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MATRIX ANALYSIS OF RISK OF INTERRUPTIONS IN WATER SUPPLY IN TERMS OF CONSUMER SAFETY

MATRYCOWA ANALIZA RYZYKA PRZERW W DOSTAWIE WODY W ASPEKCIE BEZPIECZEŃSTWA KONSUMENTÓW WODY

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***Abstract**: With regard to drinking water consumers, safety is understood as a probability to avoid threat arising from the consumption of water inconsistent with quality standards or the lack of water. Accordance with the Regulation of the Minister of Health water is safe for human health, if it is free from pathogenic microorganisms and parasites in the amount constituting a potential threat to human health, any substances in quantities hazardous to health and has no aggressive corrosive properties. Water supply reliability means providing stable conditions allowing to meet current and future demand for water in sufficient quantity and with required quality, in convenient time for water consumers and also at a price acceptable by them. In this study consumer (individual) risk r_K was defined as the sum of the first kind of risk r_{KI}, associated with possibility of interruptions in water supply and the second kind of risk r_{KII} associated with possibility of consumption of water inconsistent with quality standards. Three-parameter matrix of risk was proposed. For presented method was made an application example based on exploitation data of collective water supply system, which may help to increase safety of water consumers.*

***Keywords:** collective water supply system, consumer risk, failure*

***Streszczenie:** W odniesieniu do konsumentów wody do spożycia bezpieczeństwo jest rozumiane jako prawdopodobieństwo uniknięcia zagrożenia wynikającego ze spożycia wody o jakości niezgodnej z obowiązującym normatywem lub z braku wody. Niezawodność dostawy wody polega na zapewnieniu stabilnych warunków, umożliwiających pokrycie bieżącego i perspektywicznego zapotrzebowania na wodę w odpowiedniej ilości i wymaganej jakości w dowolnym, dogodnym dla konsumentów wody czasie, a także w akceptowalnej przez nich cenie. Pierwotnym i podstawowym podmiotem, którego dotyczy pojęcie bezpieczeństwa wodnego, jest konsument. Wtórnym podmiotem jest dostawca – producent wody. W tym względzie można rozpatrywać ryzyko konsumenta i producenta. W pracy zdefiniowano ryzyko konsumenta (indywidualnego) r_K jako sumę ryzyka pierwszego rodzaju r_{KI}, związanego z możliwością wystąpienia przerw w dostawie wody oraz ryzyka drugiego rodzaju r_{KII}, związanego z możliwością spożycia wody o nieodpowiedniej jakości. Zaproponowano trójparametryczną matrycę ryzyka. Dla przedstawionej metody przedstawiono przykład aplikacyjny dla danych eksploatacyjnych rzeczywistego systemu zbiorowego zaopatrzenia w wodę, który może przyczynić się do zwiększenia bezpieczeństwa konsumentów wody.*

***Słowa kluczowe:** system zbiorowego zaopatrzenia w wodę, ryzyko konsumenta, awaryjność*

1. Introduction

In accordance with the Act on the collective water supply and collective wastewater disposal of 2001 with subsequent amendments, water distribution subsystem (WDS) generally includes the water pipe network and its fittings, tanks and pumping stations. During WDS operation, there is a probability of failure. Failures can cause loss of water and the interruption in water supply to consumers, which, in turn, is associated with the secondary contamination in the water pipe network and loss of water consumers safety. Safety for water supply is defined as the state of water management that allows to cover current and future consumers demand for water, in a technically and economically justified way, with the observation of requirements of the environmental protection [1]. The primary and basic subject to which the concept of water safety concerns is the consumer. The secondary subject is the supplier – the manufacturer of water. In this regard, the risk can be considered as the consumer's risk and the manufacturer's risk. With regard to drinking water consumers, safety is defined as the likelihood of avoiding the threat arising from the consumption of water with quality incompatible with the existing regulation or the lack of water. According to the Regulation of Health Minister water is safe for human health if it is free from pathogenic microorganisms and parasites in the number constituting a potential hazard to human health, chemicals in quantities that threaten the health and has no aggressive corrosive properties [2]. In environmental engineering risk is defined as the probability of the occurrence of undesirable events and losses resulting from it [3]. Risk assessment is a comparison of the determined values to the criteria values of the risk acceptability which serve as a basis for safety analysis. These criteria should take into account the requirements associated with the WDS functional reliability. Risk is inextricably linked to the responsibility of the collective water supply system (CWSS) operator for making decisions [4], [5]. Therefore, in order to avoid the negative consequences of making wrong decisions regarding WDS operating one should learn how to assess the risk and inform others of its size, as well as acquire the knowledge necessary for proper actions while facing risk [6]. Sometimes, lack of sufficient data required for risk assessment may cause the assumption that each undesirable event is likely.

2. Research methodology

- The risk analysis for the safety of the WDS consists of the following steps:
- determining the size of the resources by determining the number of people using municipal water pipeline,
- determining the WDS vulnerability to undesirable events,
- determining the impact of threats on water consumers safety,
- determining the levels of risk and the analysis of tolerable, controlled and unacceptable risk.

One of the methods used for risk analysis is three parametric matrix for risk assessment [7]. Risk matrix shows the dependence of the probability of the occurrence of threat from its consequences, which in the WDS are the loss of water, reduction in the level of supply reliability and consumers safety which are equivalent to the loss of water consumers health or life.
In three parametric risk matrix the parameters are [8], [9]:

$$r = P \cdot C \cdot V \qquad (1)$$

where:
P – measure of the probability (the frequency of occurrence) of undesirable events in WDS, which are directly felt by water consumers,
C – specifies the size of the losses related to the occurred undesirable event (e.g. purchase of bottled water, possible medical expenses after consuming unfit for drinking water or losses immeasurable, such as domestic and economic difficulties or loss of life or health),
V – the degree of vulnerability to undesirable events.

Division of risk derives from its specificity and that is why there are two types of risks, which are based on the independent scenarios of undesirable events and the different consequences of these events. Vulnerability to the occurred events depends on the degree of WDS protection against undesirable events which, in turn, is reflected in the risk level of given subsystem [10].
The consumer as the main recipient of water is the most exposed to loss of safety associated with water supply as a consequence of undesirable events, therefore the consumer risk r_K can be determined from the formula 2:

$$r_K = r_{KI} + r_{KII} \qquad (2)$$

where:
r_{KI} – risk of the first type,
r_{KII} – risk of the second type.

The risk of the first type is associated with the risk of lack of water supply to the distribution subsystem. For the risk of the first type, the three parametric definition was assumed according to the formula 3:

$$r_{KI} = \sum (f_I \cdot C_I \cdot V_I) \qquad (3)$$

where:
f_I – the frequency of the occurrence of a given series of undesirable events or a single undesirable event that may cause the risk of the first type,
C_I – the value of losses caused by a series of undesirable events or a single event that may cause the risk of the first type,
V_I – the vulnerability associated with the occurrence of a given series of undesirable events or a single event that may cause the risk of the first type.

The risk of the second type is associated with the consumption of water with quality not compatible with valid standards. For the risk of the second type, the three parametric definition was assumed according to the formula 4:

$$r_{KII} = \sum (f_{II} \cdot C_{II} \cdot V_{II}) \qquad (4)$$

where:

f_{II} – the frequency of the occurrence of a given series of undesirable events or a single undesirable event that may cause the risk of the second type,

C_{II} – the value of losses caused by a series of undesirable events or a single event that may cause the risk of the second type,

V_{II} – the vulnerability associated with the occurrence of a given series of undesirable events or a single event that may cause the risk of the second type.

Criteria of point and descriptive scale were adopted according to the proposal made in [1]. The risk assessment process involves the determining its numerical value and comparing to the criterion value. The most common scale of the risk levels is three-stage scale [9],[11]:

- the tolerable risk- rT,
- the controlled risk - rK,
- the unacceptable risk - rN.

In quantitative matrix methods all the risk parameters have the relevant point weight assigned (depending on the adopted scale). Adopting appropriate criteria values for each scale levels depends on many factors, among others, experts opinions as well as adopting appropriate risk assessment methodology.

The point and descriptive scale for each risk parameter was proposed according to the Tables 1÷4 [1].

Table 1. Criteria of point and descriptive scale for the parameter f_{iI}; $i = \{1, 2, 3\}$

Point weight	Description of the parameter f	Frequency range of undesirable event f_i [failure/a]
1	low probability, period of time from 5 to 10 years and less	0,1 ÷ 0,5
2	medium probability, once for period of time from 1 to 2 years	0,5 ÷ 2,0
3	high probability, once each half year and more often	2,0 ÷ 12

Table 2. Criteria of point and descriptive scale for the parameter C_{jI}; j = {1, 2, 3}

Point weight	Description of the parameter C
1	Small losses: - drop of daily water production (Q_{dmax}) up to 70% of the nominal water production (Q_n), or interruptions in water supply up to 2 h, lokalne, - local reduction of water pressure in water pipe network, - single consumer complaints.
2	Medium losses: - Q_{dmax} = <30÷70) % Q_n or interruptions in water supply up to (2÷12] h for individual consumers, - local reduction of water pressure in water pipe network, - financial losses.
3	Very large losses: - Q_{dmax} < 30%Q_n, local reduction of water pressure in water pipe network - Failure of the main pipe of water supply, interruptions in water supply >24 h for particular districts and neighborhoods or for a whole city, - significant losses both financial and social.

Table 3. Criteria of point and descriptive scale for the parameter V_{kI}; k = {1, 2, 3}

Point weight	Description of the parameter V
1	Low vulnerability to failure (high resistance): - the network in the closed system, the ability to cut off the damaged section of the network (in order to repair it), - the ability to avoid interruptions in water supply to customers, full monitoring of water-pipe network (continuous measurements of pressure and flow rate at strategic points of the network) covering the entire area of water supply, utilising SCADA and GIS software, the possibility to remote control of network hydraulic parameters, - emergency reserve in network water tanks covering the needs of the city for at least 24 h, (Q_{dmax} or $Q_{d.avg}$ – daily average water production), - comprehensive emergency system of warning and response, - full ability to use alternative water sources.
2	Medium vulnerability to failure (medium resistance): - the network in the mixed system, the ability to cut off the damaged section of the network by means of gates, (water supply to customers is limited because of the network capacity), - water-pipe network standard monitoring, measurements of pressure and flow rate, - delayed emergency response system, - alternative water sources do not cover the needs completely.
3	High vulnerability to failure (low resistance): - the network in the open system, the inability to cut off the damaged section of the network by means of gates without interrupting water supply to customers, - limited water-pipe network monitoring, - delayed emergency response system, - limited access to alternative water sources.

The risk of the second type criteria for the probability parameter and vulnerability parameter were assumed in the same way as for the risk of the first type risk (Table 1, 3). The point and descriptive scale for the parameter C was based on literature [1] and proposed in Table 4.

Table 4. Criteria of point and descriptive scale for the parameter Cj_{II}; j = {1, 2, 3}

Point weight	Description of the parameter C
1	Small threat: - local deterioration of water quality, - perceptible organoleptic changes of water (odour, changed colour and turbidity), but there is minimal threat to further water quality deterioration, - water consumers complaints, - lack of threat for consumers health.
2	Medium threat: - considerable organoleptic problems (odour, changed colour and turbidity) - numerous complaints, - information in local media, - threat to consumers health (the normative values for microbiological and/or physiochemical indicators are exceeded, lack of pathogenic microorganisms).
3	Large threat: - secondary water contamination in water-pipe network, - possibility that a large group of consumers will be exposed to consume poor quality water, - professional emergency services are involved, - test results for indicator organisms reveal high levels of toxic substances, - information in national media, physiochemical indicators and/or pathogenic microorganisms are exceeded, - exposed people need hospitalisation.

Based on the values listed in the Tables 1÷4 and according to (1), a set of possible risk values can be presented as a matrix:

$$r = \begin{bmatrix} r_{1\cdot1\cdot1} & r_{2\cdot1\cdot1} & r_{3\cdot1\cdot1} \\ r_{1\cdot2\cdot1} & r_{2\cdot2\cdot1} & r_{3\cdot2\cdot1} \\ r_{1\cdot3\cdot1} & r_{2\cdot3\cdot1} & r_{3\cdot3\cdot1} \\ r_{1\cdot1\cdot2} & r_{2\cdot1\cdot2} & r_{3\cdot1\cdot2} \\ r_{1\cdot2\cdot2} & r_{2\cdot2\cdot2} & r_{3\cdot2\cdot2} \\ r_{1\cdot3\cdot2} & r_{2\cdot3\cdot2} & r_{3\cdot3\cdot2} \\ r_{1\cdot1\cdot3} & r_{2\cdot1\cdot3} & r_{3\cdot1\cdot3} \\ r_{1\cdot2\cdot3} & r_{2\cdot2\cdot3} & r_{3\cdot2\cdot3} \\ r_{1\cdot3\cdot3} & r_{2\cdot3\cdot3} & r_{3\cdot3\cdot3} \end{bmatrix} = \begin{bmatrix} 1 & 2 & 3 \\ 2 & 4 & 6 \\ 3 & 6 & 9 \\ 2 & 4 & 6 \\ 4 & 8 & 12 \\ 6 & 12 & 18 \\ 3 & 6 & 9 \\ 6 & 12 & 18 \\ 9 & 18 & 27 \end{bmatrix}$$

The calculation procedure presented above concerns a general characteristics of matrix methods used for risk assessment [8], [10], [12].

3. The application case

Characteristics of the collective water supply system of the city of Rzeszów

Rzeszów is supplied with water from two surface water intakes on the river Wisłok, with a total capacity of 76 896 m^3/d, according to permit required by Water Law Act, and two underground water intakes Rzeszów-Słocina, with a total capacity of 465 m^3/d. The daily production capacity at the end of 2011 was 84 000 m^3/d. The average daily treated water production is 37 700 m^3/d. At the end of 2011 the collective water supply system was used by 184 152 inhabitants of the city of Rzeszów and the residents of nearby towns. Services related to the collective water supply are provided by the Municipal Enterprise for Communal Economy (MECE).

The total length of the water supply network is 877.7 km (in 2011):

- the main network made of cast iron and steel - 49.8 km,
- the distribution network made of cast iron, steel, PE and PVC - 504.1 km,

The Municipal Enterprise for Communal Economy also operates:

- water pipeline connections with a length of 323.8 km, mostly made of galvanized steel, cast iron, PE and PVC,
- emergency pit intake at Mazowiecka street in Rzeszow, with capacity of 240 m^3/d,
- 32 water pumping stations,
- 12 clean water expansion tanks (Krakowska Południe, Pobitno, Słocina, Słocina Roch, Pustki), with a total volume of 34100 m^3,
- 187 public wells, 12 street springs, which are located on the property of the municipality of Rzeszów city.

Scheme of the main water network of the city of Rzeszów is shown in Figure 1.

Typical failure of water supply system is removed by qualified MECE personnel for about 6-8 hours. If there is a need to cut off the water supply, then this operation takes at least 1 hour (approximately 2 hours). If it concerns the main pipeline with such diameters as Ø 800 and Ø 1000 a break in water supply may last up to 24 hours. According to the regulations on water supply by the water supplier, if the break in water supply lasts more than 12 hours the supplier shall provide an emergency source of water and inform the inhabitants about it.

In order to repair the damaged water pipe usually a valve or some valves must be closed. If the water leakage is small, the repair fittings can be mounted without closing water supply (under pressure).

In order to quickly respond to failure, the emergency water and sanitation service has the information displayed on the screen that in the particular parts of the network the state of emergency is exceeded. It applies, for example, to pressure – its drop. In addition, information about increased flow can be obtained from the monitoring points located on the network. Any failure in the network involves some financial losses, but fast response allows to minimize them.

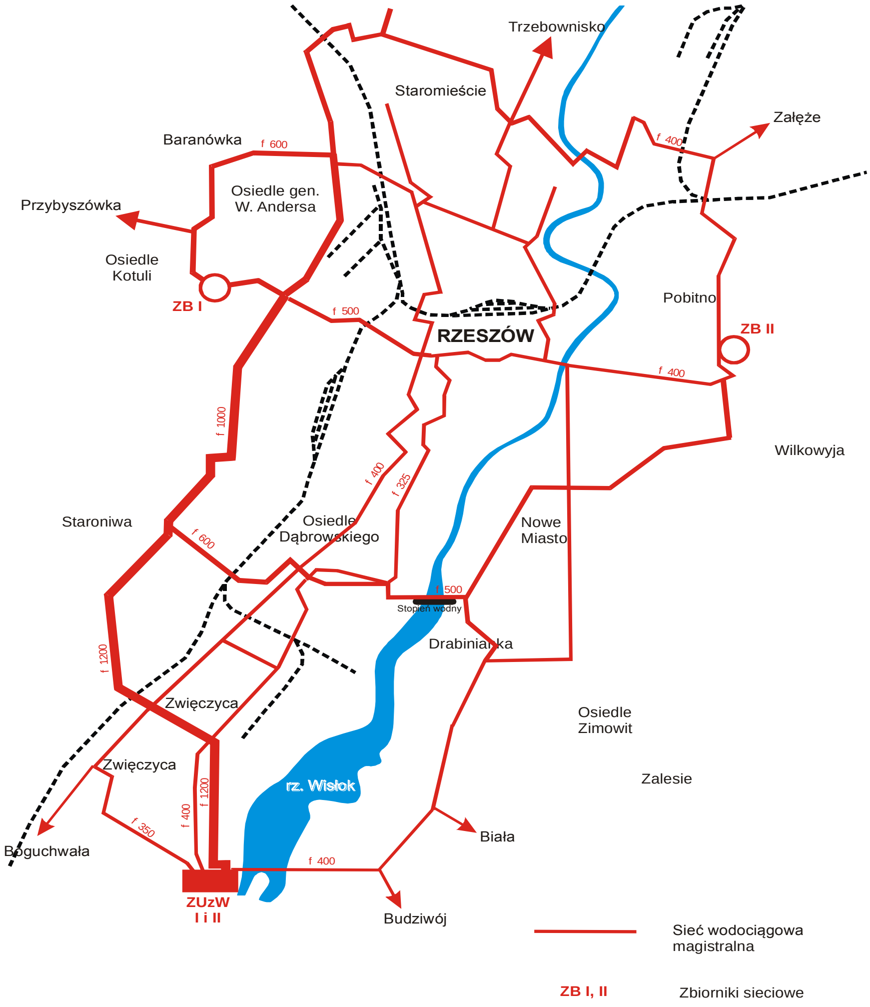

Fig.1 Scheme of the main water network of the city of Rzeszów

The Municipal Enterprise for Communal Economy in Rzeszów also uses GIS metering which includes the G/Technology system. The program allows you to create and maintain an accurate inventory management of water supply and sewage systems and fittings in the network. The system forces creating the correct image of the network. By including in its functions all the stages of cooperation with the customer, it provides an excellent foundation for Customer Service System. It gives engineering and technical staff a quick easy tool to generate a variety of reports and a tool to make a topological analysis of connections of water supply and sewage network.

Keeping records of failures by the developed module allows you to:

- quickly find the full information about any current or past failure,
- do the tracking, that is showing the next gate which must be closed for removing a failure in the given network segment,
- print a report of such failure at every stage of its removal,
- make the cumulative control chart of failures for any given period of time (a base for picking up the segments to be restored),
- warning customers about failures,
- make graphical visualization of the location of failures on the map.

The aim of the water supply system monitoring that has been working in Rzeszów since 2007 is to provide real information about the network condition and operation in the city. In 2013, the monitoring system will be improved by expanding the currently monitored points with the new hydrophore zones. It results from the extension of the city limits. The current system for water supply monitoring, Procon-Win, visualises the gathered information such as pressure, flow and flow rate, the water level in the tank, in the form of curves on the charts, where it is possible to read their values. Regardless of the current observation of the network state on the screen, you can analyse historical data (e.g. from the whole month) [13]. The data for the measurement nodes (MN) reach the network dispatcher using GSM (GPRS packet). Information about the work of water supply objects (WO), such as the pumping stations, hydrophores and tanks - is transmitted via radio modems. The information on the monitored node is introduced into the system by the locally installed controller, whose task is to read the instantaneous values and register them locally as well as to transmit them by radio every 3 minutes to the collective central unit at the operator in the MECE office in Rzeszów.

The monitoring system of the water supply in Rzeszów immediately notifies about the alarm state which allows to take the corrective action quickly, and thanks to it water quality will not deteriorate. However, such events may happen and we call them the incidental events.

The discussed water distribution subsystem has been analysed and the risk of the first type and the second type was assessed. The analysis of failures rate of pipeline was made and characteristic statistical points were determined. The analysis of the risk of interruptions in water supply was based on the proposed three parametric risk matrix according to the formula (1) and the information from the waterworks (MECE) in Rzeszów. The analysis includes risk assessment for the main network, distribution network and water supply connections.

In the failure rate analysis and evaluation the unit failure rate of water pipes λ was used [9], [10]. The values of failure rate indexes: λ_M for the main network, λ_R for the distribution network and λ_{PW} for the water connections were determined on the basis of the literature, operational data from MECE [14] and the works [1], [14], [15]:

$$\lambda(\Delta t) = \frac{n(\Delta t)}{L \cdot \Delta t} \tag{4}$$

where:
λ(Δt) – unit failure rate, failure/km·year,
n(Δt) – a number of failures within the time interval Δt,
L – the length of the analysed pipes within the time interval Δt, km,
Δt – analysed period of time, years

The assessment of water pipes failure rates is shown in Table 5, based on the data obtained from the waterworks MECE in Rzeszów in the years 2005 - 2011.

Table 5. Failure rate index for the water supply network and connections in the city of Rzeszów, over the years 2005 - 2011 [1], [14]

Year	Water supply system						Water connections		
	Main pipeline			Distribution pipeline					
	failure	length [km]	λ_M [failure./km·year]	failure	length [km]	λ_R [failure./km·year]	failure	length [km]	λ_{PW} [failure./km·year]
2005	54	49,5	1,09	108	350,5	0,31	83	283,8	0,29
2006	45	49,5	0,91	136	384,4	0,35	117	287,7	0,41
2007	5	49,5	0,10	114	443,5	0,26	90	315,8	0,28
2008	29	49,5	0,59	106	447,7	0,24	83	322,8	0,26
2009	38	49,8	0,76	114	468,0	0,24	65	323,2	0,20
2010	39	49,8	0,78	114	490,5	0,23	102	323,8	0,32
2011	52	49,8	1,04	113	504,1	0,22	134	323,8	0,41

In Table 6 the basic statistical parameters determined on the basis of the calculated values of the failure rate indexes were listed.

Table 6. The basic statistical parameters of the failure rate indexes for the seven operating years from 2005 to 2011.

Type of pipeline	average number of failures	average length [m]	λ [failure./km·year]			Median	Standard deviation	Variance
			λ_{min}	λ_{ave}	λ_{max}			
Main pipeline	37,4	49,6	0,10	0,75	1,09	0,78	0,336	0,113
Distribution pipeline	115,0	441,2	0,22	0,27	0,35	0,24	0,048	0,002
Water connections	96,3	311,6	0,20	0,31	0,41	0,29	0,077	0,006

The analysis of the risk of the first type

Using the product of the particular risk parameters according to (1) the risk matrix was obtained with numerical values within the range from 1 to 27. The results are presented in the form of the matrix which is shown in Table 7.

Table 7. Three parametric risk matrix

f	**C**								
	1	2	3	1	2	3	1	2	3
	V = 1			**V** = 2			**V** = 3		
1	1	2	3	2	4	6	3	6	9
2	2	4	6	4	8	12	6	12	18
3	3	6	9	6	12	18	9	18	27

Based on Table 7 a three-stage scale of risk levels is proposed in Table 8:

Table 8. The three-stage scale of risk levels

Levels of risk	Interval
Tolerable risk	$1{,}0 \le r \le 8{,}0$
Controlled risk	$9{,}0 \le r \le 12{,}0$
Unacceptable risk	$18{,}0 \le r \le 27$

The scale of risk levels for the water consumers is based on the formulas (2), (3), (4) as the sum of the risk of the first and second type. The results are shown in Table 9.

Table 9. The three-stage scale of risk levels for the water consumers

Levels of risk	Interval
Tolerable risk	$2{,}0 \le r \le 16{,}0$
Controlled risk	$18{,}0 \le r \le 24{,}0$
Unacceptable risk	$36{,}0 \le r \le 54$

In Table 10 the point weights for failure rates [1] are proposed.

Table 10. Criteria for the failure rate indexes

f	λ [uszk./km·rok]		
	Main pipeline	Distribution pipeline	Water connections
1	$\le 0{,}3$	$\le 0{,}7$	$\le 1{,}0$
2	$0{,}3 \div 0{,}7$	$0{,}7 \div 1{,}0$	$1{,}0 \div 2{,}0$
3	$> 0{,}7$	$> 1{,}0$	$> 2{,}0$

In order to determine the risk of the first type the values of particular parameters were assumed:

– the parameter f (the frequency of the event)
  - for the main pipelines the point weight 3 was assumed because:
    - according to Table 8 $\lambda_{śr} > 0,7$ failure/km·year,
    - according to Table 1 the undesirable event is very probable, it may happen once in 0.5 year and more often,
  - for the distribution pipelines and water connections the parameter f was assumed to be 1, because:
    - according to Table 8 for the distribution pipelines $\lambda_{śr} \leq 0,7$ and for the water connections $\lambda_{śr} \leq 1,0$,
    - according to Table 1 the undesirable event is low probable for both types of pipelines

– the parameter C (losses)
  - for the main pipelines and distribution pipelines the parameter C was assumed to be 2 because according to Table 3:
    - it means medium losses, since the value of the maximum daily demand Q_{dmax} = <30÷70)%Q_n,
    - breaks in water supply (2÷24> h for individual consumers may happen,
    - drop of water pressure in the water supply network is possible,
    - financial losses,
  - for the water connections the parameter C was assumed to be 1 because according to Table 2:
    - if the undesirable event occurs the daily water production Q_{dmax} decreases to 70% of the nominal value Q_n, or up to 2 hour break in water supply is possible,
    - local reduction of water pressure in the water supply network,
    - individual consumers complaints,

– the parameter V (vulnerability to the event)
  - for the main pipelines, distribution pipelines and connections the parameter V was assumed to be 1 since, according to Table 3, there is low vulnerability to failure (very high resistance) because:
    - 80% of water supply network is in a closed system, with the possibility to cut-off the damaged section using gates (in order to repair the network),
    - there is the possibility to avoid any interruptions in water supply to consumers,
    - the network monitoring (continuous measurements of pressure and flow rate at strategic points of the network) covers the whole water supply area,
    - the waterworks MECE uses GIS metering (GTechnology program), it is possible to remote control the hydraulic parameters of the network,
    - the waterworks MECE has the comprehensive system of warning and response in crisis situations with the full ability to use the alternative water sources.

Table 11 summarizes the values of f, V, and C for the first type of risk, depending on the type of water pipes.

Table 11. The values of the parameters associated with the risk of the first type

Parameter	Type of pipeline		
	Main pipeline	Distribution pipeline	Water connections
f	3	1	1
C	2	2	1
V	1	1	1

By creating a product of these parameters according to the formula 3 we obtain the value of the first type risk for all types of pipes which, according to the data in the Tables 7,8,10 and 11, is on the tolerable level. The results are shown in Table 12.

Table 12. The risk of the first type associated with the lack of water supply

Risk of the first type	Type of pipeline		
	Main pipeline	Distribution pipeline	Water connections
r_{KI}	6	2	1
Level of risk	tolerable	tolerable	tolerable

The analysis of the risk of the second type

The risk of the second type, associated with the consumption of poor quality water, has been determined on the basis of water quality analyses, operational data from the waterworks in Rzeszów.

In order to determine the risk of the second type the values of particular parameters were assumed:

– the parameter f (the frequency of the event)
  - for the main pipelines, distribution and water supply connections the parameter f was assumed to be 1 because:
    - the occurrence of an event associated with the consumption of poor quality water is, according to Table 1, very unlikely, it can happen once in 5 to 10 years or less often.

– the parameter C (value of the losses)
  - for the main pipelines the parameter C was assumed to be 2 because, according to Table 4:
    - threat of the occurrence of the events resulting from the consumption of poor quality water is medium,
    - significant organoleptic problems (odour, changed colour and turbidity) can happen,
    - numerous complaints,
    - if threat occurs the information in local media, threat to consumers health (physiochemical indicators are exceeded, lack of pathogenic microorganisms),
  - for the distribution pipelines and water supply connections the parameter C was assumed to be 1, because, according to Table 4:
    - threat is small,

- only local deterioration of water quality and perceptible organoleptic changes of water (odour, changed colour and turbidity) can happen , the minimal risk of further deterioration in water quality,
- water consumers complaints, but lack of threat for consumers health.

– the parameter V (vulnerability to the event)
  - for the main pipelines, distribution pipelines and connections the parameter V was assumed to be1 since, according to Table 3:
    - there is low vulnerability to the event (very high resistance) because 80% of water supply network is in a closed system, with the possibility to cut-off the damaged section using gates (in order to repair the network),
    - there is the possibility to avoid any interruptions in water supply to consumers,
    - the network monitoring covers the whole water supply area,
    - the waterworks MECE uses GIS metering (GTechnology program),
    - it is possible to remote control the hydraulic parameters of the network,
    - the waterworks MECE has the comprehensive system of warning and response in crisis situations with the full ability to use the alternative water sources.

Table 13 shows the values of the parameters f, C, V of risk associated with the consumption of water with quality that threatens water consumers life and health.

Table 13. The values of the parameters associated with the risk of the second type

Parameter	Type of pipeline		
	Main pipeline	Distribution pipeline	Water connections
f	1	1	1
C	2	1	1
V	1	1	1

By creating a product of these parameters according to the formula 4 we obtain the value of the second type risk for all types of pipes which, according to the data in the Tables 7,8,10 and 13, is on the tolerable level. The results are shown in Table 14.

Table 14. The risk of the second type associated with the lack of water supply

Risk of the second type	Type of pipeline		
	Main pipeline	Distribution pipeline	Water connections
r_{KII}	2	1	1
Level of risk	tolerable	tolerable	tolerable

The analysis of the water consumer's risk

According to formula (2) the water consumer's risk was defined as the sum of the risk of the first type and the risk of the second type. The results of the analysis are presented in Table 15, separately for the main pipeline, distribution pipeline and water supply connections. According to the proposed risk categories given in Table 9, the consumer risk in the water network and water supply connections is on a tolerable level.

Table 15. The consumer risk associated with the lack of water supply

Type of pipeline	r_{KI}	r_{KII}	r_K	Risk
Main pipeline	6	2	8	tolerable
Distribution pipeline	2	1	3	tolerable
Water connections	2	1	3	tolerable

4. Conclusions

- Risk of lack of water delivery and the possibility of drinking poor quality water are problems permanently associated with the correct use of the municipal water pipe network. Currently, more and more often risk is considered in terms of water supply reliability and water consumers safety.
- Analysis and risk assessment of failure in water distribution subsystem should also take into account risk associated with even the least likely undesirable events.
- The presented method of risk assessment is based on operational data and information from the experts who, based on their knowledge, evaluated particular risk parameters. The analysis of risk, in terms of lack of water supply and consumers safety, shows that the risk of the consumer in the city of Rzeszów takes the values corresponding to the tolerable risk.
- The presented application example of the matrix method for the evaluation of water consumer risk can be used for other systems of collective water supply system. The particular parameters can be modified according to the individual needs.
- The failure rate of the water pipe network, as well as opinions of the experts and users, play an important role. The purpose of risk assessment analysis is often to complete the lack of knowledge in order to eliminate operational errors .
- The use of three parametric risk matrix allows the waterworks to improve the functioning of the water supply system and, at the same time, increase the comfort of using the municipal water supply network.
- The use of GIS metering can be helpful at the implementation of the results of the analysis in practice.

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