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Implementing risk-based approaches to improve drinking water quality in small water supplies in the Nordic region – barriers and solutions

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ABSTRACT

Small water supplies face similar problems worldwide, regardless of ownership or management type. Non-compliance with water quality regulations is more frequent in small supplies than in large ones, as are waterborne disease outbreaks. The new European Union Drinking Water Directive requires risk-based approach (RBA) to secure water safety as is recommended in the World Health Organization's Guidelines for drinking water quality through 'water safety plans'. This is already in regulation in the Nordic countries, although less used in small supplies. In this research, we explore the challenges, barriers and possible solutions to implementing RBA and improving compliance in small supplies. This was achieved by conducting and analysing interviews with 53 stakeholders from all eight Nordic countries to produce recommendations for action by the different implicated actors. Our findings suggest the centrality of governmental policy, including support for continuous training, provision of simple RBA guidelines and increasing cooperation in the water sector. The Nordic experience reflects global challenges with small water supplies and the trend towards systematic preventive management epitomized in the framework for drinking water safety advocated by the World Health Organization since 2004.

Key words: drinking water safety, risk-based approach, small water supplies

HIGHLIGHTS

- Small systems drinking water safety are challenged by staffing, infrastructure and pollution management, single source dependence, and financing. Remote systems also face expertise and supply chain difficulties.
- Cooperation between regulators/surveillance authorities and water suppliers enhances performance.
- Governments should clarify roles and responsibilities of stakeholders in consultation with them.
- Legislation should require training and increase availability of training.
- RBA facilitates cooperation between small water supplies and would be facilitated by easy-to-use RBA form.

INTRODUCTION

The United Nations Sustainable Development Goal 6 (UN-SDG 6) is to achieve universal and equitable access to safe and affordable drinking water for all by 2030. To achieve this, the new European Union (EU) Drinking Water Directive (EU DWD 2184/2020) requires risk-based approaches (RBA) to ensure drinking water quality for supply systems that serve 50 people or more or deliver 10 m^3/day or more. The World Health Organization (WHO) advocates a risk-based management

approach through 'water safety plans' (WSPs) as a component of its Framework for Safe Drinking Water, launched in 2004 and now used in at least 93 countries worldwide (WHO 2004, 2017; WHO/IWA 2017).

Waterborne disease outbreaks and non-compliance with current EU DWD drinking water quality criteria are most frequent in small supplies (Kuusi *et al.* 2003; Hulsmann 2005; Beaudeau *et al.* 2010; Pitkänen *et al.* 2011; EC 2014; Beer *et al.* 2015; Gunnarsdottir *et al.* 2017; Messner *et al.* 2017). The population-weighted average faecal contamination incidence rate in the Nordic region is 11 times higher in smaller water supplies than in larger ones; and of the 47 registered outbreaks in Denmark, Finland, Iceland, Norway and Sweden, in 2010–2014, more than 80% occurred in supplies serving less than 5,000 people (Gunnarsdottir *et al.* 2017).

The eight Nordic countries are Denmark, Finland, Iceland, Norway and Sweden, along with three self-governing nations – the Faroe Islands and Greenland under the sovereignty of the Kingdom of Denmark and Åland under the sovereignty of the Republic of Finland. Åland, Denmark, Finland and Sweden all follow the EU DWD as part of the EU, which is also the case for Iceland and Norway (with the exception of Svalbard) as members of the European Economic Area (EEA). As exporters of processed seafood, the non-EU members – the Faroe Islands and Greenland – are interested in meeting the EU DWD requirements.

In the Nordic countries, the responsibility to enforce drinking water regulation is either with the municipality or several municipalities (Denmark, Finland, Iceland, Sweden) or the government (Åland, Faroe Islands, Greenland, Norway), see Table 2 in Gunnarsdottir *et al.* (2020).

Application of RBA has been required in most Nordic countries for less than a decade, except for Iceland where RBA has been required in legislation for nearly three decades. The requirements for RBA in Nordic country regulations already fulfil the new EU DWD (Gunnarsdottir *et al.* 2020). They apply to ca. 40% of regulated water supplies in the Nordic region that serve around 88% of the population at their place of residence. However, data are sparse on whether and how these requirements have been fulfilled. Based on preliminary information from different authorities, we estimate that 10–20% of mandated supplies, mostly the larger ones, comply with the RBA requirement.

Here, we report research into the barriers and opportunities affecting implementation of RBA in small systems. This was done through semi-structured interviews with stakeholders in all Nordic countries, designed to identify (1) water quality and management challenges; (2) experiences from implementing RBA; and (3) solutions to assist in the RBA process in small water supplies.

METHODS

An interview script was prepared in English comprising general questions and prompts for clarification about water quality and challenges; experiences with RBA in water safety management, barriers and perceived solutions for implementing RBA; and training in drinking water quality protection. The questionnaire was translated into the appropriate local language by the co-author national representative(s) in the project. The English questionnaire is shown in the supplementary material to this article.

Potential interviewees from all Nordic countries were identified at national, regional and local levels. Nationally, we targeted ministries, surveillance authorities and institutions responsible for the supervision of drinking water quality. Surveillance authorities were from national, regional or local levels, depending on the administrative structure of the country. The responsible authority and follow-up on the EU DWD are institutions responsible for food, environment or health. At the local level, our interviewees were from regulated small water supplies, preferably serving less than 500 people on a permanent basis. We also interviewed representatives of associations of suppliers.

Interviewees were sent an introduction to the project and an interview outline after they had agreed to participate. Interviews were conducted mostly via a web-based conference platform, or alternatively by face-to-face meetings or by telephone. Interviews were conducted in the preferred language of the interviewee, recorded and transcribed. Interviewees and supplies have been anonymized.

Thematic analysis was conducted, and codebooks were prepared for each country in English (for comparability between countries); these comprised themes, explanations and illustrative quotes from interviewees. The author group reviewed emerging themes and vocabularies periodically to ensure comparability among country codebooks. Codebooks for each country were analysed independently, then pooled and co-analysed.

RESULTS AND DISCUSSION

A total of 53 interviews were conducted across the eight Nordic countries (Table 1). We interviewed 27 people responsible for delivering safe drinking water. Almost half of these were responsible for multiple small (<500 people) municipal supplies, while a few of medium size (500–5,000) supplies; the other half were operators of a single small supply. The water supplies that the interviewees were responsible for operated in a total of 190 of the 13,000 regulated small water supplies in the Nordic region. In the Nordic countries, 80% of small water supplies harness groundwater (Gunnarsdottir *et al.* 2020). Around 55% of the water supplies participating in this research harness water from groundwater sources (spring, dug well or borehole), and 45% from treated surface water. The 18 authorities interviewed were responsible for external surveillance and supervision of water supplies of a large part of the water sector. The interviews were also conducted with three ministries on legal issues and the implementing process of RBA, and five water supply associations, whereof two were specifically for small and medium size water supplies.

Water quality and management challenges

The themes that emerged in this category fall into two groups: challenges to small water supplies; and training and knowledge-sharing challenges in each country.

Challenges to small water supplies

Six types of challenges emerged from interviews: (1) staff issues; (2) system management issues; (3) surveillance issues; (4) pollution problems at the source; (5) health issues; and (6) cost issues.

Most challenges were mentioned in all or nearly all countries and, when pooled, were of similar concern (Figure 1). Analysis showed that authorities were more concerned about staff issues and lack of surveillance at the small water supplies than were water supply operators, whereas both are relatively equally concerned over other water-related issues such as problems with system management or pollution at the source.

In Greenland, there is an additional challenge related to extending piped drinking water to all dwellings. As one operator in Greenland puts it: '*The goal for the future is to have running water in all the houses.*' This challenge is not shared with the other countries. The supply of drinking water in Greenland is managed by the national company Nukissiorfiit, which is responsible for delivering water to the 52 settlements and 17 towns. Most households in the settlements collect water from a tap house, about 20% have pipe water into the house, but in a few cases, water is delivered to a domestic tank by truck (Hendriksen & Hoffmann 2018; Maréchal *et al.* 2022).

Another additional challenge – language – was mentioned for small water supplies in Åland and Greenland. In Åland the main language is Swedish, whereas official papers are mostly in Finnish and are later translated to Swedish. This can take some time, and some guidelines are only available in Finnish. In Greenland, the official language is Greenlandic and

Table 1 | Participants in the interviews

Country	Ministry[a]	Authorities[b] surveillance/supervision	Association of water supplies	Water suppliers	Total
Åland		1		2	3
Denmark			2	2	4
Faroe Islands		2		3	5
Finland	1	3	1	4	9
Greenland		1		5	6
Iceland	1	5	1	4	11
Norway	1	3	1	4	9
Sweden		3		3	6
All	**3**	**18**	**5**	**27**	**53**

[a]The Ministry in Greenland is also the surveillance authority.

[b]Surveillance authorities of drinking water quality and governmental or regional institutions responsible for supervision and guidance are all included here. Note that the administrative structure varies among the Nordic countries, being either on a governmental, regional or municipal level.

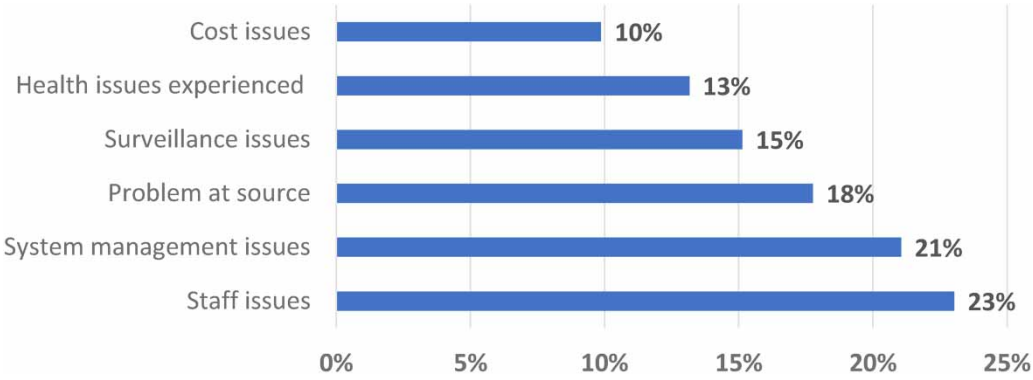

Figure 1 | Challenges facing Nordic small water supplies. The frequency is in the proportion of interviews in which the issue is mentioned.

while all legislation and official guidelines are available in Greenlandic and Danish training material and technical guidelines are often only available in Danish or English.

Staff-related issues, interviewees cited: too few employees; inadequate working conditions; voluntary work and its associated limitations; and gaps in training (e.g. computer skills). One respondent said: '*Personally, I would say that lack of knowledge is the most pressing issue for the small supplies.*' Several researchers have shown the importance of training operators at small water supplies as a key issue in securing water safety (Bowman *et al.* 2009; Hunter *et al.* 2010; Pons *et al.* 2014; Hendry & Akoumianaki 2016). The issue of training emerged in all topics in this research and is therefore discussed separately, under 'Training and knowledge sharing challenges.

System management issues, such as lack of maintenance, inadequate design and seasonality of demand, were often mentioned as challenges for small supplies. For example, in Iceland, it is considered difficult to run a water supply for summerhouse areas (where most dwellings are occupied only at weekends) because '*we need large pipes and storage tanks but are only using them on weekends*'. The same applies to seafood factories, most of which have short periods of high-water consumption that stress treatment facilities, e.g. in Greenland and the Faroe Islands. Remoteness was mentioned as part of system management issues in Greenland, Iceland and Norway, because it creates difficulties in getting assistance regarding water delivery interruption, maintenance and surveillance. '*Small populations in a large country make onsite surveillance difficult,*' states one ministry.

Problems at the source, such as pollution threats, were frequently mentioned as a challenge, sometimes associated with extreme water events such as heavy rain or drought due to climate change as mentioned by some interviewees. '*Like many other places around Sweden, we have in recent years had problems related to drought, including changes in water quality as a result*', said one surveillance authority. Some Nordic countries depend exclusively on surface water sources, which are typically considered more vulnerable to pollution, whereas others can exploit groundwater. However, previous research (e.g. Klöve *et al.* 2017; Lyons *et al.* 2021) has pointed out that groundwater has its own risks in the Nordic region, including source contamination by floods, rainwater or surface water intrusion. Reliance on a single water source was seen as a challenge for many small water supplies. In the Faroe Islands, pollution of surface water sources following heavy rain was a major concern, due to the overloading of treatment facilities. Pesticide contamination of groundwater was mentioned as affecting both large and small supplies in Denmark, and many small supplies rely on a single source and are correspondingly more vulnerable. A study among Danish households shows that 11% of households were potentially exposed to pesticides over 0.1 μg/l in the period 2015–2019 (Voutchkova *et al.* 2021). In Finland, local population growth and increased human activities (snowmobile use, motorized vehicles and burning of waste) were perceived to have increased local pollution around water resources by one of the interviewees. Some places in Greenland rely on seawater desalination by reverse osmosis (RO), which is energy demanding and therefore prevents the establishment of freshwater-demanding industries, such as fish factories.

Surveillance issues: The lack of surveillance and inspection of small water supplies was mentioned by many authorities. '*There are many very small water supplies without surveillance in rural areas,*' according to one surveillance authority, while others reported increasing regulation and bureaucracy: '*It is beginning to feel like there is too much bureaucracy from many sides, so that we are struggling to answer them in the middle of our daily work,*' to quote an operator. These challenges also include a lack of guidelines and support from the authorities, as well as follow-up on incidents and lack of communication.

Other studies have also revealed this need to respond to water quality challenges with practicable solutions, such as a simple template for the small and remote water supplies (Ford *et al.* 2005; Rickert *et al.* 2014; Kot *et al.* 2015), though including all the key elements of RBA of risk assessment and risk management.

Health issues: several interviewees mentioned waterborne outbreaks as a looming challenge. Two surveillance authorities had experienced an outbreak in their district, although other interviewees were sensitized by hearing of outbreaks elsewhere. Sometimes waterborne illnesses due to faecal contamination were suspected without being confirmed or they knew of diarrhoea cases suspected to be caused by contaminated small supplies. Some interviewees considered this a hidden problem and complained about the lack of follow-up and reporting of faecal contamination to the district physician and the health authority. Endemic or sporadic illnesses are greatly underreported, and go unnoticed by the health surveillance system, especially in the smallest supplies and there is a need for improved connectivity between water quality and medical tracking (Ford *et al.* 2005; Hrudey & Hrudey 2014). Several interviewees stated that health should be the main focus of water supplies and emphasized the importance of learning from mistakes.

Cost issues and insufficient financial resources for maintenance, renovation and upgrading underlie several of the reported challenges facing small supplies. '*We need new equipment and better water pipes and have few users to cover the cost,*' maintained one operator. '*It is expensive to build a good water supply, and lack of investments over time will increase contamination risk,*' said another. Financial issues have appeared in other research studies, such as in a survey of 350 small water supplies in Midwestern USA (Dziegielewski & Bik 2004). Their comments about water rates focused on chronic under-pricing of water services, often driven by local decision-makers seeking to keep rates low and the resulting inability to raise adequate funds for infrastructure renewal in small systems, or the use of water system revenue for other community needs in municipal water supplies.

Training and knowledge sharing challenges

In the interviews, the topics of training and knowledge sharing were raised and discussed under various themes, revealing similarities and differences in the status of training and the feasibility of knowledge sharing at various scales.

Regulations in Greenland, Iceland, Norway, the Faroe Islands and Sweden do not require formal education (or a specific qualification) for operators of a water supply. Specific themes mentioned within 'training' included increased training demand and the inclusion of risk assessment in training. For example, in Norway, a short 1-week course was suggested for operators of small water supplies.

Knowledge sharing, through national associations and working with neighbouring supplies, was considered very helpful. As one operator put it: '*People need to look at how others have done it.*' In our previous research, we estimated that around 27% of regulated water supplies in the Nordic region are participants in a national water association (Gunnarsdottir *et al.* 2020). Denmark and Finland have specific associations for small supplies, which were considered beneficial. Elsewhere, few small water supplies participate in national associations, which are dominated by larger systems. Creating a forum for small supplies within such associations was suggested. The large-sized and medium-sized water supplies in the Nordic countries are mainly municipally owned, whereas the small systems are most often user-owned or cooperative, both with a non-profit approach (Pietilä *et al.* 2009). Perrier *et al.* (2014) interviewed 15 small water supplies in Alberta, Canada, and concluded that RBA can act as a bridge for communication between stakeholders and thereby facilitate communication about water supplies.

The country-by-country training and knowledge sharing situation, derived from interviews, is as follows:

In **Åland,** the main challenge in training is language, including scarce training opportunities because all training is in Finnish while the mother tongue of the islanders is Swedish. This underlies a lack of accredited personnel in the country. Operators have basic knowledge and seek to expand this online and in personal interactions with, e.g. the authorities. There is no national association for water supplies and because of language constraints, the only major relevant event for knowledge exchange is held by the Swedish Water and Wastewater Association. '*We are finding it difficult to attract competent staff with adequate training*', stated one operator. The suggested ways forward were to increase the availability of training locally, through the promotion of training material and guidelines in Swedish.

In **Denmark,** it is compulsory to have a certificate in elementary hygiene to run a water supply. Small water supplies are usually owned by the consumers in a cooperative association, run by a board elected at a general assembly as part of local democracy. The association for small water supplies is the Danish Water Works (DVV). DVV has been active for more than 40 years and has around 1,900 members, collectively serving 38% of the population. The association offers a 3-day course in

hygiene in water supply, while the association for large supplies (DANVA) also offers courses. Operators seek knowledge from these associations, which provide materials and courses on subjects related to water supply, e.g. an easy-to-use RBA template from DVV. DVV also provides daily on-demand telephone consultancy. Small suppliers also seek knowledge from the municipalities, which are the authorities responsible for surveillance. Interviewees suggested training could be improved: adding minimum length and quality of training to legislation, especially for RBA; improving online training; and use of instructional videos. '*I think that the requirement for training in legislation could be tightened*,' said one operator.

In the **Faroe Islands,** no training courses are available, and more training is needed. Sometimes supplies get new equipment without being trained in its use (an example given concerned UV treatment). The Food Authority held a course on the then-new water regulation in 2013. Operators seek knowledge from the Internet, from colleagues at other supplies – mostly the larger ones – and from authorities. It was suggested that the Food Authority should deliver regular water-related courses. There is no national water supply association in the Faroe Islands, and it was suggested that more collaboration among supplies was needed and should be fostered.

In **Finland**, public health act defines that the water supply has to have a hygienic competence certificate renewed every 5 years (11.11.2016/942, §20b). Considering RBA, training is available but is not mandatory. An RBA manual and instructional videos are available on the website https://wspssp.fi/Wsp/Content/documents/help.html. Training and a pilot programme are considered to have improved attitudes towards RBA. The National Supervisory Authority for Welfare and Health (Valvira) arranges training. Interviewees reported that water supply training improves skills in securing hygiene during maintenance, but RBA training could be improved. A great deal of material is available online, although some RBA material is intended for larger supplies. Out of more than 800 small water supplies in Finland, most are cooperatives. The Association of Finnish Water Cooperatives (SVOSK) was established in 2009 and now has 120 members – and this number is growing. Its stated purposes include strengthening know-how and promoting cooperation. The Finnish Water Utilities Association (FIWA) is primarily for the large water supplies, which are active on RBA questions, as in Denmark. Based on the interviews, there is generally good support from the local surveillance authority, especially to the small supplies from the technical office of the municipality for technical matters. Where remoteness is an issue, some interviewees suggested that RBA training should be updated and delivered nearer to the cooperatives, or as one operator put it: '*Having training nearby would attract participants.*'

In **Greenland,** both remoteness and language provide special challenges. There is only one large state-owned water supply company, Nukissiorfiit, which is responsible for all training, and one government institution responsible for surveillance. The remoteness of some settlements makes visits from the government surveillance authority infrequent to non-existing, limiting direct knowledge transfer. The language issue arises within Nukissiorfiit because settlement level operators mainly speak Greenlandic while head office personnel speak Danish and training material and instructions for operation are often only in Danish. However, regional team leaders in the towns speak both languages and train operators face-to-face when visiting settlements. Nukissiorfiit head office organizes monthly update meetings with team leaders. Access to training in settlements is uneven, with one respondent mentioning that they took a training course which was helpful, but '*could be renewed*', while two others reported '*we do not get any training or courses about water in the settlements*'. Operators seek knowledge from their team leaders at the regional or head offices. With the new regulations that align with the EU DWD, Nukissiorfiit has plans for future education and technical training in RBA.

In **Iceland,** there is no requirement in the drinking water regulation for training and education of staff of water supplies in hygiene and preventive management. There is currently (2023) no training available, although a comprehensive training program for operators ran annually until 2012 and included RBA training initiated by the association. There are open-ended requirements in the Food Act (93/1995) that staff shall have knowledge of handling food and that managers of food companies are responsible for providing training. While this applies to water supplies – because drinking water is defined as food in the Act – this has not been followed in the water sector. Few interviewees knew of these requirements. Operators of small supplies mostly seek knowledge from the surveillance authority, through talking to their colleagues at other supplies, and on the Internet. Samorka (www.samorka.is), the association of water suppliers, has published a Water Supply Handbook including an RBA template for small water supplies. However, small water supplies are rarely members of the association. Access to the handbook is open to all, but it is difficult to access and does not come up in online searches. Interviewees suggested that education and training be stipulated in the regulation, along with producing learning material, providing new courses – e.g. on the Internet – and establishing a web-based cooperation platform and forum for operators of small supplies.

In **Norway,** water suppliers are responsible for training through regulation which requires 'sufficient competence' from operators, but like the Icelandic situation, this is not further specified. One surveillance interviewee maintained: '*The paragraph in the legal framework about knowledge is a dead paragraph and it is almost impossible for me to monitor their level of knowledge on my visits.*' The association Norwegian Water runs 3-week courses for its members that many operators have attended. However, most small suppliers are not members of the association, limiting their training possibilities and access to newer reports. There is no training provided by the authorities (governmental or regional) and the information available on the Norwegian Food Safety Authority website was described as very difficult to find. The authorities try to educate during surveillance visits, but there is often insufficient time. Tailored training for small supplies is deficient. Additional challenges are how to reach smaller supplies and how to cover costs. The suggested way forward for training is to improve courses, adapt them to small supplies and include online versions. Guidance, an organized webpage, and information on who to contact for questions are also desirable. Interviewees were not specific about who should provide the training.

In **Sweden,** there are no formal requirements for education or training of operators and little training is available, except by the Swedish Water and Wastewater Association, which provides courses and guidance to its members. These were considered to be good and are available to everyone working in the field. Information is also available on the website of the Swedish Food Agency on specific legal and administrative aspects of drinking water supply and control. In general, municipalities focused on surveillance and were largely inactive in training and information provision. Operators of small water supplies seldom use the available education opportunities due to lack of funds, although they are open to anyone. Instead, they seek knowledge through contact with the authorities or their websites. To improve the situation, interviewees suggested making courses mandatory, ending with a test and to increase online access.

RBA – The new EU DWD and experience gained

The new EU DWD

The new EU DWD (EC 2184/2020) requires the application of RBA in water supply systems except for '*water intended for human consumption from an individual supply providing less than 10 m^3 a day as an average or serving fewer than 50 persons*' (Article 3.2b and 3.6), allowing that '*Member States may exempt water suppliers supplying between 10 and 100 m^3 a day on average or serving 50–500 people from the requirement to carry out risk assessment and risk management requirements of the supply system, provided that authority is satisfied that such an exemption would not compromise the quality of water intended for human consumption*' (Article 9.6). Monitoring of small supplies is also increased in the new Directive.

Many (79%) of interviewees were aware of the new EU DWD requirements and water suppliers often indicated that RBA would be easy to implement because it is already mandatory in the countries and experience has been acquired. As one interviewee said, '*I do not think that risk-based approach is a problem for small water supplies in Denmark, we are so used to it.*' The remaining (21%) interviewees, equally distributed between water supply staff and authorities (according to the number of interviews), had received no information on the new EU DWD.

The main concerns expressed by the authorities were that RBA was not adapted to the small supplies, and the demand for increased monitoring would increase costs – for instance, in the Faroe Islands '*increased sampling is likely to lead to more expensive water*'. It was suggested that parameter selection and sampling frequency be adapted to local circumstances.

Some issues with the application of the Directive were raised. These included the Directive not demanding training, specification of responsibilities – who is to do what and inadequately reflecting the long timeframe of groundwater chemical pollution: '*The protection strategy and geology we have is not reflected in the Directive,*' according to an interviewee in Denmark.

Experience gained with RBA

The main themes from the interviews concerning RBA experience already gained, including support, barriers and consequences are summarized in Figure 2.

Experiences from RBA were often stated, e.g. having public health as the main focus. For example, in Denmark, one reason identified for success with RBA was lessons learned following a large waterborne outbreak in the town of Køge in May 2010 (Vestergaard *et al.* 2007; Gubbels *et al.* 2012). The same was the case in Finland, because responses to the waterborne outbreak in the town of Nokia in 2007 (Laine *et al.* 2011) enhanced the implementation of RBA and initiated a pilot project that was repeatedly referred to positively in interviews. The authorities interviewed primarily reported good experience with RBA: '*My experience is that as soon as this RBA is used then there are results.*' Similar positive experiences were obtained

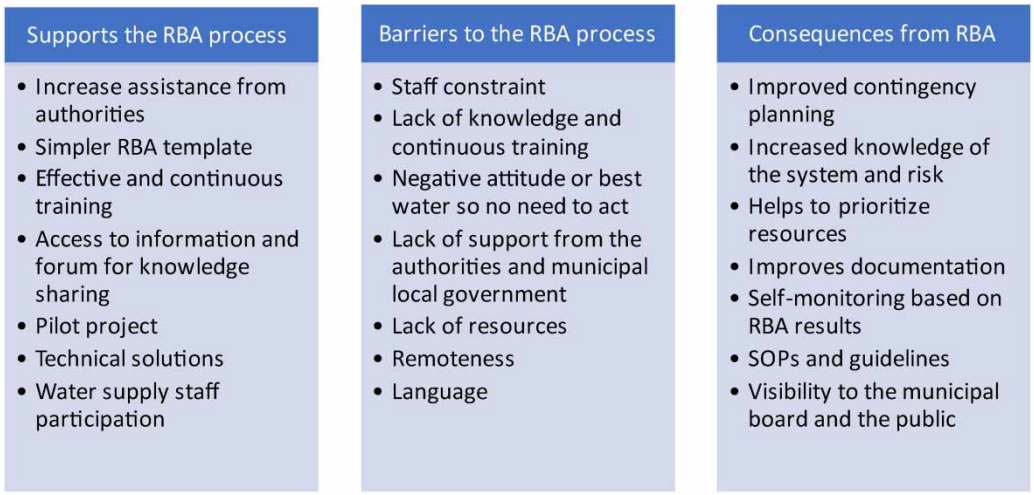

Figure 2 | Interviewee-identified factors identified as supporting or impeding implementation or describing consequences of the RBA process applied to small systems (SOPs, standard operational procedures).

elsewhere. '*They do not have to rely on memory as it is all documented*' and '*In this process, I learned a lot of things and how to think differently in water-related issues*', as recalled by interviewees in Iceland and the Faroe Islands, respectively.

Support for the RBA process mentioned was multiple. Water supplies which had received templates and assistance from the association of water supplies or the authorities often described these as helpful. Most interviewees emphasized training and platforms for sharing experiences as supportive, some noting that RBA is inherently a learning process. Finnish authorities launched an RBA pilot project that was considered helpful by interviewees. Technical solutions giving alerts if something fails were also considered helpful. Remote monitoring, which gives the ability to control and adjust processes far away, was mentioned by some interviewees as a helpful tool when people and time were limited. As one operator in the Faroe Islands explained: '*For example, alarms are triggered when UV efficiency drops below the threshold limit or water consumption unexpectedly increases that could be a signal to a broken pipe.*' Involvement of water supply staff in the process was described as essential: '*When consultants do all the work, no learning or ownership is achieved on how to work in a risk-based setting,*' according to an operator in Faroe Islands. The importance of an enabling environment for implementing RBA has also been emphasized by Baum & Bartram (2018), while Schmoll *et al.* (2011) noted that small water supplies especially benefit from external support.

Barriers or hindrances to implementing RBA that were most often mentioned were staff related: insufficient staff and insufficient training associated with a weak understanding of risk (58% of mentioned hindrances). This is coherent with the challenges faced by small-scale supplies (see the section on Water quality and management challenges). A water supply operator that had recently implemented RBA said, '*Probably staff constraint is the main reason for not being able to implement RBA in small water supplies,*' and '*We can see RBA function if staff of three in the water supply, [but] if less not working*', while a slightly irritated surveillance inspector commented on slow RBA progress in the local area: '*The main obstacle is lack of staff and in some cases lack of education and knowledge. The operators think it will be too much work, which is not true. They have the template and can start to fill in. I do not understand the barriers. They got the template free of charge and are still not doing it.*'

Attitude hindrances were sometime mentioned as a barrier: '*I am not sure that RBA will improve the situation, [I] cannot see what it is supposed to improve.*' The notion that drinking water has always been good can also be a barrier: '*The old attitude that our water has always been good, and nothing can happen to it, has been the biggest reason slowing RBA implementation in the small supplies,*' was stated by one ministry interviewee. Similarly, the notion that clean water is abundant in nature may detract from user engagement and willingness to pay.

The initial steps of the implementation were often considered difficult without external assistance and easy-to-use guidelines. Local government and the local population can pose a hindrance. One operator described local government hindering the start-up of RBA, though he had repeatedly tried to get support; while another cited good local government support fostering success with RBA for 14 years: '*RBA is just an advantage, so I see no obstacles in implementing it.*'

Cost was mentioned several times by an operator as a hindrance to implementing RBA, though mostly in terms of increased sampling and new parameters in the new EU DWD: '*By not only increasing the frequency but [also] the number of parameters, the costs are likely to increase*' and '*The certainty of water quality comes with a price tag, and I don't see that by increasing sampling we achieve any added value*'. Remoteness and language challenges were identified as barriers to RBA.

Several consequences, some unexpected, were identified. For example, RBA was seen to increase security, especially through emergency preparedness and contingency planning for a high-risk water source. It also assisted in planning of monitoring: '*This risk-based approach should enable tailor-based testing plans,*' said a Swedish operator. RBA was considered helpful when prioritizing improvements to high-risk parts of the system and explaining/justifying necessary expenses to the local government and the population. RBA was described as improving documentation and the resulting standard operational procedures (SOPs) were considered beneficial. Also, RBA increased visibility in the community through information and transparency; led to staff being more interested in their work; and helped staff think outside daily routines. '*I can see that the people who work with RBA get more interested in their work,*' noted a surveillance authority in Norway.

In a new study by Herschan *et al.* (2023) on an RBA requirement in regulations and challenges regarding drinking water quality faced by private water supplies (mostly small water supplies) in England and Wales, a similar result was found to that in this study – that RBA increased awareness and the understanding of risk; that tools need to be more tailored to the private water supplies; and that cooperation between the supplies was helpful in the process. Similar to this study, in England and Wales a barrier to success with RBA was a lack of human resources and financial support.

RBA and water quality solutions for small water supplies

The solutions suggested to enhance the use of RBA and to improve water safety at the small water supplies fall into five interacting categories, each comprising several related factors. These factors were almost equally mentioned as solutions by interviewees. They are: (1) simpler and easy- to-use RBA forms together with increased support in the implementing process by the authorities; (2) improved governance and governmental policy for safe water; (3) improved water supply systems and infrastructure; (4) increased training availability, demand and learning; and (5) facilitate cooperation among or the merging of small water supplies (see Figure 3).

(1) Simple and easy-to-use guidelines, accompanied by assistance from the authorities in the implementing process, are claimed to be one of the important keys to success in implementing RBA in small water supplies. Where it had been provided, it was claimed very helpful. Standardized sanitary inspection (SI) forms are used in some countries and can be further developed into RBA. SI was mentioned in interviews in Finland, Iceland and Norway. Such forms comprise checklists of sources of, vectors for and protection against pollutant intrusion (Kelly *et al.* 2020). Iceland has recently

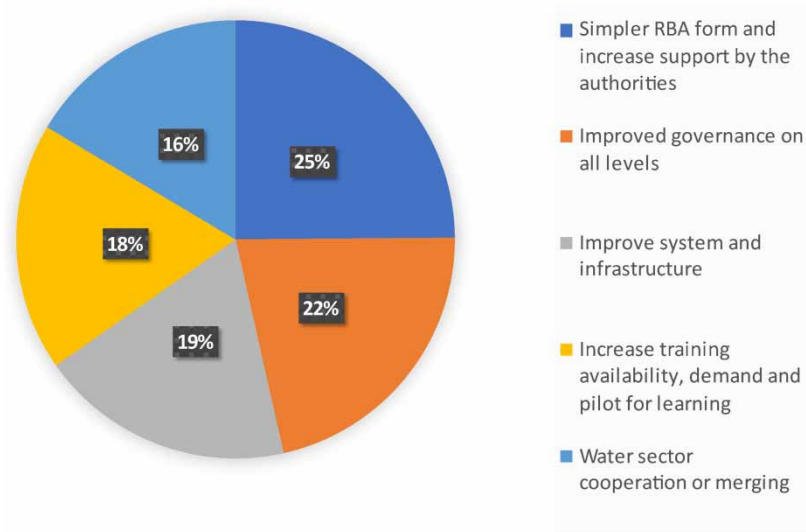

Figure 3 | Responses (solutions) suggested by interviewees for small water supplies. The frequency of mentioning these solutions is given in percentages.

adapted SI forms from WHO to Icelandic conditions; these are now used during the inspection of small water supplies by several surveillance authorities (King *et al.* 2022). We argue here that SI forms can be usefully standardized and better developed by pooling experience across many systems, and that while they are a component of 'template RBA' management, they are not a complete response to the expressed demand for this. As also stated by Pond *et al.* (2020) SI is a first step in RBA and helps to identify hazards and hazardous events. However, if the level of risk and likelihood is not estimated it is difficult to prioritize action.

(2) Improving governance on all levels appeared clearly as a need from the interviews. Within the 'governance and governmental policy' theme, many interviewees mentioned the need for explicit governmental policy, of a funding programme to improve small water supplies, for flexible and simpler legislation and for practical guidelines (e.g. on boil water advisories). Improving surveillance and inspection was emphasized by both authorities and operators. Specific recommendations included actively informing suppliers about legislative requirements and increasing communication in general. '*It would be brilliant to have a website with information for the public, the surveillance authority, and the water supplies,*' said one ministry interviewee. Increased efforts to support the implementation of legislation were suggested by an operator in Sweden: '*While legislation is clear, the problem lies in making sure that smaller water suppliers comply*.' To encourage application, governmental authorities can adopt coercive and/or facilitating and motivating approaches, with suggestions of both cited in interviews. Coercive approaches are often (Ernhart & Glicksman 2015) considered less applicable to small supplies, especially where volunteer staffing predominates; nevertheless, the mandate and capacity for auditing and follow-up on the functionality of RBA in the legislation were cited as important.

Specific suggestions concerning grants or subsidies following the outcome of RBA included reduced value-added tax for system improvements (new water sources, system renewal, technology updating and automation). '*There must be some subsidies or discounts available for the small supplies to be able to invest in infrastructure, as is in place for improving sewage systems where there is 20% refund of value-added tax,*' said an operator in Iceland. Notably, however, some interviewees referred to insufficient financial and staff resources to cope with all water quality issues at the authorities, which should provide support. One Swedish operator said: '*We believe it is important that the Swedish Food Agency has a sufficient number of staff working on drinking water issues.*' Further governance recommendations included the need for the authorities to collaborate and coordinate toward a common approach in guidance and surveillance.

(3) To improve design and to renew and upgrade systems were almost exclusively suggested by water supply operators and associations. Supported by subsidies in some form as described in the previous paragraph would enhance that process. They were largely related to infrastructure improvement, reflecting the proximity and concern of operators of often old or out-dated infrastructure and equipment. The suggestions for system improvement concerned the raw water source (Faroe Islands and Iceland), improved infrastructure or regular maintenance (Finland and Denmark) or improved treatment (Åland, Greenland and Norway). Improving source water protection and increasing raw water storage capacity were also suggested.

Most small water supplies in Denmark are fully automated and can be managed remotely, which proved very beneficial during the COVID-19 pandemic. In Greenland, new modular treatment systems that have been recently installed in some settlements show considerable benefits. The systems can be monitored from the head office in Nuuk and are credited with reducing boil water advisories by 86%, from over 2200 local daily warning per year to just over 300 local daily warnings per year, from 2016 to 2020 (Maréchal *et al.* 2023). Greenland's Nukissiorfiit is also working on having a small stand-by mobile RO unit in a 6-foot container, which can be airlifted to supply emergency water from sea water in case of water contamination (Jensen *et al.* 2022).

(4) Increasing training demand and availability followed by pilot projects were recurring suggestions. Finnish interviewees mentioned the utility of pilot projects. In Finland, several small supplies implemented RBA in an authority-led pilot project. Positive feedback from the participating supplies was cited: a regional authority noted, '*I feel that through the pilot project, the role of RBA comes in positively and in an encouraging way,*' while an operator claimed that '*this project has provided support and has been outstandingly good*'. This positive experience with pilot projects, which increases access for stakeholders (decision-makers) to directly relevant experience is congruent with the theory of diffusion of innovation (Rogers 2003) and provides a well-understood early-phase approach to increasing adoption and application of RBA.

(5) Several respondents emphasized merging or some form of cooperation of the small water supplies as the main solution, such as one in Iceland who maintained that '*the most important thing for the small water supplies is cooperation*'. Various interviewees perceived that increased cooperation between the small cooperatives, e.g. by administrative merging, would lead to improvements such as increased staffing, improved working conditions, having more time for training, being able to invest in boreholes and better water intakes, facilitating implementation of RBA and being better prepared for emergencies and emerging challenges such as COVID-19 and climate change. Denmark and Finland have a long tradition of water cooperatives (Takala *et al.* 2011), which was mentioned as providing an advantage in these countries since it is considered to provide an atmosphere akin to democracy and active participation of owners in the decision processes.

CONCLUSIONS AND RECOMMENDATIONS

Small water supplies are numerous in the Nordic region. Although only serving a minor part of the population on a permanent basis, they are used intermittently by large numbers of people (Gunnarsdottir *et al.* 2020). Small systems are disproportionately associated with contamination and non-compliance with regulations. We therefore explored the challenges, barriers and possible solutions to implementing RBA and improving compliance in the small supplies.

Our research reveals specific challenges to ensuring safe drinking water in them. The most prominent of these are staff issues (e.g. because many of these water supplies rely on volunteers); management of the infrastructure system; and dealing with pollution threats, especially at the source, including reliance on a single source. These are aggravated by remoteness and insufficient contact with the surveillance authority for guidance and testing. Training emerged as a major theme region-wide, because opportunities tailored for small supplies are sparse, except in Denmark and Finland.

Operators of the small water supplies are often isolated in their work and are seldom members of professional groups. Often their principal professional contact is with the surveillance authority. In Denmark and Finland, there are dedicated associations for small water supplies that are considered supportive whereas Åland, the Faroe Islands and Greenland have no national association for professional knowledge sharing. In Greenland, however, there is one state-owned company responsible for all water supplies. This presents a specific opportunity for using the regular monthly meetings for training or knowledge sharing between team leaders and operators in the settlements.

The improvements that are deemed to be most important to enhance the use of RBA are authority-supported endeavours to help the supplies in their first steps, as well as with simpler requirements and an RBA template; improving government policy; training; and more cooperation in the water supply sector. The three actors are therefore the government deciding on the policy and legislation, the surveillance authority and the water sector – including the national associations. The following recommendations are for each of the actors that appeared in the interviews.

The government, in consultation with stakeholders, should formulate a policy to secure safe water for all according to the new EU DWD and the UN-SDG 6. It should include motivation for action and minimum legislative requirements for RBA. This was the pressure needed to implement RBA for one of the small water supplies interviewed: '*The motivation was that we did not get an operating license without RBA*.'

Recommended actions at a governmental level are firstly, to ensure that legislation identifies clear requirements and responsibilities, including the requirement to sustain adequate, accredited staffing, the requirement to have RBA in place before an operational licence is issued; and the requirement that operators receive initial and periodic training and are potentially accredited; accordingly. Secondly to provide appropriate incentives for improvements, such as tax reduction.

Government policy about the safety of small water supplies is necessary and may be either free standing or embedded within policies concerning small communities in general or water supply in general or elsewhere. However, it is organized, and important inclusions relate to a national framework for training adapted to the specifics of small systems. The surveillance agencies should report periodically, for instance annually, to government on status, trends and major issues in small system water safety. Technical support to small system operators may be provided through surveillance authorities (with some risk that they both assist operators and judge their sufficiency) or by others such as local government or professional associations. Technical support should include the provision of small system-adapted RBA procedural guidelines and organization of systems for knowledge exchange. Our work highlights the benefits of pilot or 'demonstration' projects at the early stages of country-wide RBA implementation and these should be supported accordingly.

Surveillance authorities are important actors in securing safe water. Our work shows that they are often the only professional contact for operators. It is important to increase communication between the small supplies and the appropriate

surveillance authority, since this dialogue is seen as a key part of implementing RBA. The feedback from the supplies is that they should not be left alone with RBA and that support is needed. To succeed in the process, various aspects were considered essential: easy-to-use guidelines and templates in a language suitable for the people working with them; making the guidelines available online; and training. When support is provided, the supplies give positive feedback from the process and can see why RBA is beneficial. '*We are lucky to have an authority that is skilled and willing to co-operate,*' cites an operator in Finland.

Recommended actions on the level of surveillance and supervision are to increase communication; provide guidance, including a simple template; improve data collection and information exchange; initiate pilot projects in cooperation with the national association and small water supplier; improve cooperation between the surveillance authorities; and coordinate demand to supplies.

The water sector and the professional associations have a potentially catalytic role to play in improving the water quality from the small supplies. However, only a very small fraction of the 13,000 Nordic small water supplies are members of national associations, and most such associations are oriented substantively towards the distinct issues and concerns of larger supplies.

We recommend efforts to include small supplies, for example, through an interest group or forum in an established national association or led by pioneers of RBA in small supplies, or by the establishment of specific associations of small supplies.

Overall, the small water supply systems are not as safe as they should be and have distinct challenges that need to be addressed. Their challenges differ from those of larger systems and are more similar to small systems elsewhere.

Our findings are relevant to the Nordic countries, across the EU and likely elsewhere including low-, middle- and high-income countries worldwide because small systems are confronted with similar issues worldwide. The new EU DWD provides pointers as to how that situation could be improved with a RBA. This research identifies specific barriers and opportunities and based on them we recommend practical achievable actions that have the potential to substantively improve drinking water quality at the small water supplies.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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