

A basic bottom-up approach for small systems of safe-water supply: a decentralized case study in Uganda

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ABSTRACT

In developing countries, diarrhea is known as the major cause of burden among children. Diarrhea is associated to poor quality of drinking water, inadequate sanitation and insufficient hygiene behavior. This work introduces a bottom-up approach for the implementation of a borehole installation in conjunction with proper water handling in rural areas. A pre-intervention survey was performed as a basic decision tool, and a post-intervention survey was performed to evaluate the quality of the intervention. In particular, information was collected regarding the water source, the health status, the water related behavior, hygiene and on other issues. Furthermore, coliforms and fecal contamination of the water sources used during the dry season were determined. Prior to the intervention the monthly diarrhea incidence was estimated to be around 22.0% among children. Microbiological analysis showed that sources of water (river, swamp and waterhole) presented a high fecal contamination (>250 for river and swamp, 110 most probable number index 100 mL⁻¹ for waterhole). After the intervention, the monthly diarrhea incidence dropped to 10.2% among children, showing a significant reduction of 11.8% ($p < 0.01$). Even though this represents an exciting result, more intervention projects at household level are required in order to further reduce the diarrhea incidence.

Key words | borehole, bottom-up approach, developing countries, diarrhea, drinking water, questioner, water contamination

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INTRODUCTION

In developing countries about 80% of diseases are water originated (Boschi-Pinto *et al.* 2008) and diarrhea is the most common gastrointestinal infection and major cause of deaths among children (Kosek *et al.* 2003; WHO 2012).

Water-quality standards refer to substances and physico-chemical parameters that may have health implications (WHO 2011). In particular, microbiological quality is the most important parameter in order to evaluate the level of contamination and consequently the level of potential risk of water related diseases (Macler & Merkel 2000; Yassin *et al.* 2006). The microbiological water quality is typically monitored by means of bacterial indicators consisting of total and fecal coliforms (Gadgil 1998). However, even though the presence of fecal coliforms indicates fecal contamination, therefore strongly suggesting the existence of

pathogenic organisms (Ogden *et al.* 2001; Ferguson *et al.* 2003), their actual presence has to be confirmed by other means. In fact, it is important to underline that the results of bacteriological analysis may provide ambiguous information regarding the presence or absence of pathogens.

Water quality interventions have proven to be really effective in reducing diarrheal infection (Fewtrell *et al.* 2005; Clasen *et al.* 2007). In particular, the access to a point of source (POS) of safe drinking water by means of 'hardware' intervention, such as boreholes or tube wells, was demonstrated to be highly effective in reducing diarrhea incidence (Waddington & Snilstveit 2009; Opryszko *et al.* 2010). However, although the initial microbiological quality of water might be acceptable, it can be contaminated during transport, storage and by means of unhygienic

handling practices (Trevett *et al.* 2004; Wright *et al.* 2004). Furthermore, the use of household technologies (points of using water treatment (POU)) is likely to improve health conditions (Doocy & Burnham 2006; Graf *et al.* 2010). Several techniques have been developed to eliminate pathogens from water at household level. Well-known methods are: chlorination, flocculation/disinfection, boiling, filtration and solar disinfection (Sobsey 2002, 2008). Finally, it was reported that appropriate hygiene education raises the awareness toward water handling and increases the effectiveness of structural interventions (Opryszko *et al.* 2010).

The selection of the most effective drinking water intervention (or a combination of different interventions) is a complex task. Due to the socio-economic heterogeneity of communities in developing countries, the impact of the same intervention can drastically change among different areas. Therefore any assessment to be used as a decision support tool, has first to investigate the environmental conditions, the health of the inhabitants, their hygienic practices and the social situation. An accurate assessment can highlight the most suitable infrastructure or suggest solutions that may allow better hygiene behaviors.

This work presents a bottom-up approach used to assess the impact of boreholes in improving the health conditions of inhabitants living in rural areas. Prior to the installation of the borehole, social/hygienic assessment was performed. It included (i) water supply, (ii) sanitation scenario and hygiene awareness, which were used to (iii) quantify the health implications. Moreover, microbiological analyses of the sources of drinking water were carried out. Based on the collected data, it was decided to perform a single structural intervention jointly with the implementation of a focused hygiene education program. Finally, the social and health impact of the intervention was evaluated by means of a post-intervention assessment.

MATERIALS AND METHODS

Study site

The research was carried out in a small and decentralized village in south-west Uganda. The Republic of Uganda is a country seated in central east Africa with a population of approximately 36 million. The Joint Monitoring for Water

Supply and Sanitation reported that since 1990 the average access to safe water in Uganda had increased from 43 to 72% (WHO & UNICEF 2012). However, access to safe water sources varies considerably among districts, urban and rural areas. For example, in rural areas, where 87% of the total population lived in 2010, the access to water reached 68% of the population (WHO & UNICEF 2012). The most common options for supplying water are protected springs, boreholes and protected wells. People not having access to a safe source of water supply have to rely on surface water (e.g. rivers and lakes) and unprotected wells (UN-Water 2006). The level of per capita water consumption in rural areas was estimated in 13 L person⁻¹ per day (UN-Water 2006).

The present study was undertaken in Karuhisi rural village, located in Kashari sub-county, Mbarara District. The village is about 40 km from Mbarara town and 4 km from Rubindi trading centre on the Mbarara-Ibanda road. Here, the non-governmental organization ‘Youth Support Group (YSG)’ located in Mbarara (Registration No – S.5914/3988, 21 June 2002) in collaboration with the association ‘Monastero del Bene Comune’ seated in Verona (Italy) support the ‘Karuhisi Training Farm’ project. In this area rainwater is the main source of drinking water during the rainy season. However, during the dry season it becomes insufficient and rainwater is replaced with surface water. This includes: tap water, streams and a small waterhole, which opens concerns about their microbiological quality. Therefore, actions were put in place in order to improve the water quality and to reduce the water originating diseases.

Data collection

The study comprised of two assessment surveys. A pre-intervention assessment was conducted prior to the installation of the borehole while the evaluation survey was realized after the intervention. Therefore, two assessments were conducted in the same area and most of the households have been surveyed twice.

Questionnaire

Both the pre- and post-assessments were performed by means of a questionnaire. The covered aspects addressed

the socio-demographic situation, health status and water-related behavior. The questionnaire was issued both in English (official language in Uganda) and in Runyankore (the most spoken language in the area). Only one member per household (usually the mother) was questioned with the support of young members of the Karuhisi Training Farm, who were trained concerning the questionnaire and its contents. The questionnaire was related to the following topics:

- (i) Since no demographic data were available for this area, the number of householders and children was firstly monitored.
- (ii) Specific questions were included regarding sources of drinking water and water-related behaviors. Water boiling practices were also questioned. Furthermore, the perception on the safety issues related to the quality of water was investigated by the question: 'How should the drinking water be?' The possible answers were: good taste, odorless, clear, does not make you ill, other.
- (iii) Health status among children was monitored, through diarrhea occurrence, during both the dry and the rainy season (for more detailed information about surveillance strategy, see pre- and post-intervention assessment paragraphs). Diarrhea was not unambiguously defined inasmuch as it relied on the perception of the mother. The opinion of the inhabitants about the cause of diarrhea was also questioned and the most common childhood diseases were examined; three open-ended answers were provided.
- (iv) Finally, the social acceptance of the intervention was evaluated. The list of questions to be answered by the post-intervention questionnaire is reported in Table 1.

Pre-intervention assessment

The pre-intervention assessment was conducted at the end of August 2011. Diarrhea incidence among children was monitored in August (dry season) and November (rainy season) 2011. Weekly active diarrhea surveillance was conducted by the youth member resident in Karuhisi Training Farm.

Table 1 | List of aspects and relative questions reported in the post-assessment questionnaire. The diarrhea incidences were reported after the periods of surveillance

Householder data

1. Family's name and composition (how many children)
2. Do you live in this village before or after the installation of the borehole?

If after:

3. Did the presence of the borehole trigger you to move into this village?

Drinking water sources

1. Where do you take your drinking water from during rainy/dry season?
2. If you do not use the water from the borehole: do you boil water before drinking?
3. If you go to the borehole, do you meet other people? If yes, how many?
4. Do you go to the borehole only for water or even to meet other people?
5. In your opinion, how should our drinking water be?
6. Since the installation of the borehole, have you saved wood, time or money?

Health status

1. Number of children that have suffered diarrhea during the rainy/dry season?
2. What are the most common diseases among the children of your family?
3. In your opinion, what are the causes of diarrhea?

Social acceptance for the operation and maintenance of the borehole

1. The borehole needs some fixing or adjustment?
 2. Can you supply money together with all the community for the maintenance of the borehole?
 3. Do you have some advice, suggestions or criticisms?
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Post-intervention assessment

The post-intervention assessment was performed in December 2012. The following aspects were addressed: (i) Since the installation of borehole, have you saved woods, time or money? More than one answer was accepted. (ii) How many people do you meet at the borehole? (iii) Do you have suggestions, criticisms, regarding the borehole and its maintenance? Weekly diarrhea surveillance among the children was conducted in August (dry season) and November (rainy season) 2012 by the youth member resident in Karuhisi Training Farm.

Statistical analysis

Chi-square test (χ^2) was used as statistical analysis in order to investigate whether distributions of categorical variables differ from one another with statistical significance. The critical value p , as probability level, was set at $p = 0.05$. If the calculated chi-square value resulted in less than 0.05, the difference among the data was considered significant. High significant level was assessed to data with $p < 0.01$.

Microbiological analysis

Water sampling

The water samples were collected in a sterile 1 L glass bottle and preserved between 4 and 10 °C until the microbiological analysis was performed. The time intercourse between sampling and analysis was always less than 5 h. All the analyses were performed in triplicate form.

Heterotrophic bacterial count

Serial dilutions of water samples were performed. Thus, the number of heterotrophic bacteria was estimated by colony forming unit (CFU) counts on a nutrient medium (Oxoid) incubated at 35 °C for 48 h. Uninoculated plates were used as blank control.

Total coliform bacteria

Four different volumes (0.1, 1, 10 and 100 mL) of each sample of water were filtered through 0.45 μm pore-size sterile cellulose membranes. The filters were placed both on a plate containing m-Les Endo agar added with 1.2 mg L⁻¹ of basic fuchsin (Oxoid) and on MacConkey agar (Oxoid). The plates were incubated for 24 h at 35 °C. Golden-green metallic sheen colonies – considered as presumptive coliforms – were counted on each m-Les Endo agar plates. Furthermore, fermenting (*Escherichia coli*, *Enterobacter* and *Klebsiella*) and non-fermenting (*Salmonella*, *Proteus* species, *Pseudomonas aeruginosa* and *Shigella*) lactose were counted on differential MacConkey medium agar. Sample volumes, yielding between 20 and 80 fecal coliform colonies per membrane, were used for counting the total amount of coliform

bacteria. Finally, sterile water was filtered through cellulose membrane and used as negative control.

Fecal coliforms

EC broth (Oxoid) fermentation tubes containing inverted Durham tubes were used for the differentiation of fecal coliforms. Gas production and bacterial growth after 24 h of incubation at 44.5 °C were considered as a positive. Sterile water was used as negative control. Most probable number (MPN) was thus applied to quantify the fecal coliforms. The range of MPN index of fecal coliform for 100 mL of water was between 0 and 250. The risk of contamination considered in this study recalls WHO (2003) Guidelines and Copeland et al. (2009). In particular, 0 fecal coliforms (for 100 mL of water)⁻¹, no risk; 1–10, low risk; 11–50, medium risk; 51–100, significant risk; 100–250 high risk and more than 250, very high risk.

Intervention

On the basis of the results obtained both from the microbiological water quality and from the pre-intervention assessment, a borehole was built between December 2011 and January 2012. The construction was committed to a Ugandan company. The shallow well was installed as follows: a drilling of 20.5 cm diameter was carried out, and uPVC casing and screen were thus fixed (12.5 cm diameter). Bottom cap and sanitary seal were also included. Moreover, a platform with pedestal, water tank and U2 pump head were supplied. Finally, U2 rising pipes (3.5 cm diameter; 9 m length), connecting rods and cylinder were provided. The geological survey was carried out by means of vertical geoelectrical Schlumberger methods.

Safe water is essential for improving the sanitary status, but poor results will be achieved in terms of public health if hygiene practices are not appropriate. Thus, a simple but fundamental program of hygiene promotion was also performed. The chosen communication strategy was to avoid flyers, workshops and, in general, all the strategies that tend to involve lectures or theoretical concepts. Furthermore, the promoters of this project stayed in the Karuhisi Training Farm together with the young members of Karuhisi farm and in contact with the families of the neighboring village. During the intervention period, the researchers

visited the families without carrying out any formal kind of research, aiming to observe and identify the hygienic practices, attending and aiding the families during their routine activities such as cooking, washing and boiling water. At the same time, the supervisors engaged in conversation with the village people concerning the applied methodology therefore suggesting and showing the most suitable hygienic practices. The efforts were focused towards few, but essential, aspects of daily activities. Finally, the adopted strategy was to interact with the village people without appearing like teachers, but instead discussing with them as peers.

RESULTS

Pre-intervention assessment

Householder data

The pre-intervention assessment has identified a target of 34 families with 184 children (mean 5.4 children for family) plus eight youths seated in Karuhisi Training farm.

Drinking water sources

During the rainy season 29 families used rainwater for drinking (85%). Moreover, three householders collected water from the river (9%) and two from the waterhole (6%). On the other hand, during the dry season, the sources of drinking water were the river and the waterhole (13 families; 38%). Eventually, four households collected tap water and water from the swamp (12% each) (Table 2). Among the 34 families, only nine (26%) were used to boiling water before drinking.

The perception of, 'how should the drinking water be', revealed that 29 families (85%) believed the water should 'not make you ill'. The percentage drops to 6% (two families each) both for 'clear' and 'good taste'; for one householder (3%) the drinking water should be 'odorless' (Figure 1).

Health status

The prevalence of diarrhea was monitored before the intervention in order to obtain the baseline data. The incidences of diarrhea among children of the village were 34 during the

Table 2 | Sources of drinking water

	Pre-assessment		Post-assessment	
	Dry season	Rainy season	Dry season	Rainy season
River	13	3	0	0
Waterhole	13	2	0	0
Swamp	4	0	0	0
Tap water	4	0	0	0
Rainwater	0	29	0	25
Borehole	–	–	46	21
Total	34	34	46	46

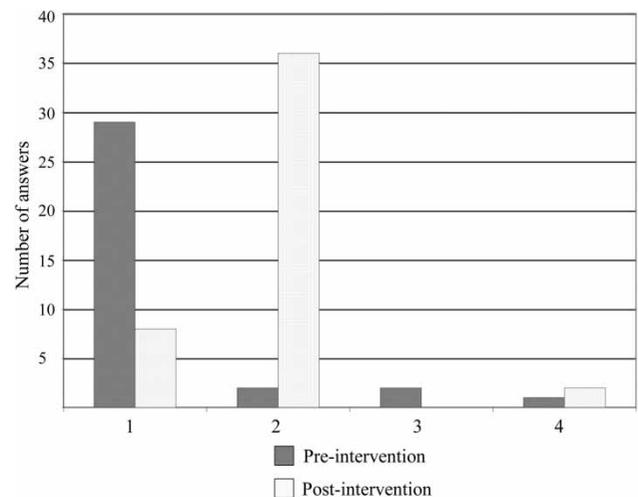


Figure 1 | Number of answers before and after the intervention concerning the question: 'How should the drinking water be?' (1) No ill, (2) clear, (3) good taste and (4) odorless.

dry season (mean value 18.5% of children every month) and 47 during the rainy season (mean value 25.5% of children every month). Overall, taking into account both data, an average of 22.0% was calculated. No correlations in diarrhea incidence were found either between the rainy and dry season or among the different water sources ($p > 0.05$) (Figure 2). Similarly, boiling water was not effective in diarrhea prevention among children, during either the dry nor the rainy season ($p > 0.05$).

In the opinion of the inhabitants, the causes of diarrhea were related to contaminated water (20 householders; 59%), unboiled water (seven householders; 20%), worms, mosquito and dirty hands (one householder; 3% each). Among the householders, four (12%) did not answer (Figure 3).

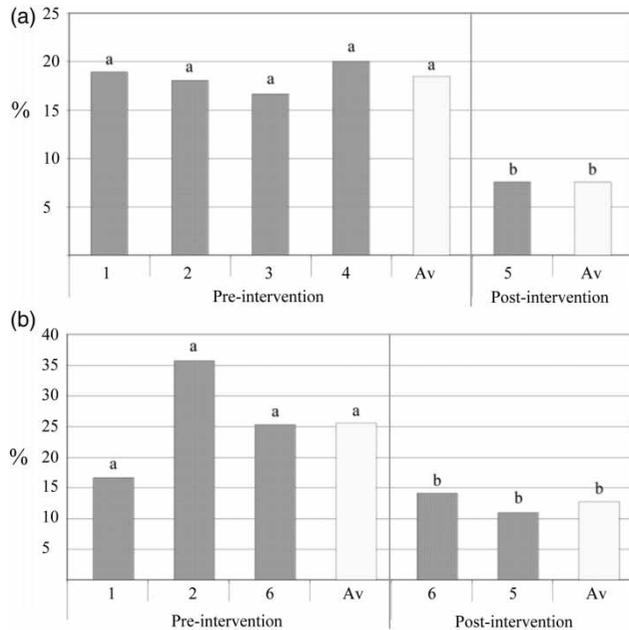


Figure 2 | Diarrhea prevalence for children during 1 month of surveillance before and after the intervention among the different sources of water. (a) Diarrhea prevalence during the dry season. (b) Diarrhea prevalence during the rainy season. (1) River, (2) waterhole, (3) swamp, (4) tap water, (5) borehole, (6) rainwater and (Av) average. Values followed by the same letter are not significantly different according to Chi-square test (χ^2) ($p < 0.01$).

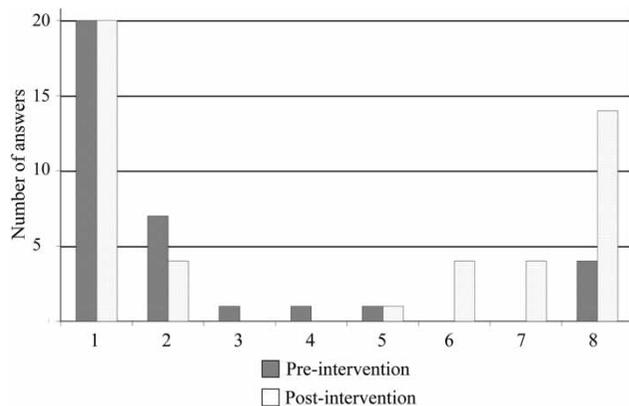


Figure 3 | Number of answers before and after the intervention at the question: 'In your opinion, what are the causes of diarrhea illness?' (1) Contaminated water, (2) unboiled water, (3) worms, (4) mosquito, (5) unclean hand, (6) dirt, (7) diet and (8) no answer.

Among the most common childhood diseases the inhabitants perception was diarrhea (26 answers) followed by malaria (24 answers). Finally, six answers were given for typhoid, three for skin rashes, two for flu and cough and one for fever (Figure 4).

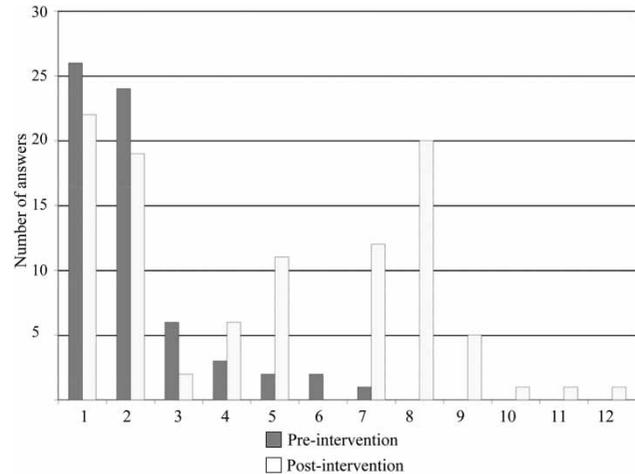


Figure 4 | Number of answers before and after the intervention at the question: 'Which are the most common diseases among your children?' (1) Diarrhea, (2) malaria, (3) typhoid, (4) skin rashes, (5) flu, (6) cough, (7) fever, (8) stomach-ache, (9) headache, (10) measles, (11) pneumonia and (12) mumps.

Social acceptance for the operation and maintenance of the borehole

The population of the village was well informed that the borehole would have been a new common structure. Therefore, the community should take care of its functionality and maintenance. The householders accepted these conditions and showed good sensibility and willingness.

Microbiological analyses of water

The water quality is defined by physical, chemical and biological parameters. On the basis of the current knowledge, no chemical pesticides and phytopharmaceuticals were used in the area under investigation. On the other hand, high turbidity and solid suspensions were observed in the river, the swamp and the waterhole.

Microbiological analyses of heterotrophic bacteria, total coliforms and fecal coliforms were performed on sources of water used during the dry season (river, swamp, tap-water and waterhole). Microbiological results of water are summarized in Table 3. The results indicated that the river and the swamp exhibited more than 10^5 CFU (100 mL^{-1}) and more than 250 MPN index for 100 mL of total and fecal coliforms, respectively. Furthermore, the waterhole showed a concentration of $3.95 \times 10^4 \pm 3.5 \times 10^3$ CFU (100 mL^{-1}) of total coliforms and 110 MPN index for 100 mL of fecal

Table 3 | Microbiological results obtained from the sources of water used during the dry season

Sources of water	Heterotrophic bacteria (CFU/mL)	Total coliforms CFU (100 mL) ⁻¹	Lactose fermenting	Fecal coliforms MPN index (100 mL) ⁻¹
River	>10 ⁴	>10 ⁵	–	>250
Swamp	>10 ⁴	>10 ⁵	–	>250
Tap water	35 ± 3.54	80 ± 29.7	70 ± 15%	11
Waterhole	3,350 ± 262	3.95 × 10 ⁴ ± 3.5 × 10 ³	75 ± 25%	110

coliforms. On the other hand, the contamination level of total and fecal coliforms in tap water was 80 ± 29.7 CFU (100 mL⁻¹) and 11 MPN index for 100 mL respectively.

Therefore, the results showed that 50% of the householders fell into the ‘very high-risk’ category (river and swamp), while 38% were in the ‘high-risk’ category (waterhole) and only 12% of the householders were classified as ‘medium-risk’ category (tap water).

Intervention

On the basis of the data collected both from the questionnaires and from the microbiological analysis, the installation of a borehole was planned. The daily water flow was estimated to be approximately 7 m³ day⁻¹ for the needs of the farm and the Karuhisi community. The local geology comprises of Karagwe–Ankolean rock system. Past experiences and previous drilling results suggested that the groundwater potential in the area might be classified as medium to high. The sounding showed good ground water potential and a spot was selected for drilling within the land owned by the Karuhisi Training farm. GPS co-ordinates of the spot are: S-00°20.958', E-030°32.644' at an altitude of 1,429 m. The investigation showed that the groundwater was expected mainly at the transition zone to the quartzite formation layer, therefore recommending a borehole depth of 25 m. The water extracted from the borehole respected both the quality and the quantity previously planned.

During the visits to the families, the supervisors observed different hygienic practices. The focus of the surveillance was on water handling. The main hygienic risk practices were the following. (i) Excessive quantity of water was boiled at once which led to a poorly boiled water. After boiling, water was transferred into a dirty container with no lid and kept for more than one day. (ii) In order to disperse the smoke outside the kitchen, the door

was opened during cooking activities. Thus, chickens or dogs had free access to the kitchen. The supervisor addressed the inhabitants towards better hygienic practices by means of discussion and practical examples. The first reaction of the inhabitants was suspiciousness, but soon after they became interested and curious. The main strengths of hygiene education were the improvement of water boiling/storage and the cleanliness of the kitchen and containers.

Post-intervention assessment

Householder data

One year after the first assessment the selected area showed significant demographic changes. From August 2011 to December 2012, the families settled in the area increased from 34 to 46. On the other hand, the children decreased from 184 to 172 (mean 3.1 children for family). Nevertheless, only four new families moved to this area after the intervention (the presence of the borehole triggered three householders to move in this area). Thus, the occurrence of fewer children and more families could be attributed to the setting of new householders (with none or one child) that were classified as children in the previous year. Conclusions about infant mortality were not possible inasmuch as these data were not monitored.

Drinking water sources

The presence of the shallow well drastically changed the sources of drinking water. During the dry season all householders had water supplied from the borehole. During the rainy season 21 (46%) and 25 (54%) families collected water from the borehole and rainwater, respectively (Table 2). The number of householders that boiled water

(if the water was not supplied from the shallow well) increased from nine (26%), as observed in August 2011, to 20 (43%) in December 2012. Unexpectedly, even the perception of 'how should the drinking water be', significantly changed. In fact, 36 families (78%) answered that safe water should be 'clear', and only eight (18%) answered 'not make you ill'. This result is significantly different from the data revealed before the intervention (Figure 1). The inhabitants noticed that the presence of the borehole allowed firewood (26 answers), money (19 answers) and time (13 answers) saving.

Health status

The prevalence of diarrhea after the intervention was accurately monitored (Figure 2). In the dry season 13 cases of diarrhea were reported (mean value 7.6% of children every month), a number that increased to 22 (mean value 12.8% of children every month) during the rainy season, when almost half of the householders collected rainwater. Taking into account both dry and rainy season the average was 10.2%.

In comparison to the pre-assessment survey, the diarrhea incidence decreased to 10.9% and 12.7% during dry and rainy seasons, respectively ($p < 0.01$). A mean value of 11.8% between the two seasons was obtained ($p < 0.01$).

Unlike the results obtained in 2011, a significant difference ($p < 0.05$) in diarrhea incidence was detected between families that boiled (8.2%) and did not boil (24.1%) rainwater. The latter group showed similar diarrhea prevalence to the pre-assessment investigation ($p > 0.05$). Furthermore, similar diarrhea percentage was found within families boiling rainwater as well as those who were supplied from a borehole ($p > 0.05$).

The opinion about the causes of diarrhea for the household did not change between pre- and post-intervention: for 20 interviewed (43%) these were related to contaminated water; for four householders (9%) they were associated with unboiled water, dirty and diet; no bathing for one household (2%); 13 householders (28%) did not answer (Figure 3).

The main diseases observed among children were diarrhea (22 answers), stomach ache (20 answers) and malaria (19 answers). Fever and cough had 12 and 11 answers,

respectively. Furthermore, typhoid was reported with two answers; measles, pneumonia and mumps were answered once (Figure 4).

Suggestions and criticisms about the functionality and maintenance of the borehole

During the first year the shallow well did not require any maintenance work. The advice from the families were the following: it would be important to clean the area and cut the grass around the borehole, and avoid children playing near the structure. However, the long queue and time needed to collect water from the borehole was the main criticism. In fact, a mean of 13.5 persons waited to collect water from the borehole. This happens because most of the householders collect water at the same time, especially in the evening. A note of curiosity: householders tend to enjoy chatting while waiting at the borehole.

DISCUSSION

This work describes the health impact of an intervention aimed at reducing diarrhea in a rural area of Uganda. Once identified, the sources of water and their microbiological quality was investigated. In particular, sources used during the dry season were considered. The microbiological analysis showed that 50% of the householders fell into the 'very high-risk' category (river and swamp), while 38% were in the 'high-risk' category (waterhole). Only 12% of the householders could be classified as 'medium-risk' category (tap water). Although sources of water fell in different categories risk, no significant correlations were found between sources and diarrhea incidence. The major factor that contributed to the coliform contamination may be the presence of animals grazing around the river and the swamp. In fact, surface water was the most contaminated water. Unfortunately tap water, the safest source of water, was situated far away from the village. This explains the limited number (four) of householders using this kind of water source.

The data collected during the pre-assessment (baseline data) showed mean values equal to 18.5 and 25.5% for diarrhea incidence among children during dry and rainy season,

respectively. Previous studies showed an incidence of diarrhea of 22.1% in Afghanistan (Opryszko *et al.* 2010), 34.3% in Cameroon (Graf *et al.* 2010) during 2 weeks of surveillance, and 36.8% in Niger during a recall period of 27 days (Page *et al.* 2011). The present work showed less diarrhea prevalence in comparison with the aforementioned studies. On the other hand, the previous reports were conducted on children under 5 years of age. Conversely, this work included all the children of each family (no age limitations) in order to increase the statistical population. In particular, when all the members of the family are integrated in the analysis, the incidence of diarrhea would decrease from 22.1 to 6.4% (Opryszko *et al.* 2010). To be noticed that the data of this work are consistent with the literature, hence they can be considered reliable for further analysis and considerations.

The results achieved from the pre-assessment survey were used as a decision tool to plan the most suitable intervention. The borehole installation was selected for several reasons. Firstly, the sources of uncontaminated water in the area were limited. Secondly, the high turbidity and the high concentration of organic matter in the river, swamp and waterhole prevented the use of chlorine and SODIS for water disinfection (Crump *et al.* 2004; Graf *et al.* 2010), without considering that suitable chlorine solution is also very difficult to be purchased in the area. Likewise, biosand filter installation was considered. Albeit it is reported that this technique can improve health among the inhabitants, high decontamination performance requires long and appropriate training/education and periodic surveys and maintenance (Fiore *et al.* 2010; Sisson *et al.* 2013). In fact, filters should be cleaned every few months, and they provide reduced effectiveness regarding pathogens removal for the first 3–5 days after cleaning. Therefore, the opportunity in using this technology strongly depends on the family in relation to the behavior and willingness of householders. As a consequence, the actual contribution of a biosand filter on improving health in village inhabitants has two variables: (i) the technical variable and (ii) the human variable. In order to minimize the human variable, a long and appropriate training/education has to be performed. On the basis of the visits to the families, the promoters observed important risks in hygienic practices. Therefore, it was preferred to address the education of the inhabitants towards basic

hygienic practices instead of long and tedious lessons regarding the maintenance of a biosand filter.

After the intervention, the borehole became the main source of water for the inhabitants. Owing to this source of water, the cases of diarrhea decreased to 7.6 and 12.8% during the dry and rainy seasons, respectively. The post-assessment survey revealed that the number of families boiling water had increased from 26 to 43%. Prior to the installation of the borehole, wood (which is expensive in the region) was mainly used for cooking and only a limited amount was used for boiling drinking water. The post-assessment survey showed that the borehole installation resulted in wood saving. Taking into account that the wood used for cooking purposes was the same before and after the borehole installation, the families could use the remaining wood for boiling water. Briefly, after the intervention, more householders could afford water boiling. In fact the post-assessment reported that the presence of a borehole resulted in time, money and firewood saving. These three factors are closely associated: cost of boiling water consists of a combination of direct (mainly firewood) and indirect cost, where the time to purchase or collect firewood is included (Clasen *et al.* 2008). Moreover, the hygiene education performed by the supervisor may have encouraged this practice.

At the same time, activities towards hygiene promotion improved the effectiveness of the boiling practice ($p < 0.05$). In fact, the prevalence of diarrhea recovered from boiled and unboiled rainwater was 6.5 and 24.1%, respectively. The supervisors observed some hygienic gaps during the visits to the families. In particular, the inappropriate water storage and free access for small animals to the kitchen acted as sources of water contamination. These may explain why before the intervention, boiling was not effective in diarrhea prevention. The further decrease of diarrhea incidences may be the result of good hygienic communication. In fact, two main hygienic risks were addressed: the storage of water, solved by using only one, clean and covered recipient, and the animals' access to the kitchen, which had to be avoided. These behaviors tend to reduce the sources of contamination and, in turn, increase the health of the inhabitants.

The intervention also impacted on the perception of the most frequent childhood diseases. Prior to the intervention, malaria and diarrhea were by far the most frequent answers.

Although these diseases remained the most frequent, flu, fever and stomach ache significantly increased after the intervention, together with diseases which were not considered in the pre-assessment survey such as headache, measles, pneumonia and mumps. Probably, after the intervention, the reduced incidence of diarrhea changed the perception of the common diseases.

Another significant change in the assessment was the perception of 'how the drinking water should be'. Prior to the intervention, the householders rightly answered: 'the water should not make you ill'. Surprisingly, after the intervention this answer dropped and the most frequent answer was: 'the water should be clear'. The explanation may be attributed to the turbidity difference between the water that the householders were used to drink before the intervention (river and swamp) in comparison with the water collected from the borehole. The visible decrease in water turbidity, that was associated with less prevalence of diarrhea, may have suggested that this parameter can affect the occurrence of diarrhea.

Eventually, after the intervention, the prevalence of diarrhea decreased to 10.2% among children every month, showing a significant reduction of 11.8%. Statistical analysis showed that this difference was highly significant ($p < 0.01$). Thus, the reduction of the diarrhea incidences has to be ascribed to the presence of the borehole, and not to random chance. In the literature it is widely reported that improving the quality of water at the source can result in variable incidences of diarrhea (Esrey *et al.* 1991; Esrey 1996; Fewtrell *et al.* 2005). In fact, recontamination of water from the water source may occur during water collection, transport, unsafe storage and/or handling of water at home (Trevett *et al.* 2004; Wright *et al.* 2004). However, recent articles (Zwane & Kremer 2007; Waddington & Snilstveit 2009) reported that a safe point of the source of water could exert a positive effect of about 20%, and several other reports describe that household intervention strategies can be effective (Clasen *et al.* 2004; Doocy & Burnham 2006; Graf *et al.* 2010). Moreover, meta-analysis studies performed by Clasen *et al.* (2007) described significant heterogeneity among the intervention, and even if an intervention technique such as flocculant-disinfectant treatment can be effective in pathogen removal (Souter *et al.* 2003), it is not always effective in villages (Luby *et al.* 2008).

The presence of the borehole was well accepted from the inhabitants of the village. Much advice and suggestions concerning the maintenance of the structure were collected. This suggests the determination of the people to preserve the structure. Eventually, the awareness of the inhabitants for the reduction of diarrhea and wood-, time- and money-saving may increase the acceptance of the intervention.

CONCLUSIONS

The obtained results show that the presence of a safe water source combined with proper hygiene education reduces the cases of diarrhea. Moreover, after the intervention, we observed significant differences in water quality perception and water handling practices. This study underlines the importance of a pre-intervention survey to investigate both the hygienic practices and the local environment. Based on this analysis, further activities can then be planned. The study also supports previous studies concluding that hygiene education provided through direct and repeated contact with household members help in the reduction of diarrhea.

There were a number of potential limitations in this study. Firstly, recall of bouts of diarrhea might have affected the obtained findings. Another limitation of the diarrhea surveillance was the adverse weather conditions during the rainy season. This condition prevented youths of Karuhisi from traveling to the families, limiting the ability to consistently monitor surveillance data collection. Finally, few efforts were made for monitoring the social acceptance of the intervention.

The presence of a safe source of water is only the first step in the prevention of diarrhea. Further interventions at household level are required. Future actions and studies should be carried out by improving both the hygiene education and the investigation about the social acceptance of the intervention. Eventually, the issues of improving structure and the use of effective latrines will become a critical point towards the prevention of diarrhea.

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