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Domestic Water Quality in Jeddah, Saudi Arabia

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Abstract. Due to water resources shortage in Saudi Arabia, the water authority relies on intermittent water supply system. In this system, the city is divided into a number of small sectors, and water is pumped rotationally between the sectors according to an operational schedule. The frequency of water pumping to a given sector varies from several days to weeks. Between the intermittent water supply, pipes remain empty and dry for long periods. Consumers construct the underground storage water tanks to meet their demands. Lack of sewerage systems in many areas with high water table in the city lead to the presence of cesspools near the underground storage water tanks. Potential leakage of polluted water into the distribution network is very high and the pipe system is exposed to the pressure of contaminated surrounding water table. These factors enhance the risk of drinking water contamination. The first objective of this study is to assess the quality of domestic water supply in Jeddah. One hundred and thirteen water samples were collected in a five-month period between January and June 2009. Thirteen parameters were evaluated and compared to the maximum level of the WHO and Gulf standards for un-bottled drinking water. The results showed a compliance with the drinking water standards regarding the physical and chemical parameters, except five samples which have exceeded the maximum allowable limit for iron. The bacteriological results showed that up to 60% of the samples were contaminated with total coliform. The second objective is to evaluate the suitability and reliability of the most purchased domestic water purification units (point-of-use) POU, and to select the suitable water purification unit for the residential water in Jeddah. Unit III, which consists of fiber filters, activated carbon filter and the ultraviolet UV- Sterilizer of ultraviolet (UV), was found to be suitable for domestic use in Jeddah.

Keywords: Domestic water, Quality, Purification, POU.

1. Introduction

The Kingdom of Saudi Arabia faces severe water problems and needs new water policies to achieve sustainable development in its harsh environment. To overcome the water shortage, Saudi Arabia is the largest producer of desalinated water in the world. Nonetheless; its big cities, like Jeddah and Riyadh, are struggling to provide safe water for domestic, commercial and industrial usages. In urban setting, water supply distribution systems are designed for continuous water supply to deliver safe drinking water that is also adequate in quantity and acceptable in terms of taste, odor and appearance. However, as a result of rapid population growth and high water losses from the distribution network, the total water demand of the system in many urban setting of developing countries exceeds available production capacity.

To limit total demand and provide an equitable distribution of available water, intermittent water supplies with reduced system pressures are often introduced. The primary cause of intermittent supply is extending distribution systems beyond their hydraulic capacities to provide 24-hour service. One of the assumptions is that under intermittent water supply, water consumption in residential areas is less compared to continuous supply.

The distribution system of Jeddah city comprises two water reservoirs, and about 5,500 km of distribution pipelines which covers about 90% of the city and connects 158,456 households to the network [1]. The amount of water that was allocated to Jeddah city is - 630,000 cubic meter - in 2004. However, the actual demand of the city is almost one million cubic meters [2].

Jeddah suffers from a deficiency in water supply. With a population exceeding 3 million, drinking-water service authority follows a policy of ‘water rationing’ through intermittent water supply to keep pace with the ever increasing demand of both quantity and quality water. Consumers, in their turn, have found means to secure their water supply through the use of underground water storage tanks. Such setting of intermittent water supply and water storage engender water quality problems. Biofilms in potable water distribution systems consist of microorganisms that can survive and grow under the low nutrient concentrations commonly found within water distribution systems [3].

Consumers, also, seem to be aware of these likely problems and struggle to provide their households or premises with safe water for domestic and other usages. This awareness, combined with consumers' demand for high quality water, creates a big market of home water treatment systems. Point-of- Use (POU) filter is widely used; many consumers install one sort or another of these filters for further treatment of costly treated sea water. Confusion and rumor over water quality, efficiency and reliability of the POU filters are widely circulated in the city. This paper reports the results of water quality assessment in Jeddah City. The paper also deals with quality assessment of home water treatment systems.

2. Study Area

Jeddah city is located on the coast of the Red Sea in the Western part of Saudi Arabia. It is located at 21°32′36″N and 39°10′22″E as shown in Fig. 1. The city spreads out over an area of 1, 320 square km.

Fig. 1. Map of Saudi Arabia showing the location of Jeddah city.

3. Methodology

3.1 *Sampling*

To address the first objective of the study, 113 samples were collected from 36 districts, three samples were randomly collected from each district. Water in the consumers' residential buildings might be chemically and bacteriologically contaminated; therefore both bacteriological and chemical tests are conducted in all water samples. Figure 2 shows the sampling locations.

Fig. 2. Sampling locations in Jeddah city.

Samples were taken from a convenient source; however, the only condition was that the samples collected must come directly from the household underground tank. Also collected samples had not been subjected to further household level treatment. Sampling involves the collection and transferring of water samples from the original collection point to the laboratory, ideally, without causing any change in its properties. All samples were collected in clean, sterile, 250 ml glass bottles containing few drops of (1.5%) solution of sodium thiosulfate to neutralize any residual chlorine. Samples were kept cold at about 4^{o}C during transition to laboratory.

3.2 *Laboratory Tests*

Samples were analyzed within a maximum of 12 hours from the time of collection at the Environmental Engineering Laboratory of Civil Engineering Department in King Abdulaziz University. Table 1 shows the Physical and chemical parameters that have been tested and the standard methods of each test [4].

Table 1. Physical and chemical methodologies for water quality analysis.

No.	Parameters	Methods
1	pH	Potentiometeric method.
2	Electrical conductivity	Electrical Conductivity method.
3	Turbidity	Nephlometeric method
4	Total dissolved solids	Gravimetric method
5	Total Hardness	EDTA titrimetric method
6	Sodium	Flame emission photometric method
7	Total Alkalinity	H_2SO_4 titrimetric method
8	Chloride	Argentometric method
9	Nitrate	UV-screening method.
10	Sulfate	Turbidimetric method
11	Heavy metals	ICP/MS method.
12	Residual chlorine	DPD method.

3.3 *Point-of-Use Filtration Units*

The second and third objectives of the study were to assess the efficiency of the POU filter units and to select the most efficient and economical (POU) filter unit that is suitable for domestic purposes. The filters are used by consumers to upgrade water quality. An experimental study was carried out to determine its efficiency. Coliform bacteria determination would test the reliability of the filters to purify water from microbial contaminants. The heavy metals Iron, Lead, Nickel and

Chromium have been chosen to test the efficiency of the filter to reduce or to eliminate these types of pollutants from water.

3.3.1 *Point-of-Use Filtration Specifications and Tests*

Four different Point-of-use filters (POU) were selected for this study. These are the most purchased types of filters that are installed inside the consumer's houses in Jeddah City. Table 2 shows the description of each filtration unit. Table 3 shows the parameters that were tested in the lab for different POU units.

Table 2. Description of the four POU units.

Unites	Description
Unit I	Fiber filters (20 micron), (5 micron) + activated carbon
Unit II	(RO) membrane + Fiber filters
Unit III	(UV) Sterilizer + Fiber filters
Unit IV	(RO) membrane + UV Sterilizer + Fiber filters

Table 3. List of the Parameters that were measured in the (POU) units.

No.	Parameters	Unit
1	Turbidity	(NTU)
2	Electrical conductivity	(µS/cm)
3	pH	-
4	Iron	(µg/L)
5	Total coliform	(colonies/100 ml)
6	Percentage of wasted water	%

4. Results and Discussion

4.1 *Residential Drinking Water Quality Parameters*

Water in consumers' residential buildings might be chemically and bacteriologically contaminated; therefore both bacteriological and chemical tests were conducted on all samples in addition to physical examinations.

4.1.1 *Physical Parameters*

Turbidity is a very important parameter in drinking water. Turbidity, a measure of the light refractiveness of water, is routinely used to indicate drinking water quality. Although microbiological contamination is commonly accompanied by increase in turbidity, no correlation was found between water turbidity and the degree or incidences of microbiological contamination. Water turbidity in the study area was found to be quite high as shown in Fig. 3. Turbidity ranged from 0.03 to 2.4 NTU with standard deviation of 0.286 and average value of 0.293.

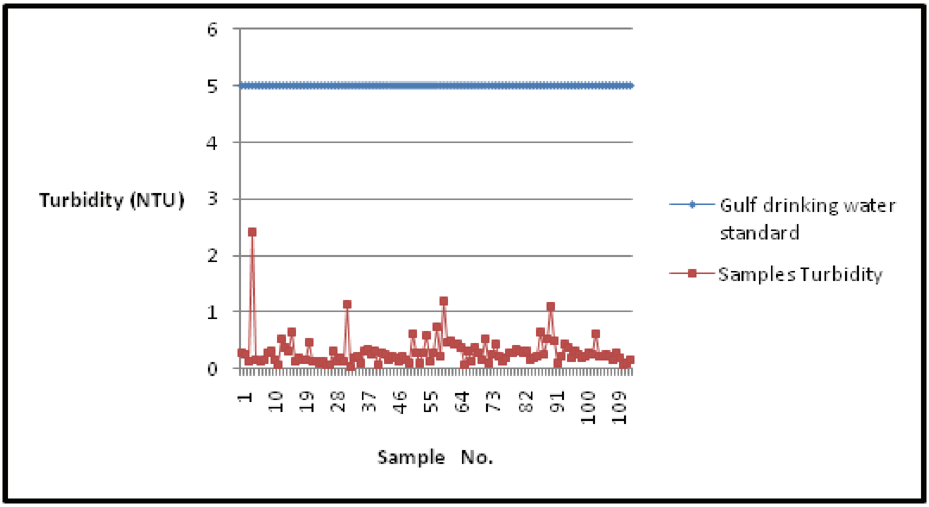

Fig. 3. Turbidity values comparison with Gulf Standards.

4.1.2 *Chemical Parameters*

The means and the standard deviations of the measured chemical parameters in comparison with Gulf drinking water maximum permissible levels [5] are shown in Table 4. The average residual Chlorine is 0.12 mg/L and it ranges from 0.0 to 0.56 mg/L. In the vast majority of cases residual chlorine is less than adequate. Eighty seven out of one-hundred and thirteen samples contain chlorine less than 0.2 mg/L.

Table 4. Measured chemical parameters and Gulf Standard.

Parameter		Mean	Standard deviation	Gulf Standard [5]
pH	-	7.89	0.48	6.5-8.5
Conductivity	(µS/cm)	320.57	93.57	-
Alkalinity	(mg/L)	38.98	9.23	-
TDS	(mg/L)	194.17	52.36	1000
Hardness	(mg/L)	43.66	11.65	500
Chloride	(mg/L)	85.66	35.40	250
Sulfate	(mg/L)	7.39	3.81	500
Sodium	(mg/L)	56.90	19.31	200
Iron	(µg/L)	124.49	90.39	300
Lead	(µg/L)	0.97	5.51	10
Nickel	(µg/L)	5.88	4.29	20
Chromium	(µg/L)	0.18	0.23	50

Three heavy metals and iron were tested to check the quality of water with respect to this type of contaminants. Apart from iron it is clear that heavy metals concentration is far less than maximum permissible levels for the respective metals.

4.1.3 *Biological Parameters*

Some forms of coliform bacteria naturally occur in the environment and are of fecal origin, while others are found exclusively in the environment. A subset of the total coliform group, known as the thermotolerant coliforms (fecal coliforms), has been used as a surrogate for E.coli in water quality testing. Fecal coliforms are considered more fecal specific than total coliforms, and also E. coli testing can be considered.

Figures 4 and 5 illustrate that the incidence of microbial pollution is quite high; more than 60% of samples were found to contain coliform bacteria. However, 5 samples were found to contain fecal coliform bacteria. The presence of total coliform in stored water can reveal re-growth and possible biofilm formation or contamination through ingress of foreign material, including soil or plants.

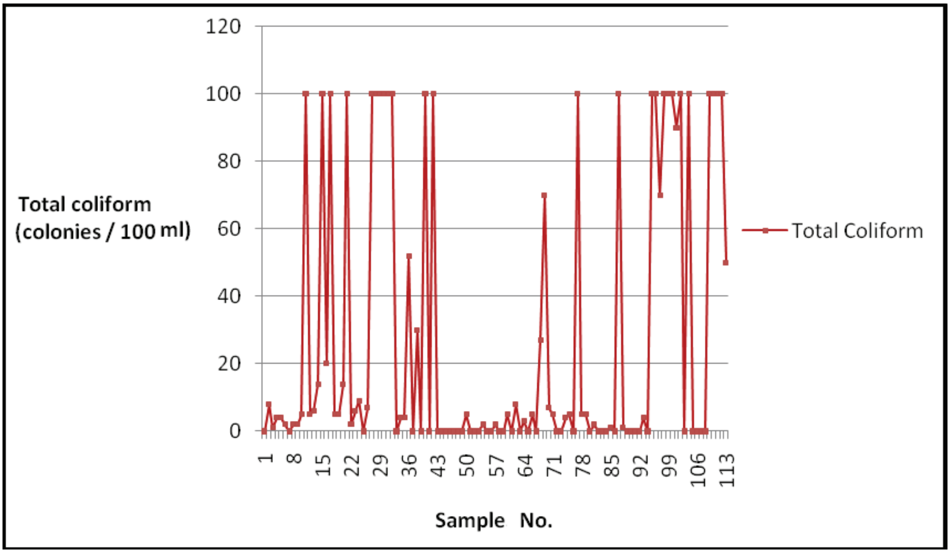

Fig. 4. Total coliform in residential drinking water samples.

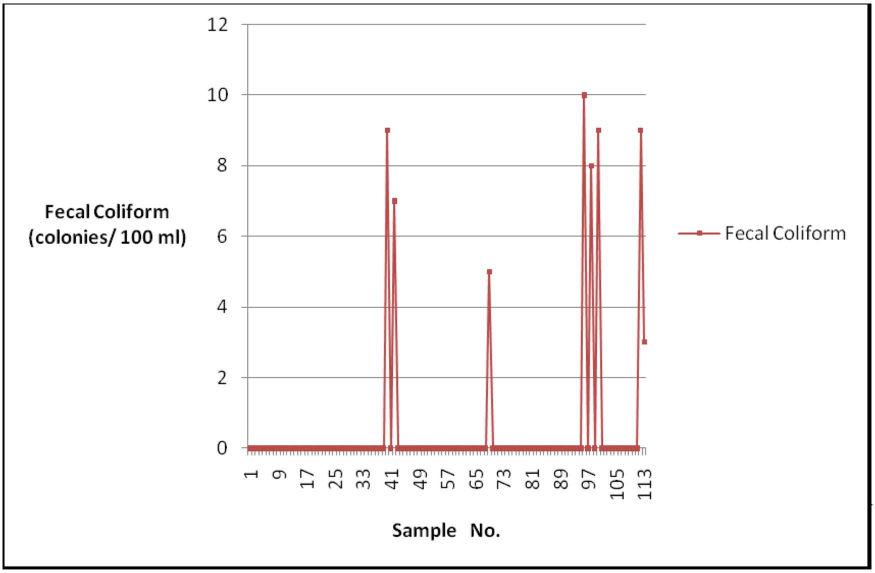

Fig. 5. Fecal coliform in residential drinking water samples.

Although the presence of total coliform is not necessarily an indicator of recent water contamination by fecal waste; however the presence or absence of these bacteria in treated water is often used to determine whether water disinfection is working properly.

4.2 *Point-of-Use Filtration Units*

4.2.1 *Experimentation on Filtration Units*

Four controlled experimental units were set to test the capabilities and drawbacks of the POU filtration units for treating or capturing the most likely contaminants in drinking-water. The objective is to select the most efficient and economical (POU) filter unit that is suitable for domestic water.

Forty two samples from (POU) filter units were collected to investigate the efficiency and the reliability of these units in treating drinking water. Not a single sample of the residential drinking water showed turbidity in excess of the Gulf permissible limit (5 NTU). The reliability of the filter with respect to turbidity was investigated. Also turbidity less than (1 NTU) is a desirable water characteristic. One main usage of filters is to remove turbidity. Electrical conductivity (EC) is a direct measure of amount of ions in water, and pH-value gives indication about constituents of alkalinity. EC and pH-value were measured to determine the extent of ions stripping from water. Also it was noted that several samples from consumers' taps contain iron content higher than the permissible limit. In addition, drainage-water and filtered-water flow rates were also measured to determine the percentage of wasted water in the process of filtration.

4.2.2 *Quality Parameters*

Table 5 summarizes the results that have been done on the four POU filtration units including tap water that feeds the filter for comparison. The reduction in the value of the parameters is quite clear; even using the fiber- filter (unit I) reduced the turbidity. However, the real absolute reduction in pH-value, electrical conductivity and turbidity is quite clear in the case of (RO) filtration (unit II). Some studies about filters found that reduction of more than 95% in ion contents are common[6]. The reverse osmosis membrane has a pore size between 0.00025 and 0.001 μm, which will allow water and molecules less than 200 Daltons in size to pass; the liquid on the other side of the membrane that contains the retained contaminants is conveyed away as waste. For POU treatment, typical clean water production rates are 20 to 40 L/h, while the wastes, usually 60 to 75 percent of the influent water are discarded [7].

Table 5. Results of quality parameters tested for different filtration units.

Parameters / Units		pH – value	EC (μS/cm)	Turbidity (NTU)	Iron (PPb)	Total coliform (colonies /100 ml)	Percentage of wasted water
Influent (tap water)		8.66 ±0.02	128.7 ± 0.41	2.91 ± 0.5	538.74	20	-
Effluent	**Unit I** (Fiber Filters)	8.43 ± 0.07	106.6 ±1.92	0.44 ±0.02	1.20	8	23
Effluent	**Unit II** (RO + Fiber Filters)	7.03 ± 0.02	19.77 ± 1.34	0.05 ± 0.02	0.00	Nill	66
Effluent	**Unit III** (UV + Fiber Filters)	8.25 ± 0.03	99.2 ± 1.82	0.46 ± 0.03	1.22	Nill	23
Effluent	**Unit IV** (RO + UV + Fiber Filters)	8.11 ± 0.02	18.21 ± 1.37	0.04 ± 0.02	0.00	Nill	68

It is clear from the results in Table 5 that the filter units are very efficient in removing iron; even the fiber filtration (unit I) reduces the iron dramatically. In case of (unit II) iron is stripped beyond detection level.

As in case of physical and chemical constituents, only fiber filtration (unit I) suffices to upgrade water with respect to its iron content to excellent quality. Therefore one can deduce that, concerning chemical quality problems of drinking water in Jeddah, if any, conventional filtration is more than adequate and there is absolutely no need for RO filtration units in this respect. As a matter of fact one can argue that RO compromise water chemical because of stripping some beneficial ions from water. The POU filters used in this study are highly effective in reducing coliform density, particularly in (unit II).

4.3 *The Appropriate Purification Unit for the Residential Drinking Water*

Selecting an appropriate water treatment unit begins with knowing exactly what is in the water and what is needed to be treated. Therefore, selecting a treatment device begins with a water test. The quality of the residential drinking water has been thoroughly investigated in this study. The most compromising quality was found to be the bacteriological quality of the water. Therefore, it must take into consideration microbial examination of water quality. Turbidity is closely related to microbial quality of water. Low turbidity less than (1 NTU) is usually recommended. Therefore any system must also remove or improve turbidity. Iron was found in several samples; and we found that its reduction is correlated with turbidity reduction. Therefore any system that reduces turbidity will reduce iron as well. From the experiments that have been done on filtration units, Unit (III) was found the most appropriate filtration unit which contains the following:

- Fiber filters, course (5 μm) and fine (1 μm) meshes.
- Activated carbon cartridge is needed to remove odor and taste problems.
- UV- Sterilizer to assure the removal of all pathogens and bacterial.

Figure 6 shows the flow diagram of the selected filtration (unit III) that would remove all expected contaminants from residential drinking water.

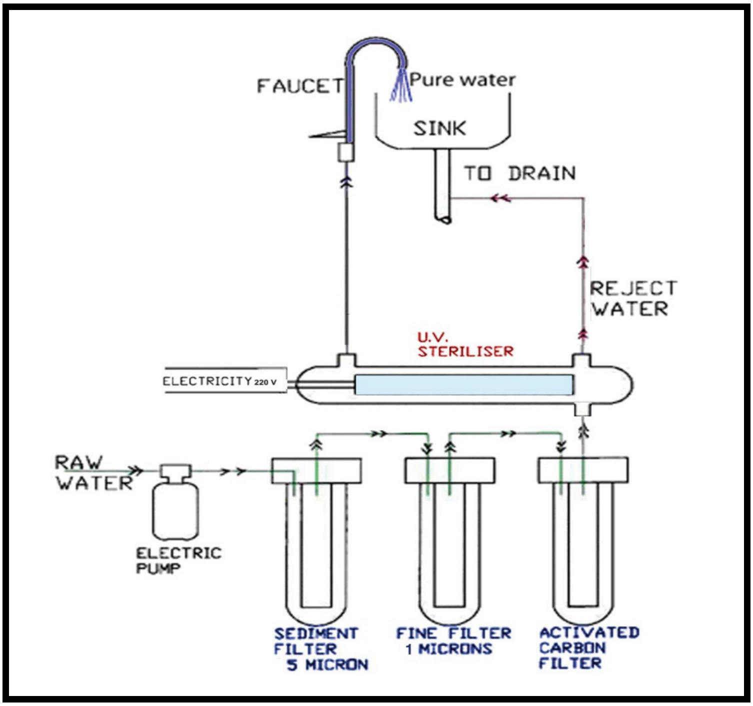

Fig. 6. Flow diagram of the (POU) Unit III.

4.3.1 *Fiber Filters*

Because the underground water tanks proved to be relatively clean (turbidity around 1NTU) the suggested filter has to be relatively fine. Hence, instead of 20 µm stage-1 fiber that is widely used with the traditional filter, 5 µm can be used. The finer fiber stage could be 1 µm. This arrangement will have the advantage of efficiency in removing turbidity and some microorganism with less frequent filter change.

4.3.2 *Activated Carbon Cartridge*

Filter's effectiveness depends on how long the water stays in the unit. The longer the water stays in contact with the filter medium, the more time the carbon has to remove impurities. Those packed with a large volume of charcoal generally remove more organic material at the beginning of the cartridge life. Performance of filter decreases less rapidly over time than it does for those containers with a small amount of charcoal.

4.3.3 *UV- Sterilizer*

Ultraviolet (UV) light produced from UV lamp has been shown to be an effective bactericide for water. In disinfecting water, the quantity of radiation required is dependent on such factors as turbidity, color and dissolved iron salts. The dissolved iron adversely affects the penetration of UV energy through the water fiber filters which can remove un-dissolved materials and turbidity which inhibits the disinfection process. The UV can kill any bacteria left in the system from fiber filter. Hence UV would be the final treatment stage. In addition a suitable design should provide:

1) Maintenance with easy tube and lamp removal.

2) Flow rates that provide adequate contact time between radiation and bacteria.

3) Easy visual inspection of the lamp and tube.

The U.S. Department of Health and Human Services has established a minimum exposure of 16 (mJ/cm^2) for UV disinfection systems. Most manufactures provide a lamp intensity of 30-50 (mJ/cm^2). Coliform bacteria, for example, are destroyed at 7 (mJ/cm^2). Since lamp intensity decreases over time with usage, lamp replacement is a key maintenance consideration with UV disinfection. In addition, UV systems should be equipped with a warning device to alert the owner when the lamp intensity falls below the germicidal range. Hence, a nationally regulated fiber-filter device equipped with carbon-filter cartridge and efficient UV-series of lamps that emits enough energy to destroy all microorganisms is the recommended device.

5. Conclusions

In a five-month monitoring period, the chemical and bacteriological quality of drinking water in houses has been examined. A total of 113 water samples were collected during that period. Generally speaking the physical and chemical quality of residential water were found to be satisfactory. The bacteriological quality of water, as indicated with total coliforms and fecal coliforms, is found to be concerning. More than 60% of samples examined show presence of coliform bacteria; in some samples the density of total coliform is more than 100 colonies/ 100-ml of water. Eight samples (0.05%), show fecal contamination as indicated with the presence of fecal coliform. The bacteriological quality shows negative correlation with residual chlorine. Samples with adequate residual chlorine (>0.3 mg/L) were found to be free of any indication to bacteriological pollution.

The POU filters used in this study was found to be highly effective in reducing coliform density, but unit II is not the suitable technology to eliminate bacteria and viruses. As a matter of fact, it is observed that unit III, UV-disinfection filters, with slow flow rate of water is quite efficient in eliminating bacteriological contamination. Unit II RO, was also found to be effective in eliminating or reducing iron, heavy metals, and turbidity. More than 66% of already costly treated water would be drained to waste. In addition unit II strips beneficial ions, like Calcium, Magnesium and Fluoride, from an already low mineral water. It has been demonstrated that unit III, POU filter consist of conventional fiber filter, activated carbon cartridge and adequate UV- Sterilizer to eliminate bacteriological contamination. It is also observed that such a filter reduces iron content level beyond the maximum limit allowed by the standards. Therefore we conclude that unit III, is quite adequate in addressing residential water quality problems.

6. Recommendations

1. Further research should be conducted to find out the causes of the pollution in the underground water storage tanks.

2. It is recommended to add more locations to inject chlorine dosage into water distribution network to eliminate any bacterial contamination

3. Speeding up the process of covering the city with both sewerage and groundwater discharge systems. The two systems will decrease the probability of any intrusion into the domestic water network system.

4. Providing sufficient amount of water supplying the whole city will end the problem of the intermittent water supply that causes the construction of the underground water storage tanks.

5. It is recommended that consumers should install the POU filter (Unit III) in their houses for further drinking water treatment.

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نوعية المياه المنزلية بمدينة جدة – المملكة العربية السعودية

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المستخلص. نظرا لنقص الموارد المائية في المملكة العربية السعودية، فقد اعتمدت مصلحة المياه على نظام الضخ المتقطع لشبكة إمدادات المياه. في هذا النظام يتم تقسيم المدينة إلى عدد من القطاعات الصغيرة، ويتم ضخ المياه بالتناوب بين القطاعات وفقا للخطة التشغيلية. وتختلف وتيرة ضخ المياه إلى قطاع معين من عدة أيام إلى أسابيع. وأثناء فترات انقطاع المياه فإن الأنابيب تصبح فارغة وجافة لفترات طويلة مما اضطر المستهلكين لبناء خزانات مياه أرضية لتلبية مطالبهم. إن عدم وجود شبكات الصرف الصحي في كثير من المناطق مع ارتفاع منسوب المياه الجوفية في المدينة أدى إلى بناء بيارات الصرف الصحي بالقرب من خزانات المياه الأرضية. لذلك فإن احتمال تسرب المياه الملوثة إلى شبكة إمدادات المياه عالية جدا حيث تتعرض الأنابيب الفارغة للضغوط الخارجية من المياه الجوفية الملوثة المحيطة. وتعزز كل هذه العوامل من مخاطر تلوث المياه في شبكات المياه بالمدينة.

ويتمثل الهدف الأول من هذه الدراسة في تقييم نوعية المياه المنزلية في جدة حيث تم جمع مائة وثلاثة عشر عينة من المياه في فترة خمسة أشهر خلال الفترة من يناير / يونيو ٢٠٠٩م. وجرى تقييم ثلاثة عشر معاملا، وبالمقارنة مع المستويات القصوى لمنظمة الصحة العالمية والمواصفات القياسية الخليجية لمياه الشرب أظهرت نتائج التحليلات الامتثال لمعايير مياه الشرب فيما يتعلق

بالمعاييرالفيزيائية والكيميائية، باستثناء خمس عينات تجاوزت الحد الأقصى المسموح به للحديد. وأظهرت النتائج أن نسبة التلوث البكتريولوجي وصلت إلى ٦٠ ٪ من العينات التي كانت ملوثة بالكوليفورم الكلي.

ويتمثل الهدف الثاني من الدراسة في تقييم مدى ملائمة وحدات تنقية المياه المنزلية الأكثر شراء في المدينة واختيار وحدة تنقية مياه مناسبة للمياه المنزلية في جدة. وقد وجد أن الوحدة الثالثة لتنقية المياه والتي تتألف من مرشحات الألياف وفلتر الكربون النشط والتعقيم بالأشعة فوق البنفسجية مناسبة للاستخدام المنزلي في جدة.

الكلمات المفتاحية: المياه المنزلية، نوعية المياه، تنقية المياه، وحدات تنقية المياه المنزلية.