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Quality Assessment of Egyptian Drinking Water Supplies and Disinfecting Using Ultraviolet Radiation

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Abstract: Drinking water, surface and underground water were microbiological and chemical analyzed during storage in covered and uncovered tanks for four months. Microbiological analyses were carried out to determine the microbial indicators namely, Total bacterial counts, total coliform, *E.coli*, *Enterococcus faecalis*, *Pseudomonas aeruginosa* and *Clostridium perfringens*. Drinking water of Amiria municipal water station was microbiologically safe after storage in covered tanks however, in uncovered tanks the total bacterial counts increased gradually to reach $8x10^2$ cfu/ml at the fourth month.With respect to underground water, all tested groups of microorganisms were attained high values except *E.coli* and *E.faecalis* counts were not detected. During storage the densities of total bacterial counts, total coliform and *P.aeruginosa* increased in both covered and uncovered tanks to reach at the fourth month 10^5-10^7, 58-68, 51-65 cfu/ml respectively. As to bottled water, samples of four companies producing it in Egypt were taken for analysis during the steps of production. Companies A, B and C were used underground water and company D used surface water. Results revealed that all companies were microbiologically unsastifactory where final product still contained total bacterial counts, *P.aeruginosa* and *C.perfringens* exceeding the drinking water quality guideline values. An experiment was conducted to study the efficiency of uv radiation in reducing the densities of certain bacterial isolates inoculated in sterilized tap water. *P.aeruginosa* was the most sensitive bacteria followed by *E.coli* whereas *E.faecalis* and *B.cereus* were more resistant toward uv radiation.

Keywords: drinking water - storage water - underground water- microbial indicators - bottled water - uv radiation

Introduction

There is an increasing demand for potable water to satisfy the need of the uncontrolled increasing population in Egypt. The quality of surface and ground water is as important as their quantities where the chemical, physical and bacteriological characteristics determine, to a great extend, their suitability to municipal, industrial, agriculture and domestic water demands.

WHO (1971) reported that water intended for human consumption must be free from pathogenic organisms and from excessive chemical substances that may be hazardous to health.

Storing drinking water in the home is common in the developing world. Several studies have documented increased concentrations of *faecal coliforms* during household storage. This has led to the belief that in house water contamination is an important transmission route for enteric pathogens and, moreover, that improving water source quality is not warranted until that quality can be maintained in the home (VanDerslice and Briscoe,1993).

Bottled drinking water is defined as a natural water packaged in bottles that has definite physical, chemical and microbiological specifications. These specifications are met through physical treatment. The source from underground must be far from any source of contamination and is not treated by chlorine. Bottled water must be at least as good in bacteriological quality as unbottled potable water and thus the total bacterial count should not exceed 50 cells/ml at 37 °C after 24h. It should also be free from coliform organisms, *E.coli*, *E. faecalis*, *P.aeruginosa* and *C.perfringens* (WHO,1984). Several methods are used for bottled water to meet the required specification. Among these methods are filtration by using special kinds of filters and ultraviolet exposure.

Ultraviolet disinfection represents an innovative technology being implemented today. The reasons for increased popularity are the improvements in modern u.v lamp at system design. Lack of toxic chemical residual, excellent virucidal properties, improved reliability and simplicity of operation. In addition, the economics have improved considerably, the costs having closely approached these of chlorination-dechlorination (Sheible and Bassell,1981). The present work was carried out to evaluate microbiological and chemical analyses of drinking water of surface and underground water stored in covered and uncovered tanks. The steps during the production of drinking bottled water of some companies as well. In addition, using ultraviolet radiation as a disinfectant.

Materials and Methods

Efforts to provide water have resulted in various types of water supplies being used. This study examined municipal water treatment plant at Amiria, Cairo in which water treated by coagulation, precipitation, filtration and chlorination. Also, Underground water derived from a well (depth about 20 m) at Bilbais, Sharkia Governorate, 50 km from Cairo and not treated with any chemical agent only filtration by using granular activated carbon filter and ceramic filter represents the mode of physical treatment. Water from both types was storing in six holding tanks (ca. 3 m^3) on the house roof as storage reservoirs after cleaning with chlorine, three tanks were covered and the rest were uncovered and used for domestic purposes over a period of four months.

Finally, bottled drinking water samples used in the present investigation were obtained from four companies producing it in Egypt. Samples used for microbiological and chemical analysis were collected from the factories during the steps of production. For company A, samples comprised the well sample (source of water), carbon filter and katadyne filter (used as purification methods), empty bottle, swab from knife used in cutting the neck of the bottle and filling the water, final product (bottled water) as well. Companies B and C, similar samples were obtained except ceramic filter is used instead of katadyne filter and in company B, u.v lamp is used to sterilize the air for empty bottles. As to company D, it uses surface water and chlorination as a chemical treatment. Samples comprised water sample, carbon filter, swab from the knife after cutting the neck and filling the water, after chlorination and from final product.

Microbiological examination was carried out where representative water samples were taken from the tanks at monthly intervals till

the fourth month. Three replicates were taken from each site in sterile bottles and microbiological examination was carried out within two hours. Analysis carried out according to the methods and media recommended by (WHO,1984) and standardized by International Standardization Organization (ISO,1984) for the detection and identification of total bacterial count, total coliform, *E.coli*, *E.faecalis*, *P.aeruginosa* and *C.perfringens*. Bacterial isolates were identified according to Bergey (1994).The isolates were grown in the appropriate broth and incubated at 30°C for 24 h to attain its maximum growth of about 10^5 - 10^7/ml. The cultures were inoculated in sterilized tap water and irradiated at increasing doses of ultraviolet, after which the bacterial count was determined on the appropriate medium.

Physical and chemical analysis comprised electric conductivity, pH, Ammonium ion, nitrate ion, iron ion, manganese ion, chloride ion, chlorine in addition to total hardness for well water according to that recommended in the American Public Health Association (1992).

Irradiation process: Sterilized tap water was inoculated and irradiated in open petri-dish 15x15 cm, about 2 cm thickness by u.v unit. 50 Hz power, 8 watt, 254 nm.

Results and Discussion

Water samples from Amiria municipal water station treated with chlorine indicated that samples were free from all microbial indicators under investigation namely, total bacterial counts, total coliform, *E.coli*, *E.faecalis*, *P.aeruginosa*, and *C.perfringens*. Chemical analysis revealed that electrical conductivy was 340 /umohs; pH 7.3; Cl, 28; chlorine, 0.2 ppm as well as NH_4, NO_2, NO_3, Fe, Mn were nil.Miettinen *et al.* (1998) demonstrated that treatment of surface water and ground water intake plants with chlorine prevent the growth of microbes in drinking water. Chlorine is used because its lacting and bacteria-killing abilities (Karazewski,1994). The same results were obtained after cleaning 6 containers of storage tanks located near Amiria municipal water station with chlorine except total bacterial counts were present in 2x10 cfu/ml and this is agreement with guidelines of Egyptian water. Isolates were identified as *B.subtilus and B.pumilus*.

Results of storage water tanks for 4 months indicated that, total bacterial counts in covered tanks were slightly increased to reach 3x10 cfu/ml and remained unchanged till the 4th month. Whereas uncovered tanks increased gradually to reach 8x10, 30x10, 40x10 and 80x10 cfu/ml for 1, 2, 3 and 4 month respectively. However, other bacterial indicators were not detected during the same period of storage. Previous investigations have reported the contamination of drinking water storage. Genthe *et al.* (1997) mentioned that in developing communities the source of water was of good microbial quality, but water quality was found to have deteriorated significantly after handling and storage and exceeding drinking water quality guidelines values by 1-6 orders of magnitude. During storage at the user site, heterotrophic bacteria grew while faecal coliform decayed (Dahi and Thogersen, 1996). Three of 21 holding tanks supplying stored water to a hospital were not covered. *Y.entercolitica* was isolated from the uncovered tanks supplying the medical residence as reported by Gafferkey *et al.* (1993). Isolates from uncovered tanks were identified as *B.subtilus, B.cereus, B. pumilus* and *Enterococcus faecium*. All chemical tests were recorded the same results and no changes has happened but chlorine was decreased.

Regarding the underground water samples, total bacterial counts, total coliform and *P.aeruginosa* counts were $1.2x10^3$, 1x10, and 8 cfu/ml respectively. *E.coli* and *E.faecalis* were not detected and *C.perfringens* was present. Brock *et al.* (1994) mentioned that aerobic bacteria were determined to be the only bacteria present in ground water and ranged from 80 to more than $1.6x10^4$/ml.Chemical and physical analysis of the underground water recorded,550 umhos/cm^{-1} for electrical conductivity, pH 7.5;NH_4 ,0.2; NO_3 ,0.4;Fe, 1.2; Mn, 0.8; Cl, 48 and total hardness 240 umhos/cm^{-1}.

Samples of 6 containers from underground water after cleaning were taken for analysis as shown in Table 1. Total bacterial counts were $5.4x10^3$ cfu/ml, total coliform with an average of 20 cfu/ml; *E.coli* and *E.faecalis* were not detected, *P.aeruginosa* present in the range of 15 cfu/ml and *C.perfringens* was detected in all samples under investigation.Sartory *et al.* (1993) reported that *Clostridia* were isolated from 26 of the 224 ground water and drinking water samples. Results of storage covered and uncovered well water tanks indicated that mean counts of total bacteria in covered storage water tanks at the first month were $3.5x10^5$ increased gradually to reach $5x10^6$ cfu/ml at the fourth month. Whereas counts of uncovered tanks were $1.4x10^6$ and slightly increased to attain $8.7x10^7$ cfu/ml. Regarding total coliforms, it could be observed that their initial counts of about 31 cfu/ml increased to attain 58 cfu/ml whereas the initial counts of uncovered was 39 cfu/ml and reached 68 cfu/ml.Shears *et al.* (1995) reported that although tube wells provided water with low faecal coliform counts, 62 % of household storage pots contained water with moderate to high counts. As to *P.aeroginosa* counts were 25 cfu/ml and increased to reach 51 and 65 cfu/ml in covered and uncovered respectively.With respect to *E.coli and E.faecalis* were not detected and *C.perfringens* were present in all samples examined during the 4 months.

All chemical analysis tested for well water tanks during the 4 months period were not changed and recorded that electrical conductivity was initially 550 umhos/cm^{-1} and reach 600 after 1 month and remained unchanged till the 4th month, pH 7.5, NH_4 ,0.2; NO_2 ,nil; NO_3 ,0.4; Fe, 1.4; Mn, 1; Cl, 48 and total hardness 240 umhos/cm^{-1}. The results were in agreement with Pathak *et al.* (1994) who investigated samples of dug wells, piped supplies and tube wells and hand pumps.They found that iron was in a maximum number (53 %) of water samples from hand pumps, followed by lead in 43% of the tube wells, chromium in 16% of dug wells, manganese in 7% of hand pumps above their maximum admissible concentrations. In general, 42-85% of water samples from districts surveyed was found to be bacteriologically unsatisfactory.

Samples of four companies producing bottled water were taken for analysis (Table 2). Each company has a different method in treating the water. Empty bottles tested for total bacterial counts only and all samples were free from total coliform as well as *E.coli*. Data from company A revealed that total bacterial counts were present in all steps and materials used in the company. Counts in well water were $5x10^4$ cfu/ml, whereas carbon filter and katadyne filters were contained 10^6 and 10^2 cfu/ml, respectively. Empty bottles contained $5x10^2$cfu/unit and swab from the knife was 70 cells/cm^2 and final product attained 10^5 cfu/ml. *C.perfringens* were present in well water, carbon filter and final product and all samples were free from *E.faecalis*. *P.aeruginosa* recorded 10^2-10^3 in swab from knife and final product respectively. Isolates were identified as *B.subtilis, B.polymixa, S.epidermis, S.aureus* and *P.aeruginosa*.

With respect to company B, results showed that the densities of total bacteria were 10^5cfu/ml and in well water,carbon and ceramic filters attained 10^5 cfu/ml. Empty bottle was recorded 7 cells /unit and swab from the knife $1x10^7$ cfu/ml. Mean densities of final product resulted in $4.1x10^2$ cfu/ml. *E.faecalis* and *P.aeruginosa* were not detected in all samples examined. However, *C.perfringens* was present in well water, carbon and katadyne filters as well as final product. Isolates were identified as *B.cereus, B.subtilis, B. polymixa* and *S.epidermis*.

Table 1: Mean counts of bacterial groups contaminated under ground water samples during storage for four months (cfu/ml).

Microorganisms	Covered tanks (Storage in months)					Uncovered tanks(Storage in months)			
	0	1	2	3	4	1	2	3	4
Total bacterial counts	$5.4x10^3$	$3.5x10^5$	$3.3x10^6$	$4.7x10^6$	$5x10^6$	$1.4x10^6$	$3.7x10^7$	$4.7x10^7$	$8.7x10^7$
Total coliform	2.0x10	3.1x10	4.3x10	4.8x10	5.8x10	3.9x10	5.7x10	6.1x10	6.8x10
E.coli	*	*	*	*	*	*	*	*	*
Enterococcus faecalis	*	*	*	*	*	*	*	*	*
P.aeruginosa	1.5x10	2.5x10	3.6x10	4.6x10	5.1x10	2.7x10	3.7x10	5.6x10	6.5x10
C.perfringens	+	+	+	+	+	+	+	+	+

*not detected +Present

Table 2: Mean counts of bacterial groups contaminated bottled water during the steps of production (cfu/ml).

Microorganisms Company A	Well water	carbon filter	katadyne filter	empty bottle/unit	swab from knife/cm^2	final product
Total bacterial counts	$5x10^4$	$7.2x10^6$	$2.1x10^2$	$5x10^2$	7x10	$4.6x10^5$
Total coliform	*	*	*	N.T	*	*
E.coli	*	*	*	N.T	*	*
Enterococcus faecalis	*	*	*	N.T	*	*
P.aeruginosa	*	*	*	N.T	$1.1x10^2$	$3.7x10^3$
C.perfringens	+	+	---	N.T	--	+
Company B						
Total bacterial counts	$2.1x10^5$	$8.8x10^5$	$4x10^5$	7	$1x10^2$	$4.1x10^2$
Total coliform	*	*	*	N.T	*	*
E.coli	*	*	*	N.T	*	*
Enterococcus faecalis	*	*	*	N.T	*	*
P.aeruginosa	*	*	*	N.T	*	*
C.perfringens	+	+	+	N.T	--	+
Company C						
Total bacterial counts	8x10	3.1x10	1.1x10	$7x10^2$	8x10	$5.0x10^3$
Total coliform	*	*	*	N.T	*	7
E.coli	*	*	*	N.T	*	*
Enterococcus faecalis	*	*	*	N.T	*	*
P.aeruginosa	*	*	*	N.T	$1.7x10^2$	$1.7x10^2$
C.perfringens	+	+	---	N.T	--	+
Company D						
Total bacterial counts	$4.5x10^5$	$9.4x10^5$	8x10	$8.5x10^2$	2	0.8x10
Total coliform	$2x10^2$	$3.1x10^2$	*	*	*	*
E.coli	*	*	*	*	*	*
Enterococcus faecalis	*	*	*	*	*	*
P.aeruginosa	*	*	$3.2x10^2$	*	*	*
C.perfringens	+	+	N.T	N.T	+	+

N.T = Not Tested * = Not detected

As to company C, total bacterial counts ranged 1-8 x10 cfu/ml in well water, carbon and ceramic filters as well as swab from the knife. Empty bottle recorded $7x10^2$ cfu/ml and final product was $5x10^3$ cfu/ml. *P.aeruginosa* counts were $1.7x10^2$ cfu/ml in swab from the knife and final product.*C.perfringens* was present in well water, carbon filter and final product. Isolates were identified as *B.subtilis, B.pumilus, B.cereus, S.aureus, P.aeruginosa, M.varians* and *S.epidermis*. Results of company D showed that, total bacterial counts were 10^5 cfu/ml in well water and carbon filter. Empty bottle contained $8.5x10^2$ cfu/unit whereas swab from the knife contained 8x10, after chlorination recorded 2 and final product counts were 8 cfu/ml. Total coliform densities were 10^2 cfu/ml in well water, carbon filter and swab from the knife. *P.aeruginosa* recorded $3.2x10^2$ cfu/ml in swap from the knife and not detected in all other samples. On the other hand, *C. perfringens* was present in all samples and the knife and empty bottle were not examined. Isolates were identified as *B.subtilis, B.cereus* and *M.varidans*. Warburton (1993) indicated that indigenous bacteria from the natural water source, bottled water may contain bacteria that enter as contaminants, including a wide range of saprophytic and human pathogens.

Physical and chemical properties of the four companies producing bottled water (Table 3) indicated that Electrical conductivity ranged 400-650 mmohs/cm^{-1} .The average of the parameters were 7.5 for pH, 0.02 ppm for NH_4, NO_2 measurements were nil, NO_3 were 0.02 in companies A and B and nil for C and D. As to K ion ranged 5.5-10 ppm, Na ion varied from 27-60 and iron ion was nil except company D recorded 0.05 ppm. Chlorine ion ranged 30-90 ppm, SO_4 ranged 28-45 ppm and finally fluoride recorded 0.4 ppm. From the above mentioned results company D recorded the least numbers in all parameters and this due to the source of water is surface water whereas company C was the highest in most parameters tested. Companies A and B were moderate in their numbers of the parameters under investigation. Regarding physical

Table 4: Effect of increasing u.v doses on pure cultures of certain bacterial isolates in water.

UV dose w/cm²	P.aeruginosa			E.coli			E-faecalis			B.cereus		
	N	log N/No	Reduction %	N	log N/No	Reduction %	N N/No	log %	Reduction	N N/No	log %	Reduction
0	$3.6x10^7$	0	0	$5.7x10^7$	0	0	$2.7x10^6$	0	0	$3.5x10^5$	0	0
2450	$5.1x10^5$	-1.85	98.58	$8.4x10^6$	-0.83	85	$7.3x10^5$	-0.57	72.96	$1.4x10^5$	-0.4	60
4900	$2.2x10^3$	-4.21	99.99	$7.3x10^5$	-1.89	98.7	$1.2x10^5$	-1.35	95.55	$3.7x10^4$	-0.98	89.4
9800	2.6x10	-6.14	99.999	$5.5x10^4$	-3.0	99.9	$5.4x10^4$	-1.70	98.0	$7.6x10^3$	-1.66	97.8
12250	-	-0	100	$3.1x10^3$	-4.26	99.99	$6.1x10^3$	-2.65	99.77	$1.4x10^3$	-2.40	99.6
14700	-	-	-	$1.2x10^2$	-5.7	99.999	$9.3x10^2$	-3.46	99.97	$4.7x10^2$	-2.87	99.87
17150	-	-	-	-	-	100	$2.5x10^2$	-4.0	99.99	6.6x10	-3.72	99.98
19600	-	-	-	-	-	-	6.4x10	-4.63	99.999	-	-	100
22050	-	-	-	-	-	-	-	-	-	-	-	-

Table 3: Physical and chemical analysis of four companies producing bottled water.

Parameters	A	B	C	D	Maximum* Permissible
E.C	550	500	650	400	-
pH	7.5	7.5	7.5	7.4	6.5-8.5
NH_4(mg/1)	0.02	0.02	0.02	0.03	-
NO_2(mg/1)	nil	nil	nil	nil	0.005
NO_3(mg/1)	0.02	0.02	nil	nil	-
K(mg/1)	5.5	7	10	6	10
Na(mg/1)	38	60	42	27	-
Fe(mg/1)	nil	nil	nil	0.05	0.3
Mn(mg/1)	nil	0.05	nil	nil	0.1
Cl(mg/1)	88	90	62	30	250
SO_4(mg/1)	28	39	45	35	200
F(mg/1)	0.4	0.4	0.4	0.3	0.8

*Guidlines values reported by WHO (1984)
- = Not mentioned

and chemical properties of all companies producing bottledwater were in agreement with the standard guidelines of drinking water. Appleyard (1996) mentioned that contaminated groundwater contains high concentrations of ammonia, iron and bacteria at levels that commonly exceed national drinking water guidelines. From aforementioned data it reveals that drinking water of the storage water tanks of municipal water treatment plant at Amiria, underground water from a well at Bilbais used for domestic purposes as well as the four companies producing bottled water were microbiologically unsatisfactory. Densities of microbial groups were exceeding the drinking water quality guideline values. To approach these guideline values, uv radiation was used as a physical treatment. The effect of increasing doses of u.v on the survival of dominant bacterial isolates introduced at high population densities of 10^5-10^7/ml was carried out. Data representing changes in bacterial counts is given in Table 4. As a result of exposure to increasing levels of u.v, bacterial counts invariably decreased. However, the lethal dose of radiation that could induce complete sterility varied from one organism to the other indicating a significant variation among the tested microbes in their response towards radiation. *P.aeruginosa* proved to be the most sensitive bacteria where counts decreased by about 4 log cycles on exposure to 4900 w/cm². *E.coli*, *E.faecalis* as well as *B.cereus* were comparatively less sensitive where their counts were reduced by 4 log cycles when exposed to the 12250, 14700 and 17150 w/cm² respectively. Montogomery (1985) mentioned that microorganisms are susceptible to ultraviolet radiation. The sensitivity of organisms will vary according to their resistance to penetrate of ultraviolet energy, to their possession of certain intrinsic repair mechanisms, and to some environmental factors. It has been suggested that it is the chemical composition of the cell wall and its thickness that ultimately determines the relative resistance of microorganisms. Snowball and Hornsey (1988) mentioned that *B.subtilus* mixed (vegetative and spores) required 7100 w/cm² for 90% reduction of the viability in statistic air. Wolf (1990) determined the approximate doses of 90% inactivation of some microorganisms in potable water. The inactivation doses of *E.coli* and *S.aureus* were 3000 and 4500 w/cm² respectively, however, Hassan and Hussein (1998) found that doses of 2350 and 4700w/cm²were achieved the same results. It could be concluded that drinking water should be stored in clean, tightly covered, containers not subjected to corrosion and cleanness process periodically is must. It is important to use uv irradiation due to it is economical and efficient method of ensuring bacteriologically safe water in addition to the traditional treatment in disinfecting municipal water supplies.

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