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The Effect of Excessive High-Rise Buildings on Hydraulic Performance of Water Distribution Network for the City of Ahar

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ORIGINAL ARTICLE

ABSTRACT: Regarding the population growth and city development at Ahar city, old houses in lanes and alleys of Ahar city are changing into high-rise buildings and in most of them the regulations are violated. This issue has created a lot of problems for the inhabitants. Our aim in the present research is to study the effects of constructing high-rise buildings without observing the regulations of the comprehensive city design in Ahar city on the performance of water distribution network. Thus, the hydraulic status of the network was simulated for different conditions before and after constructions and they were assessed by using Fuzzy Reliability Index (FRI), Hydraulic Benefit In Terms of Adequate Nodal Pressure (HBNP), and Hydraulic Benefit In Terms of Satisfactory Demand (HBSD). The results showed that water distribution network of Ahar city enjoyed from a good performance after the constructions being carried out. Meanwhile, this network faced shortage of pressure in some areas before the constructions and these constructions have made the problem more severe. If the present trend in constructions violating the comprehensive city design continues, the hydraulic performance of the network will be endangered because it has been concentrated in certain areas of the city. For example, the pressure in node 56 will decrease to 6.24 m. from 22.61 m. and the areal amount of Fuzzy Reliability Index will be reduced to 0.13 from 0.24.

Keywords: High-Rise Building Construction, Comprehensive City Design, Water Distribution Network, Hydraulic Reliability Index

INTRODUCTION

During some previous years, the population growth in cities has created high rise buildings in old areas of these cities. Population growth and urban residential areas' development has created another concern about the need to approve some rules and regulations about constructions in cities. The construction of high rise buildings while observing urban rules and regulations is effective in optimizing fuel consumption (Mahmoodi, 2002; Rahimi and Nourtaghani, 2006), the consistent development of constructions in cities (Sobhaninejhad, 2005; Fard and Zaeemdar, 2008), conferring an identity for urban spaces (Nouriyan, 2008), and resolving the housing problems. There is no doubt that the effects of establishing high rise buildings in older parts of cities regarding the lack of observing urban rules and regulations could be investigated regarding different perspectives. Some of these problems are: causing environmental and urban problems (Aminzadeh, 2002; Rahbar, 2002), inharmonious development of the cities (Jonobi, 2005), and the lack of having the spirit and identity of an urban area (Mehrjoo and Afaridi, 2010). There are not any researches focusing on the problems caused by constructions on urban water distribution networks directly and we can only refer to some studies regarding the consumptions' effects on the performances of urban water distribution networks and have devised some approaches to design such networks considering the revised demand patterns (Moradi et al, 2009, 1495). Recently Dini and Azizi (2011) have studied the effect of high rise building on the performance of water distribution networks. In their study, they have modeled the conditions created regarding the high rise building constructions in Ahar city on the water distribution network as the model applied in Branford in the United States and have shown that some limited high rise building constructions did not have significant effects on the performances of the networks. Meanwhile when there is overuse of this process, the performance of the network will be endangered. In recent years some high rise buildings were constructed in Ahar city and started to absorb some population and their floors are a lot. Regarding the documentations, rules and regulations of comprehensive city designs in Ahar city have not been observed. Nowadays, there are several different opinions about the advantages and disadvantages and effects of these programs. On the one hand, the authorities such as municipality and city inhabitants stress on the advantages of these constructions and on the other hand some critics especially the inhabitants of the vicinity of these high rise buildings complain about their disadvantages. The goal of the present research is to

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answer this question: "what are the consequences of high rise building constructions without observing urban rules and regulations on the performances of hydraulic water distribution network in Ahar city?". To answer this question, a part of water distribution network in Ahar city being affected by these constructions was selected as a case study and its hydraulic performances were investigated in different situations.

Case study

Ahar city in located in Eastern Azerbaijan province and its distance from Tabriz is 90 kilometres. This city is about 100 hectares. The farthest part of this city in south is located along with Ahar city-Chaee River and it is located in geographical coordinates of 38 degrees, 27 minutes and 46 seconds in northern latitude and the farthest point of it in north is located in GhizilGhaya laps in coordinates of 38 degrees, 29 minutes and 49 seconds of northern latitude. The main part of the city is densely populated. And as a result of its development along the main roads, it is going to get the form of a star gradually.

Ahar city has an old context where most buildings are one or two floors and in certain areas the floors are 4 at most. In recent years, incidentally some approvals were issued to construct high rise buildings up to 12 floors in Ahar city and regarding the documentations, the comprehensive city design's rules and regulations have not been observed. All high rise buildings were constructed in central and western parts of the city and there are not any buildings with these characteristics in eastern part of the city which is almost located in Riverside areas to Meshkin Road. In figure 1, the estimated statuses of these buildings are presented. The construction of these buildings has changed the demands needed for network nodes. To study the effects of these changes on hydraulic performances of water distribution network in Ahar city, a part of the network structure containing pipes and main nodes were selected as case study for our research and figure 2 shows this structure. The final structure of water distribution network included 118 pipes, 100 nodes, 6 tanks, and 3 pumps. The data related to the characteristics of these elements were driven from Ahar city Water Distribution Company and the estimated demands of nodes were calculated regarding the water bills of households in Ahar city. To apply the changes related to the consumptions of the newly constructed buildings, one of the buildings which had been constructed recently and had 40 housing units was considered as our base, supposing that every household has an average of 5 inhabitants regarding the average daily consumption of water in Ahar city which is 300 liters per person per day. In this case, by constructing one of the buildings above, almost 0.7 L/S will be added to network consumption amount.

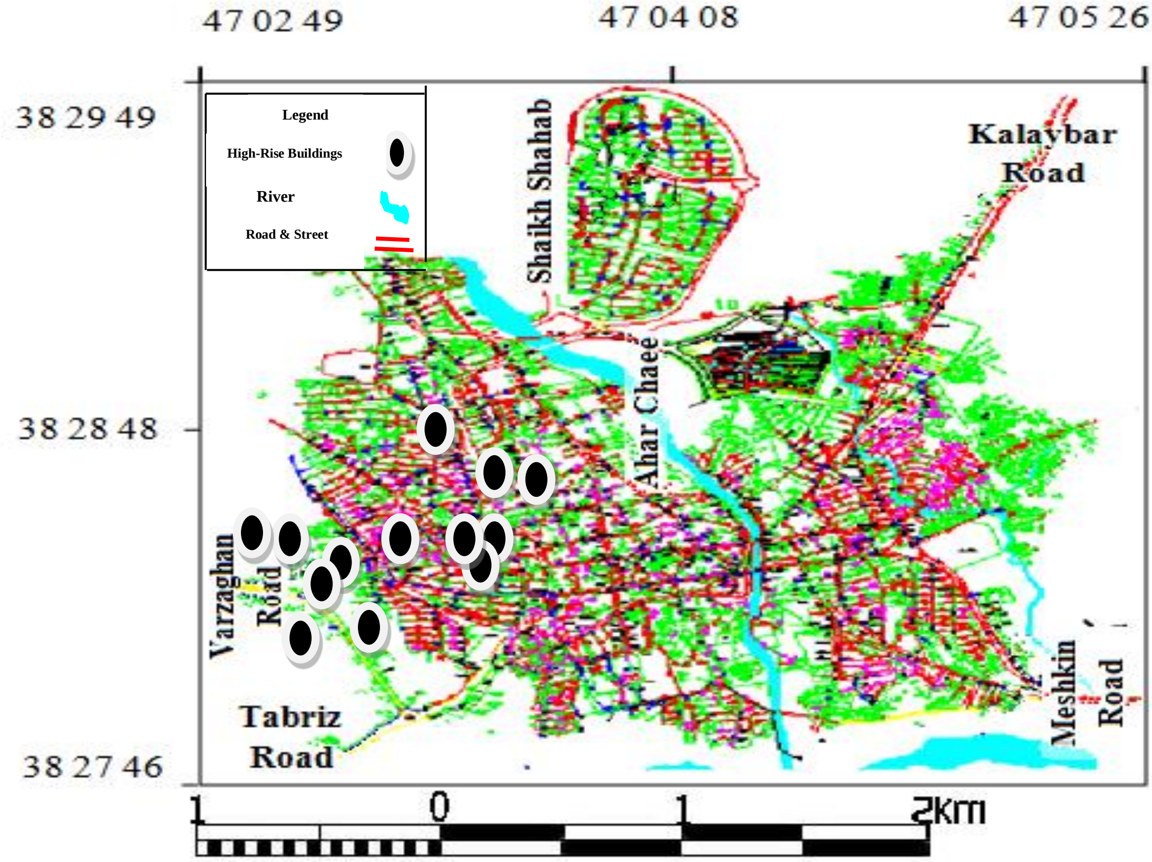

Figure 1: The estimated position of high rise buildings in Ahar city

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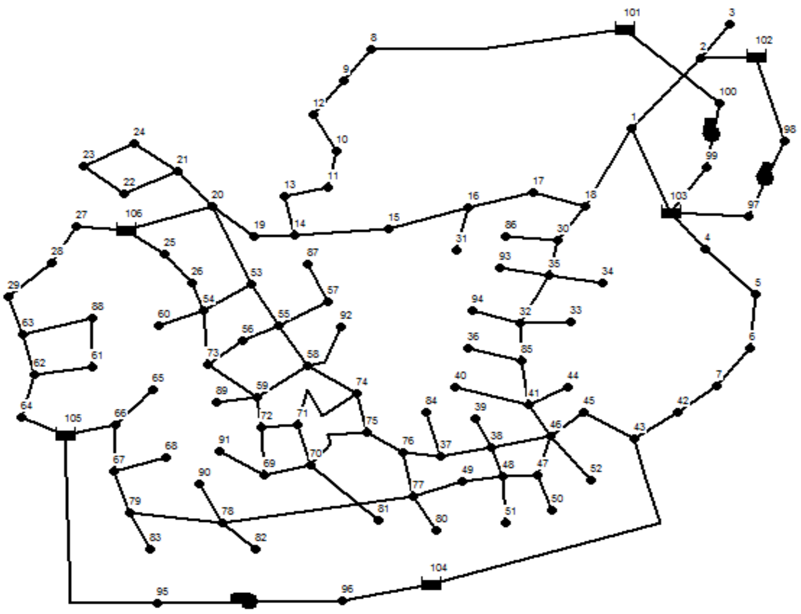

Figure 2: The structure of water distribution network in Ahar city

MATERIALS AND METHODS

In this research EPANET software based on hydraulic analysis according to the fixed demand (DDSM) was utilized to simulate Ahar city Water Distribution Network hydraulically (Rossman, 2000). To study the hydraulic performance of Ahar city Water Distribution Network, we have used Fuzzy Reliability Index (FRI), Hydraulic Benefit In Terms of Adequate Nodal Pressure (HBNP), and Hydraulic Benefit In Terms of Satisfactory Demand (HBSD). Ghajarniya (2009) identified Fuzzy Reliability Index regarding the following equation.

$$FRI_j = \mathrm{Mem}F_j \times C_j^1 \times C_j^2$$
$$C_j^1 = 1 - \frac{Q_j^{req}}{\sum_{j=1}^{NN} Q_j^{req}} \qquad (1)$$
$$C_j^2 = \frac{\sum_{i=1}^{NP_j} D_{ij}}{NP_j \times D_{max_j}}$$

Where, MemF_j: the amount of membership function considered at node j, C_j^1: the water demand coefficient at node j to implement the importance of nodes with high consumptions, Q_j^{req}: required demand at node j, C_j^2: index of the uniformity diameters of pipes connected to jth node, D_{ij}: the diameter of ith Pipe connected to jth node, NP_j: the number of pipes connected to jth node, D_{maxj}: the diameter of the thickest pipe connected to jth node. According to the researchers the node is more reliable that all pipes connected to it have the same diameters. The fuzzy membership function used in this research is like figure 3. The amounts more than the index are related to those nodes in which the pressure is close to the average amount of the highest authorized pressure and the least demanded pressure.

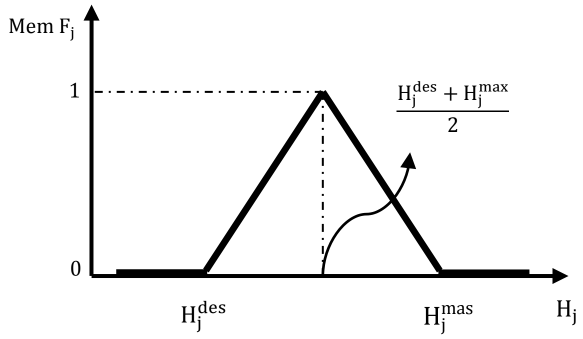

Figure 3: the membership function of FRI

Hydraulic Benefit In Terms of Adequate Nodal Pressure (HBNP) and Hydraulic Benefit In Terms of Satisfactory Demand (HBSD) were posed by Karijoo et al (2004) and they are calculated regarding equations 2 and 3. The maximization of Hydraulic Benefit In Terms of Satisfactory Demand in the whole network will increase the pressure present in nodes which have more important roles in supplying the water needs of the total network

$$\mathrm{HBNP} = \sum_{t=1}^{24}\sum_{j=1}^{NN}\left(\frac{H_{j,t} - H^{des}}{H_t^{max} - H^{des}}\right)^{0.5} \quad \text{if } H^{des} \le H_{j,t} \le H_t^{max} \qquad (2)$$

$$HB_{SD} = \sum_{t=1}^{24}\sum_{j=1}^{NN}\left[\left(\frac{H_{j,t} - H^{des}}{H_t^{max} - H^{des}}\right)^{0.5} \frac{Q_{j,t}^{req}}{\sum_{j=1}^{NN} Q_{j,t}^{req}}\right] \qquad (3)$$

Where, Hj,t: the present pressure in jth node in time t, Hdes: the desired head to satisfy the demand, Hmax: the maximum authorized pressure in network, Qjreq: required demand at node j, NN: the number of nodes, T: measurement times during the 24 hours, The indexes above were calculated and assessed by EPANET and MATLAB linked software and supplying Mfile in MATLAB.

RESULTS AND DISCUSSION

To study the effects of constructions not observing comprehensive city design and urban development in Ahar city Water Distribution Company, three states including the status before constructions, the present status (after the recent constructions), and the future status (developing the constructions in central parts of the city in future) were taken into consideration and modeling was carried out regarding the maximum consumption, average consumption and the least consumption of the network where consumption pattern coefficients were 1.3, 1.0, and 0.7, respectively.
Regarding the fact that the critical status is only emerged when the maximum consumption occurs, we will only consider the modeling results in maximum consumption status.

The status before constructions refers to the condition in which there is not any high rise building constructed without considering the comprehensive city design in Ahar city. The hydraulic model simulation results of water distribution network in Ahar city in this situation and in maximum consumption time is shown in figure 4 as the pressure in network nodes. As it can be observed, before constructions some points in the network have had pressure shortage and the node pressure amounts for them are shown in another color. The studies showed that the two parts of the city called Bahar and Varzaghan Road, which are among the highest parts of the city in longitude suffer lack of pressure due to the height of network nodes. The highest nodal pressure in the network are the parts near Chaykanar (riverside) which are located next to the river and are among the low height areas of the city. In figure 5, the height codes of the network nodes are shown.

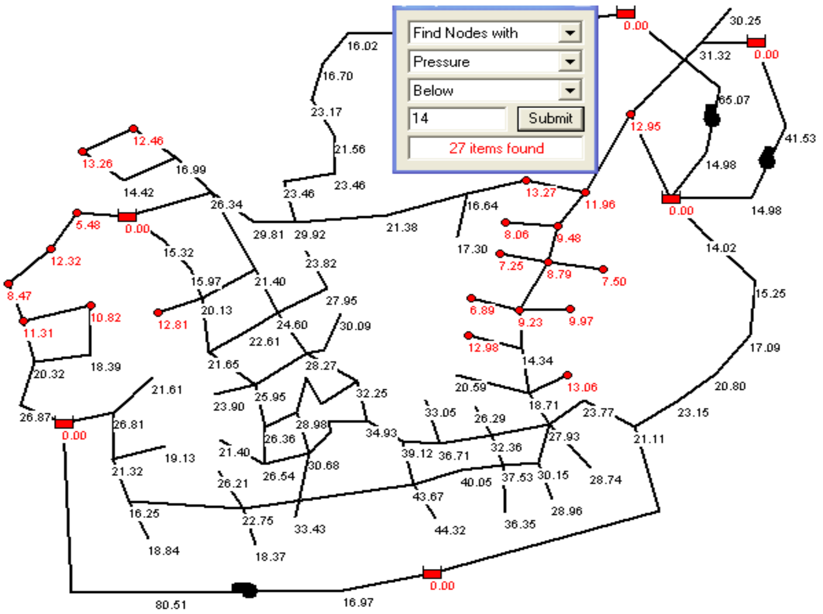

Figure 4: Pressure changes in network and nodes with a pressure of less than 14 meters before constructions

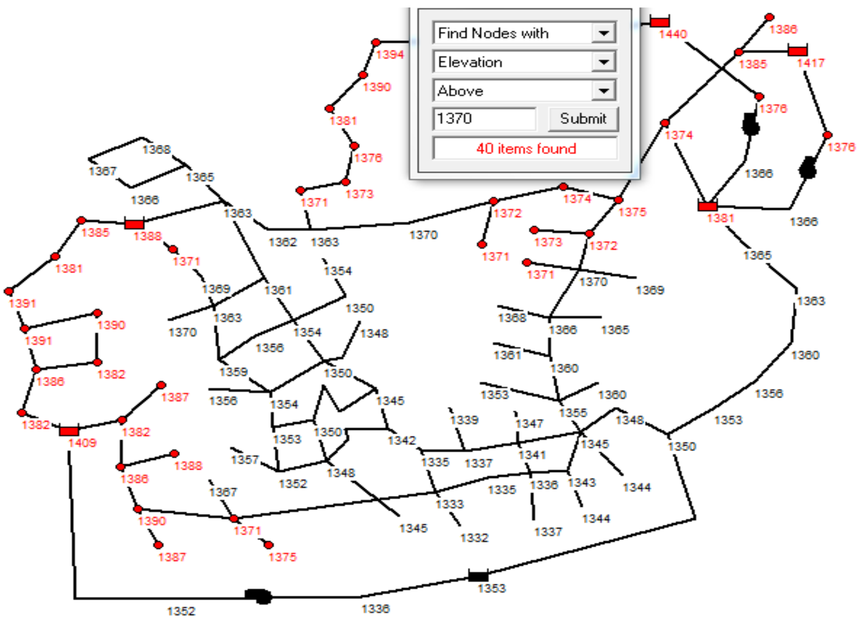

Figure 5: The height code of network nodes in Ahar city water distribution network

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To study the hydraulic efficiency of the network before constructions and when the consumption is maximum, Mfile was supplied and it was administered in MATLAB and the results are shown in table 1 as Fuzzy Reliability Index (FRI), Hydraulic Benefit In Terms of Adequate Nodal Pressure (HBNP), and Hydraulic Benefit In Terms of Satisfactory Demand (HBSD) for the area under investigation and for the total network. Also in this table, the pressure and on spot water needs of the network nodes are shown.

The results showed that in this situation, Fuzzy Reliability Index (FRI) in total network is 0.33, Hydraulic Benefit In Terms of Adequate Nodal Pressure (HBNP) is 0.37, and Hydraulic Benefit In Terms of Satisfactory Demand (HBSD) is 0.25. The areal amount of Fuzzy Reliability Index is 0.24 and it is 0.28 for Hydraulic Benefit In Terms of Adequate Nodal Pressure. Regarding the fact that the minimum needed pressure in the network is 14 meters and the maximum authorized pressure is 50 meters, the low amounts of the indexes in this situation shows that the network is working with low pressure amounts and near the minimum pressure needed. In some nodes in the network such as the nodes 27, 28, 29, 60, and 63 the nodal pressure amounts are less than the minimum pressure needed and thus the reliability index amount for these nodes equals 0. In other words, in these nodes all water needs will not be supplied completely.

Table 1- Areal and total network nodal reliability in Ahar city network in the status before constructions

node	FRI (%)	HBNP (%)	HBSP	Nodal D (L/S)	Pressure (m)
25	0.07	0.19	0.00	2.34	15.32
26	0.11	0.23	0.00	3.51	15.97
27	0.00	0.00	0.00	0.00	5.48
28	0.00	0.00	0.00	0.00	12.32
29	0.00	0.00	0.00	0.00	8.47
53	0.38	0.45	0.00	3.51	21.40
54	0.23	0.41	0.00	2.34	20.13
55	0.58	0.54	0.00	3.51	24.60
56	0.43	0.49	0.00	2.34	22.61
57	0.69	0.62	0.00	2.34	27.95
58	0.66	0.63	0.00	3.51	28.27
59	0.50	0.58	0.00	2.34	25.95
60	0.00	0.00	0.00	8.19	12.81
61	0.22	0.35	0.00	5.85	18.39
62	0.26	0.42	0.00	0.00	20.32
63	0.00	0.00	0.00	0.00	11.31
64	0.71	0.60	0.00	0.00	26.87
65	0.42	0.46	0.01	7.02	21.61
66	0.59	0.60	0.00	2.34	26.81
67	0.34	0.45	0.00	2.34	21.32
68	0.28	0.38	0.01	8.19	19.13
69	0.62	0.59	0.00	2.34	26.54
70	0.65	0.68	0.00	3.51	30.68
71	0.61	0.65	0.00	2.34	28.98
72	0.53	0.59	0.00	3.51	26.36
73	0.32	0.46	0.00	3.51	21.65
74	0.79	0.71	0.00	2.34	32.25
Total	0.33	0.37	0.25		
Areal	0.24	0.28	-		

The present situation refers to the situation where some of high rise buildings in which comprehensive city design of Ahar city is not observed are built and are being used. In this status, based on the approximate positions of the buildings which are shown in figure 1, the consumptions changed for the network nodes were identified and the model was reapplied for the water distribution network in Ahar city. In figure 6 the pressure changes in network nodes and in table 2 the results of hydraulic reliability of the network in maximum consumption time are shown.

Table 2- Areal and total network nodal reliability in Ahar city network in the present status of constructions

node	FRI (%)	HBNP (%)	HBSP	Nodal D (L/S)	Pressure (m)
25	0.07	0.18	0.00	2.34	15.20
26	0.10	0.22	0.00	3.51	15.75
27	0.00	0.00	0.00	0.00	5.43
28	0.00	0.00	0.00	0.91	12.20
29	0.00	0.00	0.00	0.91	8.28
53	0.36	0.44	0.00	3.51	21.08
54	0.22	0.40	0.00	2.34	19.78
55	0.56	0.53	0.00	3.51	24.13
56	0.41	0.48	0.00	2.34	22.15
57	0.67	0.61	0.00	2.34	27.49
58	0.63	0.62	0.00	3.51	27.78
59	0.47	0.56	0.00	3.25	25.38
60	0.00	0.00	0.00	9.10	12.38
61	0.19	0.33	0.00	5.85	17.86
62	0.25	0.42	0.00	0.91	20.22
63	0.00	0.00	0.00	0.91	11.12
64	0.71	0.60	0.00	0.91	26.86
65	0.42	0.46	0.01	7.02	21.60
66	0.59	0.60	0.00	2.34	26.81
67	0.34	0.45	0.00	2.34	21.32
68	0.28	0.38	0.01	8.19	19.12
69	0.58	0.58	0.00	3.25	25.91
70	0.63	0.67	0.00	3.51	30.10
71	0.58	0.63	0.00	3.25	28.38
72	0.50	0.57	0.00	4.42	25.77
73	0.30	0.44	0.00	4.42	21.12
74	0.79	0.70	0.00	2.34	31.80
Total	0.32	0.37	0.25		
Areal	0.23	0.28	-		

As it can be observed in the present status, the network encountered a little pressure drop compared to the status before constructions. For example in nodes 55, 56, 57, 58, and 59 and before the constructions it was 24.60, 22.61, 27.95, 28.27, and 25.95 meters, respectively. And after the constructions in the present status they have been reduced to 24.13, 22.15, 27.49, 27.78, and 25.38 meters, respectively. Studying the amounts of hydraulic reliability for the total network and for different areas shows that the amounts of network reliability encountered a little change. The Fuzzy Reliability Index in total network is 0.32, Hydraulic Benefit In Terms of Adequate Nodal Pressure is 0.37, and Hydraulic Benefit In Terms of Satisfactory Demand is 0.25 and the areal amount of Fuzzy Reliability Index is 0.23 and it is 0.28 for pressure reliability index.

Studying the performance of water distribution network in Ahar city before constructions and in the present situation showed that it still has a good level of performance although due to the lack of the pressure before the constructions, this problem has been reinforced and made more sever after the constructions. But still there is not any big problem in network performance. And the constructions have created these trivial changes compared to the status before them.

The future status refers to a status in which a large number of high rise buildings not observing the comprehensive city design have been constructed and started to be used.in this situation, regarding the fact that the central parts of the city and the older parts such as areas in the vicinity of the market and Hezbollah street are highly attractive, the constructions are concentrated in these parts and a lot of apartments will be constructed there eventually. According to the field studies, it has been presupposed that about 50 to 100 high rise buildings are going to be constructed in central parts of the city. The hydraulic network modeling was carried out regarding the consumptions above in nodes in central parts of the network and the results are shown in figure 7 and table 3.

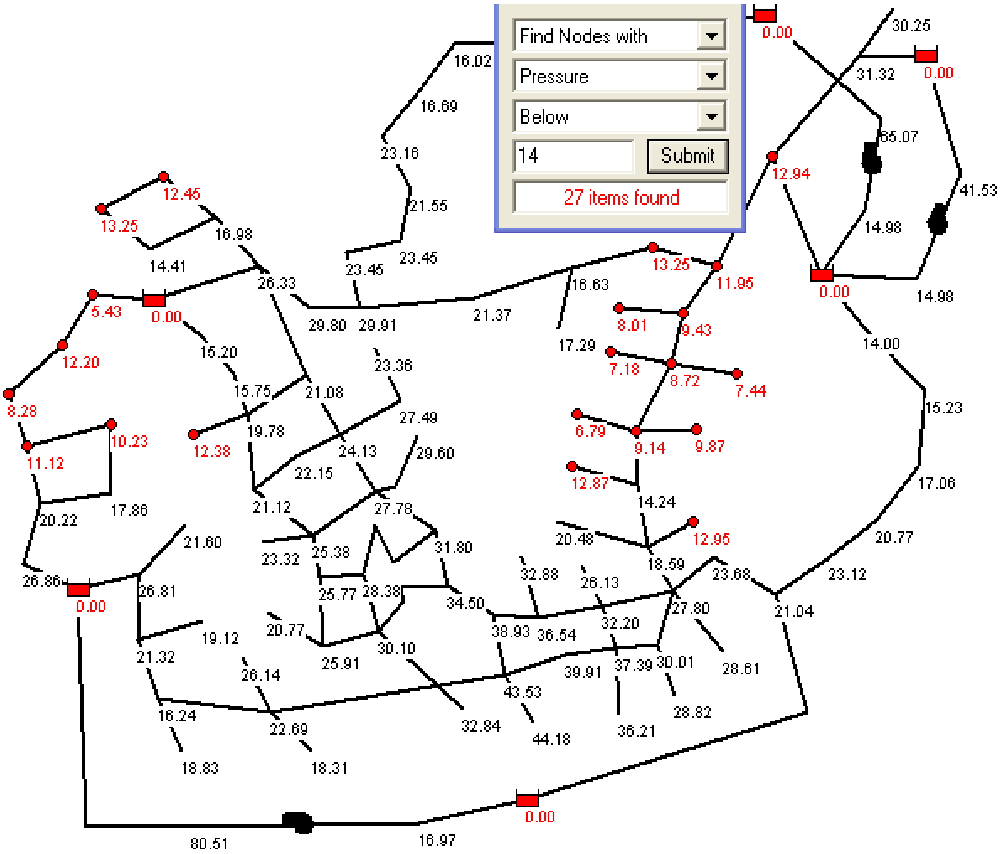

Figure 6: Pressure changes in network and nodes with a pressure level of less than 14 meters in the present status

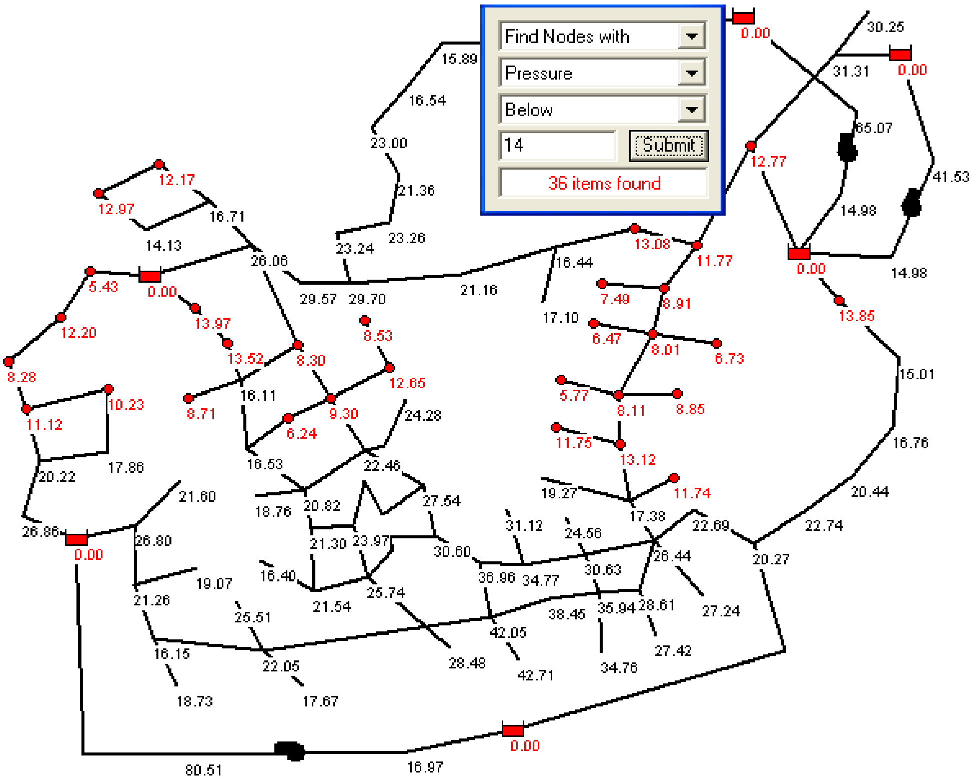

Figure 7: The pressure changes in network and nodes with a pressure level of less than 14 meters in the future status

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Table 3- Areal and total network nodal reliability in Ahar city network in the future status of constructions

node	FRI (%)	HBNP (%)	HBSP	Nodal D (L/S)	Pressure (m)
25	0.00	0.00	0.00	2.34	13.97
26	0.00	0.00	0.00	3.51	13.52
27	0.00	0.00	0.00	0.00	5.43
28	0.00	0.00	0.00	0.91	12.20
29	0.00	0.00	0.00	0.91	8.28
53	0.00	0.00	0.00	16.51	8.30
54	0.08	0.24	0.01	15.34	16.11
55	0.00	0.00	0.00	16.51	9.30
56	0.00	0.00	0.00	15.34	6.24
57	0.00	0.00	0.00	2.34	12.65
58	0.39	0.48	0.00	3.51	22.46
59	0.28	0.44	0.00	3.25	20.82
60	0.00	0.00	0.00	9.10	8.71
61	0.19	0.33	0.00	5.85	17.86
62	0.25	0.42	0.00	0.91	20.22
63	0.00	0.00	0.00	0.91	11.12
64	0.71	0.60	0.00	0.91	26.86
65	0.42	0.46	0.01	7.02	21.60
66	0.59	0.60	0.00	2.34	26.80
67	0.33	0.45	0.00	2.34	21.26
68	0.28	0.38	0.01	8.19	19.07
69	0.37	0.46	0.00	3.25	21.54
70	0.46	0.57	0.00	3.51	25.74
71	0.41	0.53	0.00	3.25	23.97
72	0.31	0.45	0.00	4.42	21.30
73	0.10	0.27	0.01	17.42	16.53
74	0.60	0.61	0.00	2.34	27.54
Total	0.27	0.31	0.22		
Areal	0.13	0.17	-		

The comparison of the results for the status before the constructions and the future status shows that the pressure reduction in network nodes has been considerable. In other words, the comparison of the results in table 1 and table 3 shows that the number of nodes in which the pressure is less than 14 meters in future status has increased as much as a double in a way that 5 nodes have increased to be 11 nodes in such a situation.

The comparison of pressure amounts in status before the constructions were 21.40, 20.13, 24.60, 22.61, and 27.95, respectively. They have decreased to 8.30, 16.11, 9.30, 6.24, and 12.65, respectively in future status. Also the comparison of Fuzzy reliability index in the two situations showed that this index for the total network decreased from 0.33 to 0.27 and in areal status it has been reduced from 0.24 to 0.13. The amount of pressure reliability index in the situations before and after the constructions showed that the amount of this index for the total network has been 0.37 and it has decreased to be 0.31 and the areal amount for this index was 0.28 but it has decreased to be 0.17. The amount of Hydraulic Benefit In Terms of Satisfactory Demand index for the total network in the two situations above, were 0.25 and 0.22, respectively.

On the whole if the constructions continue as the trend before and out of regarding the comprehensive and developmental city design in Ahar city and considering that the constructions are mainly focused in city center, the performance of the network will be endangered. The high drops in pressure in nodes ending in areas under constructions and the great drops in the hydraulic performance of the network in that area are among the consequences.

CONCLUSIONS

Our aim in the present research was to find out whether the construction of high rise buildings violating the comprehensive city design in Ahar city affect the performance of water distribution network in Ahar city or not. To achieve our goal, first we considered three situations of before constructions, the present status (after construction), and the future status (the development of constructions in central parts of the city). Modeling was done in the maximum consumption, average consumption, and the minimum consumption, but we only analyzed the results in maximum consumption condition. For network modeling we used EPANET simulator and its link with MATLAB program in the form of Mfile. Also three indexes of Fuzzy Reliability Index (FRI), Hydraulic Benefit In Terms of Adequate Nodal Pressure (HBNP), and Hydraulic Benefit In Terms of Satisfactory Demand (HBSD) were used for assessing the hydraulic performance of the network. The comparison of the results of the simulations showed that although water distribution network in Ahar city has encountered a little pressure drop in nodes and a drop in hydraulic efficiency, it benefits from a good performance in the present situation. If the constructions continue in the form previously done and without regarding the rules and regulations and out of the comprehensive city design and development, the network performance will be endangered and a great deal of drop in pressure will occur in network nodes and the hydraulic efficiency of the network will decrease a lot. For example, the pressure in node 56 will decrease from 22.61 to 6.24 meters and the areal amount of the Fuzzy reliability index will decrease from 0.24 to 0.13.

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