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Drinking water vulnerability assessment after disinfection through chlorine

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Abstract

The objective of present paper is to propose a criterion for performing a vulnerability analysis in a water distribution system, which involves the estimation of the consumers' exposure to pathogenic risk and to elevated trihalomethanes concentration, deriving from the reaction of natural organic matter with sodium hypochlorite, widely used for the drinking water disinfection.

The analysis is carried out by introducing some index parameters, linked to a trihalomethanes fixed threshold, which has not to be exceeded. The results of the methodology show that the considered factors identify different vulnerable nodes respect to the different kind of exposure they refer to.

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Keywords: Vulnerability assessment; chlorine; trihalomethanes; drinking water quality; exposure index parameters

1. Introduction

Users' safety against microbial contamination and proliferation in water distribution system (WDS) is made sure by the disinfection of drinking water [1]. Chlorine compounds are still the mainly worldwide used, due to their ability to ensure a residual concentration in the network, which limits the re-growth of microbial species escaped from treatment plant or entered into the system from external contamination, preventing waterborne diseases. Nevertheless, increasing overly chlorine dosage injection during disinfection process causes an increasing of

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unwanted disinfection by-products (DBPs). Trihalomethanes (THMs) are some of the main DBPs produced by the reaction of sodium hypochlorite with natural organic matter (NOM) [2]. They could be carcinogenic substances [3,4] and also the exposure to them via non-ingestion routes, such as inhalation and dermal contact during showering, may pose risks to human health [5,6]. Therefore, in a WDS an important management problem after water disinfection is to keep chlorine residual and THMs concentrations above and below fixed thresholds, respectively, in all system. In this context, a great support may be the identification of the more vulnerable areas of the network. In particular, in [7] the vulnerability of a node is related to the residual chlorine concentration and it is defined as the probability that this value will be below the minimum level indicated in drinking water standard. Other studies paid attention to estimate the exposure of the users to a specific contaminant during contamination events; for instance, in [8] an exposure index to evaluate the response of the network during accidental/intentional contaminations and an influence map, based to the percentage of the users exposed by varying the contaminant injection node, are introduced.

In present paper a procedure to assess the vulnerability respect to the THMs exposure in a WDS is described; the identification of the system zones and the population with a higher risk respect to THMs exposure is carried out by introducing some specific index parameters, which will be described in detail in the following paragraph. All of them are related to exceeding the upper regulation limit by which in almost all countries the THMs quantities are bounded. The proposed analysis is applied to one of the example networks from the EPANET User's Manual [9]. The hydraulic and water quality simulations were performed using EPANET 2.0 and the EPANET Programmer's Toolkit. Among the various kinetic models developed in literature for chlorine decay evaluation the simplest first-order one has been adopted for its simplicity and comparable good performances [10,11], while THMs concentration has been evaluated as a linear function of consumed chlorine [12].

The results of the presented procedure are useful for implementing methodologies for the optimization of the chlorination process in WDS or for planning network modifications, but they furnish also important indications for epidemiological investigations performed through case-control studies [13].

Nomenclature

t	time (h)
T	total observation time (h)
j	node index
$q_j(t)$	actual demand node (l/s)
$[Cl]_{j0}$	initial chlorine concentration (mg/l)
$[Cl]_j$	chlorine time variable concentration (mg/l)
$[THMs]_{j0}$	initial THMs concentration (μg/l)
$[THMs]_j$	THMs time variable concentration (μg/l)
$[THMs]_{lim}$	THMs regulation limit (μg/l)
M_j^{THMs}	contaminated mass load (μg)
$V_j^{c,n}$	normalized contaminated volume
C_j^{THMs}	THMs average concentration (μg/l)
T_j^E	exposure time (h)
$I(t)$	dimensionless factor
D	THMs yield coefficient (μg/mg)
k_b	bulk chlorine decay coefficient (1/h)

2. Vulnerability assessment

2.1. Chlorine decay and trihalomethanes formation kinetic models

In literature, different approaches for estimating THMs formation have been proposed [5,12,14], but the numerical simulation using kinetic models represents the more convenient option when different functioning