Journal of Advances in Environmental Health Research

Effect of temperature on pH, turbidity, and residual free chlorine in Sanandaj Water Distribution Network, Iran

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Original Article

Abstract

One of the parameters responsible for decreased water quality in a distribution system is temperature changes. This study was conducted to examine the effect of temperature on pH, turbidity, and residual chlorine in Sanandaj, Iran, Water Distribution System. The required water samples were taken from 85 stations during April to October 2014. Sampling was carried out over 6 months and twice per month. The average amount of residual chlorine measured at these stations was 0.58 and 0.52 mg/l, and turbidity was 0.86 and 0.98 nephelometric turbidity unit (NTU) in winter and spring, respectively. The temperature did not have any effect on pH, the amount of pH in winter and spring were 7.56 and 7.57, respectively. The results showed significant differences in the concentration of residual chlorine and turbidity of Sanandaj Water Distribution Network between winter and spring ($P \leq 0.01$). Thus, the concentration of residual chlorine and turbidity varies in warm and cold seasons. However, no significant difference was observed in pH ($P \geq 0.01$). The research results indicated that temperature does not have any effect on the qualitative parameters measured in the study area.

KEYWORDS: Chlorine, Temperature, Water Quality, Iran

Date of submission: 12 Apr 2015, ***Date of acceptance:*** 10 Jun 2015

Citation: Nouri A, Shahmoradi B, Dehestani-Athar S, Maleki A. **Effect of temperature on pH, turbidity, and residual free chlorine in Sanandaj Water Distribution Network, Iran.** J Adv Environ Health Res 2015; 3(3): 188-95.

Introduction

Water distribution networks are considered vital arteries of rural and urban communities.[1] The purpose of any water distribution system is not only to provide water pressure, but also to provide high quality water in terms of taste, smell, appearance, and health.[2] The least treatment performed on water resources is disinfection. Chlorine and its derivatives are used as disinfectants due to their low relative cost, ease of use, and appropriate functionality to eliminate pathogenic microorganisms in drinking water distribution networks.[3]

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Before drinking water leaves the treatment plant, a final chlorination step is frequently carried out to maintain residual chlorine in the distribution system, and thus, to prevent microbiological regrowth.[4] When chlorine reacts with water, it is hydrolyzed and produces hypochlorous acid (HClO) and hypochlorite ion (ClO^-). It is well known that HClO is more efficient than ClO^- as disinfectant.[5] The relative concentrations of HClO depend on pH and somewhat on temperature.[6] At pH of 7.6 and 6.6, the ratio of $HClO/ClO^-$ roughly equals 50% and 90%, respectively. The disinfecting power of chlorine increases with increasing pH and reduces with increasing temperature.[5] Raising the temperature increases the amount of chlorine in the distribution network and the amount of residual chlorine is variable in winter and summer.[3] In water supplemented with biodegradable organic matter (BOM), a strong linear correlation was found between temperature and free residual chlorine required to control biofilm.[7] According to the Iranian Drinking Water Standards (Code 1053), the optimum amount of free residual chlorine at any point of the distribution network should be 0.2-0.8 mg/l under normal conditions. This value should be 1 mg/l in the case of natural disasters, emergencies, and epidemics, considering pH.[8]

Turbidity of water is a physical parameter that is determined through measuring the absorption or scattering of light by suspended solids.[9] The Safe Drinking Water Act (SDWA) has recommended the turbidity value of 1 nephelometric turbidity unit (NTU) and a maximum limit of 5 NTU.[10] Turbidity in water distribution systems may result from incomplete removal of particles during treatment, from the pipe material itself, and from line repair within a system. All of these cases can present a potential health threat through decreasing disinfection effectiveness.[11] Water quality degradation could occur in municipal drinking water systems because of intermittent short duration events resulting in high turbidity, particle counts, and heterotrophic plate counts.[12]

The pH of a solution is a numeric scale used to specify the acidity or alkalinity of that solution. It is usually expressed as the negative of the logarithm to base 10 of the activity of the hydrogen ion. The solution is referred to as acidic if pH is less than 7 and it is considered as alkaline or basic if pH is higher than 7.[13]

Pure water is neutral.[14] Water pH is a crucial parameter in water treatment, disinfection, and corrosion control. Water corrosion rate depends largely on water pH.[15] One of the most important physical factors in the occurrence of corrosion and deposition is temperature changes, which have destructive impact on water pH.[16] The Iranian National Standard for pH is 7-8.5 and the maximum allowable range is 6.5-9.[8]

Therefore, the aim of this study was to assess the effect of temperature on residual chlorine, pH, and turbidity in Sanandaj, Iran, Water Distribution Network, in two different seasons.

Materials and Methods

Sanandaj City is located at 14° 35´ north latitude and 46° east longitude (Figure 1) from the meridian of Greenwich and it is between 1450 and 1538 meters above sea level, varying in different parts of the city, and has an area of 2906 km[2].[17]

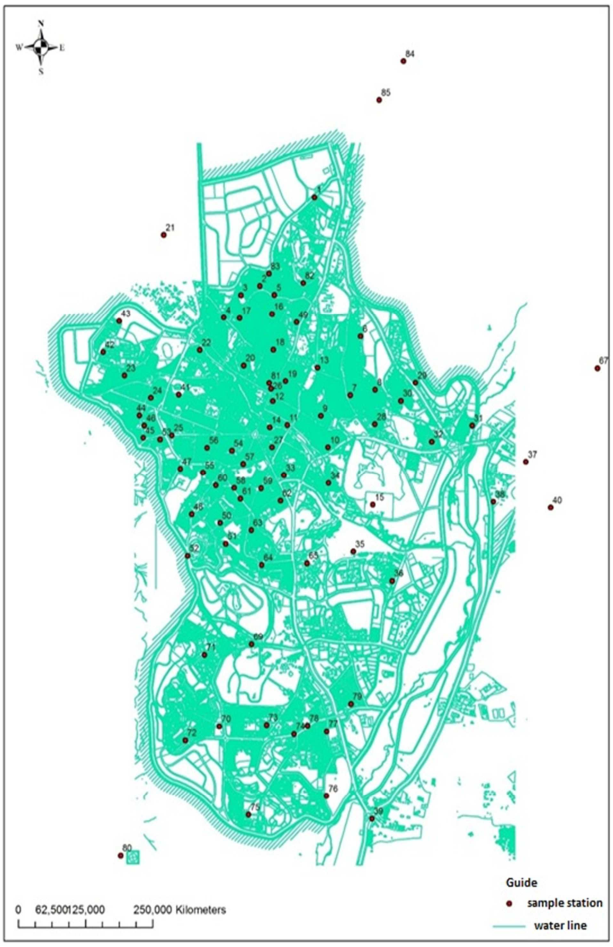

Figure 1. The location of sampling stations in Sanandaj

The main water supply for Sanandaj is Vahdat Dam. Because of the special topography of the city, 14 active tanks provide the required pressure for 1397 km long distribution network and serve 373,987 people. These tanks are fed by the main tank, Faizabad, which takes its water directly from the water treatment plant.

This study was conducted during 6 months from April to October 2014. First, the map of water distribution network and the layout of tanks were obtained from the Urban Water and Wastewater Company, Kurdistan Province, Sanandaj. In order to determine sampling stations, various factors were considered including topographic conditions, texture of the city, the population under coverage of the distribution network, area of the distribution network, type of network, number of tanks, chlorination system, and financial constraints.

The total length of the main lines, substations, and water network connections in Sanandaj is 1397 km. Therefore, the total length of the network was assumed as the sample size; a sample station was considered at every 16.5 km of pipeline. On the other hand, considering the abovementioned parameters, 85 sample stations were selected randomly from the areas which had the inclusion criteria.

The amount of residual chlorine and temperature were measured using portable digital devices (DKK-TOA model RC-31PT, UK). Turbidity and pH were measured using turbidity and pH meters (Wagtech, UK), respectively. Before the measurements, the digital devices were calibrated according to the manufacturers' instructions using standard solutions.

Results and Discussion

The normality of data was assessed using Kolmogorov-Smirnov test, then, the data obtained were analyzed using paired t-test and the Pearson correlation matrix in SPSS software (version 16, SPSS Inc., Chicago, IL, USA). Results of analyses of independent t-test and Pearson correlation are presented in tables 1 and 2, respectively.

The results of independent t-test indicated that the seasonal (spring and winter) difference was statistically significant ($P \leq 0.01$) in the case of residual chlorine (Table 1). Moreover, a significant correlation was found between residual chlorine and temperature ($P \leq 0.01$) (Table 2).

In addition, in the case of turbidity, the results of independent t-test (Table 1) indicated that the seasonal (spring and winter) difference was statistically significant ($P \leq 0.01$); however, no significant correlation existed between turbidity and temperature ($P \geq 0.01$) (Table 2).

As presented in table 1, the results of t-test showed that the seasonal (spring and winter) differences in pH were not statistically significant ($P \geq 0.01$). The Pearson correlation coefficient test (Table 2) showed no significant relationship ($P \geq 0.01$) between temperature and pH.

Table 1. The results of the Pearson correlation

		Paired Differences						
		Mean ± SD	SD Error Mean	95% Confidence Interval of the Difference		t	df	P (2-tailed)
				Lower	Upper			
Pair 1	Cl Winter-Cl Spring	0.056 ± 0.156	0.017	0.022	0.089	3.31	84	0.001
Pair 2	pH Winter-pH Spring	-0.003 ± 0.426	0.462	-0.095	0.088	-0.77	84	0.939
Pair 3	Turbidity Winter-Turbidity Spring	-0.126 ± 0.371	0.040	-0.206	-0.046	-3.14	84	0.002
Pair 4	T Winter-T Spring	-5.960 ± 1.830	0.198	-6.354	-5.565	-30.02	84	< 0.001

SD: Standard deviation; df: Degree of freedom

Table 2. The results of paired samples statistics for winter and spring

Correlations		Cl	pH	Turbidity	Temperature
Cl	Pearson Correlation	1	-0.370*	0.610*	-0.230*
	P (2-tailed)		< 0.001	< 0.001	0.002
	N	170.000	170.000	170.000	170.000
pH	Pearson Correlation	-0.370*	1.000	-0.035	0.078
	P (2-tailed)	< 0.001		0.652	0.312
	N	170.000	170.000	170.000	170.000
Turbidity	Pearson Correlation	0.610*	-0.030	1.000	-0.075
	P (2-tailed)	< 0.001	0.650		0.330
	N	170.000	170.000	170.000	170.000
Temperature	Pearson Correlation	-0.230*	0.078	-0.075	1.000
	P (2-tailed)	0.002	0.312	0.332	
	N	170.000	170.000	170.000	170.000

* Correlation is significant at the 0.01 level (2-tailed)

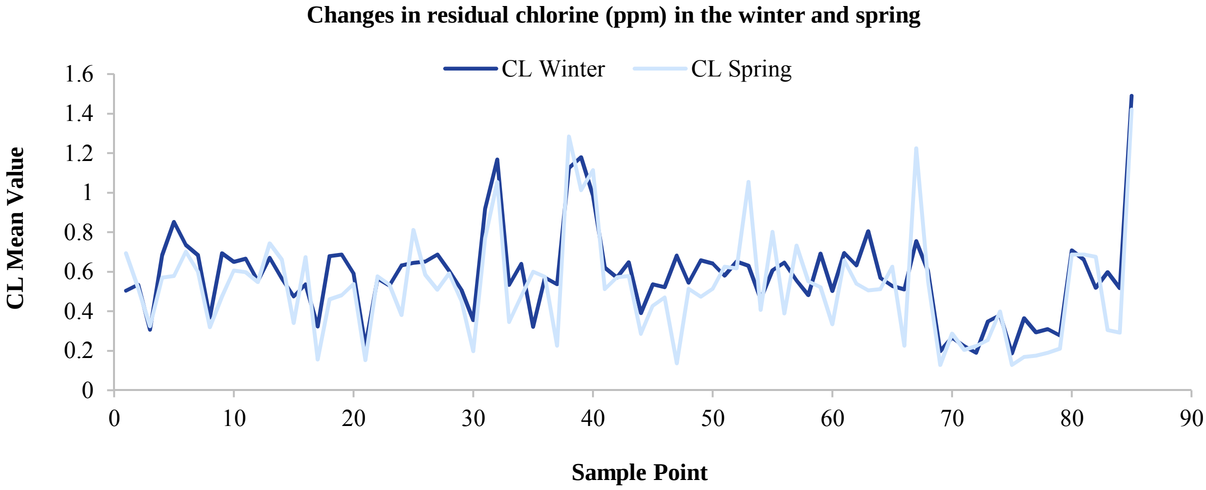

Figure 2. Average residual chlorine in winter and spring

The results of independent t-test, in the case of temperature indicated that the seasonal (spring and winter) difference was statistically significant (P ≤ 0.01) and the amount of temperature differs in winter and spring (Table 1).

The results of statistical tests showed that the average concentration of residual chlorine varies during winter and spring (Tables 1 and 2). The average amount of residual chlorine measured at 85 stations in winter and spring was 0.58 ± 0.22091 and 1.45 ± 0.26401 mg/l, respectively. The range of the residual chlorine measured in winter and spring was 0.186-1.49 and 0.128-1.42 mg/l, respectively. Temperature has a crucial impact on chlorine decay; this effect should be considered in chlorine decay modeling because of the large seasonal variability, common in many distribution systems.[18,19] Temperature and pH are important factors and have inverse relationships with the reduction of residual chlorine in water distribution networks.[20,21]

As shown in figure 2, residual chlorine changed over winter and spring at different stations; the difference between the amount of residual chlorine in stations 37, 47, 53, and 67 was much higher than elsewhere. Based on the line slope of the liner equation (Figures 3 and 4), variation coefficient of the amount of residual chlorine with the temperature in both winter and spring is 0.05585, indicating the negligible effect of temperature on residual chlorine. Such results could be attributed to the special weather conditions during the study time. Although Sanandaj was once famous for its very cold winter, the temperature fluctuation has not been tangible during recent years.

Case; they reported a direct relationship between temperature and turbidity.[22] Moreover, Ghorbani et al. found a significant difference in heterotrophic plate count (HPC), free residual chlorine, temperature, and turbidity between different months and seasons of the year.[23]

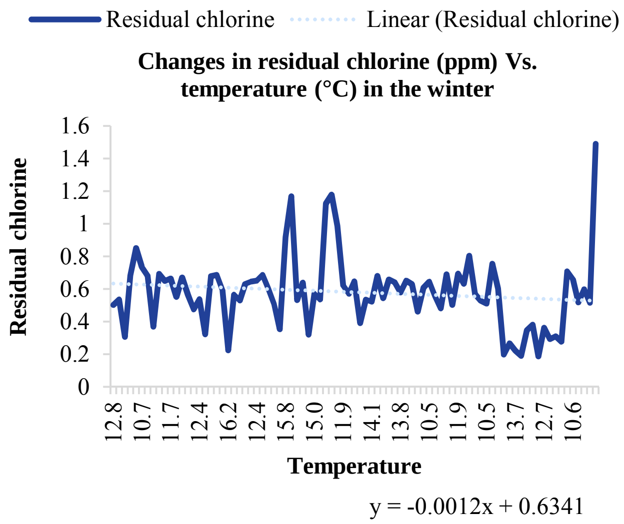

Figure 3. Residual chlorine fluctuation in winter

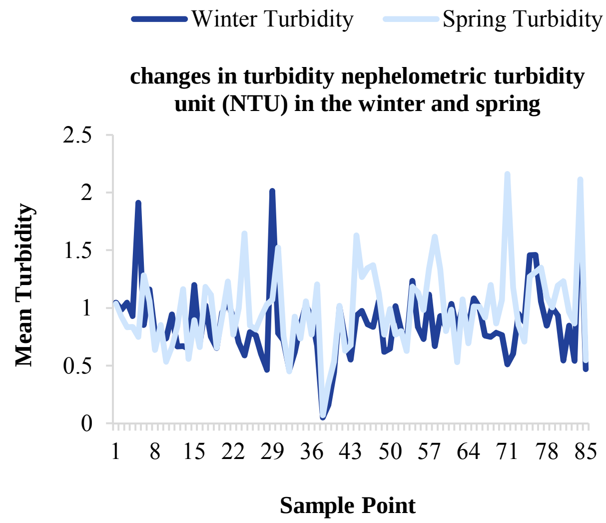

Figure 5. Average turbidity in the winter and spring

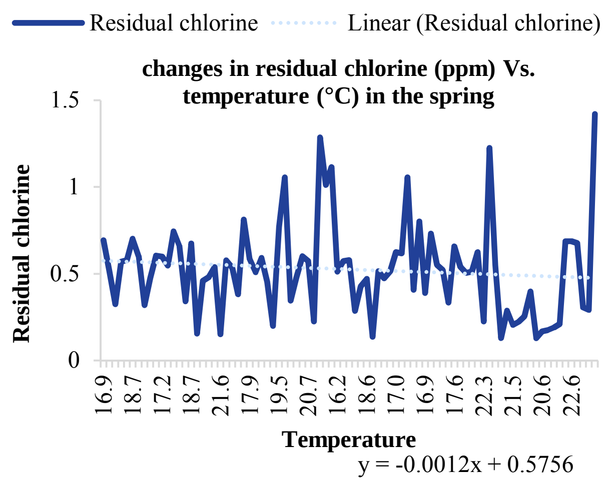

Figure 4. Residual chlorine fluctuation in spring

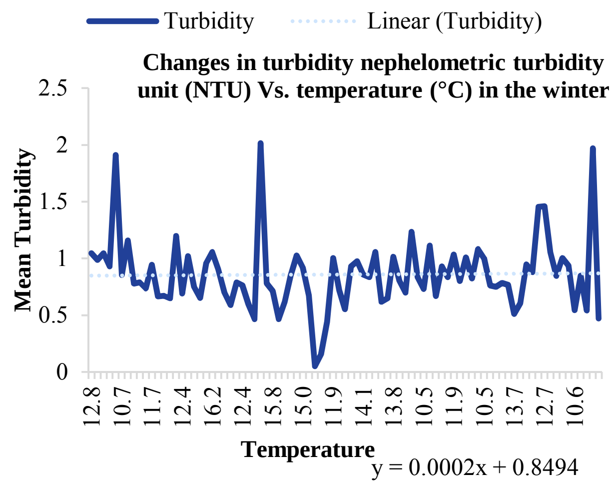

Figure 6. Turbidity fluctuation in winter

The average amount of turbidity measured was 0.859 ± 0.3156 NTU and 0.985 ± 0.3420 NTU in winter and spring, respectively. This research found that the range of turbidity fluctuation was 0.05-2.015 and 0.07-2.16 NTU in winter and spring, respectively (Figures 5, 6, and 7). This finding is in contradiction with the reports of

These changes could be attributed to the fact that Sanandaj Water Distribution Network is very old and, in some areas, the pipeline has not been replaced for more than 30 years. Moreover, the long retention time in end points may result in decreased residual chlorine and increased turbidity.[24,25]

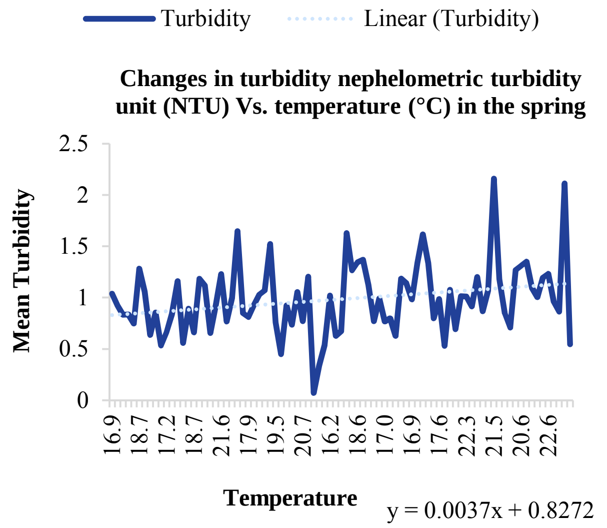

Figure 7. Turbidity fluctuation in spring

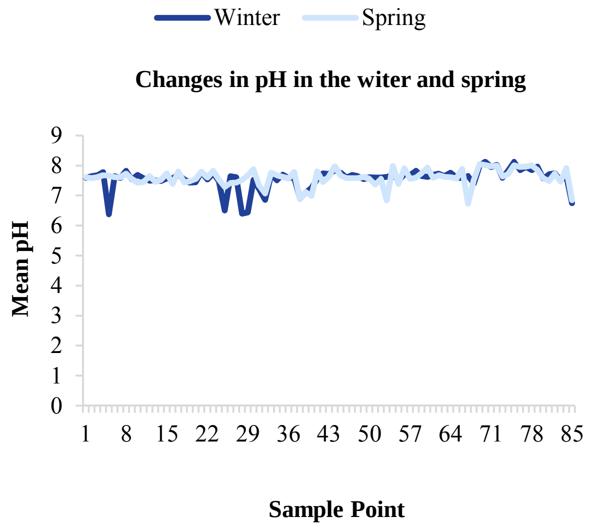

Figure 8. Average pH in the winter and spring

Paired t-test results showed that pH changes in winter and spring were not statistically significant ($P \geq 0.01$), which means pH was not affected by temperature. Molar relationship between residual chlorine and pH is presented in equation 1.[26] Moreover, the relationship between pKa and temperature is presented in equation 2, which yields a range of 7.82-7.39 over a temperature range of 0-50 °C. The temperature impact on pK_α could be neglected as the impact of temperature on the species-specific rate constants which is more significant in the typical pH range of distribution systems than the impact of temperature on the extent of dissociation of HOCl.[27] On the other hand, the changes in pH are independent of temperature, as confirmed in this research (Figures 8 and 9).

$$\frac{[HOCl]}{OCl^{-}} = 10^{apK_a - pH} \quad \text{(Eq. 1)}$$

$$pK_a = \frac{3000}{T} - 10.0686 + 0.0253T \quad \text{(Eq. 2)}$$

Conclusion

This research assessed the effect of temperature fluctuation in winter and spring on 3 physicochemical parameters (free residual chlorine, turbidity, and pH) in Sanandaj Water Distribution Network.

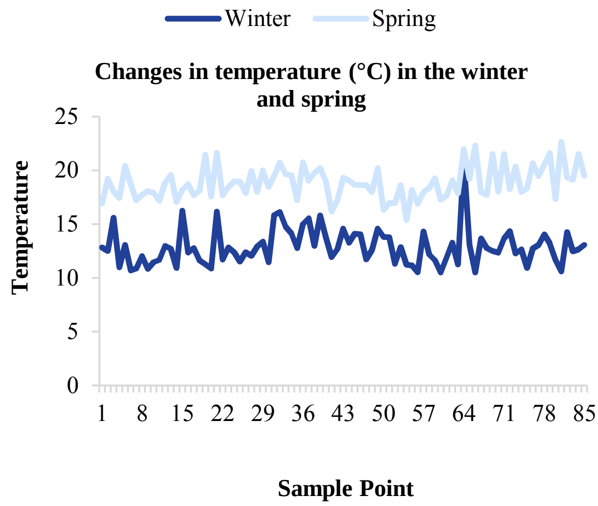

Figure 9. Average temperature in the winter and spring

The research showed that temperature did not cause significant changes in pH; however, turbidity and free residual chlorine were influenced by temperature changes, as data from 85 sampling stations revealed. Although Sanandaj Water Distribution Network has a loop form, the water quality was not uniform with respect to the parameters studied; thus, this factor requires further examination.

Conflict of Interests

Authors have no conflict of interests.

Acknowledgements

This paper is a part of the first author's MSc. dissertation and the authors are thankful to the Kurdistan University of Medical Sciences, Sanandaj, for the financial support.

References

1. Bostani A, Golmaie SH, Ansari H. Pipe water distribution network modeling platform and by finite element method with Ansys and Plaxis. Proceedings of the 2nd National Conference on Water; 2010 Mar 19-20; Mashhad, Iran. [In Persian].
2. Stavros G, Vantas K, Tzimopoulos C, Christos E. Modeling distribution system water quality with hydrosim model. Proceedings of the 7th International Conference European Water Resources Association (EWRA); 2009 Jun 25-27; Limassol, Cyprus.
3. Tabesh M, Azadi B, Rouzbahani A. Optimization of chlorine injection dosage in water distribution networks using a genetic algorithm. Water and Wastewater 2011; 22(1): 2-11. [In Persian].
4. Hassani AH, Jafari MA, Torabifar B. Trihalomethanes concentration in different components of watertreatment plant and water distribution system in the north of Iran. In ternational Journal of Enviromental Research 2010; 34(4): 887-92.
5. Lu W, Kiene L, Levi Y. Chlorine demand of biofilms in water distribution systems. Water Research 1999; 33(3): 827-35.
6. Qasim SR, Motley EM, Zhu G. Water Works Engineering: Planning, Design, and Operation. New York, NY: Prentice Hall PTR; 2000.
7. Ndiongue S, Huck PM, Slawson RM. Effects of temperature and biodegradable organic matter on control of biofilms by free chlorine in a model drinking water distribution system. Water Res 2005; 39(6): 953-64.
8. Institute of Standards and Industrial Research of Iran. Drinking water -Physical and chemical specifications. No. 1053. 5th ed. Tehran, Iran: Institute of Standards and Industrial Research of Iran; 2006. [In Persian].
9. Crittenden JC, Hand DW, Howe KJ. MWH's Water Treatment: Principles and Design. New Jersey, NJ: John Wiley & Sons; 2012.
10. Power KN, Nagy LA. Relationship between bacterial regrowth and some physical and chemical parameters within Sydney's drinking water distribution system. Water Research 1999; 33(3): 741-50.
11. Obi CL, Igumbor JO, Momba MN, Samie A. Interplay of factors involving chlorine dose, turbidity flow capacity and pH on microbial quality of drinking water in small water treatment plants. Water SA 2008; 34(5): 565-72.
12. McCoy WF, Olson BH. Relationship among turbidity, particle counts and bacteriological quality within water distribution lines. Water Research 1986; 20(8): 1023-9.
13. Lewis MJ, Bamforth CW. Essays in Brewing Science. Berlin, Germany: Springer Science & Business Media; 2007.
14. American Water Works Association. Water Quality and Treatment: A Handbook of Community Water Supplies. 4th ed. New York, NY: McGraw-Hill; 1990.
15. Ghanizadeh G, Ghanian MT. Evaluation of corrosion and scaling potential sources of drinking water in Noor city by using of corrosion indices. J Military of Medicine 2009; 11(3): 155-60. [In Persian].
16. Nemerow NL, Agardy FJ, Salvato JA. Environmental Engineering: Water, Wastewater, Soil and Groundwater Treatment and Remediation. 6th ed. New Jersey, NJ: Wiley; 2009.
17. Governor Sanandaj. Detailed results of the general census of population and housing in 2011 [Online]. [cited 2011]; Available from: URL: http://ostan-kd.ir/Default.aspx?TabID=51 [In Persian].
18. Andalib A, Ganjidoust H, Ayati B, Khodadadi A. Investigation of Amount and Effective Factors on Trihalomethane Production in PotableWater of Yazd. Iran J Health Environ 2011; 4(2): 137-48.
19. Powell JC, Hallam NB, West JR, Forester CF, Simms J. Factors which control bulk chlorine decay rates. Water Res 2000; 34(1): 117-26.
20. Liu B, Reckhow DA, Li Y. A two-site chlorine decay model for the combined effects of pH, water distribution temperature and in-home heating profiles using differential evolution. Water Res 2014; 53: 47-57.
21. Li X, Gu DM, Qi JY, M U, Zhao HB. Modeling of residual chlorine in water distribution system. J Environ Sci (China) 2003; 15(1): 136-44.
22. Case ME. Determining the Relationship between a Water Sample's Temperature and Its Turbidity Level [Project]; California, CA: California State Science Fair; 2010.
23. Ghorbani J, Moradianfard Sh, Reisi P, Shehni Gheysari M. Survey of heterotrophic bacteria population changes in Kerman drinking water distribution system and GIS zoning. Eur J Exp Biol 2013; 3(2): 476-83.
24. Wang S, Qian X, Wang QH, Xiong W. Modeling Turbidity Intrusion Processes in Flooding Season of a Canyon-Shaped Reservoir, South China. Procedia Environmental Sciences 2012; 13: 1327-37.
25. Shamsaei H, Jaafar O, Basri N. Effects Residence

Time to Water Quality in Large Water Distribution Systems. J Sci Res Eng 2013; 5(4): 449-57.
26. Liu B, Reckhow DA. DBP formation in hot and cold water across a simulated distribution system: effect of incubation time, heating time, pH, chlorine dose, and incubation temperature. Environ Sci Technol 2013; 47(20): 11584-91.
27. Morris JC. The Acid Ionization Constant of HOCl from 5 to 35°. J Phys Chem 1966; 70(12): 3798-805.