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Combining Sanitary Inspection and Water Quality Data in Western Uganda: Lessons Learned from a Field Trial of Original and Revised Sanitary Inspection Forms

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Abstract: Risk assessment for drinking water systems combines sanitary inspections (SI) and water quality testing and is critical for effectively managing the safety of these systems. SI forms consist of question sets relating to the presence of potential sources and pathways of contamination specific to different types of water points, piped distribution systems, and household collection and storage practices. As part of the revision to the Guidelines for Drinking-water Quality (GDWQ), the World Health Organization (WHO) is updating the suite of SI forms to reflect and include the most recent technical and scientific information available. This paper reports the results from a field pilot of a selection of published and revised SI forms and water quality testing in the municipality of Bushenyi-Ishaka, Uganda. We collected data from 45 springs, 61 taps from piped distribution systems, and 129 household storage containers filled with water from those springs and taps. The median total risk scores, according to the revised forms, for spring, tap, and household practices were 36, 53, and 33%, respectively, with higher percentages indicating greater risk. The median *Escherichia coli* concentrations of spring, tap, and household storage systems were 17, <1, and 7 CFU/100 mL, respectively. We found that increased questioning in the revised SI forms do not necessarily translate to a higher total risk. There is potential for misinterpretation of terminology in the revised SI forms and occasional redundancy of concepts. For the revised SI form for springs, we suggest specific text changes to reduce potential bias. We recommend that users of SI forms receive training in their use and be familiar with their locale. Furthermore, the revised SI forms may need to be adapted in accordance with the local context.

Keywords: sanitary inspection; water quality; water safety; risk assessment; Uganda; small town

1. Introduction

Water that is free from fecal and priority chemical contamination is a requirement of safely managed drinking water services, as defined by the United Nations Sustainable Development Goal 6, target 6.1. Despite significant progress towards this target, three in ten people worldwide still used contaminated drinking water sources in 2017 [1]. A meta-analysis also revealed that microbial water quality deteriorates after collection in many settings in developing countries [2].

To aid the water sector in the protection of public health, the World Health Organization (WHO) advocates for the risk-based monitoring of drinking water supplies [3]. While water supply monitoring generally consists of visual observations and water quality testing, these activities can serve different purposes. For example, operational monitoring is usually performed by water operators or caretakers to inform the operation and maintenance of the water supply system. Verification monitoring may be performed by external authorities or by local system operators and ensures that the water supplied complies with national regulatory standards. These various types of monitoring are not always implemented, especially in small-scale water supplies. Irregular monitoring in small supplies can be attributed to a lack of adequate financial resources and technical knowledge [4–6]. The lack of adequate water quality testing equipment is also an obstacle against regular water quality monitoring [7,8].

Risk-based monitoring of drinking water supplies emphasizes the importance of identifying potential means of contamination and implementing adequate preventive actions. To promote and aid this approach, sanitary inspections (SI) have been included in each edition of the WHO Guidelines for Drinking-water Quality (GDWQ) [9]. Though the most widely used SI forms for piped distribution systems and springs are the 1997 GDWQ version [10], nongovernmental organizations (NGOs) and international agencies have also developed their own SI form templates, (e.g., [11,12]). The 1997 GDWQ forms, hereinafter referred to as the “original” forms, contain questions to systematically evaluate potential sources and pathways of water contamination, with a focus on small-scale water supply systems. SIs have been widely used in many settings in low to high income countries [4,13–18]. The WHO initiated an update of the 1997 SI forms and, in early 2019, launched a call to pilot test the revised SI forms. The pilot testing aimed to provide evidence-based feedback on the content and design of the revised forms, especially for practical applications.

For years, researchers have investigated the extent to which SI scores align with fecal indicator bacteria levels, with mixed results [13,14,19]. A recent review concluded that “the value of sanitary inspection is not derived from its ability to predict risks to water quality, but from its utility in the ongoing effort to protect water safety” [9]. Therefore, the published SI forms cannot be considered a substitute for direct water quality sampling, but rather a complementary activity for effective management of water supply systems [14,20].

However, little is known regarding the implementation of the forthcoming revised SI forms, including their comparability to the previously published SI forms, the association between their individual questions and microbial water quality, and their general practicability in the field. Based on these knowledge gaps, the objectives of this study are to (a) compare the total risk scores generated by the original and revised SI forms for springs, taps, and households in Bushenyi-Ishaka municipality, Uganda; (b) assess the microbial water quality of these sources and investigate the extent to which microbial concentrations correspond with SI scores from the original and revised forms; and (c) identify the practical lessons learned from the field pilot testing of the revised SI forms, with recommendations for their improved design, use, and interpretation by water sector practitioners.

2. Materials and Methods

2.1. Study Area

The study was conducted in Bushenyi-Ishaka municipality of the Bushenyi district in southwestern Uganda (Figure 1). Bushenyi-Ishaka municipality covers 81.2 km^2, has a hilly topography with an average altitude of 1432 m.a.s.l., and a population of approximately 40,000 inhabitants [21,22]. The piped water supply system is managed by the National Water and Sewerage Corporation (NWSC), which is owned and operated by the national government. This study is the continuation of a previous water and sanitation study conducted in the same area [22], which reported that almost half of the households relied on protected springs (48%) as their main drinking water source, followed by unprotected springs (20%), and piped supply (18%) [22]. About one in five households had their water source located on-plot. Almost all households used either basic or limited sanitation services, according to the WHO/UNICEF Joint Monitoring Programme (JMP) classification [1].

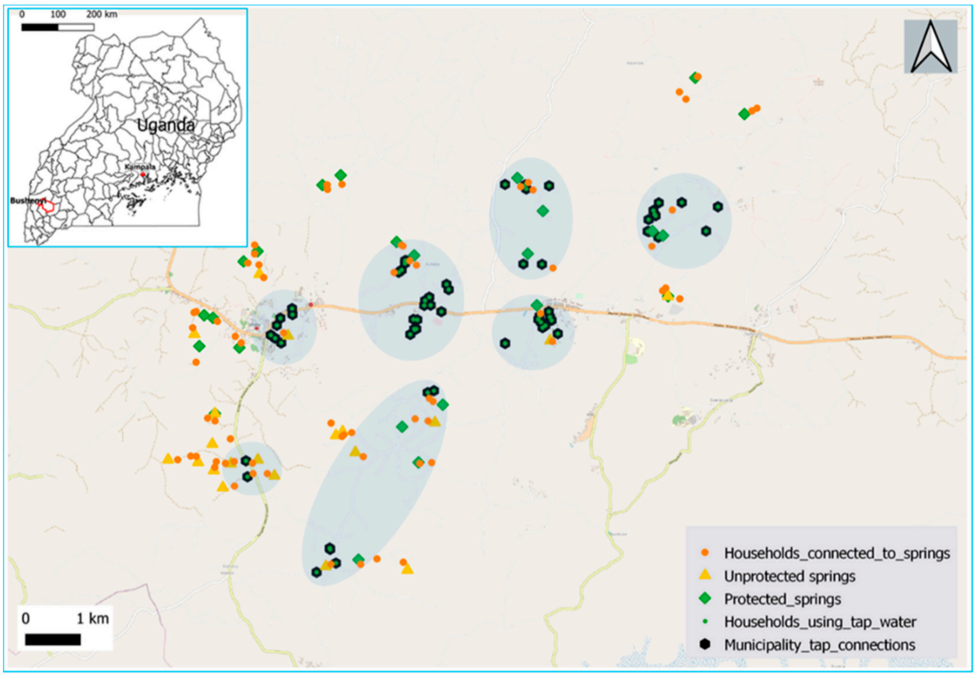

Figure 1. Map of the study area and location of the sampling points. The shaded areas are the seven service areas of the municipality's piped distribution system that were visited during this study. Taps in the same shaded area share a branch of the piped distribution system.

In the current study, we revisited a total of 129 households that were surveyed in the previous study. Detailed information on the site and household selection can be found in the previous study [22]. We conducted SIs and collected water samples from household storage containers and the main drinking water sources used at the time of visit (i.e., springs and piped distribution taps). We conducted the water sampling in two phases. During the first phase (September–November 2019), we collected 45 samples from spring sources (21 unprotected springs and 24 protected springs) and 68 samples from the household storage containers, wherein the water originated from those springs. During the second phase (January–February 2020), we collected 61 samples from piped distribution taps and 61 samples from household storage containers, wherein the water originated from those taps. The average temperature during the first and second phases was 19 and 20 °C, respectively. Both phases were conducted during the rainy season.

2.2. Sanitary Inspections

We used the original and revised SI forms for springs, piped distribution systems, and household practices. The number of questions in each SI form type and version are presented in Table 1. The revised SI form questions are shown in Table 2, and the original SI form questions can be found in Appendix A, Tables A1 and A2.

Table 1. Total number of questions in the original and revised SI forms.

Type of SI Form	Number of SI Questions		
	WHO (1997)	WHO and UNICEF (2012) *	WHO (1997)
Spring	10	n.a.	14
Piped distribution system	11	n.a.	15
Household practices	4	10	18

n.a. = not applicable. * The WHO and UNICEF (2012) version is only for household practices.

Table 2. List of questions in the draft of the revised 2018 WHO sanitary inspection forms for spring, piped distribution system, and household practice, as well as the total number of "yes" answers recorded for each question during both studies.

No.	Household Practices SI Questions (*n* = 18) [c]	Total "yes" [a]	Piped Distribution System SI Questions (*n* = 15) [b]	Total "yes" [a]	Spring SI Questions (*n* = 14)	Total "yes" [a]
1.	Is drinking water collected from more than one source?	129	Is the reservoir open (i.e., uncovered), or if there is a cover, is it damaged or inadequate to prevent contamination?	0	Is a protective wall *or* spring box structure absent or inadequate to prevent contaminants entering the spring?	36
2.	Is the collection container cracked, leaking or unclean?	69	Is the reservoir structure cracked, leaking or unclean?	61	Is the outlet pipe unsanitary or inadequately positioned to prevent contaminants entering the spring?	20
3.	Is the collection container used to store any other liquids?	35	Is there any point of entry to the reservoir that is inadequately covered or sealed?	0	Is the backfill area eroded or prone to erosion due to the absence of vegetation?	5
4.	When not in use, is the collection container kept in a place where it may become contaminated?	89	Are there any visible signs of contaminants inside the reservoir (e.g., animals and/or their waste, sediment accumulation)?	61	Is the drainage inadequate, which may result in stagnant water in the spring area?	37
5.	Does the collection container have a large opening that is uncovered?	3	Is the drainage around the reservoir inadequate, which may result in the collection of stagnant water?	61	Is the fencing or barrier upstream of the spring absent or inadequate to prevent contaminants entering the spring?	45
6.	Is the bulk storage container cracked, leaking or unclean?	1	Is the fencing or barrier around the reservoir absent or inadequate to prevent animals or unauthorized persons from entering the area around the reservoir?	0	Is a stormwater diversion ditch above the spring absent or inadequate to prevent contaminants entering the spring?	44
7.	Is the bulk storage container used to store any other liquids?	0	Can signs of other sources of pollution be seen within 10 m of the reservoir (e.g., animals, rubbish, human settlement, open defecation, fuel storage)?	0	Is there sanitation infrastructure within 10 m of the spring?	0
8.	Is the bulk storage container located in a place where it may become contaminated?	1	Is the tap leaking or otherwise defective?	31	Is there sanitation infrastructure on higher ground within 30 m of the spring?	1
9.	When not being filled, is the bulk storage container inadequately covered to prevent contamination?	1	Are there any tap attachments (such as hoses, etc.) that are unclean or stored in an unsanitary manner?	13	Can signs of other sources of pollution be seen within 10 m of the spring (e.g., animals, rubbish, human settlement, open defecation, fuel storage)?	41
10.	Is the tap or utensil used to draw/collect water from the bulk storage container inappropriate or unclean?	1	Is drainage around the tap inadequate, which may result in the collection of stagnant water?	61	Is there any point of entry to the aquifer that is unprotected within 100 m of the spring?	0
11.	Is the water from the bulk storage container directly used for other purposes (e.g., washing or bathing)?	1	Is the fencing or barrier around the tap missing or inadequate to prevent animals entering the collection area?	61	Does the spring box contain any visible signs of contaminants (e.g., animals and/or their waste, sediment accumulation)?	0
12.	Is the final storage container cracked, leaking or unclean?	68	Can signs of other sources of pollution be seen within 10 m of the tap (e.g., animals, rubbish, human settlement, open defecation, fuel storage)?	61	If there is an inspection port, is the lid missing or inadequate to prevent contaminants entering the spring?	0
13.	Is the final storage container used to store any other liquids?	0	Are there any leakages visible between the entry point to the distribution system and the point of delivery to the user?	61	Is the overflow pipe inadequately positioned or covered to prevent contaminants entering the spring?	0
14.	Is the final storage container stored in a place where it may become contaminated (e.g., on the ground)?	84	Are there any exposed pipes within the distribution system?	61	If there are air vents, are they inadequately positioned or covered to prevent contaminants entering the spring box?	0
15.	Is the final storage container inadequately covered to prevent contamination?	103	Is there heavy vegetation that could damage network assets (e.g., reservoirs, tanks, break-pressure tanks, tap-stands)?	0		
16.	Is the tap or utensil used to draw/collect water from the final storage container inappropriate or unclean?	43				
17.	Is the water from the final storage container directly used for other purposes (e.g., washing or bathing)?	96				
18.	If household-level treatment is practiced, is there evidence that it is being carried out ineffectively?	0				

[a] Data are *n* of "yes" responses; maximum "yes", i.e., total samples for spring, tap, and household practices are 45, 61, and 129, respectively. [b] Questions 1–7 relate to the reservoir, 8–12 relate to tap, 13–15 relate to the whole piped network. [c] Questions 1–5 relate to water collection, 6–11 relate to bulk or intermediate storage, 12–17 relate to the final storage, and 18 relates to the household water treatment.

During inspections, we recorded the global positioning system (GPS) coordinates and unique identification codes of the sampling points. We also recorded any additional observations not covered by the SI form. We photographed each storage container and utensil for water drawing and saved them with their identification code after sampling. All SI questions required a "yes" or "no" answer, in which a "yes" answer indicated the presence of the risk under observation. The inspection results were recorded on paper and subsequently copied into an Excel spreadsheet. All SIs and water quality sampling and analysis were conducted by the same person.

We implemented SIs for piped distribution systems in seven areas. Each area combined the cells that shared a piped network from the main pipeline (areas in gray in Figure 1). The piped distribution system was supplied by one common reservoir, meaning that for each gray area shown in Figure 1, the answers to reservoir-related questions were identical (see piped distribution system questions 1–7 in Table 2). If any household revisited from the Marks et al. study [22] no longer used their tap or if the tap did not work, that household was then excluded from this study. The number of taps assessed in each of the gray areas shown in Figure 1 varied from 2 to 18, for a total of 61 taps. To answer questions 13–15 of the revised piped distribution system SI form (see Table 2), the piped networks were walked and examined for potential and actual risks.

We summed the number of "yes" answers in each SI form to identify the total number of risks. The maximum total risk score is equal to the number of "yes" answers, with higher scores indicating higher risk. To allow comparison between the old and revised forms, we then converted the total risk score into a percentage. For example, if the total risk score is 10 (out of a maximum 18) in the revised household practices form, then that household gets a final score of 55.6%.

2.3. Water Quality Sampling and Analysis

For protected springs with an outlet pipe, we collected samples directly from the pipe after running the water for 1 min to dispose of any solid residue. For unprotected springs, we collected samples by dipping a sterile sampling bag into the pond while ensuring the sample collector's hand did not touch the water. For the collection of samples from taps, we ran the water for 1 min before collecting into a sterile sampling bag. For the collection of samples from household storage containers, we requested study participants pour water from the storage container into a utensil and then into a sterile sampling bag. We collected approximately 100 mL of water sample per sterile 100 mL Whirl-Pak bag (Nasco, Fort Atkinson, WI, USA). We stored the samples in a cooler box and transported them to the field laboratory for processing within 24 h after collection.

We used the membrane filtration method with a filtration unit by Palintest (Tyne and Wear, UK) to process samples for *Escherichia coli* (hereafter *E. coli*) enumeration. Since bacterial concentrations were expected to vary widely in the study area, we analyzed water quality samples at various dilutions (1, 50, and 100 mL). We filtered samples through a 0.45 µm pore size membrane, placed them on compact dry plates (CDP) (HyServe GmbH and Co, Uffing, Germany), and incubated them at 37 °C for 24 h. We also ran a daily negative control using a phosphate saline buffer. The colony forming units (CFU) that appeared on the CDP after incubation were counted. Microbial counts are reported in units of CFU/100 mL, with counts higher than 250 colonies reported as too numerous to count (TNTC) [23]. We measured turbidity, pH, and free residual chlorine with a 2100P portable turbidimeter (Hach, Dusseldorf, Germany), an HQ40d portable multimeter (Hach, Dusseldorf, Germany), and a HACH DR890 pocket colorimeter (Hach, Dusseldorf, Germany), respectively.

We compiled the water quality data and the results of the SI forms in Microsoft Excel and imported the data into IBM SPSS 25 for statistical analysis. Since the data did not meet the assumptions of normality or linearity, we applied nonparametric tests to analyze the potential relationship between microbial water quality and the risk scores, (e.g., the Spearman rank–order correlation (rs), Wilcoxon signed-rank (Z), Chi-squared (X2), and Kruskal–Wallis test (H)). To reduce the potential for a type 1 error (false-positive results) in multiple pairwise comparisons, we applied the Bonferroni adjustment of the *p*-value [24].

3. Results and Discussion

3.1. Sanitary Inspection

The median total risk score for all springs (n = 45) was 36% based on the revised SI form for springs (Table 3). The most common risk for springs was the absence of adequate fencing protection upstream (100%), followed by the absence of a stormwater diversion ditch above the spring (97.8%), and visible pollution within 10 m of the spring (91.1%) (Table 2) (see examples in Figure 2). Similarly, a previous SI study in the same area found that almost all inspected springs lacked the protection of a perimeter fence or wall [25]. The median total risk score based on the revised SI form for piped distribution systems was 53% (Table 3). Eight types of potential risks were detected at the reservoir, tap, and throughout the network (Table 2).

Table 3. Total risk scores, with higher values representing greater risk.

Type of Form	Median (Min–Max) Total Risk Scores (%)		
	WHO (1997)	**WHO and UNICEF (2012) ***	**WHO (2018)**
Spring (n = 45)	60 (30–70)	n.a.	36 (21–50)
Piped distribution system (n = 61)	45 (27–55)	n.a.	53 (40–60
Household practices (n = 129)	25 (0–75)	50 (0–80)	33 (6–72)

n.a. = not applicable. * The WHO and UNICEF (2012) version is only for household practices.

Figure 2. Photos of observable risks to water infrastructure in the study area: (**A**) a reservoir containing algae growth (greenish color on the inside stairs); (**B**) a tap stand with poor drainage; (**C**) a spring with an outlet pipe and inadequate drainage; and (**D**) an unprotected spring.

For household practices, the median risk score was 33% according to the revised household practices SI form (Table 3). The most frequently identified risks regarding household practices were the use of multiple water sources (100%) and inadequate coverage of the final storage container, i.e., the container from which drinking water is directly accessed by household members (80%) (Table 2). This is consistent with a previous study in the same area that found households dealt with unreliable, seasonal, or costly water supplies by using multiple sources [22]. There were almost no risks identified in bulk storage containers, i.e., intermediate containers used between collection and final storage, while many potential risks were found for collection and the final storage containers. For example, water at the final storage stage was often used for other purposes besides drinking. In addition, we found that the total risk scores for households who collected water from a tap were generally lower than for households who collected water from a spring, based on the revised household practices SI form (median values are 33% and 44% for households connected to a tap and collecting from a spring, respectively, H(1) = 28.79, $p < 0.001$).

Table 3 compares total risk scores from the original and revised SI forms. The comparisons indicate that even though the revised SI forms have more questions (and thus more potential for capturing risk observations), there was no apparent bias toward a greater total risk score. For example, for household practices, the revised form (18 questions) generated a median total risk score of 33%, which fell between the risk score generated by the 1997 form (25% from 4 questions) and the 2012 WHO and UNICEF form (50% from 10 questions). For spring sources, the revised form captured a median of 5/14 risks (36%), indicating that the springs inspected were relatively low risk in terms of contamination. However, the original SI form recorded a higher median total risk for the same spring supplies, at 6/10 (60%).

3.2. Water Quality Testing

In samples taken from springs, 40/45 (88.9%) contained *E. coli* (median = 17 CFU/100 mL). The share of samples with detectable *E. coli* was significantly greater than those reported in a previous study in the same location [24], which found the presence of *E. coli* in only 6.3% of samples. We may reason that the time of collection explains this difference, as Mbina et al. [25] collected their samples in the dry season (June–July 2019) and we conducted the present study in the rainy season (September 2019–February 2020). We therefore recommend that local authorities should build community awareness about the seasonal nature of microbial risks and the need to ensure effective and consistent treatment of drinking water prior to consumption. At the household level, proven strategies for ensuring good quality of stored drinking water include promoting household water treatment among households most willing and able to adopt it [26]. Outside of the home, a promising intervention that reduces reliance on individual behavior change includes installation of passive inline chlorinators in piped distribution schemes [27]. For non-networked water sources, such as dug wells and boreholes, chlorine dispensers at public water points paired with local promoters can achieve sustained uptake of chlorination [28].

In contrast to the sampled springs, only 1 out of 61 tap samples (1.6%) contained fecal contamination (median $\leq$ 1 CFU/100 mL). These findings indicate that tap water was much safer than spring water at this study site, as is confirmed by global patterns [2]. In a previous study in the same location, 54% of the samples collected from the taps tested positive for fecal contamination [29]. Following the dissemination of the results of the aforementioned study with key stakeholders in the area, several operational changes were implemented, including increasing chlorine dosage, more frequent flushing of the distribution network, and cleaning of the sedimentation tank in the water treatment plant. These measures likely significantly improved water quality, as reflected in the current study.

The median *E. coli* concentration among household storage container samples was 7 CFU/100 mL (77% of the storage container samples had detectable fecal contamination). Among households whose primary water source was the piped distribution system, stored water quality was significantly better than households whose primary water source was a spring (H (1) = 48.82, $p < 0.001$). In other words, 63 out of 68 households (92.6%) that relied on springs had contaminated stored water (median = 50 CFU/100 mL), while only 23 out of 61 households (37.7%) that collected water from the piped distribution system had contaminated stored water (median $\leq$ 1 CFU/100 mL). Statistical analysis showed that source water quality (spring and tap samples) were significantly correlated with water quality at the household level (storage container samples) (r_s (129) = 0.61, $p < 0.001$), in line with previous studies [15,30].

Figure 3 shows that water quality deteriorated from the point of collection (POC) to the point of use (POU) among all source types, as was confirmed by statistical analysis ($Z = -4.18$, $p < 0.001$). These findings are also in line with previous studies in other low-middle income countries [2,31–33].

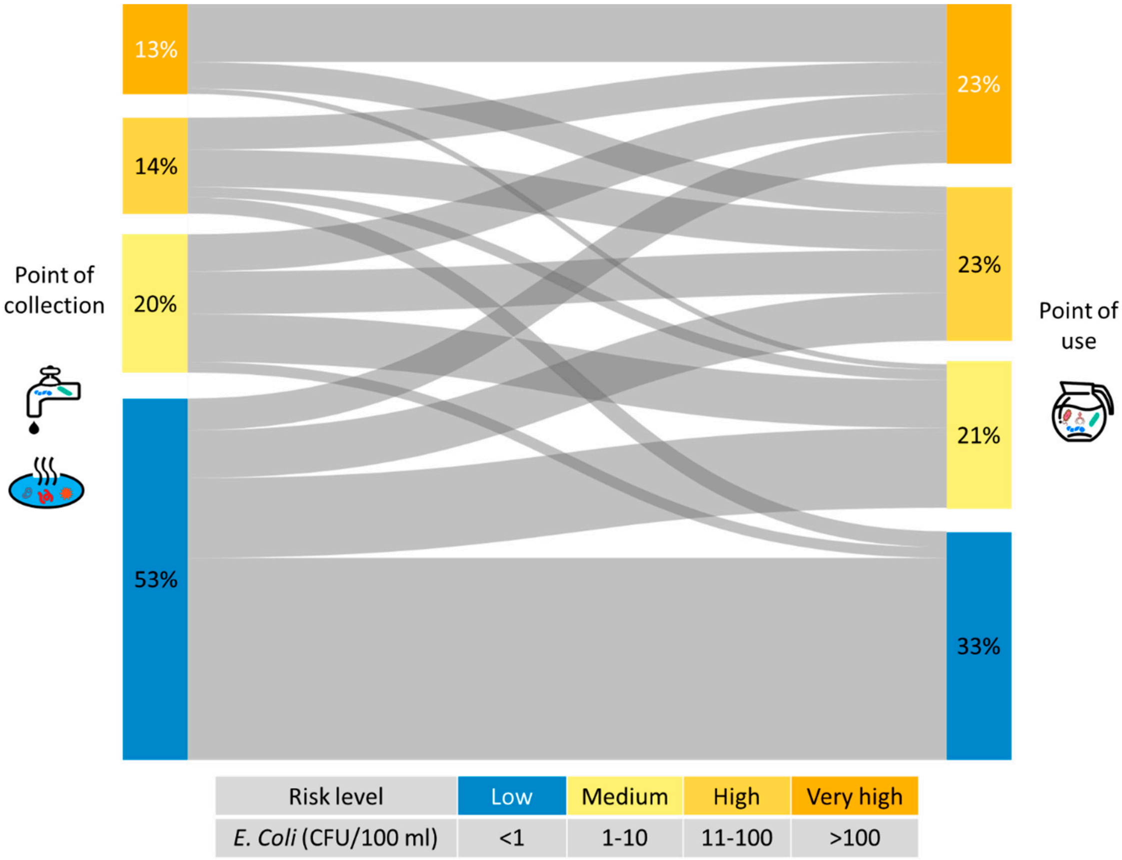

Figure 3. A Sankey diagram of water quality of the paired point of collection (POC) (spring and tap) and point of use (POU) (household) samples (n = 129). Some households used the same POC. The percentages indicate the proportion of samples at either the water source or household storage. The thickness of the line portrays the proportion of the samples.

More than half of the samples were within the WHO [3] pH guideline range of 6.5–8.5 (Table A3) for achieving effective chlorination, avoiding corrosion, and ensuring taste acceptability for consumers. Although the median pH level was within the recommended range, 41.3% of all samples were below pH 6.5, indicating a need to adjust the pH, especially for the piped distribution system (28% of the tap samples had pH < 6.5).

We found that water from spring sources was relatively more turbid compared to tap and household stored water (Table A3). The median turbidity of tap water was 2.8 NTU, which is above the WHO recommendation of <1 NTU for effective chlorination in piped systems [3]. Turbidity issues should not be considered trivial because high turbidity levels may have negative health consequences [34].

Relatedly, approximately 39.3% of the tap samples and 34.4% of the household storage samples had residual chlorine below 0.2 mg/L, (i.e., the recommended minimum concentration by WHO [3]). The observed elevated turbidity in the piped system is a potential reason for the low residual chlorine at two out of five taps sampled, while boiling practices could explain the low chlorine levels in many households (all households reported boiling their drinking water). However, statistical analysis revealed a significant association between residual chlorine levels and the presence of fecal bacteria in the household storage samples (X^2 (1) = 9.577, $p = 0.002$). The mean, maximum, and minimum values of the aforementioned physicochemical parameters are presented in Appendix A, Table A3.

3.3. The Relationship between Sanitary Inspection Risk Scores and Microbial Water Quality

We investigated the correlation between total risk scores and microbial water quality. We found a significant negative correlation between the *E. coli* concentration and total risk score for spring supplies using the revised SI form for springs (r_s (45) = −0.340, $p = 0.022$). This result shows that the higher the risk detected in the spring, the better the water quality, which is contradictory to the prevailing hypothesis, which assumes a higher risk leads to higher contamination. This result may be driven by the form's current wording, which assumes presence of an outlet pipe (see Section 3.4 for further discussion). There was no significant correlation between microbial water quality and total risk scores using the original SI form for springs. Similarly, there was no significant correlation between water quality results and the total risk scores from both the original and revised piped distribution SI forms (we note that variation was limited in this analysis since almost all taps had no detectable *E. coli*). Finally, there was a significant positive correlation between *E. coli* concentrations in household storage containers and the total risk score using all versions of the SI form for household practices; r_s (129) values for the original (1997) SI form, WHO and UNICEF (2012), and revised SI form were 0.56, 0.48, 0.44, respectively, ($p < 0.001$). Taken together, these results indicate inconsistencies in the relationship between microbial water quality and total risk score for springs, piped distribution systems, and household practices. Therefore, SI forms cannot reliably predict microbial water quality at the time of visit, which is in line with the review by Kelly et al. [9].

These results again underline how reviewing water quality test results and mitigating identified risks are complementary tasks to ensure water safety post-inspection. For example, in our case, the microbial water quality within the piped distribution system was very good, but sanitary inspections indicated that efforts are still needed to reduce the potential for contamination (Table 3). These efforts can include repairing cracked and leaking reservoirs and taps, adjusting pH levels to the appropriate range, and maintaining a residual chlorine level to a minimum of 0.2 mg/L in the piped system [3].

We then investigated the correlation between water quality and individual questions in the revised SI forms. We found one question, the outlet pipe condition, was significantly associated with *E. coli* concentration at spring supplies—(r_s (45) = −0.474, $p = 0.001$), the adjusted Bonferroni *p*-value is 0.0035 (0.05/14). However, this result was unconvincing because the outlet pipe question is not applicable for unprotected springs (i.e., the revised form assumes the presence of an outlet pipe). We then separated the protected and unprotected spring and undertook the analysis for this variable again. This variable was then found to be not significant for either type of spring. For other pairwise comparisons of individual SI questions and water quality at piped distribution systems, we found no significant correlation. This incompatible wording in the revised form could be a source of bias toward a "no" answer and result in counterintuitive results, as mentioned previously, i.e., the higher the total risk detected in the spring, the better the water quality.

For the revised household practices form, eight SI questions were significantly associated with the *E. coli* contamination levels of stored drinking water; the adjusted Bonferroni *p*-value is 0.0027 (0.05/18) (Table 4). Among those eight significant SI questions, seven confirm the common hypothesis suggesting that the water quality was worse if the risk was present. Moreover, five out of eight significant SI questions were related to the final storage, which suggests that (re)contamination occurs mainly at this stage, even after household water treatment (HWT) is reportedly practiced. There was no SI question regarding the intermediate or bulk container that was significantly related to water quality, which is due to very few risks being observed at this point (Table 2).

Table 4. Variables in the household practices form that were significantly associated with the *E. coli* contamination levels of stored drinking water.

	Variables	**Correlation ***		**Variables**	**Correlation ***
Collection Storage	storage is cracked or unclean	$r_s = 0.529$, $p < 0.001$	**Final Storage**	storage is cracked or unclean	$r_s = 0.508$, $p < 0.001$
	storage is used to store other liquid	$r_s = -0.369$, $p < 0.001$		storage is placed in contaminated place	$r_s = 0.250$, $p = 0.004$
	storage is placed in a contaminated place	$r_s = 0.279$, $p = 0.002$		storage cover is inadequate	$r_s = 0.360$, $p < 0.001$
				the storage's tap or utensil to draw water is inappropriate or unclean	$r_s = 0.577$, $p < 0.001$
				the final storage is used for other purposes	$r_s = 0.240$, $p < 0.006$

* $n = 129$.

3.4. Reflection of the Revised Sanitary Inspection Form

Based on this study, the main potential risk factors appear to be well represented in the revised SI forms overall. However, there are two specific questions that may create confusion in the revised form for springs. First, question 2 assumes the presence of an outlet pipe of some kind, yet an outlet pipe is not applicable for unprotected springs. We found that this inaccurate wording could lead to inspectors applying a default "no" answer, thereby biasing the risk assessment toward safety (when in fact the lack of protection suggests the opposite). To amend this form, we suggest that the question be changed to (edit in bold), "Is an outlet pipe **missing**, unsanitary, or inadequately positioned to prevent contaminants entering the spring?". Second, question 9 relates to the unprotected point of entry to the aquifer within 100 m of the spring (Table 2). It may be quite difficult for an inspector to thoroughly assess the surrounding 100 m of the spring, especially in a hilly area like Bushenyi-Ishaka municipality. There is also a potential for redundant questions (e.g., questions 11–14 are not needed if a spring box does not exist), which suggests the need for adaptation of the SI form according to the local context.

Based on this pilot study, several advantages and disadvantages of the revised SI forms were identified. As one advantage, the revised forms capture a broader array of potential hazards compared to the original forms and include more detailed descriptions of the hazards. For example, this question in the original form for springs "is the backfill area behind the retaining wall eroded?" is presented in the revised form as "is the backfill area eroded or prone to erosion due to the absence of vegetation?" The revised form for piped distribution covers more detail regarding the sanitary condition at reservoirs (e.g., pollution around and inside the reservoir), taps (e.g., condition of the tap attachment), and along the distribution system (e.g., exposed pipe and heavy vegetation that could damage the system). However, the main disadvantage is that the inspectors have to be familiar with the whole network to thoroughly inspect for leakages, exposed pipes, and heavy vegetation (i.e., questions 13–15 could take a considerable amount of time).

In the case of this study, the variation in collected data for the piped distribution system only appears in questions related to taps (i.e., 8–12), since all taps shared the same reservoir (questions 1–7) and distribution network (questions 13–15). Therefore, we suggest that the revised form offer guidance regarding the scale of SI implementation in the piped distribution system [29] (e.g., whether the inspection is limited to a branch of the distribution system or should encompass the entire piped network). Based on our experience, we hypothesize that questions regarding the integrity of "upstream" aspects of the piped system (e.g., the intake and reservoir) may not have equal influence on final water quality as compared to "downstream" observations such as pipeline and tap integrity. Future research is necessary to further refine the piped distribution form and determine if there is a need for relative weighting of various items. We also suggest an investigation into how to appropriately scale the application of SIs to the piped distribution system to allow meaningful comparison of risk scores across different distribution systems.

Another advantage of the revised forms is that the addition of extra questions did not require much additional time or effort spent on the inspection. For example, the number of questions in the revised household practices form (18 questions in the draft version and 19 in the final published form) is nearly a two-fold increase compared to the original form (10 questions). Despite this increase, the inspection time spent on a supply did not differ significantly when the inspector was well-trained with the new questions (e.g., the definition of terminology). Still, there were doubts about some of the terminology in the revised forms. For example, the question of whether the collection container has a large uncovered opening was difficult to assess since "large" is unclear in this context. Another example is the definition of container cleanliness and what defines an "inappropriate" tap or utensil used to draw water from the container. Our observations are echoed by Pond et al. [35] and Okotto-Okotto et al. [36], who argued that the way sanitary inspectors think about a specific term and risk can vary and will influence the assessment's validity. Moreover, the misinterpretation of terminology can backfire if the water, sanitation, and hygiene (WASH) officers use the SI form as part of behavioral change intervention in household practices. For instance, using the previous example of a large opening and uncovered storage, one may consider that narrow uncovered openings present no risk, which is not true. Therefore, we suggest implementation teams adapt the forms by harmonizing them with locally used terminology.

The revised household practices form aims to capture the whole process: water collection, bulk or intermediate storage, final storage, and household water treatment. However, the questions for the three stages of collection and storage will not be relevant to all households encountered and may lead to confusion during data collection and analysis. For example, the questions for intermediate storage are not relevant to households that directly treat their collected water (Pathway C, Figure 4).

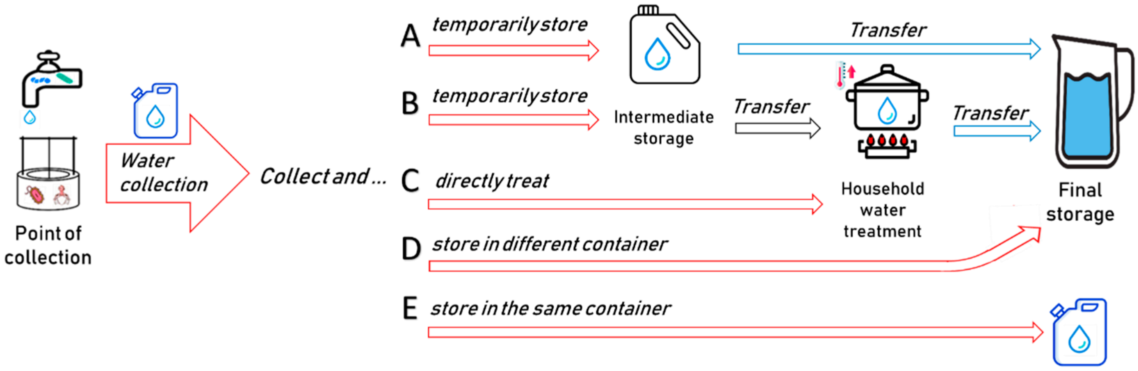

Figure 4. Five potential pathways (**A**–**E**) from water collection to final storage in the context of off-plot water supplies.

To avoid potential confusion, we suggest adapting the form for each unique household context shown in Figure 4, or alternatively, allowing the possibility for the inspectors to indicate a particular risk factor is "not applicable". Reporting total risk as a percentage would then allow for comparison across households following different pathways.

Another potential source of confusion is the question regarding whether household water treatment is being carried out ineffectively, especially if the inspector is not familiar with all types of HWT. Therefore, the inspector needs to be trained and familiarized with the proper procedures of all types of HWT. Moreover, the term "ineffective" in the household practices form seems inadequate since effectiveness can only be measured by water quality testing before and after treatment. The term "incorrect" is more appropriate and can be assessed by observation of the HWT as demonstrated by the respondent. Given this fact, we again highlight the complementary aspect of SI and water quality monitoring in risk-based surveillance strategies. Combining SI and water quality testing at the household level can also "verify" whether locally applied HWT has effectively removed fecal contamination.

We also note that question 18 in the revised household practices form does not consider those who do not practice treatment at all. It is likely that treatment done incorrectly and the absence of treatment altogether both pose considerable risk, so the form should be amended as follows (edit in **bold**): "**Is** household-level treatment **not practiced or practiced incorrectly**?" That option is also suggested if we want to emphasize a message, such as in the WASH or HWT promotion, that correct and consistent use of HWT is necessary. Any incorrect locally applied treatment, such as "strain through cloth" or "let it stand and settle" as noted in the Demographic Health Survey (DHS) [37], should not be practiced. In addition, households that collect drinking water from a safely managed water source do not require HWT according to the WHO/UNICEF JMP classification [38]. In this situation, the question of HWT could be marked as "not applicable".

Finally, we noted that some information relevant to drinking water safety was not included in the revised household practices form, such as: the duration of water storage; the volume of water inside the final storage container; whether the respondents used the same container for collection, intermediate storage, and final storage; and the last time the final storage container was cleaned with soap [31,39–43]. This information may be relevant, especially if the SI aims to suggest effective control measures to improve drinking water quality.

4. Conclusions

The revised SI forms cover a wider and more detailed set of potential sources of contamination compared to the original forms. Despite broader coverage, the total risk scores captured by the revised SI forms were not consistently higher than those arising from the original forms, and the time required to conduct inspections with the revised forms was comparable. Based on our analysis of the water quality in Bushenyi-Ishaka municipality, contamination at the majority of spring sources sampled indicated an intermediate health risk (between 11–100 CFU *E. coli*/100 mL), while the samples from household storage containers indicated a low health risk (between 1–10 CFU *E. coli*/100 mL). Almost all of the taps sampled (98%) met the WHO guidelines (<1 CFU *E. coli*/100 mL). In line with previous studies, scores derived from the revised SI forms did not consistently predict water testing results, indicating that SI forms should not replace but rather complement water quality monitoring activities as part of a comprehensive management strategy.

We suggested minor revisions of some technical terms to improve the practical application of the revised forms. These revisions are: including the absence of a spring outlet pipe and household treatment practices as specific risks; replacing the word "ineffective" with "incorrect" when referring to household water treatment risks; avoiding relative terms such as "large opening" when referring to storage containers; adapting household practices forms to accommodate different collection and storage scenarios; and allowing inspectors to indicate "not applicable" for irrelevant questions. We also identified certain redundant or missing questions that may be important for assessing drinking water safety, e.g., the need for a question on storage container cleaning practices. Sanitary inspectors should be familiar with the characteristics of local water sources, household water management, and general hygiene practices. Alternatively, intensive training may be required for new inspectors. Finally, we suggest that the SI forms be carefully adapted to their local context to maximize their applicability for small water supply schemes.

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Appendix A

Table A1. List of questions in the original 1997 (WHO) and 2012 (WHO and UNICEF) sanitary inspection forms for household practices, and the total number of "yes" answers recorded for each question during both studies.

No.	SI Form 2012 (n = 10) [a]	Total "yes" [a]	SI Form 1997 (n = 4) [a]	Total "yes" [a]
1.	Is the water storage container used for storing any other liquid or material?	0	Can contaminants (e.g., soil on the inside of the lid) enter the tank during filling	55
2.	Is the water storage container kept at ground level?	129	Does the tank lack a cover?	102
3.	Is the water storage container lid or cover absent or not in place?	103	Does the tank need a tap for withdrawal of water?	0
4.	Is the storage container cracked, leaking or insanitary?	32	Is there stagnant water around the storage tank?	1
5.	Is the area around the storage container insanitary?	1		
6.	Do any animals have access to the area around the storage container?	69		
7.	Is the tap or utensil used to draw water from the container insanitary?	37		
8.	Is the water from the container also used for washing or bathing?	90		
9.	Has there been discontinuity in water supply in the last 10 days?	6		
10.	Is the water obtained from more than one source?	129		

[a] Data are n of "yes" responses; maximum "yes", i.e., total samples, for household practices are 129.

Table A2. List of questions in the original draft 1997 (WHO) sanitary inspection forms for spring and piped distribution system, and the total number of "yes" answers recorded for each question during both studies.

No.	Piped Distribution SI Questions (n = 11)	Total "yes" [a]	Spring System SI Questions (n = 10)	Total "yes" [a]
1.	Is there any point of leakage between source and reservoir?	0	Is the spring unprotected?	21
2.	If there are any pressure break boxes, are their covers unsanitary?	0	Is the masonry protecting the spring faulty?	15
3.	If there is a *reservoir*: Is the inspection cover unsanitary?	0	Is the backfill area behind the retaining wall eroded?	2
4.	Are any air vents unsanitary?	0	Does spilt water flood the collection area?	34
5.	Is the reservoir cracked or leaking?	61	Is the fence absent or faulty?	45
6.	Are there any leaks in the distribution system?	31	Can animals have access within 10 m of the spring?	43
7.	Is the area around the tap-stand unfenced (dry stone wall and/or fencing incomplete)?	61	Is there a latrine uphill and/or within 30 m of the spring?	0
8.	Does water accumulate near the tap-stand (requires improved drainage canal)?	61	Does surface water collect uphill of the spring?	2
9.	Are there human excreta within 10 m of the tap-stand?	55	Is the diversion ditch above the spring absent or non-functional?	44
10.	Is the plinth cracked or eroded?	0	Are there any other sources of pollution uphill of the spring?	39
11.	Does the tap leak?	31		

[a] Data are n of "yes" responses; maximum "yes", i.e., total samples, for spring and tap are 45 and 61, respectively.

Table A3. Median values of physicochemical water quality parameters.

Type of Sample	pH (Range)	Turbidity (NTU) (Range)	Residual Chlorine (mg/L) (Range)
Spring (n = 45)	6.2 (5.0–7.3)	5.8 (1.1–80.7)	n.a.
Tap (n = 61)	6.7 (4.8–7.8)	2.8 (0.86–7.10)	0.17 (0.02–0.54)
Household practices (n = 129)	6.6 (4.8–8.5)	3.2 (0–78.40)	0.17 [a] (0.03–2.10)

[a] Only for households connected to a tap (n = 68); n.a. = not applicable.

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