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ANALYSIS AND EVALUATION OF HAZARDS IN EMERGENCY SITUATIONS IN WATER SUPPLY SYSTEMS

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ABSTRACT: The new regulation concerning the quality of drinking water offers a number of delegations on the waterworks inform users about the quality of tap water. The study analysis on the public risk health should be prepared. In the paper the analysis and assessment method of the population and property related to failure occurrence of collective water supply systems is presented. Four categories of factors having impact on the multiplicative risk: purity category or probability of danger occurrence, material damage, loss of population health and security were adopted. On this basis four-parametric risk matrix was developed. In the study also examples of application methods were presented. The method can provide a planning tool in crisis management at the local government level.

KEY WORDS: water supply, risk, risk matrix

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Introduction

The Act of 2001 (Ustawa, 2001) on collective water supply and collective sewage disposal gives public health minister a competent to determine by requirements of water quality intended for human consumption. The new regulation (Ustawa, 2015) in came into force on November 28, 2015. Currently, information about the water quality deterioration the water supply company is obliged to transfer within no longer than 7 working days to the sanitary state inspector and mayor or president of the city.

Scope of the information contained in the request for a waiver was extended to:

- reasons why water of the required quality cannot be delivered,
- justifications with an indication of actions to ensure good quality water,
- a study analysis prepared by a research institution conducting studies,
- in the field of public health regarding, the impact of the derogation (concentration and duration) on the health of water consumers.

In addition, an obligation to provide a systematic (every 3 months) detailed report on corrective actions taken and actions planned to be taken in the next reporting period was introduced. Information for consumers about water quality includes data on granted consents to deviation from acceptable water quality parameters. Standard information for residents about water quality should include:

- area covered by water quality research,
- area not covered by water quality research with reasons,
- hazards resulting from lack of water quality research,
- identification of activities that should be taken against contaminated water.

The provisions of the regulation also apply to water from individual water intakes supplying less than 50 people or providing less than 10 m^3/d.

The aim of the paper is to present analysis and assessment method of the population and property related to failure occurrence in collective water supply systems (CWSS). Four categories of factors having impact on the multiplicative risk: probability category of danger occurrence, material damage, loss of population health and security were adopted. On this basis four-parametric risk matrix was developed. In the study also example applications of the methods were presented. The method can provide a planning tool in crisis management at the local government level.

An overview of literature

Risk related to CWSS is the possibility of an event having an impact on safe water supply achievement. According to the international ISO standard (ISO, 2009) the risk assessment consists of its identification, analysis, estimation and evaluation. The Method of Analysis and Assessment of Population and Property Threat requires determining the upper limits of tolerated and controlled risk (Cooper et al., 2005). The goal of risk management is to bring risk level to at least tolerated, and preferably to the "as low as reasonably practicable" ALARP level (Clifton, Ericson, 2005; Pietrucha-Urbanik, Studziński, 2016; Szpak, Tchórzewska-Cieślak, 2015). The novelty of the material and human losses separation method is presented in paper.

In crisis management, a proper risk assessment is the basis for taking actions to effectively and efficiently ensure safety (Boryczko, Piegdon, Eid, 2014; Boryczko, 2016; Rak, Boryczko, 2017). Effective actions should be understood as fully achieving the goals set. In turn, achieving certain results is considered effective.

Risk analysis methods are mainly developed to meet the needs of safety engineering (Vocabulary ISO, 2009). It implies the use of risk assessments in crisis management. The Act on Crisis Management (Ustawa, 2007) obliges the estimation of risk with regard to at least human losses (fatalities, missing persons, injured persons requiring hospitalization and qualified medical aid) and property losses. The classic definition of risk shows that its estimation consists in multiplying the probability or frequency of occurrence of a threat by the losses. Risk estimation requires determining the value of both these factors. The joint consideration of human damages and material losses raises ethical concerns. For this reason, separation should categorize both the risks associated with material losses and human damage. The People and Property Risk Analysis (PPRA) method assumes the adoption of five-stage scales for human damages and material losses (very small, small, medium, large, very large).

The problem of probability estimation

The estimation of danger probability can be made based on modified Bernoulli distribution. Bernoulli's classic formula for the probability of obtaining k successes in n samples is calculated from the formula:

$$P(k) = \binom{n}{k} p^k \cdot q^{n-k}$$

where:

P – the probability of success,

q=1-p – the probability of failure,
k – number of successes,
n – number of samples.

Assuming that:

$$P(A) = 1 - P(A_1)$$

and:

$$P(A_1) = \binom{n}{k} p^k \cdot q^{n-k}$$

and for A_1 event, $n = k$, and $p = 1 - y$, then the formula takes the form:

$$P(A) = 1 - \left[\binom{n}{k} p^k \cdot q^{n-k}\right] = 1 - [1 \cdot (1-y)^n \cdot q^o] = 1 - (1-y)^n$$

where:
y – the frequency of occurrence of hazard A, the value obtained from experience and can be identified with a posteriori probability.

When determining the time perspective, for which the probability of risk is calculated, analysis should take into account time that has elapsed since the last year when threats have occurred. Thus:

$$n = N + (n_1 - n_2)$$

where:
n_1 – the year in which the analysis is carried out,
n_2 – the year in which the last threat occurred,
N – time of prospective analysis.

Table 1 presents the scale of the frequency and probability categories of undesirable event.

Table 1. Categories of frequency and probability of hazard occurrence

Category	Frequency – f	Probability – P
Very small	from once every 100 years up to once every 50 years	0,01–0,02
Small	from once every 50 years up to once every 20 years	0,02–0,05
Average	from once every 20 years up to once every 5 years	0,05–0,2
Large	from once every 5 years up to once every 2 years	0,2–0,5
Very large	from once every 2 years at least once a year	>0,5

Source: author's own work.

Application case of probability estimation

In 2011, the probability of surface water intake contamination was estimated. In 30 years (from 1981), contamination occurred four times, and the last time in 2010. What is the probability of contamination in the perspective of 5 years?

$$n = 5 + (2011 - 2010) = 6$$

$$p = \frac{4}{30} = 0{,}1333$$

$$P(A) = 1 - (1 - p)^n = 1 - (1 - 0{,}1333)^6 = 0{,}57615$$

The probability of water contamination in 2016 with the perspective of the next 5 years was also estimated. The last threat occurred unchanged, i.e. in 2010:

$$n = 5 + (2016 - 2010) = 11$$

$$p = 0{,}1333$$

$$P(A) = 1 - (1 - 0{,}1333)^{11} = 0{,}79272$$

The probability of water contamination in 2011-2016 was 0.57615, and in 2016-2021 it increased to 0.79272.

Problems of estimating material losses

Estimation of material losses resulting from an undesirable event is a complex and multifaceted. The valuation of assets of people, enterprises, real estate, etc. is subject to many researches (Gołębiewski, 2011). At work the interest on local government level income as a measure of losses was assumed.

Table 2. Category of material losses

Category	The amount of material losses – C
Very small	up to 2% of annual income
Small	up to 5% of annual income
Average	up to 15% of annual income
Large	up to 30% of annual income
Very large	over 30% of the annual income or the inability to pass a budget for another year due to exceeding the individual debt ratio

Source: author's own work.

Problems of human losses

The indicator used in analyzes and assessments of accidents at work was adopted. The failure frequency rate indicates the number of undesirable events per 1000 employed. By analogy, the number of undesirable events per 1000 people using the public waterworks was adopted. Three types of human losses were distinguished:

- granting qualified medical help – FM,
- required hospitalization – FH,
- fatal descent – FF.

Table 3 presents the scale of the category of human losses.

Table 3. Category of human losses

Category	Human loss rate		
Very small	FM≤5	FH=0	FF=0
Small	FM≤25	FH≤2	FF=0
Average	FM≤100	FH≤20	FF≤0,05
Large	FM≤250	FH≤100	FF≤0,5
Very large	FM>250	FH>100	FF>0,5

Source: author's own work.

For example the commune (population P=4000 people) uses CWSS. For an undesired event related to secondary water pollution in the water supply network, F_M=20, F_H=0 and FF =0. The number of people who should be given a qualified medical aid is:

$$\frac{P \cdot F_M}{1000} = \frac{4000 \cdot 20}{1000} = 80\, people$$

A four-parameter risk matrix

In the proposed method, the risk is determined by the formula:

$$r = \frac{P \cdot C \cdot F}{O}$$

where:

P – the probability of a threat,
C – material losses,
F – human losses,
O – protection.

Table 4. Four-parameter risk matrix (VS – very small; S – small; A – average; L – large; VL – very large)

	O						O						O				
	no protection						**passive protection**						**active protection**				
F	P					F	P					F	P				
	VS = 1						VS = 1						VS = 1				
	C						C						C				
	VS = 1	S = 2	A = 3	L = 4	VL = 5		VS = 1	S = 2	A = 3	L = 4	VL = 5		VS = 1	S = 2	A = 3	L = 4	VL = 5
VS = 1	1	2	3	4	5	**VS = 1**	0,5	1	1,5	2	2,5	**VS = 1**	0,33	0,67	1	1,33	1,67
S = 2	2	4	6	8	10	**S = 2**	1	2	3	4	5	**S = 2**	0,67	1,33	2	2,67	3,33
A = 3	3	6	9	12	15	**A = 3**	1,5	3	4,5	6	7,5	**A = 3**	1	2	3	4	5
L = 4	4	8	12	16	20	**L = 4**	2	4	6	8	10	**L = 4**	1,33	2,67	4	5,33	6,67
VL = 5	5	10	15	20	25	**VL = 5**	2,5	5	7,5	10	12,5	**VL = 5**	1,67	3,33	5	6,67	8,33
F	**P**					**F**	**P**					**F**	**P**				
	S = 2						**S = 2**						**S = 2**				
	C						**C**						**C**				
	VS = 1	**S = 2**	**A = 3**	**L = 4**	**VL = 5**		**VS = 1**	**S = 2**	**A = 3**	**L = 4**	**VL = 5**		**VS = 1**	**S = 2**	**A = 3**	**L = 4**	**VL = 5**
VS = 1	2	4	6	8	10	**VS = 1**	1	2	3	4	5	**VS = 1**	0,67	1,33	2	2,67	3,33
S = 2	4	8	12	16	20	**S = 2**	2	4	6	8	10	**S = 2**	1,33	2,67	4	5,33	6,67
A = 3	6	12	18	24	30	**A = 3**	3	6	9	12	15	**A = 3**	2	4	6	8	10
L = 4	8	16	24	32	40	**L = 4**	4	8	12	16	20	**L = 4**	2,67	5,33	8	10,67	13,33
VL = 5	10	20	30	40	50	**VL = 5**	5	10	15	20	25	**VL = 5**	3,33	6,67	10	13,33	16,67
F	**P**					**F**	**P**					**F**	**P**				
	A = 3						**A = 3**						**A = 3**				
	C						**C**						**C**				
	VS = 1	**S = 2**	**A = 3**	**L = 4**	**VL = 5**		**VS = 1**	**S = 2**	**A = 3**	**L = 4**	**VL = 5**		**VS = 1**	**S = 2**	**A = 3**	**L = 4**	**VL = 5**

BM = 1	3	6	9	12	15	VS = 1	1,5	3	4,5	6	7,5	VS = 1	1	2	3	4	5
M = 2	6	12	18	24	30	S = 2	3	6	9	12	15	S = 2	2	4	6	8	10
S = 3	9	18	27	36	45	A = 3	4,5	9	13,5	18	22,5	A = 3	3	6	9	12	15
D = 4	12	24	36	48	60	L = 4	6	12	18	24	30	L = 4	4	8	12	16	20
BD = 5	15	30	45	60	75	VL = 5	7,5	15	22,5	30	37,5	VL = 5	5	10	15	20	25
	P						P						P				
F	L = 4					F	L = 4					F	L = 4				
	C						C						C				
	VS = 1	S = 2	A = 3	L = 4	VL = 5		VS = 1	S = 2	A = 3	L = 4	VL = 5		VS = 1	S = 2	A = 3	L = 4	VL = 5
VS = 1	4	8	12	16	20	VS = 1	2	4	6	8	10	VS = 1	1,33	2,67	4	5,33	6,67
S = 2	8	16	24	32	40	S = 2	4	8	12	16	20	S = 2	2,67	5,33	8	10,67	13,33
A = 3	12	24	36	48	60	A = 3	6	12	18	24	30	A = 3	4	8	12	16	20
L = 4	16	32	48	64	80	L = 4	8	16	24	32	40	L = 4	5,33	10,67	16	21,33	26,67
VL = 5	20	40	60	80	100	VL = 5	10	20	30	40	50	VL = 5	6,67	13,33	20	26,67	33,33
	P						P						P				
F	VL = 5					F	VL = 5					F	VL = 5				
	C						C						C				
	VS = 1	S = 2	A = 3	L = 4	VL = 5		VS = 1	S = 2	A = 3	L = 4	VL = 5		VS = 1	S = 2	A = 3	L = 4	VL = 5
VS = 1	5	10	15	20	25	VS = 1	2,5	5	7,5	10	12,5	VS = 1	1,67	3,33	5	6,67	8,33
S = 2	10	20	30	40	50	S = 2	5	10	15	20	25	S = 2	3,33	6,67	10	13,33	16,67
A = 3	15	30	45	60	75	A = 3	7,5	15	22,5	30	37,5	A = 3	5	10	15	20	25
L = 4	20	40	60	80	100	L = 4	10	20	30	40	50	L = 4	6,67	13,33	20	26,67	33,33
VL = 5	25	50	75	100	125	VL = 5	12,5	25	37,5	50	62,5	VL = 5	8,33	16,67	25	33,33	41,67

Source: author's own work.

The values of parameters *P*, *C*, *F* are taken according to table 1, 2 and 3. The *O* parameter is set to:

- 1 – no protection,
- 2 – passive protection (monitoring of the CWSS, but without the possibility of immediate reaction to the existing situation),
- 3 – active protection (monitoring of CWSS with the possibility of immediate reaction to the existing emergency event).

Table 4 presents a four-parameter risk matrix, which, based on formula, allows to estimate risk.

The three-grade risk score has been adopted arbitrarily. The individual risk intervals result from the ALARP (As Low As Reasonably Practicable) risk management methodology:

- tolerated risk – from 0.33 to 15,
- controlled risk – from 16 to 45,
- unacceptable risk – from 48 to 125.

Summary

- The methodology of risk analysis and assessment from the author's assumption is simple, with the possibility of easy applying. It can be used for preliminary hazards estimation. The method can be easily adapted to other municipal management systems.
- The People and Property Risk Analysis method presented in the paper is a kind of development of the Preliminary Hazard Analysis method. It allows to analyse human and material losses separately.
- The People and Property Risk Analysis method can be a planning tool in crisis management at the level of local government units.

The contribution of the authors

Krzysztof Boryczko – conception, literature review, acquisition of data, analysis and interpretation of data – 50%
Janusz Rak – conception, literature review, acquisition of data, analysis and interpretation of data – 50%

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