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Safety of water supply in crisis conditions

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Abstract
The paper presents the concept of safety in water distribution systems, which is an important issue connected with its functioning in crisis situations. The research undertaken is directed towards methods of safety assessment relating closely to current world trends, aiming to ensure safety of water supply and use. The paper pays special attention to water consumer safety. Safety levels were assumed on the basis of failure intensity, exposure of water consumers and a number of undesirable event groups. Individual values of the immediate risk index were presented and three categories were distinguished as permissible, tolerable, or unacceptable risk categories, according to presumed action. The risk index can characterize the safety of the functioning of technical systems. The risk index definition is considered as the product of threat ranking. The paper contains the original proposal for a new method of risk analysis and assessment.

Introduction

The subject and the main aim of this work is to present the issues related to the safety of the collective water supply systems (CWSS) and the proposal of a method to determine criterion safety levels (CSL).

With regard to CWSS, safety is considered primarily from the perspective of consumers of water intended for human consumption. In this regard, it considers the risks associated with the possibility of water consumption of inadequate quality, which would result in poisoning, disease, and lack of water supply, as a result of system failure. Analysis and assessment of CWSS is now becoming standard in the modern management of water supply enterprises. Water supply safety ensures stable conditions, enabling the current and prospective demand for water in sufficient quantity and quality required to be covered at any convenient time for water consumers, at an acceptable cost.

The safety of water supply systems is threatened by many different factors, both internal and external. Climate change, pollution of water resources, as well as demographic change and aging infrastructure, threaten the stability of the water supply systems' functioning. Lack of access to water was, is and will be the cause of population migration and armed conflict. International organizations expect that this lack of water could lead to a global threat to the population. Today in many parts of the world lack of water is the direct cause of death, particularly for the elderly and children. In addition, where it seems that there is no problem of access to safe water for human consumption, there are threats which we must be prepared for by considering various scenarios concerning the risk of a lack of water supply. A separate issue is the safety analysis of CWSS in so-called crisis situations, for example floods and droughts, which should be considered as incidental events causing catastrophic consequences. This type of event can have very serious consequences for local communities and cause problems of health and hygiene, as well as financial difficulties.

Not without reason, EU regulations include water supply infrastructure as so-called critical infrastructure. The drought in summer 2015 is an example that visible climate change and the resulting threats including water supply should not be underestimated.

CWSS exploitation, in terms of belonging to critical infrastructure, is an important issue and requires detailed analysis. Therefore it is important to develop safety analysis for the supply of drinking water for different crisis situations, as well as detailed analysis of the risk of possible undesirable events in CWSS, in order to develop a comprehensive safety management program for the system. The main goal of this work is to present the problems associated with CWSS safety in terms of belonging to critical infrastructure.

Safety concept of water distribution subsystem

The concept of CWSS safety appears in many references (Rak & Wieczysty, 1991; Cabrera & Vela, 1995; Hrudey & Hrudey, 2004; Ostfeld, 2004; Pollard, et al., 2004; Mays, 2004, 2005; Rak, 2005; Rak & Tchórzewska-Cieślak, 2005, 2006; Michaud & Apostolakis, 2006; Johanson, 2008; Rogers, Garrick & Louis, 2008; Rosen, et al., 2008; Lu, Wang & Zhang, 2009; Tchórzewska-Cieślak, 2009; Kochubovski, 2011; Doro-on, 2012), and is usually defined as the ability of a system to safely perform its functions in the community. The measure of the safety loss in CWSS is the risk function understood as the expected value of losses associated with the occurrence of catastrophic consequences.

CWSS safety describes its adoption to avoid hazards and to function as a sustainable system. In particular, this concept can be described by analyzing the following features:

- adaptation so as to protect the operator and users (consumers of water) against the effects of external and internal exposures;
- adaptation so as to avoid them;
- adaptation so as to reduce the harmful effects on the environment of the system;
- adaptation to the system in an emergency for its user.

Safety standards are certain numerical limits for determining the acceptable probability of which certain undesirable events may occur in the system. This requires, in the first place, groups of undesirable events that may occur in CWSS to be defined.

Some definitions connected with the functioning of CWSS in crisis situations include:

- incident (IN) – e.g. water leakage, failure in the pipeline not causing significant problems in the operation of CWSS, etc.;
- failure (FA) – e.g. pipeline failure resulting in interruptions in water supply for individual consumers, small pressure drop in the network;
- severe failure (SFA) – e.g. pipeline failure resulting in interruptions in water supply for individual settlements, neighborhoods or the city, pressure drop in the pipe network;
- critical failure (CFA) – e.g. pipeline failure resulting in lack of water supply for the entire city, secondary contamination in local water.

Identification of threats to the life or health of water consumers

The aim of identifying the threats for water consumers is to indicate the type of substances present in the water for human consumption, while assessing the level of threat should be based on the identification of the undesirable event effects on human health and the classification of substances on the basis of all available data. The impact of individual substances on human health is determined by the appropriate professionals (doctors, chemists, biochemists, microbiologists) on the basis of surveys conducted through laboratory trials and many years of experience.

The basis for the classification of harmful substances that may be present in drinking water should be in the first instance in the current regulation of the Health Minister on the quality of drinking water, WHO guidelines, EU legislation, and the knowledge and experience of experts.

Due to the nature of harm we can distinguish the following types of substances that may be in water for human consumption: pathogenic micro-organisms (bacteria and viruses) and parasites, chemical substances including carcinogenic substances and noncarcinogenic (toxic).

Sometimes one substance can cause several types of threat. The oldest known problem was microbiological contamination, which poses a direct threat to health and even human life.

For mutagenicity and carcinogenicity, this can be determined according to whether the substance has the ability to exert such action or not.

The International Agency for Research on Cancer (IARC) (IARC, 2010), has made the distribution of chemicals into groups according to their potential carcinogenic properties, as presented in Table 1.

In Poland in 1977, the National Institute of Hygiene (NIH) introduced (not mandatory at present) for the use of the State Sanitary Inspection “Drinking water tolerance criteria content of chemical substances and quantities of microbial indicators”.

Table 1. Properties of carcinogenic chemical compounds by the IARC, on the basis of (IARC, 2010)

The group number	Severity of potential carcinogenic properties for humans
1	factor is carcinogen
2A	factor is probably carcinogenic
2B	factor is possibly carcinogenic
3	factor is not classified as carcinogenic
4	factor is probably not carcinogenic

Therein the upper limit of the tolerance levels of the quality of water for drinking and domestic purposes are presented, the exceeding of which does not disqualify water nor require the closure of waterworks. Tolerance criteria were referred to the local waterworks and wells, while for municipal water supply systems were used only in cases of crisis situations. Although at the moment these criteria are not valid, they may however be helpful in determining levels of risk of injury to human health. Also, the regulation of water quality during crisis situations may be helpful, especially for military forces during an armed conflict.

CWSS safety levels

The proposed method belongs to the group of indexing methods and consists in determining in the first place the so-called risk index (RI) and immediate risk index (IRI) according to (1):

$$\mathrm{IRI} = \mathrm{RI/S} \tag{1}$$

where:

IRI − immediate risk index;

S − safety system.

Risk index is determined as the sum of the partial index risk IR_i associated with the presence of particular groups of undesirable events. For each group (IN, FA, SFA, CFA) a certain rank of R_i validity is assigned as follows: IN = 1, FA = 2, SFA = 3, CFA = 4.

Risk index is determined according to the formula (2):

$$\mathrm{IR} = \sum_{i=1}^{n} \mathrm{IR}_i = \sum_{i=1}^{n} (R_i \cdot I_i \cdot C_i) \tag{2}$$

where:

RI − risk index;

R_i − rank of i-th undesirable event (degree of importance);

I_i − weight of i-th event related to the failure intensity;

C_i − weight related to the degree of exposure of water consumers;

n − number taken into account of undesirable events groups (in this case $n = 4$).

- For the “I” parameter associated with the failure intensity λ, [No. of failure·km^{-1}·year^{-1}]:
  - $I = 1$ – failure intensity $\lambda < 0.5$ [No. of failure·km^{-1}·year^{-1}];
  - $I = 2$ – 0.5 [No. of failure·km^{-1}·year^{-1}] $\leq \lambda \leq 1.0$ [No. of failure·km^{-1}·year^{-1}];
  - $I = 3$ – $\lambda > 1.0$ [No. of failure·km^{-1}·year^{-1}].
- For the “C” parameter associated with the degree of exposure to water consumers:
  - $C = 1$ – if the drinking water meets water quality regulation;
  - $C = 2$ – if drinking water does not meet the quality parameters in regulations, which have no direct threat to the health and life of water consumers;
  - $C = 3$ – does not meet the tolerances criteria.

If there are several different contaminants, we always assume the risk degree as the highest. In this way, IR assumes values in the range ⟨1, 90⟩.

To determine the value of IRI according to the formula (2), the following weights for monitoring-warning-blocking parameter were assumed (protection parameter – S):

- S = 1 – no protection, no system information of risks for water consumers;
- S = 2 – standard protection (standard, simplified monitoring of the water supply network measuring pressure, lack of opportunity to respond to small water leaks, conducted standard tests of water quality in the water supply network, the standard procedure of information about the risks for water consumers);
- S = 3 – protection above standard (using the so-called security barriers, full monitoring of the water supply system by measuring pressure and water flow, early and late warning monitoring, surveillance system and archiving SCADA, comprehensive safety management system of CWSS along with an extensive program of information about threats for water consumers, etc.).

The individual values of IRI take values in the range ⟨0.33, 90⟩. On this basis, the following safety criteria of CWSS were assumed, as shown in Table 2.

Application example

Risk determination for severe failure (FA = 2) resulting in interruptions in water supply for individual settlements:

- the failure intensity $\lambda = 0.75$ [No. of failure·km^{-1}·year^{-1}], ($I = 2$);
- the degree of exposure to water consumers: water does not meet the quality parameters in

Table 2. Safety categories for CWSS

IRI values	⟨0.33, 20⟩	⟨20, 30⟩	⟨30, 90⟩
Safety category SC	**Permissible** – risks associated with the operation of CWSS is widely acceptable; – need to maintain assurance that the IRI remain at this level	**Tolerable** – the so-called ALARM area; – risk is undertaken only when the benefits are desired, otherwise need to implement reduction procedures IRI	**Unacceptable** – the risk cannot be justified except in exceptional circumstances; – procedures to reduce IRI should be immediately implemented each time

regulations, which have no direct threat to the health and life of water consumers, this corresponds to the category $C = 2$;
- protection parameter belongs to standard $S = 2$.

The following path was received, which defines the assessment of risk parameters: FA = 2 → $I = 2$ → $C = 2$ → $S = 2$, which corresponds to the immediate risk index – permissible.

Conclusions

- The issue of determining the required level of safety through analysis and evaluation of risks associated with the operation CWSS and the whole WSS should now be a priority task for scientists, engineers, practitioners, managers risk management specialists from water companies and the legislative authorities.
- The safety management (PZB) for SZZW should include:
  - the identification of undesirable event groups;
  - the identification of risks for water consumers;
  - the cause and effect analysis of these events;
  - development of a method of analysis and risk assessment of the CWSS functioning with emphasis on the uncertainty;
  - development of operating procedures in the event of an unacceptable safety levels;
  - development of informing-warning scenarios for water consumers;
  - development of a program to respond to the crisis situation.
- The criterion for certain levels of risk should be included in legal rights, as happens for other systems (eg. in systems related to air transport and health safety of food).

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