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ASSESSMENT OF RISKS FOR DRINKING WATER INFRASTRUCTURES BY CARVER METHOD: CASE STUDY – İZMİR

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ABSTRACT

Critical infrastructures are the most attractive targets for the elements that threaten the security of societies. Threats on critical infrastructures such as energy, information and communication technology, transportation, health and water are amongst the most vulnerable sectors that national and international institutions are focused on. In this regard, both the United States and the European Union consider water/wastewater infrastructure as one of the most important critical sector. In this study, assessment of the risks for the drinking water infrastructure of İzmir was conducted by using the CARVER method to identify system components that are under higher risk with different scenarios. The results showed that the most critical components of the system were the dam reservoir for the case of an intentional contamination scenario; and, the drinking water treatment plant, water intake structure, pumping stations and dam body for the case of physical and natural threats.

Keywords: Critical drinking water infrastructures, CARVER methodology, risk assessment.

1. INTRODUCTION

In the changing world, factors such as international political and diplomatic crisis, social and economic injustices, environmental and health problems, wars and migrations are threatening the peace and security of societies all over the world, particularly in the Middle East. Even the most developed cities of the world can be targets of large scaled terror actions due to advances in technology and telecommunication. In majority of these terrorist acts, either innocent civilians are directly targeted in highly populated metropolitan areas such as New York, Paris, Beirut, Brussels and Ankara, or critical infrastructure systems such as power generation facilities, energy transmission lines, drinking water systems and communication networks are deliberately attacked to undermine modern societal life.

Critical infrastructures are defined as systems or parts which are essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact in the country as a result of the failure to maintain those functions [1]. The threats to infrastructures such as energy, information technology, telecommunications, transportation, health and water/wastewater are

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among the issues that national and international institutions emphasize. Water/wastewater infrastructures are one of the most important critical infrastructure elements determined by the United States and the European Union [2]. In particular, if natural or human-caused threats act on drinking water infrastructures, there occurs a serious public health risk on the masses of society. Taking all risks into consideration, it can be said that water/wastewater infrastructure systems have turned into targets with great sensitivity in terms of sustainability of modern social life.

In this study, the "CARVER" method is used as an evaluation tool to prioritize the current status of critical infrastructures and to prioritize the risks to which they would be exposed under natural and terrorist threats. CARVER method evaluates the risks for a critical infrastructure element by giving a numerical value for six factors: **C**riticality, **A**ccessibility, **R**ecuperability, **V**ulnerability, **E**ffect and **R**ecognizability [3]. Although CARVER method is initially developed as a method for performing target priority analysis for military purposes, it has eventually became a technique that is widely used in evaluating the possible risks that may arise in different critical infrastructures under distinct scenario conditions.

In this study, Tahtalı system which is one of the main elements of Izmir drinking water infrastructure was examined. Risks caused by natural disasters, terrorist attacks and cyber threats on numerous components including the dam body, water intake structure, pumping stations, water transmission line, treatment plant, distribution network and reservoir were evaluated using CARVER methodology. Considering the fact that the Tahtalı system meets a significant portion of the drinking water needs of Izmir metropolitan area, it is a vital component of the drinking water system of İzmir. Thus, the status of these components is determined against the mentioned threats and the measures necessary to be taken by the authorities in order to ensure the safety of these facilities are determined.

2. CARVER METHOD

The CARVER method is a widely used method that was developed to perform risk analysis. The method consists of six factors criticality, accessibility, recuperability, vulnerability, effect and recognizability. All criteria are scored according to its significance on a scale ranging from 1 to 10 and a total cumulative priority score is then calculated. The method was originally developed to analyze and prioritize potential targets for military purposes and to select the best target or target components for the attack. Each target is scored on a criterion basis to reveal the numerical score indicating how appropriate it is to attack to that particular target. All the numerical values given for the criteria are arranged in a matrix and the total scores for each target are obtained. The total score is considered to be the target score and the target with the highest score is considered to be the best target for attack. Within the scope of this study, CARVER was adapted for defensive purposes and applied to critical drinking water infrastructures. The sensitivity of infrastructure components is determined and components are prioritized using the method. As a result, each component of the system is comparatively ranked under different scenario conditions and the level and urgency of the measures to be taken are determined more realistically.

Criticality (C): This criterion represents the public health, social perception and economic importance of the threat to the critical infrastructure component. In this context, ranking is done by the number of people who might be effected or possibly lose their life in case of a threat/attack to the subject component. (Table 1).

Table 1. *Critical ity* criterion and scaling

Criticality	Scale
1,000,000 or more people would be effected	9 - 10
Between 500,000 and 1,000,000 people would be effected	7 - 8
Between 100,000 and 500,000 people would be effected	5 - 6
Between 10,000 and 100,000 people would be effected	3 - 4
Less than 10,000 people would be effected	1 - 2

Accessibility (A): This criterion represents the physical accessibility of the target prior to the attack and the ease to leave facility after the attack. If someone can enter/exit the component without being detected for the purpose of an attack, then this component could be classified as easily accessible. In other words, this criterion indicates how much the target is open to the threat. This criterion should be assessed independently from the likelihood of the threat being successful (Table 2).

Table 2. Accessibility criterion and scaling

Accessibility	Scale
Easily accessible (e.g. Target is in open area, not surrounded by any fence). Limited level of barrier and observation. The target is almost easily accessible. The attack can be carried out by transport of medium or large volume of pollutants without detection. Information about the target can easily be obtained via multiple sources.	9 - 10
Accessible (e.g. Target is in a building but in an unsecure part of the facility). Limited level of barrier and observation. Attacker can reach the target in 1 hour or less. The attack can be carried out by transport of medium or large volume of pollutants without detection but still needs hiding. Information about the target can be obtained via limited sources.	7 - 8
Partially accessible (e.g. Target is in a building but in a relatively unsecure, busy part of the facility). Possible to be under regular human observation. There could be some extra physical barriers. Attacker can reach the target in limited time and needs to hide the pollutant. Not specific but only general information about the target can be obtained.	5 - 6
Hardly accessible (e.g. Target is in a building and in a secured, protected part of the facility). Under regular human observation and behind effective barriers. Only authorized personal and operators can reach the target. Attacker can reach the target in a serious limited time and needs to hide the pollutant. Only general and limited information about the target can be obtained.	3 - 4
Not accessible or inaccessible without extreme difficulty Under regular human observation with alarm systems and behind physical barriers. Attacker has to reach the target in only 5 minutes or less by carrying the pollutant on its own. There is no public information about the target.	1 - 2

Recuperability (R): A target's recuperability is measured in time; that is, how long it will take to re-operate the system in full capacity after the destruction or the damage. This criterion includes time required for repairing or replacing the system (Table 3).

Table 3. Recuperability criterion and scaling

Recuperability	Scale
Replacement, repair, or substitution requires > 1 year	9 - 10
Replacement, repair, or substitution requires 6 - 12 month	7 - 8
Replacement, repair, or substitution requires 3 - 6 month	5 - 6
Replacement, repair, or substitution requires 1 - 3 month	3 - 4
Replacement, repair, or substitution requires < 1 month	1 - 2

Vulnerability (V): It can be defined as an indication of how effective the target will be within the system after a successful threat/attack. In another words, it is an assessment that quantifies to what extent the system will be affected as a result of the damage to the target. This criterion does not consider the accessibility of the target, in contrary, the target is assumed to be completely accessible. Using this assumption, both the target itself and its environment are evaluated (Table 4).

Table 4. Vulnerability criterion and scaling

Vulnerability	Scale
The target is extremely vulnerable for the success of the attack (%90-100). It does not require any level of expertise or ability to achieve objectives.	9 - 10
The target is very vulnerable for the success of the attack (%60-90). It requires low level of expertise or ability to achieve objectives.	7 - 8
The target is partly vulnerable for the success of the attack (%30-60). It requires moderate level of expertise or ability to achieve objectives.	5 - 6
The target is less vulnerable for the success of the attack (%10-30). It requires high level of expertise or ability to achieve objectives.	3 - 4
The target is almost invulnerable or much less vulnerable for the success of the attack (<%10). It requires very high level of expertise or ability to achieve objectives.	1 - 2

Effect (E): It represents the amount of loss that occurs in the production potential of the system after the threat/attack. This criterion was categorized by considering the percentage of the loss that could occur on the system (Table 5).

Table 5. Effect criterion and scaling

Effect	Scale
More than 50 % of the system production is affected	9 - 10
The system production is affected about 25-50 %	7 - 8
The system production is affected about 10-25 %	5 - 6
The system production is affected about 1-10 %	3 - 4
Less than 1 % of the system production is affected	1 - 2

Recognizability (R): A target's recognizability is the degree to which it can be recognized by the attacker without being confused with other targets or components. However, recognition is also a measure of how much technical knowledge and expertise are required to identify the target. In addition, the complexity of the system must also be considered within this criterion (Table 6).

Table 6. Recognizability criterion and scaling

Recognizability	Scale
The target is clearly recognizable; it requires no training for recognition.	9 - 10
The target is easily recognizable and requires a small amount of training for recognition.	7 - 8
The target is difficult to recognize, might be confused with other targets or target components; it requires some training for recognition.	5 - 6
The target is very difficult to recognize; it is easily confused with other targets or components. It requires extensive training for recognition	3 - 4
The target cannot be recognized under any conditions, except by experts.	1 - 2

Based on these criteria, each target and its components are evaluated and a score is assigned for each CARVER criterion. Once the evaluation phase is completed, each target gets a single score by adding the scores it receives per criterion, and the system components are comparatively ranked. The magnitude of this cumulative score is an indication that the system is open to attack and means that the corresponding component needs to receive a priority in the preventive measures to be taken. Therefore, the sums represent the relative desirability of each potential target and this constitutes a prioritized list of targets.

3. DRINKING WATER INFRASTRUCTURE OF IZMIR

Izmir is the third largest city of Turkey with a population of about 4 million people. The city supplies its drinking water from various ground and surface water resources. While central and northern parts of the city are fed by Sarıkız-Göksu, Menemen-Çavuşköy, Pınarbaşı and Halkapınar-Çamdibi wells; southern parts are mostly fed by surface water resources such as Tahtalı and Balçova reservoirs. Tahtalı Dam constructed on Tahtalı Stream is the most significant surface water resources of the city. The water stored in the dam lake are intaken by a tower type water intake and pumped to a stabilization tank. The water is then transferred to Görece Water Treatment Plant through a transmission line. The treated water is then pumped to Karabağlar storage tank and is later distributed by the distribution network [4]. Water supplied from Tahtalı Dam serves the requirements of districts such as Gaziemir, Karabağlar, Buca, Bozyaka, Hatay, Basın Sitesi, Yeşilyurt and Limontepe which are located to the south of the city. It is also possible to supply water obtained from Tahtalı system to northern and central districts of the city if necessary. In this study, CARVER method was implemented on the critical infrastructure elements of Tahtali water supply system to evaluate potential risks under various scenario conditions.

3.1. Main and Water Body of Dam

Tahtali Dam is a clay-cored rock fill structure and is the largest surface water resource of İzmir. It has a total watershed area of 546 km^2 and an annual water potential of 128 million m^3. The height of the dam body from foundation is 57.5 m. The water surface elevation in the lake varies between 31 and 60.5 m above mean sea level. The active storage volume of the dam is 287,050,000 m^3 [4].

3.2. Water Intake Structure and Pumping Station

The water intake structure, which was constructed as a 35 m high reinforced concrete tower, has a 17 m diameter and consists of six pumps with a total capacity of 6.134 m³/s. It was designed to intake water from 29 m, 36 m, 43 m and 50 m water surface elevations. The intaken water is pumped to the stabilization tank located at Sakartepe via 2 steel pipes of 1600 mm diameter and 580 m length. The stabilization tank is 6 m in diameter and 15 m in height and has a volume of 400 m³ [4].

3.3. Water Transmission Lines

Water from the stabilization tank is transmitted to drinking water treatment plant at Görece with a 17505 m long pipeline. The treated water from the treatment plant is transferred to the main water reservoir with another pipeline of 14730 m in length and later distributed to the network from the storage reservoir at Karabağlar. The transmission line between Tahtalı Dam and Karabağlar water reservoir has a total length of 32235 m in length and is composed of steel-coated prestressed concrete pipe with an inner diameter of 2200 mm. This line has a total capacity of 5.94 m^3/s [4].

3.4. Drinking Water Treatment Plant

Tahtalı drinking water treatment plant located in Görece has a total capacity of 520,000 m³/day and contains rapid mixers, clarifiers, filters, chemical storage units, chlorine plant and filter press unit. The treatment plant consists of two parallel lines of 260,000 m³/day capacity [4].

3.5. Pumping Stations

İzmir drinking water network is fed by 78 pumping stations or pumping groups. 7 of these are used only for monitoring, while 71 of are served for pumping water. These stations contain 2 to 14 variable and constant flow pumps and these pumps are activated or deactivated according to pressure conditions of the network through Supervisory Control and Data Acquisition (SCADA) system.

3.6. Distribution Network

Distribution network of the city consists of pipe lines that vary from 80 mm to 2200 mm in diameter. Tahtalı system mostly feeds Buca, Gaziemir, Karabağlar, Hatay and Yeşilyurt districts located to the south of İzmir. Karabağlar reservoir that serves these districts was deactivated according to the converter system operating principles and is currently kept ready for use.

3.7. Storage Tanks and Reservoirs

As of 2015, there are 78 main and secondary tanks and reservoirs in İzmir drinking water system with storage volumes ranging from 100 to 55,000 m^3. The largest of these is the Halkapınar reservoir which has a total storage capacity of 55,000 m^3 and is the main distribution structure for the southern parts of the city. The other two largest reservoirs that serve the Tahtalı system have capacities of 21,000 m^3 and 15,000 m^3 and are located at the exit of Tahtalı treatment plant and at Karabağlar, respectively.

4. RESULTS AND DISCUSSIONS

In this study, Tahtalı water supply system was evaluated by using the CARVER method to assess the potential risks originating from threats caused by 4 different scenarios. The components of the system analyzed in this study included the dam body and the lake, the water intake structure, pumping stations, the water transmission line, the water treatment plant, the distribution network and storage reservoirs. The scenarios included the assessment of the risks associated with: (1) intentional addition of contaminants into the system, (2) physical attack in order to disrupt or completely stop the operation of critical infrastructure units, (3) a natural disaster (earthquake) and (4) the exposure of critical infrastructure components to cyber attacks. The evaluations of CARVER parameters for these scenarios were conducted with the help of system analysis, field studies and expert opinions. The results are presented in Tables 7 through 10.

The risks that would arise in case of intentional contamination of critical infrastructure components were analyzed in the first scenario. Here, the attacks included the entrance of a biological or chemical agent into an infrastructure component. Based on this scenario, infrastructure components were investigated according to the contaminants' potential to reach the end user and their effect on human health. The results associated with Scenario 1 are presented in Table 7.

Table 7. Results of scenario 1

Name of the infrastructure element	C	A	R	V	E	R	Total
Main body of dam	1	1	1	1	1	10	15
Lake	8	9	10	10	9	10	56
Water intake structure and pumping station	10	4	1	3	10	6	34
Water transmission line	10	1	2	2	10	1	26
Drinking water treatment plant	10	4	3	1	10	5	33
Pumping station	8	6	1	2	5	5	27
Distribution network	8	2	4	2	2	1	19
Reservoirs	6	7	1	2	3	8	27

Within the scope of this scenario, it can be seen that the main body of dam has the lowest score for the total CARVER score compared to the other system components. In this scenario, the Tahtalı Lake is the component that received the highest score and thus considered to have the highest risk in terms of being a target. Considering accessibility and potential impacts, it can be seen that the Tahtalı Lake is likely to receive the biggest threat. On the other hand, the water intake structure and pumping station and the drinking water treatment plant are the other components that preventive measures need to be taken for this particular threat. The distribution network is found to have lower risk levels for this scenario because it is typically not easy to mix contaminants due to high operating pressures and the difficulty to recognize the underground distribution system components (Table 7).

In the second scenario, a physical attack to disrupt or stop the operation of the critical infrastructure component was evaluated. Components that are located on the ground are likely to experience the maximum impact in the case of a complete collapse. As a result, the main dam body, water intake structure and drinking water treatment plant units are more likely to be influenced from this type of an attack and become primary targets. It is considered that lake and distribution network will have lower risks than other components in the case of a physical attack (Table 8).

Table 8. Results of scenario 2

Name of the infrastructure element	**C**	**A**	**R**	**V**	**E**	**R**	**Total**
Main body of dam	10	1	10	5	10	10	**46**
Lake	1	9	1	1	1	10	23
Water intake structure and pumping station	10	6	8	7	10	6	**47**
Water transmission line	10	3	6	5	9	1	34
Drinking water treatment plant	10	6	10	6	7	5	44
Pumping station	8	6	5	7	5	5	36
Distribution network	6	2	4	3	4	1	20
Reservoirs	6	8	4	5	4	8	35

In the third scenario, risks on critical infrastructure components caused by a natural disaster were investigated. Because natural disasters have different effects, only "earthquakes" were considered in this scenario. Earthquake magnitude was assumed to be the highest that can occur in the region in order to put the risks seriously and evaluate them regardless of the magnitude of the threat. One of the points to be noted at this point is the precautions that were taken during the construction of the existing structures. For instance, potential earthquake risks are already considered in the design of large buildings such as the main body of dam and the treatment plant and these structures are typically built to withstand these risks. However, different scores were obtained due to the characteristics of the components because earthquake is likely to effect a large area and cannot isolate and impact a single target. The main body of dam, water intake structure and pumping stations and the drinking water treatment plant are the most threatened components. All other infrastructure components excluding the lake are under significant risk in this scenario (Table 9).

Table 9. Results of scenario 3

Name of the infrastructure element	**C**	**A**	**R**	**V**	**E**	**R**	**Total**
Main body of dam	10	10	10	8	10	1	**49**
Lake	1	4	1	1	1	1	9
Water intake structure and pumping station	10	10	8	8	10	1	47
Water transmission line	10	8	5	6	9	1	39
Drinking water treatment plant	10	10	10	8	10	1	**49**
Pumping station	8	10	4	8	7	1	38
Distribution network	6	8	5	5	6	1	31
Reservoirs	6	10	3	8	5	1	33

In the fourth scenario, the cyber threats, which became comparatively important in recent years and can target a wide variety of systems, were analyzed. It is known that critical infrastructure systems are under risk because they are managed by electronic control systems (i.e., SCADA systems). A distinguishing feature of cyber attack from other threats is that it does not require any physical access to the facility and can easily be done remotely. In this particular scenario, it was assumed that the control of the system is captured by non-authorized malicious persons through remote access. Measures such as the use of username and passwords, firewalls and ease in switching to manual operation against malicious remote access were considered to be risk mitigating factors. When Tahtalı system components are analyzed, the dam body, lake and water transmission line were considered to be fairly safe with regards to cyber attacks. On the contrary, water intake structure and pumping station, drinking water treatment plant, in-line pumping stations and storage reservoirs were determined as significant targets in this particular scenario (Table 10).

Table 10. Results of scenario 4

Name of the infrastructure element	**C**	**A**	**R**	**V**	**E**	**R**	**Total**
Main body of dam	1	1	1	1	1	1	6
Lake	1	1	1	1	1	1	6
Water intake structure and pumping station	10	6	1	7	10	6	**40**
Water transmission line	1	1	1	1	1	1	6
Drinking water treatment plant	10	6	2	8	10	4	**40**
Pumping station	8	6	2	6	10	5	37
Distribution network	6	6	1	5	10	1	29
Reservoirs	6	6	1	5	10	7	35

5. CONCLUSIONS AND RECOMMENDATIONS

Globalization and widespread use of technology have caused new threats for the existence and wellbeing of societies. Increased violence also increases the responsibilities of authorities. Critical infrastructure systems have a significant place as being targets of these threats that risk the overall safety of communities. In particular, potential threats on drinking water infrastructures create serious public health concerns on large masses of population. The “CARVER” method used in this study is one of the techniques applied to prioritize the risks that will arise due to potential natural and man-made threats. The method is applied to the Tahtalı System of İzmir Drinking Water Infrastructure and risks to be caused by natural disasters, terrorist attacks and cyber threats on the components of the system (such as dam body, lake, water intake structure, pumping stations, water transmission line, treatment plant, distribution network and storage reservoirs) were evaluated and prioritized.

According to the results of the analysis, the most vulnerable structures were identified as the Tahtalı dam lake for contamination; dam structure, water intake structure, drinking water treatment plant and pumping stations for physical attacks; dam structure and drinking water treatment plant for natural disasters; and water intake structure and pumping station and drinking water treatment plant for cyber attacks. These components were found to be more vulnerable and can alter the overall operational performances as they are the predominant components of the system. In case of emergencies, the presence of parallel units in the system will be effective in reducing the damage that may occur. Further, continuous monitoring of lake, water intake structure and the distribution system as well as the limited access to the system components improve the system’s overall resilience to intentional attacks. Nevertheless, it is necessary to perform leak detection tests and integrate additional preventive barriers for cyber attacks. Overall, the Tahtalı system of İzmir Drinking Water Infrastructure was found to have low to moderate level risks for the threats analyzed in this study.

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