

# WATER SUPPLY SYSTEM AS CRITICAL INFRASTRUCTURE OF A CITY

Ivica Turčić<sup>1</sup>, Alen Stranjik<sup>1</sup>, Sanja Jozić<sup>2</sup>

<sup>1</sup>University of Applied Sciences Velika Gorica, Velika Gorica, Croatia

<sup>2</sup>Kindergarten "Gajnice", Zagreb, Croatia

## Abstract

Critical infrastructure involves the systems, networks and facilities of great importance for the normal functioning of society. Interruption in the proper functioning of critical infrastructure can have serious repercussions for human health and/or serious economic consequences. Water and water management are among the key sectors of critical infrastructure in the countries comprising the European Union and as such hold great importance for the entire union, as well as for the each individual member state. This paper presents research results whose aim is to show how informed are the respondents about critical infrastructure in the Republic of Croatia, as well as their attitudes regarding the importance of critical infrastructure. In addition, the practical implications of this paper point to the necessity of stronger and systematic protection of water as critical infrastructure. Based on research results, the paper presents a proposal in which direction might be developed the corrections of the extant protection system, with the aim of improving the efficiency of the water supply system protection.

**Key words:** critical infrastructure, risk assessment, water supply

**Address for correspondence:** Ivica Turčić, University of Applied Sciences Velika Gorica, Zagrebačka c. 5, Velika Gorica, Croatia, e-mail: ivica.turcic@vvg.hr

## 1. INTRODUCTION

Critical infrastructure is a crucial or essential system without which it is impossible to function and whose endangerment endangers the entire system. Water and water management are one of the key sectors of critical infrastructure in the European Union member states. As such, they are of extreme importance for them and their communities.

This paper examines and explains the concept of critical infrastructure and the importance of water as a natural and social need of man, as well as the importance of the water supply system as critical infrastructure. In addition, it provides the analysis, assessment and representation of the possibility of threats to the water supply system as a critical infrastructure and its protection. For the purposes of this paper, a survey has been conducted whose aim has been to show how informed are the respondents about critical infrastructure in the Republic of Croatia, as well as their attitudes on the importance of critical infrastructure.

### 1.1. Conceptual definition of critical infrastructure

Critical infrastructure is a system or network in a certain society, which is the basis for the operation of the entire system, and is of particular importance for the functioning of something, meaning that it is an essential or crucial system without which it is impossible to function and whose endangerment endangers the entire system [1].

### 1.2. Critical infrastructure in the Republic of Croatia

Critical Infrastructures Act (NN 56/13) which regulates and conceptually defines critical infrastructures in the Republic of Croatia is in compliance with the European Union Directive and serves to provide their conceptual definitions [2]. According to the same Act and the Decision on the designation of sectors from which the central state administration bodies identify national critical infrastructures, and the list determining the or-

der of critical infrastructure sectors, the following systems have been defined as critical infrastructures:

- energy sector (production, transfer, storage, transportation of energy sources and energy, distribution systems)
- communications and information technology (electronical communications, data transmission, information systems, provision of audio and audiovisual media services)
- transportation (road, railway, air, maritime and inland waterways)
- healthcare system (health care, production, sales and control of medicines)
- water and water management (regulatory and protective water structures and utility water structures)
- food (food production and supply and the food safety system, commodity reserves)
- financial sector (banking, stock exchange, investments, security and payment systems)
- production, storage and transportation of hazardous materials (chemical, biological, radiological and nuclear materials)
- public services (ensuring public order and security, protection and rescue services, emergency medical services)
- national monuments and values [2]
- science and education [3]

Both in Croatia and elsewhere in other European Union member states, one of the most common sectors involves water and water management, so it is interesting to see how much is this sector protected and whether it is sufficiently secured against potential hazards.

### 1.3. Water and water management

Water is part of the ecosystem and one of the most important factors in maintaining its balance. Disruption in the water system inevitably leads to the disruption and changes in the ecosystem,

while the ecosystem disruption endangers the human community since water is a daily necessity for man. It manifests itself as man's natural and social need [4]. Therefore, water systems are very vulnerable systems. For their security, it is necessary to assess their vulnerability, develop the strategy for reducing exposure to attacks, ensure local and central funds for water infrastructure protection; develop and apply management in special conditions, analyze past events related to water systems malfunctions, identify physical threats to water infrastructure, understand the dangers of chemical and biological agents, protect critical infrastructure from attacks, utilize the early detection systems and monitoring [4].

### 1.4. City of Zagreb's water supply system

Public water supply activities in the Republic of Croatia are performed as public service and are of interest to local administrative units. They are required to ensure the functioning of the public water supply activities and have obligations proscribed by the Water Act [5]. According to this Act, public water supply is the abstraction of groundwater and surface water intended for human consumption and their conditioning and delivery to the end user or another water service provider [6]. It is essential to ensure water supply that is reliable and of high quality in the long term, while simultaneously being cost-effective [7].

At the same time, water protection is of utmost importance. Under the aforementioned Water Act, it is realized through the adoption of implementing regulations, monitoring water quality and sources of pollution, controlling pollution, prohibiting the release of pollutants into waters and the prohibition of other activities and behaviours which may cause pollution of the water environment and the environment as a whole; constructing and managing the facilities for drainage and treatment of waste water and other measures aimed at the preservation and improvement of water quality and utility [6].

The city of Zagreb is the capital of the Republic of Croatia, the largest city in Croatia with regard to population size and the cultural, scientific, economic, political and administrative center of the Republic of Croatia. Zagreb's water supply system covers an area of 800 km<sup>2</sup>. Water abstraction is performed on 8 water well fields from 30 water wells. The most important of those are: Mala Mlaka, Petruševac, Sašnak and Strmec and Zapruđe (Bundek). The system encompasses 3000 km of pipelines, 27,500 hydrants, 53 water pumping stations and 52 water reservoirs. 310,000 m<sup>3</sup> of water are pumped daily, while the service area includes approximately 900,000 inhabitants of Zagreb and its surroundings [8].

One of the largest water well fields is Petruševac, consisting of five buildings with a central management building. The wellfield has been devised within the so-called intervention programme, but the first water well was completed in 1987 and a pump installed. Nowadays, five deep wells have submersible pumps installed and all information is brought to the central building from which the wellfield is managed and operating data transferred to the dispatch center [9].

Apart from drinking water for the population, water is likewise important for the economy and economic development of a community – water is the basis for the industry, agriculture, energy sector, food production – in short, it spreads through virtually all critical infrastructure sectors and through all aspects of life for the local population, so a stable and high-quality water supply system is of primary importance for the local population and the survival of the community. It is of paramount importance to protect water resource systems and water infrastructure and to pay attention to the early detection of water contamination [4].

Based on everything that has been observed so far, a conclusion can be drawn that water is a fundamental resource without which there is no life. It has an economic, ecological and social value. As such, it may be a very tempting goal to those who would be ready to undertake any measure to harm the people and the entire community. Therefore, everything needs to be done to protect it from unwanted effects which are abundant and affect people's lives and health, the economy, social stability and politics, as well as the long-term disruption of the community.

### **1.5. Risk assessment for critical infrastructure on the example of the Petruševac waterwell field**

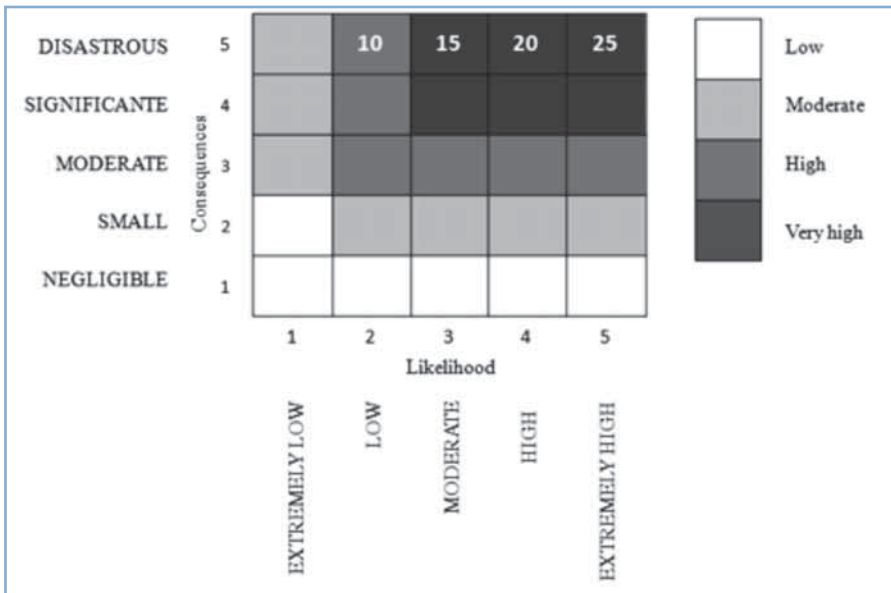
Risk assessment representation for critical infrastructure has been taken from literature available, and it has been devised on the example of contaminating Petruševac water well field with one of the deadliest chemical warfare agents [10]. In this example, the calculation has been made of the quantity of VX nerve agent needed to contaminate the entire water supply system covering the aforementioned water well field. The calculation has shown that it would take just under 150 kg of the VX nerve agent to contaminate the amount of water pumped within a month, which would certainly cause the entire population supplied from this water well field to come into contact with poisoned water, resulting in devastating consequences including the mortality rate of at least 50 percent of the given population. In addition, the entire system would be contaminated, which would subsequently jeopardize all further water abstraction from this water well field. The same source uses risk matrix 5x5 for further purposes of risk representation, combining the results of consequence and likelihood scenarios [10].

**Table 1.** Likelihood of worst-case unwanted event and consequences due to chemical warfare agent contamination for the facilities of Petruševac water well field. Source: created by the authors according to their own assessment.

Critical infrastructure marking	CI name	Likelihood of chemical warfare agent contamination	Level of consequences (due to contamination)	Risk	
Facility 1	Water pumping stations/wells	Water	4	5	20
Facility 2	Main pipelines	Water	2	5	10
Facility 3	Main pipeline hydrants	Water	4	5	20
Facility 4	Water reservoirs	Water	5	5	25
Facility 5	Secondary pipelines	Water	3	5	15

Table 1 shows the input parameter, or the product of the likelihood of worst-case event and consequences of chemical warfare agent contamination for the facilities of the Petruševac water

well field. It was then included into the worst-case event risk matrix for the chemical warfare agent contamination of the Petruševac water well field facilities.



**Figure 1.** Risk matrix for an event with worst-case consequences due to chemical warfare agent contamination of facilities at the Petruševac water well field. Source: created by the authors according to their own assessment.

Figure 1 shows the result obtained by the inclusion into the matrix, or that the event has been listed at the very top with disastrous consequences and with high and very high likelihood of occurring. The results of the aforementioned

paper present the conclusions drawn from data collected on the water wellfield itself and the given state of the protection of the entire infrastructure, both material and human. The paper concludes that the protection itself has remained as it was

during the time when the wellfield was put into operation. The investments into the protection system with regard to technology development and the availability of hazardous substances have not been sufficient, while protection has not been examined from all necessary aspects (such as the possibility of a terrorist attack, diversion or sabotage) in order to devise a high quality protection system. A conclusion is suggested that it is extremely important to invest in the development of crisis management, which is indispensable in the protection plan design and not only in the plants and facilities in order to gain as much material gain as possible. The need for stronger protection of water as critical infrastructure is emphasized, as well as the proposal in which direction should the corrections to the extant protection system be developed. Based on the tools used in this paper, it is possible to create various scenarios and models of risk assessment which may serve as a valuable foundation for the upgrading of extant protection systems since they provide insight into the weakest points and worst-case outcomes with the highest likelihood.

### 1.6. Research objectives and problems

The aim of the survey conducted for the purposes of this paper is to examine how informed are the respondents with regard to critical infrastructure in the Republic of Croatia, as well as their attitudes regarding the importance of critical infrastructure.

Pursuant to defined survey objectives, the following problems are addressed in this paper:

- *Problem 1:* Examine respondents' attitudes regarding the importance of critical infrastructure in the Republic of Croatia.
- *Problem 2:* Examine how informed are the respondents regarding individual critical infrastructure systems in the Republic of Croatia.
- *Problem 3:* Examine whether there are significant gender and educational differences in relation to how pronounced are the respon-

dents' attitudes on the importance of critical infrastructure in the Republic of Croatia.

## 2. METHODS

Primary and secondary data has been used for the purposes of this paper.

The examined theoretical framework was based on secondary data from relevant national and international literature, various online databases and secondary data from available materials regarding the defined critical infrastructure sectors from individual European Union member states and the City of Zagreb water supply system.

In collecting and analyzing secondary data, various research methods have been used, such as the descriptive method that simply describes or interprets facts, the comparative method that compares same or related facts, phenomena and relationships, the compilation method by which observations, conclusions and findings of other authors are propagated, the classification method that divides general terms into specific ones and other research methods.

Primary data has been obtained through an online questionnaire survey on a convenience sample of 250 respondents, and has been analyzed using statistical methods.

### 2.1. Survey respondents

The survey was conducted on a convenience sample of 250 respondents, whereby the average age amounted to  $M=36$  ( $sd=9.9$ ) and the number of male and female respondents was the same, 125 of males and 125 females.

The highest number of respondents (77%) is gainfully employed, while 14% of respondents are university students and 4.8% of them are unemployed. The respondents are equally employed in the service industry (16.40%), trade and distribution (14.00%), as well as the educational services sector (9.20%), public administration and administrative services (7.60%) and industry (7.20%). Considering the level of education completed, the-

re are equal shares of respondents who have attained secondary school degrees and lower (38.80%) and those who have university degrees (35.60%), while the share of respondents who have college degrees amounts to 19.2%.

## 2.2. Research procedure and instrument

The research was conducted in February and March of 2017 with the purpose of proving the research hypotheses. It was conducted using an online questionnaire survey developed by the authors themselves on a convenience sample of 250 respondents.

The sample of respondents utilized in this survey was a deliberate (convenience) sample, meaning that systematic sampling was not used. The respondents were guaranteed anonymity with a motivating brief explanation of the purpose of this survey. Time needed to complete the questionnaire was estimated to be 2 to 3 minutes. Statements used in the questionnaire were originally developed for the purposes of this survey bearing in mind the theoretical importance and the content of individual variables. Data was analyzed using IBM SPSS Statistics 20 software.

The following data was obtained through the questionnaire survey:

- Sociodemographic data (gender, age, level of education, employment status and the field of activity for the organization in which the respondent is employed).

- Attitudes regarding the importance of critical infrastructure.
- How informed are the respondents about the individual sectors of critical infrastructure in the Republic of Croatia.
- Respondents' self-assessment regarding their own knowledge related to critical infrastructure, gained through formal education.

## 3. RESULTS AND DISCUSSION

Below are the results related to the objectives and hypotheses of the survey, with a brief explanation of the results obtained and interpretations inferred during analysis.

### 3.1. Attitudes regarding the importance of critical infrastructure

Several questions or questionnaire statement were used to form a variable evaluating the attitudes regarding the importance of critical infrastructure. To be more specific, statements "*Endangering critical infrastructure puts the entire social system in danger*", "*It is necessary to identify critical infrastructure*" and "*Critical infrastructure is important for the normal functioning of government*" form a variable *Attitude regarding the importance of critical infrastructure* consisting of 3 statements on a scale from 1 – 5. Its reliability is satisfactory and the Cronbach's alpha coefficient amounts to 0.847.

Table 2 shows that the respondents agree that

Table 2. Representation of descriptive data for statements examining attitudes regarding the importance of critical infrastructure. Source: created by the authors according to questionnaire survey data.

	Min	Max	M	sd
Endangerment of critical infrastructure endangers the entire social system.	1	5	3.8	1.35
It is necessary to identify critical infrastructure.	1	5	4.06	1.58
Critical infrastructure is important for the normal functioning of the government.	1	5	3.92	1.27
<b>Attitude on the importance of critical infrastructure</b>	<b>3</b>	<b>15</b>	<b>11.78</b>	<b>3.68</b>

critical infrastructure is important, and they range from 1-5 with an average grade approximately 4. The three specified statements form the variable *Attitude regarding the importance of critical infrastructure whose average value amounts to  $M=11.78$  ( $sd = 3.68$ )*. Therefore, this survey shows that the respondents relatively highly evaluate the importance of critical infrastructure, that is, they are aware of its importance for the functioning of the social system.

Previous sections of this paper showed the possibilities and risks of contamination for one of critical infrastructure systems, water and water management, as well as the devastating effects it would have for the water supply system of a city.

For this reason the questionnaire examined the percentage of respondents who use drinking water from the city water supply system, as well as the level of trust they put in the system itself, or the number of respondents who would consume water from the city water supply system again subsequent to the contamination of the city water

supply network. Survey results have shown that more than 95% of respondents use water from the city water supply system, which is additional proof that water and water management truly constitute critical infrastructure of great importance for a city. At the same time, a little more than 60% of respondents would continue to consume water from the city water supply system after its decontamination, which indicates that trust in the system itself is not so high and it would unsettle the system and reduce the usage of city water supply network.

### 3.2. How informed are respondents about individual critical infrastructure sectors in the Republic of Croatia

In order to examine how informed are the respondents regarding critical infrastructure in the Republic of Croatia, the respondents have been asked to indicate those sectors defined as critical infrastructure sectors among the sectors listed in the survey. The frequency of responses is shown in Table 3.

Table 3. Percentage of respondents who consider individual systems to be critical infrastructure sectors in the Republic of Croatia. Source: created by the authors according to questionnaire survey data.

Respondents' answers	%
Energy sector is a critical infrastructure sector in the Republic of Croatia	79.6
Tourism is a critical infrastructure sector in the Republic of Croatia	17.2
Finance is a critical infrastructure sector in the Republic of	44.0
Water and water management are a critical infrastructure sector in the RoC	74.4
Production, storage and transportation of hazardous substances are CI sectors in the RoC	50.0
Marketing is a critical infrastructure sector in the Republic of	3.2
Food is a critical infrastructure sector in the Republic of Croatia	58.8
Transportation is a critical infrastructure sector in the Republic of Croatia	58.8
Sport is a critical infrastructure sector in the Republic of Croatia	4.8
Healthcare services are a critical infrastructure sector in the Republic of Croatia	66.4
Communications and information technology is a CI sector in the Republic of Croatia	42.8
Banks are a critical infrastructure sector in the Republic of Croatia	23.6
Public services are a critical infrastructure sector in the Republic of Croatia	42.4
National monuments and values are a critical infrastructure sector in the RoC	9.6
Science and education is a critical infrastructure sector in the Republic of	39.2

From the results shown we can see that a large majority of respondents, more than 65%, consider *energy sector, water and water management*, as well as the healthcare system are critical infrastructure systems, while food, transportation services and production, storage and transportation of hazardous substances are seen as critical infrastructure systems by the half or more than half of respondents. Only about forty percent of respondents mention *communications and information technology, finance, science and education and public services* as critical infrastructure systems. By far the smallest number of respondents recognizes national monuments and values as a critical infrastructure sector, which was indicated by less than 10% of respondents.

It is interesting that respondents were offered four sectors which are not critical infrastructure sectors among the possible answers and approximately twenty percent of respondents included *banks and tourism* among critical infrastructure sectors, although they are not. Most interestingly, of all 250 respondents who completed the questionnaire only one respondent listed all 11 defined critical infrastructure sectors in the Republic of Croatia. It is evident that the results suggest the need for a clearer plan to inform the population regarding critical infrastructure systems in the Republic of Croatia.

### **3.3. Gender and educational differences in relation to how pronounced are the respondents' attitudes on the importance of critical infrastructure in the Republic of Croatia**

The testing of statistical significance of gender differences regarding the results of the scale on the Attitude regarding the importance of critical infrastructure has been conducted with the purpose of examining gender differences in relation to the attitude on the importance of critical infrastructure. The difference between male and female respondents concerning the attitude on the importance of critical infrastructure has not been

statistically significant ( $t=-1.23$ ,  $p > 0.05$ ), thus the attitude on the importance is not dependent on gender and in this respect there are no significant differences between the respondents' attitudes.

Likewise, considering the equal number of respondents with secondary education or lower and respondents with higher education, possible differences in the expression of attitude on the importance of critical infrastructure have also been tested for these two groups. The results show that there are no differences between respondents with secondary education and those with higher education with regard to the attitude on the importance of critical infrastructure ( $t=-0.714$ ,  $df=184$ ,  $p > 0.05$ ), which confirms that level of education has no significant impact on the attitude regarding the importance of critical infrastructure.

Therefore, the findings of the results' analysis point to the conclusion that, notwithstanding gender and level of education, the respondents do not differ with regard to the attitude on the importance of critical infrastructure, that is, everyone thinks it is important.

### **3.4. Respondents self-assessment of their own knowledge related to critical infrastructure gained through formal education**

Concerning the attitude whether formal education provided sufficient knowledge of critical infrastructure to the respondents, on the scale of 1-5 the respondents give an average grade of  $M = 2.86$  ( $sd=1.33$ ) which means that on average they neither agree nor disagree with the statement, or they in any case confirm that there is room for additional information which they have not acquired during their formal education. Taking into account previous data and research results which show that respondents consider critical infrastructure to be important, the implication here is that, given the importance of the matter, respondents clearly state that their education has not provided them with sufficient knowledge of the subject. Therefore, there is room to further edu-



cate the general population on the topic of critical infrastructure, its importance, systems belonging to it, ways in which it is managed, protection methods and systems and other details important for broader information and education regarding critical infrastructure.

### 3.5. Discussion

Similar surveys on this topic were conducted in Croatia and neighbouring countries in 2015 and 2016 during the implementation of the RECIPE international project funded by the European Commission. Using a questionnaire survey, information was gathered and analyzed on the awareness of extant legislation and protection practices regarding critical infrastructure in the Republic of Serbia and the Republic of Croatia, vulnerability assessment and identification of threats to critical infrastructure in the Republic of Serbia and the Republic of Croatia, applicability of current methods and critical risk assessment analysis for infrastructure, analysis of critical infrastructure interrelationships in the Republic of Serbia and the Republic of Croatia, establishment of procedural strategies to improve cooperation and communication between national entities and between relevant entities at the international level, as well as future modalities for an efficient exchange of experiences and knowledge transfer among relevant entities and defining mechanisms to exchange sensitive information. Bearing in mind that critical infrastructure has for decades been treated as objects and facilities very important for defense, greater awareness of critical infrastructure itself and its protection was to be expected, however, questionnaire results have shown a similar situation or low level of information and awareness as has been established in the survey conducted for the purposes of this paper. It should be noted that the RECIPE project survey involved a targeted sample of respondents who should have had a high level of awareness regarding critical infrastructure

by virtue of their professional occupation. Feasibility study developed through the project provided recommendations for activities necessary to raise awareness at all social levels in order to exert influence on a more active protection and preservation of critical infrastructure in the future [11].

## 4. CONCLUSIONS AND PRACTICAL IMPLICATIONS

Research results show that the respondents relatively highly assess the importance of critical infrastructure, that is, they are aware of its importance for the proper functioning of the social system. On the other hand, given the importance of the matter and a relatively high assessment of its importance, the respondents clearly state they have not been sufficiently informed regarding critical infrastructure during their formal education. Critical infrastructure sectors which have received the highest level of recognition among the respondents are the energy sector, water and water management and healthcare services, while the least recognition is given to the sector of national monuments and values, which likewise confirms the need for further education regarding the defined critical infrastructure sectors.

Research results presented in this paper have unquestionably shown there is room to further educate the general population regarding critical infrastructure, its importance, its complimentary systems, ways in which it is managed, protection methods and systems and other details important for broader information and education on critical infrastructure. Likewise, a conclusion may be drawn that the low level of awareness regarding critical infrastructure is compounded by the new critical infrastructure terminology as opposed by previously used terminology, which is very likely the reason for poor results of surveys conducted in this paper, but also previous surveys conducted within the scope of the RECIPE project in the Republic of Serbia and the Republic of Croatia.

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## VODOVOD KAO KRITIČNA INFRASTRUKTURA GRADA

### Sažetak

Kritična infrastruktura su sustavi, mreže i objekti od velike važnosti za normalno funkcioniranje društva. Prekid funkcioniranja kritične infrastrukture može imati ozbiljne posljedice po zdravlje ljudi i/ili ozbiljne ekonomske posljedice. Voda i vodna gospodarstva jedan su od ključnih sektora kritične infrastrukture u zemljama Europske unije te su kao takvi od iznimne važnosti za cjelokupnu zajednicu, ali i svaku pojedinu članicu. U ovom radu prikazani su rezultati istraživanja čiji je cilj pokazati informiranost ispitanika o kritičnoj infrastrukturi u Republici Hrvatskoj kao i njihove stavove o važnosti kritične infrastrukture. Uz to, praktične implikacije ovog rada odnose se na ukazivanje nužnosti snažnije i sustavne zaštite vode kao kritične infrastrukture. Na temelju rezultata istraživanja, rad prikazuje prijedlog u kojem smjeru bi se mogle razvijati korekcije postojećeg sustava zaštite s ciljem poboljšavanja učinkovitosti zaštite vodoopskrbnog sustava.

**Ključne riječi:** kritična infrastruktura, vodoopskrba, procjena rizika