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Risks in the Drinking Water Supply

A comparative study of Norway and Denmark

Stavanger, June 2021

Abstract

The Norwegian and Danish consumers trust that the drinking water they receive is safe and free of contaminations. Although the drinking water is locally sourced and is treated with simple purifications steps, the two countries face risk challenges related to drinking water safety.

The characteristics of the applied risk framework and methods for safety and security in the drinking water supply in Norway and Denmark are examined and compared. Risk communication in relation to potential drinking water contaminations was also studied as previous water supply contaminations have shown that risk communication plays a crucial element in maintaining trust in the water supply companies and the municipalities.

Through a combination of literature review and performed interviews with key persons in both countries following was found: In Norway, the water supply companies apply a Risk and Vulnerability Analysis (RVA) developed exclusively for the water supply industry to handle safety-related risks. In practice, a recommended triplet approach for security aspects was rarely used as this is time-consuming and requires special competence. Assessment of potential intended malicious acts as terror was sometimes entered as an unwanted event in the water supply RVA.

It was found that Hazard Analysis and Critical Control Points (HACCP) principles are required by legislation for midsize and large drinking water supply companies in Denmark. The HACCP principles are followed by using the DDS management system or the FSMS ISO 22000:2018 standard. A notable difference is that the water supply RVA is internally reviewed, and the FSMS ISO 22000:2018 have an external audit both to achieve certification and maintain certification. Some security aspects such as access limitation are addressed in the ISO 22000:2018 standard.

The practical aspects of risk communication differ between the countries as the Danish drinking water supply companies communicate directly to their customer. Whilst in Norway, the water supply companies notify the municipalities, which then alert the customers in the respective municipality. The theoretical knowledge of risk communication presented in the thesis suggests it is preferable not having the extra link in the risk communication chain to save time in the acute phase after an event such as a drinking water contamination. Furthermore, as often several municipalities receive drinking water from the same water supply company, it can create inconsistency regarding releasing information and the content of the message. Therefore, risk communication cooperation groups across the municipality's borders must be encouraged.

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List of abbreviations

CCTV	Closed-Circuit Television
CIM	Crisis Information Management
CSR	Corporate Social Responsibility
DDS	Documented Drinking Water Safety
DSB	Norwegian Directorate for Civil Protection
FMEA	Failure Modes and Effects Analysis
FSMS	Food Safety Management System
GIS	Geographic Information System
HACCP	Hazard Analysis and Critical Control Points
ISO	International Organization for Standardization
NFSA	Norwegian Food and Safety Authority
NIPH	Norwegian Institute of Public Health
NOU	Norges Offentlige Utredninger
NSM	National Security Authority
PDCA	Plan, Do, Check, Action
PET	Danish Security and Intelligence Service
PHA	Preliminary Hazard Analysis
RVA	Risk and Vulnerability Analysis
TQM	Total Quality Management

1 Introduction

1.1 Motivation

In Scandinavian societies, the consumers expect clean and safe water in the household taps. Compared to the rest of the EU, the Scandinavians consume little bottled water (Statista, 2019). In Norway and Denmark, all drinking water is locally sourced and are treated with simple purifications steps before consumers can use it (Danish Environmental Protection Agency, 2021c; Ødegaard, 2014, p. 25). Consumers rarely experience downtime of drinking water delivery service. The Norwegian and Danish consumers trust that the drinking water they receive is safe and free of contaminations (Gelbjerg-Hansen, 2020; Norsk Vann, 2020b). These two countries face different challenges regarding the origin of water source and geographical dimensions. Hence, hazards and threats are presumably not identical. Therefore, it would be interesting to examine whether the same risk frameworks are utilised in these countries to ensure safe drinking water for consumers.
A recent severe contamination case on Askøy, Norway received much media attention (Paruch, Paruch, & Sørheim, 2020). The case was thought to impact the public level of trust in safe drinking water on a national level from 91% just prior to the event to 84% the following year (Norsk Vann, 2020b). The risk communication of the event was criticised in the aftermath. This poses the question whether the theoretical knowledge of risk communication aligns well with the practical risk communication in the water supply industry.

1.2 Objective

The main objective of this thesis is to understand how risks in the drinking water supply industry are assessed and controlled in Norway and Denmark. These two countries have many similarities regarding our expectation of the water coming from the household tap and similar values when it comes to many risk decisions in society. The answers to the research questions below will address the main objective of the thesis.

I. Which comparative characteristics of the applied risk frameworks or methods for safety and security are observed within the drinking water supply in Norway versus Denmark?
II. To what extent is the practical risk communication regarding drinking water towards the consumers built around the theoretical knowledge of risk communication?

1.4 Scope and Limitation

The scope of the thesis is to compare how the water supply in Denmark and Norway handles the risk with regards to safety, security and risk communication. Findings from literature and performed interviews form the basis for the comparison. The thesis will focus on drinking water for households coming from water supply facilities considered midsize (70.000m3/year) or larger. In the thesis, the term drinking water is used to clarify that the purification process has been carried out at the water supply facility, and the quality of the water meets the requirements defined by law. Hence, drinking water is not only water which is drunk but represents all water used in household and society in general. In the thesis, water supply facilities include purification steps, pumps, pipelines and distribution facilities. The legislation of the drinking water sector is currently increasing, particularly in Denmark; hence the achieved information used in the thesis is from before and including May 2021. However, it is published on the website of the Danish Ministry of Environment that further executive order is to be announced.

Risks are separated into safety and security to clarify whether an event is caused by an intended malicious act or not. The findings from literature together with performed interviews are then used to compare the two countries. Two severe contamination cases are presented with the focus on the following risk communication and impact on costumer's trust in the water supply company or municipality.

1.5 Structure of the thesis

The thesis is organized as follows: Chapter 2 contains risk theory of relevance. This includes a bowtie diagram, risk perspectives and matrix, Failure Modes and Effects Analysis (FMEA), and risk communication related to hidden dangers and institutional trust. Also, there will be distinguished between safety and security. Chapter 3 provides a general description of the water resources in both Norway and Denmark. The risk frameworks or analysis' used within the water supply industry is reviewed. Additionally, whether the water supply is classified as the critical infrastructure in the societies will be examined. This is followed by a review of hazards and threats considered in the water supply industry. Chapter 3 closes with the presentation of two recent cases of drinking water supply contaminations. Chapter 4 explains the methodology of the thesis, and Chapter 5 presents the findings of the series of interviews. Chapter 6 discusses the findings and compares them with previous findings in the literature, and a comparison across the two countries will be completed. Finally, a conclusion will be provided in Chapter 7.

2 Theory

2.1 Risk assessment tools and methods

2.1.1 Bowtie diagram

A bow tie diagram is a graphic and pedagogical way to present an informative risk picture that can contribute to useful and understandable barrier management (Aven, 2015, p. 1; Wiencke, 2020). The bowtie diagram can clarify where potential vulnerabilities in a system are found, and new barriers can be implemented, or an old barrier can be improved or adjusted. See figure 1. Hence, the bowtie represents a tool to evaluate the risk strategy and current probability reducing or consequence reducing barriers. In a bowtie diagram, an initiating event also referred to as event A, is placed in the centre of the figure and represents a hazard, a threat or an opportunity (Aven, 2015, p. 1). When the event is considered a negative event, it will be referred to as an “undesirable event”. On the left side of the diagram, potential causes of the occurrence of event A are listed. Causation can be related to numerous classes, e.g. people concerns (competence, management, culture), technical concerns (age, maintenance, condition), organization (contractors, owner, operator) or management systems (Wiencke, 2020). Next to the potential causes are the proactive measures to reduce the probability of event A taking place. These measures are also known as preventive barriers (Aven, 2015, p. 1). Potential outcomes of event A are listed on the right side of the diagram (Aven, 2015, p. 1). Next to the potential consequences, reactive activities are listed in order to reduce the consequences. The reactive activities represent recovery measures post-event A in order to limit possible harm and disruption (Wiencke, 2020). On top, it is possible to list risk- or performance-influencing factors. These are factors that may perhaps influence the occurrence of the initiating event or the performance of the barriers.

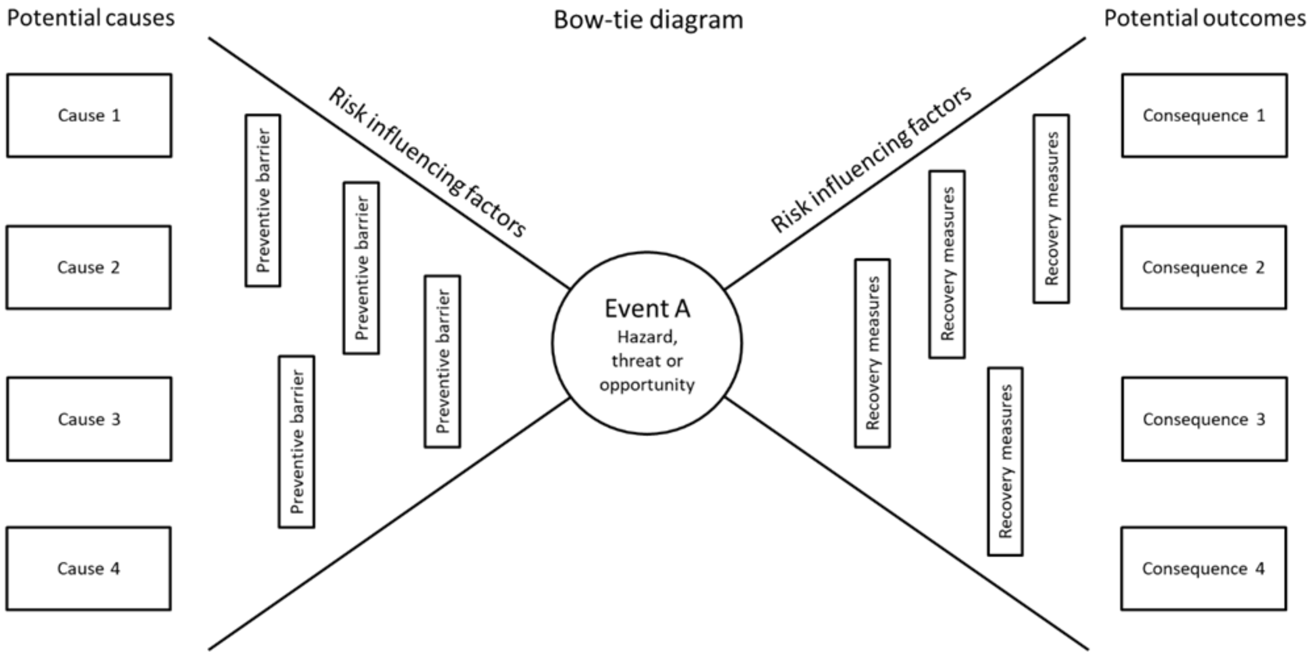

Figure 1. An example of a bow-tie diagram (Based on information from Aven, 2015, p. 1.).

2.1.2 Risk Matrix

The concept of risk has two main components (*C*, *U*), where *C* is the future consequence of an activity and *U* is the uncertainty related to *C* (Aven, 2020, p. 58). The notation (*C*, *U*) expresses all the consequences of any activity (Aven, 2015, p. 13). Often the consequences clearly refer to the events *A* that can take place, resulting in some effects (Aven, 2020, p. 58). Hence, the consequences are broken into events *A* and their consequences *C*. The risk definition can then be written (*A*, *C*, *U*) but is equivalent to the (*C*, *U*) (Aven, 2015, p. 13).

In the thesis, the following risk concept is applied: The concept of risk includes event *A* that result in consequences (*C*) and the uncertainties (*U*) associates with those (Aven, 2015, p. 13).

The risk concept (C, U) does not offer the possibility for assessing or managing the risk. This is obtained by describing or measuring the risk. The description of risk is achieved through specifying the consequences and applying a description of uncertainty *Q*. The probability *P* is the most common tool (subjective probability or knowledge-based probability) used to describe or measure uncertainty *Q* (Aven, 2015, p. 14). To specify the consequences, one must identify a set of quantities or qualitatives of interest *C'* that describes the consequences *C*. It is the value of the quantities that one wants to know at the time of decision making. Given the principles for specifying *C´* and the choice of *Q*, the description of risk can be written as risk = (*C´*, *Q*, *K*) (Aven, 2015, p. 14). *K* is the background knowledge or assumptions that *C´* and *Q* are based on. Often the approach in risk assessments is that *Q* equals *P*, where *P* is the knowledge-based probability applied to describe uncertainty (Aven, 2015, p. 14). Therefore, the risk description can be written (*C´*, *P*, *K*).

Risk can be described by using a risk matrix (Aven, 2015, p. 143). A risk matrix is a risk assessment tool to determine the level of risk, not a risk analysis method. A risk matrix consists of expected consequences *C* against the probability *P* that an event will occur given the knowledge *K*. See figure 2. Probabilities are to be understood as a subjective measure of an uncertainty or degree of belief in an event, with reference to an uncertainty standard (Aven, 2015, p. 185). Different attributes can be used for the consequences, e.g. loss of lives, economic quantities, or reputation (Aven, 2015, p. 21). The values of both consequences and probabilities are differentiated into broad categories, e.g. low, medium, and high, depending on the defined criteria for each category (Aven, 2015, p. 178). Depending on how many categories have been defined, matrices can be, e.g. 3x3, 4x4 or 5x5. Thus, the level of risk can be estimated as the sum or product of the category of frequency probability and consequences.

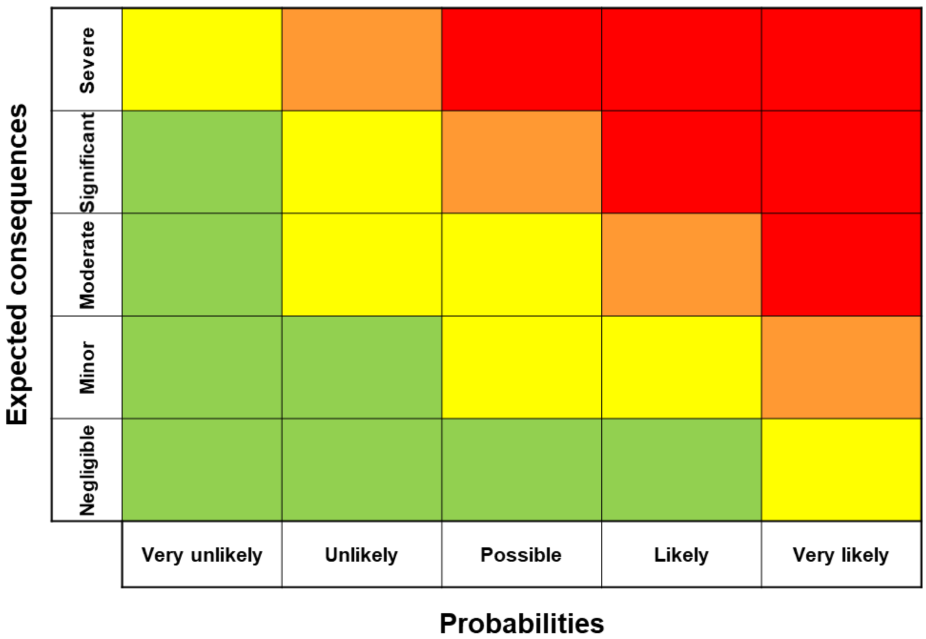

Figure 2. An example of a risk matrix.

The traffic light colour of the cells in a 3x3 matrix will indicate low, medium or high risk based on the acceptant criteria values for each level (Cox, 2008). A green cell (low risk) and a red cell (high risk) cannot be juxtaposed. Risk matrices have been widely criticised for several reasons, e.g. lack of transparency, subjective judgement of categorization and not indicating the strength of knowledge (Aven & Flage, 2018; Cox, 2008). Although the risk matrix has several undesired issues, it is still widely used as a contribution to management decision making by visualizing the level of risk, as later shown in this thesis.

2.1.3 Failure modes and effects analysis

Failure modes and effects analysis (FMEA) is an analysis method utilized to expose failures in a technical system by investigating each component and determine the impact of a failure on the complete system (Aven, 2015, p. 62). For each component in the system, the potential failures modes, failure causes, and failure effects are described (Rausand, 2011, p. 237). The downside of the method is that although each component is evaluated thoroughly and classified according to its severity, it is assumed that the rest of the system works as expected. Hence, the method does not expose situations when a combination of multiple critical failures occurs and is not suitable for aggregating the risk at the system stage (Aven, 2015, p. 62; Rausand, 2011, p. 528). The first guideline for this systematic method issued in 1949 to identify problems in military systems (Rausand, 2011, p. 215). The method has been integrated into many industries, e.g. suppliers to the defence, aerospace and the automobile industry and was later used in the offshore oil and gas industry.

Some of the benefits of using the FMEA method are that it provides a systematic overview of potential failures within the system and encourages the system designer to consider the system's reliability (Aven, 2015, p. 68). FMEA can furthermore function as a foundation for other analyses, e.g. event tree analyses and fault tree analyses. FMEA focus mainly on the technical aspect of the system and does not account for human error; however, to some extent, human activity could be added as a component to compensate for this (Aven, 2015, p. 68). One weakness of using the FMEA method is the extensiveness of the methods as each component is evaluated and documented even though it might have little or no consequences. Additionally, the FMEA method is not appropriate for systems including numerous components with the same functionality as interruption of one component will not affect the system or bring the system to a halt.

2.2 Safety and security

This section briefly draws attention to the fact that security differs from safety in some respects. In practicality, security is often assessed differently than safety in risk management, and the security field uses different tools and standards (Jore, 2019). The recommended practical approach for security risk analysis supplied by three Norwegian standards for protection against intentional acts is the triplet approach (Jore, 2015). In the triplet approach, the risk is understood as a combination of threats (risk source), value (e.g. people, assets, reputation) and vulnerabilities (possible sensitivities and weaknesses, or lack of resilience). The element of intentionality plays a crucial part in distinguishing between safety and security. However, this demarcation of safety and security is not necessarily so rigid as perceived (Jore, 2019). Jore (2019) reasons that in the safety field, there is consensus that accidents in organisational safety do not just randomly happen, but rather is a lack of safety planning. Risk assessment should be performed, and barriers implemented to prevent accidents. Hence, intentionality plays a part in the safety field as well. Jore (2019) suggests that the element of maliciousness is an essential parameter to differentiate security from safety. See figure 3.

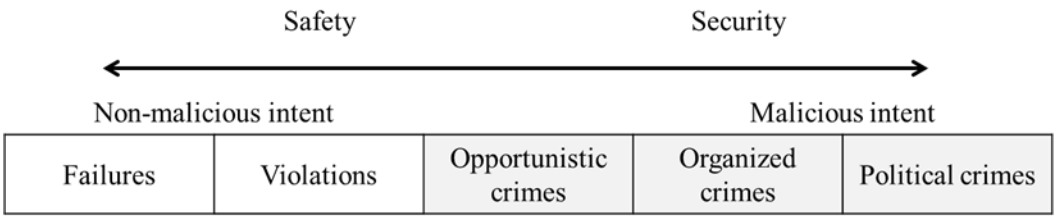

Figure 3. Illustrates the demarcation between safety and security. From Jore (2019).

A definition of security is purposed as " *The perceived or actual ability to prepare for, adapt to, withstand, and recover from dangers and crises caused by people´s deliberate, intentional, and malicious acts such as terrorism, sabotage, organised crime or hacking*" (Jore, 2019).

For years safety and security have developed as separate disciplines with their own set of tools and methods (Jore, 2019). However, security and safety share many theories and perspectives. There is not a consensus amongst academics or practitioners on what is best practice to conduct a security risk analysis. Likewise, there is an ongoing discussion whether there is a need for a security risk concept or, in fact, security risk can be made compatible with safety definition (Amundrud, Aven, & Flage, 2017; Askeland, Flage, & Aven, 2017; Jore, 2019). It is unclear if security should be a sub-discipline of safety science or considered a science in itself. The security field is less described and understood, but security is also a younger field as we understand it today. Historically, until after the Cold War, security was mainly under the police and military control (Jore, 2019). Currently, security is a part of the risk field for municipalities, organisations, and companies. This thesis distinguishes between safety and security due to the presumed practical aspects that security is assessed differently than safety in risk management and the security field uses different tools and standards.

2.3 Trust as a foundation to perform successful risk communication

Trust in the risk communicator is essential on both sides of the bowtie diagram. Trust can be built on preventive barriers, e.g. by the implementation of risk frameworks. Trust is likewise essential when communicating risk after an event to implement consequence reducing measures.

Risk communication can be a challenging balance act when communicating regarding hidden dangers, e.g. radon, asbestos or water pollution (Aven & Renn, 2010; Bouder et al., 2019). People feel vulnerable when they cannot see, smell or sense the danger and have to rely on second-hand information from the authorities or experts, which requires trust in the authorities or experts (Aven & Renn, 2010).

Trust is crucial for achieving effective risk communication results (Kasperson, Golding, & Tuler, 1992; Lofstedt, 2003). Top-down risk communication is less successful as authorities or experts seek to convince the public when alleviating public fears rather than a dialogue with involved stakeholders (Leiss, 1996; Lofstedt, 2003). The dialogue approach is believed to promote an increase in public trust. The discussion of trust as a concept contributes to a better understanding of elements that are essential when communicating risk. There is a linear relationship between the level of trust and confidence in the risk communicator and the believability of the information provided when there is a risk of potential personal harm (Kasperson, 1986). In other words, if the perception of the communicator is negative, e.g. lack of competence, then the value of information is weakened accordingly. Furthermore, a history of mismanagement or negligence by authorities will hurt their efforts when later communicating risks to the public.

The concept of trust means different things to different people, and there is not a clear cut consensus of the definition of this multiple dimensional concept (Renn, 2008). Renn (2008) propose seven founding components of trust built on previous work (Renn, 2008; Renn & Levine, 1991).

The seven components are *perceived competence*, *objectivity*, *fairness*, *consistency*, *sincerity*, *faith*, and *empathy*. Each component is described in table 1. Trust depends on each component, but a strong component can offset another component that is weakened.

Table 1. The seven components of trust from Renn, 2008, p. 223 adapted from Renn & Levine, 1991.

Components	Description
Perceived competence	Degree of technical expertise in meeting an institutional mandate
Objectivity	Lack of bias in information and performance as perceived by others
Fairness	Acknowledgement and adequate representation of all relevant viewpoints
Consistency	Predictability of arguments and behaviour based on past experience and previous communication efforts
Sincerity	Honesty and openness
Faith	Perception of goodwill in performance and communication
Empathy	Degree of understanding and solidarity with potential risk victims

Slovic (1993) states that trust is fragile as it builds slowly but can be destroyed instantly. Trust can be restored to the previous level over time but might never be regained. Slovic (1993) named this the asymmetry principle. Negative events or trust-destroying events, e.g. accidents, lies, the discovery of errors or mismanagement, tend to be remembered. On the contrary, positive events or trust-building events are often overlooked or forgotten. Lofstedt (2009) states that “In ‘post-trust societies’, public trust does not simply disappear altogether, but is rather re-allocated” (Löfstedt, 2009). In other words, the trust that the public historically had in their regulators and industry can be transferred to individuals or interest groups who are perceived to be neutral or have no conflicting interest with the given issue.

People’s perception of confidence in an institution is based on its track record of communicating trust without disappointments (Renn, 2008, p. 223; Renn & Levine, 1991, p. 180). Trust and confidence are required to achieve credibility. Credibility arises from a long-term perception of good performance concerning competent, fair, flexible to new demands and related only to communication. Subsequently, Renn (2008) defines credibility as “the degree of shared and generalized expectancy that the communication efforts of an organisation match to the subjective and/or socially shared expectations in terms of honesty, openness, responsiveness and professionalism” (Renn, 2008, p. 223).

These definitions of trust, confidence and credibility lead to a classification of trust at different levels when investigating an event: trust in a message; confidence in a communicator; confidence in an institution based on source perception; credibility of institutional performance; and climate for trust and credibility in a macro-sociological context (Renn, 2008; Renn & Levine, 1991). A diagram by Renn and Levine (1991) shows the cumulative classification with the degree of abstraction versus the complexity (see figure 4). Each level forms part of the higher level. This enables prediction on how changes in communication may impact trust on a lower level, in contrast to changes in higher levels. Thus, the given circumstances at a higher level act as a limitation on creating trust on a lower level. Positive and negative factors for credibility for each level are listed in Table 2 (Renn & Levine, 1991).

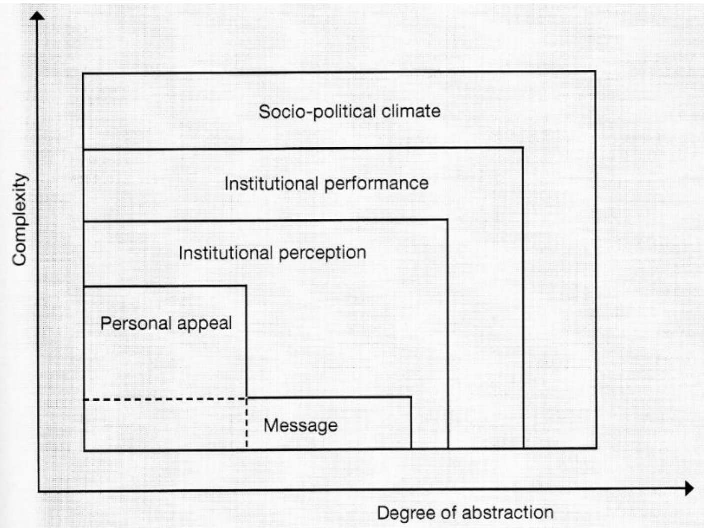

Figure 4. Diagram with different levels of trust in risk communication from Renn (2008, p 225).

Several researchers within the risk field have likewise proposed definitions to the concept of trust based on theoretical and empirical studies (Poortinga & Pidgeon, 2003). Kasperson et al. (1992) suggested four critical dimensions of trust, which contribute to gaining and sustaining trust: *commitment, competence, caring* and *predictability* (Kasperson et al., 1992). Pootinga and Pidgeon (2003) discuss some of the trust definitions and question, e.g. Renn and Levine's categories containing *objectivity* and *fairness* in regard to their independence. They also challenge Kasperson et al. (1992) regarding distinguishing *caring* and *commitment*. While other scientists claim that trust is a two-dimensional factor combined by, e.g. *honesty* and *competence* (Poortinga & Pidgeon, 2003). This thesis will apply the findings of Renn and Levine (1991) and Renn (2008).

Table 2. Factors of credibility for different levels of analysis from Renn, 2008 p. 226. Modified from and updated from Renn & Levine 1991. See Renn (2008) for further references.

Positive	Negative
Message	
Timely disclosure of relevant information	Stalled or delayed reporting
Regular updating with accurate information	Inconsistent updating
Clear and concise	Full of jargon
Unbiased	Biased
Sensitive to values, fears and public perception	Inconsiderate of the public's concerns
Admits uncertainty	Claims the absolute truth
From a legitimate reputable source	From a questionable source
Organized message	Internally inconsistent, ambiguous
Use of metaphors	Too abstract.
Explicit conclusions.	Receiver derives own conclusion.
Positive information recorded in early part of message	Fear or anxiety arousal in early part of the message
Forceful and intense	Dull
Personal	
Admits uncertainty	Self-assured1
Responds to the emotions of the public	Indifferent
Appears competent	Appears insecure
Similarity to receiver	Perceived as an outsider
Has some personal stake in the issue	Seems uninterested or not involved
Clear and concise	Too technical
Perceived as an expert	Perceived as a person with opinions rather than expertise
Perceived as attractive	Perceived as unattractive
Charismatic	Boring, not inspiring
Trustworthy, honest, altruistic and objective	Lack of trustworthiness
Empathy for receiver	Display s no empathy
Institutional	
Positive personal experience	Negative personal experience
Strong, competent leaderships	Perceived incompetences
Positive labour relations	Lay-offs/hiring freeze/strikes
Sound environmental policy	Irresponsible environmental policy
Produces safe and good services	Poor-quality goods and services
Positive past record of performance	Negative past record of performance
Reasonable rates	Exorbitant prices
Undertakes socially relevant tasks	Seems to be centred on own benefits
Practicable contributions to everyday life	No recourse to everyday life experience
Benefits outweigh costs	Magnitude of risk-taking greater than benefits
Political/cultural context	
Faith in institutional structures	Perception of structural declines
Checks and balances	Poor leadership/incompetences
Well-functioning system	
Integrity of institutions	Corruption/scandals
New and innovative ideas	Well-known arguments

3 System description

3.1 Water supply

Although the societies of Norway and Denmark share many aspects and expectations of drinking water, some significant differences impact the supply system in various ways. For example, where the water resource comes from, the geography both in terms of dimension and composition of soil and the extent of pipelines system.

3.1.1 Water resources in Norway

Approximately 90% of the Norwegian population received their drinking water from surface water resources (80% from lakes/ponds and 10% from rivers), while 10% received drinking water from groundwater resources (Ødegaard, 2014, Chapter 6). The surface water quality is affected by the surroundings, e.g. type of bedrock, soil, and human activity. The water intake for drinking water production in lakes is often placed below the thermocline, also known as the metalimnion in lakes. This will serve as a barrier during the summer towards contamination. Likewise, ice will, during the winter, have the same function. The water intake in larger lakes is situated in a depth of 20-40m and a minimum of 2m above the presumed bottom-level (Ødegaard, 2014, p. 145). Often a decision is required to either choose between rural lakes where the water has high quality and requires little treatment or more nearby lake where there is less distance to the households but requires more treatment (Ødegaard, 2014, p. 143). Disinfection of all water is required by the Norwegian health authorities apart from well-protected groundwater, which have shown satisfactory water quality (Norsk Vann, 2020a; Ødegaard, 2014, p. 143). Groundwater is naturally better protected than surface water but can still be contaminated with, e.g. pesticides, fertilisers, industrial chemicals and sewage (Ødegaard, 2014, p. 143). The composition and thickness of the sediments in the soil can impact the quality of the groundwater as it will work as a filter purifying the water as it travels through. Thus, low permeable sediments will act as filters in contrast to high permeable sediments (Ødegaard, 2014, p. 143).

The individual water supply decides the disinfection method in order to obtain approval of the water supply (Norsk Vann, 2020a). Chlorination and UV radiation are the two primary disinfection methods applied in Norwegian water supply facilities. Data from 2006 (Norsk Vann, 2020a) shows that the former is the most used method for three million customers, while 1.1 million customers got their drinking water purified by the latter (Norsk Vann, 2020a).

There are approximately 1600 water supply facility companies in Norway, accounting for 90% of the population, while 10% of consumers have their own well or smaller communal facilities (Norsk Vann, 2020a). The latter is not considered in this thesis. The majority of (1100 of 1600) water supply facility companies are owned by the municipal or are inter-municipal owned. Four hundred smaller water supply companies are cooperatively owned by the users, and 100 are water supply cooperatives in cabin communities. Each consumer in Norway uses, on average, approximately 200 litres of drinking water per day (Norsk Vann, 2020a). The drinking water loss in the pipeline system between the water supply facilities and the consumers is estimated to 32% on average (Ødegaard, 2014, p. 155). Some water supply facilities have a loss of 10%, while others have a loss of 60% (Ødegaard, 2014, p. 155). This average water loss due to leakage in the pipeline system is significantly high compared to other Western countries. However, it is explained by several causes due to the age of pipelines, water resources, economy/budget, high pressure, and weather condition. For further details, see table 3 based on Ødegaard, 2014, p. 155-156.

Table 3. The table describes the causes leading to leakages in the pipeline system and clarifies the complex challenges in the pipeline system. The table is based on Ødegaard, 2014, p. 155-156.

Cause	Description
High pressure	Norway utilize a higher pressure than other countries in the pipeline system to compensate for the topographic and to be able to cover a greater distance
Water resources	The amount of water resources is usually large, and water shortage is therefore not a problem in most parts of the country.
Economy/budget	There is a lack of economic motive to repair a potential leakage. The marginal cost of leaving the leakage is minimal compared to a systematic search of leakage, digging, repairing/replacing, filling up the site, and possibly paving.
Age of pipeline	The pipelines of older date (1940-1970) are of poor standard due to low-quality materials and constructions procedures. Post Second World War, it was of high priority to rebuild the critical infrastructure in the society rapidly, despite a deficiency of quality materials and expertise.
Weather conditions	In some areas, the water supply facilities have challenging conditions with bedrocks in the ditches and frosty pipeline, which can damage the pipes. To avoid freezing pipeline, it can be necessary to let the water run.

3.1.2 Water resources in Denmark

Drinking water in Denmark is based exclusively on groundwater except for one small desalination plant on Christiansø (Danva, 2020). There are about 2600 water supply facilities in Denmark, and 89 of these are considered drinking water companies owned by the municipalities. The rest are private water supply companies often owned by the consumers. In addition, there are approximately 50000 small water plants mainly in the category "Own water supply for single households". The latter group is not considered in this thesis.

The Danish Environmental Protection Agency states that the ground water in Denmark is considered suitable for the production of drinking water (Danish Environmental Protection Agency, 2021c). The ground water is relatively clean, and thus many water supply facilities have a low task of groundwater treatment consisting of filtration and aeration, respectively. Filtration is performed to remove iron (Fe), manganese (Mn) and occasionally ammonium (NH_4^+); this is done through a granular filter material like sand. The aeration is performed to add oxygen to the water and to remove dissolved gases such as hydrogen sulphide (H_2S), carbon dioxide (CO_2) and methane (CH_4). A limited water supply facilities have to treat the groundwater additional by, e.g. using carbon filters, adding chemicals or disinfecting water with UV light (Danish Environmental Protection Agency, 2021c). There are some overall trends, which are interesting in the development within the water supply and drinking water usage for households in Denmark, e.g. the drinking water loss between the water supply facilities and the consumers have the last decade decreased from a weighted average of 8.75% to 6.51% (Danva, 2020). In 1993, a penalty tax was introduced to water supply companies that exceed 10% water loss measured as the ratio of pumped water to the quantity of water sold. This has led to a strong incentive to prioritise the repair of the pipeline system. Another tendency is that the water consumption per consumer is decreasing. This trend started in 1983 where an Action Plan for the Aquatic Environment was introduced. Other measures e.g. charging for pipelines and wastewater purification and taxes, have led to consumer awareness and following lowered drinking water consumption. In 2020 the average consumer in Denmark used 101 litres per day (Danva, 2020).

3.2 Risk frameworks and methods applied in the water supply

3.2.1 RVA theory

The standard of water quality in Norway is protected by the Drinking Water Regulation (Lovdata, 2016). Water supply, treatment, capacity, and quality are the responsibility of the municipals, which are predominantly the owners of the water plants (Ødegaard, 2014, p. 568). The Norwegian Food Safety Authority (NFSA) plays a key role in planning, supervision and controlling the water plants, as stated in the Public Health Law by the Norwegian Institute of Public Health (NIPH) (Ødegaard, 2014, p. 569).

The water supply is a critical societal service, and it is required by law to provide a contingency plan to maintain the water supply in the society in case of disruption (Ødegaard, 2014, p. 599). The contingency plan is based on risk and vulnerability analysis (RVA). There are two general guidances for RVA within societal safety in Norway (Mattilsynet, 2017).

The Norwegian Directorate for Civil Protection (DSB) has produced a guide to an overall RVA (2014), providing helpful guidance for the municipalities' risk management. While the National Security Authority (NSM) provides RVA guidance (2006), that deals with threats that require a focus on securing information and property or installations. Both of these guidelines can provide helpful background information for water supply production. The water supply RVA is limited to the conditions that the water supply itself can affect or be responsible for. The municipals must prepare an overall RVA based on the guideline of DSB. The objective for the water supply RVA is to identify the need for risk-reducing measures, rank the possible events to risk for prioritizing preventive (probability-reducing) measures and provide a basis for preparing a contingency plan (Mattilsynet, 2017). The regulations require that the RVA include assessments of the consequences of various incidents for socially critical functions and critical infrastructure. This involves understanding how events can affect each other (Sintef, n.d.). Excessive or overlapping measures can be uncovered by the water supply RVA, which then can lead to support cost-effective measures that can replace existing solutions (Mattilsynet, 2017).

In the water supply RVA following questions are asked to understand the main cause of an event (Sintef, n.d.):

• What can go wrong within the entire water and sewage systems?

• What barriers/measures can reduce the possibility of an event?

• What barriers/measures can reduce the consequences of an event?

A RVA is essentially the same as a preliminary hazard analysis (PHA) or a coarse risk analysis (Aven, 2020, p. 55; Vinnem, 2014a, p. 82). Although these methods are named differently in the literature, they are equivalent in practice and aims to provide a risk picture. The analysis covers some or the entire bowtie (see section 2.1.1). This requires a relatively modest work of a team consisting of 3-10 people (Aven, 2020, p. 55). The analysis is frequently separated into sub-elements, which are done in succession. Hence, the initial step is to identify subsystems and operational mode (Vinnem, 2014b, p. 558). Then hazards are identified and analysed for each sub-element. Checklists can be used in this step (Aven, 2015, p. 54). The particular hazardous events caused by the hazard are defined, and the probability is estimated of each of the events to take place. A rule-set is utilised for the categorisation of the level of the probabilities and the consequences of the event (Vinnem, 2014b, p. 558). Then a risk matrix is used to determine the risk, where risk is understood as risk equals Probabilities · Consequences. See section 2.1.2. The events can then be ranked according to the assessed level of risk, and the need for implementing measures can be reviewed (Ødegaard, 2014, p. 599). To reduce the probabilities of a hazard or reduce the consequences, actions are identified and evaluated. The interaction effect of the various hazardous events is evaluated as well as consideration of the effect of common-mode or cause failures (Vinnem, 2014b, p. 558). The analysis is presented in a structured approach and typically positioned in tables; this allows easy identification of the most important contributors to risk.

Following a performed RVA and once the necessary risk-reducing measures have been installed, the objective is that the water supply system is recognized as a robust system that can maintain its function after being exposed to an event (Sintef, n.d.).

3.2.2 Denmark is moving from DDS towards ISO standards.

The drinking water in Denmark is regulated via the requirements of the Water Supply Act to fulfil the quality criteria for drinking water (Danish Environmental Protection Agency, 2021c). This differs from other EU countries, which follows the EU Food Regulation as drinking water is considered as an area of food.

An Executive Order on quality assurance at public water supply facilities from 2013 (retsinformation.dk BEK nr 132 af 08/02/2013) distinguish water supply system according to annual drinking water production and states in § 3 that a water supply system that annually produces 17.000 m3 of water or more must introduce a 5 step quality assurance (Retsinformation.dk, 2021a). §4 states that water supply systems that deliver more than 750.000 m3 or more of water annually are obligated to meet the requirement of § 3 by introducing ISO 22000, or systems based on the HACCP principles (Hazard Analysis and Critical Control Points) such as Documented Drinking Water Safety (DDS) or similar systems. The DDS is a risk management system that can be certified by external audit. The DDS management system is developed in collaboration between DANVA and The Danish Environmental Protection Agency, which is built on HACCP principles where risks are identified. Each identified risk is prioritized accordingly to events that need to be prohibited. Priority is based on the assessment of probability and consequence. According to Appendix 6 in the Executive Order of the Drinking Water Directive (Drikkevandsbekendtgørelsen, BEK nr 1070, 28/10/2019) (Retsinformation.dk, 2021b), it is required that a risk assessment must be based on the general principles for risk assessment described in international standards, e.g. EN15975: Safety in drinking water supply - Guidelines for risk and crisis management (Retsinformation.dk, 2021b). Hence, the selection of which framework of risk assessment within the requirement is up to each water supply. The municipality role is only to ensure that a certified risk framework has been implemented. A guide was in 2019 developed by consultant engineer company NIRAS upon request from Danish water supplies and the interest group DANVA. This guide evaluated whether established risk analysis methods could be used to establish an adapted control programme and to examine if any analytical parameters were to be eliminated or the frequency of analysis could be reduced. Further, risk frameworks are assessed in this guide, where it suggested that EN15975 (Safety in the drinking water supply), the standard mentioned in the Executive order, is too focused on risk and crisis management and hence geared towards how to overcome an emergency rather than preventive measures during normal operation. As the water quality is based on controlling the quality of the drinking water rather than being in an emergency, the guide suggests other standards as applied risk frameworks (Retsinformation.dk, 2021b). Hence, the Danish water supply facilities use a variety of ISO standards. See table 4.

Table 4 shows some of the applied ISO standard used in the Danish water supply facilities.

ISO Standard	
ISO 22000	Food safety management system
ISO 31000	Risk Management
ISO 14001	Environmental Management
ISO 9001	Quality Management

Some water supply facilities use several ISO standards, e.g. Skanderborg water supply has ISO certification ISO 22000, ISO 9001 and ISO 14001. There no record of how many water supply facilities in Denmark uses the different standards. On websites of the more extensive water supply facilities, many ensure their customer that they are ISO 22000 certified.

HACCP

HACCP is the acronym for Hazard Analysis and Critical Control Points, a systematic method developed in the 1960s by scientist and engineers at the Pillsbury Company to provide safe food for

NASA astronauts (Wareing, 2010, p. 1). The goal was to make a system that ensured zero defects in food products, and the basis of the system was founded on the principle of Failure Mode and Effects Analysis (FMEA). See section 2.1.3. The American meat industry was the first to implement HACCP. However, HACCP quickly got applied in other branches of the food industry and used by regulatory authorities to identify and assess potential risk associated with risk that can lead to unsafe food. The HACCP method is recognized to focus on preventing hazards by strictly monitoring and controlling each critical point of the production in an efficient manner in order to reduce the inspection of the end product. The concepts of HACCP are compatible with ISO standards within quality management, such as ISO 9001 (Wareing, 2010, p. 2). At the beginning of the 1990s, scientist began to implement the HACCP in the drinking water supply system (Tsitsifli & Tsoukalas, 2019). Bryan (1993) focused on improving the drinking water treatment processes by utilizing the HACCP concepts and suggested that appropriate maintenance and repair of the distribution grid could reduce potential drinking water contamination (Bryan, 1999; Tsitsifli & Tsoukalas, 2019). Havelaar (1994) showed how HACCP could be introduced to prevent microbiological hazards in drinking water, and critical control points were identified for both groundwater and surface water, including appointed corrective actions (Havelaar, 1994; Tsitsifli & Tsoukalas, 2019). Iceland and Switzerland were in the mid-1990s the first European countries to implement HACCP in the drinking water treatment, and within the next decade, many others followed, e.g. Germany, Finland, Sweden, France, Italy and countries further away like New Zealand, Australia and South Africa (Tsitsifli & Tsoukalas, 2019).

Tsitsifil and Tsoukalas (2019) published a literature review of the use of HACCP implementation in water utilities around the world, in which previous data/published papers have contributed to an overview of identified benefits and difficulties using the HACCP (see table 1 in Appendix 1). Although there are numerous benefits, they found some aspects that challenge a successful implementation of HACCP, e.g. old distribution pipelines, a large amount of distribution network, limited staff experience or financial resources, and problems identifying critical control points.

ISO 22000

Governments of more advanced countries have for decades utilized different management methods to ensure food safety both on a national level and when trading with other nations (H. Chen et al., 2020). At the beginning of the millennium, there were several standards around the world developed by both private companies and national organisations (Ruggieri, 2020). This generated complications as companies used different standards and suppliers struggled to meet the requirements in the global market. To overcome the confusion, The International Organisation for Standardisation (ISO) started to design a standard for Food Safety Management System (FSMS) integrating and harmonizing already existing standards; this led to a new standard that was released in 2005 known as FSMS ISO 22000:2005 (Escanciano & Santos-Vijande, 2014; Ruggieri, 2020). FSMS ISO 22000 is founded on the integration steps of ISO 9000 (Quality Management) and the HACCP principles and belonging application steps (H. Chen et al., 2020). FSMS ISO 22000 includes a complete system and requires external auditing to achieve certification (Tsitsifli & Tsoukalas, 2019). FSMS ISO 22000 was proclaimed to be an international standard that effectively ensured food safety by analysing and qualifying hazards continuously from farm to table to provide consumers with a safe end product (H. Chen et al., 2020). The standard was quickly embraced globally by organisations, food producers, manufacturers and other businesses involved in the food supply chain (Ruggieri, 2020).

ISO specifies that ISO 22000:2005 is a FSMS that can be utilised by companies in the food chain to demonstrate the capacity to control food safety hazards and hence guaranty that food is safe at the time of human consumption (International Organization for Standardization, 2021). ISO further states that the standard applies to all sizes of organisations involved in all part of the food chain.

Escanciano and Santos-Vijande carried out an extensive empirical study in 2014 on the reasons and constraints to implementing an FSMS ISO 22000 for Spanish companies (Escanciano & Santos-Vijande, 2014). They focused specifically on ISO 22000 as this was the only FSMS that was international and applicable to each step in the food chain. They found that the primary motivations of the companies that implemented the standard were related to increased efficient food safety management and a desire to reinforce the company's competitiveness. Another finding was that companies that had implemented the standard found that the benefits obtained from doing so outweighed the company's financial effort to invest in implementing the standard and the following certification. Further, it was found that the majority of companies expectations of implementing the FSMS ISO 22000 standard were met. Finally, three limitations by implemented the standard were observed by companies. Firstly, they pointed to that FSMS ISO 22000 is not to its full extent known and understood by the food sector enterprises that did not fully utilize this standard regarding the export market of food. Secondly, although the FSMS ISO 22000 standard´s ability to coexist with other and better established and often required EU standards, it seemed like FSMS ISO 22000 could be perceived as redundant by many companies. Finally, the economic perspective plays a considerable restraint of the FSMS ISO 22000 to be implemented on a broader scale (Escanciano & Santos-Vijande, 2014).

FSMS ISO 22000 got revised and updated in 2018 (ISO, 2018). This means that FSMS ISO 22000:2005 is withdrawn, and all certification must be based on the FSMS ISO 22000:2018 version. Organisations have a 3-year buffer period for its implementation. In the ISO 22000:2018, Food Safety Management System Practical Guide (p. 9) are the changes in the 2018 version listed. Some central points are: 1) adopting a high-level structure that facilitates easy integration of other ISO management systems. 2) It also defines several terms and concepts more precisely and adds new key terms. 3) There are emphasis on two PDCA ("plan, do, check, action") cycles operated independently integrated at both organizational and operational level. 4) The concept of risk has been introduced. Risk is assessed as severity (consequences), and possibilities can in the new version be turned into an opportunity when following the new method of risk evaluation based on the CODEX HACCP. 5) the scope of the FSMS ISO 22000:2018 has been extended to include food for animals.

The updated version of FSMS ISO 22000 follows the risk science development and can be seen as a response to the new trends of international food trade and food safety (H. Chen et al., 2020).

3.3 Water supply as a critical infrastructure

The water supply facility provides water to society, which is essential for health, safety, economic and social well-being (Rodrigues, Borges, & Rodrigues, 2020). Therefore, it is critical to maintain the facility's proper function and ensure that the drinking water quality fulfils the requirement determined by law.

After the 9/11 terror attack on the World Trade Center and Pentagon in 2001, many Western countries started the process to identify, evaluate and prioritize critical infrastructures in the society to prohibit further attacks (Beredskabsstyrelsen Danmark, 2004, p. 43). To achieve this, it was important for each country to define the criteria for critical infrastructures. In order to protect critical infrastructures and key resources, an identification, evaluation and prioritisation must be carried out across different sectors in the society (T. Y.-J. Chen, Washington, Aven, & Guikema, 2020; NOU 2006:6, 2006, p. 16). A risk management method or framework can then be assigned to implement risk-reducing measures for protection against natural hazards or potential attacks to create more societal resilience. A resilient system refers to the ability to withstand an event or surprise without interruption of performing the asset or systems´ function or that the function of the system rapidly returns to normal (Aven, 2020, p. 266). The Norwegian Directorate for Civil Protection (DSB), which reports to the Ministry of Justice and Public Security, produced a rapport on vital functions in the society in 2017 (Norwegian Directorate for Civil Protection, 2017). The definition of critical society functions in this rapport was taken from the governmental Blue Paper NOU 2006:6. In the assessment report, the committee defined the critical infrastructures as " the facilities and systems which are necessary to maintain the critical functions of society which in turn cover society´s basic needs and the population´s sense of security" (NOU 2006:6, p. 32). In the 2017 "Vital functions in society" rapport, the basic needs of the population and society are divided into three major categories: "governability and sovereignty", "security of the population", and "societal functionality". The latter category includes power supply, electronic communication, transport, satellite-based services, security of supply, water, sanitation, and financial services. In the extensive NOU rapport, both water supply and sewage system were identified as societal vital. The committee recommended that both these systems should be in public ownership in a safety and emergency preparedness perspectives (NOU 2006:6, p. 25).

Likewise, in Denmark, a national vulnerability assessment report was carried out in 2004. The report was limited to matters, which have significance for or threatens fundamental societal values, and thus, might require the implementation of extraordinary contingency measures. Critical infrastructure is understood as "the elements of an overall system (society) that are so vital that disrupting and crashing just one of them could threaten the very functioning of the system itself" (Beredskabsstyrelsen Danmark, 2004, p. 38). In this rapport, the drinking water supply and sewage system were recognised as vulnerable both towards natural hazards like contamination and attacks like sabotage or terror. However, the drinking water supply and the sewage system were not defined as critical infrastructure.

3.4 Hazards and threats for the drinking water supply system

Event A located in the middle of the bowtie diagram (see section 2.1.1), is referred to as a hazard or a threat (Aven, 2015, p. 18). Commonly, the term hazard is associated with accidental events (safety), while the term threat is related to intentional acts to inflict harm, fear, pain or misery (security) (Aven, 2015, p. 18, 2020, p. 62). These two terms can be further subdivided into categories for identification. In the water supply industry, drinking water hazards can be divided into four different categories: biological, chemical, physical and radiological (Tsitsifli & Tsoukalas, 2019).

Hazards

Biological hazards can be bacteria, fungi, yeasts, protozoa or viruses (Ashbolt, 2015). Drinking water must be tested for microbiological hazards and disinfected if needed. However, contamination in the pipeline of the distribution system can also take place, which will impact the quality of the drinking water at the tap. The microorganisms can be separated into waterborne and water-based pathogens depending on their origin. Water-based pathogens occur naturally in water and are typically not transmitted from human to human, while waterborne pathogens are transmitted from faecal contamination, e.g. from sewage system or manure from field fertilization (Ashbolt, 2015; Tsitsifli & Tsoukalas, 2019). The techniques for investing biological hazards within the drinking supply is in rapid change. Using whole-genome sequencing has made it possible to carry out an epidemiological investigation of waterborne microbiological outbreaks, which include identification of related cases, determination of the source and preventing further scale of the outbreak (Ronholm, Nasheri, Petronella, & Pagotto, 2016).

Contamination with a large quantity of inorganic or organic chemical compounds in drinking water causes a variety of health problems (Danish Environmental Protection Agency, 2021c; Tsitsifli & Tsoukalas, 2019). Chemical compounds in water can appear naturally, e.g. nickel or arsenic. Other chemical compounds can originate from industries (e.g. cadmium, mercury, benzene, styrene or toluene), households (e.g. cleaning chemicals, paints) or agricultural sources (e.g. pesticides or nitrate) or disinfectant residues from the water treatment or materials in contact with the drinking water, e.g. coating in the pipeline system.

Physical hazards in the drinking water are caused by sediments or organic material from lakes, rivers and streams where surface water is harvested. Other examples of physical hazards are wood, glass, metal, rubber, stone and plastic (H. Chen et al., 2020; Tsitsifli & Tsoukalas, 2019).

Radioactive substances in the drinking water, both naturally occurring and human-made, should also be considered. In case the level of radioactive substances are too high, it represents a health risk. A high level of radionuclides naturally occurs in groundwater, e.g. radon, a noble gas quickly dispersed/released (Ødegaard, 2014, p. 130; Tsitsifli & Tsoukalas, 2019).

Threats

As previously mentioned in section 2.2, different security threats are related to intentional malicious acts. Water supply facilities can potentially be exposed to theft, vandalism, terror attacks or cyberattacks.

After the terror attack on the U.S. in 2001 increased the attention for potential attacks on the water supply system (States, 2009, p. 18). Physical attacks on the system itself, intentional contamination, e.g. waterborne pathogens or chemicals and cyberattack have been feared. Also, cascading effects from attacks on other critical infrastructure such as the power supply must be considered as the water supply facilities needs electrical power to pump the drinking water to the consumers (States, 2009, p. 23). Adding chemical compounds to the drinking water is both by Norsk Vann and by The Danish Environmental Protection Agency considered unlikely to lead to a poisoning of consumers as this would require significant amounts of poison (Danish Environmental Protection Agency, 2021a; Norsk Vann, 2020a). In Denmark, in 2006, a water supply facility in Greve was broken into, and the rat poison strychnine was added to the water. Although no customers got sick, the Danish water supply organisation required increased focus and resource to prevent similar threats (DR Indland Nyheder, 2006).

3.4.1 When failure strikes

Safe drinking water in the household tap is expected by society in both Norway and Denmark. However, sometimes failure strikes, and it can have a severe impact on the consumers and society. In this section, two recent and well-known examples within the drinking water industry are briefly described to illustrate the impacts and consequences of contaminated drinking water.

Askøy, Norway 2019

On 6th June 2019, a *Campylobacter* outbreak occurred in the drinking water on Askøy, an island northwest of Bergen, Norway (FHI, 2019; Paruch et al., 2020). This outbreak is the largest outbreak of *Campylobacter* registered in Norway (Paruch et al., 2020). The acute situation was alerted by the local emergency room and Haukeland University Hospital in Bergen, where staff observed patients with addresses near each other seeking medical help having similar symptoms of abdominal pain, diarrhoea and fever (FHI, 2019; Paruch et al., 2020). It is estimated that more than 2000 people became ill, 76 people were hospitalized, and two deaths were connected to the *Campylobacter* outbreak (Otterlei, Andersen, & Baisotti, 2019; Paruch et al., 2020).

The attention was quickly focused on an elevated caved storage basin installed in the supply line to accommodate steady and sufficient pressure in the pipeline system (FHI, 2019; Ødegaard, 2014, p. 247). *Campylobacter* bacteria was found in the drinking water in the storage basin and the downstream distributions network. It was confirmed by genetic analysis that it was the same strain as found in stool samples of hospitalized patients (FHI, 2019; Paruch et al., 2020). Contamination from the sewage system was ruled out as it was concluded that the contamination originated from animals. The basin was drained and laser scanned by geologists. Minor open fractures were discovered in the roof of the basin, and hence it could be inferred that after massive rainfall, contaminated water with excrements of wildlife and/or domestic animal had percolated into the drinking water storage basin (FHI, 2019; Paruch et al., 2020). The NIPH evaluation rapport of the outbreak states that the construction of the storage basin was old. Another key finding in the NIPH evaluation rapport was a connection between the quantity of drinking water consumption and the severity of the symptoms, which indicated the urgency of critical risk communication (FHI, 2019). The risk communication of the municipality at the emergency stage of the outbreak was criticized by customers and lead to distrust of the municipality (Asvall, Olsen, & Granli, 2019). Although an SMS warning system was utilized, it fell short to inform all affected customers on the island as it was unclear which of the customers received contaminated drinking water. Also, the SMS warning system was not updated correctly (Baisotti, Svendsen, & Otterlei, 2019).

An independent review group made an extensive open audit rapport, which was published in 2021. The rapport states that it is believed that the municipality and the administration before the event had too little focus on drinking water supply as critical infrastructure and that there was a lack of municipal responsibility concerning the requirements of the Drinking Water Regulation for the water supply facility (Eikebrokk et al., 2021, p. 213). Inadequate compliance with the following paragraphs in the Drinking Water Regulation was believed to be the underlying causes of the disease outbreak and its consequences: (§ 6) The water supply facility did not follow up its own procedures for performing ROS analyses. (§7) Lack of internal control. (§11) The municipality lacked an updated and accessible contingency plan for the water and sewage system. (§15) The Agency for Water and Sewerage Works lacked updated plans and tools to ensure that the distribution system was operated and maintained adequately. (§19) Lack of routine sampling from an existing crane in the height basin, even though the water and sewerage department had already in 2011 decided that this should be carried out. Weekly tests would probably have shown that the storage basin was polluted (Eikebrokk et al., 2021, p. 212).

Køge, Denmark 2007

On 15th January 2007, a waterborne outbreak in the drinking water causing gastrointestinal illness occurred in Køge, a municipality located south of Copenhagen (Vestergaard et al., 2007). This case became one of the most comprehensive drinking water contaminations in Denmark in recent times. A total of 224 citizens fell ill, eight people had to be hospitalized, and some of the illnesses were long-lasting (Vogt-Nielsen, Hagedorn-Rasmussen, & Larsen, 2007, p. 13). The first complaint from citizens was received on Monday at 9 am and several more followed. People had been getting sick over the weekend with vomiting, abdominal pain, fever and severe diarrhoea. Furthermore, the drinking water appeared discoloured and had an unusual taste and smell (Vestergaard et al., 2007). The patients mainly lived in the same area, but also some people who had visited the affected area, such as shoppers or employees in the companies within the area, had fallen ill.

Within two hours, the municipality had issued a drinking water ban alert to the police and collected a crisis coordination team (Vogt-Nielsen et al., 2007). The police informed the media and utilized loudspeakers on police cars in affected neighbourhoods (Public Address systems). The emergency air raid siren was activated six hours after the first complaint to alert the citizens who were not informed of the drinking water contamination.

To find the cause and map the affected geographic area, water samples were collected across the entire drinking water supply network and the local water supply facility itself, which supplied approximately 7000 customers (Vestergaard et al., 2007; Vogt-Nielsen et al., 2007). The water samples from a part of the distribution pipeline contained a high concentration of faecal indicator bacteria and endotoxins were found, which indicated faecal contamination (Vestergaard et al., 2007).

Although contamination from the local sewage system was quickly suspected, the cause of the event was unclear, and 11 days passed until the sewage treatment plant was declared/acknowledged as the source (Vogt-Nielsen et al., 2007, p. 12). The board of the municipality was reluctant to point to the sewage treatment plant before excluding other potential contamination sources in fear of a possible lawsuit from the sewage treatment plant in case of misplaced guilt. Further, the board wanted to avoid a situation where they would have to go back on what was the source and alternate the cause of contamination. Hence, they decided not to publish information of suspected backflow sewage water into the drinking water (Vogt-Nielsen et al., 2007, p. 12).

Tracing the exact cause was challenging; however, the investigation based on technical and microbiological circumstances indicates that the most plausible cause was due to a combination of a technical and a human error at the sewage treatment facility (Vestergaard et al., 2007). As nobody acknowledged to have made an illegal coupling of the system on the sewage treatment plant, final documentation of the event could not take place, and after months of investigation, the municipality decided to stop the investigation of the exact circumstance of the incident (Vogt-Nielsen et al., 2007, p. 11). It was estimated that a minimum of 27 m3 of partially filtered but grossly contaminated wastewater originated from households, industrial enterprises, food production companies and a hospital entered the drinking water system at a point between 12th and 14th January 2007 (Vestergaard et al., 2007).

The affected distribution pipeline system was flushed immediately after the event and in the following weeks to clean the pipeline system. Nevertheless, after two weeks of flushing, faecal indicator bacteria were still present in the water samples collected in the system (Vestergaard et al., 2007). At the beginning of February, it was decided by the crisis coordination group in line with conversations with the Danish Environmental Protection Agency to disinfect the system by chlorination, which was successfully carried out on 10th and 11th February (Vestergaard et al., 2007; Vogt-Nielsen et al., 2007). In the extensive evaluation rapport of the management of the drinking water pollution written by Vogt-Nielsen and colleagues in 2007, several recommendations were put forward. In particular, the risk communication of the municipality towards the public the days after the event was criticised, both terms of *which* information was shared and *when* it was shared and *how* it was shared. Amongst others, it was recommended to utilize the technological notification methods to direct the SMS alert system (Vogt-Nielsen et al., 2007, p. 15).

4 Methodology

This chapter explains the methodological procedures and approaches applied in the thesis. The data collection for the thesis is based on a combination of a comprehensive literature review and interviews of key people within the water supply industry in both countries. This contributes to insights and knowledge of the two countries' water supply industries that form the foundation for comparing and discussing safety and security perspectives.

4.1 Research questions and design

Initially, the first research question must be addressed through a literature review to understand the risk frameworks and methods used within the drinking water industry in Norway and Denmark. Thus, these findings provide the premise to proceed with the actual research question, which is a comparison of the risk frameworks and methods. Hence, the research question is addressed through a literature review combined with information obtained through interviews of key people within the industry. The second research question examines selective aspects of the practical risk communication in the water supply industry, e.g. notifying customers after an event. Furthermore, it is discussed how is the theoretical knowledge of risk communication is integrated into these practical aspects. The second question addresses the practical aspects of risk communication using information obtained through interviews whilst the theoretical knowledge is obtained by literature.

An inductive research strategy is primarily applied in this thesis as it starts with the collection of information through literature and interviews and then proceeds to derive some generalisations using inductive logic that will result in a qualitative conclusion (Blaikie, 2010, p. 18). Thus, the literature findings related to the first research question are considered descriptive answers (Blaikie, 2010, p. 60). These findings enable the opportunity of comparing and discussing the risk frameworks and speculating why they are selected in the respective country. The countries have common societal expectations when it comes to the drinking water supply system. Hence, the purpose is to illuminate and understand, in contrast to, a quantitative approach that seeks results measured in numbers and where the final result can be expressed in statistical terminologies (Golafshani, 2003). Nonetheless, the combination of numbers and words provides excellent credence to the validity of the findings.

4.2 Selection of literature and analysis of documents

Careful selection of literature showed to be important as there is a significant amount of accessible information available online regarding drinking water. There are, however, many stakeholders with different interests, which might compromise the quality of the information. For ensuring the validity of the data collected, it was essential to make reflections concerning credibility and authenticity. Much information was collected from governmental and officially sources such as The Danish Environmental Protection Agency, The Norwegian Institute of Public Health and legislation information from both counties (LOVDATA and Retsinformation). Likewise, the water supply industry interest organisations (Norsk Vann and Danva) in respective counties and information from International Organization for Standardization (ISO) have played a crucial role in the data collection. Literature such as peer-reviewed papers, reviews and books were mainly collected using the Oria portal, Scopus database or Google Scholar, which the University of Stavanger provided access to. The library at the University of Stavanger has also offered a helpful class on finding information aimed at master students writing their thesis. Furthermore, literature from the syllabus of various courses on the Master program for Risk Analysis and Governance was used in addition. Limited data were also collected from the media concerning contamination of drinking water, and for this purpose, mainly national media such as NRK or DR were referred to.

4.3 Selection of interview objects

Danva and Norsk Vann facilitated the selection of the relevant key people to interview by referring individuals who have much relevant experience within the safety and security of the drinking water industry and have daily responsibility for the water supply for hundreds of thousands of customers. The experts are not mentioned by name in this thesis, only referred to by the organisation name accordingly to an agreement with the participants (Dalen, 2004, p. 219; Yin, 2014, p. 194). The supervisor is informed of the names of the experts and the dates of the interviews. The codes of ethics listed by Blaikie 2010 p. 31 were all fulfilled (Blaikie, 2010). These are: voluntary participation, obtaining informed consent of research participants, protecting the interests of the research participants, and researching with integrity.

4.4 Preparation and conduction of interviews

All formal interviews and supervision meetings have, due to the Covid-19 situation, been conducted on Microsoft Teams, while some informal conversations with the staff of Danva and a water supply company have been on the phone. As a part of the interview process described in Dalen (2004 p. 26), questions were prepared before the interviews. Two customised sets of questions were designed according to the knowledge collected from the literature. Certain pieces of information from each country were evident before the interviews. Hence, to limit the number of questions, only relevant questions were asked. The sketch for the interview guide can be found in Appendix 2. Some questions were specific, whilst some were more open for the interview objects resulting in semi-structured interviews. It was taken into consideration that a too rigid form of interview would suppress unknown issues to appear.

It proved helpful during the interviews to stay adaptive to developments as sometimes new and unexpected information was unveiled, which aligned with the theoretical knowledge (Yin, 2014, p. 74). During interviews, it is central to stay objective and listen to the exact words of the interview objects and still understand what is communicated between the lines (Yin, 2014, p. 74). Avoiding bias and remaining open to the contrary than believed is central and instead, strive for credibility and understanding of the subject (Yin, 2014, p. 77).

Leading questions were avoided, and it was considered beforehand that some areas, e.g. security, could be too sensitive to discuss. These considerations align with the preparation of questions described in Dalen (2004 p. 31). Regarding security questions, the purpose of the thesis was at no time, e.g. to assess the lock or key system. The goal was rather to understand which theoretical frameworks or methods were used to implement barriers to prevent vandalism, sabotage, or terror attacks.

The initial analysis was started immediately after the first formal interview, and sufficient time was allowed between the interviews to allow time to transcript each interview, which is a recommendable approach (Pidgeon, Turner, & Blockley, 1991). Two experts from each country were interviewed approximately for 1½ hour each. The collected data from each set of experts were compared to create a sense of validity. When the empirical findings appear similar and potentially also found in the literature, it strengthens the data (internal validation) (Yin, 2014, p. 143).

The development of relevant and meaningful subject categories slowly formed as the interviews progressed, and these are presented in chapter 5. Each subject category was analysed and compared across the two countries in the discussion in chapter 6. Links or interactions between the subject categories were also discussed when relevant to the thesis research questions. Finally, some conclusion and recommendations were made.

4.5 Strengths and weaknesses of method selection

The questions asked and the selection of subject categories is based on judgements and are a weakness of the method selected. Also, it would have been preferred to have a more extensive collection of interviews from both countries. This would be rather time-consuming; furthermore, it would be challenging to persuade people to do interviews. The experts interviewed represents some of the largest water supply companies in Denmark and Norway and thereby face the most significant challenges in terms of safety, security, and communication. This strengthens the value of the information obtained through the interviews.

5 Findings

In this chapter, findings from the interviews are presented. The findings are not presented in raw data, but the relevant information is extracted to answer the research questions. The shown information represents therefore, to an extent, an interpretation. A representative of the interview objects from each country has reviewed the presented interview result before submitting the thesis to avoid misinterpretations or misunderstandings of the interviews performed.

Two sets of key persons within the water supply industry were interviewed from Norway and Denmark, respectively. The data collected will be presented in sections of categories and, to some extent, illustrated schematically.

As described in the Methodology chapter, the interview objects are anonymised. Still, their organisation is listed in table 5, together with attached information of the organisation and an assigned abbreviation for identification used in this chapter and following discussion chapter. The interview guide can be found in Appendix 2. None of the water supply companies is private. They are not integrated with the municipality either but are independent shareholder companies fully owned by the municipality.

Table 5. Overview of formal interviews.

Organisation/Company	The approximate number of costumers	Country	Date of interview	Abbreviation in text
IVAR	340.000	Norway	12th May	NO1
Drammen Municipality	100.000	Norway	20th May	NO2
HOFOR, Copenhagen	1.000.000	Denmark	21st May	DK3
Aarhus Vand	280.000	Denmark	5th May	DK4

5.1 Safety

Norway

As presented in section 3.2.1, the Norwegian water supply industry utilises a risk and vulnerability analysis (RVA) modified for the water supply industry. Software system tools such as TQM (Total Quality Management) or CIM (Crisis Information Management) facilitates the RVA in the water supply (NO1 & NO2). TQM and CIM software systems have provided a lift for the water supply industry (NO1 & NO2). The RVA is applied to each installation (NO1). An extensive list of events is available and only events considered relevant for the individual installation are selected in the RVA. The RVA is carried out in groups consisting of individuals with different backgrounds; amongst those must be a safety representative and a management representative (NO1). Such a group will carry out the mapping, discussion, consider implemented measures and previous learnings regarding considered events (NO1). The risk in the RVA is understood as risk equals Consequences · Probability in a 5 x 5 risk matrix. Consequences considered are, e.g. economics, reputation, supply service, water quality and health. A person will be responsible for the analysis process and will update the RVA in the TQM (NO1). It was found that ISO 9001 and ISO 14001 were used in some Norwegian drinking water supplies.

The municipalities in Norway also have a license for using CIM, a digital crisis support tool (NO2). Within the CIM software tool, an RVA modified explicitly to the drinking water supply industry has been developed based on the water supply guidelines provided by the Norwegian Food Safety Authority. Performing the RVA for the drinking water supply in the CIM software is considered more thorough than a regular coarse analysis, and it takes longer and requires competence within the emergency preparedness field (NO2). Highlighted as a positive feature using RVA was the flexibility of the analysis depending on which installation applied to (NO1). Both sources emphasized that competence plays an important factor in performing RVA in the water supply industry. A drawback of the RVA was that it is not so presentable in talks (NO1). Both sources were satisfied with the RVA for the drinking water supply in regards to safety aspects.

Denmark

As presented in section 3.2.1, the Danish water supply industry utilised the DDS management system and the FSMS ISO 22000 standard, which was verified in the interviews (DK3 & DK4). While the FSMS ISO 22000 were fully implemented, the DDS was still used actively (DK3). The DDS functions well for educating service personnel, entrepreneurs, and managers. All must have completed a DDS course provided by Danva in hygiene, which provides an understanding of risk factors in the drinking water supply and insight into good work habits as well as train to detect deviations from good hygiene practice (DK3). The two management framework systems talk to each other to make the system more robust. The negative aspects of utilising FSMS ISO 22000 were named to be complex to implement as the first ISO standard. It was also stated (DK3) that when once the structure and systems were understood, it was easy to implement other ISO standards as they have a similar structure, methodology and risk analysis. This was highlighted as a positive feature of ISO 22000. Another issue was that it requires resources to implement a certificated ISO standard. Sometimes it was decided to follow ISO standards principles but wait with the certification until making sure the requirements can be fulfilled before proceeding to official certification by external auditing (DK3). The risk in the framework is measured as risk = Consequences · Probability in a 5 x 5 risk matrix. The consequences consider personal safety, health, environment, economics, and reputation. Both sources were satisfied with the use of the ISO 22000 standard in the drinking water supply regarding safety aspects. See table 6 for a summary of findings obtained from the interviews concerning risk frameworks and methods used in the water supply.

Table 6. Summary of the findings obtained from interviews concerning risk frameworks used in the water supply industry in Norway and Denmark.

	Norway	Denmark
Framework or methods applied for safety aspects	RVA	ISO 22000:2018
How does the frame describe risk	Summarised by consequence and probability in a risk matrix	Summarised by consequence and probability in a risk matrix
Satisfied with the used framework	yes	yes
Drawbacks of the framework/method	-RVA is not suitable for presentation -requires competence	-ISO 22000 can require extensive work to implement. -It costs resources to audit
Benefits of the framework	Easy to adapt to specific installation	Easy to implement more ISO standards when first is implemented. ISO standards work together

5.2 Security

The literature review did not clarify which security methods are used in Norway and Denmark´s drinking water supply industry. From the interviews, it was found that different frameworks and methods applied, and sometimes a combination was used depending on the situation.

Norway

Diverse methods are used to address security matter in the water supply industry. Some use a step in the RVA, where vandalism/sabotage/terror is handled as an unwanted event in the RVA (NO1). At the same time, others are more critical towards using a risk matrix for security issues and have, in certain situations have decided to use a triplet approach (threat, value, vulnerability) (NO2). The triplet approach is time demanding and requires competence.

The water supply facilities have limited the access to installations using key cards programmed for day or night (NO1). Some smaller installations have physical keys, where it is documented who got handed out keys. There is a good control on which employees are assigned keys to which installation (NO1). IT systems are handled by competent IT staff. There is a widespread focus on using specialists within specific areas (NO1 & NO2) and providing the staff with the opportunity to continue education by taking courses in, e.g. within security risk (NO2).

Sources recognised that the water supply facilities are vulnerable to a terror attack. It is difficult to protect something, which has to be accessible everywhere in society and at the same time protect it against intentional malicious acts (NO1 & NO2).

Denmark

The addition of the food safety and food fraught in the FSMS ISO 22000:2018 standard provides helpful guidance in how to limit the access to the installations of the water supply facilities (DK3 & DK4). The FSMS ISO 22000 requires that the water supply annually must present how it handles food safety and terror threats (DK4). It also offers recommendations for lock systems and CCTV system installation. Safety and security aspects regarding access area within the facilities are intertwined as the hygiene zone (yellow and red) applies alike. Key cards determine how much access is given, and an unauthorised door opening will automatically stop the system. Likewise, pressure sensors will also notify in case of abnormalities and tests of the drinking water are continuously performed. IT systems are separated into operational IT system on an external network, which is not accessible online and a regular IT system (DK3 & DK4). External IT services shielding cyber-attacks have been acquired together with internal IT staff. Awareness campaigns have been used to train staff to look out for suspicious emails or IT events (DK3). It is recognised that the IT system of water supply is vulnerable to cyber-attacks like other organisations (DK3 & DK4). It considered that the drinking water supply industry is supportive of internal sharing relevant information to relevant equivalent (DK3 & DK4).

Internal attacks are also considered, but there is great respect for drinking water within the industry and the notion that everyone has the rights to get water (DK3). Also, people who work in the water supply industry often stay within the field for many years (DK3). Sometimes a security situation needs to be weighed carefully before deciding, e.g. to which extent should hotline employees have IT access at home during the night shift.

Regarding well-organised terror threats, the water supply industry relies on The Danish Security and Intelligence Service (PET) or police to prevent and inform of these.

5.3 Some practical aspects of the risk communication

There is a notable difference between the risk communication regarding drinking water supply in Norway and Denmark. In Norway, the customers buy the water from the municipalities and therefore, it is the municipalities that are responsible for the risk communication to the customers. Whilst in Denmark, the customers buy the drinking water directly from the drinking water supply companies, which thus are responsible for the risk communication.

Based on the case studies in section 3.3.1, the main focus of risk communication considered in the interviews was alerting customers in case of an event in the drinking water supply causing contamination.

Norway

The water supply company notifies the municipalities in case of an event. Then, in turn, the municipalities alert the customer on their website, their Facebook page, media and SMS warning, which also includes weblink for more detailed information. Vulnerable customers, e.g. nursing homes or hospital, received a direct warning by phone (NO2). The connection point of the pipeline system is registered in their map system, which provides an accurate overview. This might not, however, be the case in all municipalities (NO2). A national address database, which is based on the tax authorities (Skatteetaten), the internet portal for digital dialogue authorities (Altinn) and Norwegian health services (HelseNorge), provides affected customers based on addresses when drawn on the map. Most municipalities use this service, while a few municipalities buy a service at the telecommunications companies where mobiles present in the area all receive the alert (NO2). This applies to the visiting people in the area, such as hotel guests and shoppers.

When an inter-municipal drinking water supply has an event, which requires an SMS warning, an important factor for the risk communication effort made is a collaboration between the involved municipalities (NO2). The release point and the overall message sent to the customers in different municipalities must be the same. Each municipality has an independent decision-making responsibility, but in these situations, the risk communication is more effective when no municipalities decide to go solo (NO2). It can be beneficial to create a network collaboration across the municipalities buying drinking water from the same drinking water supply facility (NO2).

Denmark

The water supply companies used their website, their Facebook page, local media (tv and radio) and SMS warning in case of alerting the customers of contaminated water according to the scale of the event (DK3 & DK4). It is possible through the use of the GIS system to identify the affected addresses (DK4). Then the alert is sent via Blue Idea, which sends out the SMS message to the customers. Blue Idea is an international software company that specialises in digital communication used by, e.g. municipalities and utility companies. In addition, a phone call to the municipality is made, which then notifies all units within the municipality, such as nursing home and Kindergartens.

It is challenging to reach all customers (DK4). However, after a recent contamination case, a statistical study was carried out afterwards on how many customers the water supply company had been able to reach. It was found that approximately 75% had received SMS alerts, and a further 10% were informed by other communication channels or word of mouth, which adds up to 85% of affected customers (DK4). A minor incident due to an update in Blue Idea caused, however, that not all customers were notified immediately that the boil alert was cancelled, resulted in some critic.

The SMS warning system is utilised frequently due to regular repair work of the pipeline system and functions in a satisfying manner (DK3 & DK4).

There have been cases where misinformation has been spread based on misunderstandings, e.g. on Facebook by customers regarding boil alert or contamination; hence there also a concern of people overreacting (DK3).

Trained communication staff are handling the communication channels and sometimes also contribute to more preventive measures, e.g. hire an influencer to promote pesticide-free gardens or pop-up stand in the city centre to promote regular drinking water from the tap (DK4).

5.4 Critical infrastructure classification in Denmark

As suggested in the literature findings, it was confirmed by the interviews that Denmark has not currently classified the water supply system nor the sewage system as critical infrastructure. This might change soon as the authorities have more attention on the subject (DK4). The corona crisis has made it more evident that the drinking water supply and the sewage system were not a part of the crisis team of critical infrastructures (DK3). One of two scenarios that can transpire is either the entire drinking water supply and the sewage system will be classified as critical infrastructure, or it could be some designated utility companies, e.g. in larger towns and cities (DK4). In the case of a new classification, the industry expects a stricter set of requirements for safety and security (DK3 & DK4). This will require hiring more competent and specialized staff (DK3).

5.5 Risk events of concern for the water supply industry

All interview objects were asked which probable challenges they were most concerned about within the next five years for drinking water supply. The primary concern of ill interview objects was cyber-attacks. Climate change causing extreme weather was also of concern (NO1, DK3, DK4). A source gave an example of much rainfall could potentially force the water supply company to move one of its water source installations which were exposed to flood (DK4). Another source also added landslides in this concern (NO1).

The Danish interview objects had concerns about pesticide contamination of groundwater from gardens and agriculture (DK3 & DK4). One source gave an example of a water source they decide to shut down because a small amount of pesticide was found (DK3). Addressed as a future challenge is the balancing act of CSR (Corporate Social Responsibility) (DK3). The water supply companies must continuously ensure high-quality drinking water to maintain credibility and trust in the product and the company. Potential pesticide contamination could lead to a lack of trust, and in turn, customers could react by, e.g. installing their own filters and buying bottled water (DK3).

The Norwegian interview objects expressed concern about not having considered events in the RVA (NO1). Another source highlights a potential supply facility investment backlog (NO2). It is also mentioned that installation security is expensive as installations and facilities are not built with respect to security protection (NO2).

See table 7 and 8 for summarized findings from the interviews carried out.

Table 7 summarized some of the concerns the organisations/municipality have for the next five years.

Norway	Denmark
Cyber-attacks	Cyber-attacks
Climate change/extreme weather	Climate change/extreme weather
Specialised and competent staff	Specialised and competent staff
Events in RVA not considered	Pesticide contamination
Investing backlog	Balancing CSR

Table 8. Results from interviews summarized.

	Norway	Denmark
Framework or method used for safety	RVA	DDS or ISO 22000 (DDS = HACCP)
Risk framework targeted exclusively towards food production	No	Yes
ISO standards used the industry	ISO 9001 (Quality) ISO14001 (Environment)	ISO 22000 (FSMS) ISO 9001 (Quality) ISO14001 (Environment) ISO 31000 (Risk Management)
Audit of implemented framework/method	Mainly internal	External
Framework or method used for security	Vandalism/sabotage/terror handled as an unwanted event in the RVA or the triplet approach	ISO 22000:2018 step for Food security and Food fraud.
Acknowledge water supply as critical infrastructure	Yes	Not currently
Crisis communication performed by	Municipality	Water supply companies
Who is an advocate for further safety/security of the water supply facility (e.g. politicians/customers)	Board members of the water supply companies	Board members of the water supply companies

6 Discussion of findings

In this chapter, the findings from the interviews and the literature review will be discussed. The discussion of findings will lead to some insights and conclusions for the research questions asked.

The research questions are:

I. Which comparative characteristics of the applied risk frameworks or methods for safety and security are observed within the drinking water supply in Norway versus Denmark?

II. To what extent is the practical risk communication regarding drinking water towards the consumers built around the theoretical knowledge of risk communication?

6.1 Safety

6.1.1 Utilized risk framework and methods in Norway and Denmark

It was found in the literature review and confirmed in the interviews that the drinking water supply companies in Norway and Denmark do not use the same risk framework and methods.

In Norway, the RVA is used as a risk assessment in the drinking water industry. Whereas in Denmark, the DDS risk framework and/or the FSMS ISO 22000:2018 standard, which are both based on HACCP principles, are used. The FSMS ISO 22000 standard is based on the compositions of HACCP principles and ISO 9001 (Quality Management). Several larger drinking water supplies in Norway also used ISO 9001 for quality management. The use of ISO 9001 in the water supply industry provides quality assurance and operational efficiency. However, ISO 9001 does not systematically identify the critical risk factors that can influence the safety of drinking water. ISO 22000 identifies critical risk factors and areas within water supply facilities and seeks to minimise the risk of contamination (Danish Environmental Protection Agency, 2021b). The core difference between Norway and Denmark is thus the HACCP principles and RVA (Hazard Analysis and Critical Control Points and the Risk and Vulnerability Analysis). In Denmark, the HACCP principles are required by regulation in the law. While a risk and vulnerability analysis is required in Norway, this lead to the use of the water supply RVA. However, this could also have been covered by using FSMS ISO 22000, where risk and vulnerability are likewise are assessed. It appears, however, that the Norwegian municipalities are focused on the RVA.

The HACCP method was developed decades ago specifically for the food industry and is still used globally. The FSMS ISO 22000 standard has been used and tested globally since 2005 and updated in 2018. The water supply RVA is explicitly developed for the water supply industry but is not to the same extent developed as a food safety management system, nor does it follow HACCP principles. Hence, the FSMS ISO 22000:2018 could be an appealing framework to utilize in Norway and would work well with other ISO standards already implemented in the water supply industry. As earlier presented in section 3.2.2, Tsitsifil and Tsoukalas (2019) listed benefits and difficulties using the HACCP principles in the water supply industry (see Appendix 1). Some factors that challenged the successful implementation of HACCP were, amongst others, old distribution pipelines and a large amount of distribution network. These two factors could influence the HACCP implementation in Norway as there is an extensive distribution network. Also, some of it has considerable weaknesses and is outdated (see section 3.1.1 & section 6.4).

Both the water supply RVA and FSMS ISO 22000 consider risk as the product of consequences and probabilities using a 5 x 5 risk matrix as a risk assessment tools to determine the level of risk. Using risk matrices does entail some challenges, which one must be aware of when applying them, as mentioned in section 2.1.2.

6.1.2 Audit of the implemented framework or method

An audit is an independent systematic review of whether a water supply company follows the implemented management system. The audit reviews if there is an agreement between practices and rules. Nonetheless, it is also an opportunity to create trust and value in the implemented system.

FSMS ISO 22000

It is possible to hire specialised engineer consultants for guidance in the build-up to achieve the FSMS ISO 22000 certification. It might be a desirable solution for smaller water supply companies with perhaps less competence to hire a consultant to help with the transition to fulfil the requirements before seeking FSMS ISO 22000 certification. An external audit will inspect the water supply companies to certify that they fulfil the requirements of the ISO standard. Then, the certification represents a quality stamp for the water supply companies (see section 3.2.2).

A smaller water supply company implementing DDS (based on HACCP) can choose to get an external audit or settle for an internal audit. DDS implementation is less extensive to implement and is not as costly as the FSMS ISO 22000. However, there is a trend in Denmark to upgrade to FSMS

ISO 22000 from DDS (see section 3.2.2). Stricter requirements and the initiative of trust-building effort can explain this trend. Once the ISO certification is received, this can contribute to increased trust among consumers and at the same time give the board members ease of mind that the water supply meets the rules. In case of events covered by the FSMS ISO 22000 framework, the responsibility can be, to some extent, be shared with ISO.

The water supply RVA

An internal group of 3- 10 people carries out the RVA by assessing each possible event for every installation within the water supply facility. The TQM software system provides an overview of all previous events, and the group select which events are relevant for the installation assessed. The selected events and implemented barriers are entered into the TQM system. The system allows for later updates to the events or implementation of new measures (NO1). Later updates to the TQM system require approval by management. Hence, the RVA is flexible towards which installation is considered and potential developments, contrasting with the more rigid framework of ISO 22000. The Norwegian Food Safety Authority carries out public control of the water supply facilities but, unfortunately, does not have the capacity to inspect all the water supply companies in Norway (The Norwegian Food Safety Authority, 2021). Thus, there not a regular external audit or a framework that ensures practice and rules agrees. Although the water supply companies do best practice, it could be valuable to have an external audit to strengthen and improve the system. An external audit could perhaps also lift some of the heavy responsibility the water supply has and facilitate know-how from other water supply companies.

6.2 Security

As mentioned in section 2.2 and 3.4, security threats are related to the degree of intended malicious acts, and the water supply facilities can potentially be exposed to theft, vandalism, terror attacks or cyberattacks. In this discussion of the security at the water supply facilities, it is beneficial to differentiate between planned attacks and unplanned attacks. The planned attacks are further separated into physical attacks and cyber-attacks.

6.2.1 Theft and vandalism

We choose to consider vandalism and theft as a primarily unplanned spontaneous act committed by, e.g. bored youngster or drunk people on the way home from the pub targeting water supply facilities above ground and not the pipeline network underground. In these cases, Norway and Denmark's risk assessment methods and tools will prevent these types of threats from escalating. In Norway, these events are handled as unwanted events in the RVA (NO1), and in Denmark, these events will be addressed in the food safety and food fraud step of FSMS ISO 22000 (DK4). In both cases, escalation of these events will be prohibited by implemented preventive barriers that lead to limited access to the water supply facilities by, e.g. locks, key cards, CCTV, and system shut down in case a door is opened unauthorised.

6.2.2 Sabotage and terror attacks

We choose to consider sabotage and terror attacks as planned physical attacks. The water supply facilities are vulnerable to terror attacks are recognized by sources in both Norway and Denmark (NO2, DK3).

As Norway has classified the water supply and sewage system as critical infrastructure, terrorism targeted against the water supply facilities has been addressed. In Norway, the recommended practical security analysis approach is the triplet approach (Jore, 2015). The guidance for increased safety and preparedness in the water supply provided by the Norwegian Food Safety Authority also refer to the triplet approach for intentional events referring to Norsk Standard 5831:2014 Society security (Mattilsynet, 2017, p. 9). This guidance also states that “while the assessment of adverse events is normally based on experience, statistics and forecasts, intentional events are treated based on threat assessments” (Mattilsynet, 2017, p. 10). It seemed, however, that the triplet approach is rarely used as it is time-consuming and required staff trained in security risk (NO1 & NO2). Some water companies enter intentional events into the water supply RVA and use a 5 x 5 matrix with probabilities and consequences (NO1). The water supply industry, in general, has little focus on intentional physical events (NO2). Some designated water supply companies e.g. in Oslo belongs to the Security Act, this status enables them to receive guidance and knowledge from the police.

In Denmark, the water supply facilities and the sewage systems are not currently classified as critical infrastructure. Therefore, there is no official guide to a practical security approach in the water supply industry. Security is covered by safety in FSMS ISO 22000 and cooperation between Danva and PET where lock systems and CCTV have been approved. The water supply industry relies on the police or PET regarding planned terror threats.

If the water supply facilities or some designated water supply companies get classified as critical infrastructure, presumably stricter requirements will be implemented. This was also confirmed by sources in Denmark (DK3 & DK4)

6.2.3 Cyber-attacks

We choose to consider cyber-attacks as planned non-physical attacks. Cyber-attacks were found to be a significant security concern of all sources interviewed. Presumably, the water supply companies are particularly vulnerable to ransomware cyber-attacks. Both countries focused on using IT specialists internally and adding external IT services in the form of shielding and a separate system for the operational system. A source mentioned new legislation from the EU coming soon regarding cybersecurity (DK3). On the website for European Union Agency For Cybersecurity, a new cybersecurity certification is announced and features the following: "*This has been named EUCC scheme (Common Criteria based European candidate cybersecurity certification scheme) and it looks into the certification of ICT products cybersecurity, based on the Common Criteria, the Common Methodology for Information Technology Security Evaluation, and corresponding standards, respectively, ISO/IEC 15408 and ISO/IEC 18045*" (European Union Agency For Cybersecurity, 2021). If this is helpful for the water supply industry remains to be seen. In case this cybersecurity certification is introduced in the industry, it will be interesting to see how this can be implemented. Presumably, the industry would benefit from a common guideline or standard on how to prevent cyber-attacks. Still, this requires competence, and perhaps external services will make the most sense for small and midsize water supply companies.

6.3 Communication

In the evaluation rapports of the events on both Askøy and Køge, it was found that the municipalities and other members of the authorities in the acute situation handled the situation conscientiously based on the precautionary principle and that the overall effort in both cases proved rather efficient (Vogt-Nielsen et al., 2007 p. 11; Eikebrokk et al., 2021 p. 10). Still, both rapports highlights that the risk communication in the acute phase alerting the consumers not to drink the drinking water was not optimal (Vogt-Nielsen et al., 2007 p. 10; Eikebrokk et al., 2021 p. 212). In situations where minutes and hours can be crucial to how many consumers become ill, and the severity of their symptoms increase with the continued consumption, alerts must be comprehensive and efficient. These findings establish the importance of critical risk communication towards the public during drinking water contamination. Therefore, the questions asked during the interview regarding risk communication were mainly targeted towards risk communication in relation to a potential drinking water contamination.

6.3.1 Who is responsible or liable for risk communication?

As mentioned in section 5.3, the risk communication is carried out by the municipalities in Norway and the water supply companies in Denmark. The Danish drinking water supply companies communicate directly to their customer using an SMS warning system, website, and local media, e.g. in relation to no service delivery due to regular maintenance of the system or in case of drinking water contamination. Whilst in Norway, the water supply companies notify the municipalities, which then alert the customers in the municipality by SMS warning system, the websites of the municipality and media.

One can assume that direct communication from the water supply companies to the customers would be preferable for several reasons.

Firstly, the risk information travels through another transmitter (municipalities) that then relates to the information before passing on the information. This step could be time-consuming. From the severe drinking water contamination cases on Askøy and Køge, it was found that every minute counts as there was a direct correlation between the amount of water consumed and the severity of symptoms (FHI, 2019). Hence, having an extra link in the risk communication chain during an urgent situation could be a disadvantage. As mentioned in section 2.3, the message of risk communication can impact trust and result in changes in the confidence and credibility of the institution (see figure 4). Factors that have a negative impact on trust and credibility is stalled or delayed reporting and inconsistent updating (see table 2). People wish timely disclosure of relevant information and regular updating with accurate information

Secondly, the risk communication directly from the water supply companies will not be influenced by a potential political agenda or disappear amongst other information from the municipalities. The latter was also pointed out by source NO2 in the interview. NO2 also emphasised the importance of inter municipality collaboration and uniformity of risk communication. Factors influencing trust and credibility also point to the negative impact of internal inconsistency, which damage an organised message (see table 2). This would be the case if one or several municipalities decided not to coordinate the time and message of the risk communication towards the customers.

To overcome the challenge of the timing of releasing SMS alerts and having the same or similar content of the message, the source (NO2) and corresponding colleagues from other municipalities using the same water supply company had formed an exclusive collaboration program (https://www.godtvann.no/). NO2 believed that that this collaboration contributes positively to manage the risk communication and to supply consumers with a safe and sound water supply and sewage management. Presumably, such inter municipality association would be advantageous to many other areas in Norway where several municipalities receive drinking from the same drinking water supply company. Another option that could be considered is the Danish model, where customers buy the water directly from the water supply company owned by the municipality, and hence there would not be a need for an additional link in the risk communication or an inter municipality collaboration.

6.3.2 SMS warning systems

The evaluation report of the Køge drinking water contamination case in 2007 recommended switching to a direct SMS warning system rather than only relying on Public Address Systems by police, air raid siren and media (Vogt-Nielsen et al., 2007, p. 15). In the Askøy case, the SMS warning system was much criticised as the applied SMS warning system fell short to inform all affected customers as it was unclear which customers received contaminated drinking water. Further, the SMS warning system was not updated correctly (Baisotti et al., 2019). Therefore, it is essential to have a good overview of where affected customers are located in the pipeline network and that the contact information is updated. The SMS warning systems were discussed in the interviews, and it was found that the SMS warning system utilised in both countries represents an essential part of the communication channel towards the public in case of a drinking water contamination. After a recent contamination case (Dec. 2020) statistics showed that approximately 75% of the costumers received the SMS alert of boil notice (DK4).

In both countries, SMS warning systems were mainly address-based using reliable sources. However, it was apparent that it is possible to buy a service from some telecommunications companies where SMS alerts are sent to all mobile phones within a specific area depending on the base transceiver station (NO2). Hence, a message of boil notice would also target people visiting the area with contaminated drinking water. This would be favourable for shoppers and workers visiting an area in which they do not have an address. Such service is offered by a few municipalities in Norway (NO2). Considered as an additional service to address based SMS warning, this extra service option would be ideal for reaching a larger percentage of people who potentially would have consumed the drinking water. However, it is often down prioritized due to cost-benefit assessment as, in reality, this service would be rarely used (NO2).

Another source (DK3) was less worried about reaching the last few percentages of the customers by SMS alert as it was assumed the word of mouth and media would spread the boil notice fast. This assumption could be right as the area the source referred to has a high density of people. This source was also concerned about misinformation spreading, as this was experienced previously. It is crucial to maintain trust in the drinking water supply to avoid customers buying bottled water and installing filters in their home.

In Norway, the SMS alert message included a link to the municipality's website, which made it easy for the customers to get more information about the event (NO2). In Denmark, it was possible to enter one’s address in the system of the water company website and continuously received updated information for that specific address. Both options are seemingly catered for a modern society in which people expect to receive information of risk. In case the communication channels fall short of expectation, people get frustrated. An example of this was seen after the mentioned contamination case in December 2020 (DK4), where the boil notice was cancelled. However, the cancellation did not reach all affected customers due to an update of the SMS warning system at Blue Idea. This resulted in some critic although the message was only delayed half a day. This critic could also be associated with lost income for a specific type of businesses, e.g. restaurants.

6.3.3 The risk communication message

The table of Renn and Levine (1991) in section 2.3 indicates which factors influence the trust in the message and the credibility of the institution. The wording of the message send to the customers are important. It can have a negative impact on the credibility, e.g. in case, the message seems inconsiderate of the publics concerns or the person delivering the message provided is too technical. These are some of the risk communication challenges the water supply or the municipality are faced with in case of water contamination. Exactly these aspects were highlighted in the Køge evaluation report as the message of risk communication seemed sterile and lack empathy and understanding for the customer who had become ill due to water contamination (Vogt-Nielsen et al., 2007, p. 60).

The risk communication needs to be carried out by competent staff having qualifications within risk communication, and this is also the case for the water supply companies and municipality interviewed. It was pointed out by a source (NO2) that the duty officer has many tasks in case of water contamination, and a civil engineer might not have the necessary competence to communicate about risk. The emergency preparedness team within the water supply company need another person with risk communication skills in parallel to the operations civil engineer (NO2). The risk communicator could then be responsible for alerts, updating of the website and etc. This would, as mentioned in section 6.3.1, increased the rate of risk communication as the municipality would not be a part of the risk communication process. It is likely that smaller water supply companies could share personnel with this competence to make such a scheme more economically.

It was found that pro-active risk communication was also actively used by some water supply companies (DK4). Pesticide-free gardens were promoted by hired influencers and “Come and taste your drinking water” pop-up stands in the city centre to promote drinking water from the tap rather than bottled water. This type of actions will likely contribute to more awareness regarding the use of pesticide in gardens and perhaps lead to a decrease in pesticide usage. Pesticide contamination of the groundwater was by Danish drinking water supply companies mentioned as a concerning risk event within the next five years. The “come and taste your drinking water” pop-up stands could increase the awareness and the appreciation of living in a society where tap water is safe, clean and good tasting. When the water source is protected, there is no need to buy bottled water, which contributes to plastic usage.

6.4 Future risk events

In section 5.5, risk events of concerns within the next five years were discussed with the interview objects and are presented in table 7. Can today´s applied risk tools, methods and frameworks safeguard against the challenges industry have for the near future?

All sources pointed to cyber-attacks of different sorts. IT security is currently being handled in each water supply company, but they do not have any official cybersecurity guideline. If a cybersecurity certification scheme based on the ISO standard system would be compatible with the water supply industry, this would probably be of interest to the water supply companies.

Sources from both countries also mentioned extreme weather caused by climate changes as a concern. For example, extreme rainfall and winds can, e.g. cause floods or landslides. It would therefore be beneficial to take these concerns into account when planning new installations and pipeline network. Also, assessing old installation in this matter is significant, but this is assumably done in the current risk assessment.

In Denmark, pesticide contamination of the groundwater source is a significant concern. There is much uncertainty about the previous and current use of pesticides and how they may affect the groundwater. It is not clear which pesticides were used where and if they are still in the original form or as degradation products of pesticides, which could also be associated with health risks. Another issue is pesticide screening of drinking water, as not all water supply companies test for all pesticides. Hence, the Danish Environmental Protection Agency has completed a mass screening of pesticide in the water supply in 2020 to achieve an overview (Danish Environmental Protection Agency, 2020). The screening included 263 water samples from boreholes in groundwater monitoring distributed in all areas of Denmark. The samples were screened for 415 pesticides. A total of 10 pesticides and degradation products of pesticides in too high concentrations were found in six boreholes (Danish Environmental Protection Agency, 2020). Further, 22 pesticides or degradation products of pesticides were found in low concentration that meets the drinking water quality requirement. The Danish Environmental Protection Agency will publish results in 2021 from a new mass screening. Therefore, it is plausible to believe that contamination of pesticides or degradation products of pesticides will affect the water supply companies in the near future. This could lead to e.g. shutdown of drinking water wells or introducing purification steps of the groundwater at the water supply facilities.

Potential pesticide contamination of the groundwater was also mentioned in connection with the balancing act of CSR, referring to reducing negative impacts and maximizing positive value for people, the environment and the economy. To maintain credibility and trust in the water supply companies, their product must continuously meet the drinking water quality requirements. Otherwise, people could potentially start using bottled water.

In Norway, a potential supply facility investment backlog was mentioned as a concern. This information is also confirmed in the State of the Nation report 2021 (Rådgivende Ingeniørers Forening, 2021, p. 81). The rapport discusses the pipeline systems having considerable weaknesses and is partly outdated. The condition of some of the pipeline system presents a hazard for drinking water contamination that could lead to health risks. The report provides an overview of required updates in the water supply facilities and an estimated cost. In section 3.1.1, the causes leading to leakages in the pipeline system were listed (see table 3).

Finally, the interview objects expressed concern about having competent staff with the required skill set. This cannot be considered a risk event; however, it is a challenge the water supply will face. Primarily in Denmark, it was assumed more staff would be required to face future challenges, especially in case the water supply got classified as critical infrastructure.

7 Conclusion

The main objective of this thesis is to understand how risks in the drinking water supply industry are assessed and controlled in Norway and Denmark. In the thesis, risks were differentiated into safety or security to clarify when an event was unintended or intended by a malicious act. This was done due to the presumption that the practical aspects that security is assessed differently than safety in risk management using different tools and standards. Risk communication in relation to future potential drinking water contaminations was also examined as previous contamination cases were not limited to safety aspects. The risk communication after an event played a crucial element in maintaining trust in the water supply companies and the municipalities.

It was found that in Norway, the water supply companies apply a Risk and Vulnerability Analysis (RVA) developed exclusively for the water supply to target safety hazards. The results of the water supply RVA was used to limit access to the water supply facilities, and in some cases, intended malicious acts were entered as an unwanted event in the RVA. In practice, the recommended triplet approach for securing objects was rarely used as this is time-consuming and requires special competence that is not always available.

It was found that the Hazard Analysis and Critical Control Points (HACCP) principles are required by legislation for midsize and large drinking water supply companies in Denmark. The HACCP principles are followed by using the DDS management system or the FSMS ISO 22000:2018 standard. Some security aspects such as access limitation are addressed in the FSMS ISO 22000:2018 standard. Observations were made in the literature review and confirmed during interviews that there is a trend of moving from the DDS management system to FSMS ISO 22000:2018. The shift is caused by an increase in restrictions and a desire to demonstrate that the water supply company is a competent and trustworthy operator. An external audit is required to receive the ISO certification; this contrasts the water supply RVA, which operates with internal control. The Norwegian Food Safety Authority carries out public control of the water supply facilities but unfortunately does not have the capacity to inspect all the water supply companies in Norway.

The practical aspects of risk communication differ between the two countries as the Danish drinking water supply companies communicate directly to their customer using an SMS warning system, website, and local media in case of drinking water contamination. Whilst in Norway, the water supply companies notify the municipalities, which then alert the customers in the municipality by SMS warning system, the websites of the municipality and media. According to the theoretical knowledge of risk communication presented in theory, section 2.3, it would be preferable not having the extra link in the risk communication chain to save time in the acute phase after an event such as a drinking water contamination. Stalled or delayed risk information has a negative impact factor on trust and credibility. Furthermore, as often several municipalities receive drinking water from the same water supply company, it can quickly create inconsistency regarding the timing of releasing information and the content of the message. Therefore, risk communication cooperation groups across the municipality's borders must be encouraged.

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Appendix 1

Table 1. The main benefits and difficulties of HACCP implementation in the water utilities (Tsitsifli & Tsoukalas, 2019).

Benefits	Difficulties	References
	Heterogeneity of potential risks Large extent of the distribution network	Hellier 2000
Better understanding of water supply network	Application for communication reasons	Metge et al. 2003
Reduction of potential hazards Improvement of drinking water quality Employee awareness	Staff shortages Limited staff experience Inappropriate materials Incorrect management procedures	Bosshart et al. 2003
	Difficulties in determination of critical control point and their critical limits in water sources and distribution networks	Nokes and Taylor 2003
	Old distribution pipelines Large extent of the distribution network	Walski et al. 2003; National Research Council 2006; Berardi and Giustolisi 2008
Reduction of consumers' complaints Improvement of drinking water quality Improvement of operational efficiency Improvement of processing Improvement of employees' skills Reduction of production cost Better understanding of hazardous management Establishment of effective documentation systems Increase of compliance with microbiological limits Reduction of potential hazardous incidents Better prevention of "predictable hazard"		Fok and Emde 2004; Kuslikis and White 2004; Mullenger et al. 2002; Smith 2004
Improvement of employees' awareness to legislation and regulations of drinking water quality Improvement of employees training programs efficiency		Kuslikis and White 2004
Better response to emergencies, infraction of protection zones and water pressure fluctuations by employees Better internal communication among the departments of water utility		Pedersen 2004
	Inability of effective hazard detection Mistaken estimation of occurrence probability and severity of each hazard	Hrudey and Hrudey 2004
	Limited staff experience Lack of financial resources Lack of effective coordination in drinking water quality management	Martel et al. 2006
Rapid improvement of drinking water quality Reduction of undesirable incidents		Yokoi et al. 2006
Systematic assessment and identification of hazards Improve understanding of water safety issues Increase of consumer confidence Better response to emergencies from authorities		FSAI 2006
Increase of employees' awareness Application of appropriate corrective and preventive actions Increase of compliance with legislation Improvement of drinking water quality Better understanding of risk management Faster response to failures Creation of a system for recording deviations	Lack of external audit Inadequate control by health authorities	Gunnarsdottir and Gissurarson 2008
Improvement in water quality compliance		String and Lantagne 2016
	Necessity of preparation procedures (GMPs, GHPs, equipment maintenance program, sanitation program)	Khaniki et al. 2009
Improvement of drinking water quality Establish appropriate monitoring system for critical parameters Prevention of hazardous incidents Prioritize hazards		Baum and Bartram 2018

Appendix 2

Interview guide

Who is your employer?

What is your current position?

How long have you worked in your current position?

Is that a private water supply company or owned by the municipality?

How many customers receive water from your company?

What frameworks do you use to secure clean drinking water?

How does that work? What are the advantages or disadvantages of the chosen framework?

Does the chosen framework consider water as food?

How does the analysis/framework describe risk?

Which ISO standards have you implemented? Would you be interested in implementing more in the future? Why/why not?

What methods/models/frameworks are used in the water supply company in order to prevent vandalism or terror attacks?

What do you expect the challenges will be in the next five years?

Do you have an employee that is responsible for the risk communication?

What channels for communicating with the public in the event of water contamination?

Are these communication channels in operation today? Twitter? Website?

Do you use SMS warning alert system services for this?

If so, how is the text-messaging system updated with regards to contact details? How do you ensure that it is only the affected people that will get the message?

Do you run exercise to test the system? If yes, what was the result of that? Did the telecommunication network manage the sudden increase in text-messaging traffic?

Do you consider the people visiting the area (working/shopping) when you notify people via the text-messaging system?