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# EXTENDED ABSTRACTS

# Investigating the Effect of Pressure-Based Hydraulic Analysis on the Quality Reliability of Water Distribution Networks as for Residual Chlorine and THM using EPANET-MSX.

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## 1- Introduction

In recent decades, with the rapid growth of industries and population, environmental pollution, especially water resources, has increased greatly. One of the common methods to disinfect water and eliminate pathogenic microbes is chlorination. But this process, especially when the water contains naturally occurring organic matter (NOM), can lead to the production of dangerous byproducts such as trihalomethanes (THMs). (Maheshwari et al., 2018; Wang and Zhu, 2022). These compounds, which have carcinogenic properties, can give an unpleasant taste and smell to water. To investigate and model these complex processes in water distribution systems (Zilin et al., 2024), specialized software such as EPANET-MSX is used. which, based on the demand-based hydraulic analysis, enables simultaneous simulation of qualitative species interacting with each other (Fisher et al., 2023). One of the important points in these studies is paying attention to water pressure in distribution networks (Sayyed Abdy et al., 2014). Pressure-based analysis helps researchers to better understand the actual performance of the network and provide appropriate solutions to improve water quality. In the present study, the undeniable role of HDSM[1] hydraulic analysis on the quality analysis results of the network was considered, and the EPANET-MSX multispecies qualitative analysis model is combined with the HDSM hydraulic analysis model. Also, in this study, based on the laws and criteria of drinking water quality standards, penalty curves are provided for the quality parameters of residual chlorine and trihalomethane, and based on that, the quality reliability of the network is checked in terms of these two important parameters.

[1] Head Depend Simulation Method

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## 2- Methodology

The research methodology combines hydraulic pressure analysis (HDSM) and multi-species water quality simulation using the EPANET-MSX software. This involves modeling chlorine decay, THMs[2] formation, and the impact of water age on chemical reactions. The software can simulate interactions between different chemical species in water, providing a dynamic model of chlorine's effectiveness and the growth of harmful byproducts like THMs.

### *2-1- Hydraulic Analysis (HDSM)*

This method models the relationship between water pressure and flow. It addresses a limitation of demand-based models, which assume full water supply even in low-pressure conditions. In reality, water pressure impacts how much water can be distributed, so HDSM provides a more accurate representation of flow in the network.

### *2-2- Water Quality Analysis (EPANET-MSX)*

The MSX version of EPANET allows for multi-species simulations that consider the interaction between chlorine and organic materials, leading to the formation of THMs. By simulating water age, the study observes how longer water retention times increase the decay of chlorine and the concentration of THMs.

### 2-3- Quality Reliability

#### *2-3-1- Quality Penalty Curves*

Maximum or minimum limits are set for the allowable concentration of substances present in water. These limits may be upper, lower, or both, depending on the substance being considered. To accurately assess the condition of a substance in water, you can use a penalty curve. This involves defining a function for different values of the substance concentration in water. This function assigns a number between zero (undesirable condition) and one (desirable condition) to different concentration values of the substance. This curve represents the actual performance of water distribution networks based on water quality parameters (Fig1).

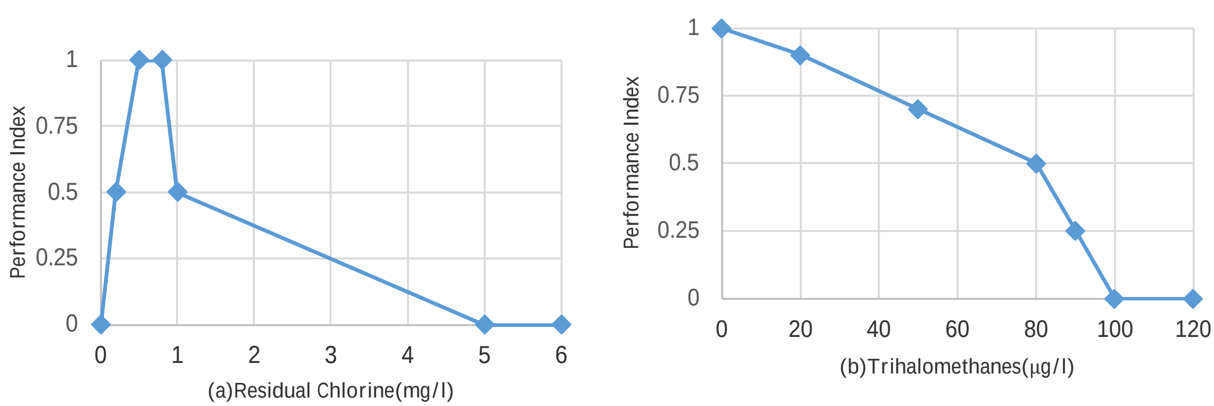


**Fig. 1**: Proposed penalty curve for (a)residual free chlorine and (b) trihalomethane

2 Trihalomethanes

*2-3-2- Combined Qualitative Reliability Index of Residual Chlorine and Trihalomethane*

Different researchers have proposed various indices to evaluate the water quality performance of distribution networks, including water quality reliability. A water quality failure occurs when the water supplied by the network doesn't meet the required quality for consumption. In this study, eq. (1) was used to calculate water quality reliability (Gupta et al., 2012).

$$\frac{\sum_s \sum_j PI_{js} Q_{js}^{avl} t_s}{\sum_s \sum_j Q_{js}^{req} t_s} = R_{WQ} \qquad (1)$$

where $Q_{js}^{avl}$: is the available flow rate at node j in stage s, $Q_{js}^{req}$: is the demand at node j in stage s, $PI_{js}$: is the performance factor obtained based on the residual chlorine and trihalomethane levels at the nodes and from the performance factors shown in Figure 1 (performance capability of node j in stage s), $t_s$: is the duration of stage s, j: index representing the demand node, and s: index representing the operating stages. It is necessary to use an index that considers both residual chlorine and formed trihalomethane parameters at the same time. In order to consider the residual chlorine and formed trihalomethane at the same time, the integrated reliability index is used in the form of eq. (2).

$$R_{WQ}=\sqrt{R_{WQCl} * R_{WQTHM}} \qquad (2)$$

## 3- Case Studies

The model was applied to two different water distribution networks: Sample network 1 (4 nodes and 5 pipes) and sample network 2 (water distribution in the city of Mahalat)

*Case Study 1:*

In the first network, the study tested normal and reduced pressure scenarios to observe changes in chlorine and THM levels. Under normal pressure, both chlorine and THM concentrations were stable. However, in scenarios where only 64% of the water demand was met due to pressure loss, chlorine levels dropped significantly, while THM concentrations rose, indicating a degradation in water quality (Table 1).

**Table 1**- Calculation results of integrated qualitative reliability index using EPANET-MSX-HDSM software (network 1)

| Scenario | Demand supply ratio (%) | Consolidated qualitative reliability |
|---|---|---|
| scenario1 | 100 | 0.928 |
| Scenario2 | 86 | 0.798 |
| Scenario3 | 64 | 0.593 |

*Case Study 2:*

The second case, which focused on Mahallat's larger network, tested scenarios where only 30% and 90% of water demand was met. Results showed a nearly 70% drop in the water quality reliability index when only 30% of demand was supplied. The findings emphasized the severe impact of reduced pressure on water quality, where insufficient water flow led to the formation of harmful by products (Table 2).

**Table 2**- The results of the calculations of the integrated quality reliability index using the EPANET-MSX-HDSM software (network 2)

| Scenario | Demand supply ratio(%) | Consolidated qualitative reliability |
|---|---|---|
| scenario1 | 90 | 0.857 |
| Scenario2 | 40 | 0.367 |
| Scenario3 | 30 | 0.265 |

## 4- Conclusion

The integration of hydraulic pressure analysis with multi-species water quality simulations provides a more reliable approach for assessing the performance of water distribution networks. The findings underscore the need for utilities to monitor not only the flow of water but also the pressure, especially under conditions where demand exceeds supply. Ensuring proper chlorine levels while minimizing harmful byproducts like THMs requires dynamic and pressure-sensitive models like EPANET-MSX-HDSM. In low pressure conditions, it's necessary to use a pressure-based hydraulic model. To perform a quality analysis, a model is also needed that simultaneously considers the interacting species of interest. For this purpose, EPANET-MSX software was used, which is essentially a development of EPANET software and has the capability to simulate multiple chemical and biological species interacting with each other.EPANET-MSX performs quality analysis based on demand-driven hydraulic analysis. To address this issue and enable the use of the EPANET-MSX software package to perform multi-species quality analysis in conjunction with HDSM hydraulic analysis, a program was developed in the MATLAB programming environment that integrates the HDSM hydraulic analysis model with the EPANET-MSX multi-species model.the water quality reliability index was assessed for chlorine and THM. To do this, penalty curves were defined for these substances. The method used in this study was implemented on two water distribution networks.

### The Key Findings Results

- Impact of Pressure: The study found that hydraulic pressure has a direct impact on water quality. Low-pressure conditions result in a significant reduction in chlorine levels and an increase in THMs, affecting the overall safety of the drinking water.
- Water Age and Quality: Water stagnation increases the decay of disinfectants like chlorine and fosters the formation of THMs. The longer the water remains in the network, the more likely it is to degrade in quality.
- Software Effectiveness: The EPANET-MSX-HDSM software proved to be an effective tool for simulating both hydraulic and water quality changes in real-time. It offered a more accurate picture of water quality under different pressure scenarios compared to traditional demand-based models.
- Using the results of EPANET-MSX-HDSM software in determining the integrated reliability index (in terms of chlorine and trihalomethane), with a decrease in the demand supply ratio, a significant decrease in the index value was observed. Therefore, this index varies significantly in different operating pressures, and in some network pressure conditions, the changes are very large and significant. For example, in the first sample network, in a scenario where 64 percent of the demand is met, a 36 percent decrease in the integrated

water quality reliability is observed, and in the second sample network, in the scenario where 30 percent of the demand is met compared to the scenario where 90 percent of the demand is met, a decrease of approximately 70 percent in the integrated water quality reliability index is observed.

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