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LOCAL, REGIONAL AND GLOBAL BEST PRACTICE FOR WATER

Risk management in water supply networks: Aveiro case study

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Abstract

Water supply networks are critical infrastructures essentials to health, safety, economic and social well-being which have to be maintained and preserved to ensure their proper functioning. Considering the importance of these critical infrastructures, the risks to which they are exposed and the consequences of such risks must be analysed. Thus, it is important that companies responsible for the management of these assets incorporate risk management in their activities. In the scope of risk management, this paper intends to identify the vulnerabilities of water supply infrastructures, by analysing the risks they are exposed and identifying the measures that need to be implemented or reinforced. Risk assessment methodologies were analysed to identify the advantages and disadvantages of each one. As a case study, the water supply network of the Aveiro municipality in mainland Portugal was used. This network was analysed resourcing ArcMap, ArcGIS desktop software, which allows a better understanding of the water supply network. Risk management was applied and the probability and possible consequences of six distinct categories of threats were determined in eight scenarios, allowing the development of risk maps concluding that all these scenarios are in a low or medium level of risk. To decrease the vulnerability of the water network, a set of plans and specific measures have to be developed.

Keywords Critical infrastructures · Risk assessment · Water supply network · ArcGIS · ArcMap

Introduction

Infrastructures' safety management is a current challenge for governments and for the respective owners and operators (Pye and Warren 2006). The critical infrastructures' systems and installations are subject to several failure modes. Thus, it is important to anticipate the possible hazards, its probability of occurrence and the severity of its consequences (Baker et al. 2003). The hazards under which the critical structures and infrastructures may be subject can be intentional (e.g. terrorism, sabotage, cyberattacks) or non-intentional (accidents, ageing, natural events). Hazards are defined as an element as itself or more than one hazard in combination with others and the possible interrelations between them, including their simultaneous or cumulative occurrence and their potential interactions. A situation that represents a threat level to life, health, property or environment corresponds to a hazard (Vasyl et al. 2013). The urban network of water supplies is almost always composed by water abstraction sources, adductor conducts, treatment stations and supply networks being exposed to a variety of hazards that may affect its functioning (Roozbahani et al. 2013). As water is essential for human life, it is considered a resource that has to be preserved (Halfaya et al. 2012), being the analysis, mitigation or elimination of those risks a priority.

The ISO 31000: 2009 defines risk as the effect of uncertainty on objectives, where an effect is a deviation from the expected—positive and/or negative (ISO 2009). The standard considers that objectives can have different aspects (such as financial, health and safety and environmental goals) and can be applied at different levels (such as strategic, organization-wide, project, product and process). During the risk, assessment measures can be taken for risk elimination or reduction.

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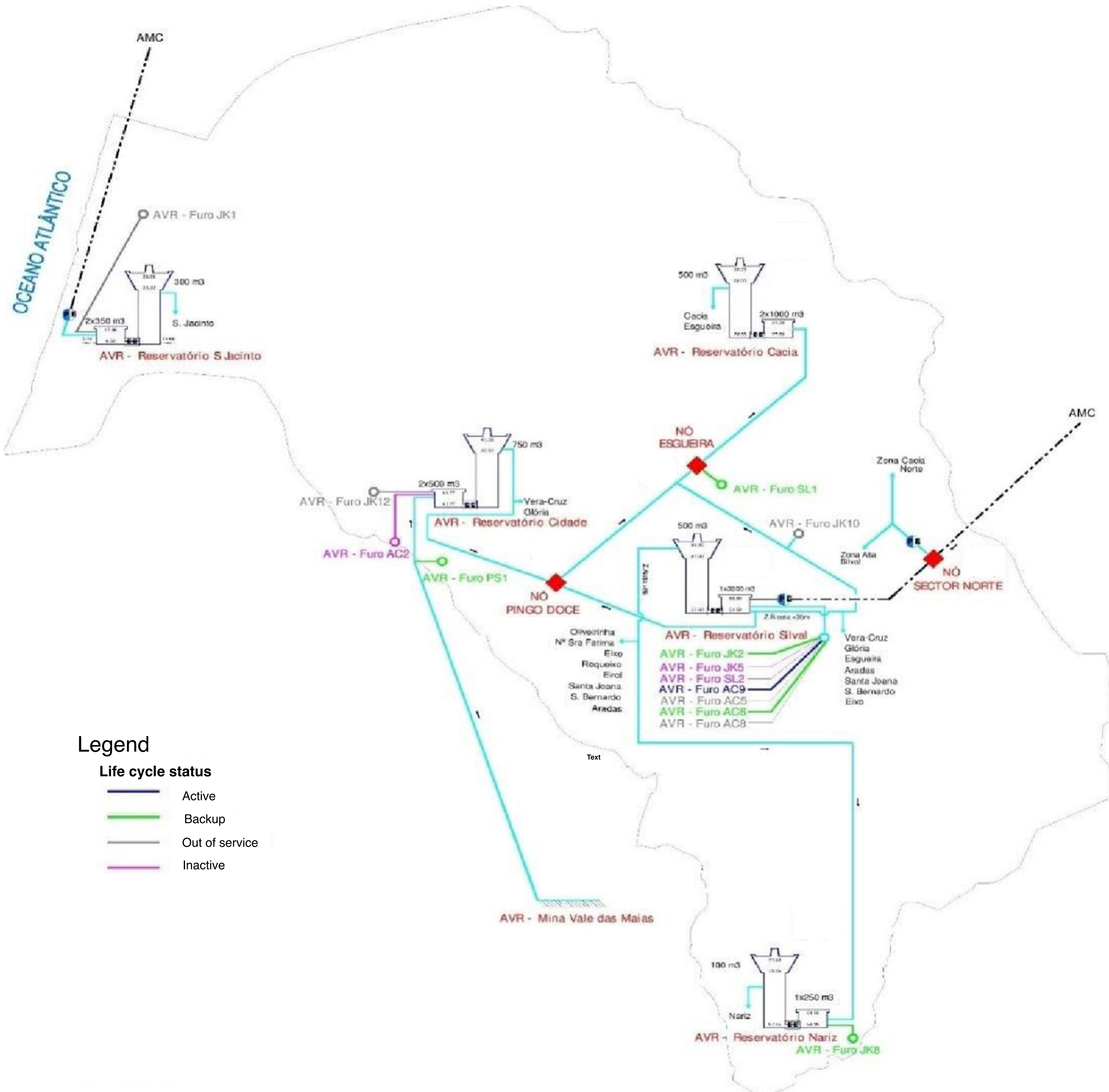

Fig. 1 General water supply network of the Aveiro municipality

When these are impossible to be implemented, mitigation and protection measures can be established. The more effective way to analyse the benefits between risk reduction and protection measures is to implement a decision support system that integrates information about threats, vulnerability assessment and the consequences of the service interruption, through advanced modelling and simulation (Bush et al. 2005). The vulnerability is the manifestation of the inherent states of the system that can negatively affect it (Haimes 2006). The ESPON Hazards project defines vulnerability as the combination of the potential damage and the response capacity, considering its versatility to recognise 3 dimensions of vulnerability: economic, social and ecologic (Kumpulainen 2006). Nowadays, different network infrastructures, such as transports, energy, water and communications, are intrinsically connected. This interconnection implies that changes in the capacities of one are felt in others. Those dependencies are not limited to the localization of the original incident that caused the change, and the resulting effects are frequently adverse and lasting. Local changes in a network several times have regional effects or even global in certain domains (Goodwin and Lee 2005; Ouyang et al. 2012). Interdependencies between infrastructures and its resilience (the capacity to recover the former function after the occurrence of non-desirable

Table 1 Water pipe characterization

Material	Total length (m)
PVC	488052.2
PEHD	11542.5
Cast iron	33.3
Fibre reinforced polyester	6167.8
Asbestos cement	79246.2
Ductile cast iron	1615
Galvanised iron	41.8
Polyethylene	134.4
Total	586833.2

events) are the key aspects in critical infrastructure management.

The evaluation and characterisation of the different hazards in water distribution systems are a difficult task, mainly due to the many kilometres of pipes, infrastructures of different ages, uncertain operational and environmental conditions and unavailability of reliable data that make it extremely challenging. For these reasons, high uncertainties are inherent in any risk measure that may be assigned to the distribution system (Sadiq et al. 2004).

The studies developed in recent years are mainly focused on the water supply networks' failure, water quality failures and pipe failures, using several methodologies in engineering literature using different approaches (Wilson et al. 2017), like Bayesian model approach (Kabir et al. 2016), with sensor data (García-Mora et al. 2015), decision trees (Winkler et al. 2018), hydraulic models (Bartkiewicz and Zimoch 2018) and ranking-based approaches (Choi et al. 2017), among many others.

The present paper aims to present the risk assessment for the upcoming risk management of a water supply network applied to a case study: the Aveiro municipality water supply system, located in mainland Portugal.

Methodologies for critical infrastructure protection

The current economic and social prosperity is dependent upon a set of highly critical infrastructures. Examples of these infrastructures include the electrical grid, oil and natural gas systems, telecommunication and information networks, transportation networks, water systems and banking and financial systems (Rinaldi 2004), with several interconnections and interdependencies between them (Kroger 2008). Hence, it is important that these infrastructures are reliable and robust (Johansson et al. 2013).

The European Programme for Critical Infrastructures Protection (EPCIP) consists of a plan that involves different tools permitting to protect European critical infrastructures. The European Directive 2008/114/EC of 8 of December is part of the Critical Infrastructure Protection (CIP) programme which only considers the energy (electricity, gas, oil) and transport sectors. Article 3 establishes that each Member State shall identify potential critical infrastructures.

The Homeland Security Presidential Directive (HSPD-7) establishes a US law to protect the critical infrastructures, introducing a structure for the Internal Safety Department (DHS) that permits to identify, prioritise and protect the critical infrastructures from terrorist attacks (DHS 2017). The critical sectors identified include among others the waste-water and the water supply system (DHS 2009). Comparing the DHS approach with the European one, EPCIP, it is possible to conclude that both represent sectorial approaches. However, contrary to EPCIP, HSPD-7 focuses on the resilience and the EPCIP contains a formal procedure to identify and designate the critical infrastructures, not considered in the HSPD-7.

The Canadian National Strategy for Critical Infrastructure Protection establishes a structure to reinforce the resilience of critical infrastructures, being resilience as the final objective to

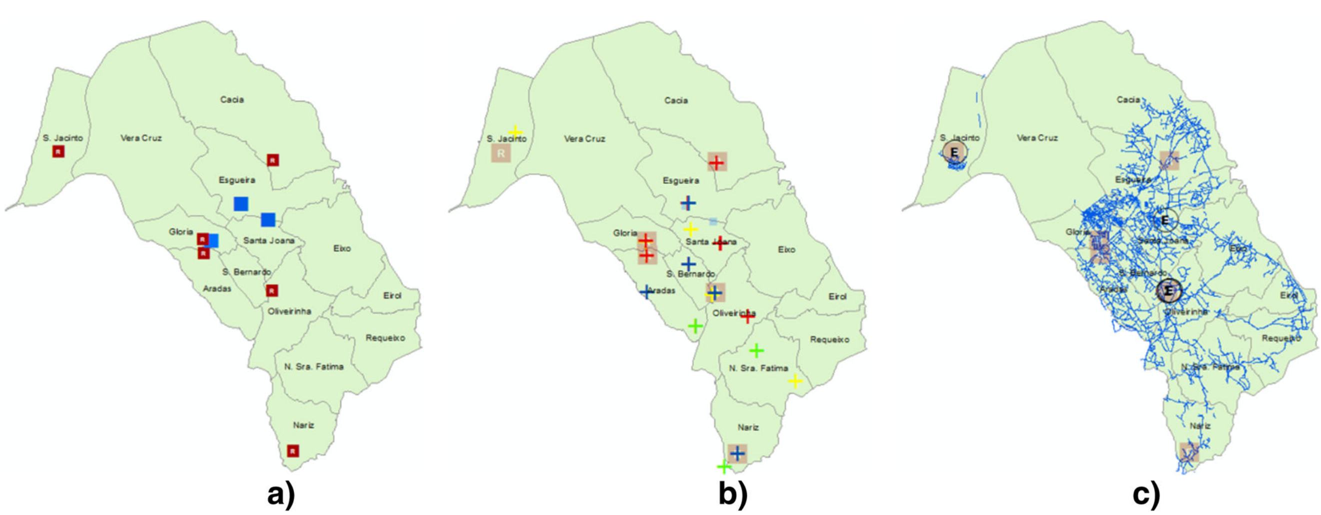

Fig. 2 Water supply network's elements. **a** Significant points. **b** Abstraction points. **c** Pipelines and handover points

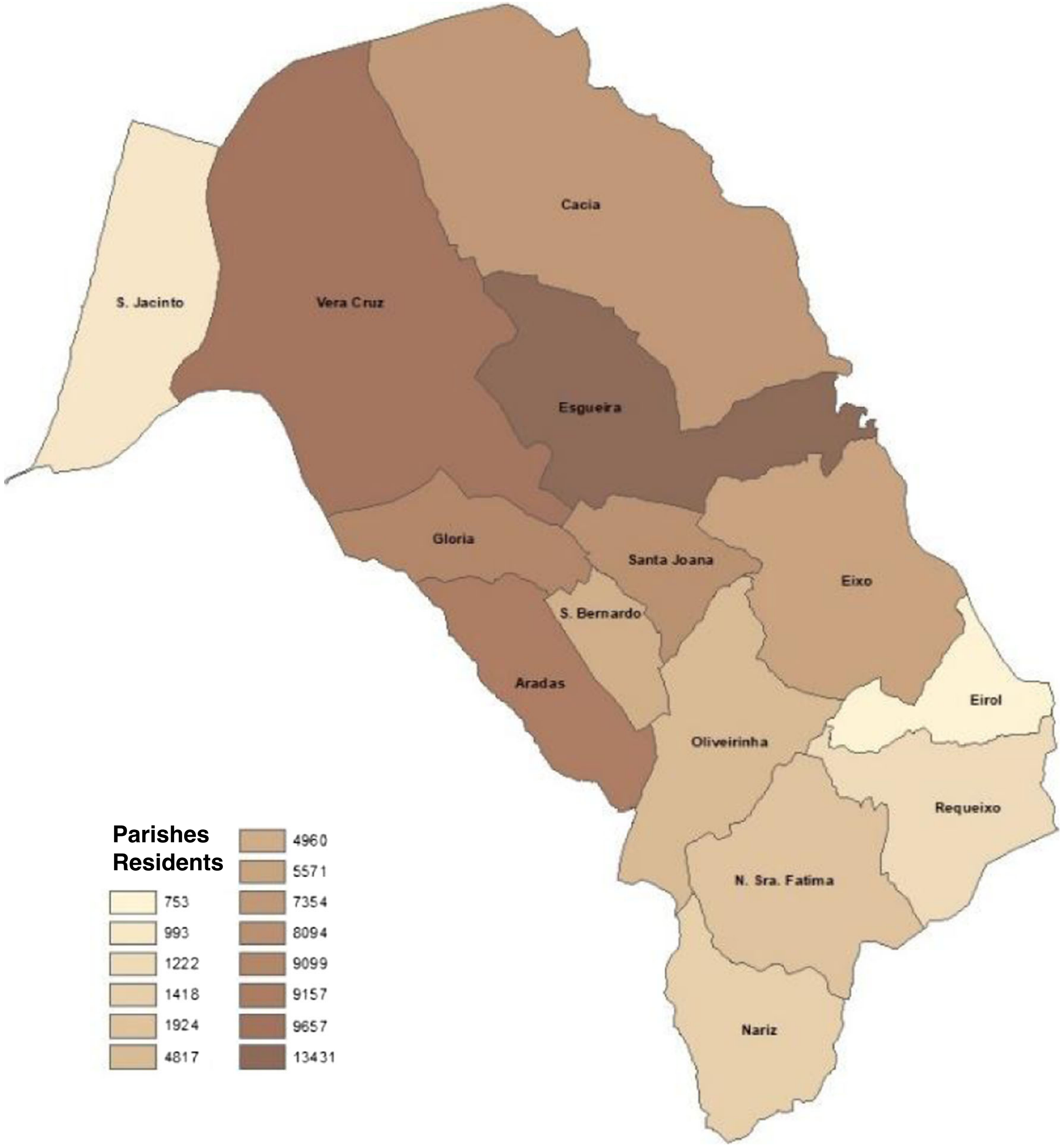

Fig. 3 Population density of the Aveiro municipality (Source: Census 2011)

be achieved. This objective is achieved through a plan, the execution element of the national strategy that establishes the actions in the area of partnership organizations, the implementation of all risk management and the information sharing (Giannopoulos et al. 2012).

Critical infrastructures' risk assessment methodologies

A successful Critical Infrastructure Protection Program depends on the effective risk assessment methodologies implemented, indispensable in order to identify threats, assess vulnerabilities and evaluate the impact on assets, infrastructures or systems taking into account the probability of the threats' occurrence. There is a significant number of risk assessment methodologies for critical infrastructures, consisting on some main elements: identification and classification of threats, identification of vulnerabilities and evaluation of impact (Giannopoulos et al. 2012). Currently, beyond the determination of the principal elements mentioned, a methodology definition considering the users, the interdependencies between critical infrastructures of different sectors and the analysis at infrastructure/system levels and at the systems of systems level is necessary.

Giannopoulos et al. (2012) present a selected number of these risk assessment methodologies (RAM) and in order to obtain a structured review, the evaluation of these

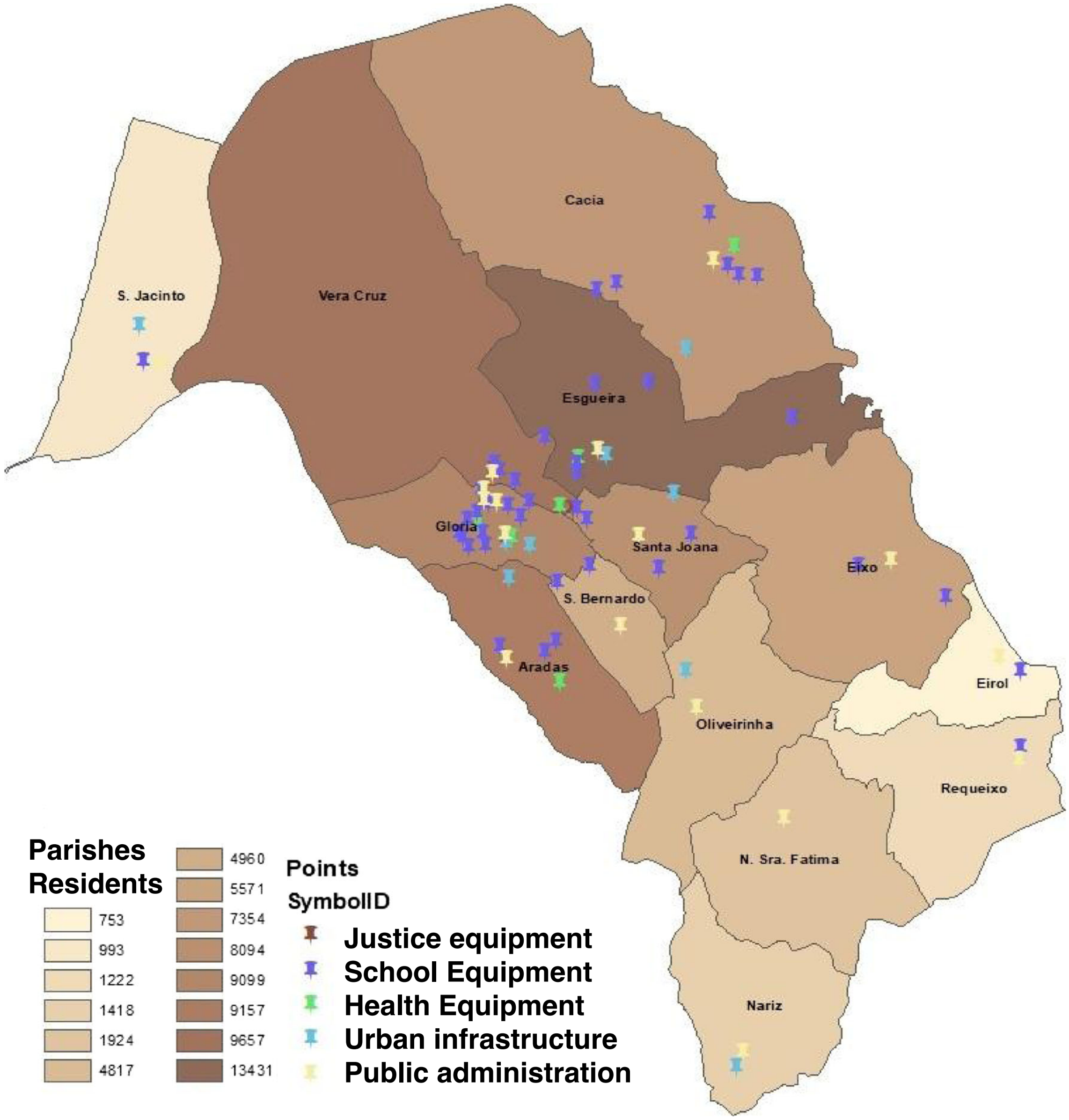

Fig. 4 Infrastructures that can be affected by the events that can strike the water supply system

methodologies took place according to the following criteria: scope of the methodology (which sector is addressed, to whom it is addressed (policymakers, researchers, operators, etc.)); objectives of the methodology; applied techniques and standards; interdependencies' coverage; is resilience addressed?; if cross-sectoral methodology; how are risks compared across sectors? So, different RAM were analysed: Better Infrastructure Risk and Resilience (BIRR) developed by Argonne National Laboratory - USA Department of Energy (Petit et al. 2013); Protection of Critical Infrastructures - Baseline Protection Concept (BMI) developed by the Federal Ministry of Interior, the Federal Office for Civil Protection and the Disaster Response and the Federal Criminal Police Office - Germany (Giannopoulos et al. 2012); CARVER2, Criticality Accessibility Recoverability Vulnerability Espyability Redundancy developed by the NI Centre for Infrastructure Expertise - USA (Giannopoulos et al. 2012); Critical Infrastructure Modelling Simulation (CIMS) adopted by Idaho National Laboratory supported by the U.S. Department of Energy (Giannopoulos et al. 2012); Critical Infrastructure Protection Decision Support System (CIPDSS), developed in the USA that is a tool for information and decision support for the protection of critical infrastructures being a pure risk assessment tool that accounts the probability of a threat, vulnerabilities and impact for all hazards and different types of infrastructures (Bush et al. 2005); the Critical Infrastructure Protection Modelling and Analysis (CIPMA) launched by the Australian Government in order to build the capacities for the protection of nation's critical infrastructures (Giannopoulos et al. 2012); CommAspen

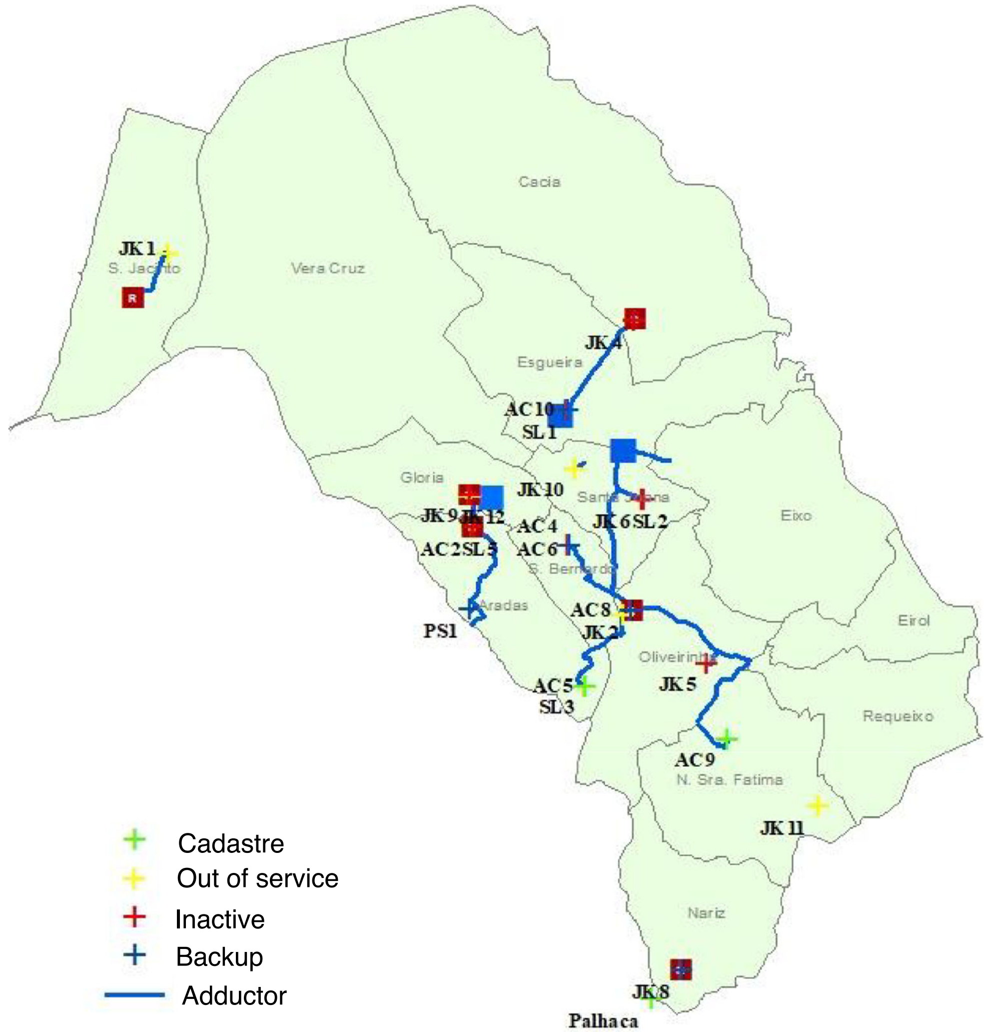

Fig. 5 Infrastructures' water abstraction and supply points

which is the evolution of the first version of an agent-based tool that has been developed in the 1990s in order to model the interdependencies between electric power systems and other infrastructures that are essential for the US economy (Barton et al. 2004); Counteract (Cluster of User Networks in Transport and Energy relating to Anti-terrorist Activities) developed under a FP6 funded project, focus on the transport and energy sectors and on terrorist threats (Giannopoulos et al. 2012); DECRIS project/approach build on the existing capacities in the sectoral risk assessment methodologies in Norway (Utne et al. 2012); European Risk Assessment and Contingency Planning Methodologies for Interconnected Energy Networks (EURACOM) (SFP 2011); National Infrastructure Simulation and Analysis Centre developed the Fast Analysis Infrastructure Tool (FAIT) in the USA (Kelic et al. 2008); Multilayer Infrastructure Network (MIN) which is a methodology that has been developed by the Purdue School of Civil Engineering in the USA (Giannopoulos et al. 2012); Agent-Based Laboratory for Economics (N-ABLE) developed by NISAC (National Infrastructure Simulation and Analysis Centre - USA) (Eidson and Ehlen 2005); Network Security Risk Assessment Modelling (NSRAM) that has been developed by the Institute for Infrastructure and Information Assurance at James Madison University - USA (Giannopoulos et al. 2012); RAMCAP-Plus methodology that has been developed by ASME (American Society of Mechanical Engineers) (ASME 2009); Risk and Vulnerability analysis (RVA) developed by the Danish Emergency Management Agency (DEMA 2006); Sandia Risk Assessment Methodology developed by Sandia National Laboratories in the USA (Jaeger et al. 2008); Risk Management Framework of the National Infrastructure Protection Plan (NIPP) developed by the Department of Homeland Security and the corresponding Risk Management framework in Canada (PSC 2009); in Portugal, the Risk Management of the Portuguese Safety Association based on the ISO (2009) (PSA 2017).

Aiming to choose the RAM to be used in a case study, the authors considered the following factors: the availability of tools for its implementation, the easy application and the

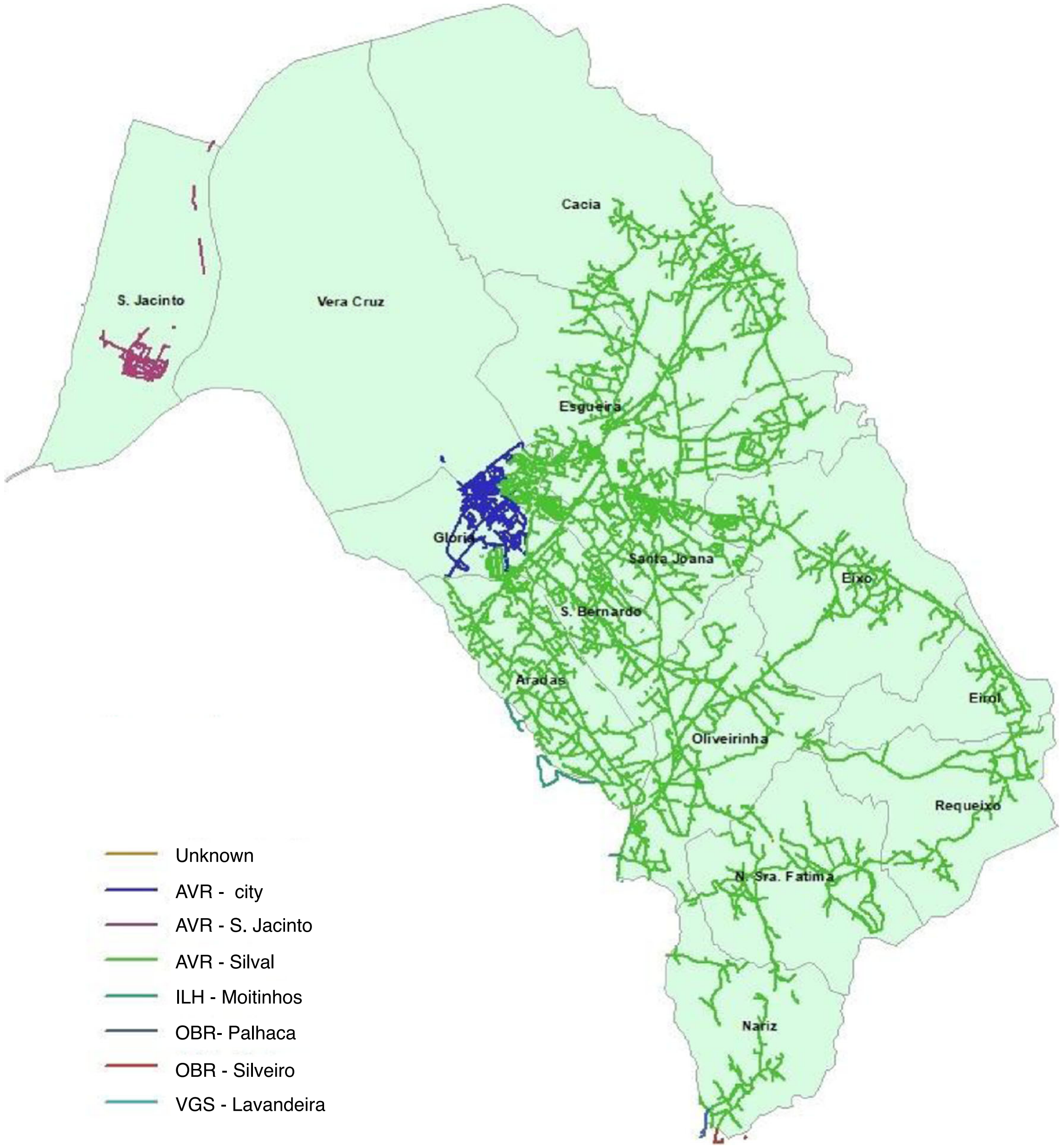

Fig. 6 Area of influence of each system

Table 2 Scenarios to be considered

Scenario	Title	Threat category/incident type
1	Electric energy failure in the significant point of Silval	Destruction or failure of critical society functions
2	Earthquake – intensity VII, according to the historical intensity (Carvalho and Albarello 2016)	Extreme natural event
3	Remote management failure	Destruction or failure of critical society functions
4	Failure of sodium hypochlorite dosing pumps	Destruction or failure of critical society functions
5	a) Cyberattacks against IT systems (remote management)	Other threats: crime
	b) Destruction of Silval reservoir	Other threats: crime
	c) Water contamination	Other threats: crime
6	Failure in the abstraction system of Carvoeiro	Destruction or failure of critical society functions

Table 3 Probability indexes

1	Very unlikely
2	Unlikely
3	Probable
4	Likely
5	Very likely

importance given by the RAM to the interdependencies and resilience, considering that the severity of the consequences is related with these two criteria. Respecting interdependencies, e.g. an electrical energy failure, lead to consequences not only in the energy sector but also in other sectors of critical infrastructures as in the water supply or transports. Resilience permits to decrease or mitigate the consequences of adverse events being that considered an important factor.

Methodologies like NEMO and FAIT, in spite of their interest, are difficult to implement because they depend on the application of specific software that is not available. CARVER2 software is wide-ranging and considers important points referring to risk assessment, namely the resilience, interdependencies and vulnerability, contrary to almost the other methodologies that do not consider resilience. This is the highlighted parameter in RAMCAP-plus methodology that develops expressions permitting to quantify the owner and community resilience being well structured and broad. In the FAIT methodology, the Fastmap application permits to generate maps and reports of active risks, in real time, during an event occurrence, e.g. floods, forest fires and tsunamis.

The on/off relation possible in the NEMO methodology would be a beneficial resource for water supply networks because it permits to analyse the cascade effect that one network element can cause in the others. In this methodology, SIG software is used to map analysis, as it will be done in the work herein presented.

The NSRAM methodology considers human behaviour as, e.g. in the event of a failure, it has in consideration the effects of the maintenance personnel or the unavailability of pieces. CIPDSS methodology proposes the development of decision-makers' profiles taking into consideration the subjective risk assessment nature.

Table 4 Consequence levels

1	Limited
2	Moderated
3	Serious
4	Severe
5	Critical
	Not relevant
	Unknown

Table 5 Levels of risk

1	Very low risk	9	Medium risk
2	Very low risk	10	Medium risk
3	Very low risk	12	Medium risk
4	Low risk	15	High risk
5	Low risk	16	High risk
6	Low risk	20	Very high risk
8	Medium risk	25	Very high risk

Without needing to apply specific software, it is possible to use the EUROCAM, BIRR and RVA methodologies that are composed by similar risk assessment structures. Thus, due to the existence of available tools to its application, RVA methodology was chosen to be applied in the case study developed, being complemented to improve the risk assessment with ArcGIS. This tool permitted a better understanding of the consequences of the potential risks and the identification of plans permitted to improve the response of the enterprise to adverse events as explained in the next section.

Methodology

Case study

The case study under analysis consists of the water supply network of the Aveiro municipality that supplies almost 78,450 inhabitants (according to Census (2011)); it is composed of 8 significant points in 5 parishes as represented in Fig. 1 (AdRA 2017).

Each one of these significant points consists of water reservoirs with different capacities:

(1) 3 water reservoirs, one with 300 m^3 and two with 350 m^3, to supply 1000 inhabitants, in which the number increases during the summer season due to the littoral location, and touristic pressure.
(2) 3 water reservoirs, one with 500 m^3 and two with 1000 m^3.

Table 6 Indexes for the preparation assessment, response capacity, relief and recovery capacity

1	Adequate
2	Mostly adequate/some faults
3	Some severe faults
4	Many severe faults
5	Unsuitable
	Not relevant
	Unknown

Table 7 Results for scenario 1

Probability	1 – Very unlikely
General consequences	4 – Severe
Risk	4 – Low risk
Preparation	2 – Mostly adequate/some faults
Recovery capacity and relief	4 – Many severe faults
Recovery capacity	1 – Adequate

(3) 3 water reservoirs, one with 750 m^3 and two with 500 m^3.
(4) 4 water reservoirs, three with 500 m^3 and one with 3500 m^3.
(5) 2 water reservoirs, one with 100 m^3 and one with 250 m^3.
(6) Without a reservoir but permitting strengthen the network
(7) and (8) are points of operation and of control of the supply system.

The main supply system for the water supply network is represented with AMC (see Fig. 1). The main reservoirs to the storage and water release to the main city are the Silval reservoirs (pointed in Fig. 1 with (4)) with a total capacity of 3500 m^3, which was considered the most critical point of all the system.

The extension and material types of the pipe network are depicted in Table 1, being 83% constructed with PVC, 14% with cement pipes and 2% with PEHD.

Network modelling

For the integral understanding of the water network under study, fundamental in the risk management, the software ArcGIS desktop, of ESRI – Environmental Systems Research Institute, was used. Geographic Information System (GIS) is an informatics system that captures, stores, analyses and shows geospatial data (Chang 2007). The analyses were performed using the ArcGIS desktop, through ArcMap that allows to show and explore sets of data, to attribute information and symbols and do layout maps to be analysed and discussed. It also allows to create and edit ranges of data through the toolbox (ESRI 2017).

Table 8 Results for scenario 2

Probability	3 – Probable
General consequences	4 – Severe
Risk	12 – Medium risk
Preparation	5 – Unsuitable
Recovery capacity and relief	2 – Mostly adequate/some faults
Recovery capacity	2 – Mostly adequate/some faults

Table 9 Results for scenario 3

Probability	3 – Probable
General consequences	4 – Severe
Risk	12 – Medium risk
Preparation	3 – Some severe faults
Recovery capacity and relief	3 – Some severe faults
Recovery capacity	Unknown

Figure 2 shows the available information of the water supply network, namely the location of the significant points (Fig. 2a), the abstraction points (Fig. 2b) and the pipelines and the handover points (Fig. 2b).

Figure 3 shows the population density distribution obtained through the Census (2011) data. Finality resourcing Google Earth, it was possible to locate infrastructures that can be affected by the occurrence of an event in the water supply network, as public administration buildings, hospitals, health centres, schools, elderly centres, fire departments and police departments (see Fig. 4).

Figure 5 represents the water supply points, which are the information essential for the risk management of this critical infrastructure, and Fig. 6 shows the area of influence of each system of the water supply network.

Risk and Vulnerability Analysis implementation

The risk assessment of the water network was performed using the Risk and Vulnerability Analysis (RVA) methodology developed in Denmark consisting of the filling of 4 templates available in the Danish Emergency Management Agency (DEMA). The methodology was chosen considering the possibility of the free and easy use of the correspondent tools, needed for its implementation, and also because it considers the Risk and Vulnerability analysis of each scenario. In the first template, all the stakeholders involved in the analyses and the critical function of the society that has to be analysed are identified. The second and third correspond respectively to the identification of threats and to the analyses of the threats' scenarios. In the fourth, a risk profile and the vulnerability analyses estimation is done.

According to the DEMA threat scenario catalogue, it was decided to develop 6 scenarios as depicted in Table 2,

Table 10 Results for scenario 4

Probability	4 – Likely
General consequences	3 – Serious
Risk	12 – Medium risk
Preparation	2 – Mostly adequate/some faults
Recovery capacity and relief	2 – Mostly adequate/some faults
Recovery capacity	1 – Adequate

Table 11 Results for scenario 5a

Probability	1 – Very unlikely
General consequences	4 – Severe
Risk	4 – Low risk
Preparation	5 – Unsuitable
Recovery capacity and relief	5 – Unsuitable
Recovery capacity	4 – Many severe faults

Table 13 Results for scenario 5c

Probability	1 – Very unlikely
General consequences	5 – Critical
Risk	5 – Low risk
Preparation	3 – Some severe faults
Recovery capacity and relief	3 – Some severe faults
Recovery capacity	Unknown

integrated into 3 types of incident/category of different threats: destruction or failure of critical society functions, crime and extreme natural phenomenon. For each one, the probability of occurrence, the consequences and the vulnerability of the assets, according to the levels and indexes established in Tables 3, 4 and 5, were estimated.

The vulnerability assessment considers the preparation before the event occurrence, through planning and mitigation measures, response capacity and relief during and the recovery capacity after the incident, scored according to Table 6.

According to the water consumption data, it was possible to calculate the period during which it is possible to supply the population with the stored water in the reservoirs, without being supplied by the abstraction points. This is essential data for the crises management as it corresponds to the period in which the management enterprise has to solve the problem that hinders the reservoir's supply.

Results discussion

Resourcing RVA methodology, the 6 scenarios were assessed (results are in Tables 7, 8, 9, 10, 11, 12, 13 and 14), enabling the last methodology step: the development of risks and vulnerability profiles as depicted in Tables 15 and 16.

The risks profile is summarised in one matrix showing for each scenario the level of probability and gravity of its consequences (Table 15) giving the risk level accordingly with the respective evaluation. It can be verified that the considered scenarios have low or medium levels of risk. This analysis gives information to the management staff about the importance of each one and which scenario must be prioritised regarding the investment and implementation of preventive, mitigation and preparation measures to face the risks and its consequences. This is an important information to support decision-making. Table 15 shows that in scenarios 1, 5a, b and c and scenario 6 in spite of being associated with low probabilities in case of occurrence, the gravity of its consequences (severe and critical) would have a great impact. So, the existing preventing measures have to be improved. Scenarios 2, 3 and 4 can also be considered critical (in spite of its level of risk is also classified as medium) as their occurrence is probable or very probable and the severity of their consequences is serious or severe. So the preventive plans for these scenarios have to be improved and continuously maintained.

The vulnerability profile permits to analyse the vulnerability of each one of the eight scenarios developed, as depicted in Table 16, according to the assessment of the indexes for the preparation assessment, response capacity and relief and recovery capacity, based on Table 6. Though by this analysis it is possible to verify that the water supply network has high vulnerability for some particular scenarios, in most cases, low-to medium-vulnerability profiles are identified. Nevertheless, it is recognised the subjectivity of the vulnerability assessment included in Table 16. The approach is an attempt to include several threats in the same analysis, and the options for the vulnerability profiles for each threat are based just through engineering judgements. This is an area the researchers will need to study and further develop in the future to reduce the high level of the subjectivity of the analysis. Scenario 1 (electrical failure of Silval, the main reservoir to supply the water network of Aveiro) has high vulnerability concerning the response and relief capacities, and scenario 2 (earthquake that can damage equipment and the pipe network) has very high vulnerability in the preparation actions (plans, preventive measures, etc.). The scenarios with higher vulnerability in all the assessment parameters are the cyberattacks (scenario 5a)

Table 12 Results for scenario 5b

Probability	1 – Very unlikely
General consequences	4 – Severe
Risk	4 – Low risk
Preparation	3 – Some severe faults
Recovery capacity and relief	2 – Mostly adequate/some faults
Recovery capacity	Unknown

Table 14 Results for scenario 6

Probability	2 – Unlikely
General consequences	5 – Critical
Risk	5 – Medium risk
Preparation	4 – Many severe faults
Recovery capacity and relief	5 – Unsuitable
Recovery capacity	2 – Mostly adequate/some faults

Table 15 Matrix of risk

Probability						
Probability	Very Likely (5)					
	Likely (4)			Scenario 4		
	Probable (3)				Scenario 2; 3	
	Unlikely (2)					Scenario 6
	Very Unlikely (1)				Scenario 1; 5a); 5b)	5c)
Very high risk / High risk / Medium risk / Low risk		Limited (1)	Moderate (2)	Serious (3)	Severe (4)	Critical (5)
Very low risk		Consequences				

and failure in the abstraction system of Carvoeiro (the main abstraction point of the system) (scenario 6a). For this one, because Carvoeiro is the main source of the water supply of the Aveiro water supply system, the cyberattacks were because all the system is managed through informatics systems. It must be highlighted that for this scenario, it was considered that the management enterprise has no preparation or mitigation measures. As this kind of attacks to critical infrastructure is increasing, it must be a scenario that has to be deeply analysed and considered.

Final conclusions

Risk management aims to minimise the impacts of potential hazards that can affect a certain activity being necessary to deeply know them. For critical infrastructures, the analysis of its performance when subject to events associated with potential risks permits to identify measures that have to be implemented to minimise the respective consequences. Currently, the critical infrastructure threats are increasing being essential that its management enterprises have to do a reliable risk assessment and management. Nowadays, these threats are not only due to human actions like terrorism and crimes but also to natural phenomena that are resulting to more extreme consequences. The present work aims to contribute to lead the management enterprises responsible for critical infrastructures to do reliable risk management of their assets granting its suitable functioning, especially under a damage situation. The study herein presented was developed in the water supply system of the Aveiro municipality composed of 15 reservoirs, 5 elevated and 10 supported on the floor, located in 5 different parishes. The water network supplies almost 78,450 persons with almost 587 km of network pipes. The analyses were performed using the ArcMap of ArcGIS desktop software that permitted to analyse the network functioning and the population depending on the water supply being possible to identify the network critical points. The risk assessment was done using the Risk and Vulnerability Analysis (RVA) methodology developed in Denmark consisting of the filling of 4 templates available in the Danish Emergency Management Agency (DEMA) website. The network risk assessment permitted to verify the scenarios with a higher level of risk and identify the network vulnerability. After the template filling for each scenario, a general analysis was carried out and possible measures to be implemented to improve the preparation or the enterprise response to incidents were identified. Regarding the risk profiles and vulnerability, the risk matrix permits verify that the developed scenarios have low or medium levels of risk. This matrix also leads to the scenarios' identification with a higher probability of occurrence and with severe consequences permitting to prioritise scenarios which must have higher invest in mitigation and prevention measures. Risk maps to each scenario

Table 16 Vulnerability profile

■■■■■ Very high vulnerability ■■■■ High vulnerability ■■■ Medium vulnerability ■■ Low vulnerability ■ Very low vulnerability		Assessment of vulnerability levels		
		Preparation (plans, preventive measures, etc.)	**Response and relief capacities**	**Recovery capacities**
Threats` scenarios	**Scenario 1 – Electrical failure Silval**	■■	■■■■	■
	Scenario 2 - Earthquake	■■■■■	■■	■■
	Scenario 3 – Remote management failure	■■■	■■■	Unknown
	Scenario 4 – Failure of dosing pumps	■■	■■	■
	Scenario 5 a) – Cyberattacks **Scenario 5 b) – Destruction of Silval reservoir**	■■■■■ ■■■	■■■■■ ■■	■■■■ Unknown
	Scenario 5 c) – Water contamination	■■■	■■■	Unknown
	Scenario 6 – Failure in the abstraction system of Carvoeiro	■■■■	■■■■■	■■■■

were developed to the water network and specific ones to the most critical point of Silval and Carvoeiro. It was concluded that to decrease the vulnerability of the water supply network of the Aveiro municipality, a set of plans must be developed: maintenance plans; investment plans; contingency plans (aiming to prepare the organisation to respond efficiently to emergencies and to its potential human impact); emergency plans (systematising a set of standards and rules to minimise the forecast catastrophe effects, managing effectively the available resources); evacuation plan and an action plan. In the scope of this plans, it is essential to do the seismic reinforcement of the pipe network substituting the pipes by low-vulnerability seismic material as PEHD and ductile iron pipes (that currently represent a little bit more than 2% of the network), and the seismic reinforcement of the concrete structures specially of the water reservoirs. Nowadays, the abstract system of Carvoeiro is automatically managed through digital systems as well as all the water network system of the Aveiro municipality. For both, a remote management system that is highly vulnerable to failures and cyberattacks exists. So the management enterprises have to implement permanently maintenance and protection measures to avoid those threats. According to the severity of the consequences of any water contamination, the access of all the reservoirs or other elements where this kind of contamination can occur must be enforced.

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