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Environmental Impacts Assessment of Water Demand Management Policies on Urban Water Systems Using Life Cycle Approach

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ABSTRACT: Although increasing the population and urbanization worldwide have led decision-makers to consider urban water management policies more often, any policies, in turn, can positively and negatively affect urban water systems. In recent years, in response to intensifying water crisis across Isfahan province, pressure management has been applied in order to reduce water access as a new water demand management strategy in most cities of this province. The present study investigated the environmental effects of such a policy in Baharestan city (Isfahan province) during the 2018-2036 period, using a life cycle approach and different percentages of available water shortages. By considering the conditions of the study area, the life cycle assessment was conducted to explore the environmental impacts of processes such as network failure and energy consumption at the pumping station through SimaPro software. The results revealed that a significant part of the environmental effects in the water supply and distribution network were related to network failures, which, in comparison with energy consumption, have many effects on most midpoint and endpoint environmental effects. Based on the result, the endpoint environmental effects caused by network failures are, on average, 2.2 times greater than pumping systems. The finding suggested that by applying pressure management, the endpoint environmental effects in both short-term and long-term scenarios were reduced by 14.7% and 20.2%, respectively. Hence, it can be deduced that the pressure management policy can be an effective policy instrument in minimizing the environmental impacts of the water distribution network and pumping system.

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1- Introduction

Although water security is the most critical prerequisite for achieving sustainable development, more than half of the world's population is suffering from water insecurity resulting from water scarcity nowadays [1]. Urban areas are particularly susceptible to water scarcity [1]. Water scarcity is a real problem in these areas and poses a severe threat to the sustainable development of human societies [2]. As a fundamental response to water scarcity and environmental concerns, water demand management policies are viewed as a practical approach to reducing urban water consumption [3, 4]. These policies will help to provide the most water services with the least amount of water supply [5]. Escalating water scarcity across the province of Isfahan has prompted policymakers to apply pressure management to reduce water access as a new water demand management strategy in most cities of the province. This is while that the implementation of any policy in urban water management, including water demand management, which is implemented to improve current and future conditions, will have wide positive and negative consequences on various system dimensions. Consequently, these might affect even urban water infrastructure [6]. The review of previous studies has shown a significant research gap in applying a comprehensive approach that utilizes a precise data set to comprehensively assess the environmental impacts of water demand management policies on urban water systems, specifically pressure management policy aimed at reducing water access. Among the previous research, only Safarpour et al. [6] examined the environmental effects of such policy only on the municipal wastewater system (including wastewater collection networks and treatment plants). Therefore, there is no assessment of the environmental impacts driven by applying pressure management policies aimed at reducing water access in municipal water distribution systems. The current study focused on evaluating the environmental impacts of implementing such policy in a real water supply system (including pumping station and distribution network) and the operation phase of the system. Ultimately, the present research findings can provide a tangible and valuable perspective for policymakers and researchers.

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Table 1. Population changes and reduced per capita water consumption of end-users based on different scenarios

Scenario	Time period		Population	Water Shortage (%)	Water consumption (lpcd)
1	Short term	1 Year	86011	0	204.2
2		1 Year	86011	8.8	186.2
3	Mid term	14 Year	131118	20	163.36
4	Long term	19 Year	148467	0	204.2
5		19 Year	148467	30	142/94

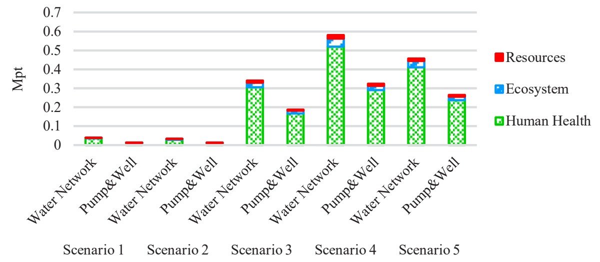

Fig. 1. Comparing environmental impacts between the water distribution network and pumping system in every scenario by the ReCipe endpoint method

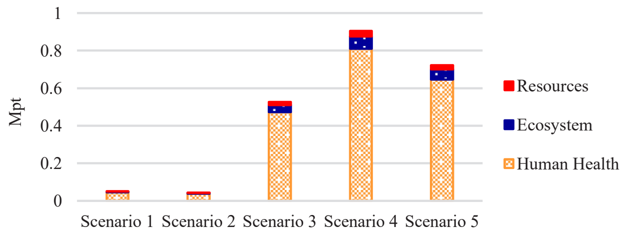

Fig. 2. Comparing scenarios using ReCipe endpoint method

2- Methodology

2.1. Case study and comparison of scenarios

Based on a case study (Bahararestan city), this paper appraised the environmental effects of applying pressure management policies during periods of water shortage in the water supply system. Using five different scenarios, the results of this study were analyzed, reviewed, and compared. The scenarios were classified into short-term, mid-term, and long-term, depending on the reduction in pressure in the distribution network and the water volume delivered to consumers (Table 1).

2- 1- Life cycle assessment

As part of an environmental assessment, life cycle assessment is widely adopted as one of the primary methods of assessing environmental processes, products, and services [7]. Life cycle assessment has been used to analyze urban water systems, including treatment plants, supply and distribution systems, and water collection and treatment systems [8-10]. The LCA study consists of four main stages [7]: (1) Determining the goal and scope of the study, which establishes the boundaries of the system, purpose, and limitations of the study. This study aimed to assess the environmental effects of applying several real and/or hypothetical scenarios of pressure management in facing water shortage conditions on the urban water supply system, including pumping station, water supply well, and urban water distribution network. The research frontier of the present study was also energy consumption by pumping stations and wells, network and asphalt failures, and transportation during operation; (2) Life cycle inventory (LCI) involved recording various types of data (input and output) within the system's boundaries. All data must be relevant to the functional unit defined in the objectives. In the operation stage, the water distribution network (including replacement or repair of damaged pipes and branches within the urban water distribution networks, re-asphalting in case of trench surface damage and additional damaged asphalt layers, as well as other operational processes related to the urban water distribution network) and water pumping system (including the electricity consumption for water pumping) are considered; (3) Life Cycle Impact Assessment (LCIA), in which the data collected had been appraised based on the evaluation methods and using SimaPro software; and (4) Interpretation of the results [7, 11, 12]. Following are the LCA steps by ISO standards that assess the environmental impacts of the municipal water distribution network and the water pumping system.

3- Results and Discussion

By using 18 midpoint indicators, this research compared the environmental effects of implementing the pressure management policy aimed diminishing households' water access during water scarcity conditions for two phases of the municipal water distribution network and the pumping system. Comparing Scenario 2 with Scenario 1 (short term) and Scenario 5 with Scenario 4 (long term), midpoint environmental impacts in the water distribution network phase decreased by 16% and 21%, respectively, while in the pumping system phase, they decreased by approximately 8.7% and 18.5%. According to Figure 1, in all scenarios, the municipal water distribution network's endpoint environmental impacts were more extensive than the pumping energy consumption. Furthermore, it had the most significant effect on human health in the group of final impacts. Most of the phases considered in all scenarios can threaten human health.

Figure 2 illustrated that by increasing the years of pressure management and the end of the design period approaches, the endpoint impacts intensify in scenarios 3 and 5, respectively. Scenario 4's endpoint impacts were approximately 1.25 times greater than Scenario 5. Human health had the most significant impact on this study, representing the most effects of the final effects group.

The values of scenarios in this category consisted of Scenario 4 (Mpt 0.81), Scenario 5 (Mpt 0.64), Scenario 3 (Mpt 0.47), Scenario 1 (M45 0.045), and Scenario 2 (Mpt 0.039). By implementing a water demand management policy in low water conditions, less energy and water were consumed in the long run, and the environmental impacts were reduced.

4- Conclusion

In general, the results of the study suggested the importance of addressing the various affective and influential aspects of the urban water system (e.g., assessing the environmental impacts) following the implementation of water demand management policies, particularly regarding pressure management when water scarcity occurs, which has relatively received little attention in previous studies. According to findings of evaluating the environmental impacts of pressure management policy aimed at reducing water access in the face of water scarcity conditions based on the life cycle approach, asphalt and network failures were almost twice as energy-intensive as operations. On the other hand, due to a large number of breaks in the branch pipes of the study city's water network, the environmental impacts of asphalt were considerable. As a result of reduced water consumption by end-users and fewer incidents and failures in the water distribution network, there were fewer environmental impacts associated with pressure management. However, the environmental burden was relatively low in the short term; as by approaching the end of the project period, with an increasing population and demand, the environmental burden increased even after demand management measures had been implemented. It demonstrated how vital water demand management policies are to reduce the impacts of urban water supply systems on the environmental categories. The research results not only can contribute to an in-depth understanding of this area and inform decision-makers to make comprehensive decisions in urban settings but may also provide a suitable practical guide for scholars for future studies.

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