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ENVIRONMENTAL LEAKAGE POLLUTIONS EVALUATIONS IN URBAN WATER DISTRIBUTION NETWORK USING UNACCOUNTED WATER PRINCIPLES (SHOKUHIEH INDUSTRIAL TOWN IN IRAN)

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ABSTRACT

Consideration of non-revenue water in urban water distribution networks is of special importance in planning urban water distribution network and in water consumption. Water loss, especially in the distribution networks, forms a large part of the unaccounted for water (UFW). Considering the serious crisis in water resources, and taking into account the existing limitations of supplying hygienic drinking water, increasing attempts must be made at reducing the volume of water loss. The present study evaluated the environmental effects of pollution leakage from broken pipes into the water distribution network in the Shokuhieh. General principles and concepts of UFW, apparent loss was reviewed. Based on these concepts, probable pipe break points, and the resulting contaminants entering the network were considered. A software model of the water distribution network in the study area was then used to investigate qualitative and quantitative results related to intrusion of contaminants into the water distribution network and diffusion of pollutants into the network. Results of the present study and physicochemical tests performed on water revealed that BOD and COD concentrations increased from 5-10 to 10-20 mg/L and the coliform count rose from zero to 20 MPN as a result of pipe breaks in the distribution network.

KEYWORDS

Unaccounted for water, Diffusion of contaminants, Pipe breakpoints, Contamination load, the Shokuhieh Industrial Town, Environmental effects

INTRODUCTION

Urban water supply networks serve various functions the most important of which are supplying drinking water for the urban population and providing the water required for sanitary facilities such as bathrooms, toilets, etc., small and large factories and various workshops, irrigation of green spaces, street washing, public lavatories, and for the fire-department when fires break out. Urban water supply networks must be able to carry out the mentioned duties and meet the named needs, and other similar ones well, both qualitatively in accordance with present standards. It must be possible to supply the required water even under the worst temporal and spatial conditions and also under emergency conditions. The volume of UFW is mainly used as a criterion for the efficiency of water supply systems. According to the World Bank, efficient water supply systems have UFW values of less than 15 percent. In the developing countries, 15 to 20 percent are the usual values for UFW. Water loss in water distribution networks in England, based on the characteristics, structure, and special factors governing each water distribution network, varies from 8 to 33% of the total volume of water entering these networks while the corresponding figures are 16% for the United States less than 10% for Singapore and 50 to 60% in the developing countries. In Iran, the value of UFW ranges from 20 to 50%, and it was 31.2% in 2001. Based on results obtained from study areas, the average level of UFW in Iran was 40.6% from 1997 to early 2000s, and was caused by physical and non-physical losses of 54 and 45%, respectively.

A review on unaccounted water

According to the definition by the World Bank, UFW is the difference between the net volume of water entering the network and the volume of consumed water. It must be mentioned that the concept of non-revenue water (NRW), which was introduced by the IWA, has been used as a substitute for UFW since the year 2000. In the present study the following definition relation has been used:

$$UFW_{total} = V_{in} - V_{out} \tag{1}$$

Where UFW_{total} is the total UFW in an urban area, V_{in} is the measured volume of water entering the network and V_{out} known as the volume of output water measured during the same specified period. The volume of consumed water is measured by consumer gauges and output meters in the area, whether billed to consumers or not, and it specifically does not include factors such as pipe burst, illegal connections, leakage and reservoir overflow, network cleaning, broken-down meters, etc. In the above definition, leakage created after the customers gauge is not included as UFW because, if the meters are of high accuracy and sensitivity, the volume of internal leakage is calculated as a part of the customer water consumption and billed to the customer. However, if the water gauges are of low accuracy, the leakage is not included as UFW and is evaluated as gauge inaccuracy.

Relationship between pressure loss and leakage

It is known that water pressure and leakage are related in urban water supply systems. Limited field research has been done and not much experience has been gained in this regard in Iran. Theoretically, discharge through an orifice with fixed dimensions corresponds to the square root of water pressure; i.e.

$$Q = KP^{0.5} \tag{2}$$

A series of experiments has demonstrated that this relationship does not apply to the effects of water pressure on leakage in urban water distribution networks. It can be predicted that a logical pressure distribution pattern has high values at night, low values in the morning and evening, and intermediate values before noon and in the afternoon. Sometimes, pressure diagrams may not exhibit the expected changes due to errors in data and in reading manometers and because of water flow from faucets on the boundaries of the separated area and/or at locations of house connections to water transmission lines. Therefore, fluctuations in water consumption in the area along the way do not considerably affect the pressure diagrams.

Characteristics of the study area

The study area is the Shokuhieh Industrial Town in Qom province. Shokuhieh Industrial Town is located 12 kilometers of the city of Qom. Its population is 63 in 21 families and it has 1057 industrial units.

Fig. 1 – Shokuhieh industrial town's location

Besides Table 1 lists the information on pipe material, length, and diameter in the transmission lines.

Tab. 1 - Length (km) and diameter of pipes (mm) and pipe material in the transmission lines

Diameter (mm)	200	350	600	
Pipe material				
Asbestos (km)	10	2	5	-
Steel (km)	-	-	-	3

The present research was based on available geographical and demographic information and other information obtained from the various departments of the Qom Water and Wastewater Company including the Company's customer service department and the departments of financial affairs, water production and utilization, and maintenance of facilities and of transmission lines. The collected statistics were confirmed and the required information was completed (Table 2). Operational measures such as meter installation at sites of water resources, network pressure assessment, gauge accuracy test using the in-situ test method, measurement of leakage at facilities and in the network using the volumetric method are taken to determine the UFW components.

The total length of the network and of the water transmission lines is 225 kilometres and the water supply is provided by seven wells in alluvial calcareous soil. A one-hectare area of the network with a length of 2046 meters was selected for the present study. Information concerning customers, accidents, and network pressure and water quality was collected, customer consumption pattern was estimated, and information concerning public and services-related water consumption was obtained to perform the analysis.

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Tab. 2 - General characteristics of the study area together with lengths of the surveyed pipes

Item	Address	Pipe length (m)
1	The distance between the Moshtagh and Bahrami Streets	120
2	The distance between the Bahrami and Golzarmanesh Streets	175
3	The distance between the Golzarmanesh and Shaghayegh Streets	140
4	The distance between the Shaghayegh and Shahid Khosropour Streets	250
5	The distance between the Shahid Khosropour and Imam Khomeini Streets	230
6	The distance between the Imam Khomeini and Vahid Streets	270
7	The distance between the Vahid and Sangsar Streets	110
8	The distance between the Sangsar and Sanat Streets	180
9	The distance between the Sanat and Enghelab Streets	240
10	The distance between the Enghelab and Bahrami Streets	331
11	Total	2046

RESEARCH PROCESS

Following steps have been done and the performed analysis of the information are presented below :

- As started above, a part of the area covered by the water distribution network was selected as the pilot area for the research.
- Survey operations and leak detection were carried out by dividing the pilot area into smaller parts and through using leak detection equipment.
- Data obtained from the survey including pipe diameters and material, soil type on which the pipes were laid, water pressure inside the pipes, etc. was entered into the software system and the required information was extracted.
- After studying and comparing the software and theoretical results related to the way contamination infiltrated through the pipe breaks, the expected results were obtained.
- Physico-chemical tests were performed on water samples before and after the locations of pipe breaks and the related results were extracted.
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Analysis of information regarding accidents

Table 3 presents information related to leak detection and accidents based on analyses performed in the pilot area. Moreover, information concerning the survey of the pilot area was studied and modelled together with the output of the LOOP software, and the results were presented.

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Tab. 3 - List of locations were leaks were detected together with the lengths of the pipes

Item	Address of the location of the leaks	Pipe length (meters)	Number of leaks
1	Distance between the Moshtagh and Bahrami Streets	120	5
2	Distance between the Bahrami and Golzarmanesh Streets	175	3
3	Distance between the Golzarmanesh and Shaghayegh Streets	140	2
4	Distance between the Shaghayegh and Shahid Khosropour Streets	250	6
5	Distance between the Shahid Khosropour and Imam Khomeini Streets	230	5
6	Distance between the Imam Khomeini and Vahid Streets	270	8
7	Distance between the Vahid and Sangsar Streets	110	5
8	Distance between the Sangsar and Sanat Streets	180	8
9	Distance between the Sanat and Enghelab Streets	240	3
10	Distance between the Enghelab and Bahrami Streets	331	10
11	Total	2046	55

Figures 2, 3, 4 and 5 indicate accidents in the mentioned water supply network based on obtained information. As shown in these figures, the majority of accidents happened at connection sites followed by those that occurred inside the network, while a negligible percentage was caused by other factors.

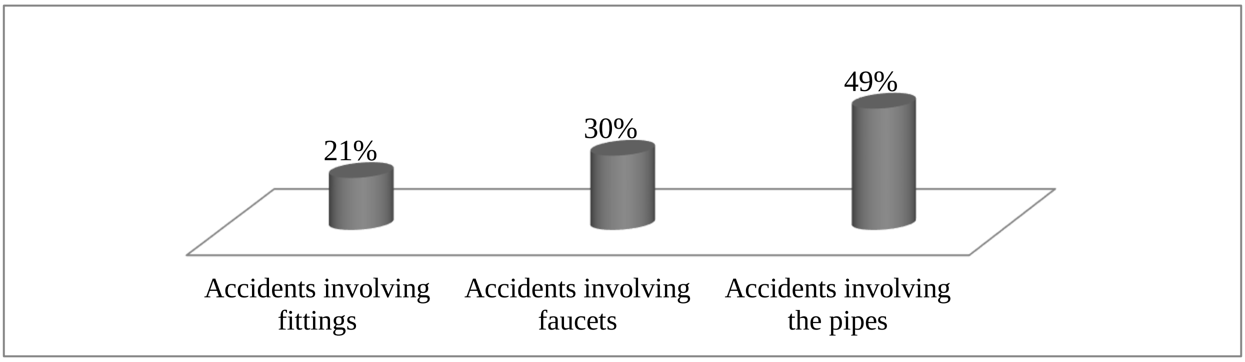

Fig. 2 – Various equipment responsible for accidents that happened in the water supply network

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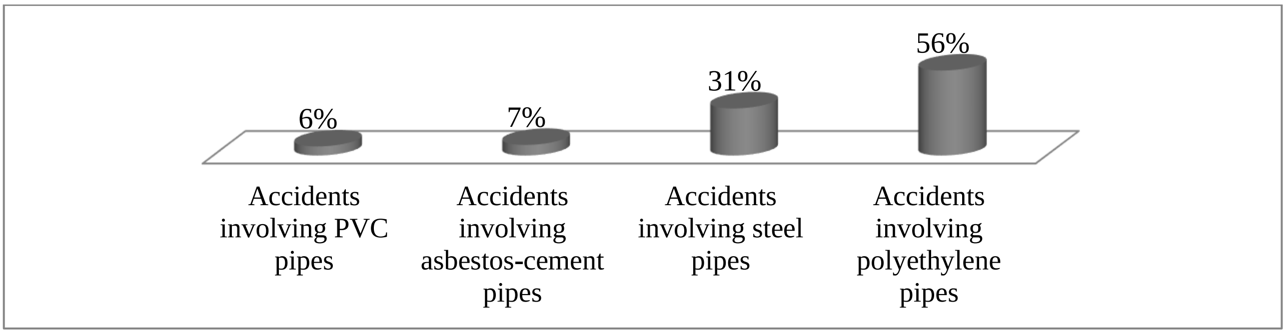

Fig. 3 – Various types of pipes involved in accidents in the water supply network

Moreover, accidents involving connection sites were mainly caused by breaks and rupture. Study of the reasons for these accidents revealed that they were mainly due to external loads. Of course, low quality of the pipes was one of the main causes of accidents that happened at connection sites.

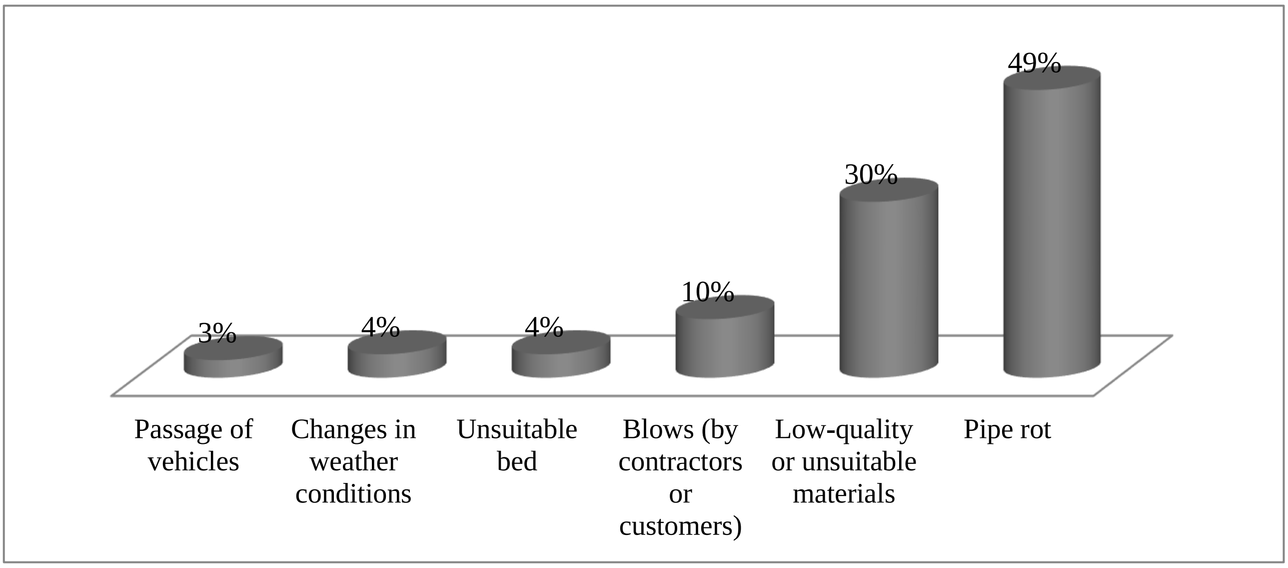

Fig. 4 – Various reasons for accidents that happened in the water distribution network

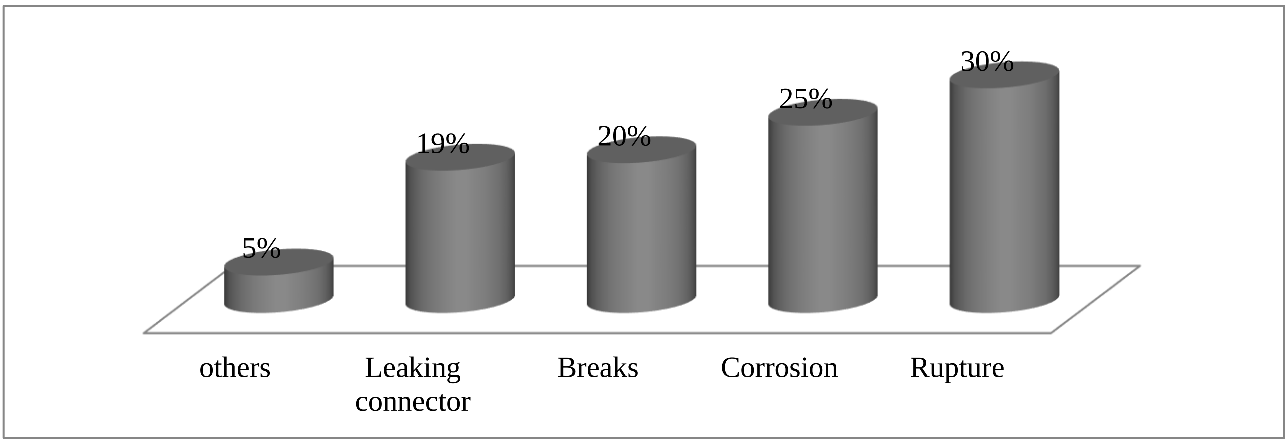

Fig. 5 – The various accidents that happened in the water distribution network

RESULTS AND DISCUSSIONS

Output results were studied by placing the information in Table 3 including pipe diameters and routes and division of the network in the various nodes. The output results included the following:

- Pressure surges followed by breaks were created at some places in the studied area due to the unsuitable design.
- Pressure drop occurred at locations with invisible leak and resulted in generation of negative pressure.
- Suction was created where negative pressure or negative flow existed. Consequently, contamination infiltrated into the pipes from the surrounding area and affected the customers.
- After physical and chemical tests were performed on the water samples, the final results of these breaks and the resultant contamination infiltration were determined.

Effects of pollution diffusion due to pipe breaks

After pipe breaks, while the operational teams are solving the problem and/or when there are invisible leaks, contamination present in the soil infiltrates into the water distribution network through the broken pipes. This pollution can include various types of viral and microbial infections including fecal and non-fecal coliforms. The present research showed that pipe breaks and the consequent leakage were unavoidable due to the lack of pressure management in the water distribution network, aged and rusted components in the water distribution network, and incorrect pipe laying likely unsuitable fill, material, and equipment used in filling, unsuitable frost depth, low-quality pipes, sediments in water pipes followed by their clogging and generation of additional pressure in other places, non-compliance with determined traffic load. Moreover, because of unsuitable design of networks in some places including improper design of fittings and knees, and lack of attention to regulations for designing and implementing urban water distribution networks including uniform pressure distribution and prevention of pressure drop in some areas, longitudinal supports along pipe routes. When pipe breaks happened and pressure drop known as a negative pressure occurred, suction was created in the broken segment of the pipe. This suction influenced infiltration and spread of contaminants.

Furthermore, since integrated urban wastewater systems have not entered into the operational phases in most Iranian cities, especially in Tehran, and traditional wastewater disposal using absorbing wells is used, this type of waste disposal continuously contaminates soil with organic and mineral matter mostly nitrogen and phosphorous present in the wastewater. In addition, if standard wastewater methods are not employed, the wastewater also includes fecal and non-fecal coliforms that cause digestive and intestinal problems. It should be mentioned that, depending on soil texture and topographic conditions in the soil in the absorbing wells can be saturated after some time and cannot be able to absorb salts, bacteria, etc. Therefore, these contaminants can remain in the soil and, after pipe breaks occur, enter the distribution network and are directly introduced into the water consumption cycle.

Since this type of contamination enters the described cycle after preliminary and final water treatment processes are carried out, no measure can be taken to control it. Therefore, the related Water and Wastewater Companies must study the different areas covered by them to determine the total UFW and its components. This process was carried out thoroughly in the present research. The mentioned companies can then use the methods described in the present research to investigate how the leakage and pipe breaks occurred in areas where they were likely to happen and to take the necessary remedial measures.

In addition, after the pipe break was fixed by the operational team, several random water samples were taken from various faucets that were closest to the point of pipe break at a distance of one meter from it in the control area. Random samples from the area were taken for the duration of one month and the parameters of interest in the physicochemical analysis of the water, including $(BOD)_5$, (COD), TDS, heavy metals, and fecal coliforms, were measured in Tables 4 and 5.

Tab. 4 - Results of physicochemical analysis of water samples taken at spots one meter before the point the pipe break happened (after disinfection and sterilization)

Item	Test	Average measurement	Number of measurements	
1	Biological oxygen demand $(BOD)_5$	5 ppm	20	Standard level
2	Chemical oxygen demand (COD)	10 ppm	20	Standard level
3	Total dissolved solids (TDS)	450ppm	20	Higher than the standard level
4	Fecal and non-fecal coliform bacteria	Zero	20	Standard level

Tab. 5 - Results of physicochemical analysis on water samples taken from various faucets one meter from the pipe break in the control area and from spots close to the point of pipe break

Item	Test	Average measurement	Number of measurements	
1	Biological oxygen demand $(BOD)_5$	10 ppm	20	Higher than the standard level
2	Chemical oxygen demand (COD)	20 ppm	20	Higher than the standard level
3	Total dissolved solids (TDS)	780 ppm	20	Higher than the standard level
4	Fecal and non-fecal coliform bacteria	20 MPN	20	Higher than the standard level
5	Heavy metals (lead)	0.05 ppm	20	Higher than the standard level

Results of the tests show that the required water entering the network after preliminary treatment operations, which include infiltration, sedimentation, and use of chemicals, satisfied the necessary standards and could be used as drinking water. However, it seems that in various parts of the network where visible and invisible pipe breaks had happened and had caused water loss in the network, existing soil contaminants infiltrated into the network and caused problems for customers. According to present study Figure 6 shows the diffusion of various pollutions in water distribution network in Shokuhieh industrial town.

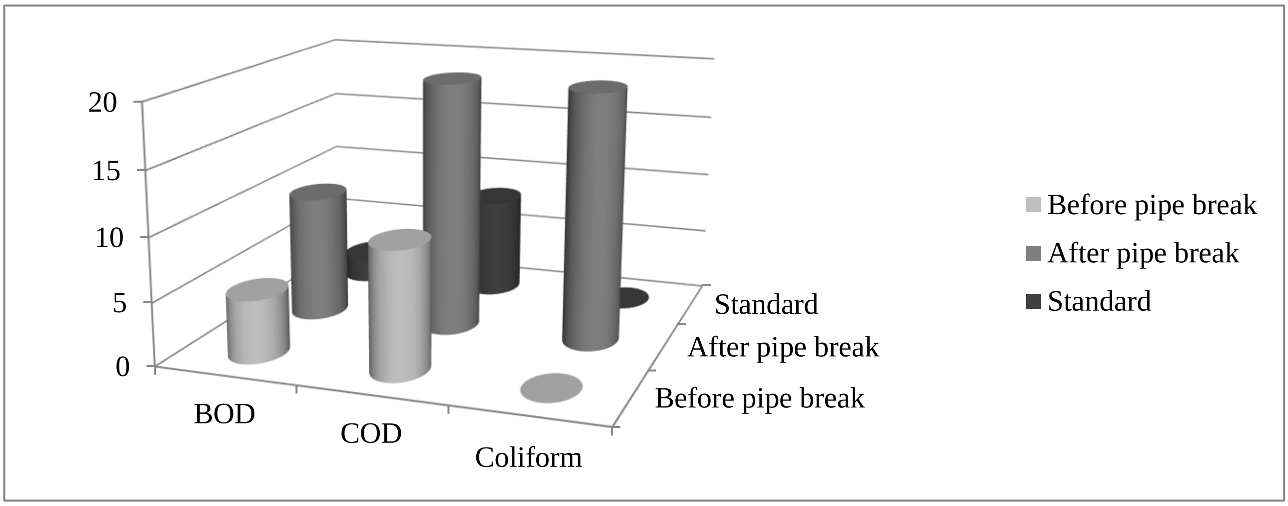

Fig. 6 - Diagram of pollution diffusion in the water distribution network

CONCLUSIONS

According to present study following results have been achieved:

- The guidelines offered in the present research should be used for pressure management and for prevention of intolerable pressure build up that causes pipe breaks.
- In the areas where conventional wastewater disposal method with adsorbing wells is still used, infiltration of wastewater from the lower lays and scour below the pipelines because of using low quality material and due to non-compliance with regulations related to pipe laying caused the maximum number of pipe breaks in the distribution mains that were often located within an 80-meter diameter from the wastewater well.
- Within a distance of one meter from the point where a pipe break happened in the study area, it was unfortunately observed that the wastewater main pipe passed from the vicinity of an old well. The pipe break was fixed within 48 hours. Moreover, a sample of the soil near the pipe break was personally and secretly taken by the author and transferred to the soil laboratory where physicochemical tests were performed to determine its phosphorous, nitrogen, free chlorine, and bacteria contents. It was found that the soil was saturated with these contaminants and these salts could be used as agricultural fertilizers.
- Tests were also carried out to determine fecal coliform count, and results showed it was far greater than the standard one and reached about 20 MPN, while it should be zero in drinking water. In the long-term, these bacteria cause digestive and intestinal problems.
- Furthermore, as mentioned before, it was observed that at some locations where pipe breaks happened, because the pipes were aged and their installation regulations were not followed, fake fittings and flanges had been used. The alloys used in these fittings also contained heavy metals that dissolve in water over time and enter the bodies of the customers.

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