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Adapting sanitary inspections for the monitoring of small drinking water supplies in Iceland

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ABSTRACT

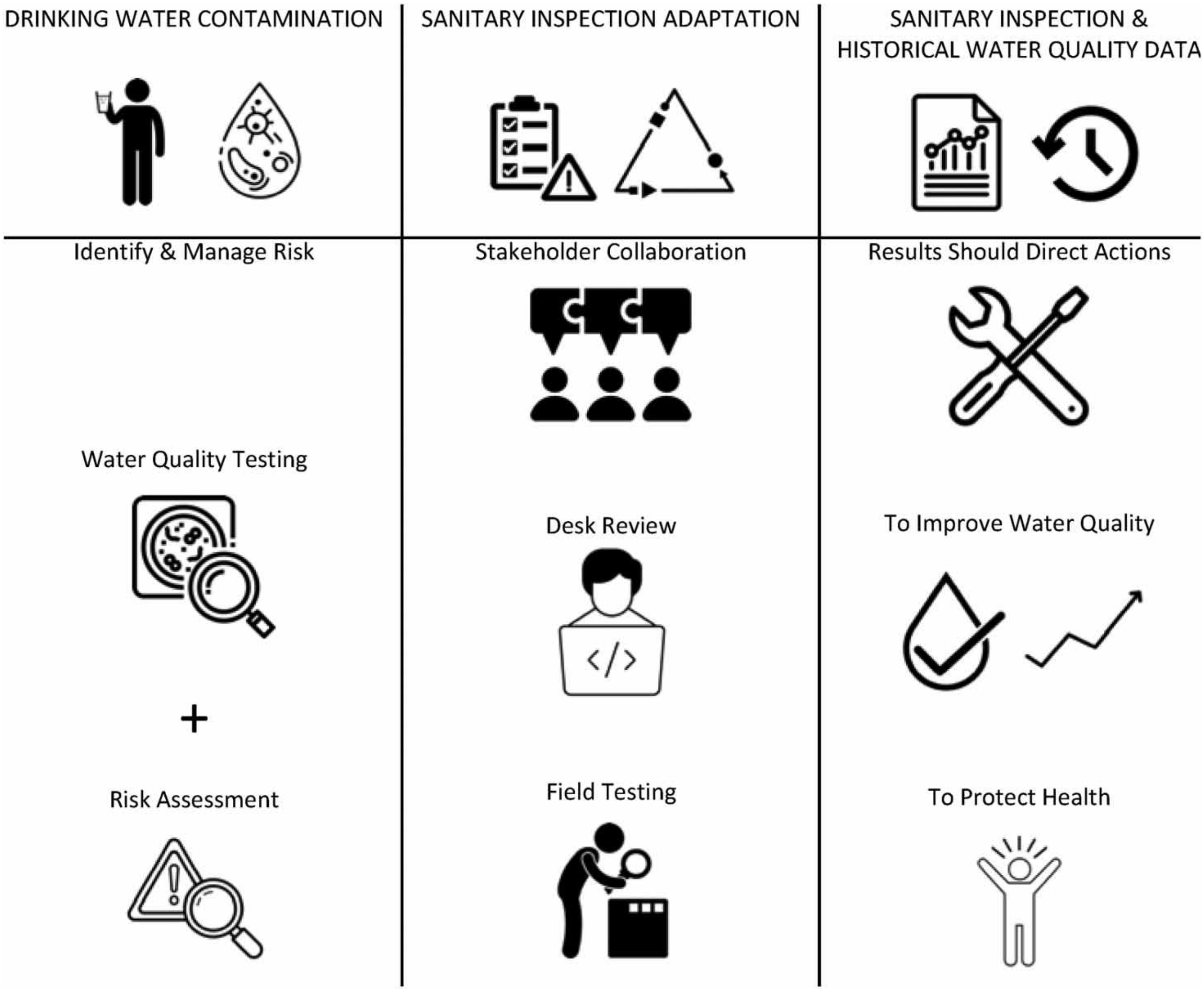
Sanitary inspections (SIs) are checklists of questions used to identify actual and potential sources and pathways of drinking water contamination. Though the importance of SI adaptation to local contexts is widely acknowledged, there is currently limited guidance on how this should be undertaken in practice. During this research, World Health Organization (WHO) draft template SI forms for spring and borehole supplies were adapted for use in Iceland based on a series of desk reviews and field tests, an approach which may guide other future SI adaptation processes. SI results were collected from 25 spring supplies and nine borehole supplies in three regions of Iceland using adapted SI forms. These results were combined with 10-year historical water quality data from the same supplies to explore potential relationships between both data sets. Binary logistic regression test results indicated a statistically significant association ($P = 0.025$; odds ratio (OR) 1.864, 95% CI 1.080–3.220) between SI Question 3 (*Does ponding from surface water occur around the spring/borehole?*) receiving a 'High' risk level assignment and at least one historical incidence of water quality noncompliance for the parameters heterotrophic plate count 22 °C, total coliforms, *Escherichia coli*, and turbidity at the same supply. The significant modifications applied to the starting template during the testing and development of the Icelandic SI form emphasises the importance of a robust adaptation process to ensure SI forms are appropriate for the local context. Results from the analysis of SI and water quality test results demonstrated the potential for these data sets to identify the primary risks at a supply. This information may then be used to direct remedial actions, especially when the amount of relevant data increases over time.

Key words: adaptation, developed settings, development, risk assessment, sanitary inspectors

HIGHLIGHTS

- Development of an approach for adapting template drinking water SI forms to a local context.
- Analysis of the relationship between current and historical water quality test results and SI results.
- Demonstration of a statistical approach to link water quality test results' noncompliance and the presence of individual SI risk factors.

GRAPHICAL ABSTRACT



INTRODUCTION

The European Union (EU) defines small drinking water supplies as those supplying less than 1,000 m^3/day or serving less than 5,000 persons (EC 2014a). Common within rural communities throughout Europe, there is an estimated 85,000 small supplies in the EU providing drinking water to approximately 20% (65 million citizens) of the population (EC 2016). Small drinking water supply types such as springs and boreholes are often susceptible to contamination for a number of reasons, including limited levels of knowledge among operators; lack of investment; and, in some countries, less consideration within drinking water legislation compared with large supplies (Rickert *et al.* 2016; McFarlane & Harris 2018). Across Europe, countries report greater water quality testing compliance in large supplies compared with small supplies (EC 2014b; Gunnarsdottir *et al.* 2016). Limited available water quality data indicate levels of compliance to national drinking water standards averaging at 60% for microbiological parameters in small supplies in the EU (EC 2014a).

The safety of water intended for human consumption from small supplies in the EU has traditionally been managed by setting minimum quality standards along with requirements for monitoring (EC 1998); however, the World Health Organization (WHO) (WHO 2004) recommends water quality testing and risk assessment be undertaken as complementary activities, where possible. On 16 December 2020, the European Parliament formally adopted the revised Drinking Water Directive 2020/2184 (DWD), which entered into force on 12 January 2021. The DWD states the new requirement for a mandatory risk-based approach to drinking water safety for supplies of all sizes and regulations which includes risk assessment and risk management of the catchment area(s) for the abstraction point(s) of water intended for human consumption; risk assessment; and risk management for each water supply system that includes the abstraction, treatment, storage, and distribution of water to the point of supply carried out by the water suppliers; and risk assessment for domestic distribution systems (EC 2020). The recast updates will improve the coherence between the DWD and the EU Water Framework Directive (WFD) by establishing the risk-based approach to water safety from abstraction to tap, consistent with the WHO's Water Safety Plan (WSP) 'catchment to consumer' approach (EC 2018).

WSPs have been advocated by the WHO since 2004 as best practice for ensuring the supply of safe drinking water using a comprehensive risk assessment and risk management approach (Bartram *et al.* 2009). Though WSPs are typically employed in large supplies with adequate resources for WSP implementation, simple or 'introductory' WSPs for small supplies have also been trialled successfully in many countries, including Iceland (Gunnarsdottir & Gissurarson 2008), Romania (Samwel *et al.* 2010), and Finland (Hendry & Akoumianaki 2016). Despite the guidance available for risk-based management approaches in small water supplies (Hulsmann & Smeets 2011; Rickert *et al.* 2014), even simple WSP implementation may be challenging for such supplies, especially those with limited resources (Gunnarsdottir *et al.* 2012).

A sanitary inspection (SI) is a fundamental element of a WSP (Pond *et al.* 2020) often used in the hazard identification and verification stages to identify the presence or absence of contaminant pathways, actual and potential sources of contamination, and breakdowns in barriers to contamination (Kelly *et al.* 2020). SIs may also be used as a standalone tool for the surveillance and/or monitoring of small supplies. Though typically presented as a set of equally weighted Yes/No questions (where a Yes response indicates the presence of a risk factor), different SI scoring methods using pre-weighted questions or risk matrices may also be employed depending on the desired SI output, and the level of inspector capacity in a given context.

The widely-used SI templates presented in WHO (1997) include distinct point-source supply types (such as springs and boreholes) and methods of storage and distribution commonly associated with developing settings. Though suitable for direct use in certain circumstances, WHO (1997) recommends adapting SIs to a regional or local context. There is, however, currently limited practical guidance on undertaking this activity, which may result in the WHO SI forms being incorrectly applied in a given context without adaptation to the local setting. Kelly *et al.* (2020) reviewed 25 studies investigating the relationship between water quality and SI, of which at least 48% used WHO SI forms without modification. Bain *et al.* (2014) examined 44 studies that used SI forms, of which 27% used WHO SI forms without modification. Where SI forms are adapted, it is difficult to quantify the impact or appropriateness of the adaptation being undertaken.

As a result of the continued and increased emphasis on the importance of a risk-based approach for ensuring the safety of drinking water supplies, there will soon be a growing requirement for a large number of health authorities and water supply operators/owners in Europe to undertake risk assessments on small supplies without prior experience of doing so. In such cases, SIs offer an easy-to-use and flexible approach to risk assessment in small supply settings. Given SIs are most effective when adapted for local conditions (Pond *et al.* 2020), and considering the WHO (1997) SI form templates are designed with a focus on developing settings, this research had the following two objectives: (1) to document the development of a customised SI form for the surveillance of small drinking water supplies in developed settings, specifically, small supplies in Iceland and (2) to determine how analysis of SI and water quality test results may be used together to contribute toward the effective management of small supplies.

METHODS

To investigate the research objectives, the study design was divided into the following two distinct activities: (1) adaptation of a draft WHO template SI form based on desk review and field testing in Iceland and (2) analysis of SI and water quality test results taken during an inspection of 25 spring supplies and nine borehole supplies in three regions of Iceland. An overview of the study design is provided in Figure 1.

SI form adaptation – starting template, study area, and research team

During the study period, the WHO was revising the 1997 *Guidelines for Drinking-water Quality, 2nd edition: Volume 3 – Surveillance and control of community supplies* (WHO 1997) to reflect the current and best practices relevant to the safe management of small drinking water supplies. As this task also included a revision of the suite of SI forms contained within the guidelines, a draft WHO spring SI form was used as a starting template (Version 1) in this study for adaptation to the Icelandic context. The spring SI form was specifically chosen as the primary source type for adaptation in this

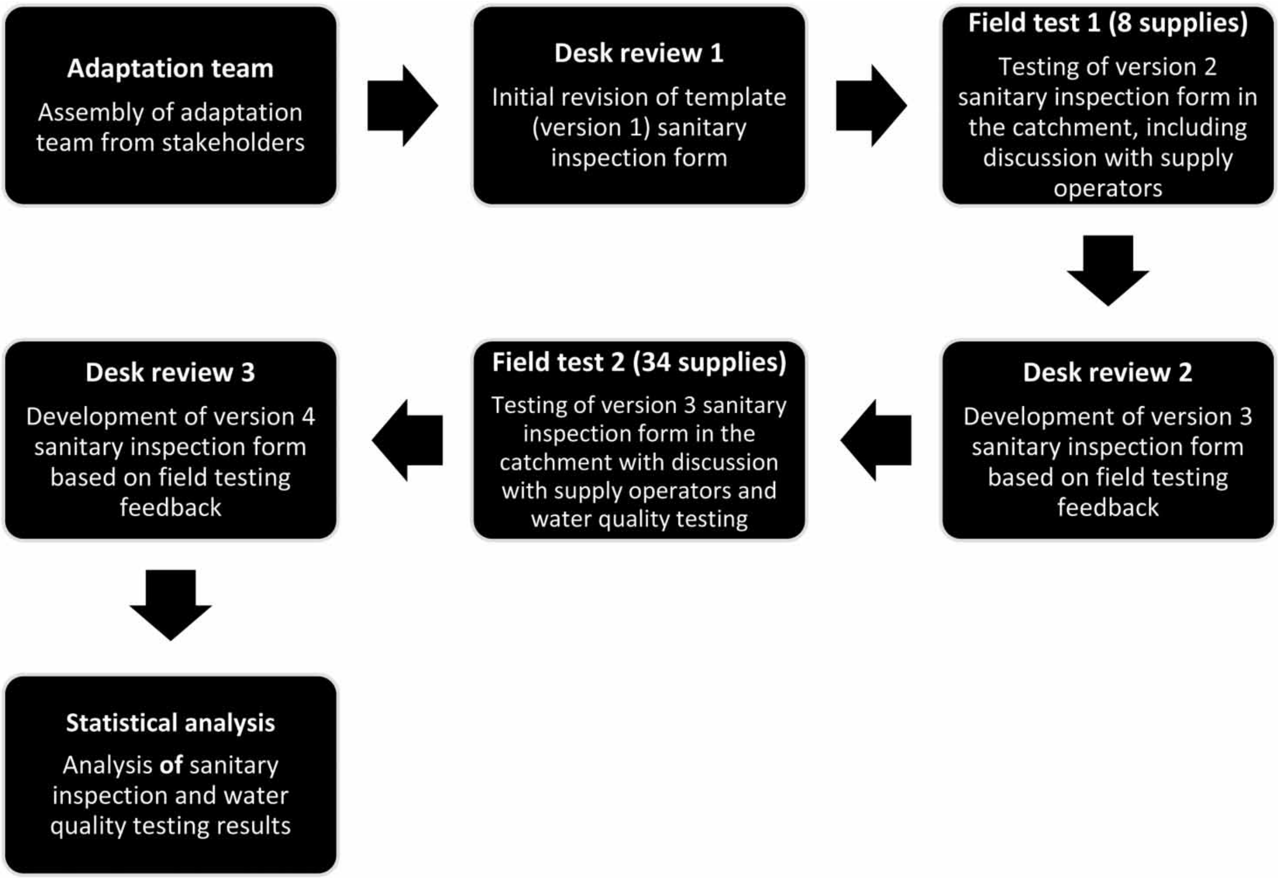


Figure 1 | Overview of the SI adaptation and analysis study design.

study as spring supplies are abundant in each of the three regions of Iceland (Northern-metropolitan, North-western, and Southern) in which the research was undertaken (Table 1). Nationally, spring sources supply 58% of Iceland's small drinking water supplies (<500 users) (Gunnarsdottir *et al.* 2019). In addition, spring supplies offer a sound example of how the same supply type may vary significantly in terms of configuration. During the same period, an SI form for boreholes was developed for use in Iceland using the same approach as the spring SI form adaptation process described in the following paragraphs. Borehole sources supply 18% of Iceland's small drinking water supplies (Gunnarsdottir *et al.* 2019).

The starting template SI form consisted of a 'General information' section to collect data on the spring location and supply characteristics, and 12 SI questions with accompanying explanatory notes that were developed based on the review of available published SI resources ($n = 8$). Compared with the WHO (1997) spring SI form, the template form collected greater detail in the 'General information' section to allow for the compilation of metadata that could provide additional context for interpretation of the SI results and results from any water quality tests undertaken during the SI. The SI question set

Table 1 | Total number of regulated drinking water supplies in each Icelandic study region (Northern-metropolitan, North-western, and Southern) per supply typology

Region	Number of water supplies	Boreholes	Springs
Northern-metropolitan	24	2 (0)*	9 (6)
North-western	141	35 (4)	78 (10)
Southern	167	38 (5)	115 (9)
Total	332	75 (9)	202 (25)

*The number of supplies inspected during field testing is given within the parentheses.

was more comprehensive, focusing on the most significant globally relevant risk factors identified in the literature. Additional significant changes to the WHO (1997) SI forms at the time of this study incorporated the inclusion of a 'what action is needed' option, to prompt remedial action when a risk factor was identified, as well as a basic risk assessment element, where each risk factor identified could be ranked as Low/Medium/High, to enable basic risk prioritisation, in line with the WSP philosophy. As with the WHO (1997) SI form, the template was designed for inspecting small spring supplies in developing settings and was therefore not tailored specifically for the Icelandic context.

The research team consisted of two members of academia, one each from the University of Surrey and the University of Iceland, and three Icelandic Health Inspectors. The University of Surrey researcher who undertook each SI during this study had previous experience undertaking SIs and working on the revision of the suite of WHO SI forms. The Icelandic members of the research team were experienced inspecting small water supplies; however, none had specifically used a SI.

Desk review 1 – May 2018

The template SI form (Version 1; Table 1, Supplementary Materials) was circulated among the Icelandic members of the research team for desk review. The suitability of the Version 1 form for use inspecting spring supplies in Iceland was considered, with feedback relating to the relevance of the format and content of the form to the Icelandic context collated and processed based on the team's expertise and experience. Version 2 (Table 2, Supplementary Materials) of the form was subsequently developed based on the suggested revisions stemming from the desk review. The key changes applied to develop the Version 2 form were:

- expanded metadata collection in the 'General information' section to account for features and considerations relevant to Iceland, e.g., diverse geological formations and
- removal/adaptation of components/component names that are rarely/never found in Iceland, e.g., latrine pits.

Field test 1 – June 2018

Inspections were undertaken on eight spring supplies in the Northern-metropolitan Region of Iceland using the Version 2 SI form. A member of the research team from the University of Surrey, whom had previous experience using and developing SIs, undertook the inspections that took between 1 and 2 h to complete, depending on the complexity of the system and location of various components, e.g., intake, storage tanks. These eight supplies were chosen for inspection as they were scheduled for routine monitoring by the accompanying local Icelandic Health Inspector. Through observations and discussions with supply operators, notes were taken at each supply relating to the relevance of the Version 2 SI form for use on Icelandic spring supplies. These notes were logged for later review by the research team.

Desk review 2 – Autumn 2018

Based on the notes recorded during Field test 1, the research team discussed potential adaptations to the Version 2 SI form which would make it more suitable for use in the Icelandic setting. The SI form was subsequently revised accordingly to develop Version 3 (Table 3, Supplementary Materials), considering aspects such as:

- the different types of risks relevant to spring supplies in Iceland;
- the knowledgebase of the proposed user-group of the SI form (i.e., Icelandic Health Inspectors); and
- the desired output from the SI.

Field test 2 – May 2019

Inspections were undertaken on 25 spring supplies by the University of Surrey researcher alongside Icelandic Health Inspectors in three different regions of Iceland: Northern-metropolitan, North-western, and Southern. The Version 3 SI form was used during these inspections that took approximately 1 h to complete, depending on the complexity of the supply and the location of various supply components. These 25 supplies were chosen for inspection as they had not been inspected previously and were scheduled for routine monitoring by the accompanying local Icelandic Health Inspector. The researcher and the Health Inspectors held discussions with supply operators and made observations and notes at each supply relating to the suitability of the Version 3 SI form in terms of user-friendliness and comprehensiveness. These notes were logged for review by the research team.

Desk review 3 – June 2019

Following Field test 2, the research team discussed further revisions that were required for Version 3 of the SI form before it could be approved for use by the local competent authorities (LCAs). Minor issues were discussed and addressed before Version 4 (Table 4, Supplementary Materials) of the SI form was translated into Icelandic context. These minor issues included the following:

- removal of potential duplicate SI questions and
- rephrasing of ambiguous questions.

SIs and water quality sampling

During Field test 2, the researcher also undertook SIs on nine borehole supplies using an adapted SI form that was being developed for the Icelandic context concurrently to the spring SI form using the same adaptation approach (Table 5, Supplementary Materials). As with the inspected spring supplies, these nine borehole supplies were chosen for inspection as they were scheduled for routine monitoring by the accompanying local Icelandic Health Inspector. To measure the quality of water at each of the 25 spring and nine borehole supplies inspected during Field test 2, water samples were taken by the Health Inspectors as part of their regular surveillance activities, following standard ISO 5667-5:2006 sampling procedures. As all inspected supplies fed commercial activities, samples were taken from a tap within the relevant area of commercial work. Nitrates (NO_3-N) were measured on-site using a Hach colorimeter (method 8039), with duplicate samples analysed and the average result recorded. As part of the local Icelandic Health Inspectors' routine work, samples were transported in an opaque cooler box to a local IST/ISO 17025/2005-accredited laboratory where they were analysed for total coliforms, faecal coliforms, and heterotrophic plate count (HPC) bacteria @ 22 °C (methods SM, 23. ed.2017, 9215B; ISO 6222:1999 mod.; ISO 9308-1:1990; ISO 9308-1:2000). Due to geographical circumstances, some samples arrived after 6 h from the sampling site but before 24 h, as prearranged with the laboratory. Weather conditions were unusually warm and dry during the 3-week sampling period with very little rain and temperatures averaging between 15 and 20 °C.

The limit for HPC in the Icelandic Drinking Water Regulation is 100 in 1 ml, for total coliform and for *Escherichia coli* it is 0 in 100 ml, and for turbidity it is 1 NTU. The history of noncompliance for these parameters for all 34 supplies was obtained by the LCAs.

Statistical analysis

The binary logistic regression test was used to assess whether incidences of noncompliance to Icelandic drinking water regulations during the 10 years prior to the SIs being undertaken during Field test 2 were significantly associated to 'High' SI scoring of any of the five source questions (Q1–5). Source SI Questions 1–5 for springs and boreholes relate to construction and design, maintenance, stagnant water around intake, fencing for protection, and pollution in the vicinity. Only these first five questions were analysed as they are common categories for both springs and boreholes. In addition, many springs did not have storage tanks (Q6–9) and only two spring supplies exhibited risks in the distribution system (Q10), making results from analysis of those questions insignificant.

If noncompliance had occurred at a supply once or more during 2010–2019, e.g., if one or more of the parameters in the HPC 22 °C, total coliform, *E. coli*, or turbidity sample was above limit, the supply was coded '1'. Otherwise, the supply was coded '0'.

The binary logistic regression test also provides the Odds Ratio (OR). The OR indicates the probability of an outcome given a particular exposure, or lack thereof. The Mann–Whitney *U* test was used for non-parametric analyses between noncompliance and the individual questions. The 10-year history analyses for noncompliance included monitoring results from a combined total of 213 samples from the 34 supplies. Statistical analysis was conducted using SPSS 26.

Research ethics

The University of Surrey Self-Assessment for Governance and Ethics (SAGE) tool was used to confirm this project met all ethical requirements as outlined by the University of Surrey Research Ethics Committee.

RESULTS

SI form adaptation

The full Icelandic spring SI form (Version 4) developed during this study is available in the Supplementary Materials (Table 4). The key revisions made to the SI form from the starting template were applied to the type of general supply information collected, the content and design of the SI questions, and the scoring method used.

In terms of general information collected, the Icelandic SI form differs from the starting template due to the additional collection of information on geology of the supply area; upgrades previously made to the supply; estimated flow and flow intermittency; requirement for pumping; types of water use; and storage tank size. Information on chemical audit monitoring and water catchment area zones is also collected with space provided for inspectors to sketch the supply system if they so require.

SI questions in the Icelandic SI form were largely adapted from the starting template with additional relevant questions identified and added subsequent to field testing. The questions in the starting template were developed for use at a point-source spring supply, whereas spring supplies in Iceland are typically piped directly into dwellings/businesses. To account for this, additional questions for storage tanks and piped distribution systems were added. WHO (1997) provides separate individual SI forms that consider these components of the drinking water supply chain, so questions from those forms were also adopted and adapted for use in the Icelandic SI form.

Unlike the starting template whose questions typically refer to a single supply component or area (e.g., outlet pipe), the Icelandic SI form was developed to have general questions relating to the construction, maintenance, etc., of each supply with suggested common risk factors underneath each question so that the inspector can then note the exact nature of the risk. If a specific risk factor is not prescribed beneath the question, there is additional space provided for the inspector to take notes. A comparison of the starting template question set and the Version 4 question set is presented in Table 2.

The type of SI scoring method used in any SI form is determined by the manner in which each individual SI question is answered. The starting template had a Yes/No answer type followed by a prompt to grade 'Yes' answers with a basic risk assessment score of 'Low/Medium/High'. This approach was maintained in the Icelandic SI form with the addition of a third 'N/A' answer option for use when a question was simply not applicable to the supply under inspection. This extra option was required as the configuration of spring supplies differed greatly, especially in terms of the presence/absence of storage tanks. The adjusted scoring method incorporated into the Version 4 Icelandic SI form (Figure 2) provides a final 'Risk %' which, unlike the starting template form, discounts questions that were not applicable (N/A) to the supply under investigation. This allows for a dynamic risk percentage to be generated and provides a better opportunity for risk comparison across supplies and types of supply.

SI and water quality test result statistical analysis

The binary logistic regression test results presented in Table 3 indicate a statistically significant association ($P = 0.025$; OR 1.864, 95% CI 1.080–3.220) between SI Question 3 (stagnant water around intake) on the SI form receiving a 'High' risk level assignment and at least one historical incidence of water quality noncompliance for the parameters HPC 22 °C, total coliform, *E. coli*, and turbidity at the same supply. A non-parametric Mann–Whitney U test showed that there was a significant correlation between SI Question 3 (stagnant water around intake) and a historical incidence of noncompliance ($U =$ 68,000, $P = 0.031$). None of the other source questions (Q1, Q2, Q4, and Q5) were shown to have any significant association with the 10-year history of water quality noncompliance.

DISCUSSION

The scope of the WHO (1997) SI forms is reflected in Kelly *et al.* (2020) where 24 of the 25 (96%) SI-related studies investigated were undertaken in a developing setting. This high percentage is likely due to the increased feasibility of undertaking large-scale studies in such settings and does not imply SIs, or other types of drinking water risk assessments, are not routinely carried out in developed settings. Rather, Kelly *et al.* (2020) reveal that experiences related to the use of SIs in developed settings are less widely shared via published studies, a knowledge gap that this research contributes toward closing.

WHO (1997) acknowledges the importance of SI adaptation to local contexts, however, no practical guidance or examples are provided in relation to which aspects of the forms require most attention during adaptation, or how these aspects may be tailored to a given local context. With the increased momentum toward mandatory risk assessment in the EU, this study is, to

Table 2 | List of questions in the starting template SI form (Version 1) for a spring source and the Version 4 Icelandic SI form following adaptation to the Icelandic context

Question	Starting template spring SI form (taken from draft WHO SI form)	Question	Version 4 Icelandic spring SI form
			CONSTRUCTION AND DESIGN OF SPRING BOX
1	Is the masonry, concrete wall or spring box absent or inadequate to prevent contamination?	1	Is the spring box design or construction inadequate to prevent contamination?
			(a) Is the spring box constructed with a material that will support microbiological growth or breakdown over a short period (e.g., wood)?
			(b) Can light enter the spring box? (Do not use white plastic as it will allow light to enter.)
			(c) Is the overflow pipe on the spring box missing or inadequate? (It is adequate if a nearby storage tank has an overflow pipe that also prevents the spring box from overflowing.)
			(d) Are any of the following components absent on the spring box: a manhole for inspection; an air vent for air circulation; a filter for water intake; a bottom valve for emptying; and a gravel filter material at intake into the spring box?
			(e) Can vermin access the spring box?
			(f) Can water seep down between the spring box and surrounding ground?
			(g) Is the top of the spring box less than 0.5 m above ground level?
			(h) Is the spring structure vulnerable to loss or breakage from natural disasters (e.g., flood, fire, and landslide)?
			MAINTENANCE OF SPRING BOX
2	If there is a spring box, is the inspection cover or overflow pipe absent or inadequate to prevent contamination?	2	Is there evidence that the spring box has not been maintained to an appropriate standard?
			(a) Are there cracks in the concrete, corroded pipes, or untightened joints?
			(b) Is the manhole lid for the spring box inadequately sealed and locked?
			(c) Are the air vents and overflow pipe outlets inadequately covered (e.g., with a gauze) to prevent vermin from entering the spring box?
			(d) Is there debris or heavy sediment within the spring box?
			(e) Is there vegetation up to the water intake that will risk surface water access to water intake?
			STAGNANT WATER AROUND INTAKE
3	If there is a spring box, and there is an air vent, is it inadequately covered to prevent contamination?	3	Does ponding from surface or spring water occur around the spring?
			(a) Does the topography of the surrounding area above the spring slope toward the spring extraction point?
			(b) Is the water diversion ditch absent or inadequate, allowing flooding of the spring site?
			(c) Does the gradient of the ground in front of the spring slope toward the extraction point, allowing ingress back into the spring?
			FENCING FOR INTAKE PROTECTION
4	If there is a spring box, does it contain any visible sign of contamination (e.g., animal waste, sediment accumulation)?	4	Is the fencing around the spring absent or inadequate to prevent contamination and access from animals?

(*Continued.*)

Table 2 | Continued

Question	Starting template spring SI form (taken from draft WHO SI form)	Question	Version 4 Icelandic spring SI form
			(a) Is the fencing around the spring absent or does it allow access to animals as a result of being in poor condition?
			(b) Is there any animal faecal material or other waste on the ground inside the fencing?
			(c) Is the distance from spring to fence less than the minimum 5 m radius as required in Icelandic regulation?
			POLLUTION IN THE VICINITY OF THE INTAKE
5	Is the backfill area eroded or prone to erosion due to absence of vegetation?	5	Is there any other source of pollution within 500 m upstream from the water intake?
			(a) Are there signs of septic tanks or sewer lines?
			(b) Are there signs of animal breeding, cultivation, golf courses, or the use of pesticides and/or fertilizers?
			(c) Are there signs of roads, garages, craft enterprises, tourist facilities, waste dumps, or uncapped wells/boreholes?
			(d) Does the water supply representative recall old waste dumps or past activities near the spring that may not be obvious?
			(e) Is there potential faecal contamination from sources at greater distances? (Pathogens have been shown to survive for long periods in groundwater. Travel distances of viable pathogens depend on inactivation rates and strata conditions.)
			CONSTRUCTION AND DESIGN OF STORAGE TANK
6	Is the fencing or barrier around the spring absent or inadequate to prevent contamination?	6	Is the storage tank design or construction inadequate to prevent contamination?
			(a) Is the storage tank constructed with a material that cannot withstand breakdown over a long period (e.g., soft plastic)?
			(b) Is the storage tank missing any of the following components: an overflow pipe; a manhole for inspection and cleaning; an air vent for air circulation; a bottom valve for emptying?
			(c) Can light enter the storage tank?
			(d) Is the manhole lid for the storage tank inadequately sealed and locked?
			(e) Are the cover, air vents, and overflow pipe outlets inadequately covered (e.g., with a gauze) to prevent vermin from entering the storage tank?
			(f) Is the storage tank vulnerable to loss or breakage from natural disasters (e.g., flood, fire, and landslide)?
			MAINTENANCE OF STORAGE TANK
7	Is the fencing or barrier upstream of the spring inadequate to stop local pollution? [b]	7	Is there evidence that the storage tank has not been maintained and its surrounding area not well-kept and clean?
			(a) Are there cracks in the concrete, untightened joints, or other signs that the exterior structure is in disrepair?
			(b) Is the manhole lid for the storage tank inadequately sealed or locked?
			(c) Is there debris or heavy sediment within the storage tank?
			FENCING FOR STORAGE TANK PROTECTION
8	Is a storm water diversion ditch above the spring absent or inadequate to prevent contamination?	8	Is the fencing around the storage tank absent or inadequate to prevent contamination from animals and access from vandals?

(*Continued.*)

Table 2 | Continued

Question	Starting template spring SI form (taken from draft WHO SI form)	Question	Version 4 Icelandic spring SI form
			(a) Is the fencing around the storage tank absent or does it allow access to animals as a result of being in poor condition?
			(b) Is there any animal faecal material or other waste on the ground inside the fencing or near to the tank?
			(c) Is the storage tank unsecured from public access and potential vandalism?
			DESIGN AND MAINTENANCE OF THE DISTRIBUTION NETWORK
9	Is there a latrine, septic tank or sewer line within 10 m of the spring?	9	Is the distribution system inadequate to prevent contamination?
			(a) If there are any pressure break boxes, are their covers inadequately sealed or locked?
			(b) Are there leaks or breaks in the distribution system?
			(c) Does water short-circuit from inlet to outlet?
			(d) Are pipelines vulnerable to loss or breakage from natural disasters (e.g., flood, fire, and landslide)?
			(e) If above ground, are pipes inadequately protected from animals and vandalism?
			SERVICE LEVEL
10	Is there a latrine, septic tank or sewer line on higher ground within 30 m of the spring?	10	Has there been discontinuity in the last year?
			(a) If the distribution pipes become empty, do pressure differences lead to ingress of water and silt from soil around the pipes?
11	Can signs of other sources of pollution be seen within 10 m of the spring (e.g., animals, rubbish, human settlement, and open defaecation)?		
12	Is there an open/uncapped well or borehole within 100 m of the spring?		

the author's knowledge, the first to document an SI adaptation process that may be used to assist others to adapt SI forms to their local contexts.

This work highlights the key SI design and content elements to consider during the SI adaptation process. It must be noted that the specific adaptation approach undertaken during this study will itself need to be tailored depending on the template SI materials used, if any, and the desired complexity of the SI version to be used by authorities. For instance, where changes to the template are subtle, unlike in this study, the first adaptation step may be a simple walk through the catchment and intake areas with supply stakeholders. SI adaptation is not an academic activity solely based on desk review, rather it requires a practical approach that should always consist of a review of catchment and supply characteristics and consultations with all relevant stakeholders. The development/adaptation of an SI can be inhibited by the lack of a true validation method to gauge against. The evidence from this study will allow potential issues to be anticipated and pre-emptively addressed prior to SI development and subsequent rollout.

Lessons learned from SI form adaptation in Iceland

The starting template in this study underwent considerable review and revision for the Icelandic context based on desk review and field testing in Iceland in 2018 and 2019. The spring SI form is now utilised as a surveillance tool by the three LCAs that participated in the testing, all of whom have found it to be effective during the evaluation of new potential water sources. The spring form will be distributed to all of the 10 LCAs in Iceland, having since been digitised as an application for use on

Enter the number of 'Low', 'Medium', 'High' risks and multiply by the relevant number to generate a 'Score'. The sum of the three scores is the 'Sanitary risk score'.

Hazard score	Number of risks	Multiply by:	Score
# High		X 5	
# Medium		X 3	
# Low		X 1	
Sanitary risk score (max. 50)		Total:	

Risk % estimate calculation:

1) No. of Q's answered 'Yes' or 'No' = A
2) A X 5 = B
3) Total/B = C
4) C X 100 = Risk % estimate

Figure 2 | SI form scoring method adapted for the Icelandic context.

electronic devices in the field (e.g., laptop, tablet, and mobile device). The spring SI form has also been added into the new inspection manual at the Icelandic Food and Veterinary Authority (MAST), which is responsible for supervising the LCAs. Drinking water is defined as food in Iceland and therefore the governmental institution responsible is MAST, whereas the surveillance role is with the LCAs. Having been developed simultaneously to the spring SI form based on the same adaptation criteria, the SI form for boreholes is currently undergoing a final trial for use in Iceland. A SI form for dug wells is also in the late stages of development.

Cronin *et al.* (2006) suggest SI results should be used to prioritise valuable supply protection interventions. Though still under consideration, it is anticipated that the Health Inspectors from each LCA will inspect water supplies using the SI forms during their future routine annual sampling of small supplies. They would then send the water supply operator/owner requests for improvements or remedial actions, if applicable, supported by the outcome of the inspection. Though this additional activity will assist the LCAs in having a much more professional and comprehensive approach to facilitating safe drinking water management practices, a persistent issue for Icelandic LCAs is the ambiguity surrounding the ownership of many supplies, often making it difficult for regulators to direct improvements.

Unlike for boreholes or wells, the Health Inspectors are typically unable to observe spring water sources every time they take an annual sample as it is often a steep walk up a hill or mountain. This will most likely require a practical solution whereby the Health Inspectors conduct an SI at intervals, e.g., every 3 years. In such cases, the operator/owner of the

Table 3 | Binary logistic regression test results for risk factor presence and historical incidence of noncompliance in Icelandic small water supplies ($n = 34$)

							95% CI for exp(*B*)	
	B	S.E.	Wald	*df*	Sig.	OR exp(*B*)	Lower	Upper
Q1 Design	0.026	0.341	0.006	1	0.938	1.027	0.526	2.005
Q2 Maintenance	−0.481	0.295	2.653	1	0.103	0.618	0.347	1.103
Q3 Stagnant water	0.623	0.279	4.993	1	0.025	1.864	1.080	3.220
Q4 Fencing	0.317	0.296	1.144	1	0.285	1.373	0.768	2.453
Q5 Pollution vicinity	−0.036	0.364	0.010	1	0.921	0.965	0.473	1.967
Constant	−2.474	1.741	2.018	1	0.155	0.084		

supply would then be obliged to undertake an annual SI and send the outcome (e.g., results and photos) to their relevant LCA. A recent study on SI citizen science (Herschan *et al.* 2020) notes the potential benefits of this approach to include a reduced workload for the Health Inspector, lower cost of surveillance/inspection, and supply operators/owners with increased knowledge of water safety. In addition to contributing toward meeting the demand for education for supply operators/owners, the uptake of SIs will proactively assist with the implementation of the new EU DWD, where there is a demand for a more risk-based approach to drinking water supply.

In terms of SI form functionality, the main obstacle during the spring SI form development was found to occur when there are two different types of water intake in the same water supply zone, or if there is more than one storage tank in use. In such cases, there is a need to fill out two SI forms for the same water supply. A solution to this issue is being investigated whereby different configurations of water supply can be merged on a digital form, allowing for the possibility of adding in a water source and/or a storage tank. Digital forms are also deemed beneficial as they can be used to save prior SI results with the option of subsequently adding changes during further surveillance, allowing for the SI results to also be updated with time. Digital forms will also allow for answer logic to be applied; auto calculation of risk score percentages; instant upload of results to a central authority; and the rapid issuing of remedial orders for priority sites and tracking of remedial actions. The potential benefits of digital SIs were noted in Pond *et al.* (2020), and the UK Drinking Water Inspectorate (DWI) has published data exhibiting promising reductions of noncompliance in private (typically small) drinking water supplies since they launched their own Microsoft Excel-based digital risk assessment form in 2010 (DWI 2021).

An approach still under investigation for use in Iceland is to have a statistical output that considers both the hazards identified by SI at a supply and the supplies water quality history. This could potentially identify the most common risks that cause contamination in small drinking water supplies. There will also be the opportunity to increase the risk score of a supply if there has been a recent noncompliance in water quality monitoring. The content and design of the SI should not be static. As more experience is gained and more evidence garnered, new SI versions should be developed to reflect the dynamic nature of risk, including risk to water quality due to pressures such as climate change. Conversely, changes to the forms should be scientifically justified where possible because all changes reduce the opportunity for a standardised approach and comparison of results across supplies and time periods.

Use of SI results

Sanitary risk scores and water quality test results do not exhibit a consistent positive linear relationship (Mushi *et al.* 2012; Oliver 2015; Ercumen *et al.* 2017; Misati *et al.* 2017; Snoad *et al.* 2017; Tosi-Robinson *et al.* 2018), meaning one metric cannot be used as a proxy for the other (Kelly *et al.* 2021). This is due to the dynamic nature of both risk and water quality, particularly that indicated by faecal indicator bacteria (Tillett 1993); the limitations associated with water quality testing; and the often non-standard, potentially subjective (Lloyd & Suyati 1989; King *et al.* 2020) SI approach. Though SI scores represent an actual and potential risk to water quality, water test results only indicate the immediate quality of water sampled at a specific point in time.

Drinking water in Iceland is typically 'pristine' at source (Gunnarsdottir *et al.* 2016), a statement reinforced by the water quality test results obtained during Field test 2 which were all compliant with Icelandic drinking water regulations. Weather conditions were unusually warm and dry during the 3-week Field test 2 sampling period with very little rain and temperatures averaging between 15 and 20 °C, which may have been a contributory factor to compliant samples (Engström *et al.* 2015; Kostyla *et al.* 2015). Icelandic Health Inspectors typically aim to take water samples subsequent to periods of rainfall or snow melt, however during sporadic weather patterns similar to those observed during this study, it becomes less feasible to optimise sampling schedules.

Several previous studies have reported associations between water quality test results and the presence of individual SI risk factors (Howard *et al.* 2003; Hynds *et al.* 2014; Dey *et al.* 2017; Kelly *et al.* 2021), an analysis approach which may strengthen the relationship between SI and water quality test results compared with using the potentially misleading cumulative SI score metric. To account for water quality test results which may underestimate the actual risk at a supply, especially where infrequent (typically annual in small supplies in Iceland) sampling is undertaken, often without the occurrence of co-factors such as rainfall, the researchers utilised historical water quality data to increase the likelihood of exposing incidents of noncompliance within each supply.

The results of this study showed a positive association between Q3 (*Does ponding from surface water occur around the spring/borehole?*) being observed during the SIs and incidence of noncompliance during the previous 10 years. Using a similar analysis approach, Kelly *et al.* (2021) demonstrated a weak but significant association between handpump breakdowns and *E. coli* contamination using data from more than 1,000 handpumps across 12 countries. The same study stated that for noncompliance to occur, there must be a framework consisting of a source of contamination; a pathway for contamination to reach the supply; and a breakdown in supply protection barriers. The study then concluded that associations with barrier breakdowns and *E. coli* were the only significant relationships identified because (i) important contamination sources and carriers are missing from the current SI forms and models and (ii) sources and carriers are more difficult to reliably capture than barrier breakdowns using SI tools. This details the importance of metadata such as that collected in the 'General information' section of the Icelandic SI form to provide context to both SI and water quality test results.

SIs may be used to identify sources of risk to water quality, pre-emptively or in response to failure. Each region will have unique risk factors that can only be identified by field testing and discussion with stakeholders. Taking Iceland as an example, niche risk factors and co-factors such as landslides, avalanches, etc., need to be included. Even where analysis of SI and water quality test results is not possible, simply understanding the frequencies of certain risk factors in a region provides valuable information to surveillance agencies, allowing them to direct resources more efficiently.

Study limitations and areas for future work

The approach of using historical data to investigate the association between water quality test and SI results has its limitations. The presence/absence of risk factors may vary over time, especially when the duration between water sampling and SI is significant. This can be largely offset by engaging anecdotally with supply owners/operators about significant changes to supplies and their catchments. As stated by Herschan *et al.* (2020), citizen science could play an important role in monitoring risk across extended periods between official inspections. The sample size of this study was restricted by time and resources. We suggest that large databases of SI and water quality test results with sufficient metadata will allow for valid trends to be identified over time. We also suggest that SIs should complement catchment inventories and, where relevant and possible, other aspects such as radiological information, water quality testing data, geological information, etc., to form a comprehensive understanding of the characteristics of each drinking water supply. Sanitary inspectors should always be adequately trained (King *et al.* 2020).

CONCLUSION

This study describes template SI form adaptation to the Icelandic context, which may serve as a model for practitioners in other settings. The significant modifications applied to the starting template to develop the Icelandic spring SI form emphasise the importance of the adaptation process. Fundamental elements of the starting template were significantly adapted to suit the local context, including the type of metadata collected in the 'General information' section; the structure, sequence, and content of the SI questions being adjusted and expanded to include source, storage, and distribution considerations in a single form; and the addition of an extra 'N/A' answer option to allow for a risk percentage to be generated without including questions that were not applicable.

This study demonstrated the benefit of engaging stakeholders from academia/industry, supply operators, and health authorities to design a robust and comprehensive SI form. Such collaboration may also foster a sense of ownership from the relevant stakeholders, potentially encouraging future uptake. The Icelandic spring form is now utilised as a surveillance tool by the three LCAs that participated in the testing, all of whom have found it to be especially useful during the evaluation of new potential water sources. It has been added to the new inspection manual at MAST, which is responsible for supervising the LCAs. This revision may serve to support the rollout and sustainable application of SIs in Iceland in the longer term.

In addition to being the first study to document an SI adaptation process, the authors also explored the importance of dialogue between the inspector and supply owner/operator. This is especially pertinent in Iceland where seasonal risks such as glacial runoff and avalanches are common but often unpredictable. A small minority of the previous SI studies referenced in this article noted the experience level of sanitary inspectors, a factor which we deem important validation information similar to stating the type of water quality test used. Where citizen science is utilised to reduce the workload for Health Inspectors, there should be a consistent loop of feedback between supply owner/operator and LCA to ensure the correct types of information are being reported at a sufficiently accurate level. The authors consider this relatively novel approach as necessary for meeting the demand for increased risk-based management of small water supplies.

Water quality and SI result analysis was undertaken in this study to demonstrate the potential use of both data sets in identifying the most common risks that may affect small supplies. Though the use of cumulative SI scores as a means to achieve this has been much discussed, and for the most part discounted, the authors consider analysis of individual risk factors, or sequences of risk factors, may provide a robust link to water quality test results, especially as the level of historical data within SI and water quality databases increases over time.

CONFLICT OF INTERESTS

The authors declare that there are no competing interests in this article.

DATA AVAILABILITY STATEMENT

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

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