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A comparative study of the physicochemical and bacterial characteristics of the three drinking water sources distributed in Haret-Hreik city, Lebanon

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ABSTRACT

The physicochemical and microbial characteristics of drinking water in Haret-Hreik city (Lebanon) have been studied by taking 45 samples from the three different sources of water distributed in the city. Physicochemical parameters include pH, electrical conductivity (EC), total dissolved solid (TDS), total hardness, calcium, magnesium, sodium, potassium and chloride. Microbial characterization includes total coliform count, fecal *Streptococcus* count, and identification of some fecal coliform species such as *Escherichia coli.* Physicochemical and bacterial analyses indicated clearly that municipal water is not safe for domestic use and to be drunk. It contains a high amount of dissolved inorganic substances, with EC, TDS, and chloride average concentrations equal to 2983 µs/cm, 1908 mg/L, and 1147 mg/L, respectively. These values exceed the limits described by the WHO. In addition all samples were contaminated by high amount of total coliform, with averages ranging between 216 and 4166 CFU/100 mL. All municipal water samples were contaminated by fecal *Streptococcus,* indicating the pollution of drinking water by fecal material from warm blooded animals. The analyses of water at the exit of commercial treatment companies showed that the treated municipal water satisfies the physicochemical guidelines of the WHO. However, all samples were contaminated by total coliform, and 60 % of samples contained fecal *Streptococcus.* Thus, the UV disinfection process in all the commercial companies is defective and replaced at time, in order to remove all coliforms. Moreover, the only safe water in Haret-Hreik city is that distributed by Abbas Water Project. Analyses revealed the absence of any bacterial contamination and the respect of the WHO physicochemical limits.

Introduction

Water is the most essential natural resource for human's life on earth. It is indispensable for household activities, socio-economic activities, agricultural and industrial water uses, and to the development of civilizations [1, 2, 3]. However, the access to safe drinking water remains unreachable for more than one billion people around the world, especially in developing countries [4].

The quality of water is defined in terms of its physicochemical and biological parameters. Unsafe drinking water is a major source of microbial pathogens, leading to significant health issues and to several infectious diseases [5, 6, 7, 8, 9]. Consequently, water borne diseases are important public health issues, and many of them are derived from the contact with contaminated water by human fecal material [10, 11]. An estimated 4 billion cases of diarrhea annually represented 5.7% of the global disease burden in the year 2000 [12]. Diarrheal diseases kill an estimated 1.8 million people each year [13]. Ninety percent of deaths are children, mainly in developing countries [5]. The majority of enteric pathogens in these children include: rotavirus, *Campylobacter jejuni*, enterotoxigenic *Escherichia coli*, *Shigella* spp. and *Vibrio cholerae* O1, *Aeromonas* spp., *V. cholerae* O139, management constraints, leading to a depletion of safe water resources. In fact, 60 to 70% of Lebanese natural resources are contaminated by chemical and biological pollutants. 260 Lebanese children die yearly from diarrheal diseases related to inadequate drinking water, sanitation and poor hygiene conditions [22].

In fact, drinking water is collected from unprotected communal sources such as river water, springs, and groundwater. These water sources are affected by several anthropogenic inputs including domestic, agricultural and industrial discharges [23, 24, 25]. Untreated industrial effluents increase the concentration of dissolved heavy metals (Zn, Pb, Cu, Ni, and Cr) and major ions in several Lebanese rivers such as Antelias river, Nahr Ibrahim river, and ALghadir river [23, 24, 26, 27, 28]. Furthermore, the uncontrolled use of fertilizers leads to the accumulation of nitrate in river water. El fadel et al [29] and Houri & El Jeblawi [30] showed that concentrations of nitrate are around 7 mg/L in the major Lebanese rivers. Hydrocarbon compounds and chlorinated organic matter were also identified in river water, corresponding to a signature of pesticides pollution.

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Moreover, pesticides and nitrate are leached in high levels to groundwater. A report published by the ministry of Environment in Lebanon shows clearly the connection between groundwater pollution and drinking water quality [31]. In addition, domestic wastewater is discharged into rivers without any treatment, resulting in rivers and drinking water contamination with bacteria, viruses, and a wide range of inorganic pollutants. Identification of fecal and total coliform bacteria under high concentration is a sign of the discharge of untreated domestic wastewater [30]. Furthermore, 44% of wells in Ras Beyrouth (coastal area of Beirut City) are contaminated by total coliform and *Escherichia coli*. This contamination is related to the infiltration of wastewater into groundwater.

However, the quality of drinking water which is collected from protected sources (wells, boreholes and public standpipes), can be disturbed during its transport through the drinking water distribution network. In fact, these sources are substantially distances from households, leading to a post-source contamination from the infiltration of sewage from sewer network into drinking water distribution system, through cracks in sewer pipes, leading to a chemical and microbial contamination of drinking water. Such post-source contamination gives a poor water quality in storage reservoirs within households [32].

In the Haret-Hreik city, our study area in the Southern Suburb of Beirut city (Lebanon), drinking water sources are anticipated to be microbiologically contaminated due to use of unsafe water source from Ain-ElDelbeh river, and to the infiltration of sewage into drinking water network through the cracks into sewer and drinking water pipes after the War 2006. To solve this problem, more than 35 commercial filtration companies were installed in Haret-Hreik to treat and sale drinking water. In addition, Jihad Al Binaa Company had built several drinking water reservoirs (Abbas Water Project) which are filled daily by treated water from the Establishment of The Water of Beirut and Mount Lebanon, at Burj AbiHaidar city.

As the assessment of water quality (biological, chemical, and physical) is crucial before any intended use [33], the main purpose of this study is to carry out an initial assessment of some physicochemical, chemical, and biological parameters of the water distributed in Haret-Hreik city, in order to determine whether or not the water meets the previously defined objectives of safe water. The three sources of water supplied were analyzed: Municipal drinking water network (MW), treated municipal water by commercial companies (CC), and Abbas Water (AW). Thus, the pH, the electrical conductivity (EC), the TDS and the total hardness were determined. The concentrations of Ca2+, Mg2+, K+, Na+, and Cl- were evaluated. The total and fecal coliforms were enumerated, and several bacterial species were identified. Experimentally measured parameters were compared with the world heath organization (WHO) guidelines.

Materials and Methods

Study area

Water samples were collected from Haret-Hreik city. It is a city of about 95 000 inhabitants located in the Dahieh Suburb, southern of Beirut city (Lebanon). Haret-Hreik has a surface of about 1.82 km2, contains 22 000 residential units, and around 750 non residential units (commercial, industrial, high school, office, and warehouse).

Haret-Hreik is supplied by drinking water from Ain-ElDelbeh river. This surface water is only chlorinated before being pumped in the drinking water distribution system. It covers 26% of the population needs in drinking water. After the War 2006, the distribution network suffers from cracks in pipes, leading to the leak of tapwater in the soil and to the contamination of tapwater by the infiltration of sewage into the drinking water distribution pipes through these cracks also.

In order to satisfy the population needs in potable water, 35 commercial treatment companies have been installed in Haret-Hreik city in order to sale treated municipal water. All these companies use the same treatment process. A sediment filter (fiber filter), in order to remove suspended particles. This filter is followed by a solid block activated carbon filter (0.5-1 µm) to remove dissolved contaminants, bad odors, and colors. Finally, water is physically disinfected by UV radiations. The majority of these companies are not certified, and do not undergo periodical physicochemical and bacteriological controls.

Furthermore, since 1988 Jihad AL Binaa Company had built more than 130 drinking water reservoirs (Abbas Water Project) in all Dahieh Suburb. These reservoirs are daily filled by treated drinking water from the Establishment of The Water of Beirut and Mount Lebanon, at Burj AbiHaidar city. At reservoirs exits, water undergoes periodical chemical and biological analyses in order to check if water satisfies the WHO guidelines.

Water sampling and samples conditioning

For this study, sampling campaigns were conducted during the first week of April 2014. Water is sampled from the three drinking water sources supplied to Haret-Hreik city: (i) municipal water (MW), (ii) commercial treatment companies (CC), (iii) and Abbas water (AW). For each source, 5 sampling sites were randomly selected, and from each site, 3 samples were taken along 3 successive days (one sample per day). A total of 45 water samples were collected.

Prior to sampling, faucets were left open for 15 seconds. At each sampling site, two sterile glass bottles (1 L) were completely filled by drinking water, one bottle for physicochemical analyses, and the second one for bacterial characterization. Samples were then stored at 4°C, brought back to the laboratory and processed within 1 hour of sampling. Samples for bacterial characterization were directly processed for bacterial enumeration and identification. Whereas, samples for chemical and physicochemical analyses were processed within four days.

Physicochemical analyses

Water characteristics such as pH, electrical conductivity, and total dissolved solid (TDS) (Orion 4 star/Thermo scientific™), were measured immediately at the laboratory. Part of the water was filtered through a pre-washed 0.22 mm pore size cellulose-acetate membrane (Chromafil CA-20/25) and split into four aliquots for cations and anions analyses. The filtrates were stored at 4 °C in glass bottles until analysis. Total dissolved Ca and Mg cations were determined by a Perkin-Elmer PinAAcle 900T AAS (Atomic Absorption Spectrometry). Total hardness was calculated by the summation of calcium and magnesium hardness. Total dissolved Na and K cations were measured using a Sherwood 420 Flame Photometer. Sodium and potassium were detected at a wavelength of 589 nm and 766.5 nm, respectively. Nitrate anions were measured by spectrophotometry using a Biochrom Libra S22 spectrophotometer, after the addition of salicylic and sulfuric acids to the water sample in a basic medium (pH>12). The absorbance was detected at 410 nm [34]. Chloride anion concentrations in water were evaluated by silver nitrate 0.1 N titration using the Mohr's method [35].

Bacterial characterization

The number of bacterial colonies (CFU/100 mL) was used to evaluate the number of total coliform and fecal Streptococcus. 2 times 100 mL from each water sample were filtrated through two different membranes filters (Millipore / cellulose ester 0.45 µm). Each filter was then placed on the surface of a petri dish containing a nutrient agar medium. A M Endo Broth MF™ (Difco), and Slanetz and Bartley medium were used to cultivate total coliform and fecal *Streptococcus*, respectively. Total coliform were incubated at 35.5 °C for 24 hours. Whereas, fecal *Streptococcus* were incubated at 35°C for 4 hours, and then at 44-45°C for 44 hours. All enumerations were carried out using five replicates. Furthermore, identification of total coliform species was carried out using API® 20 E kits.

Results and Discussion

pH, Electrical Conductivity, Total Dissolved Solid

The range and the average results of the physicochemical parameters for water samples from the three different sources of drinking water are summarized in Table 1.

The pH, EC and TDS of different water samples are illustrated in the Figure 1. The pH of water determines its softness and its corrosion capacity [36, 37]. The pH values of water collected from residences (MW) are slightly alkaline (MW1-›MW5), ranges from 7.4 to 7.7, and only minor fluctuation in pH was recorded. The pH values of AW water (AW1-›AW5), are also in the alkaline range (7.7 to 8.2), but more alkaline than MW. However, water collected from CC (CC1-›CC5), is close to the neutrality, except for the sample CC1 in which pH is equal to 7.6. These previous results indicate that the pH levels of all collected samples were within the limits set for domestic use as prescribed by the WHO (6.5-8.5).

Maximum values of EC were found in samples of MW (2846-3070 µS/cm), indicating the presence of high amount of dissolved inorganic substances in ionized form [38, 39]. These inorganic elements may be due to the discharge of untreated industrial effluent from several marble factories located at the Ain-ElDelbeh river sides. Electrical conductivity of MW samples exceeds the permissible limit of drinking water as prescribed by the WHO by 2 folds (1500 µS/cm). An increase in EC may lead to an excessive hardness and corrosive water [40]. However, Electrical conductivity of AW (556-664 µS/cm) and CC (247-305 µS/cm) samples fits within the permissible limit.

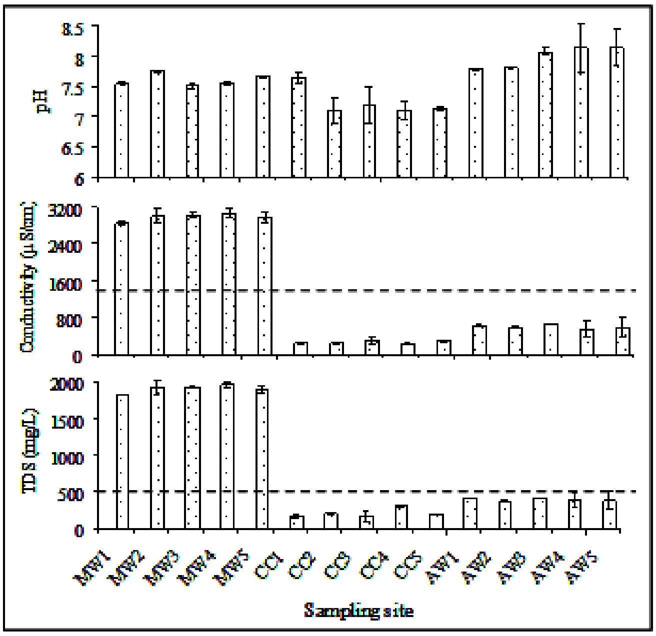

Figure 1. pH, Electrical Conductivity, and Total Dissolved Solid in water samples from the three sources of drinking water (Municipal water - MW / Commercial companies - CC / Abbas Water – AW). Dotted lines indicate the permissible limit.

The WHO has suggested a limiting value of 500 mg/L for TDS in drinking water. In the present study, TDS concentrations in water samples varie between 158 mg/L and 1965 mg/L. Excessive concentration of TDS is noticed in MW samples (1820-1965 mg/L). Whereas, TDS concentrations of AW and CC samples don't cross the permissible limit. Consumption of water with a TDS concentration upper the limit may affect persons suffering from kidney and heart diseases [41], and may lead to diarrhea or constipation [42].

Calcium, Magnesium, Total Hardness.

Calcium and magnesium in the three water sources follow the same trend. Calcium concentrations in all samples range between 0.85 mg/L and 106.48 mg/L (Fig. 2), and they are below the WHO limit (75 mg/L), except samples from MW in which calcium concentrations are greater than 86.75 mg/L. The highest average concentrations (Ca: 96 mg/L / Mg: 46 mg/L) are found in the MW and the lowest one in CC water (Ca: 2.3 mg/L / Mg: 1.9 mg/L). Calcium content in MW is 7 and 42 folds greater than that in AW and CC, respectively (Fig. 2).

Table 1: Analyses of physicochemical parameters for the three sources of drinking water in Haret-Hreik city.

Parameters	MW			AW			CC			WHO (2006)
	Range	Mean	St. Dev.	Range	Mean	St. Dev.	Range	Mean	St. Dev.	
pH	7.51-7.66	7.60	0.09	7.78-8.13	7.99	0.17	7.09-7.64	7.23	0.23	6.5-8.5
EC	2846-3070	2983	41	556-664	610	43	247-305	272	24	< 1500
TDS	1820-1965	1908	54	371-411	388	18	158-296	201	32	< 500
Total hardness	408-457	432	19	86-95	90	3	5-19	12	5	< 500
Ca^{2+}	87-106	96	8	12-15	13	1	0.8-4.1	2.3	1.4	< 75
Mg^{2+}	45-47	46	2	13-15	14	2	1.6-2.3	1.9	0.3	< 50
Na^{+}	516-527	524	11	31-44	34	6	41-51	45	4	< 150
K^{+}	7.8-11.7	8.6	1.7	ND	ND	ND	ND	ND	ND	< 12
Cl^{-}	1124-1242	1147	47	74-112	83	9	72-87	77	6	< 250

All parameters are in mg/L except pH and Electrical Conductivity (EC). EC in µS/cm.

The high quantity of calcium in MW may be related to the presence of several tiles factories on the Ain-ElDelbeh river sides. Magnesium content in all analyzed water samples ranged between 1.62 mg/L and 46.65 mg/L which fall within WHO limit (50 mg/L). Moreover, concentrations of calcium in MW water are two folds greater than those of magnesium.

CC water is very poor in divalent cations (Ca2+/Mg2+). Consumption of water with low level in magnesium has health consequences. Several studies demonstrate an inverse relationship between magnesium level in drinking water and risk of death from ischemic heart diseases [43, 44].

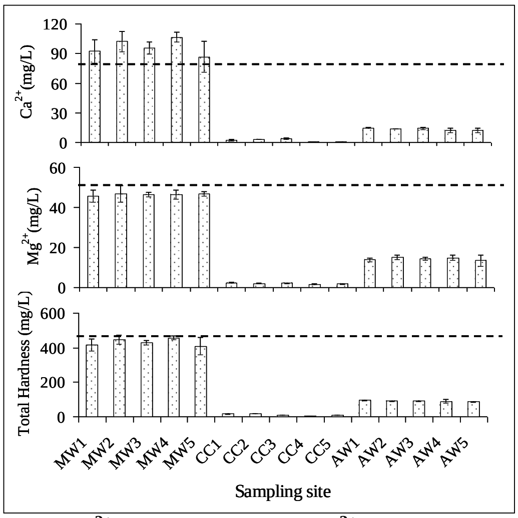

Figure 2. Ca^{2+} concentrations, Mg^{2+} concentrations, Total Hardness in water samples from the three sources of drinking water (Municipal water - MW / Commercial companies - CC / Abbas Water – AW). Dotted lines indicate the permissible limit.

Total hardness of drinking water for all the three sources are within the permissible limit of WHO (500 mg/L). Water from MW has the highest total hardness (408-457 mg/L), which is 36 folds greater than that of CC (5-19 mg/L) (Fig. 2). Water with high hardness is not suitable for drinking, washing, and laundering. However, the available information supports the hypothesis that intake of hard water, especially rich in magnesium, decreases the risk of CVD [45]. In addition, several epidemiological studies have reported the lower coronary heart disease (CHD) risk in areas with hard water, having high levels of magnesium or calcium.

Chloride, Sodium, Potassium.

Samples from MW registered a high value of chloride (1023-1246 mg/L), which exceeds the permissible limit (WHO: 250 mg/L) by 4-5 folds (Fig. 3). The increase of chloride in MW is related to the use of chlorine pellet by the municipality to disinfect the Ain-ElDelbeh river water before its distribution in the municipal network. Whereas, chloride concentrations in CC and AW samples fall within the prescribed limit (Fig. 3). High chloride level in drinking water harms metallic pipes [46], and population exposed to high chloride level in water is subjected to laxative effect. Moreover, nitrate concentrations in the three water sources range between 3 and 10 mg/L, and they fit within the WHO limit (< 50 mg/L).

Sodium concentrations follow the same trend of calcium and chloride. Sodium concentrations in MW exceed theWHO limit (150 mg/L) by 3.5 folds, unlike those of CC and AW (Fig. 3). Furthermore, potassium is below the limit of WHO (12 mg/L) in MW, and below the detectable limit for all the remaining samples.

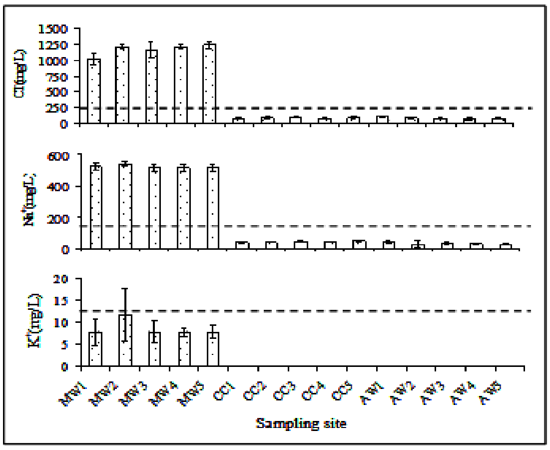

Figure 3. Cl^- concentrations, Na^+ concentrations, and K^+ concentrations in water samples from the three sources of drinking water (Municipal water - MW / Commercial companies - CC / Abbas Water – AW). Dotted lines indicate the permissible limit.

Sodium concentrations follow the same trend of calcium and chloride. Sodium concentrations in MW exceed the WHO limit (150 mg/L) by 3.5 folds, unlike those of CC and AW (Fig. 3). Furthermore, potassium is below the limit of WHO (12 mg/L) in MW, and below the detectable limit for all the remaining samples.

The physicochemical analyses of drinking water from different sources in Haret-Hreik city show clearly that drinking water from municipal network is not safe for domestical use. It has a high electrical conductivity (2 folds greater than WHO limit), a high TDS concentration (3.8 folds greater than WHO limit), a total hardness near the upper limit prescribed by the WHO, an excess of chloride (4.6 folds greater than WHO limit). The treatment of MW by commercial companies decrease strongly the average values of the physicochemical parameters, and make the water physicochemicaly safe to be drunk. Furthermore, water stored in reservoirs through Abbas Water Project can be safely drunk and used in domestic activities.

Microbial characterization

Table 2 illustrates the enumeration of total coliform and the characterization of existing bacterial species in all water samples. MW samples contain the highest number of total coliform. 47% of all collected samples are contaminated by

Table 2: Bacterial enumerations and species characterization in the three sources of drinking water distributed in Haret-Hreik city.

	MW					CC					AW				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Total coliform (range CFU/100 mL)	3150 - 4166	33 - 1100	383 - 700	667 - 1033	132 - 350	1 - 52	1	1 - 33	283-300	1	0	0	0	0	0
Escherichia coli	+	+	-	+	+	+	-	+	+	-	-	-	-	-	-
Enterobacter Cloacae	-	-	+	-	-	+	-	+	-	-	-	-	-	-	-
Enterobacter Sakazakii	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Klebsiella Oxytoca	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-
Serratia ficaria	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Fecal *Streptococcus* (CFU/250 mL)	+	+	+	+	+	+	-	+	+	-	-	-	-	-	-

Escherichia coli and 53% of these samples contain fecal coliform.

The bacteriological analysis of water determines its potability. Referring to the WHO, drinking water must contain zero CFU per mL. Bacterial contamination in water samples was tracked along 3 successive days (D1, D2, and D3). Results show that all MW samples are contaminated with high amount of total coliform (Fig. 4). The highest amount is found at the sampling site MW1, with bacterial number ranges between 3150 and 4166 CFU/100 mL. The remaining MW samples contain lower bacterial number, ranging between 216 and 1100 CFU/100 mL. The high density of total coliform may be related to the discharge of untreated wastewater into Ain-ElDelbeh river and to the infiltration of wastewater from the Haret-Hreik sewer network into drinking water distribution system through pipe cracks. According to the EPA standard, every water sample that has coliform must be analyzed for either fecal coliforms or *Escherichia coli* [47] with a view to ascertaining contamination with human or animal waste (EPA, 2003). Characterization of total coliform in MW at the sampling site MW1 indicates that coliforms are mainly *Escherichia coli* (96 %), the remaining bacteria are *Enterobacter Sakazakii* (4%). However, all total coliforms in MW2, MW4, and MW5 are E. coli. MW3 is not contaminated by *Escherichia coli*, existing coliforms correspond to *Enterobacter Cloacae* (44%) and *Klebsiella Oxytoca* (56%). Moreover, bacterial identification indicates that MW contains fecal *Streptococcus*, ranging between 2 and 10 CFU/100 mL.

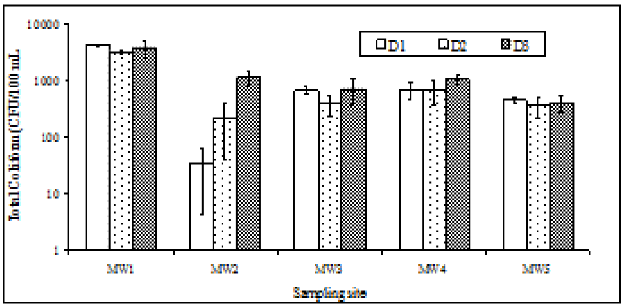

Figure 4. Enumeration of total coliform in municipal water (MW), from 5 different sampling sites. Enumeration was carried our along three successive days (D1: first day / D2: second day/ D3: third day).

The drinking water distributed in Haret-Hreik city is mainly contaminated by E. coli bacterial species. It is found in all mammal feces at concentrations of 10 log 9−1, but it does not multiply appreciably in the environment [14]. The presence of E. coli at high level and fecal Streptococcus in tapwater, is an indicator of contamination by fecal coliforms [11]. The more number of fecal coliform, the more presence of fecal material from warm blooded animals [14].

Other bacteria isolated from water samples such as Enterobacter Sakaskii, Enterobacter Cloacae, and Klebsiella Oxytoca are also of public health significance. Enterobacter are example of non fecal coliform and can be found in vegetation and soil which serves as sources by which the pathogens enter the water [48].

Water collected from CC is less contaminated by total coliform than MW. Total coliforms average range between 1 to 300 CFU/100 mL. Sampling sites CC1 (1-52 CFU/100 mL) and CC3 (1-33 CFU/100 mL) show a wide variation in total coliform number from the first to the third sampling day (Fig. 5). However, samples CC2 and CC5 show a constant average of total coliform number along the 3 sampling days (1 CFU/100 mL). The occurrence of coliform bacteria was significantly high in samples CC4, where total coliform number ranges between 283 and 300 CFU/100 mL.

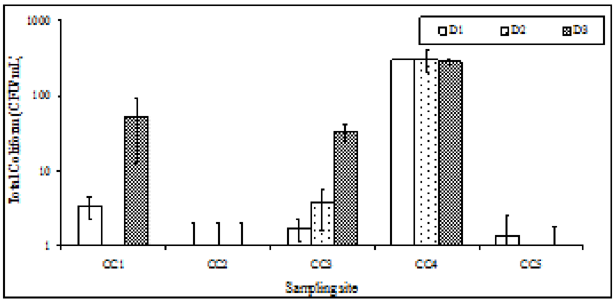

Figure 5. Enumeration of total coliform in water samples collected from commercial companies (CC), at 5 different sampling sites. Enumeration was carried our along three successive days (D1: first day / D2: second day/ D3: third day).

Characterization of total coliform in water from CC indicates that CC1 is contaminated by *Escherichia coli* (75 %), *Enterobacter Cloacae* (14%), and *Klebsiella oxytoca* (11%). Water from CC3 contains E. coli (60 %), *Serratia ficaria* (30%), and *Enterobacter Cloacae* (10%). However, All total coliforms in CC4 are *Escherichia coli*. Furthermore, enumeration of fecal coliform indicates that samples CC1, CC3, and CC4 contain fecal *Streptococcus* with averages 6, 3 and 10 CFU/100 mL, respectively. However, samples CC2 and CC5 do not contain any fecal *Streptococcus*. Thus, the process of water treatment in private companies CC1, CC3, and CC4 remove partially the total and fecal coliform, existing in untreated municipal water. This deficiency in the treatment may be related to the bad maintenance of the UV disinfection process used in these companies, and to the non replacement of the UV lamp directly just before the end of its life time.

Biologically, water from CC1, CC3, and CC4 are not safe to be drunk and to be used for domestic activities. Whereas, water from CC2 and CC5 can be used for domestic activities with precaution.

Finally, all water samples collected from AW reservoirs don't contain neither total nor fecal coliforms, and they are biologically safe to be drunk.

Conclusion

The aim of this study was the assessment of the quality of different drinking water sources distributed in Haret-Hreik city. On the basis of physicochemical analyses and bacterial characterization, it could be concluded that, municipal water (MW) is not safe for domestic use and to be drunk. The majority of physicochemical parameters such as total dissolved solid, electrical conductivity, calcium, sodium, and chloride exceed the limits described by the WHO. Furthermore, bacterial enumeration showed a high number of total coliform and the water is contaminated by fecal coliform, indicating the contamination of municipal water by animal feces. The consumption of municipal water may have a potential risk of getting infected by water borne diseases.

The analyses reveal that water sold by the commercial companies fit within the limits of physicochemical parameters described by the WHO, showing that the treatment process in the commercial companies is efficient. While as per the bacteriological standards, the treated water in all water samples are contaminated by total coliform and the 60% of them contain fecal coliforms. Thus, the disinfection treatment process in all commercial companies is

defective, making their water unsafe for domestic use and to be drunk. Industrialists should be advised and controlled by municipal authorities to correctly manage their disinfection process in order to obtain properly treated water for drinking purposes.
The present investigations have led to conclude that the physicochemical and bacteriological quality of water samples collected from Abbas Water reservoirs (AW) satisfies the limits prescribed by the WHO.

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