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Risk assessment of water distribution service

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Abstract

The paper proposes a model that evaluates the risk of a water distribution system looking to three aspects, namely; available pressure, water demand, and water quality. Three failure modes were considered for examining the risk. The risk has been defined imitating the original definition of Hashimoto's vulnerability, and expressed as the failure magnitude with respect to each level of service provided at a certain location and during a certain period of time. When assessing the risk rather than focusing on just one aspect the overwhelming task has been used for better evaluation and mitigation of the overall risk. The model was developed using Analytic Hierarchy Process (AHP) coupled with Fuzzy Set Theory. The first assigns weight for each kind of risk that reflects its relative importance among the other risks. The second is a fuzzy building methodology that employs the assigned weight and others external information to harmonize all risks into a unique platform and allow one to obtain the system's overall risk. The model has been implemented and tested through the real network of Matera city.

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Keywords: Risk assessment; pressure; flow; water quality; analytical hierarchy process; fuzzy set theory

1. Introduction

Water distribution systems (WDS) play a crucial role in supplying sufficient water to users with acceptable volume, pressure, and quality. These infrastructures are usually designed to fulfill base demands with additional capacity for emergency conditions. WDS must satisfy all consumers needs but are vulnerable to a range of failure

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types that can occur during an intentional extreme events and compromise their normal functions. It is important for the utility managers to assess the component of the WDS in order to manage the threat. Normally, one would want to minimize the risk of undesirable consequences. In most cases it is not possible to completely eliminate risk; however, one can mitigate it. Furthermore, an effective risk assessment serves as a guide to the water service by providing a prioritized plan for security upgrades, modifications of operational procedures, and/or policy changes to reduce the utility's critical assets.

Previous studies were conducted to identify threats toward WDS, and more attention has been focused on vulnerability analysis. The most widely used and cited definition of risk of water resource systems may be the one by [1], though a similar concept has been applied earlier to show the sensitivity of a water supply system to drought [2]. [1] defined the risk as vulnerability measures of the probable damage subsequent to a failure. [3] defined risk as the degree of susceptibility and environment to hazards. In the same context [4] defined risk as the notion of susceptibility to a scenario whereas risk focuses on the severity of consequences to a scenario. [5] defined risk as a property associated with a component, a subsystem, or the overall water system to represent the possibility of being influenced by threats with given likelihoods and severities. [6] developed risk to quantify future water supply sustainability based on multiple scenarios. The integrity of any WDS to transport water to consumers depends on a number of factors that are strongly linked to each other, and as a result, when one kind of failure occurred it also influences the other type of failure. However, assessing the risk looking to lonesome service, it is likely to miss possible risk happening to other services.

In this paper, a model has been proposed that evaluates the risk of WDS looking to three aspects, namely; available pressure, water demand, and water quality. Three failure modes were considered for examining the risk of WDS. The risk has been defined imitating the original definition of Hashimoto's vulnerability [1], and is expressed as the failure magnitude with respect to each level of service provided at a certain location and during a certain period of time. For better evaluation and mitigation of the overall risk, the overwhelming task has been used rather than focusing on just one aspect of risk. The model was developed using Analytic Hierarchy Process (AHP) coupled with Fuzzy Set Theory. The first assigns weight for each kind of risk that reflects its relative importance among the other risks. The second is a fuzzy building methodology that employs the assigned weight and others external information to harmonize all risks into a unique platform and allow one to obtain the overall risk. To demonstrate the applicability of the current model, the methodology has been implemented and demonstrated through the WDS of Matera city (Basilicata).

2. Methodology

The development of the overall risk model requires i) estimation of available pressure, available flow and free residual chlorine at each node, ii) risk evaluation with respect to aforementioned aspects, iii) weight assignment through the analytic hierarchy process, iv) fuzzification of the estimated risks, v) aggregation of the risks; and vi) defuzzification and estimation of the overall risk.

2.1. Estimation of the parameters

The estimation of available flow, pressure and water quality is the starting point to initiate the process of the current methodology. An ideal approach is to investigate the quantity of water needed for each individual customer, the period of time they need water for, and the appropriate level of water quality that is suitable for their needs. In the current study, an approach called Demand Adjusted Epanet Analysis (DAEA) has been applied to estimate those parameters. [7] developed the model based on the standard Epanet hydraulic solver. It is a modified hydraulic analysis of Demand Driven but takes into consideration the influence of pressure condition on the allowed demand. The model is based on an iterative logical process, starting from a pre-assigning demand allocation (initial condition) and making a series of Demand Driven analysis where demands are calculated and adjusted according to three conditions as showed in Equation (1) [7,8].