorite ( $ClO_2^-$ ) are determined by Waters ion chromatography (IC) system (Waters, Milford, MA, USA) according to the USEPA Method 300.1. Elemental analysis was carried out using Agilent ICP/MS 7500ce (Agilent, Palo Alto, CA, USA) and Varian 800 AA-GFA (Varian, Walnut Creek, CA, USA) using the USEPA methods 200.8 and 200.9,<sup>(19)</sup> respectively. Volatile Organic Compounds (VOCs) and Trihalomethanes (THMs) are determined by using Agilent 6890/5975N GC/MS (Agilent, Palo Alto, CA, USA) equipped with Tekmar purge and trap autosampler and preconcentrator system according to the USEPA method 524.2.<sup>(19)</sup> Semivolatiles (SVs) were determined with similar GC/MS system equipped with large volume injector and liquid autosampler according to the USEPA 525.2 method. Haloacetic acids (HAAs) were determined using Agilent 6890GC equipped with two micro-electron capture detectors according to the USEPA method 552.2.

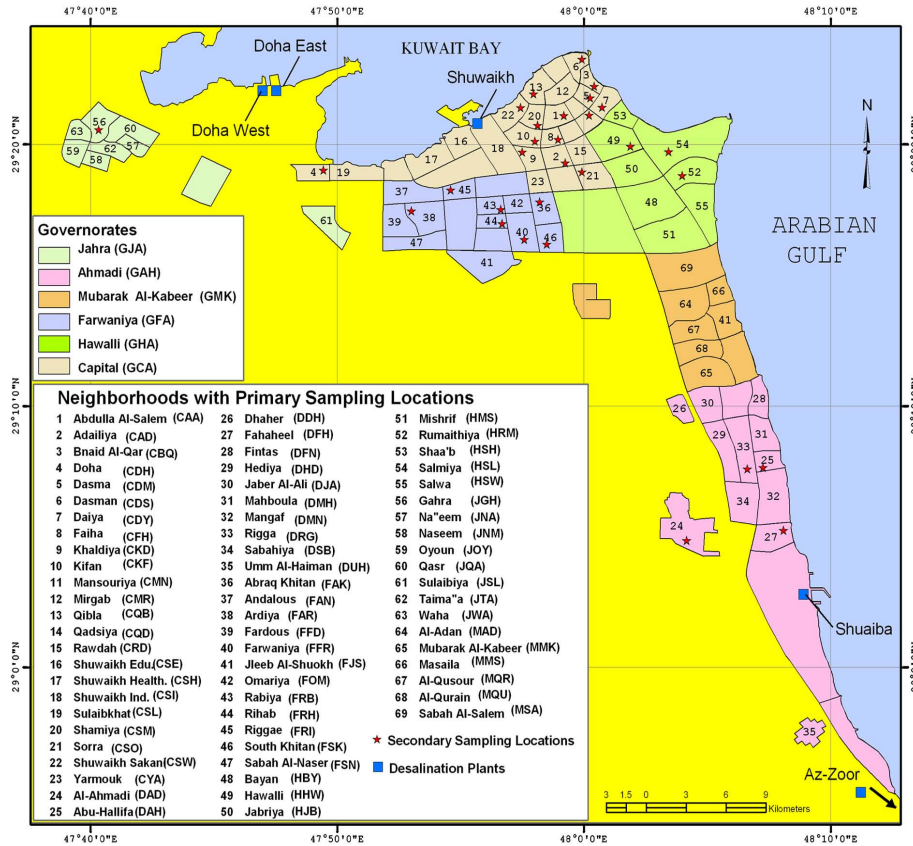
Quality control was performed according to the specified conditions of the specific USEPA method. This includes analysis of laboratory reagent blanks, fortified blanks and samples as a continuing check of performance. Rinse blanks and five calibrated standard solutions of all monitored analytes are used at variable ppm or ppb concentration ranges for the different analytes and as specified in the method.

## RESULTS AND DISCUSSION

Water samples were collected from private residencies (houses and apartments) and governmental buildings at 99 locations in 69 neighborhoods of the six Governorates of the State of Kuwait. One sampling location was selected for repeated sampling within each of the 69 neighborhoods, designated as primary sampling locations. Out of the same 69 Neighborhoods, an additional 30 locations were selected for one time sampling, designated as secondary sampling locations. Chemical studies were performed for 644 household tap water samples collected during the time period from December 2003 to May 2005. This number includes: i) 334 samples collected periodically between 7 to 21 times from each of 12 different fixed locations in 12 different neighborhoods of the State of Kuwait (represented as *locations, which represent high frequency sampling from each individual location*), and ii) the other 310 samples were collected from 87 different locations in other 57 neighborhoods within the six Governorates (represented as *Governorates, which represent low frequency sampling from various locations within individual Governorate*).

Figure 1 shows the distribution of all sampling locations within various Governorates and the locations of desalination plants. Each sample collection involves two sampling points at each location, outdoor and indoor. The outdoor (designated by the letter *-O-*) is an outlet located outdoor prior to water flow into the building and the indoor (designated by the letter *-I-*) is an indoor tap after drinking water had passed through

plumbing and storage tank of each building. Three replicates of each sample were collected after water was left running for at least 10 minutes and until the measured temperature remained constant.



**Figure 1.** Location of desalination plants and distribution of sampling locations within different neighborhoods of the Governorates of Kuwait.

Samples were delivered to laboratory in ice-cooled boxes, and stored refrigerated (at 4°C) upon arrival until analysis was completed. All water samples analyzed were within the recommended holding times, and any sample exceeded it was discarded. Table 1 shows concentration ranges and percentage of detection for trace and heavy metals. Table 2 illustrates the calculated mean values of water quality parameters, anions, and trace and heavy metals at different locations and Governorates.

### 1. Water quality parameters and inorganic anions

Analysis of the recorded values of temperature show that the minimum and maximum temperatures for the samples collected from *I* and *O* of collection points are 14.5, 41.9 and 15.6, 43.8°C, respectively. These values show that there is a slight difference in temperature between samples collected from *I* and *O*, and reflect the difference between samples collected in summer and in winter seasons. The optimum pH often

being in the range 6.5-9.5 or 6.5-8.5 as set by WHO or USEPA, respectively. In this study, all recorded values of pH are within the acceptable range with lowest and highest recorded values of 6.46, and 8.11, respectively. TDS comprise inorganic salts and small amounts of organic matter that are dissolved in water. A concentration value of 500 mg/L is regulated for TDS by USEPA- Secondary Drinking Water Regulations (SDWR)<sup>(20)</sup>. The lowest and highest values of 181.5 mg/L and 610.4 mg/L are found, respectively. Few samples (4%) showed measured values above 500 mg/L. Fluoride is detected in 82.8% of analyzed water samples and the highest value of 0.52 mg/L is measured, which is below the WHO-recommended level of 1.5 mg/L. The lowest and highest measured values of chlorides are found to be 33.56, and 112.10 mg/L, respectively. The bromide ion is detected in 11.7% of the samples analyzed and the highest value of 4.76 mg/L is found. Nitrate is detected in 89.7% of the analyzed samples. The highest value measured is 9.82 mg/L. Nitrite is detected in very few samples (8.8%) with the highest value of 3.21 mg/L in only one sample; which is slightly higher than the value of 3.0 mg/L recommended by WHO and USEPA. The lowest and highest values of 34.05 and 198.00 mg/L are found respectively for sulfates. Phosphate is detected in 38.1% of samples with the highest value of 1.88 mg/L. All chemical disinfectants used for water treatment produce the DBPs: bromate ( $\text{BrO}_3^-$ ), chlorite ( $\text{ClO}_2^-$ ), and chlorate ( $\text{ClO}_3^-$ )<sup>(21)</sup>. In this study,  $\text{BrO}_3^-$  is detected in few samples (10.3%) with the highest value of 2.53 mg/L which is much higher than the value of 0.01 mg/L recommended by both WHO<sup>(22)</sup> and USEPA<sup>(20)</sup>. The value recommended by WHO for both  $\text{ClO}_2^-$  and  $\text{ClO}_3^-$  is 0.7 mg/L, and the value set by USEPA as MCL for  $\text{ClO}_2^-$  is 1 mg/L.  $\text{ClO}_3^-$  and  $\text{ClO}_2^-$  are detected in approximately 1% of the analyzed samples. The highest detected value for  $\text{ClO}_3^-$  is found to be 0.45 mg/L. For  $\text{ClO}_2^-$ , the highest value of 1.05 mg/L is recorded, which exceeds the recommended value (0.7 mg/L) set by WHO.

## **2. Trace and heavy metals**

The 25 elements studied are aluminum (Al), antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), boron (B), cadmium (Cd), calcium (Ca), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn), mercury (Hg), molybdenum (Mo), nickel (Ni), potassium (K), selenium (Se), sodium (Na), strontium (Sr), titanium (Ti), vanadium (V), and zinc (Zn). Elements including Ca, Mg, K, Na, and Sr are found at ppm levels and are reported as mg/L. All remaining elements are found at ppb levels and are reported as  $\mu\text{g/L}$ .

**Table 1. Concentration Ranges and Percentage of Detection for Trace and Heavy Metals.**

<b>Element</b>	<b>Concentration Range</b>	<b>% of samples detected</b>	<b>Recommended levels by WHO (USEPA)</b>
<b>Al</b>	0.55-53.33 µg/L	100	200µg/L (50-200 µg/L)
<b>Sb</b>	0.06-5.47µg/L	33%	20 µg/L (6 µg/L)
<b>As</b>	0.05-2.74µg/L	95%	10µg/L (5 µg/L)
<b>Ba</b>	1.28-24.42 µg/L	100	700 µg/L (2000 µg/L)
<b>Be</b>	Below QL (0.02 µg/L)	0	- (4 µg/L)
<b>B</b>	37.46-538.0 µg/L	100	500 µg/L (-)
<b>Cd</b>	0.05-1.58 µg/L	56%	3 µg/L (5 µg/L)
<b>Ca</b>	19.34-61.72 mg/L	100	- (-)
<b>Cr</b>	0.05-5.2 µg/L	100	50 µg/L (100 µg/L)
<b>Co</b>	0.05 µg/L	100	- (-)
<b>Cu</b>	2.60 µg/L	100	2000 µg/L (1300 µg/L)
<b>Fe</b>	4.41 µg/L	100	- (300 µg/L)
<b>Pb</b>	0.02-4.18 µg/L <i>(18.66 µg/L for one sample)</i>	56.4%	10 µg/L (-)
<b>Mg</b>	2.24-16.18 mg/L	100	- (-)
<b>Mn</b>	0.14-18.60 µg/L	100	400 µg/L (50 µg/L)
<b>Hg</b>	0.05-3.09 µg/L	5%	1.0 µg/L (2.0 µg/L)
<b>Mo</b>	0.27-52.30 µg/L	100	70 µg/L (70 µg/L)
<b>Ni</b>	0.25-33.84 µg/L	100	20 µg/L (-)
<b>K</b>	1.11-2.14 mg/L	100	- (-)
<b>Se</b>	0.05-8.16 µg/L	75%	10 µg/L (50 µg/L)
<b>Na</b>	24.13-73.82 mg/L	100	- (-)
<b>Sr</b>	0.3-28.2 mg/L	100	- (-)
<b>Ti</b>	0.05-1.35 µg/L	100	- (-)
<b>V</b>	0.31-3.57 µg/L	100	- (-)
<b>Zn</b>	5.5- 423.6 µg/L	100	- (5000 µg/L-SDWR)

**Table2. Mean Values of Water Quality Parameters, Anions, and Trace and Heavy Metals at Different Locations and Governorates**

Parameter→ Location ↓	pH		TDS, mg/L		Cl <sup>-</sup> , mg/L		NO <sub>3</sub> <sup>-</sup> , mg/L		SO <sub>4</sub> <sup>2-</sup> , mg/L		Al, μg/L		B, μg/L	
	I <sup>1</sup>	O <sup>2</sup>	I	O	I	O	I	O	I	O	I	O	I	O
<b>CKF</b>	7.60	7.67	434.24	436.61	64.69	66.00	2.30	2.05	128.02	127.96	34.38	29.53	126.78	127.46
<b>CQB</b>	7.61	7.57	424.60	432.79	72.81	76.08	1.56	1.74	129.50	120.04	12.82	5.64	163.60	153.28
<b>CSE</b>	7.67	7.56	440.63	436.28	58.00	58.24	2.51	2.33	104.42	104.18	3.17	1.71	110.19	110.70
<b>CSH</b>	7.60	7.65	443.24	433.67	69.58	65.95	1.82	2.40	124.59	118.23	8.83	6.56	176.10	174.4
<b>CSL</b>	7.60	7.63	444.68	449.86	69.58	64.16	1.82	4.20	129.55	118.23	4.64	5.33	128.00	130.36
<b>CSO</b>	7.55	7.66	325.48	352.69	67.55	64.76	1.32	2.22	97.97	78.54	22.28	10.75	67.65	65.598
<b>CSW</b>	7.50	7.57	441.61	439.14	61.74	64.19	1.98	2.29	104.40	100.60	5.92	4.07	120.43	119.75
<b>DUH</b>	7.51	7.54	251.66	250.01	57.98	59.65	0.75	0.90	49.81	50.68	9.19	9.32	45.83	45.87
<b>FAR</b>	7.66	7.54	442.69	443.33	64.13	67.64	2.64	3.14	118.53	111.00	6.14	5.21	126.92	129.16
<b>FRI</b>	7.68	7.71	439.70	444.43	58.82	59.32	2.45	2.69	114.01	110.79	8.87	8.44	123.22	124.19
<b>HSL</b>	7.55	7.54	368.00	370.12	53.75	53.90	2.13	2.18	91.56	90.64	5.43	5.35	93.17	92.84
<b>JOY</b>	7.60	7.62	488.62	489.73	67.22	68.91	2.94	2.88	123.27	121.81	6.06	6.67	131.84	129.72
<b>GAH</b>	7.51	7.53	272.43	274.06	79.75	78.94	2.199	1.87	88.21	86.424	14.76	13.96	48.90	45.820
<b>GCA</b>	7.61	7.62	397.88	388.49	69.24	71.92	2.52	2.48	138.55	136.68	12.16	13.62	90.71	102.700
<b>GFA</b>	7.60	7.62	415.15	412.80	74.39	74.01	2.871	2.89	142.16	141.994	8.55	8.05	.....	.....
<b>GHA</b>	7.69	7.66	344.05	412.82	60.00	73.94	1.66	2.92	145.49	91.52	8.96	11.66	.....	.....
<b>GJA</b>	7.61	7.62	444.50	449.00	73.83	75.73	4.04	3.55	142.10	141.59	6.57	6.57	109.56	109.563
<b>GMK</b>	7.58	7.57	290.43	287.12	65.74	67.35	1.88	1.87	90.83	90.37	20.27	19.02	.....	.....

Table 2, contd.

Parameter→ Location ↓	Ca, mg/L		Co, µg/L		Cu, µg/L		Fe, µg/L		Mg, mg/L		Mn, µg/L		Mo, µg/L	
	I	O	I	O	I <sup>1</sup>	O <sup>2</sup>	I	O	I	O	I	O	I	O
CKF	52.96	52.43	0.59	0.68	31.63	33.04	9.50	9.40	13.51	13.5	0.99	0.94	8.97	8.14
CQB	43.06	43.2	0.57	0.46	52.72	30.41	326.80	53.27	12.87	12.65	9.46	10.08	5.38	5.57
CSE	51.02	51.05	0.45	0.49	48.34	27.63	73.01	42.02	12.72	12.73	0.82	1.14	8.31	8.65
CSH	47.44	47.03	0.61	6.12	47.78	22.05	73.67	40.75	13.23	12.94	3.2	2.15	13.34	8.21
CSL	51.66	52.23	0.57	5.06	55.42	52.61	10.96	13.30	13.52	13.7	3.66	1.13	15.5	9.37
CSO	32.44	29.87	0.11	0.35	60.24	29.09	157.90	22.60	6.08	6.08	1.85	1.39	3.32	3.22
CSW	45.45	44.23	0.41	0.64	65.79	60.77	50.92	10.70	13.19	12.35	1.7	1.31	6.32	6.01
DUH	26.05	26.38	0.71	0.25	48.20	36.42	10.25	14.03	3.68	3.73	0.9	1.61	2.42	2.46
FAR	51.95	51.88	0.28	0.29	128.38	50.99	17.85	7.90	13.49	13.72	1.85	0.9	7.86	8.24
FRI	51.84	52.99	0.40	0.42	57.68	47.10	25.95	15.63	12.06	12.17	1.53	1.34	8.48	8.76
HSL	38.32	37.91	0.58	0.45	46.10	44.30	30.13	30.54	9.44	9.43	1.72	1.71	6.19	6.18
JOY	49.36	49.37	0.38	0.68	33.35	34.78	20.24	16.58	13.8	13.62	1.51	1.12	11.04	10.89
GAH	28.27	28.350	0.34	0.62	39.57	30.21	72.89	27.03	3.92	3.9	2.1	2.2	2.61	2.68
GCA	39.77	38.970	1.02	0.98	46.51	44.51	31.33	35.16	11.48	11.3	2.55	1.93	5	5.08
GFA	.....	.....	0.72	0.75	53.22	44.42	41.42	27.13	.....	.....	2.27	2.22	6.37	6.65
GHA	.....	.....	0.66	0.66	51.98	27.94	19.42	27.45	.....	.....	2.52	1.47	4.22	4.13
GJA	44.10	43.930	0.85	0.85	47.90	47.90	43.77	39.17	11.63	11.64	1.76	2.13	6.59	7.72
GMK	28.39	28.480	0.50	0.41	37.69	77.78	10.65	18.34	3.45	3.42	1.48	1.19	2.99	3.02

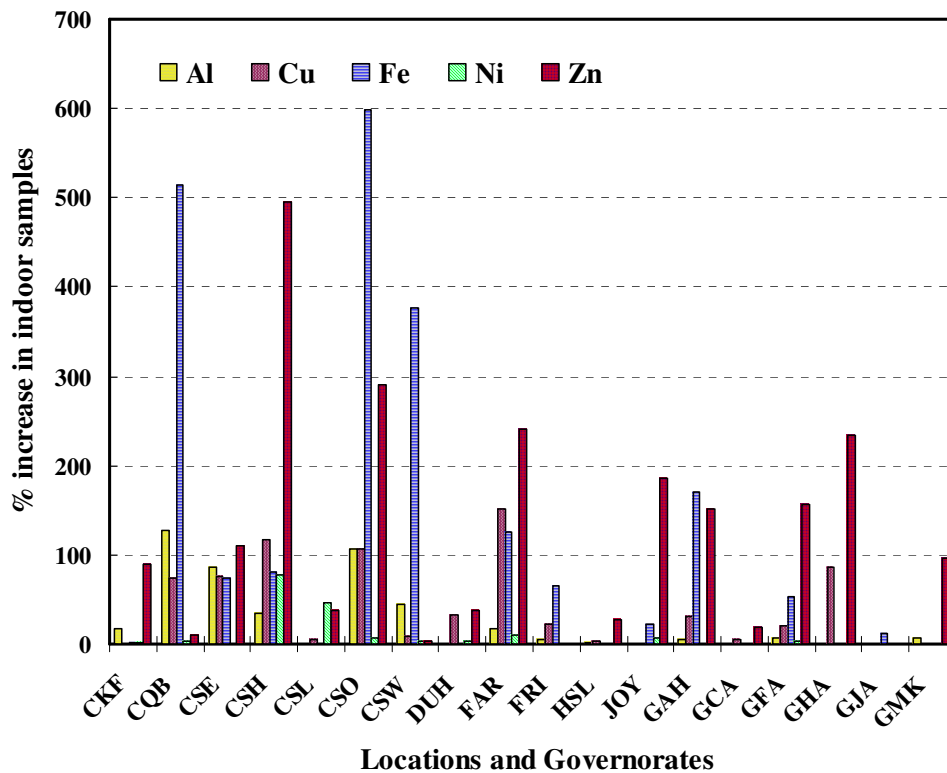


Table 2, contd.

Parameter→ Location ↓	Ni, µg/L		K, mg/L		Na, mg/L		Sr, mg/L		Ti, µg/L		V, µg/L		Zn, µg/L	
	I	O	I	O	I	O	I	O	I <sup>1</sup>	O <sup>2</sup>	I	O	I	O
<b>CKF</b>	5.81	5.72	1.54	1.55	52.78	52.91	1.27	1.27	2.00	1.90	2.87	2.86	16.27	8.58
<b>CQB</b>	9.17	8.91	1.53	1.52	51.04	52.25	1.19	1.16	1.60	1.40	0.93	1.63	201.19	183.27
<b>CSE</b>	7.64	8.17	1.50	1.50	52.04	44.26	1.06	1.18	0.90	1.30	0.83	2.15	18.18	38.21
<b>CSH</b>	9.27	5.22	1.68	1.63	55.91	56.67	1.27	1.20	2.30	1.50	2.58	1.39	202.13	33.99
<b>CSL</b>	8.97	6.12	1.55	1.57	53.71	53.00	1.28	1.30	2.50	2.00	2.71	2.81	51.92	37.45
<b>CSO</b>	3.45	3.21	1.74	1.73	36.61	36.64	0.60	0.59	2.30	2.40	0.78	0.82	64.91	16.61
<b>CSW</b>	11.29	10.85	1.77	1.48	50.87	54.38	1.16	1.18	1.40	1.30	1.62	1.84	25.34	24.30
<b>DUH</b>	1.98	1.92	1.43	1.46	28.93	28.64	0.37	0.38	1.40	3.50	0.50	0.58	29.48	21.44
<b>FAR</b>	7.36	6.71	1.51	1.57	53.12	53.36	1.28	1.30	2.30	1.80	2.95	3.10	67.46	19.83
<b>FRI</b>	6.10	6.10	1.49	1.50	54.09	53.52	1.20	1.22	1.60	1.90	2.64	2.70	36.57	38.67
<b>HSL</b>	6.98	6.95	1.50	1.50	43.92	44.38	0.90	0.90	2.10	2.10	1.81	1.83	28.71	22.64
<b>JOY</b>	7.10	6.62	1.72	1.71	56.55	56.64	1.29	1.28	1.90	1.60	2.44	2.54	31.48	11.02
<b>GAH</b>	2.85	2.94	1.29	1.29	25.59	25.76	0.32	0.31	3.20	3.40	0.45	0.48	45.78	18.16
<b>GCA</b>	6.37	7.03	1.59	1.59	51.67	51.53	1.35	1.57	0.90	1.00	1.60	0.96	20.47	17.24
<b>GFA</b>	6.30	6.12	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	32.38	12.63
<b>GHA</b>	3.93	4.10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	35.85	10.76
<b>GJA</b>	5.90	5.90	1.45	1.45	48.53	48.53	1.06	1.06	1.20	1.20	2.35	2.35	18.27	18.27
<b>GMK</b>	2.85	2.87	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	26.07	13.26

As shown in Table 1, Be is not detected in any of the analyzed samples and is found less than the method quantification level (QL) of 0.05 µg/L. The elements Sb, As, Cd, Pb, Hg, and Se, are detected in 33%, 95%, 56%, 56.4%, 5%, 75% of samples analyzed. The remaining elements Al, Ba, B, Cd, Ca, Cr, Co, Cu, Fe, Mg, Mn, Mo, Ni, K, Na, Sr, Ti, V, and Zn are detected in all samples analyzed. In few samples, the elements B, Fe, Pb, Hg, and Ni are found higher than the recommended levels of WHO and USEPA.

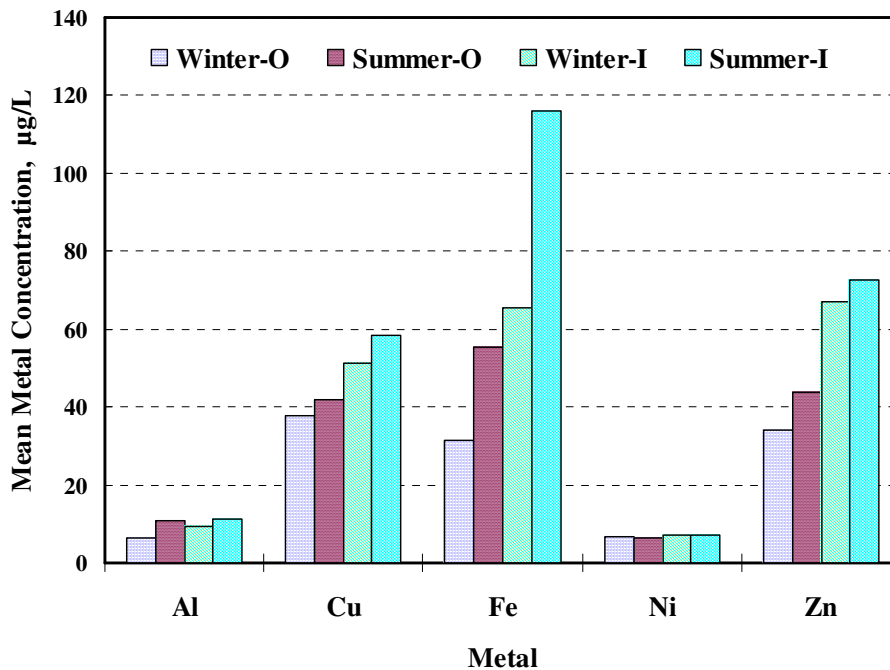
Figure 2 shows the percentage increase of indoor samples compared to that of outdoor for Al, Cu, Fe, Ni, and Zn within different locations and Governorates over the duration of the study. Al levels reach around 100% increase at the locations CQB (127.4%), CSE (85.4%), CSO (107%). The same for Cu at the locations CQB(73.3%), CSE (74.9%), CSH (116.7%), CSO (107.1%), FAR (151.8%).



**Figure 2.** The relation between the percentage increase of indoor samples of some metals within different locations and Governorates

The percent increase of Ni is evident at CSH (80.8%), CSL (46.7%) and less than 10% increase or zero for other locations and all of Governorates. Fe showed a very high percent increase at CQB (513%), CSO (599%), CSW (376%), FAR (126%), and GAH (170%). Also Zn showed a very high increase at CSH (495%), CSO (291%), FAR (240%), and GHA (233%). All these locations are using storage tanks, piping and connections constructed from different types of metal alloys.

Figure 3 shows the seasonal variations of the corroded Al, Cu, Fe, Ni, and Zn metals. It is evident that the corrosion is higher in the summer season than that of the winter for both indoor and outdoor samples, which is attributed to the large difference in temperature. The largest difference is shown by Fe, which shows about 100% increase in summer in comparison with winter.



**Figure 3.** Seasonal variations of corroded metals

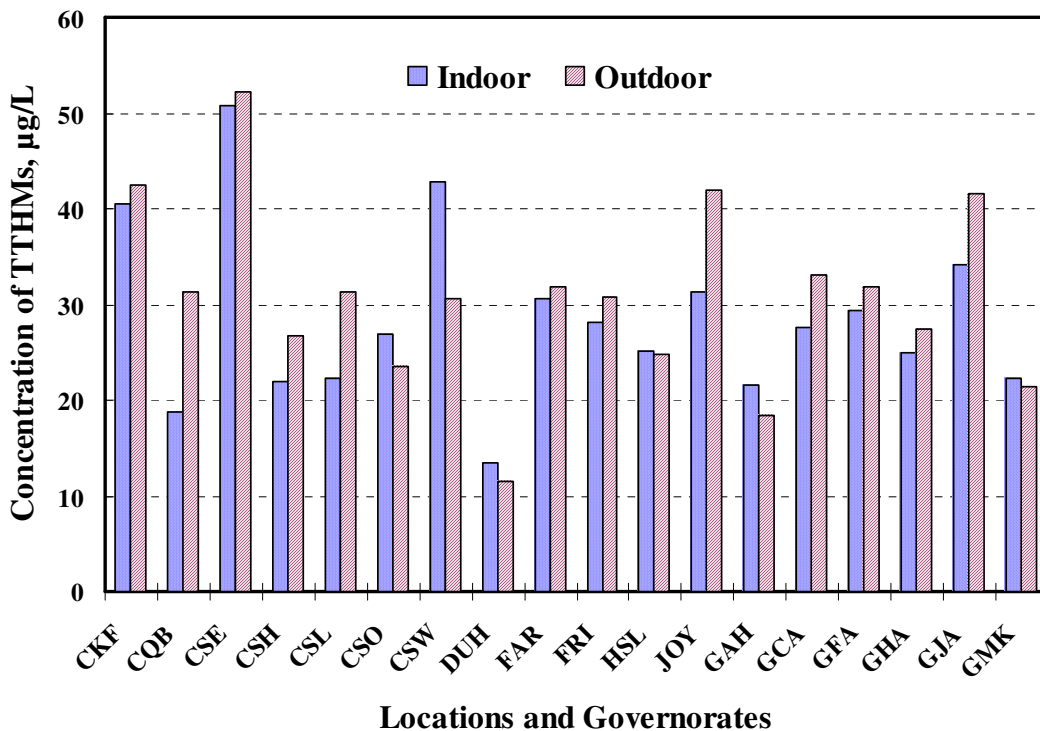
### 3. Organic Disinfection Byproducts (DBPs)

A major objective of drinking water treatment is to provide water that is both microbiologically and chemically safe for human consumption. Disinfection is of unquestionable importance in the supply of safe drinking water. Chlorine is the most commonly used disinfectant for water treatment. Disinfection for drinking water reduces the risk of pathogenic infection but may pose chemical threat to human health due to disinfection residues and the formation of a group of chemical compounds known as disinfection by-products (DBPs), when the organic and inorganic precursors are present in water.<sup>(1, 2, 23)</sup>

The DBPs are formed when the disinfectant reacts with natural organic matter (NOM) and/or inorganic substances present in water. Trihalomethanes (THMs), and haloacetic acids (HAAs) are the most important groups of chlorinated disinfectant by-products (CDBPs) in drinking water.

THMs include bromodichloromethane (BDCM), dibromochloromethane (DBCM), bromoform and chloroform. Total THMs (TTHMs) refers to the sum of these four substances. The USEPA<sup>(20)</sup> has established the maximum allowable contaminant level (MACL) of 80 µg/L for TTHMs.

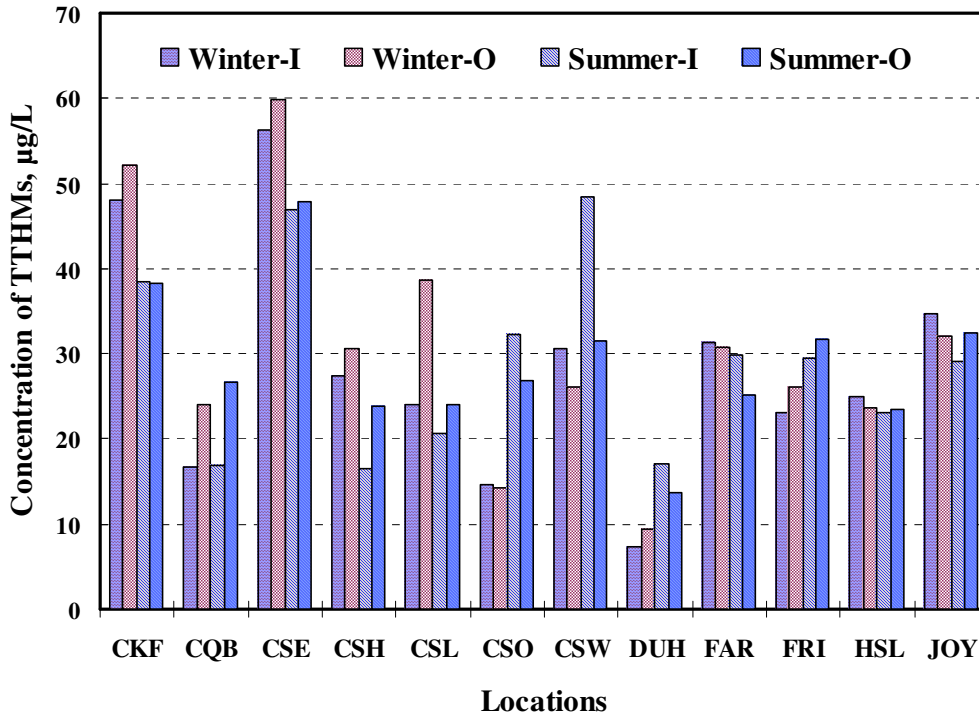
Figure 4 shows the variation of the mean values of TTHMs with the different locations and various Governorates. From the figure we can conclude: 1) the lowest levels of TTHMs for the inside and the outside for all locations and Governorates are found at Umm Al-Haiman location (DUH), 2) Al-Ahmady Governorate showed the lowest values between all other Governorates, 3) the highest level within all locations and Governorates is shown by Shuwaikh Education neighborhood (CSE), with approximately the same values for the inside and the outside, and 4) the outside means are significantly higher than the inside for CQB, CSH, CSL, FAR, FRI, and JOY locations, in addition to GCA, GFA, GHA, and GJA Governorates. The inside is higher than the outside for only CSO, CSW, and DUH locations, in addition to GAH and GMK Governorates.



**Figure 4.** Variation of mean values of TTHMs with different locations and Governorates

Figure 5 illustrates the comparison of the seasonal variation of TTHMs concentration within various locations. The figure shows the following: 1) the mean values are higher in the Winter season for 7 locations (CKF, CSE, CSH, CSL, FAR, HSL, and JOY), and for 4 locations (CSO, CSW, DUH, and FRI) the values are higher in

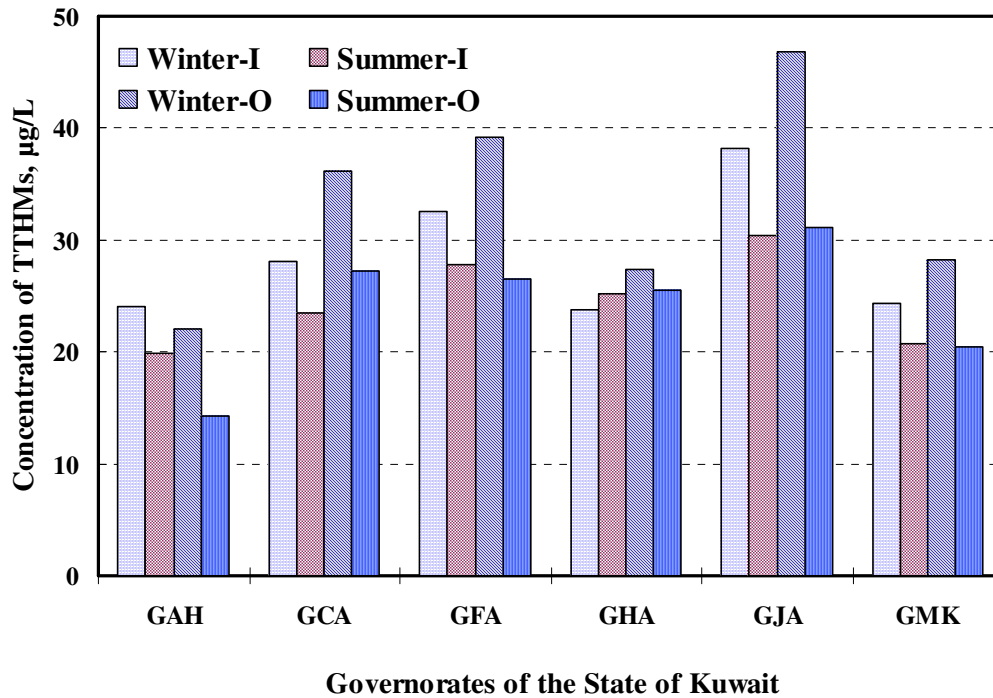
summer, while are the same in both seasons for one location (CQB), 2) in winter, most of the outside means are higher than that of the inside, and 3) the lowest levels of TTHMs in Winter and in Summer are shown at DUH, and the highest level is shown by CSE.



**Figure 5.** Comparison of seasonal variations of TTHMs concentration within various locations

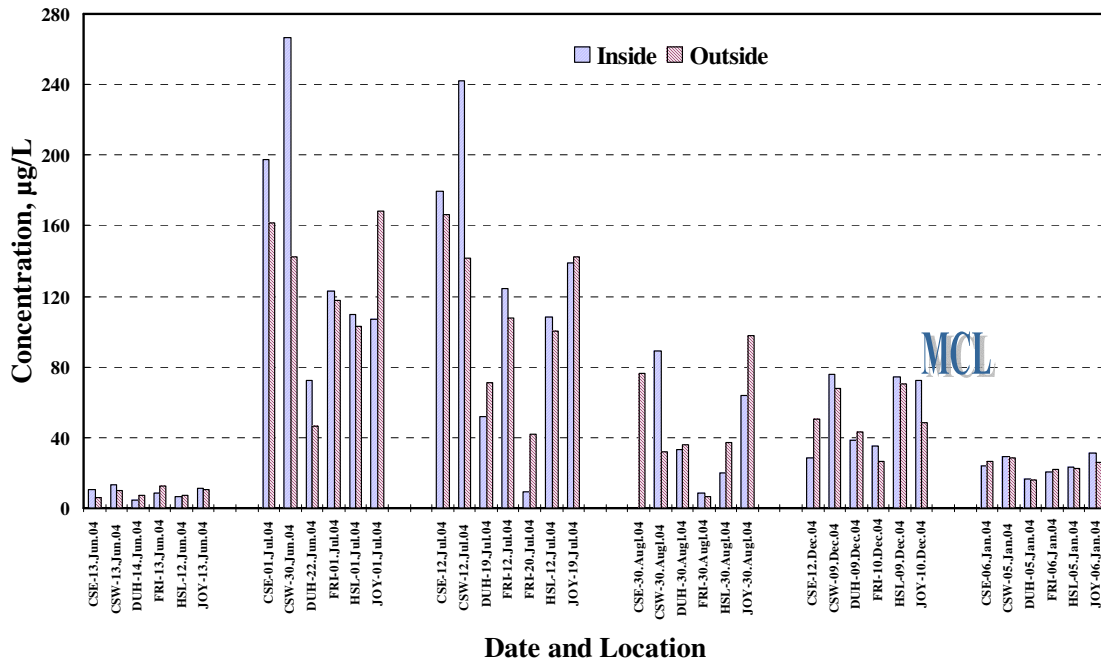
Comparison of the seasonal variations of TTHMs concentration within various Governorates is shown in Figure 6. The following is concluded: 1) Al-Ahmady Governorate showed the lowest values between all other Governorates for both seasons, and 2) the levels of TTHMS for the inside and the outside for all Governorates in Winter are higher than those in Summer (except the inside of GHA in Winter).

HAAs include the acids monobromoacetic (MBAA), monochloroacetic (MCAA), bromochloroacetic (BCAA), dibromoacetic (DBAA), dichloroacetic (DCAA), bromodichloroacetic (BDCAA), chlorodibromoacetic (CDBAA), tribromoacetic (TBAA), and trichloroacetic (TCAA).



**Figure 6.** Comparison of seasonal variations of TTHMs concentration within various Governorates

The USEPA<sup>(20)</sup> has established the maximum allowable contaminant level of 60 µg/L for HAA5 (the sum of the five HAAs; MCAA, DCAA, TCAA, MBAA, and DBAA). Comparison of the high levels of THAAs at the different dates of collection for the regular locations CSE, CSW, DUH, FRI, HSL, and JOY is shown in Figure 7. Water samples are collected and analyzed for HAAs in 175 samples from these locations during the time period from December 2003 to May 2005. In addition to the nine samples of GJA, 31 samples showed levels of THAAs that exceeded the MCL recommended by USEPA. For the samples collected between June 22 and July 01, 2004; 11 of 12 samples are significantly higher than the MCL with the highest and lowest values of 266.81 (inside of CSW-30.June.04) and 46.31 µg/L (outside of DUH, 22-June-04), respectively. Eleven of 14 samples are also significantly higher than the MCL for samples collected between July 12 and July 20, 2004. The highest and lowest values of THAAs are found to be 242.39 (inside of CSW, 12-July-04) and 9.40 µg/L (inside of FRI, 20-July-04), respectively. On August 30 and from December 09 to 12, 2004; 4 of 7 and 5 of 12 samples, showed higher levels than that of MCL, respectively. The levels of THAAs for all other samples collected and analyzed for THAAs before June 22, 2004 (during the period from December 2003 to June 13, 2004) and after December 2004 (January to May 2005) are found significantly lower than the MCL.



**Figure 7.** Comparison of the high concentration levels of THAAs at different dates between various sampling locations and different sampling dates

#### 4. Volatile Organic Compounds (VOCs), and Extractable Semivolatiles (SVs)

Out of the 50 VOCs, only the compounds dibromomethane, 1,2-dichloropropane, toluene, 1,2,4-trichlorobenzene, naphthalene, and 1,2,3-trichlorobenzene are detected with the highest measured concentrations of 3.18, 1.71, 1.85, 0.16, 0.60, and 0.16  $\mu\text{g/L}$ , respectively. All these values are much below the guidelines and MCL recommended by WHO and USEPA, respectively.

The SVs anthracene, bis(2-ethylhexyl)adipate, bis(2-ethylhexyl)phthalate, diethyl phthalate, dimethyl phthalate, di-n-butyl phthalate, 2,6-dinitrotoluene, and hexachlorobenzene are only detected in very few samples, with highest values of 0.42, 2.20, 1.40, 0.89, 1.50, 1.50, 3.19, and 0.36  $\mu\text{g/L}$ , respectively. Most of the concentrations found are very close to the QL established in this study (0.01 to 0.10  $\mu\text{g/L}$ ). All other remaining compounds of the SVs are not detected in any of the samples.

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