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Drinking water quality: comparative study of tap water, drinking bottled water and point of use (PoU) treated water in Bandar-e-Abbas, Iran

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ABSTRACT

The physical and chemical quality of the public drinking water supply (tap water), bottled water, and point of use (PoU) treated water was studied comparatively. The analyzed parameters were: turbidity, electrical conductivity, total dissolved solids, pH, hardness, sodium, potassium, chloride, and alkalinity. The samples were taken and analyzed based on standard methods references for the examination of the water and wastewater. The data analysis was conducted by SPSS 16 software. The results show that the concentration of the chemical and physical parameters in all waters is below limits as allowed by national and international drinking water guidelines and standards, although there is significant difference between three types of water. The quality of the tap water is consistent to mentioned guidelines and standards; therefore, the tap water is safe for drinking and it is no need to use other water resources instead of this water. The distrust to public water supply has caused a large number of citizens to use bottled and PoU treated waters for drinking aims. The consumption of these waters imposes huge costs to families because the costs of the 0.25, 1.5, and 20 L bottled waters are about 17,777, 1,776, and 500 times the price of the tap water, respectively. Increased public awareness and confidence about the quality of tap water is needed to prevent the loss of the income of the family.

Keywords: Tap water; Bottled water; PoU treated water; Chemical quality; Physical quality

1. Introduction

Many countries with water shortage and low quality drinking water rely on nonconventional water resources such as packaged, bottled, and point of use (PoU) treated water instead of public water systems [1]. The packaged water consumption and marketing have been increased dramatically all over the world recently because of the concerns about public water pollution and related undesirable characteristics such as taste, odor, fluoride, chlorine, and other additives. For example, the global consumption of packaged

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waters was grown to about 165 billion L in 2005 and consumption rate for each person was 25–26 L/*per capita*/year [2]; furthermore, the world market of the bottled water is being grown quickly now and exceeds a value of €165 billion [3,4]. In spite of the fact that bottled water is more expensive than tap water, many people consume bottled waters. The reasons for high consumption of bottled waters may be: (1) Bottled water has wide usage for reconstituting infant formula and immune-compromised foods, cleaning contact lenses, skin care, filling humidifiers, and nursery drinking water [3,5], (2) Bottled water is readily available, (3) Bottled water has higher social status than tap water [6,7], (4) Bottled waters are considered as pure and safe with good taste and odor, and (5) Successful marketing strategies of the bottling companies [4]. For these reasons, the most consumption rate for bottled waters has been reported in countries with safest public drinking water systems [8].

The PoU water treatment systems are valuable tools for improving drinking water quality standards and for reducing water borne diseases in many developing countries [9–12]. In addition, these systems can be used as a suitable alternative for providing safe water in emergency conditions. The minimal investment costs, concern regarding tap water quality, and wide advertising by manufacturers has caused a large number of people to use these devices for providing safe drinking water. Despite their advantages, bottled and PoU treated waters suffer from several major drawbacks: Poor quality control during production, unsuitable conditions of distribution, and improper maintenance methods [5]. For this reasons, questions about the safety of these waters have been increased in recent years [13]. Previous studies indicate that the chemical, physical, and microbiological quality of some bottled waters do not meet national and international standards [5,14,15]. The following are examples of these studies: (1) Kermanshahi et al. [7] analyzed the data from 73 bottled water brands in Iran and concluded that only 20 brands have acceptable charge balance error [7], (2) Güler [1] investigated the bottled water quality in Turkey and showed that some physical and chemical parameter concentrations in bottled waters are above the standards which have been allowed for bottled waters by the Turkish legislation and other international organizations [6], and (3) Bengharez et al. [16] studied fluoride concentration in bottled waters and showed that fluoride concentration in 48.28% of Algerian bottled waters did not exceed 0.5 mg/L and 37.93% were fluoridated weakly (0.3 mg/L) [16].

Bandar-e-Abbas (BA) is a port city that lies off the southern coast of Iran. In 2011, the estimated population of BA was 600,000. BA water supply resources include Esteghlal dam and 31 wells which provide 80 and 20% of its demand water, respectively. A field research conducted by authors shows that offensive taste and odor in BA public water supply system is the most important concern of citizen and increased tendency for other water supply systems such as bottled and PoU treated waters.

This paper will focus on following topics because of major public health problems and likely risks from potentially contaminated drinking bottled and PoU treated waters,

(1) Assessment of the tap, bottled, and PoU treated water quality.
(2) Comparative analysis between the above-mentioned water groups.
(3) And evaluation of the need to use bottled and PoU treated waters instead of the tap water.

2. Materials and methods

2.1. Sampling

The sampling methods are organized as following three sections: (1) Bottled water: In BA, many brands of mineral bottled waters and four brands of treated bottled waters with high consumption were selected as study samples. The bottled waters were purchased from supermarkets and sent to the laboratory for analysis. Three bottles of each brand were analyzed; (2) Tap water: There are nine water reservoirs in BA public water supply. Each reservoir was considered as a cluster and sampling was conducted by clustering method (Fig. 1). One sample has been taken for each cluster. The water resource for all reservoirs is same; therefore, it can be concluded that the replicative condition is meted in the sampling and (3) PoU systems: Water samples from 12 different PoU systems were used in this study. Studied systems were: three, five, six, and eleven stages membrane technology. Selected devices are the most common type of PoU treatment technologies which are used in BA. Samples were collected from influent and effluent of each system and analyzed for chemical and physical parameters.

2.2. Analysis methods and instrumentation

The analyses were conducted based on standard methods book for the examination of the water and wastewater (edition 2005) [17]. Samples were stored in cold box (4°C) during sampling and transportation. A sample handling, standards preparation, and examinations were performed in clean rooms. All glassware

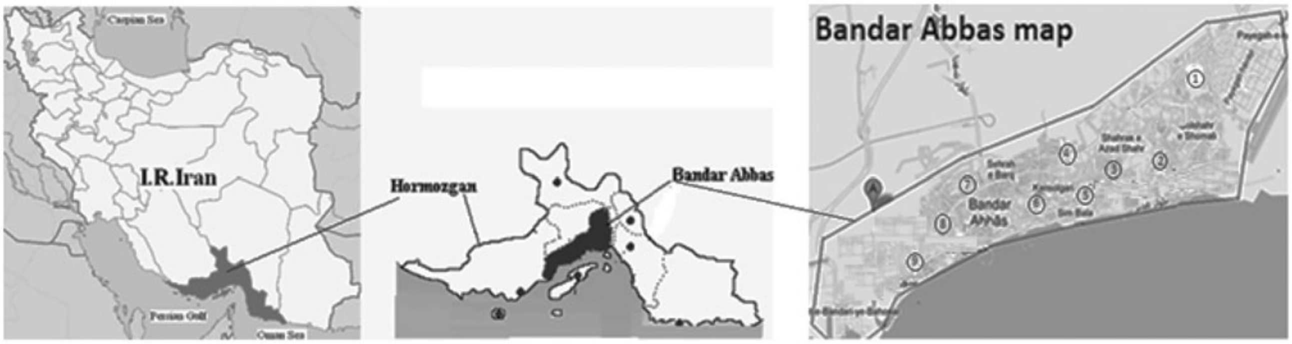

Fig. 1. Map showing the location of BA in Iran and sampling location of tap water.

and other instruments in contact with the samples were thoroughly cleaned using HNO_3 and deionized water. The analyzed parameters in all waters were included: pH, turbidity, alkalinity, total hardness, total dissolved solids (TDS), electrical conductivity (EC), sodium, potassium, and chloride. The parameters were selected on the basis of bottled water labels. Hardness and alkalinity were determined with a titration method. The pH was measured with a pH meter Elmetron Model CP-501. EC and TDS were analyzed with a TDS meter model Aqualytic CD24. The EC, TDS, and pH were measured in the sampling locations. The turbidity was analyzed by Hach turbidity meter Model 2130 B. Flame photometer was used for the determination of sodium and potassium. A chloride concentration was measured by Mohr methods. All chemicals used in this work were of GR grade and were made by Merck Company.

2.3. Data analysis

Measured values were compared with the guidelines and standards for drinking water which were established by the World Health Organization (WHO), Institute of Standard and Industrial Research of Iran (ISIRI), and International Bottled Water Association (IBWA) (Table 1). Data analysis was performed by means of statistical package for the social sciences 16.0 for Windows. The ANOVA was used to check if there were differences in the concentration of the physical and chemical parameters across the bottled water types and differences between all water types, with each other.

3. Results and discussion

3.1. Tap water quality

The mean, standard deviation, minimum, maximum, and primary values of the chemical and physical parameters in the tap water samples were presented in Table 2. The quality of the tap water was compared with WHO and ISIRI guidelines. There is no significant difference between the value of parameters in the tap water and the above-mentioned guidelines, although the massive changes are seen in the values of some parameters. The minimum pH value 7.3 and maximum pH value 8.2 was observed for clusters 8 and 6, respectively. A pH range 6.5–8 was set by the WHO, and ISIRI guideline (Table 1), thus, this parameter is

Table 1
Guidelines and standards values determined by different organizations

	Parameter								
Guideline or standard type	pH	TDS (mg/L)	EC (ms/cm)	Na (mg/L)	K (mg/L)	Cl^- (mg/L)	Hardness (mg/L)	Alkalinity (mg/L)	Turbidity (NTU)
WHO guideline (drinking water)	6.5–8	1,000	–	175	–	250	–	–	–
ISIRI standard (drinking water)	6.5–8	1,500	–	200	–	400	500	–	5
IBWA standard (bottled water)	6.5–8	500	–	200	–	250	–	–	0.5

Table 2
Descriptive analysis and values of physical and chemical quality of tap water

Point of sampling		Tap water quality parameters EC (ms/cm)	pH	TDS (mg/L)	Alkalinity (mg/L)	Na (mg/L)	K (mg/L)	Cl^- (mg/L)	Turbidity (NTU)	Hardness (mg/L)	Hardness classification
Cluster 1		1,140	8.1	740	180	165	7.5	195	0.42	220	Hard
Cluster 2		1,100	7.82	670	204	170	5	237.8	0.33	240	Hard
Cluster 3		1,000	7.93	596	176	150	6.7	230.7	0.59	236	Hard
Cluster 4		1,050	7.75	650	198	150	6.6	177	0.60	196	Hard
Cluster 5		1,000	7.87	600	190	150	6.3	223.6	0.62	192	Hard
Cluster 6		1,030	8.2	630	226	155	6.2	284	0.66	216	Hard
Cluster 7		1,189	7.8	799	208	137	5	170.4	0.57	252	Hard
Cluster 8		1,250	7.30	899	110	172	5.4	166.8	0.57	180	Hard
Cluster 9		990	7.87	589	240	145	7.5	213	0.51	200	Hard
Descriptive	Min	990	7.3	589	110	137	5	166.8	0.33	180	Hard
	Max	1,250	8.2	899	240	172	7.5	284	0.66	252	Hard
	Mean	1,083	7.8	685	192.4	155	6.2	210	0.54	214.6	Hard
	Std	92.8	0.25	106	37.11	11.7	0.95	38.1	0.104	24.5	Hard

higher than this range for Clusters 1 and 6. All water samples are classified as hard water on the basis of WHO category.

3.2. Bottled water quality

Table 3 shows the descriptive analysis of the physical and chemical parameters in the bottled drinking water samples. The values of all parameters in all brands are lower than the levels, which were allowed by WHO, ISIRI, and IBWA. All brands have pH value in range of these standards except brand C. One way ANOVA analysis shows that the concentration of the majority of parameters is different in various brands except turbidity values. The difference between concentrations of parameters in the brands may be originated from different geological sources of the water, chemistry of atmospheric precipitation, mineralogy of the aquifer rocks, water movement time in the aquifer, and climate and topography of the area [7]; besides, pretreatment and post-treatment can affect bottled waters quality. Naddeo carried out a comparison between the bottled water quality composition and the standard limits in Italy. The results demonstrated that several parameters were not meted with the standards [2].

Table 3
Descriptive analysis of physical and chemical quality of bottled waters

Brand	Descriptive analysis	Parameters EC (ms/cm)	pH	TDS (mg/L)	Alkalinity (mg/L)	Na (mg/L)	K (mg/L)	Cl^- (mg/L)	Turbidity (NTU)	Hardness (mg/L)	Hardness classification
A	Min	430	7	301	65	50	91	42.6	0.32	81	Semi hard
	Max	432	7.7	302	72	70	108	56.8	0.48	85	
	Mean	430.6	7.63	301.3	70	61.6	97	50.8	0.42	83.3	
	SD	1.15	0.057	0.577	2	10.4	9.5	7.38	0.089	2.08	
B	Min	406	6.6	284	22	91	81	88.75	0.32	120	Hard
	Max	412	6.82	288.4	28	94	84	106.5	0.4	160	
	Mean	408.6	6.71	285.8	24	92.3	82.3	94.6	0.37	1,430.3	
	SD	3.05	0.11	2.3	3.46	1.5	1.5	10.2	0.04	20.8	
C	Min	491	8.22	346	100	80	65	46.15	0.33	70	Semi hard
	Max	495	8.25	343	130	90	70	60.35	0.42	75	
	Mean	492.6	8.23	344.3	113.3	84.6	68.4	52.06	0.37	72.5	
	SD	2.08	0.014	1.52	15.27	5.03	2.9	7.38	0.04	2.5	
D	Min	712	7.61	498	46	76	64	106.5	0.31	75	Hard
	Max	715	7.69	500.5	52	83	76	142	0.48	80	
	Mean	713.3	7.64	499.1	48.6	79	70.3	123.06	0.37	78	
	SD	1.52	0.37	1.25	3.05	3.6	6.07	17.86	0.095	2.64	
p value		<0.001	<0.001	<0.001	<0.001	0.002	0.001	<0.001	0.722	<0.001	

Table 4
Descriptive analysis of physical and chemical quality of PoU water treatment systems

Descriptive analysis	Water quality parameters																	
	EC (ms/cm)		pH		TDS (mg/L)		Alkalinity (mg/L)		Na (mg/L)		K (mg/L)		Cl^- (mg/L)		Turbidity (NTU)		Hardness (mg/L)	
	In[1]	Out[2]	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Mean	1,319.88	788.38	7.44	7.08	947.56	568.25	206.31	150.06	13.64	8.64	8.66	4.22	165.97	109.88	0.70	0.37	347.56	235.06
Minimum	1,234	32.1	6.6	6.4	890	23	173	28	8.9	1.6	6	0.25	17.8	5.68	0.25	0.19	160	10
Maximum	1,422	1,327	8.1	7.6	1,025	955	260	212	14.8	13.4	12.6	7.5	215.6	209.4	2.76	0.57	945	935
SD	56.47	567.12	0.43	0.36	38.97	410.68	26.99	61.41	1.38	4.53	2.15	2.44	43.93	68.29	0.59	0.11	286.48	272.90

[1]In = influent.
[2]Out = effluent.

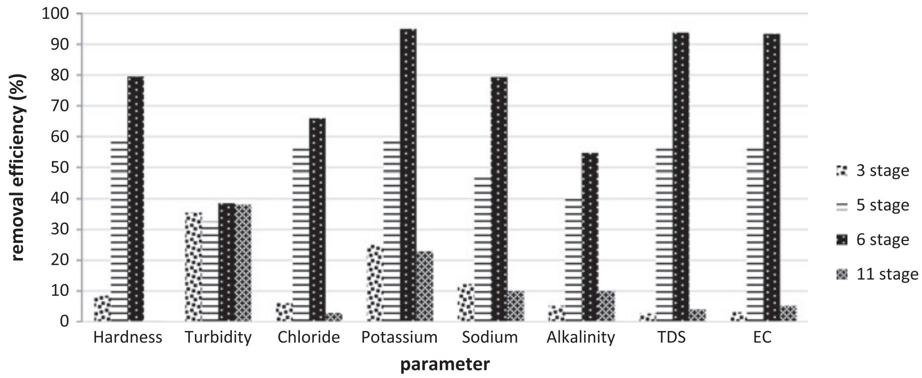

Fig. 2. Removal efficiency of different PoU treatment technologies.

3.3. PoU treated water quality

The influent and effluent water quality in PoU systems were shown in Table 4. The concentrations of all parameters in effluent are in the range which was determined by national and international organization. The efficiency of different PoU technology for removal parameters was shown in Fig. 2. It can be seen from Fig. 2 that six stages of PoU system have maximum efficiency for all parameter. Improper maintenance and operation causes decreasing performance of PoU systems after few months of usage.

Table 5
Comparative analysis of effluent concentration of parameter in different sources

Parameter	Type of water	Mean ± SD	Sig
pH	Bott	7.57 ± 57	0.007
	PoU	7.08 ± 36	
	Tap	7.85 ± 25	
EC (ms/cm)	Bott	511.5 ± 125.9	<0.001
	PoU	788.4 ± 567.1	
	Tap	1,083.2 ± 92.9	
TDS (mg/L)	Bott	357.7 ± 88.2	0.034
	PoU	568.2 ± 410.7	
	Tap	1,083.2 ± 92.9	
Alk (mg/L)	Bott	64 ± 34.92	<0.001
	PoU	150.06 ± 61.41	
	Tap	192.44 ± 37.12	
Na (mg/L)	Bott	79.41 ± 12.89	<0.001
	PoU	8.64 ± 4.53	
	Tap	155 ± 11.79	
K (mg/L)	Bott	79.52 ± 12.93	<0.001
	PoU	4.13 ± 2.6	
	Tap	6.24 ± 0.95	
Cl^- (mg/L)	Bott	80.17 ± 33.25	<0.001
	PoU	109.88 ± 68.29	
	Tap	210.94 ± 38.1	
Turbidity (NTU)	Bott	0.38 ± 0.07	<0.001
	PoU	0.37 ± 0.03	
	Tap	0.54 ± 0.1	
Hardness (mg/L)	Bott	94.29 ± 31.19	0.132
	PoU	233.69 ± 274.13	
	Tap	214.67 ± 24.49	

Notes: Bott = bottled water; PoU = PoU treated; Tap = tap water.

3.4. Comparative analysis

The mean level of EC, TDS, alkalinity, Na, K, Cl^-, hardness, and turbidity in tap water was compared with bottled and PoU treated waters (Table 5). One way ANOVA analysis shows that the mean levels of the majority of parameters in tap water are different from bottled and PoU treated waters ($p < 0.05$) except turbidity. In 2010, AbuaIkem studied volatile organic compounds concentration in bottled and tap waters and showed that 97% of all drinking water types are safe for human consumption [18]. Cidu published a paper in which they compared inorganic components in bottled water and Italian tap water. The obtained results show that in many bottled water samples there are several components that are inconsistent with the Italian regulations and the WHO guidelines [8].

4. Conclusions

The results of analyzed parameters suggest that the quality of tap water is consistent with national and international standards and cannot threat the health of the consumers. Thus, it is not required to use other waters such as bottled water and PoU treated water instead of tap water. While there are no permissible limits for odor and taste in drinking water, a concern about odor and taste have led a large number of people to consume bottled water and PoU treated water. Bottled water usage imposes a huge cost to families because the prices of the 0.25, 1.5, and 20 L, bottled waters are about 17,777, 1,776, and 500 times the price of tap water, respectively. A correct information, increase public confidence, and removal of taste and odor due to aquatic life in water resources may decrease the consumption of bottled and PoU treated waters and consequently reduces the family costs. Obtained data are essential for consumers, health care professionals, and water suppliers. Also, these data can help the bottling and PoU systems producing companies to improve their products. More studies will be required to evaluate the concentrations of other physical, chemical, and microbial parameters in tap water, bottled water, and PoU treated water.

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