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Ensuring an adequate level of quality of water supply in regard to the safety of consumers

Keywords

water supply system, reliability and safety of water supply, risk assessment, safety and quality management

Abstract

This chapter analysing the reliability, safety and operation of a water-supply system presents work whose main aim was to address strategies by which the safety of water-supply services is maintained. Water companies should prioritise this kind of analysis of the functioning of their supply systems, with a view to quality of supply remaining adequate. In this context, this paper may provide background against which management principles may be formulated. The management in question should make resources ready for situations arising in which undesirable events pose a threat to health, the environment or infrastructure. It is terms and concepts associated with the risk accompanying everyday water-supply operation that have been presented here, with procedures of the quality function deployment house of quality established and input offered in relation to the development of safety plans.

1. Introduction

A water-supply system (WSS) plays a strategic role when it comes to the health security of people residing in both urban and rural areas. Legal regulations and EU guidelines thus include these systems among so-called critical infrastructure (CI) [4], [77]. In an era in which climate change causes disturbances in the water cycle, the issue of access to water of required quality has become a priority one for local authorities. Drought is not only a threat to African countries, but also to Europe. In addition, temperatures also vary through the annual cycle, affecting the operations of water-supply systems, including as regards the stability of tap-water quality.

Standards applying in the modern world dictate that all enjoy the right to have access to water of adequate quality and in sufficient quantity. In that context, there is seen to be a global problem with, not only a lack of water in developing countries, but also the degradation of water resources in developed countries [74].

Further significant problems relate to the operation of each existing WSS, which should seek to minimise water losses, while enhancing operational reliability and safety [28], [59]–[60], [63]. The safety of WSS operation in accordance with world standards should be an expression of good engineering practice at the system design, construction, and operating stages [19], [26], [32].

However, care for the daily operating of water-supply infrastructure does not suffice as it is also necessary to ensure continuity of water supply in crisis situations [54]. The crisis management of critical infrastructure is crucial, and requires separate analysis for each type of infrastructure, including drinking-water supply systems [6], [9].

In the event of various crisis situations, e.g. floods, droughts, earthquakes, failures, technical catastrophes, etc., there is always a problem

Safety and Reliability of Systems and Processes, Summer Safety and Reliability Seminar 2020

DOI: 10.26408/srsp-2020-15

of supplying the population with drinking water [2], [5], [61]. This accounts for the importance of plans for the emergency supply of drinking water being drawn up with a variety of crisis situations in mind, along with detailed risk analysis in regard to the possible adverse events. Only in this way will it be possible to develop a comprehensive programme of safety management for the given system [8], [14], [67].

Among the most important components of any sustainable management strategy for a WSS is the integration of the aforementioned risk analysis into asset management decision-support systems, as well as the incorporation into analysis of financial and socio-political parameters associated with networks. Risk management at the waterworks responsible for the correct operation of networks of water pipes constitutes a formal programme encompassing internal procedures whose main purpose is to protect water consumers, the environment, and the (financial and personnel-related) interests of the water company. The water industry is experiencing a significant shift in its approach to risk management – in a direction that is increasingly explicit and better integrated with other business processes. And risk-management strategies and techniques applied traditionally to occupational health and safety and public health protection are now seeing broader application in asset management, watershed protection and network operation [1], [7].

In the EU Member States, the European Commission recommends the implementation of EN 15975–1: 2009 and EN 15975–2: Security of drinking water supply. Guidelines for risk and crisis management. Part 1 and Part 2. Crisis management [10]–[11].

In the paper the method of risk analysis of water supply system failure through the method of ensuring an adequate quality level of water supply services in terms of the water consumers safety are presented.

2. Operational reliability and safety of water supply systems

The European Union imposes an obligation on entrepreneurs providing all services, including the supply of drinking water to people, and the ensured safety of consumers and users including protection against possible threats.

Moreover, the security of service provision, and in particular security of supply, is an essential requirement to be taken account of when defining the service mission [15], [20]–[21], [25], [55].

The operational reliability of a WSS reflects the level of functioning of subsystems and objects of this system, resulting in the supply of water to consumers in the required quantity, under the appropriate pressure, with quality parameters compliant with the applicable norms, and at an acceptable price. Consumers of drinking water from public water supply have the right to be informed about the quality of the water in accordance with the provisions on access to public information. Such information should include:

- data on exceedances of the permissible values of water quality parameters and related health hazards,
- data on the deterioration of water quality in terms of organoleptic,
- recommendations to minimize health risks,
- information on how to improve water quality with the means available to consumers,
- information on the schedule of remedial measures.

National and global legal regulations, democratization of public life, require adaptation and development of research methods related to the safe operation of water supply systems. The terms safety and risk become meaningful and are commonly used in various aspects of everyday practice. Centralization of water production and related services, massive consumption of tap water, consumer expectations – clean, healthy, tasty water – is a challenge for science and technology, especially in the face of extraordinary adverse events and unprecedented terrorist threats. Conclusions from the history of individual accidents of mass contamination of tap water in urban agglomerations are a signpost for active risk management. In this situation, it is important to develop risk reduction procedures and decision support tools based on analyzes and assessments of risk accompanying the functioning of the WSS, taking into account the principles of sustainable development. Recipients want to live and consume safe water, in conditions of peace and certainty, in the conviction that there is no risk or that we effectively protect ourselves against it. The specialized scientific literature clearly emphasizes the views that quantitative risk analysis and assessment methods are the basis for managing the safety of WSS.

WSS operational unreliability can be measured by the probability, frequency and duration of adverse events.

Safety of WSS is the ability to perform its functions despite the occurrence of incidental adverse events. In this approach, operational reliability determines the ability to cover the water demand in steady states of system operation, and safety is defined as the ability to survive incidental states [22].

The WSS safety management should counteract against lack of water or its bad quality, which threaten health of municipal water pipe users. As to achieve this goal, water supply companies should supervise their accomplishment using processes, information resources in the given operating conditions, in compliance with the valid law and with economic justification.

The important problem is the operation of the existing WSSs, which should take into account the minimization of water losses, and operational safety and reliability. Water supply providers seek to supply high-quality drinking water at all times.

The basic measure that determines the security level of WSS is the risk associated with its functioning [70].

A schematic diagram of the reliability and safety of WSS is presented in *Figure 1*.

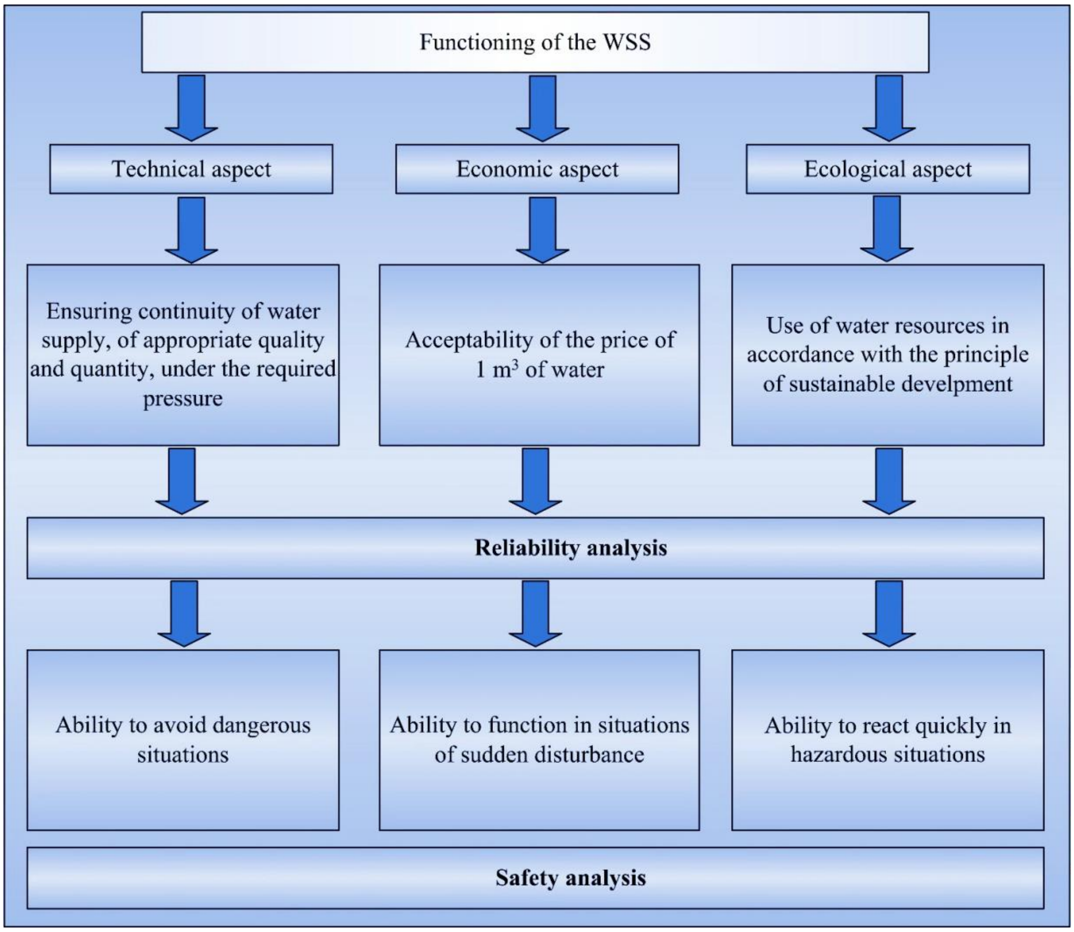

Figure 1. Diagram of the analysis of the functioning of the water supply system

The operation of the WSS consists in conducting constant control of all subsystems and their elements, taking into account the risk analysis and assessment, in particular, it includes the following processes [27], [31], [69], [73]:

- monitoring of water quality in water intakes,
- constant control of water quality parameters after its treatment, including the monitoring of the stability of tap water,
- monitoring the quality of treated water in treated water reservoirs and at selected points on the water supply network,
- control of the operation of technical devices in water pumping stations and technological devices in water treatment stations,
- modernization of water treatment technology in accordance with applicable standards,
- measurement of pressure and flow rate in the water supply network,
- monitoring of the condition of pipes, including the analysis of growths and biofilm,
- conducting inspections of utilities in the water supply network (maintenance, replacement),
- construction of new sections of water supply networks and connections, and removal of water supply network failures,
- current repairs of the water supply network,
- renovation, cable reconstruction, cable replacement,

- introduction of modern technologies of comprehensive control and monitoring of WSS, including hydraulic control of the system operation (SCADA software) and control and supervision systems (e.g. camera system for permanent monitoring of WSS facilities such as water intakes, water tanks, water treatment stations).

Water is consumed directly or indirectly by consumers like any other food and therefore contributes to the overall exposure of the consumer to the consumed substances, including chemical and microbiological contamination [16].

Management in order to obtain the required quality – QM (Quality Management) also in terms of tap water should include [64]:

- Risk Analysis Biocontamination Control – RABC,
- Good Hygienic Practice – GHP,
- Good Manufacturing Practice – GMP,
- Rapid Alert System for Food – RASF. The conduct of official food control bodies and other entities performing food safety tasks, in accordance with the principles set out,
- Hazard Analysis and Critical Control Points, hereinafter referred to as the "HACCP system" – a procedure aimed at ensuring food safety by identifying and estimating the scale of hazards from the point of view of food health requirements and the risk of hazards during all stages of production. This system is also aimed at defining methods of eliminating or reducing threats and establishing corrective actions.

The used methods of risk analysis and assessment are mostly based on operational data feedback and should take into account the analysis of the so called safety related systems that are based on the systems of barriers and systems mitigating the consequences of already existing threats.

The risk analysis process for the safety of the functioning of WSS should take place in the following exploratory phases [39], [46]:

- determining the number of inhabitants using the public water supply,
- determination of representative emergency events and determination of corresponding scenarios in order to estimate losses,
- determining the probability (frequency) of adverse events,
- determination of risk levels with a classification such as; tolerated, controlled, and not accepted.

In terms of quality and health safety of water consumers, in accordance with the regulations [10]–[11], [75], [77], the following are defined:

- risk means the danger of an adverse health effect occurring and the severity of such an effect, secondary to the hazard,
- risk analysis means a process which has three interconnected elements: risk assessment, risk management and risk communication,
- risk assessment means a scientifically based process consisting of four steps: hazard identification, hazard characterization, exposure assessment and risk characterization,
- risk management means the process, distinct from risk assessment, of examining policy alternatives in consultation with stakeholders, taking into account risk assessment and other legitimate factors, and selecting appropriate prevention and control options if necessary,
- risk communication means the interactive exchange of information and views during the risk analysis process on hazards and risks, risk factors and risk perception between risk assessors, risk managers, consumers, businesses, academia and other stakeholders, including explanation the conclusions of the risk assessment and the reasons for the risk management decisions,
- hazard means a biological, chemical, or physical agent capable of causing adverse health effects.

The risk factors connected with the possibility that the undesirable events of various types occur in the WSS can be found in the stage of system designing, construction and operation [66]:

- designing of the WSS:
  - wrong examination of ground conditions, incorrect choice of the trajectory of the water pipeline, the economic activity of the third party was not taken into account,
  - badly selected materials, fittings, anticorrosion protection, errors in hydraulic systems;
- construction of the WSS:
  - deviation from the design as concerns the technology of pipe laying, connections of the individual pipe sections, covering pipes for the passages going under and through the obstacles did not install, improper anticorrosion protection (passive and active), badly

performed pressure test and other procedures;
- operation of the WSS:
  - lack of water pipeline operation monitoring,
  - the scenarios for the emergency water supply were not taken into account,
  - incoherent protecting and warning system for water quality,
  - lack of the complex archives of failure data,
  - lack of program to manage risk connected with the WSS operating.

Consequences and losses connected with the occurrence of the undesirable events in the SWW can be divided into:
- financial consequences bear by the waterworks, connected with the breaks or lack of water supply, costs of restoration of the WSS to its correct operation (failure repair, network disinfection, compensations), etc.,
- social consequences, hygienic and sanitary (S), the possibility of the loss of health or the lives of water consumers, hygienic and sanitary inconveniences, environmental losses.

The analysis of the causes of the occurrence of the undesirable events in the WSS can be performed by means of different methods [34]–[35], [46], [52], one of which is the method called Root Cause Analysis (RCA), which requires five answers to the question why? Reducing the probability of failure of the water supply system can be done by planning modernization projects, as well as the procedures of prevention, taking into account the active protection requiring operator supervision. The essence of this method is shown in *Figure 2*, on the example of the analysis of the causes of the repeated failures in a certain section of the water-pipe network.

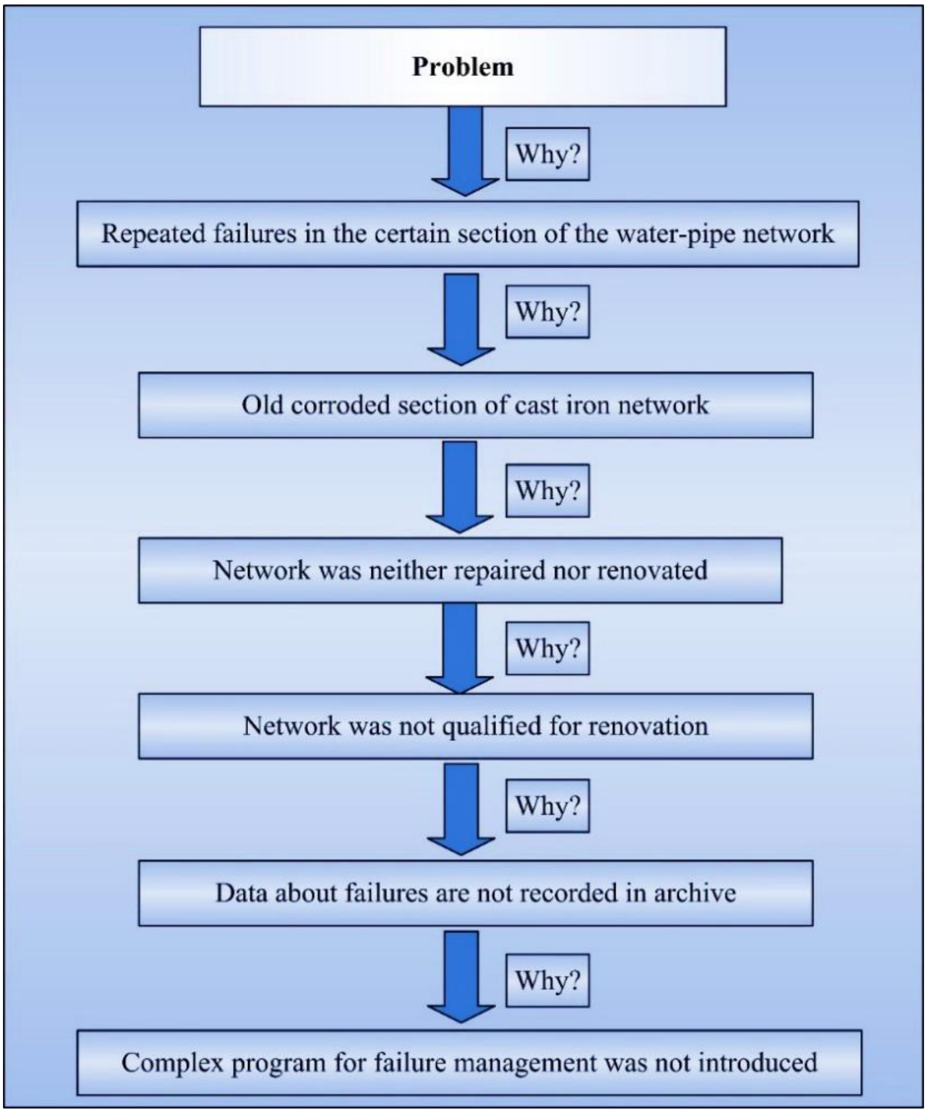

Figure 2. The example of the causes identification of the failure in the WSS [66]

Contributing to which form the probability, that the negative consequences occur are, among others, the following:

- the probability that the undesirable event occurs,
- frequency and a degree of exposure,
- the possibility of avoidance or minimization of the negative consequences.

Risk assessment is a process consisting of many systematic steps, in which the study of different kinds of threats connected with the WSS operating is carried out.

The basic purpose of this kind of activities is to collect the information necessary to estimate the safety of the system.

Risk assessment should contain:

- ranking of the undesirable events,
- determination of the level (value) of risk,
- proposal of the activities aiming at risk minimization,
- establishment of the time after which the risk can obtain its critical value as a result of different processes, e.g. materials ageing.

For effective and efficient risk management, it is necessary to collect statistical information about possible threats that may affect the security of the functioning of WSS. The scope, accuracy, and timeliness of information about hazards is of key importance in taking preventive and remedial actions to reduce risk. Practice shows that a professionally presented risk analysis leads to a change in the approach of managers and operators of WSS to security issues [42].

It is important for waterworks to identify risk correctly and to distinguish between consumer risk and water producer risk. It allows choosing the right method for calculating different types of risks.

The aim of water consumers threat identification is to show the type of substances existing in drinking water, however the evaluation of the threat level should be based on showing its harmful impact on human health and classifying the substances on the basis of all the available data. The impact of particular substances on human health is determined by qualified experts (doctors, chemists, biochemists, and microbiologist) on the basis of laboratory testing and clinical studies, as well as from experts experience. Decisions on managing risk, if they are to be effective, need to be active rather than reactive and well structured.

For safety reasons, it is important for users of the water supply systems to prevent failures in water supply networks, to avoid secondary water contamination. Possible safety measures include [47]:

- taking into account the requirements of the spatial development plan,
- application of design guidelines standards,
- executive and investor supervision,
- monitoring, detecting and localizing of leaks in the water supply network,
- proper organization and equipment of repair and repair services,
- performing analyses of the reliability and safety of the functioning of the water supply network and risk assessment,
- water quality monitoring.

The process of risk analysis for the purposes of safe operation of the water supply network takes place in the following exploratory stages [46]:

- determination of the type of water supply network,
- determination of the limit intensity of damage to water supply networks,
- determining the nuisance of repairs,
- determination of types of security related to the functioning of the water supply network,
- determination of risk levels with the division into tolerated, controlled and unacceptable.

The correct WSS risk management process should contain suitable organizational procedures within the framework of regular waterworks activity, the WSS operation technical control and supervisory system, a system of automatic transfer and data processing about WSS elements operation. The key role in this process is played by a system operator, whose main purpose is:

- to implement the reliability and safety management system,
- to operate the WSS according to valid regulations and in a way which ensures its long and reliable operation,
- to execute a program of undesirable events prevention,
- to develop failure scenarios for water supply in crisis situations,
- to develop a complex system of information about the possible threats for water consumers.

Such type of WSS risk management optimises an operation of particular WSS devices (e.g. parameters of operation of water pipe pumping stations which cooperate with network tanks), and the work of the whole system.

In the process of risk assessment in the WSS one should take into account the information concerning:

- system operating (exploitation) conditions,

- data regarding the operation of the particular system elements and the dependence between them,
- data concerning energy supply,
- data regarding the possible failures in the system,
- distinction of the states of operating and the states of failure in the system,
- information concerning the causes of failures,
- data regarding the possible consequences of the undesirable events.

Risk assessment includes the so-called risk analysis, which is the process aiming at the determination of the consequences of the failures (undesirable events) in the WSS, sources of their occurrence and the assessment of the risk levels.

3. Quality management systems of tap water

The principles of the HACCP system show that it is a procedure aimed at ensuring safety by identifying and estimating the scale of threats from the point of view of health quality and the risk of hazards during all stages of the production process [53].
The main rules are:

- identification of possible biological, chemical and physical threats and methods of counteracting,
- prevention, in the form of control of individual phases of the production and distribution of mineral waters, and not only the final product,
- use throughout the production cycle, from water intake, bottling plant, storage, distribution, delivery to consumers in shops and restaurants.

The critical control points (CCP) are places in which to ensure the safety of water supply network the control and the possibility to take the preventive measures in order to eliminate risk of threat or to minimize it to a tolerable level are necessary.
There are seven basic stages related to the implementation of the HACCP system [15], [37]:

Step 1. Hazard analysis.
It involves:

- identification of potential threats in the category of occurrence: biological, chemical, physical. According to medical reports, 90% of illnesses caused by the consumption of poor-quality water are caused by microbiological contamination,
- establishing the source and cause, and taking preventive actions,
  - general procedures,
  - direct actions;
- assessment the risk of danger [50],
  - frequency of occurrence (f),
  - the size of the effects (C),
  - determination of the risk index

$$r = f \cdot C, \tag{1}$$

  - establishing a priority list.

Step 2. Establish critical control points (CCPs).
It enables the realization of the system's goal by controlling the health safety of the mineral water.
The condition for the designation of a CCP is the possibility of its monitoring and the possibility of actually controlling the threat. You can use the "decision tree" method to determine CCP. It allows, through a logical sequence of questions and answers, concerning the possibility of eliminating or reducing to an acceptable level the risk at a given point. Below, there are examples of decision tree questions according to Dutch procedures [13], [37].

Question 1.
Are there any precautionary measures for a given risk?
Yes: go to question 2. No: go to question 1a.

Question 1a.
Are preventive measures necessary in terms of health safety?
Yes: go to question 1b. No: this is not a CCP.

Question 1b.
Is the hazard controlled using standard procedures?
Yes: not a CCP. No: modify the process and/or preventive measure.

Question 2.
Does the given preventive measure eliminate or reduce the risk to an acceptable level?
Yes: go to question 4. No: go to question 3.

Question 3.
Can the contamination with the identified hazard factor reach an unacceptable level or can it rise to an unacceptable level?
Yes: go to question 4. No: this is not a CCP.

Question 4.
Can the hazard be eliminated or reduced to a tolerable level in the further process?
Yes: it is not a CCP. No: it is a CCP.

Step 3. Establishing critical limits for each of the checkpoints.

Once a CCP has been designated, one or more indicators of contamination to be controlled, as well as target values, tolerance limits and the unacceptable critical value should be identified [16], [18].

The process of identifying potential threats and risks should also include risk characterization and its prioritization [38], [45]. Priority is important when there is documentary evidence that the risk of a health risk to consumers of water.

In the case of uncertain risk, one may require further monitoring to determine its rank [30]. However, irrelevant, not a priority, lack of documented evidence that the identified hazard poses a risk to water consumers, the risk should be monitored under the water safety plan in subsequent years of operation of the WSS [39].

Risk assessment depends on the level of the analyst's experience in dealing with a given undesirable event, analyst's knowledge about negative consequences of undesirable events influences risk assessment. Risk assessment is influenced by a magnitude of negative consequences.

Man considerably overestimates the risk of imposed actions and underestimates the risk of voluntary actions. Besides, man underestimates threats, whose negative consequences can appear in a distant, difficult to be foresee future.

The possibility to implement corrective actions lowers the level of subjective perception of risk. A level of fear has a significant influence on a size of perceptible risk.

4. Matrix methods for risk assessment in water supply system

4.1. Two parameter risk matrix

Procedures for risk analysis cover the whole activity aiming to identify threats, to estimate risk and its size. The appearance of the extraordinary event produces the state of emergency to which some potential of danger is assigned. Then determination of the acceptable risk level relies on an introduction of the criteria values. Due to the high complexity of individual elements of water supply systems and their spatial dispersion, various methods of risk assessment are used. All methods take into account both technical aspects and human factors that affect the security of water supply to the recipient. Water supply risk assessment tools have found application in the protection of WSS, also against natural risk and terrorist attacks. Safety of functioning is related to the analysis of the connections between threats, limiting the frequency of their occurrence, and in the event of their occurrence, identifying the causes of their occurrence and reducing the negative effects. The risk management process should begin with establishing an integrated ranking list (identifying priority issues). The next step is to formulate the *principles of risk management. In this regard, the* adopted technical solutions should be optimized based on the expected results and the invested financial resources. The selected solution should be implemented and its functioning monitored. This will allow the method used to be verified and a statement to what extent the risk has been mitigated. Companies to which the operational supervision of WSS belongs should be able to manage the risk, inform users about its size, take appropriate actions to minimize it and initiate actions that must be taken in the face of the risk.

The presented methods of risk analysis and assessment belong to the group of quantitative and qualitative matrix methods. The presented matrix risk analysis methods can be adapted to the analysis of a specific municipal infrastructure system (water supply, sewage, etc.) with its specificity, including a specific operational regime. It is inseparably connected with the functioning of the municipal infrastructure the possibility of undesirable events that are part of their everyday operation.

The presented matrix is one of the simplest. From the mathematical point of view risk (r) is defined as following [33]–[35], [40]:

$$r = P \cdot C, \tag{2}$$

where P is a measure of the system operating unreliability corresponding with category of probability – frequency, C is a measure of the consequences corresponding with category of consequences – damages, expressed in financial units.

In *Table 1* the two parametric risk matrix is presented, assuming the following risk scales and corresponding point weights:

- probability (P): low – 1, medium – 2, high – 3,
- consequences (C): minor – 1, medium – 2, major – 3.

Table 1. Two parameter risk matrix

C	1	2	3
P	r		
1	1	2	3
2	2	4	5
3	3	6	9

According to the basic matrix for risk assessment given above we can analyse different undesirable events assuming the following scale of risk [33]–[35], [40]:

- the tolerable risk – a number of points from 1 to 2,
- the controlled risk – a number of points from 3 to 4,
- the unacceptable risk – a number of points from 6 to 9.

If the calculated values indicate the category [33]–[35], [40]:

- tolerable – one can assume that the water pipe network fulfills its functions in the satisfying way,
- controlled – an improvement in the work of some elements or repair of some sections of water pipe network should be considered.
- unacceptable – means that the water pipe network does not fulfill its functions and should undergo a complete modernization or even redesigning.

4.2. Three parameter risk matrix

Taking into account that CI is a complex technical system built from subsystems and elements that are firmly interconnected it makes sense to expand the CI operating risk matrix by next parameters influencing risk size. The three parametric matrices for risk assessment are proposed. The parameters are following: the frequency of the threat occurrence (P), threat consequences (C) and the exposure to threat (E).

The exposure to threat should be related to the period of time when the public water pipe has been used as a source of drinking water. The numerical risk assessment is a product of the above-mentioned parameters [33]–[35], [40]:

$$r = P \cdot C \cdot E. \tag{3}$$

The following scales and weights of the particular parameters are assumed [33]–[35], [40]:

- scale of threat frequency (P):
  - almost impossible incidents (1 in 100 years); with weight 0.1,
  - occasionally possible incidents (1 in 20 years); with weigh 1.0,
  - little probable incidents (1 in 10 years), with weigh 2.0,
  - quite probable incidents (once a year), with weigh 5.0,
  - very probable incidents (10 times a year), with weigh 10.0;
- scale of threat consequences size (C):
  - little loss up to $5 \cdot 10^3$ EUR ; with weight 1.0,
  - medium loss from $5 \cdot 10^3$ to $5 \cdot 10^4$ EUR, with weight 3.0,
  - large loss $5 \cdot 10^4$ EUR – 10^5 EUR; with weight 7.0,
  - very large loss 10^5–10^6 EUR, with weight 15.0,
  - serious disaster, losses over 10^6 EUR; with weight 50.0;
- scale of exposure to threat (E):
  - slight, once a year or less often, with weight 0.5,
  - minimal, a few times a year; with weight 1.0,
  - occasionally, several times a month, with weight 2.0,
  - often, several times a week, with weight 5.0,
  - constant, with weight 10.0.

The numerical risk assessment determined in this way takes the values within the range 0.05 to $5 \cdot 10^3$. The levels of risk in the five stage scale are shown in *Table 2* [33]–[35], [40].

Table 2. The levels of risk

Class	Description	Numerical values	Risk level
1	insignificant	$0.05 < r \leq 5$	tolerable
2	minor	$5 < r \leq 50$	
3	medium	$50 < r \leq 200$	controlled
4	major	$200 < r \leq 400$	
5	significant	$400 < r \leq 5000$	unacceptable

The risk assessment we can calculation according to the formula [33]–[35], [40]:

$$r = P \cdot C \cdot S, \tag{4}$$

where P is point weight connected with the probability that the representative undesirable event occurs, from 1 to 5, C is point weight connected with the magnitude of losses, from 1 to 5, S is point weight connected with the public feelings, from 1 to 3.

Point scale to measure risk is within the range 1 to 75.

The following risk levels are assumed:

- $r = 1 \div 12$ – the tolerable risk,
- $r = 15 \div 36$ – the controlled risk,
- $r = 40 \div 75$ – the unacceptable risk.

In order to analyze the water consumer safety, it is necessary to define its operating states. Therefore, the following operating conditions of WSS, taking into account the nominal production capacity of water (Q_{dn}) and maximum daily water demand during the year (Q_{dmax}), can be distinguished:

- operational capability state – the WSS state, which is characterized by operation without. The system performs its task in accordance with applicable regulations and expectations of water consumers, in terms of the water amount for consumption, i.e. the nominal production of water capacity $Q_{dn} \geq 0.7\ Q_{dmax}$ and quality: water for human consumption meets the requirements of the existing regulation concerning water quality. The public water supply does not cause threat to the life and health of water consumers,
- limited operational capability state – the WSS state, which is characterized by short-term disruptions in the work: $0.3\ Q_{dmax} \leq Q_{dn} < 0.7\ Q_{dmax}$ or there is a lack in the water supply for 24 h, there is the possibility of undesirable events escalation (the so called domino effect). If the water does not cause health risk to consumers, it is possible to exceed the limit values specified in the regulation. If the pollutant may be removed within 30 days, the competent sanitary inspector finds water suitability for consumption under the terms of the so-called granted derogation,
- loss of operational capability state – the WSS state in which the system operates inefficiently or stops working, $0 < Q_{dn} < 0.3\ Q_{dmax}$ or there is a lack in the water supply for > 24 h. Consumers are exposed to the consumption of water with inadequate quality,
- emergency state – the WSS state, in which the system stops working, and consumers are deprived of access to drinking water. No protection of consumers from the water threats (eg. as a result of floods, hydrological drought).

In the case of consumer risk analysis, the following descriptive scale for the consequence parameter can be adopted:

- very small (point weight – 1):
  - minor deterioration of organoleptic parameters of water does not constitute a threat to consumers,
  - local reduction of pressure in the water mains;
- small (point weight – 2):
  - significant deterioration of the organoleptic parameters of water constituting nuisance for consumers,
  - no health threat,
  - single consumer complaints of water,
  - decrease the daily water production to 70% Q_{maxd} or interruption in the supply of water for 2 h,
  - lowering the pressure in the water mains;
- average (point weight – 3):
  - considerable nuisance organoleptic water (high turbidity, odor),
  - exceeding the physicochemical parameters,
  - threat to the consumers health,
  - single indisposition of consumers health associated with the consumption of contaminated water,
  - decrease the daily water production to $0.5\ Q_{dmax} \leq Q_{dn} < 0.7\ Q_{dmax}$ or local interruptions in water supply from 2 to 12 h,
  - lowering the pressure in the water mains;
- big (point weight – 4):
  - exceeding the physico-chemical and bacteriological parameters,
  - secondary water pollution in different parts of the water supply network,
  - numerous consumer poisoning associated with the consumption of contaminated water,
  - announcements in the local media informing about pollution of drinking water,
  - decrease daily water production $0.3\ Q_{dmax} \leq Q_{dn} < 0.5\ Q_{dmax}$ or local interruptions in water supply from 12 to 24 h,
  - lowering the pressure in the water mains;
- very big (point weight – 5):
  - extensive bacteriological contamination of water, the presence of pathogenic microorganisms, exceeding the physicochemical parameters,
  - secondary water pollution in the water supply network,
  - mass poisoning, hospitalization of injured,
  - messages in the national media informing about pollution of drinking water,
  - the need to involve professional emergency services: eg. State Fire Service, the State of Emergency Medicine,
  - decrease of the daily water production values $Q_{dn} < 0.3\ Q_{dmax}$,
  - interruptions in the supply of safe water for consumption over 24 h,

- failure of main equipment WTP or pumping water,
- failure of the main water pipes supplying the municipality.

In case of including the protection parameter, which is inversely proportional to the risk value, the following criteria can be distinguished:

- very low (point weight – 1):
  - monitoring of the raw water and treated water the quality carried out only in case of a threat,
  - lack of alternative treatment technologies, lack of alternative sources of water, no tanks network,
  - lack of monitoring system of water supply network,
  - the network in an open system,
  - no own services removing the consequences of any undesirable events;
- low (point weight – 2):
  - periodic monitoring raw water and treated water the quality (once a week, once a month),
  - lack of alternative treatment technologies, alternative sources of water and the water supply network reservoirs,
  - lack of monitoring system of water supply network,
  - the network in an open system,
  - a long time to wait for the intervention of emergency service in water supply;
- average (point weight – 3):
  - standard system of monitoring of raw and treated water quality,
  - lack of alternative treatment technologies, alternative sources of water and the water supply network reservoirs,
  - standard monitoring system of water supply network functioning,
  - the network in an open system, the inability to cut off the damaged pipe without interruption in water supply,
  - a long time to wait for the intervention of emergency service in water supply;
- big (point weight – 4):
  - standard system of monitoring of raw and treated water quality (sampling water several times a day),
  - the lack of an alternative treatment technology,
  - the possibility of using alternative sources of water or water stored in tanks of water supply network,
  - standard system of monitoring the work of water supply network (measurement of pressure and flow rate on the main water supply facilities),
  - the network in a mixed system;
- very big (point weight – 5):
  - a comprehensive system for monitoring of raw water and treated quality with alarm function,
  - the possibility of using alternative treatment technologies, alternative sources of water, the water stored in tanks of water supply network,
  - a comprehensive system for monitoring the work of water supply network, the use of SCADA and GIS,
  - the network in a closed system, the ability to cut off the damaged pipe,
  - reserving strategic objects on WTP or pumping water,
  - efficient emergency service in water supply.

Where the points weighting associated with vulnerability is concerned, the points-descriptive scale is one in which

- very low vulnerability to failure is assigned a weight of 1:
  - network in a closed system, the possibility of cutting off the emergency section of the network with valves (for repair),
  - the possibility of avoiding interruptions in the supply of water to consumers,
  - full monitoring of the water supply network (continuous measurements of pressure and flow intensity at strategic points of the network) covering the entire water supply area, the use of SCADA metering and
  - GIS, possibility of remote control of hydraulic parameters
  - network operation,
  - emergency reserve in network water tanks covering the city's demand for at least a day,
  - a comprehensive emergency warning and response system,
  - full use of alternative water sources;
- low vulnerability to failure, with a weight of 2:
  - network in an open or mixed system, the possibility of cutting off an emergency section with valves,
  - standard monitoring of the operation of the water supply network with

  measurements of pressure and flow intensity,
  - early warning and emergency response system,
  - availability of alternative water sources;
- average vulnerability to failure, with a weight of 3.0:
  - network in a mixed system, the possibility of shutting off the emergency section of the network with valves (limitations in the supply of water to consumers from
  - due to network capacity),
  - standard monitoring of the operation of the water supply network with measurements of pressure and flow intensity,
  - a delayed response system in crisis situations,
  - alternative water sources that do not fully cover the needs;
- high vulnerability to failure, with a weight of 4:
  - network in an open system, no possibility of shutting off the emergency section of the network with valves without interruptions in water supply for consumers,
  - limited monitoring of the operation of the water supply network,
  - a late warning system in crisis situations,
  - limited availability of alternative sources of drinking water;
- very high vulnerability to failure, with a weight of 5:
  - network in an open system, no possibility of shutting off the emergency section of the network with valves without interruptions in water supply for consumers,
  - no monitoring of the water network operation,
  - lack of a warning and response system in crisis situations,
  - very limited availability of alternative water sources to consumption.

4.3. Four parameter matrix for risk assessment

Critical infrastructure should be provided with different protection and monitoring systems which increases its operating and safety reliability. That is why the fourth parameter characterising the size of this protection has been introduced to the risk matrix connected with CI operating [43], [45].

The four parametric matrix for risk assessment has been proposed, according to the formula [43], [45].

$$r = \frac{P \cdot C \cdot N}{O} \tag{5}$$

where P is point weight connected with the probability that the representative undesirable event appears, C is point weight connected with the size of losses, N is point weight connected with a number of the endangered inhabitants, O is point weight connected with CI protection against extraordinary threat.

Parameter (O) is inversely proportional to the size of risk. Analogically as in the two and three parametric methods every time the size of parameters P, C, N and O are described according to the following point scale: low – L = 1, medium – M = 2, high – H = 3. In this way the point scale to measure risk in the numerical form within the range [0.33÷27] has been obtained.

The description of the risk components [43], [45]:

- category for a number of the endangered inhabitants – N:
  - low – a number of the endangered inhabitants less than 5000 – N = 1,
  - medium – a number of the endangered inhabitants from 5001 to 50000 – N = 2,
  - high – a number of the endangered inhabitants higher than 50001 – N = 3;
- category for the probability that failure occurs – P:
  - low – unlikely – once in 10 ÷ 50 years – P = 1,
  - medium – quite likely – once in 1 ÷ 10 years – P = 2,
  - high – likely – 1 ÷ 10 times a year or more – P = 3;
- category for consequences – C:
  - little – single complaints from recipients, financial losses up to $5 \cdot 10^3$ EUR – C = 1,
  - medium – significant nuisance, numerous complaints, communications in regional public media, financial loss up to 10^5 EUR – C = 2,
  - high – hospital treatment of exposed persons required, involvement of professional emergency services, information in national media financial loss over 10^5 EUR – C = 3;
- category for protection – O. If the total number of points equals:
  - 7÷10 – high protection level – O = 3,
  - 12÷34 – medium protection level – O = 2,
  - over 34 – low protection level – O = 1.

In *Table 3* the four parametric risk matrix is shown; the particular numerical values were obtained using the formula (6) [43], [45].

Table 3. Risk categories [43], [45]

Risk category	Point scale
tolerable	$0.33 \leq r \leq 3.0$
controlled	$4.0 \leq r \leq 8.0$
unacceptable	$9 \leq r \leq 27$

The exemplary application of the method is following [43], [45]:

- the probability that the given undesirable event occurs is $P = M = 2$,
- predicted losses are estimated as $C = M = 2$,
- the protection level defined on the base of the supplementary questionnaire $O = H = 3$,
- the number of the endangered inhabitants using the water pipe $N = L = 1$.

The numerical risk value from *Table 4* is $r = 1.33$ which, according to *Table 5*, means the tolerable risk.

4.4. Risk prioritizing in water supply network

Method of Risk Prioritizing – MRP – involves selecting the factors affecting the risk level of failure in the water supply network.

The proposed method is based on the classification of risk factors for failure of the water supply network and assigning them points values –functional criteria – FC_i and point weights – assessment criteria – AC_i, and then calculating the index of risk prioritizing – *IRP* [65].

In this way, a value of the index of risk prioritizing – *IRP* – is calculated according to the formula [65]:

$$I_{RP} = \sum_{i=1}^{n} FC_i \cdot AC_i \tag{6}$$

where *IRP* is the index of failure vulnerability, FC_i means functional criteria, AC_i means assessment criteria and n is the number of criteria taken into account in the considered method.

Each functional criterion FC_i, depending on the degree of influence of the factor on the risk prioritizing index, has assigned a point value in the following way as shown in *Table 1* (from 0 to 1 – neglected, from 2 to 3 – unimportant, from 4 to 6 – the average important, 7 and 8 – important, from 9 to 10 – very important).

The values of assessment criteria AC_i are adopted depending on the importance of the damaged pipe, according to the following scale: 1 – low, 2 – medium, 3 – high or 4 – very high.

If the given factor is not present in the analysis, the values of FC_i and AC_i are assumed as 1 [65].

The following factors were proposed to analyse and identify risk areas of water supply network failure [65]:

- type of water network (WNT): water supply connection, distribution network, mains,
- water network age (WNA) to 10 years: from 10 to 30 years, from 30 to 60 years, above 60 years,
- water network material: plastics, steel, grey cast iron,
- hydrogeological conditions: good, average, poor,
- network monitoring: above-standard, standard, none,
- corrosion protection: full, standard, none,
- the density of underground infrastructure in the area where the network is situated: small, average, big,
- dynamic loads, including the difficulty of repairs in the area where the network is situated
  - pipeline in the not urbanized areas,
  - pipeline in the pedestrian traffic (pavements),
  - pipeline in the street;
- failure rate: < 0.5 $km^{-1} \cdot a^{-1}$, from 0.5 $km^{-1} \cdot a^{-1}$ to 1.0 $km^{-1} \cdot a^{-1}$, > 1.0 $km^{-1} \cdot a^{-1}$,
- size of possible losses resulting from failure occurrence:
  - financial loss up to 10^4 EUR,
  - financial loss from 10^4 EUR to 10^5 EUR,
  - financial loss above 10^5 EUR;
- the difficulty to repair damages:
  - repair brigades are organized and equipped appropriately and they are in full readiness for 24 hours,
  - basic equipment to repair a failure, one shift work,
  - lack of mechanized equipment to repair a failure.

The method belongs to the group of experts methods and may also be a part of the decision-making process concerning modernization plans in the WSS.

The presented method of analysis of consumer acceptance of water costs that companies incur on the risk reduction, based on surveys, should be a part of proper company policy in the context of consultation with the local community [65].

4.5. Application of failure mode and effects analysis in analysis of critical infrastructure

In the Failure Mode and Effects Analysis (FMEA) method the global assessment, taking into account the fact that the undesirable events occur at random, is carried out by using a number of risk priority LPr according to the formula [49]:

$$LPr = LPP \cdot LPW \cdot LPK, \tag{7}$$

where *LPP* is a number of priority for the appearance of failure – defines probability of a possibility of the appearance from the slightly little (impossible) to the very possible.

LPW is a number of priority for the detectability – defines probability of failure detection, the early warning system or the delayed warning, *LPK* is a number of priority for an inhabitant – defines probability of the intensity of effects for people.

In *Table 4* the suggested values of the particular priority numbers were presented [49].

To each of these three numbers of priority a weight from the scale 1 to 10 is assigned. In this way LPR can take the values from a range 1 to 1000.

The assessment of *LPr* is carried out by using some evaluation forms that comprise the existing state and the improved state.

The high number of *LPr* means the high priority in the procedures of removing and minimization of the hazard connected with the undesirable events.

It is assumed that for $LPr \geq 100$ it is obligatory to take some precautions, and *LPr* reduced to 10% is treated as a negative result of the carried out actions.

5. Risk evaluation

The important challenge is to define the tolerable risk level, or so-called ALARP (As Low As is Reasonably Practicable). The ALARP principle was first introduced in the UK, where the unacceptable (impermissible) value for the risk of death of an individual worker was determined to be $r = 0.001$, while the risk of death for the public was determined to be $r = 0.0001$. The risk-reduction process should take cost-benefit analysis into account.

The task should therefore be to determine the level of risk beyond which costs of further lowering are disproportionally high.

The UK Health and Safety Executive, in its directives, introduces a notion of "the cost for preventing a fatality" which is estimated at about 1 million GBP.

The basis for the determination of criteria revolves around determination of the value of the tolerated risk. The level of tolerated risk and methods of risk assessment are often regulated by specific technical systems, e.g. in connection with transport or industry.

For a WSS, the basis for determining the criteria derive from regulations regarding the water supply and wastewater disposal and on the quality of drinking water, as well as WHO guidelines and the knowledge and experience of experts [48]. The defining of risk-acceptability criteria should first and foremost take account of the aspect of safety for consumers of water, as well as technical and economic analysis.

Table 4. The values of the priority numbers [49]

LPP		LPW		LPK	
improbable $< 10^{-6}$	1	very little probability $> 10^{-1}$	1	little $> 10^{-1}$	1
very little probability $10^{-5} – 10^{-6}$	2–3	moderately probable $10^{-1} \div 10^{-3}$	2–5	noticeable significant $10^{-1} \div 10^{-3}$	2–3
little probability $10^{-3} – 10^{-5}$	4–6	little probability $10^{-3} \div 10^{-5}$	6–8	large $10^{-3} \div 10^{-5}$	4–6
moderately probable $10^{-1} – 10^{-3}$	7–8	very little probability $10^{-5} \div 10^{-6}$	9	large $10^{-5} \div 10^{-6}$	7–8
very probable $> 10^{-1}$	9–10	improbable $< 10^{-6}$	10	catastrophic $< 10^{-6}$	9–10

Table 5. The quantitative and qualitative limits of risk connected with poor drinking water quality in public supply systems, related to 1 year [39], [45]

Consequence category	Description of consequences	Tolerable risk	Controlled risk	Unacceptable risk
insignificant	incidental difficulties that are not a threat to health, lack of consumers complaints	$< 10^{-3}$	$10^{-1} \div 10^{-3}$	$> 10^{-1}$
marginal	perceptible organoleptic changes, individual consumer complaints	$< 10^{-4}$	$10^{-2} \div 10^{-4}$	$> 10^{-2}$
significant	organoleptic changes are significant, numerous consumers complaints, reports in local media, water can be used after 10 minutes boiling	$< 10^{-5}$	$10^{-3} \div 10^{-5}$	$> 10^{-3}$
serious	mass gastric problems, relevant sanitary inspector turns off water pipe, toxic effects in pollution indicators, large number of reports in local media, general information in national media	$< 10^{-6}$	$10^{-4} \div 10^{-6}$	$> 10^{-4}$
catastrophic	mass hospitalisation as a result of health complications, deaths, front news in national media	$< 10^{-7}$	$10^{-5} \div 10^{-7}$	$> 10^{-5}$

The risk-acceptability criteria are used as decisions are made regarding the operation of the system (e.g. on renovation, modernisation and approval) [71].

The more demanding the risk acceptability criteria are, the more complex and costly the applied security and protection measures. This is therefore an important element in a water company's financial policy [68].

Table 5 presents quantitative and qualitative categories of consequences connected with the three-level risk gradation [39], [45].

Danger and hazard are factors determining the magnitude of a risk. Danger relates to a cause of loss and is characterised by some kind of arranged time sequence of successive phases.

In the first phase a threat appears to pose a danger (e.g. incidental water pollution at a source).

In the second phase, the danger becomes real (e.g. as polluted water appears in the system). In the third phase, the effects of the real danger are revealed (e.g. water consumers' gastric problems). Hazard is identified as a set of conditions and factors that have a direct impact on the second phase of danger. The scales of parameters that describe risk on its different levels of occurrence should be simple, with risk assessment and classification allowed for every discussed case [41], [44].

Much experience gained from the analysis of risk associated with the operation of a WSS can already be generalised at the level of research, and passed on in the form of publication.

Assessments of threats posed to (and hence the level of safety of) a WSS are based on databases of relevant criteria-related information that are necessary for decision-making processes, process optimisation and the operation and control of systems, as well as in the taking of protective measures to prevent adverse effects of events from occurring. Knowledge of risk does not have to be attained by means of individual trial-and-error methods. Rather, risk management requires identification, as associated directly with checks on the quality and reliability of technical systems. The latter includes all actions whose result is a product (article, object, subsystem or system) of the required quality and reliability. We are still dealing with the mistaken stereotype that technical scrutiny at the execution phase will ensure the required quality and reliability. The modern perspective is part of a trend to the effect that quality control and reliability control from the design phase, through construction, to the phase of operation of technical systems leads to a reduction of risk associated with operations [36].

The establishing of criteria values for service levels should be achieved by cooperating teams of experts in the field of risk-assessment methods, as well as experienced engineers. The process should also be based on statistical data relating to the operation of the WSS. It should be noted that the opinions and assessment arrived at by both users and experts play a very important role in the procedures making up service-level analysis. The basis for actions aimed at effective risk management entails the correct collection and archiving of data for further processing. Past experience allows for the identification of three basic reasons for restricting the processing of data collected into useful knowledge: access to data is often difficult due to their dispersal and the lack of procedures for exchanging documents within a company; data fail to achieve uniformity as in different periods the same information may well have been recorded in different forms, and stored in various formats (from paper documents, via scanned ones, through to electronic documents). Local communities should be made aware of the issues related to threats so that, following an undesirable event, their behaviour is more appropriate to the circumstances and supports the rescue operation through its rationality. Security is considered a modern measure of the chances of societies surviving and developing. It still requires in-depth theoretical analyzes, empirical research and practical projection through the implementation of preventive and compensatory programmes.

6. Quality function deployment house of quality

The *house of quality (HOQ)* is a matrix showing the interdependencies between consumer requirements (matrix rows) and system features (matrix columns), supplemented with additional tables and diagrams [3], [78]–[79]. It is a kind of table diagram. It is used in the process of quality improvement at the design stage [17], [58], [62].

This method has been developed in the 1960s by Akao, and used for the first time in 1972 at the Mitsubishi shipyard in Kobe. It can be used in the WSS management process to eliminate errors at the design stage.

The procedure for creating a house of quality for WSS's is as follows:

- determining the requirements of water consumers (on the basis of marketing research, e.g. questionnaires) and assigning appropriate point weights to these requirements:
  - good quality water, in accordance with the standard,
  - good tasting water,
  - water supplied under the right pressure without interruptions in the supply;
- technical properties (features) of WSS from the designer's point of view (minimum, maximum, nominal values):
  - water quality,
  - delivery reliability,
  - operational security;
- showing dependences between the requirements of water consumers and the technical parameters of the subsystem by using symbols from week association to strong association,
- identification of the dependences through inter-correlations between the technical parameters, what involve using symbols, as to show the level of the inter-correlation,
- determination of competitive assessment,
- prioritizing customer's requirements, which include determining:
  - importance ranking (based on 10-point scale),
  - technical assessment,
  - target values (set on 5-point scale, where 1 is no change, 3 – improve the services, and 5 – service is at good level);
- prioritizing technical requirements, which include determining:
  - degree of difficulty (based on 10-point scale, from the least to the most difficult),
  - target value,
  - absolute weight,
  - relative weight;
- the final evaluation.

The house of quality diagram is shown in *Figure 3*.

Understanding customer expectations is a key element in the assessment of water supply services. The survey can provide the necessary information about the functioning of the water companies.

7. Water safety plans

The water safety plan (WSP) is a key element in the strategy of preventing undesirable events in the WSS [23], [29], [51], [57]. It consists of a descriptive part containing a synthesis of all important information about the structure of the WSS, the principles of its operation and maintenance, and an analytical and implementation part, which presents an assessment of the system functions that affect its proper functioning in terms of the safety of water consumers [24], [56], [75], [77].

The scope of WSP includes [76]:

- characteristics of the primary goal of WSP, which is the safety of water consumers (the so-called health duty) based on health risk assessment,
- overall assessment of the WSS: assessment of whether the water supply system (from the source of water through treatment to its consumption) is able to provide water that meets health standards (in accordance with the applicable national and international quality standards for water intended for human consumption),

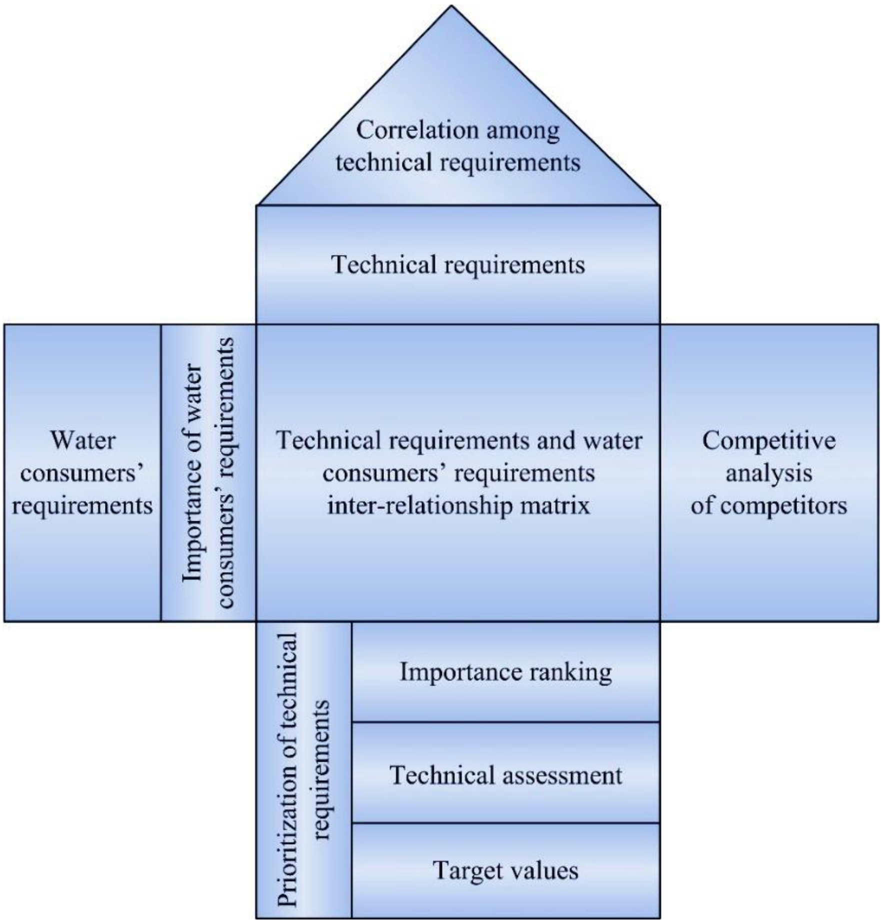

Figure 3. Scheme of the HOQ showing the interdependencies between consumer and technical requirements

- management plans: system assessment documentation, monitoring plans (routine and emergency), updates, improvements and notification of situations threatening the health of water consumers),
- validation monitoring for each subsystem of the WSS to confirm that the implemented WSP procedures lead to the planned results. An independent supervision system verifies the correct and effective operation of the WSP.

Risk management procedures under the WSP should include [72]:

- performing a threat assessment and prioritizing the risk,
- analysis of the identified risk (selection of events that may trigger a sequence of undesirable events, the so-called domino effect, development of models of emergency scenarios, development of functional models and system sequences of events: event trees and failure trees, analysis of operator errors, estimation of the probability of occurrence of threats and probable causes, and health effects for consumers),
- quantitative health risk assessment of water consumers and, on this basis, assessment of the safety level of water consumers,
- identifying the pathways through which threats can be passed on to consumers,
- identification of "critical control points",
- definition of the method of monitoring and control procedures for each identified risk, including the determination of the scope and frequency of monitoring (limits of acceptability),
- development of emergency water supply scenarios and response plans in the event of a crisis, training for WSS operators,
- development of a consistent documentation of adverse events for each WSS subsystem and an IT database,
- determining risk control options (determining how to reduce the level of risk),
- cost-benefit assessment (determining the effectiveness of costs incurred in order to reduce risk and thus prioritize various risk control options),
- preparation of recommendations for the decision-making process (proposing those variants of risk control that, according

to experts, are the most effective in terms of expected benefits and costs incurred),
- developing a procedure for informing water consumers about the risks.

Nowadays the consumer safety of functioning of technical and environmental systems has become a worldwide scientific trend.

A WSS is a complex technological system whose reliable operation conditions the safety of the consumer of water.

To ensure the safety of a WSS, operations must draw on the newest theoretical solutions, the basic categories of which relate to risk and consumer safety. There is thus an evaluation of the relationship between occurring threats and safety and protective barriers and methods. There is a visible trend towards legislation that ensures an adequate level of safety of water-supply services thanks to the implementation of risk analysis. Failure statistics for the WSS and for other municipal systems show clearly how operation reliability models and safety reliability models must take the role of the operator into account. Ensuring the safe use of a public water-supply requires the use of reliability and safety categories effectively characterising the concept of risk. This is true of assessment regarding the relationship between threats occurring and safety and security barriers applied. A multi-barrier system is a modern trend ensuring the safety of operation of a WSS. Safety barriers operating in series allow for the reduction of risk to a tolerable level.

Analysis of loss of security is a developing trend for current urban infrastructure systems, in terms of the safety of residents of an agglomeration.

A detailed risk analysis for individual stages of water supply system operation would seem to be very important. Determining the size of risks related to the construction and operation sequentially, as well as the sum total therefore, provides for a response at individual stages that is appropriate. This in turn contributes to a reduction in the level of risk associated with the system's functioning.

Experience gained from risk analysis as regards the functioning of a WSS have already been generalized at the scientific level, and dispensed in the form of guidelines. This now replaces investigation by reference to personal trial and error. However, there may sometimes be a challenge here given changing raw-water quality, or problems with treatment and distribution.

8. Conclusion

The analysis and evaluation of the safety of municipal infrastructure helps guarantee the taking of correct decisions when it comes to the selection of the best solutions in terms of technology, economy and proper operation.

The applied methods of risk analysis and assessment are mostly based on operational data and data obtained from experts.

The choice of the method of risk analysis and assessment should be adapted to systems analysed the database, and the knowledge and experience of experts carrying out the analysis.

In addition to the above-mentioned issues, criteria to be adopted are important for all risk parameters and for assessment. These criteria should reflect the nature of municipal infrastructure and the specifics of the given urban agglomeration.

It is important to stress the presented method's universality, and possibility of its being used in practice for a WSS of various different kinds relating to local specificity.

The analysis of the risk associated with the operation of the various WSS subsystems in regard to consumers of water will contribute to an increase in the latter's safety, which should after all be the standard where modern water-supply systems are concerned.

Acknowledgement

The research was granted by the Faculty of Civil and Environmental Engineering and Architecture of Rzeszow University of Technology.

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