Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

International Journal of Hygiene and Environmental Health 230 (2020) 113627

Contents lists available at ScienceDirect

International Journal of Hygiene and Environmental Health

journal homepage: www.elsevier.com/locate/ijheh

Status of risk-based approach and national framework for safe drinking water in small water supplies of the Nordic water sector

Maria J. Gunnarsdottir [a,*], Sigurdur M. Gardarsson [a], Anna Charlotte Schultz [b], Hans-Jörgen Albrechtsen [b], Lisbeth Truelstrup Hansen [b], Kim Steve Gerlach Bergkvist [c], Pekka M. Rossi [d], Björn Klöve [d], Mette Myrmel [e], Kenneth M. Persson [f], Magnus Eriksson [g], Jamie Bartram [h,i]

[a] Civil and Environmental Engineering, University of Iceland, Iceland
[b] Technical University of Denmark, Denmark
[c] Faroese Food and Veterinary Authority, Faroe Islands
[d] University of Oulu, Finland
[e] Norwegian University of Life Sciences, Norway
[f] University of Lund, Sweden
[g] Åland Islands Environmental and Health Protection Authority, Åland Islands
[h] University of North Carolina, USA
[i] School of Civil Engineering, University of Leeds, UK

ARTICLE INFO

Keywords:
Water supply
Drinking water
Risk-based approach
Water safety plan
Framework for safe drinking water

ABSTRACT

Reliable safe water supply is a pillar of society and a key to public health. The Nordic countries have an abundance of clean fresh water as a source for drinking water supplies. They have followed developments in safeguarding water, both the recommendations of the World Health Organization framework for safe drinking water and European legislation. Worldwide, including the Nordic countries, small water supplies are less compliant with water safety regulation. The forthcoming EU directive on drinking water require risk-based approaches and improved transparency on water quality. This research looks at the Nordic frameworks for safe water supply, with emphasis on risk-based approaches and smaller systems. We analyzed the legal frameworks for safe water, the structure of the water sector across the Nordic countries and explored how prepared these countries are to meet these requirements. Our findings show that, while legal requirements are mostly in place, delivery of information to the public needs to be improved. Most Nordic countries are in the process of implementing risk-based management in large and medium size water supplies, whereas small supplies are lagging. We conclude that a key to success is increased training and support for small supplies. We suggest wider adoption of the Nordic model of cooperation with benchmarking of safe water for all to transfer knowledge between the countries. This work provides insights into challenges and opportunities for the Nordic countries and provides insights relevant to countries worldwide in their effort towards realization of SDG Target 6.1.

1. Introduction

The United Nations (UN) Sustainable Development Goal 6 (SDG 6) is to ensure access to safe and affordable drinking water for all before 2030 (UN SDG, 2015). The forthcoming European Union Drinking Water Directive (EU DWD) reflects this in requiring a risk-based approach to secure drinking water safety (EC, 2020). The World Health Organization (WHO) recommends the framework for safe drinking water, comprising regulation built on health-based targets, water safety plans performed by the water supplies, and independent surveillance to safeguard public health (WHO, 2004). WHO developed a systematic preventive management system called Water Safety Plan (WSP), adapted from the food industry HACCP (Hazard Analysis and Critical Control Points) system. WHO launched the framework for safe drinking water and WSPs in 2004 and they are used in at least 93 countries (WHO, 2017; WHO/IWA, 2017). The forthcoming EU DWD requires application of risk-based

* Corresponding author.
E-mail address: mariag@hi.is (M.J. Gunnarsdottir).

https://doi.org/10.1016/j.ijheh.2020.113627
Received 16 June 2020; Received in revised form 26 August 2020; Accepted 7 September 2020
Available online 18 September 2020

approaches in water supplies. Member states are also to improve access to safe water for all and ensure that consumers can access information about their drinking water.

The Nordic countries are Denmark, Finland, Iceland, Norway, and Sweden, together with three self-governing nations, the Faroe Islands and Greenland under the external sovereignty of the Kingdom of Denmark and the Åland Islands under the sovereignty of Finland. Denmark is an EU member although the Faroe Islands and Greenland are not; Finland (including the Åland Islands) and Sweden are also EU members. Iceland and Norway are members of the European Free Trade Association (EFTA), and participate in the internal market of Europe through the European Economic Area (EEA). According to the EEA agreement EU legislation in most fields including environmental legislation is to be implemented into national legislation. Thus, all Nordic countries are set to implement the new EU-DWD except the Faroe Islands and Greenland.

All households in the Nordic countries have universal household pipe water, except Greenland where some households collect water from "tap houses" or have water delivered by truck. Drinking water in the Nordic countries is generally of good quality. Compliance with the regulations by large water supplies (5000 or more inhabitants or delivering 1000 m^3/day or more) is reported for three-year periods and published by the European Commission. For 2011–2013, which is the latest report available on the EC website, compliance with microbiological parameters was 100% in Finland, 99.94% in Sweden and 99.80% in Denmark; and for chemical parameters was 100% in Sweden, 99.8% in Finland and 98.6% in Denmark (EC, 2016). Water quality is not reported for the supplies serving less than 5000 inhabitants or less than 1000 m^3/day. The water quality for the EEA countries (Iceland and Norway) is not included in the three-year EC reports.

Water quality for the small supplies was covered in the EC 2008–2010 report. Despite incomplete information, there was much lower microbiological compliance for the small water supplies than for the larger supplies (EC, 2014). Furthermore, Gunnarsdottir et al. (2017) show drinking water from small water supplies in the Nordic countries to be of poorer quality than that from larger supplies. These authors reported 47 registered waterborne disease outbreaks in the Nordic countries in a five-year period 2010–2014, of which 39 occurred in supplies serving fewer than 5000 people. Higher level of non-compliance with microbiological standards in small supplies has also been documented elsewhere (Hulsmann, 2005; Hendry and Akoumianaki, 2016; EC, 2014; Beaudeau et al., 2010; Messner et al., 2017; Rickert et al., 2016).

The Nordic countries have a long history of working together, building on their common cultural and historical heritage. The "Nordic Model" of social and economic policies embraces both a comprehensive welfare state and free market capitalism. They are looked to as examples in part because they rank highly in the inequality-adjusted human development index, global peace index and in the world happiness report. Since 1952 the forum for cooperation between the countries has been the Nordic Council under which there has been benchmarking of performance on issues including public health, environment, economic factors, and energy use.

The general belief in the Nordic countries is that drinking water supplies are good and reliable. Therefore, there has been no strong public pressure, except in reaction to contamination events and disease outbreak; and the WHO water safety plans have not been regarded as relevant by policy makers nor stakeholders until very recently. Little attention continues to be given to small water supplies.

This research concerns small water supplies and seeks to: 1) map the national frameworks for safe drinking water and the main characteristics of the water sector in the Nordic region as relevant to small supplies, their similarities and differences; and 2) explore how a risk-based approach has been implemented into both legislation and management.

2. Methods

For each of the Nordic countries (Denmark, Faroe Islands, Finland, Greenland, Iceland, Norway, Sweden and the Åland Islands), we sought information on: 1) the legal framework for safe drinking water in legislation and regulation for drinking water quality and water protection, 2) the water sector as a whole and information related to small water supplies in local reports by the authorities and stakeholders, in reviewed articles, and reports from Nordic institutions, 3) catchment protection from legislations and local reports, 4) reports and information on water quality conveyed to consumers from surveillance authorities, 5) national platform for knowledge sharing from websites of professional associations and interviews of association representatives, and 6) risk-based approach in implementation was obtained from legislation on requirement and on progress from direct contact with personnel.

Authors searched for the information presented in Tables 1–4 in their country, in relevant publications from the government and stakeholder associations, reviewed legislations, and collected information from institutions and authorities through local reports and interviews. Not all information was retrieved for every country. Information from Greenland is especially limited.

This work represents the first phase in a project on improving drinking water from small water supplies in the Nordic countries and concerns national frameworks for safe water and risk-based approaches.

Table 1
Criteria for defining the size of protection zones.

Land	I category	II category	III category	IV category
	Water intake zone Radius for fencing	*Near zone (primary zone)*	*Distance zone (secondary zone)*	Safety zone
Denmark[a]	10 m	60 days or 300 m and 25 m ban on cultivation	10–20 years	According to land planning
Faroe Islands	Recommend fencing	Risk assessment	Risk assessment	
Finland Åland Islands[b]	10–30 m	Not mandatory case-by-case due to geological condition	The whole aquifer	
Greenland	Not mentioned in legislation	Generally 30 m	Delineation of source watershed and assessment of land use	Delineation of source watershed and assessment of land use
Iceland[c]	5 m	Case-by-case considering soil cover and groundwater flow to the water intake. (At least 50 days travel time recommended though not in regulation)	Consider fractures and faults	
Norway[d]	10–30 m	Border defined by 60 days travel time though not in regulation	Geological condition	Evaluated if sensitive activities
Sweden[d]	10–30 m	60–100 days travel time, minimum 100 m	Whole watershed or 1-year travel time	If sensitive activities

[a] Chave et al. (2006).
[b] Acts 587/2011 and 1299/2004.
[c] Regulation 796/1999; Stefansson (2005); Vatnaskil (2015).
[d] Weideborg and Krogh (1995).

Table 2
Nordic national legal frameworks 2019 for drinking water quality.

	Legal status	Denmark (DK)	Faroe Islands (FO)	Finland (FI)	Iceland (IS)	Norway (NO)	*Sweden (SE)*	*Åland Islands (AX)*
2.1	Institutions							
	Ministry	Ministry of Environment and Food	Ministry of Environment, Industry and Trade	Ministry of Social Affairs and Health	Ministry of Industry and Innovation	Ministry of Health and Care Service	Ministry of Enterprise and Innovation	The Government of the Åland Islands
	Governmental institution	Environmental Protection Agency (EPA) are to make guidelines	Faroese Food and Veterinary Authority	National Supervisory Authority for Welfare and Health (Valvira)	Icelandic Food and Veterinary Authority (MAST) is to supervise the Local Competent Authorities LCAs	Norwegian Food Safety authority (Mattilsynet)	Swedish Food Authority	The Government of the Åland Islands
	Institutions regulating drinking water quality	98 municipalities are responsible for surveillance of drinking water quality.	Faroese Food and Veterinary Authority.	311 municipalities are responsible for surveillance of drinking water quality.	10 regional LCAs on behalf of 74 municipalities are responsible for surveillance of drinking water quality.	Five regional food safety authorities (Mattilsynet) are responsible for surveillance of drinking water quality.	290 municipalities are responsible for the surveillance of drinking water quality.	Aland islands Environmental and Health Protection Authority (ÅMHM) responsible for surveillance of drinking water quality in 16 municipalities.
2.2	**Legislation, definition, and WSP demand**							
	Legislation on drinking water quality	Regulation on water quality and surveillance (BEK nr 1070 af October 28, 2019) and Water Act (nr.118 February 22, 2018)	Drinking Water Regulation (nr. 127/2013)	Regulation on Water Quality and Surveillance (17.11.2015/ 1352)	Drinking Water Regulation (no.536/2001 with am.) and Food Act (no.95/ 1995) as drinking water is defined as food	Regulation on Water Supply and Drinking Water (FOR-2016-12-22-1868). Food Act LOV-2018 -06-22-76	Swedish Food Act (SFS, 2006:804). Swedish Drinking Water Regulation (SLV FS, 2001:30, latest published as LIVSFS, 2017:2)	Regulation on Water Quality and Surveillance (17.11.2015/ 1352)
	Definition of regulated water supplies	All water supplies that serve 10 or more than one household, or if commercial or official activity	All water supplies that serve 50 people or more, or if commercial or public activity	A water supply that has an operating area defined by the municipal authority	All water supplies that serve 50 people or more or 20 households/ summerhouses, and if food production activity	All water supplies that deliver 10 m^3 a day or more or serve 50 people or more, or if commercial or public activity	All water supplies that deliver 10 m^3 a day or more or serve 50 people or more, or if commercial or public activity	A water supply that has an operating area defined by the municipal authority
	Demand on preventive management in regulation	Yes	Yes	Yes	Yes	Yes	Yes.	Yes
2.3	**Responsibilities of surveillance authority**							
	Role and responsibilities of the surveillance authority	Surveillance of drinking water quality and catchment protection. Register all water supplies in the water supply plan accessible to all	Surveillance of drinking water quality, catchment protection, network system, WSP, contamination incidents	Surveillance of drinking water quality in collaboration with the water supplier	Surveillance of drinking water quality, catchment protection, network system, water safety plans, contamination incidents	Surveillance of water supplies and water quality. Emergency preparedness. Approving water supplies. Registration of all water supplies that provide water to more than one house or cottage	Surveillance of drinking water quality. Register all water supplies and distribution networks in the municipality	Surveillance of drinking water quality in collaboration with the water supplier
	Work to fulfil surveillance responsibility	Accredited staff and or labs take samples and send the results to municipality (authority). Data are uploaded into the public data-base Jupiter. Results are to be on municipality and water supplies website. Regular inspection of	Food Authority inspects the water supplies. Municipal authority takes samples and sends it to accredited laboratories. The results are sent to the municipality and in case of non-compliance, results are	Accredited staff and laboratories take samples and send the results to the municipality that sends the information to the responsible person of water supplies that reports to municipal authority	LCAs regularly inspect water supplies and take samples. Samples are sent to accredited labs and results sent back to LCA that forwards it to the water supplies and if non-compliant then also from lab to MAST	Water supplies have the responsibility regarding fulfilling the water regulations and take samples for analyses done by accredited laboratories. The results are forwarded to the Food Safety Authorities, once a year (MATS).	The operators of water supplies shall send copies of water quality analyses to the surveillance authority, which evaluates the data every time they receive the analytical protocol or at least yearly, depending on the size of the treatment plant.	Staff with knowledge or accredited staff take samples and send the results to the authority.

(*continued on next page*)

Table 2 (*continued*)

	Legal status	Denmark (DK)	Faroe Islands (FO)	Finland (FI)	Iceland (IS)	Norway (NO)	*Sweden (SE)*	*Åland Islands (AX)*
		water supplies every second year	reported to the Food Authority					
3.4	**Action if non-compliant**							
	Action taken if non-compliant in fecal indicators	Boil advisory, technical sanitary inspection, and source tracking	Contact the Food Authority. Boil order is advised, and sanitary inspection and source tracking is performed by the municipality.	Contact municipal health authority, action led by the health authority. Informing national rymy-system[a]. Detailed steps (e.g. boil advisory and disinfection) and guidelines given by Valvira[b]	If fecal contamination LCA in cooperation with MAST demands improvement and shall inform users and ban use of water until necessary preventive measures have been taken.	Contact the Food Authorities on suspicion of a health threat. Steps must be taken; boil order, remove the source of contaminants, switch to a reserve water source or improve water treatment.	Inform the local food inspection authority. Wait for decision from them, normally it would be boil-advisory, technical sanitary inspection and source tracking.	Contact municipal health authority, action lead by the health authority. Informing national rymy-system. Detailed steps (e.g. boil advisory and disinfection) and guidelines given by Valvira.
	Action taken if non-compliant in toxic chemicals	Depending on the severity, the authority (Municipality in dialogue with the Danish Patient Safety Authority) can provide a dispensation or require restrictions of the water use, e.g. cut-off the water supply or establish alternative supply	Contact Food Authority, action lead by the authority. Decision if water source is not usable or restrictions needed.	Contact municipal health authority, that lead action. Decision if water source is not usable or restrictions needed. Detailed steps and guidelines for this situation given by Valvira[c]	LCA in cooperation with MAST shall demand improvement and evaluate risk for health. Ban use if necessary	Contact the Food Authorities on suspicion of a health threat, search for the cause, evaluate any health risk and whether the source should be banned.	Inform the local food inspection authority. Make risk assessment of the parameter/will water use cause risks for the consumer? Ban use and offer tank water if the risks are too high	Contact municipal health authority, action led by the health authority. Decision if water source is not usable or restrictions needed.
	Action taken if non-compliant in other indicators or non-toxic chemicals	Depending on the severity, the authority (Municipality in dialogue with the Danish Patient Safety Authority) can provide a dispensation or require restrictions of the water use, e.g. cut-off the water supply or establish alternative supply	Inform the Food Authority. Make a risk assessment of the parameter.	Guidelines given also to radioactive non-compliance[d]	LCA in cooperation with MAST shall evaluate risk for human health and then decide on action	Non-compliance in turbidity, smell, taste, and color is "any change that is not normal". Action will be to immediately search for the cause and whether it represents any health risk. There are guidelines for radon.	Inform the local food inspection authority. Make a risk assessment of the parameter – will the use of the water cause risks for the consumer? Ban use and offer tank water if the risks are too high.	Inform environmental and health protection authority. Make a risk assessment of the parameter
	Required information to users on water quality	Information on water quality at each water supplies should be available at the water supplies homepage. Data are also available on the database Jupiter. No summarized information available for population serving fewer than 5000.	Upon request, information should be available.	Information on water quality at each water supply should be available on database VEETI (not open database). Legislation does not define what information should be available to the user all the time.	LCAs are to deliver report to MAST every year on results from monitoring and MAST shall summarize from all LCAs in a report accessible for users. Only done once since 2001.	Information should be available from each water supply on their website or results should be mailed to the users. National database on the website of Food Safety Authorities.	Information on water quality should be made available on the website of the water supply owner. Large water supplies have yearly reports. Normally available through webpage. Small water supplies are obliged to answer quality questions from users within short notice (days).	Information on water quality at each water supplies should be available either on internet or upon request.
	Penalties	Nominally fine. Has never been applied.	Nominally fines or prison. Has never been applied.	Fines or 3–6 months in prison. Has been applied once. In the Nokia water crisis of 2007 wastewater treatment manager was	Fines, and if major or if repeated with intention then four years prison. Has never been applied.	Food Safety authorities can give daily fines to make water works follow the regulations. The police give the penalty fines. This has been	Nominally fines or prison up to two years. Östersund was taken to court after a large waterborne cryptosporidium outbreak in 2010 but were freed.	Fines or 3–6 months or prison. Has never been applied.

(*continued on next page*)

Table 2 (*continued*)

Legal status	Denmark (DK)	Faroe Islands (FO)	Finland (FI)	Iceland (IS)	Norway (NO)	*Sweden (SE)*	*Åland Islands (AX)*
			sentenced to 7 months in jail with suspended sentence.		applied a couple of times.		

[a] National food or water related epidemy registration.
[b] https://www.valvira.fi/documents/14444/1693103/Toimintatavat_tautia_aiheuttavat_mikrobit.pdf/ca40975e-d949-4ccb-a0ba-bb6279cf6eca, page 27.
[c] https://www.valvira.fi/documents/14444/249256/Haitalliset+aineet/e521d5e6-23a4-5dc5-d264-2f7f1f230171, page 21.
[d] https://www.valvira.fi/documents/14444/1693103/Toimintatavat_radioaktiiviset_aineet.pdf/2a06a7bc-19fd-43db-be1f-590b7f46eb09.

The next phase will identify the barriers, opportunities and actions needed to achieve the goal of safe water for all citizens; and explore the resilience of water supplies to climate change, and to emergencies and disease outbreaks such as Covid-19.

3. Results and discussion

3.1. Legal frameworks for safe drinking water

Drinking water quality falls under the jurisdiction of different ministries and government departments: Environment in Denmark, Greenland and the Ministry of Environment, Industry and Trade in the Faroe Islands; Health in Finland, and Norway; and Industry in Iceland and Sweden. In contrast, implementing the EU Water Framework Directive (Directive, 2000/60/EC) for water governance and protection is under the jurisdiction of the Ministries of the Environment for all Nordic countries. Drinking water is defined as food in the Faroe Islands, Iceland, Norway and Sweden and the corresponding institutions are therefore the food authorities. These arrangements require good cooperation between the different government entities involved.

All the Nordic countries have implemented into national regulations the 1998 EU DWD (EC, 1998) and 2015 amendment (EC, 2015), except The Faroe Islands (which have not implemented the 2015 amendment of the EU DWD) and Greenland (which is in the process of updating its drinking water regulation from 2008). Proposed changes in Greenland relate to implementation of water safety plans, risk assessments and design of surveillance programs (Naalakkersuisut, 2020).

There is a small variation of definition of regulated water supplies in the Nordic region. The Faroe Islands, Norway and Sweden use the definition in the EU DWD "*All water supplies that deliver 10 m^3 a day or more or serve 50 people or more, or if commercial or public activity*"; Iceland uses a similar but less strict definition; while Denmark, the Åland Islands and Finland go further than the current EU DWD (Table 2). In Denmark even water supplies supplying less than 10 m^3 a day but to more than one household must comply with the regulations. In Faroese, Finnish, Norwegian, and Swedish regulations municipalities are obliged to register all regulated water supplies, and in Finland the resulting lists should be public.

In all Nordic countries, except Greenland, legislation now demands systematic preventive management of water supplies, for example in Finland since 2016 and in Iceland since 1995. In those countries that define drinking water as food, water supplies are defined as food producers and must comply with food legislation and implement preventive management in food production (HACCP or similar).

There are three governance levels in Finland, Norway, and Sweden (national, regional, and municipal), whereas in Denmark, the Faroe Islands, Greenland, Iceland, and the Åland Islands there are two (national and municipal). Greenland's proposed regulation would change this to only one level, the national level.

All Nordic countries have been reforming and decreasing the number of governance units. In January 2017 there were 1249 municipalities in the region (Nordic Council of Ministers, 2018; Table 3). Municipalities are responsible for surveillance of drinking water quality in all except four countries: in the Faroe Islands the Faroese Food and Veterinary Authority is responsible for the surveillance; in Norway there are five regional offices of the Governmental Norwegian Food Safety Authority that are responsible for surveillance; in Greenland responsibility for surveillance is with the Government; and in the Åland Islands the Environmental and Health Protection Authority is responsible. In Iceland there are ten regional surveillance institutions run jointly by the municipalities in their area but at the responsibility of the municipalities (Table 2).

In case of non-compliance the municipality orders identification of the root cause of the contamination, provision of information to consumers and corrective action by the water supplier. If non-compliance concerns *Escherichia coli* or enterococci (or *Clostridium perfringens,* where applicable) requirements of absence in 100 ml, the consumers shall promptly be informed, and a boiled water advisory issued. Non-compliance in chemical quality shall be evaluated and all water use banned if necessary, followed by corrective actions. In all the countries' legislation there are penalties (fine or imprisonment) for the supply of unsafe water, but these have very seldom been applied.

Small water supplies in the Nordic countries are most often user-owned and are often run as cooperatives. In contrast, large and medium size water supplies are often owned by municipalities, which can cause conflict of interest with the surveillance role. In Greenland, all public water supplies are owned by the Government and run by the national energy and water company Nukissiorfiit on its behalf (Hendriksen and Hoffmann, 2018). Exceptions are three water treatment plants owned by the Greenland Airport Authority, mostly serving transient populations. Icelandic legislation states that municipalities shall operate water supplies in urban areas (Municipal Water Municipal Water Supply Act, 2004), but there is no equivalent requirement in the other countries. There is a demand to protect public health, and clean drinking water is an important component in that aspect.

3.2. Water supplies

The population of the Nordic countries totals around 27 million people, who are served by over 16 000 regulated water supplies plus a much larger number of unregulated small ones (Table 3). Of the 16 thousand regulated water supplies about 13 thousand serve less than 500 people and 80% of these small ones use groundwater source. The Nordic countries share the tradition of cottages and mountain huts and have popular tourist sites in remote areas. These are often served by small unregulated water supplies or individual wells. While large and medium size water supplies (>500 inhabitants) are registered and subject to regular surveillance, small and very small systems are registered but surveillance is irregular, and individual supplies are mainly unrecognized and not registered. Our findings therefore suggest that an important task for the surveillance authorities is to register all water supplies to secure a complete picture of water supply. This is especially important in the context of Target 6 of the UN Sustainable Goals, on safe water for all.

While the Nordic countries have broadly similar cultural backgrounds and legal systems, their geographies and geologies vary widely: from high mountains, lowlands, lakes and forests to wilderness, volcanos and glaciers, from unconfined and porous rock layers or

Table 3
Statistical information on the water sector in the Nordic countries.

		Denmark (DK)	Faroe Islands (FO)	Finland (FI)	Greenland (GL)	Iceland (IS)	Norway (NO)	Sweden (SE)	Åland Islands (AX)	Nordic region
3.1	Local administrative unit 2017[a]									
	Municipalities January 1, 2017	98	29	311	5	74	426	290	16	**1249**
3.2	Population 2017 (x1000)									
	Population of the Nordic countries[d]	5.749	50	5.474	56	338	5.258	9.995	30	**26 950**
	No. of inhabitants served by regulated water supplies (% of population)	5462 (95%)	49.5 (99%)	5118 (93%)	56	324 (96%)	4696 (89%)	8896 (89%)	28 (94%)[b]	**24 629 (91%)**
	1. Large supplies >5000 consumers or >1000 m^3/day	3300 (57%)[b]	13 (26%)	4402 (80%)	23 (41%)	246 (73%)	3802 (72%)	7896 (79%)	23 (77%)[b]	**19 705 (73%)**
	2. Medium supplies 500–5000 consumers or 100–1000 m^3/day	n.a.	28 (56%)	496 (9%)	25 (45%)	61 (18%)	684 (13%)	750 (8%)	4 (13%)[b]	
	3. Small supplies 50–500 consumers or 10–100 m^3/day	n.a.	7 (14%)	110 (2%)	n.a.	14 (4%)	157 (3%)	240 (2%)	1 (3%)[b]	
	4. Very small supplies <50 consumers or <10 m^3/day	n.a.	1.5 (3%)	110 (2%)	n.a.	3 (1%)	53 (1%)	10 (0,1%)	0.4 (1%)[b]	
	No inhabitants served by not regulated water supplies	287 (5%)	0.5 (1%)	356 (7%)	0	14 (4%)	562 (11%)	1100 (11%)	1.6 (6%)	**2321.6 (9%)**
3.3	**Number of water supplies**									
	No of regulated water supplies	2768	99	1354	73	796	6931	4450	24	**16 439**
	1. Large supplies >5000 consumers or >1000 m^3/day	347	1	154	2	9	147	250	1	**911**
	2. Medium supplies 500–5000 consumers or 100–1000 m^3/day	1213	25	300	14	39	406	450	1	**2**321
	3. Small supplies 50–500 consumers or 10–100 m^3/day	853	43	400	n.a.	138	806	1050	7	
	4. Very small supplies <50 consumers or <10 m^3/day	355	30	500	n.a.	610	5572	2700	15	
	No of water supplies not regulated (private wells)[c]	50 000	18	65 000	3	2500	100 000	400 000	300	**617** 821
3.4	**National platform**									
	No of water supplies participating in national platform and % of regulated	2020 (75%)	0	420 (31%)	0	72 (9%)	240 (3%)	1750 (39%)	n.a.	**4502 (27%)**
	Proportion of population served by water supplies participating in national platform %	n.a.	0%	90%	0%	91%	95%	87%	n.a.	
3.5	**Water harnessing at all regulated water supplies**									
	1. % of inhabitants with groundwater	100%	7%	60%	0%	95%	10%	60%	6%	**59%**
	2. % of inhabitants with surface water	0%	93%	40%	100%	5%	90%	40%	94%	**41%**
	Is water metered to consumers	High share of	Water is not metered to consumers	Yes, some have continuous,	Piped water to houses metered,	As a rule, metered to industries	In 2019, 84 of 422 municip. had water	Water metered to all customers in	As a rule, metered, but some	

(*continued on next page*)

Table 3 (*continued*)

		Denmark (DK)	Faroe Islands (FO)	Finland (FI)	Greenland (GL)	Iceland (IS)	Norway (NO)	Sweden (SE)	Åland Islands (AX)	Nordic region
		household metering		transmitting meters	truck deliveries recorded	and not to households	metered in 80% of their households	285 municip. and 5 use a fixed fee	small w.s. have a yearly fee.	
3.6	**Water harnessing at regulated small water supplies**									
	No. of small and very small regulated water supplies serving less than 500 inhabitants	1420	73	900	58	748	6381	3750	22	**13 352**
	1. % of water supplies with groundwater [b]	100%	5%	100%	0%	99%	52%	100%	77%	**80%**
	2. % of water supplies with surface water [b]	<1%	95%	0%	100%	1%	48%	<1%	23%	**20%**

[a] For Denmark the count of water supplies 3.3. was done for 2020.
[b] Estimated.
[c] Water supplies not regulated is estimated for Finland, Faroe Islands, Iceland, Norway and Åland Islands as 5–6 people on average using Denmark's estimate as base. Estimate for Sweden is for individual wells for permanent dwellers and would be many more if holiday homes were included.; n.a. = data not available.
[d] https://norden.diva-portal.org/smash/get/diva2:1146911/FULLTEXT05.pdfhttps://norden.diva-portal.org/smash/get/diva2:1146911/FULLTEXT05.pdf.

glaciofluvial deposits with groundwater aquifers to impervious rock layers with limited or no groundwater sources but abundant surface water. There are vast areas of wilderness, except in Denmark and the Åland Islands. Methods of water harnessing reflect these differences.

All the Nordic countries have sufficient (liquid) freshwater resources, except Greenland. Treated surface water is generally used for large supplies, whereas the small supplies use groundwater, mostly untreated. Use of groundwater for drinking water supply ranges from 0% in Greenland, 8% in the Faroe Islands, 10% in Norway, 60% in Sweden, 60% in Finland, 71% in the Åland Islands, 95% for Iceland and 100% in Denmark (Hendriksen and Hoffmann, 2018; Hyllestad et al., 2019; Isomäki et al., 2007; Klöve et al., 2017). In Finland and Sweden surface water is often used to artificially recharge groundwater through "managed aquifer recharge" and is then defined as groundwater. According to the Swedish Drinking Water Regulation, water that has been in the ground for more than 14 days is defined as groundwater (§3 SLVFS, 2001:30). In Finland, the goal in managed aquifers recharge is one month which takes into consideration the residence time needed to remove humic substances but is not a legal limit but (Jokela et al., 2017).

Most of **Denmark** comprises quaternary deposits overlying chalk, limestone and unconsolidated sand and clay layers. The topography is low-lying, mostly densely populated and under agricultural use. The main challenge is therefore nitrate and pesticides from farming and urban areas. All water supply is from groundwater, harnessed through boreholes. The approach is either simple treatment (aeration, pH adjustment and filtration) or none combined with protection of groundwater. The Patient Safety Board and Nature Agency reported that, in 2015, there were microbiological non-compliance incidents in drinking water from 3% of the small to very small (<500 inhabitants) Danish water supplies (Lyng and Hansen, 2016).

The **Faroe Islands** are of volcanic origin and mostly basaltic. There has been little groundwater use. Large supplies use mostly surface water; small and very small water supplies often use spring sources. The main challenge is with seasonal variations in the quality of surface water, and the variable residence time for water in the ground, which can lead to fluctuations in water quality. The most common water treatment consists of sand filtration combined with UV disinfection. Spring water should comply with the microbiological requirements in legislation; if spring water has a safe and stable microbiological status for three years, no water treatment is required. In case of non-compliance UV is used for disinfection.

Finland is on the Fennoscandian shield with two types of geological formation, the old Precambrian bedrock with low permeability and glaciofluvial deposits such as eskers (Katko et al., 2006). The glaciofluvial formation with artificial recharge is widely used as a groundwater source. The best water is in unconfined aquifers above the marine deposits (e.g. above 60–80 mosl), whereas coastal groundwater systems are overlaid by agricultural lands. Most large water supplies use surface water, whereas small water supplies all use groundwater. Among water quality problems encountered are fluoride and arsenic in bedrock boreholes. Salt for de-icing of roads increases the chloride content of groundwater in certain areas. Groundwater for municipal supplies is commonly treated and/or disinfected if the raw water does not fulfill the drinking water regulations (post-chlorination is not mandatory). Raw water quality of small water supplies is often found to be good during the planning and scheduled monitoring. Therefore, in many cases no processing of water is utilized. Small water supplies in Finland typically have boreholes or dug wells with few having a spring source, whereas large supplies mostly use boreholes when harnessing groundwater. Although the water quality in small water supplies is in general defined as good, problem do occur. In a study of 10 small groundwater supplies in central Finland, most were managed as cooperatives and served 50 to 450 people; five were observed to be fecally contaminated, with contamination associated with poor well construction or insufficient depth of protective layer above the water table, enabling surface water to pollute the water source (Pitkänen et al., 2011).

Greenland is the largest island and the most sparsely populated country in the world. Its geology is dominated by Precambrian bedrock. Approximately of 88% of the land is covered by inland ice or glaciers. Coastal areas are rocky with mountains, smaller islands, and fjords. People live in small coastal towns and settlements, mostly located along the West coast, with no or little road infrastructure, and are accessible by sea or air. Altogether, there are 73 human settlements: 17 towns and 56 villages, each with a regulated water supply. About 13% of the population live in villages (Hendriksen and Hoffmann, 2018, Statistics Greenland, 2017). All water abstraction is from surface sources: small lakes, rivers, and glacial meltwater, mainly from natural lakes, some of which are engineered for depth to allow intake below the ice during winter. Water is treated with combination of sand filters, UV and/or chlorination and seven settlements have seawater desalination by reverse osmosis. One Government-owned company (Nukissiorfiit, the Greenland National Energy and Water Company) runs all public water supplies, serving all except for three smaller villages in northern Greenland, for a current total of 70 regulated public water supplies. The

Table 4
Water Safety Plan in the Nordic countries.

Information on status 2019	Denmark (DK)	Faroe Islands (FO)	Finland (FI)	Iceland (IS)	Norway (NO)	Sweden (SE)	Åland Islands (AX)
4.1 WSP in regulation							
Demand on systematic preventive management in regulation (WHO's WSP, HACCP, ISO 22000, EN15975-2)	All water supplies delivering >46 m^3/day (230 inh) quality control system and if > 2000 m^3/day (10 000 inh) ISO22000 or HACCP (Bek nr 132 8/2/2013)	All water supplies >50 inhabitants shall have HACCP. Water supplies <50 inhabitants the Food Authority evaluate if HACCP should be implemented	All water supplies with an operating area defined by the municipal authority should have SFS-EN15975-2 or similar	Water supplies are food companies and shall have HACCP or similar if > 5000, and simpler system if 50–5000.	All water supplies delivering >10 m^3/day needs to implement a risk and vulnerability evaluation based on NS-EN 15975-2	Water supplies are food companies and shall have HACCP or similar	All water supplies that deliver 10 m^3 a day or more or serve 50 people or more, or if commercial or public activity
When implemented in legislation	2014	2013	2016	1995	2017	2011	2016
Demand in regulation of the surveillance authority to certify or audit WSP	None	None	Yes	None	Yes	None	Yes
4.2 Compliance to regulation							
No water supplies that should apply to this demand and % of all regulated	1600 (59%)[a]	72 (61%)	1354 (100%)	186 (23%)	1406 (20%)	1750 (39%)	9 (36%)
How many water supplies have applied to WSP demand (2018) and % of demanded	Considering that this is a legal demand, 100% is assumed	12 (16%)	n.a.	29 (16%)	n.a.	50 (3%)	None for the moment
% of population served by water supplies with WSP	n.a.	34%	n.a.	81%	n.a.	70%	0%
4.3 Courses and manuals							
Demand in regulation on attending courses and training teaching water supply hygiene and risk-based approach	Yes, since 2014	None	Yes since 2018	None	There is a demand of competence, but the owner of the water supply defines the need for training	Yes, since 2011	Yes since 2018
Courses and other training available teaching hygiene and risk management in water supply available for the **small** water supplies	Yes	Have been but not now. One is planned in 2020.	Yes	Have been but not now for since 2012	Yes	Available on demand, but few (no planned 2019)	Yes
Number of online courses and teaching material available	None	None	Several	None	There are online courses, but the number is not known	None	None
Up to date WSP manual available in local language	Yes	None, use HACCP instead	Yes	Manual since 2009	Yes	None, uses HACCP instead	Yes
Up-to-date sanitary inspection forms available in local language	n.a.	None	Yes- several well water quality inspection guidelines available in Finnish	None. Is being developed now. Indicative inspection from LCAs of status of intakes available	The Food Safety Authorities focus on a specific topic each year. A checklist is distributed to all waterworks in advance of inspection.	Yes. Also reports on Indicative inspections published from Swedish Food Authority	No

[a] Estimated; n.a. = data/information not available.

principal problems are that water resources are limited in some places and distribution pipes must be kept frost-free with electric heating cables. The solution for water delivery has been threefold: 1) piped water to houses, 2) tanks where trucks bring water to tanks inside individual households, and 3) tap houses where people fetch water (Hendriksen and Hoffmann, 2018). There is no record of how many households in Greenland have piped water, but it has been estimated that 10% have neither piped water nor a tank solution (Hendriksen and Hofmann, 2018). Non-compliance in microbiological quality is high and boil advisories are frequent. During the period of 2011–2013, 35 of 74 water

supplies experienced periods of non-compliance with the drinking water quality regulation; and surveillance was insufficient or absent in small supplies (Naalakkersuisut, 2015).

Iceland is volcanic and mostly basaltic and large areas are covered by postglacial lava. It is rich in groundwater due to high precipitation and porous bedrock. The sources for drinking water are predominantly groundwater with no treatment unless there is a danger of surface water intrusion. When surface water is used it is filtered and disinfected with UV treatment. Around 8% of regulated water supplies use UV disinfection (Gunnarsdottir et al., 2019). Microbiological quality is high in large supplies, whereas on average 5% of small supplies are non-compliant for *E. coli* every year (Gunnarsdottir et al., 2020). Testing of chemicals (audit monitoring) is largely restricted to medium and large supplies (>500 inhabitants) and compliance is high (99.97%) with no expected health risks in untreated groundwater. Most water intakes for small supplies are spring sources, whereas most of the larger ones have boreholes. Spring sources are often located in mountainous areas and supply water through gravity flow. They are vulnerable to increased likelihood of landslides due to climate change (Gunnarsdottir et al., 2019).

Nearly all of **Norway** is on the old Fennoscandian shield underlain by metasedimentary or metamorphic bedrock with low permeability. Therefore, the main water source is surface water. Groundwater is mainly used for small supplies and is generally provided from boreholes. The main chemical problems are iron and manganese. Legislation requires risk analysis to identify all threats to a water supply. If the analysis shows that the water source is well protected, it may be allowed to not disinfect groundwater. The requirements for demonstration of low risk increase with the size of the supply system and not all the sections of the regulation apply to all water supplies. There are fewer requirements and fewer parameters tested for water supply systems producing less than 10 m^3 per day than for larger systems. A report from the Norwegian Food Safety Authority on the status of drinking water (Mattilsynet, 2019) reported finding *E. coli* in 79 (around 6%) of water supplies serving more than 50 persons in 2018. Fifty of those serve between 50 and 500 people. Reporting from very small water supplies (<50 inhabitants) is not mandatory and no information on water quality status is available for those.

Sweden is mostly an area of consolidated metamorphic bedrock with low permeability. Most large supplies use surface water, while smaller ones use groundwater. The groundwater supplies largely have boreholes and very few have a spring source. Groundwater is treated to fulfill the requirements of the Swedish drinking water regulation, although often, groundwater can be distributed without any treatment. If treatment is needed due to high of manganese or iron content, the water is aerated, filtered in rapid sand filters, and sometimes disinfected. Occasionally, also pH-adjustment, softening, or adsorption of organic fractions to activated carbon is applied. The owner of a treatment plant is obliged to design and operate treatment to meet the requirements of the Swedish drinking water regulation; and the municipal surveillance authority visits the water supplies periodically. A report from the Swedish Food Authority for 2012 indicates insufficient visits, as only 52% of the water supplies were visited once a year as required (Svärd et al., 2014).

The **Åland Islands** consist of more than 6500 islands between Sweden and Finland, with the highest peaks rising 132 m above sea level. Sixty islands are populated. Geologically they lie on the Fennoscandian shield, like Finland, with two main types of bedrock: old Precambrian bedrock with low permeability (in the eastern archipelago) and younger Rapakivi granite bedrock (on the main island) with better permeability. The quaternary deposits mainly consist of moraine, then clay, sand, and silt in descending order. In general, the glaciofluvial deposits on top of the bedrock such as eskers (drumlins) are small (Katko et al., 2006). Larger water supplies mostly rely on surface water and smaller ones use groundwater (6.6% of the total consumption from 72% of all utilities), harnessed from bedrock drilled wells. Typical groundwater quality problems are chloride, fluoride, organics, iron, manganese, and radon gas.

3.3. Catchment protection

According to the EU Water Framework Directive (EU WFD) necessary protection for bodies of water used for water supply shall be ensured to reduce the need for treatment in the production of drinking water (2000/60/EC, Article 7.3). This entails three protection zones that apply to all regulated supplies: the water intake zone, near zone and distance zone, which have different requirements. A fourth safety zone is for control of polluting activities. Most Nordic countries demand fencing at a 10 to 30-m radius around intakes (Table 1). Few of the Nordic countries have reported information on progress with carrying out the regulation and defining protection zones for water supplies.

In **Denmark**, outside the cities, a 25-m zone (radius) is to be identified around the water source where no fertilizers, cultivation or pesticides are allowed. More than half of boreholes used for harnessing drinking water in Denmark are in agricultural areas using pesticides (Miljöministeriet, 2011). Further restrictions, particularly for pesticides, are to be implemented in the zones near to the abstraction wells (Miljö-og Födevareministeriet, 2020).

In **Faroe Islands** protection zone size is not specified, but it is recommended that water intakes be fenced. However, a general risk assessment is conducted for the entire catchment area and if sensitive activities are identified appropriate action should be taken to compensate for the risk factor(s).

In **Finland** and the **Åland Islands**, aquifers where water is abstracted are defined as important water resources and legislation specifies restrictions, e.g. on land use and sewerage for the whole aquifer. Aquifer size in Finland varies, generally from less than 10 km^2–100 km^2. In addition to legislative protection to the whole aquifer, regional environmental authorities can define safety zones for wells, case-by case. In Finland only 10% of wells had level 2 protection zones in 2018 for additional protection because the whole aquifer already has considerable protection (Britschgi et al., 2018). In the Åland Islands, the larger water supplies have protection of catchment areas, whereas progress is slower in the smaller supplies.

In **Greenland** there are provisions for protection of the source watershed within the environmental protection legislation (Naalakkersuisut, 2011). A 30-m protection zone is generally defined along source water lakes or rivers, in which roads and buildings cannot be constructed. Protection zones have been defined around the watersheds of the water supply lakes in all communities (Nukissiorfiit, 2020). The Greenland government has implemented additional source water protection rules for some communities, e.g., Sisimiut and Qaqortoq, where the proximity of existing structures or recreational and traditional land use require a specific set of rules to limit sources of contamination.

In **Iceland** water suppliers are to define water protection areas according to the WFD with a fenced-in water intake area (at least 5-m radius), near zone and distance zone. Only large and medium size water supplies (>500 inhabitants) have implemented this, whereas the smaller supplies have fenced-in water intakes if possible. In steep terrain fencing can be difficult and can be disrupted by snow. It is recommended that the border of the distance zone be based on 50 days water detention time, though this is not in regulation. No information on progress with defining water protection areas on a country level is available. A new regulation for the capital area (Nr.555/2015) of protection of water sources states that the water intake zone should be at least 50 days groundwater travel time and if not known then 50 m and 200 m in the direction of the groundwater flow. For the near zone, the demand is 400 days travel time of groundwater. This regulation also restricts access, land use and use of chemicals. A safety zone has also been defined for the capital city area.

Protection zones are also used in **Norway** where the detention time in the near zone is recommended to be no less than 60 days, though this is not regulated. The size of the zone therefore depends upon geological

conditions and protection of the water source is by regulating the use of the land surrounding the well. Contamination sources are mapped to evaluate the need for protection and how to implement measures, e.g. through municipality plans, voluntary deals with stakeholders or expropriations.

In **Sweden**, about 70% of the municipal water supply sources have a water protection area defined by the local authority, either the regional county board or the municipal council. Protection is granted in four zones, the water supply zone, the near zone, the distance zone, and the safety zone. The water supply zone is defined as an area around a production well or a group of wells. The area should be physically protected, e.g. through a locked fence, and not be accessible by anyone except the water source holder. When defining the near, distance and safety zones for groundwater, both the residence time in the groundwater reservoir and particularly sensitive (vulnerable) inflow areas must be considered. The average detention time for groundwater within the near zone is 60–100 days, while it is 1 year in the distance zone. A safety zone is not always defined in Sweden but can be used for cases where particularly sensitive anthropogenic activities, that may damage the groundwater quality for many years, should be considered.

3.4. Reporting of drinking water quality

All 31 member states of the European Economic Area (EEA) are to implement the EU-DWD and are obliged to report drinking water quality data to either EFSA (European Food Safety Authority) or ESA (EFTA Surveillance Authority) for all water supplies that deliver more than 1000 m^3/day or serve more than 5000 people. Member states are to deliver reports every three years on the quality of water intended for human consumption, which is published. Hence, water quality data from around 800 Nordic water supplies, 6% of regulated water supplies, are reported (Table 3); these supplies serve around 73% of the population of the Nordic countries. Hence, the quality of drinking water delivered to 7.2 million (27%) Nordic citizens is not reported to the EU or EFTA. Furthermore, while specific information on individual supplies is accessible to users, either openly (on-line) or on-request, overall descriptive information about status and trends in compliance is not readily available in summarized form to the public or to policymakers.

Water quality is to be tested only at accredited laboratories (ISO 17025) in all countries. In Denmark people that sample water must be accredited and in Finland and the Åland Islands people working in the water supplies are to have a "work card", which requires understanding of sampling.

Microbiological non-compliance in the Nordic region is much higher for small than large supplies (Fig. 1) and fecal contamination is at least eleven times higher (Gunnarsdottir et al., 2017).

3.5. Information on water quality to consumers

One of the objectives of the forthcoming EU DWD is to increase and improve transparency and ensure that consumers have access to information on their water supply. Information: should be given online without request or in another user-friendly way; should concern water quality, treatment, distribution, and risk assessment; and should be based on data less than one-year old. For very large supplies (more than 50 000 inhabitants) leakage rates and energy consumption per cubic meter of delivered water should also be given. All consumers shall receive, regularly and without request, information on water quality, price of water per liter or cubic meter and relevant information regarding the quality of water.

In Finland and the Åland Islands nearly all houses have meters and payment for water by quantity is legislated. In Denmark, Greenland and Sweden water is also metered to most and in Norway water is metered in households in one fifth of the municipalities. Whereas in the Faroe Islands water suppliers are installing water meters to industry but water will not be metered to households; similarly, in Iceland water is metered to industry but to households only in one water supply. Delivering information to consumers on price per liter will be difficult for some countries.

In the current EU DWD, it is stated that each Member State shall ensure that adequate and up-to date information on the quality of water intended for human consumption is available to consumers. The availability of information to consumers varies in the Nordic region. Information delivery can be classified for the individual user concerning water provided to them, and summarized information on water quality and compliance with regulation for example for the whole country. The latter is important for evaluation of whether safe water is available for all, as required in the new EU DWD and to assess progress towards the drinking water target of SDG6.

Regarding information provided to individual users on the quality of water delivered to them, the best status is in Denmark, Greenland, Norway, and Finland, where drinking water quality information is uploaded to a common database. All results from surveillance monitoring of water quality in Denmark and Greenland are uploaded on a common database, called Jupiter, which is the responsibility of the municipalities and in case of Greenland, Naalakkersuisut. This database is managed by the Geological Survey of Denmark and Greenland, GEUS, and is publicly available to all. Furthermore, the water supplier is obliged to present the water quality data on their home page. In Norway, the database is managed by the Food Safety Authorities and the data is available to all; however, the files are not simple to use. In Finland annual key figures must be uploaded into the VEETI database, managed by the Finnish Environment Institute, which presents information on

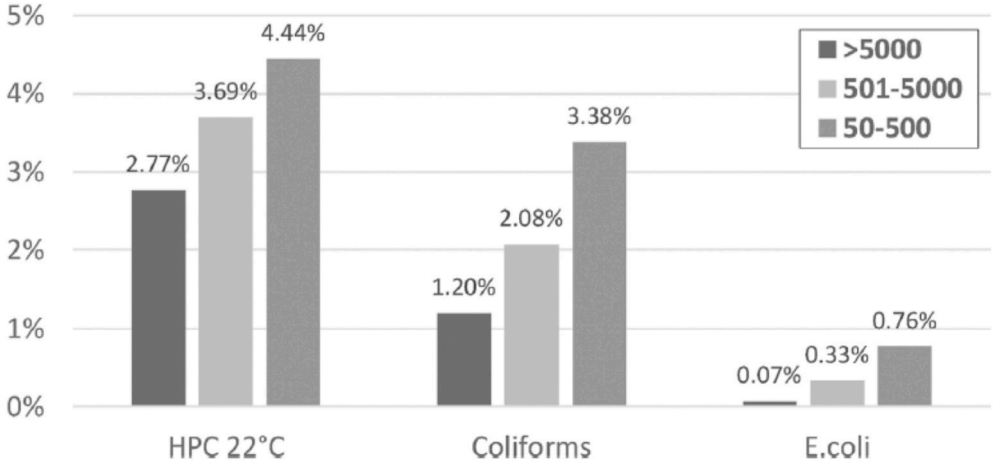

Fig. 1. Population weighted average of non-compliance in the Nordic countries according to size (from Gunnarsdottir et al., 2017).

regulatory compliance. Water quality data are reported by laboratories to the municipal authorities which, based on legislation, monitor that the water users have appropriate information concerning water quality. Hence in Denmark, Greenland, and Norway an individual can see drinking water quality about any location, whereas in Finland you can see whether drinking water complies with water quality regulations. Not with standing access to the data being public, the databases can be complicated to use, so they are probably mainly used by professionals.

In Sweden, legislation states that information on water quality should be made available on the website of the water supplier. In Icelandic legislation uploading information on water quality to public websites is not required, though most of the large water supplies and some surveillance authorities publish water quality results on their websites. In the Faroe Islands customers generally need to contact the water supply to get information on water quality, although some municipalities voluntarily upload water quality data online as a service for the consumers. Overall, all the Nordic countries, except Denmark, Greenland, Norway, and Finland, are still working towards a common database and transparency about water quality to consumers.

For summarized information, all countries except the Faroe Islands and Greenland send reports for the large supplies to EU or EFTA. These are available on the website of the responsible Governmental institutions; Denmark and Sweden also publish the EU report in the local language. The Food and Veterinary Authority (MAST) in Iceland once (for the period 2002–2012) published a summary report on water quality for all regulated water supplies (large and small alike), (Gunnarsdottir and Gardarsson, 2015). The Norwegian Institute of Public Health published its first summary report on water quality for all regulated water supplies for 2018 (Hyllestad et al., 2019). In Sweden and Denmark no authority is responsible to summarize water quality on the national level. Hence summarized information on water quality status from the smaller water supplies (<5000 inhabitants) in the Nordic region is not readily available except in the one-time Icelandic and Norwegian reports. It is therefore not possible to determine whether all the citizens have access to safe water.

3.6. National platforms for knowledge sharing in the water sector

A platform for cooperation and sharing of information and knowledge has proved to be a powerful instrument for development in many sectors including water supply (Gunnarsdottir et al., 2012b). The Nordic countries have national associations for water supply and sewerage (DANVA in Denmark, FIWA in Finland, SAMORKA in Iceland, Norsk Vann [NORVAR] in Norway and SVENSKT VATTEN in Sweden), and these associations have established formal Nordic cooperation. The Faroe Islands, Greenland and the Åland Islands do not have their own platforms for knowledge sharing. However, they often have contact with other Nordic associations and attend their meetings and courses. Members of these associations are mostly the large suppliers; they therefore represent only some of the regulated water supplies in each country (Table 3). Two Nordic countries have specific associations for small water supplies: Denmark, and Finland. Danish Water Supplies (DVV) is an association of regulated small and medium size water suppliers, mostly user owned. In Finland there is the Association of Finnish Water Cooperatives (SVOSK). The limited participation of the small water supplies in national platforms in other Nordic countries is of concern. Overall, 27% of regulated water supplies in the Nordic countries participate in the associations (Table 3).

In Denmark, DVV, has been active for more than 40 years and has 1891 water suppliers as members. It is estimated that DVV members serve around 2.2 million people (38% of the Danish population). DVV works with its members on policies and legislation, advising on legal, economic, and technical issues, as well as press relations. DVV also has an extensive portfolio of courses covering these concerns, and purchases insurance jointly at lower costs.

Finland has a long tradition of organizing water supply through cooperatives (Takala et al., 2011). SVOSK has been active since 2006 and has 120 water supplier members, with this number steadily increasing. The association has a staff of two and most of the other active personnel are representatives from cooperatives. SVOSK has annual seminars for the cooperatives, arranges training sessions and represents the interests of the cooperatives.

3.7. Risk-based approach in Nordic water supplies

One of the main objectives in the forthcoming EU DWD (EC, 2020) is to implement a risk-based approach to drinking water delivery that covers the supply chain from catchment, through abstraction, treatment, storage, and distribution, to the point of delivery from taps normally used for human consumption. It divides the supply chain into three parts, with different requirements and responsible actors in each: 1) the catchment area for the abstraction points with reference to the EU Water Framework Directive (2000/60/EC); 2) the supply system that includes the water intake, treatment, storage and distribution to the point of delivery to the premises which is the responsibility of the water supplier; and 3) the domestic distribution system, which is the responsibility of the houseowner.

The risk-based approach is to be applied to all supplies (catchment and supply systems) providing more than 10 m^3 of water a day as an average or servicing more than 50 persons or if part of a commercial or public activity. A risk-based approach is also to be applied to priority premises (non-household premises with many people, vulnerable people, e.g. hospitals, health care institutions and retirement homes). Risk assessment and risk management are required for all catchment areas from which water intended for human consumption is abstracted, with no exemption allowed. Supply systems providing 10–100 m^3 a day on average or serving 50 to 500 people may be exempted from the risk assessment and management requirements, provided that regular monitoring is carried out and the surveillance authority is satisfied that this does not compromise the quality of water intended for human consumption. In the forthcoming EU DWD, monitoring of small supplies (10–100 m^3/50–500 people) is increased from the current requirement of 'as decided by the Member State' to two sampling occasions per year for microbiological parameters, and one sample per year for chemical parameters.

All Nordic countries, except Greenland already have requirements for preventive management of water supplies in their regulations, and these requirements more than fulfill the requirements in the forthcoming EU-DWD for the supply system. Risk-based approaches for catchments and for priority premises are still to be incorporated into Nordic country regulations. Around 40% of all regulated water supplies are to implement a risk-based approach according to national legislation already in place, ranging from 20% in Norway to 60% in Denmark and the Faroe Islands. Information on the progress of implementation is sparse, as can be seen in Table 4, and it can be concluded that there is still a long way to fulfill the regulation.

In the Nordic country regulations risk-based approaches are named HACCP, WSP or EN 15975–2. All include risk assessment and risk management. When water is defined as food, usually the requirement is for a HACCP plan. Since 2005 HACCP has been reflected in the ISO Quality Management System (ISO 22000) which requires regular ISO certification. The European Standard Organization, CEN, developed standard EN 15975–2, which describes a risk management approach to drinking water supply that builds on the principles of the WHO's WSP approach. Sanitary inspection is a simple form of preventive management where hazards are identified, and control measures applied which has been widely applied to small supplies (Kelly et al., 2020). WHO has developed several manuals and guidelines for implementing WSPs and sanitary inspections which can be found on the WHO website (e.g. Bartram et al., 2009; Rickert et al., 2014; WHO, 2019). The national associations of water suppliers and some of the responsible authorities in the Nordic countries have developed manuals in local languages for

implementing WSP. Hence, the tools needed for adapting a risk-based approach in the water service has the tools are available.

Worldwide experience, including high-income countries, has shown that key success factors for WSP implementation include regulatory requirements for a risk-based approach, access to tools such as manuals and guidance, training resources, cooperation across the sector as in national platforms, and context-specific evidence of the feasibility and benefits of WSP (Schmiege et al., 2020; Kayser et al., 2019; Ferrero et al., 2019; Baum and Bartram, 2018; Amjad et al., 2016; Baum et al., 2016, Gunnarsdottir et al., 2012a & 2012b). These factors are especially important for small systems where there are typically fewer skills and resources available. The literature also points to the importance of case study examples, especially from small systems. An important player in protecting public health from contaminated water is the public health sector and involvement (not just in crisis situations) and cooperation between actors is important (Rehfuess et al., 2009). The forthcoming EU DWD and its incorporation into national legislation and regulation fulfills the regulation component, while the other components need to be secured.

In **Denmark** requirements for WSP are twofold. All regulated water supplies that deliver more than 750 000 m^3/year (estimated to serve more than 10 000 people) are to comply with ISO 22000 or have a system built on HACCP. A quality control program with most of the elements of WSP is required for all water supplies supplying 17 000 m^3/year (46 m^3/day or an estimate of 230 persons)[1] and that should have been fulfilled by Dec 31, 2014. However, information on how this has been fulfilled is not easily accessible, but since it is required legally, and it has to be checked by the authorities a high level of compliance is expected. All operators of regulated water supplies (10 or more households or commercial or public activity) are to attend a course on operation of a water supply and elementary sanitary hygiene. This also applies to contractors working for the water supplies. The regulation states that the subjects to be covered should include training about the quality control program. The DVV holds regular 3-day courses for its members. According to the DVV, up to the end of 2018 around 1000 water supplies (of the nearly 1900) had sent operators to these courses, indicating that the small water supplies in Denmark are in the process of implementing the quality control program.

In the **Faroe Islands** drinking water is defined as food and should have a management system based on the HACCP principles. The Faroese Food Agency has drawn up guidelines in the form of a manual which calls for mapping of the water supply system, risk analysis to identify critical control points and documentation that the suppliers have performed the needed control measures. The plan must be reported to the Food Agency for validation before each water supply is officially approved. The Food Authority is obliged to visit all regulated water supplies and investigate the documentation, and any follow-up that the suppliers have performed. Since 2013, when HACCP was included in the regulation, few small water supplies have been approved, mainly due to insufficient resources and little knowledge on WSP. Faroese water suppliers are not members of any platform for knowledge sharing, so their staff do not learn about these approaches from colleagues. Faroese legislation demands documentation of competence for each person working on the supply chain, though it is for the owner of the water supply to decide on what training is needed.

In **Finland,** the update of legislation in 2016 established that all water supplies with an operating area defined by the municipal authority shall have EN 15975–2 or similar. How this is done is up to the suppliers, though it must be reported to the municipal authority. There is a requirement in the regulation for staff to attend courses and training in hygiene and in risk-based approaches and several options for this are available online including courses on WSPs (e.g. by FIWA and SVOSK) and online training by the National Supervisory Authority for Welfare and Health (www.wspssp.fi). No information is currently available on progress with WSP implementation, nor on course attendance.

The new **Greenland** drinking water regulation, which is expected to be implemented in 2020, will require water supplies to implement WSPs by 2025.

In **Iceland,** drinking water has been defined as food since 1995 and is covered under the Food Act that demands systematic management to prevent contamination. This has been shown to be beneficial to management, water quality and public health (Gunnarsdottir et al., 2012a & 2012b). Large supplies (serving more than 5000 people) shall have HACCP or similar and smaller should have a simpler WSP. Most large water supplies have a WSP in place, some medium size as well (36%), whereas very few of the small size (50–500 inhabitants) or only 6%. In all 29 water supplies have WSP or simpler WSP in place; these supplies serve over 80% of the population of Iceland. The legislation establishes no requirement for training. Courses teaching risk assessment in water supply have not been available since 2012. There are no statistics available from the surveillance authority on implementation, follow-up or validating of WSP.

In **Norway,** an internal control system that includes a risk and vulnerability analysis (risk-based approach) is required. For water supplies producing more than 10^3 L a day (serving more than 50 persons), a written or electronic control system is needed. The Food Safety Authority has produced a guide, based on NS-EN 15975–2, on how to perform the analysis, and this risk-based approach is in line with implementation of WSPs. These water supplies must send a yearly report to the Food Authorities with results on the required analyses of raw water and drinking water. There is a competency requirement for each person working in the supply chain. However, it is for the owner of the supply to decide what training is needed. Courses in risk analysis of water supplies are arranged by different organizations. There are no statistics available on progress in implementation of risk and vulnerability analysis.

The **Swedish** Food Agency's regulations on drinking water require drinking water providers to control their operations and analyze hazards and critical control points when necessary to maintain satisfactory hygiene (HACCP). Svenskt Vatten has drawn up industry guidelines for HACCP/WSP in the form of a manual (Svenskt Vatten, 2014). Risk-based work is typically done by larger water supplies as an internal method to increase the capacity of the organization and to pinpoint weak links in the water supply chain. Since small water supplies often have few employees and limited management capacity, risk-based studies are done at best to the extent necessary for the organization to fulfil the requirements from the controlling authority.

The **Åland Islands** have legislation similar to Finland, which requires that risk assessment be done in collaboration between the operators and the authorities. All persons working at water suppliers must pass a test showing that they have engineering and domestic water hygiene competence. For training courses for WSP and participation in the Finnish Water Supplier's Association a language barrier means that water suppliers usually participate in associations in Sweden, such as SVENSKT VATTEN. All supplies serving over 50 persons must implement a WSP or corresponding assessment, and work towards this is in progress.

4. Conclusions

Freshwater resources are generally rich in the Nordic countries. The distribution of bedrock, quaternary deposits and surface waters varies, affecting use of groundwater or surface water for drinking water supply. Nordic governments do not have a department of water and political interest in water policy is low unless a crisis such as a waterborne disease outbreak occurs. Comparison with the WHO Framework for Drinking-Water Safety (WHO, 2004), shows that the three key components (regulation based on health-base targets, risk-based management

[1] Bekendtgörelse om kvalitetsikring i almene vandforsyningsanlæg BEK nr 132 af 08/02/2013.

performed by the water supplier and independent surveillance) are well in progress for larger and medium size systems in most of the Nordic countries, but far less so for smaller systems. The legal frameworks are similar in all Nordic countries, but the administrative framework differs, depending on power-sharing responsibilities between national, regional, and local authorities. All countries, except Denmark and Greenland, have many, usually small, municipalities that are often required to oversee the water supply systems, but often have insufficient capacity to do so. This calls for support and guidance from the governmental institutions to the municipalities.

In the Danish, Norwegian and Swedish regulations, municipalities are obliged to register all regulated water supplies, and in Denmark and Finland associated information is to be accessible to all. There are over 16 thousand regulated water supplies in the Nordic countries, serving around 91% of the population, plus an unknown but large number of unregulated supplies, serving over 2.3 million people. According to the forthcoming EU-DWD, member states shall identify people without access or with limited access to safe water. There is therefore an important task for the authorities to register all water supplies to be able to know whether they are providing safe water for all. This reflects the widespread challenge of establishing monitoring suitable for identifying deficiencies in countries with high levels of access, rather than tracking progress in countries striving to increase access, in response to the SDG target of universal access to safe drinking water and towards achievement of water security (Bradley and Bartram, 2013).

According to the forthcoming EU-DWD, member states shall ensure that information on the quality of water intended for human consumption provided by regulated water supplies shall be accessible to consumers online. A public database is available in Denmark, Greenland, Norway, and Finland where consumers can look up their water quality. In the other Nordic countries information for the public is not consistently on the website of the water supplier or the surveillance authority and in the Faroe Islands it is necessary to contact the water supplier for information. Only Iceland and Norway have published one-time summary reports on drinking water quality for all regulated water supplies including small and very small regulated water supplies. The other countries do not collect and summarize the quality from all regulated supplies. Hence, there is work ahead to improve the delivery of information to the public, including the small water supplies.

All the Nordic countries have in their legislation a requirement for preventive management. However, there is limited information on progress in implementing risk-based approaches and when information is available it reveals progress is slow in most of the Nordic countries. None, except the Faroe Islands, require the surveillance authority to certify or audit the water safety plan. In Finland, a water supply must present its WSP to the municipal authority but need not have it certified or audited. The regulatory demands for risk-based approach in water supply systems, from abstraction to delivery into domestic premises, across Nordic countries already fulfill the requirements of the forthcoming EU-DWD. The forthcoming EU DWD provides member states the possibility to exempt small water supply systems (serving 50 to 500 people) from risk assessment and risk management requirements. If applied in the Nordic countries, then over four million citizens would not have risk-based approaches applied to their drinking water delivery.

A key to success with improving water safety in small water supplies is training and support. It is a regulatory requirement to attend a course in hygiene and a risk-based approaches in all countries except the Faroe Islands and Iceland. Courses are or have been available in most of the countries; and in Finland and Norway on-line courses are available. However, there is no follow-up by the surveillance authorities on how this has been fulfilled. Research has shown that supporting programs such as training are fundamental to the success and benefits of risk-based management and these requirements and their associated follow-up should therefore be part of updates to national policies.

In the Nordic countries, as in countries worldwide regardless of their relative socioeconomic development, small water supplies are disproportionately problematic. They suffer a series of problems derived from their relative isolation, limited human and financial resources and integration into training and professional networks. These would merit special support and policy measures to tackle this problem. The national associations play an important part in promoting, training and exchange of experience, e.g. Samorka was the main catalyst in WSP implementation in Iceland (Gunnarsdottir and Gissurarson, 2008). However, less than one third of regulated water supplies (serving around 90% of the population) in the Nordic countries participate in the associations and those left out are mostly the small and very small water supplies. Here, we argue for applying the 'Nordic model' to drinking water safety and that such support should be integrated into national policy in the Nordic countries and more widely.

Mapping of the status in the Nordic countries shows their relatively high level of preparedness for the forthcoming EU DWD. Despite substantial differences regarding water resources and supply structure, water policy, legislation, and enforcement, the Nordic countries have successfully implemented risk-based approaches at a relatively high level. However, our analysis identifies work that is needed. This will affect how the risk-based approach will be implemented, especially for the small water supplies which have the highest occurrence of quality-related problems. Therefore, we suggest that safe drinking water be added as a field of cooperation and benchmarking in the realm of the Nordic Council, and as means to transfer knowledge between the countries.

This work is relevant far beyond the Nordic countries themselves. As countries worldwide have adopted SDG Target 6.1, the focus of attention has shifted to attaining universal use of household-level water supplies and to ensuring safe water. This global re-orientation suggests that countries worldwide could usefully learn from regions such as the Nordic countries that are relatively advanced in this endeavor by both learning from what has been done well and by recognizing and dealing with challenges encountered in supporting small water supplies.

Declaration of competing interest

The authors declare no conflicts of interest. Funding for this study was partly provided for by the Nordic Council.

Acknowledgements

The authors thank the Nordic Council – Nordic Working Group for Microbiology & Animal Health and Welfare (NMDD) for the financial support for this project. Furthermore, the authors would like to express their gratitude to Susanne Berglund from the Government of Greenland for information about Greenland and others that gave information regarding water supply sector in the Nordic countries.

References

Amjad, U.Q., Luh, J., Baum, R., Bartram, J., 2016. Water safety plans: bridges and barriers to implementation in North Carolina. J. Water Health 14 (5), 816–826. https://doi.org/10.2166/wh.2016.011.

Bartram, J., Corrales, I., Davison, A., Deere, D., Drury, D., Gordon, B., Howard, G., Rinehold, A., Stevens, M., 2009. Water Safety Plan Manual: Step-by-step Risk Management for Drinking-Water Suppliers. World Health Organization, Geneva.

Baum, R., Bartram, J., 2018. A systematic literature review of the enabling environment elements to promote implementation of water safety plans in high-income countries. J. Water Health 16 (1), 14–24, 2018 Feb 1.

Baum, R., Bartram, J., Hrudey, S., 2016. The Flint water crisis confirms that US drinking water needs improved risk management. Environ. Sci. Technol. 50 (11), 5436–5437. https://doi.org/10.1021/acs.est.6b02238.

Beaudeau, P., Valdes, D., Mouly, D., Stempfelet, M., Seux, R., 2010. Natural and technical factors in faecal contamination incidents of drinking water in small distribution networks, France, 2003-2004: a geographical study. J. Water Health 8 (1), 20–34.

Bradley, D., Bartram, J., 2013. Domestic water and sanitation as water security: monitoring, concepts, and strategy. Phil. Trans. R Soc. A 371, 20120420. https://doi.org/10.1098/rsta.2012.0420, 2013.

Britschgi, R., Rintala, R., Puharinen, S.-T., 2018. Groundwater areas – a guide for their designation and classification and preparation of protection plan. Environ. Admin. Guide. 3, 142, 2018. http://urn.fi/URN, 978-952-11-4818-7.

Chave, P., Howard, G., Schijven, J., Appleyard, S., Fladerer, F., Schimon, W., 2006. Groundwater protection zones. Chapter 17. In: Schmoll, O., Hoard, G., Chilton, J., Chorus, I. (Eds.), *Protecting Groundwater For Health: Managing The Quality Of Drinking-Water Sources.*World Health Organization. IWA Publishing, London. Published by.

European Commission, 2014. Report from the Commission – *Synthesis Report On the Quality Of Drinking Water in the EU Examining the Member States Report for the Period 2008-2010 under Directive 98/83/EC*.

European Commission, 2016. Report from the Commission – Synthesis Report on the Quality of Drinking Water in the EU Examining the Member States Report for the Period 2011-2013 under Directive 98/83/EC.

European Commission, 2020. Proposal for a Directive of the European Parliament and of the Council on the Quality of Water Intended for Human Consumption (Recast) – *Political Agreement 24 February 2020*. https://ec.europa.eu/environment/water/water-drink/review_en.html.

European Council, 1998. Directive 98/83/EC of 3 November 1998 on the Quality of Water Intended for Human Consumption.

European Council, 2015. Directive 2015/1787 of 6 October 2015. Amendment to Directive 98/83/EC of 3 November 1998 on the Quality of Water Intended for Human Consumption.

Ferrero, G., DeFrance, J., George, S., Setty, K., Rinehold, A., Bartram, J., Rickert, B., 2019. Capacity building and training approaches for water safety plans: a comprehensive literature review. Int. J. Hyg Environ. Health 222, pp615–627. https://doi.org/10.1016/j.ijheh.2019.01.011.

Födevareministeriet, Miljö- og, 2020. Vejledning om boringsnære beskyttelsesområder (BNBO). Vejledning nr 45 (In Danish).

Gunnarsdottir, M.J., Gardarsson, S., 2015. Drinking Water Quality in Iceland 2002-2012 (In Icelandic). The Icelandic Food and Veterinary Authority. http://www.mast.is/library/Sk%C3%BDrslur/GaedineysluvatnsaIslandi150331.pdf.

Gunnarsdottir, M.J., Gissurarson, L.R., 2008. HACCP and water safety plans in Icelandic water supply: preliminary evaluation of experience. J. Water Health 6 (3), 377–382.

Gunnarsdottir, M.J., Gardarsson, S.M., Elliott, M., Sigmundsdottir, G., Bartram, J., 2012a. Benefits of water safety plans: Microbiology, compliance and public health. Environ. Sci. Technol. 46 (14), 7782–7789.

Gunnarsdottir, M.J., Gardarsson, S.M., Bartram, J., 2012b. Icelandic experience with water safety plans. Water Sci. Technol. 65 (2), 277–288.

Gunnarsdottir, M.J., Persson, K.M., Andradottir, H., Gardarsson, S.M., 2017. Status of small water supplies in the Nordic countries: characteristics, water quality and challenges. Int. J. Hyg Environ. Health 220 (8), 1309–1317.

Gunnarsdottir, M.J., Gardarsson, S.M., Andradottir, H.O., Schioth, A., 2019. Áhrif loftlagsbreytinga á vatnsveitur og vatnsgæðin á Íslandi – áhættuþættir og aðgerðir (In Icelandic: impact from climate change on water supplies and drinking water quality in Iceland– Risk factors and action). Verktækni Tímarit VFÍ 25, 5–19, 2019.

Gunnarsdottir, M.J., Atladottir, A.S., Gardarsson, S.M., 2020. Vatnsbornar hópsýkingar á Íslandi – greining á umfangi og ástæðum (In Icelandic: waterborne outbreaks in Iceland – analysis of scale and causes). Iceland Med. J. 6/2020 (106), 283–334.

Hendriksen, K., Hoffmann, B., 2018. Greenlandic water and sanitation systems – identifying system constellation and challenges. Environ. Sci. Pollut. Res. 25, 32964–32974.

Hendry, S., Akoumianaki, J., 2016. Governance and Management of Small Rural Water Supplies: A Comparative Study. CREW Scotland's Centre of Expertise for Waters.

Hulsmann, A., 2005. Small Systems Large Problems: A European Inventory of Small Water Systems and Associated Problems. *Web-based European Knowledge Network on Water* (WEKNOW).

Hyllestad, S., Lyngstad, T.M., Nordheim, C.F., Janak, K., 2019. Rapportering Av Data for Vannforsyning I Norge for 2018 (Report on Data from Water Supplies in Norway 2018). Rapport 2019. Folkehelseinstituttet, Oslo, 2019. (In Norwegian).

Isomäki, E., Britschgi, R., Gustafsson, J., Kuusisto, E., Munsterhjelm, K., Santala, E., Suokko, T., Valve, M., 2007. The future alternatives of centralized water supply in Finland. In: Finnish). Suomen Ympäristökeskus, p. 83.

Jokela, P., Eskola, T., Heinonen, T., Tanttu, U., Tyrväinen, J., Artimo, A., 2017. Raw water quality and pretreatment in managed aquifer recarge for drinking water production in Finland. Water 9, 138, 2017.

Katko, T.S., Lipponen, M.A., Rönkä, E.K.T., 2006. Groundwater use and policy in community water supply in Finland. Hydrogeol. J. 14, 69–78.

Kayser, G., Loret, J.F., Setty, S., Blaudin De Thé, C., Martin, J., Puigdomenech, C., Bartram, J., 2019. Water safety plans for water supply utilities in China, Cuba, France, Morocco and Spain: costs, benefits, and enabling environment elements. Urban Water J. 16 (4), 277–288. https://doi.org/10.1080/1573062X.2019.1669191.

Kelly, E., Cronk, R., Kumpel, E., Howard, G., Bartram, J., 2020. How we assess water safety. A critical review of sanitary inspection and water quality analysis. Sci. Total Environ. 718, 137237, 2020.

Klöve, B., Kvitsand, H.M.L., Pitkänen, T., Gunnarsdottir, M.J., Gaut, S., Gardarsson, S.M., Rossi, P.M., Miettinen, I., 2017. Overview of groundwater sources and water-supply systems, and associated microbial pollution, in Finland, Norway and Iceland. Hydrogeol. J. 25 (4), 1033–1044.

Lyng, I., Hansen, H.L., 2016. Mikrobiologiske Drikkevandsforureninger På Almene Vandforsyninger I 2014 Og 2015. https://mst.dk/media/118690/vandforurening_2015_ver_2.pdf (In Danish).

Mattilsynet, 2019. Status for Drikkevannsområdet I Landets Kommuner. Oktober 2019 (In Norwegian).

Messner, M.J., Berger, P., Javier, J., 2017. Total coliforms and E. coli in public water systems using undisinfected groundwater in the United States. Int. J. Hyg Environ. Health 220 (4), 736–743. https://doi.org/10.1016/j.ijheh.2017.03.003.

Miljöministeriet – Miljöstyrelsen, 2011. Vejledning om 25 meters beskyttelseszone omkring indvindingsboringer, jf. miljöbeskyttelsesloven §21b,jf.§64c (In Danish).

Municipal Water Supply Act, 2004. Lög um vatnsveitur sveitarfélaga nr, 32/2004 (In Icelandic).

Naalakkersuisut, 2011. Inatsisartut Law No. 9 of November 22, 2011 about Protection of the Environment (In Danish: Inatsisartutlov nr. 9 af 22. november 2011 om beskyttelse af miljøet. http://lovgivning.gl/lov?rid=%7BDD908A25-E80F-47EA-BF4D-FF8EF8473250%7D. accessed March 18, 2020.

Naalakkersuisut, 2015. Drikkevandskvalitet I Grönland 2011-2013 (Drinking Water Quality in Greenland 2011-2013) (In Danish). https://naalakkersuisut.gl/da/Special/S%c3%b8geresultat?q=Drikkevandskvalitet+i+Gr%c3%b8nland+2011-2013.

Naalakkersuisut, 2020. Consultations about Water Quality and Oversight of Water Works. https://naalakkersuisut.gl/da/H%c3%b8ringer/Arkiv-over-h%c3%b8ringer/2020/Vandkvalitet-og-tilsyn-med-vand_forsyningsanlaeg (accessed March 18, 2020) (In Danish).

Nordic Council of Ministers, 2018. State of the Nordic Region 2018. https://www.norden.org/en/publication/state-nordic-region-2018.

Nukissiorfiit, 2020. Vandspærrezoner („Water protection zones"). https://www.nukissiorfiit.gl/vand/vandkvalitet/ accessed June 14, 2020) (In Danish).

Pitkänen, T., Karinen, P., Miettinen, I.T., Lettojärvi, H., Hekkilä, A., Maunula, R., Aula, V., Kuronen, H., Vepsäläinen, A., Nousiainen, L., Pelkonen, S., Heinonen-Tanski, H., 2011. Microbial contamination of groundwater at small community water supplies in Finland. Ambio 40, 377–390.

Rehfuess, E.A., Bruce, N., Bartram, J., 2009. More health for your buck: health sector functions to secure environmental health. PMID: 20072777. Bull WHO 87 (11), pp880–882.

Rickert, B., Schmoll, O., Rinehold, A., Barrenberg, E., 2014. Water Safety Plan: A Field Guide to Improving Drinking-Water Safety in Small Communities. World Health Organization – Regional Office for Europe.

Rickert, B., Samwel, M., Shinee, E., Kozísek, F., Schmoll, O., 2016. Status of Small-Scale Water Supplies in the WHO European Region. Results of a Survey Conducted under the Protocol on Water and Health. WHO/UNECA.

Statistic Greenland, 2017. Greenland in Figures 2017. http://www.stat.gl/publ/en/GF/2017/pdf/Greenland%20in%20Figures%202017.pdf.

Schmiege, D., Evers, M., Zügner, V., Rickert, B., 2020. Comparing the German enabling environment for nationwide Water Safety Plan implementation with international experiences: are we still thinking big or already scaling up? Int. J. Hyg Environ. Health 228, 113553. https://doi.org/10.1016/j.ijheh.2020.113553 June 2020, 2020.

Stefansson, P., 2005. Framkvæmd Vatnsverndar Og Stjórnun Vatnsauðlindar Á Höfuðborgarsvæðinu. MS University of Iceland. Juní 2004. (In Icelandic). http://www.heilbrigdiseftirlit.is/sites/default/files/vatnsritgerd.pdf.

Svärd, C., Forslund, C., Eberhardson, M., 2014. Kommunala Myndigheters Kontroll Av Dricksvattenanläggningar 2012. Swedish Food Agency (In Swedish).

Svenskt Vatten, 2014. Publikation P111. Handbok För Egenkontroll Med HACCP Vid Produktion Och Distribution Av Dricksvatten (Handbook for Self-Monitoring with HACCP during Drinking Water Supply (In Swedish).

Takala, A., Arvonen, V., Katko, T.S., Pietilä, P.E., Åkerman, M.W., 2011. The evolving role of water Co-operatives in Finland. Int. J. Co-Oper. Manag. 5 (2), 11–19.

United Nation Sustainable Development Goals – Official document, 2015. Resolution Adopted by the General Assembly on 25 September 2015. https://sustainabledevelopment.un.org/post2015/summit.

Vatnaskil, Verkfræðistofan, 2015. Vatnsvernd á höfuðborgarsvæðinu. Greinargerð um heildarendurskoðun Febrúar 2015 (In Icelandic: Water protection in the capital area). https://www.ssh.is/images/stories/vatnsvernd/vatnsvernd_heildarendurskodun_greinargerd_v15_til_auglysingar.pdf.

Weideborg, M., Krogh, T., 1995. Beskyttelse av drikkevannskilder – nordiske erfaringer. Vann 1–95, 195–205 (In Norwegian).

Who, 2004. Guidelines for Drinking-Water Quality-3rd Edition, vol. 1. Recommendations, Geneva.

Who, 2017. Guidelines for Drinking-Water Quality: Fourth Edition Incorporating the First Addendum. World Health Organization, Geneva, 2017. Licence: CC BY-NC-SA 3.0 IGO. https://www.who.int/water_sanitation_health/publications/drinking-water-quality-guidelines-4-including-1st-addendum/en/.

Who, 2019. A Guide to Equitable Water Safety Planning: Ensuring No One Is Left behind. License: CC BY-NC-SA 3.0 IGO, Geneva.

Who/Iwa, 2017. Global Status Report on Water Safety Plans: A Review of Proactive Risk Assessment and Risk Management Practices to Ensure the Safety of Drinking-Water. World Health Organization/The International Water Association.