Health gains from solar water disinfection (SODIS): evaluation of a water quality intervention in Yaoundé, Cameroon

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ABSTRACT

In developing countries, the burden of diarrhoea is still enormous. One way to reduce transmission of pathogens is by water quality interventions. Solar water disinfection (SODIS) is a low-cost and simple method to improve drinking water quality on household level. This paper evaluates the implementation of SODIS in slum areas of Yaoundé, Cameroon. Promoters trained 2,911 households in the use of SODIS. Two surveys with randomly selected households were conducted before ($N = 2{,}193$) and after ($N = 783$) the intervention. Using a questionnaire, interviewers collected information on the health status of children under five, on liquid consumption, hygiene and other issues. Prior to the intervention, diarrhoea prevalence amounted to 34.3% among children. After the intervention, it remained stable in the control group (31.8%) but dropped to 22.8% in the intervention group. Households fully complying with the intervention exhibited even less diarrhoea prevalence (18.3%) and diarrhoea risk could be reduced by 42.5%. Multivariate analyses revealed that the intervention effects are also observed when other diarrhoea risk factors, such as hygiene and cleanliness of household surroundings, are considered. According to the data, adoption of the method was associated with marital status. Findings suggest health benefits from SODIS use. Further promotional activities in low-income settings are recommended.

Key words | developing countries, diarrhoea, drinking water, household water treatment, point-of-use, solar water disinfection

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TERMS AND ABBREVIATIONS

EAWAG	Swiss Federal Institute of Aquatic Science and Technology
NGO	Non-governmental organization
PET	Polyethylene terephthalate
SANDEC	Water and Sanitation in Developing Countries (Department of EAWAG)
SD	Standard deviation
SODIS	Solar water disinfection
WHO	World Health Organization

INTRODUCTION

Diarrhoea is considered to be the cause for the annual death of 1.6–2.5 million children under five (Kosek *et al.* 2003). In the less developed countries, diarrhoeal diseases are to a large extent associated with poor access to safe drinking water, weak water supply, inadequate sanitation and insufficient hygiene practices (WHO 2004).

Water quality interventions focusing on point-of-use treatment have proven to be effective in reducing diarrhoeal illness (Fewtrell *et al.* 2005; Clasen *et al.* 2007). The World

Health Organization (WHO) also promotes treatment and safe storage of household water (WHO 2007), as households in poor societies are often not connected to piped water distribution systems and have to rely on potentially unsafe water sources like wells, springs and ponds. Furthermore, even if the water sources are of good quality, there is a substantial risk for drinking water to be (re)contaminated after collection through improper transport, storage and handling by the end user (Trevett et al. 2004; Wright et al. 2004).

Several methods (e.g. boiling, chlorination, filtration and solar disinfection) are available to eliminate pathogens from the water on household level though all have their pros and cons (Sobsey 2002). Therefore, selection of the most suitable, cost-effective and sustainable option is dependent on local conditions.

Solar water disinfection (SODIS) is an affordable and simple household water treatment method as it only requires direct sunlight and polyethylene terephthalate (PET) bottles generally available in low-income countries. SODIS uses the sun's ultraviolet radiation to improve the microbiological water quality. Furthermore, the disinfection process is supported by the infrared heat of the sun, which slightly increases the water temperature. SODIS application is simple: contaminated water is filled into empty, transparent and unlabeled PET bottles (volume up to two litres); the bottles are tightly closed and exposed horizontally to direct sunlight for at least six hours. With very cloudy skies, exposure time should be extended to two days (EAWAG/ SANDEC 2002). To prevent recontamination, the water should not be filled into a storage container after exposure but consumed directly from the bottle or poured into a clean cup. However, the SODIS method requires relatively clean (non-turbid) water and does not improve the chemical water properties. SODIS is presently promoted in dissemination projects in at least 33 countries (as of 2009, cf. www. sodis.ch).

To assess the health benefits of the method, controlled experiments were conducted in Kenya and India. They revealed that implementation of SODIS reduces diarrhoea incidence between 16 and 40% (Conroy et al. 1996, 1999, 2001; Rose et al. 2006). These findings were supported by case–control studies on the health impact of SODIS in Bolivia and Kenya (Hobbins 2003; Graf et al. 2008).

In contrast to that, a cluster-randomized controlled trial (Mäusezahl et al. 2009) conducted in Bolivia detected a diarrhoea reduction of 19% that was statistically insignificant. However, compliance with SODIS was rather low in the intervention group which suggests that the limited adoption of the method was responsible for the lack of health impact. Additionally, the authors did not consider the proportion of treated and untreated water consumed daily by the study participants. This is important because SODIS users might continue to drink untreated water and non-users might treat their water with other methods (e.g. boiling).

Further scientific investigations and case studies are required to determine whether the method can arbitrarily be applied in the wide range of cultures in developing countries and, more specifically, if SODIS is applied correctly and provides health benefits. This is especially true in the light of the recent debate if one single 'best' method for water treatment on household level can and should be identified (Sobsey et al. 2008; Hunter 2009; Lantagne et al. 2009).

This paper evaluates a water quality intervention conducted in the Cameroon capital of Yaoundé. SODIS was promoted in four slum areas of the city. Community-based organizations carried out promotional campaigns in the form of information events followed by regular household visits of field workers. A total of 2,911 households were thus trained on SODIS in this manner. The main objectives of the research were to assess the health impact of the intervention and to identify some of the conditions favouring the adoption of the method.

METHODS

The research comprises two cross-sectional surveys. A pre-intervention survey was conducted prior to the SODIS promotional activities. After the intervention, an evaluation survey was conducted comprising an intervention and a control group. The intervention group was further subdivided in terms of compliance with the intervention (SODIS application).

Since both surveys were conducted in the same study areas, some households may have been interviewed twice.

However, single households were not identified and compared over time.

Study sites

Yaoundé faces overpopulation (ca. 1.7 million inhabitants) like many other urban centres in the developing world. Large parts of the capital are slums without or with very basic water supply, sanitation and waste disposal infrastructure (Parrot *et al.* 2009). These poor neighbourhoods have to rely mainly on wells, springs and rivers for their drinking water sources. Water analysis of 40 wells revealed that 80% of the water sources exhibit a poor bacteriological quality (Tanawa *et al.* 2002). As a result, diarrhoeal diseases have become a severe problem among the population of Yaoundé (Nguendo Yongsi *et al.* 2008). The SODIS intervention and surveys were carried out in the following four slum areas of Yaoundé: Ntaba-Nlongkak, Briqueterie, Carrière and Melen. They all exhibited identical poor living conditions.

Pre-intervention survey

A baseline survey on water consumption patterns and diarrhoea incidence among children under five was conducted between 16 and 21 July 2007 in the four areas selected for intervention. A total of 2,193 interviews (Ntaba-Nlongkak 27.6%, Briqueterie 24.5%, Carrière 25.8%, Melen 22.1%) were carried out with randomly selected households having at least one child under five. Only one member per household, if possible the closest person in charge of the children, was questioned. As the data of the pre-intervention survey was only used sparingly in this paper, further details on the methodology are not provided here. A detailed description of the evaluation survey is given instead.

Intervention

In each of the four slums, community-based organizations with promotional skills were identified. A total of 60 people were trained (12 supervisors and 48 promoters) on promoting the SODIS method among the target population. Public workshops were organized in the areas at the beginning of the project. Furthermore, mass media informed about SODIS. However, an intensive door-to-door campaign was the main strategy used to disseminate the method. District-based promoters visited households and informed them about the method. Households willing to try SODIS were subsequently visited on a regular basis (biweekly at the beginning and monthly later on). The aim was to assist the persons responsible for water on integrating the new behaviour (SODIS use) into their daily routine. Hygiene practices were also addressed during these visits. Overall, 2,911 households (mainly with children under five) were visited and trained during the intervention phase lasting from July 2007 to April 2008. The terms *intervention households* or *intervention group* are used in this paper when referring to the trained households.

Evaluation survey

After the intervention, interviewers conducted from 21 April to 7 May 2008 an evaluation survey using a questionnaire. A total of 783 households (Ntaba-Nlongkak 24.4%, Briqueterie 24.3%, Carrière 25.8%, Melen 25.5%) were surveyed. All households were randomly selected and had at least one child under the age of five. The methodology used in the evaluation survey is herewith described in detail.

Questionnaire

The developed questionnaire focused on the socio-demographic situation, health status (diarrhoea, stomach pain) and on issues pertaining to SODIS. To be able to evaluate the influence of other diarrhoea-causing factors, the questionnaire also included variables like consumption of liquids, hygiene and cleanliness of surrounding area. The questions explicitly addressing SODIS aspects, and thus possibly revealing the research interest to the respondent, were placed at the very end of the questionnaire in order not to influence the answers to all other questions (health etc.). This was done to avoid responder bias as much as possible.

The questionnaire was developed in French, one of the official languages of Cameroon and widely spoken by the multi-ethnic population. The questions were mostly

open-ended, i.e. no answers were suggested to the respondents. Instead, interviewers recorded or rated the answers according to given categories or scales. A few observations also had to be completed by the interviewers. All the items in the questionnaire had to be filled in by the interviewers themselves.

The interviews were usually conducted with the closest caretakers of the children, i.e. mainly the mothers.

Health status: diarrhoea and stomach pain

Diarrhoea occurrence was the main dependent variable to assess the health impact of the intervention among children under five. The questionnaire contained the following question: *Have any of your children under five years suffered from diarrhoea in the past two weeks?* The answer was either 'yes' or 'no'. Diarrhoea was not specifically defined; we relied on the mothers' definitions. However, prior assessments in the study areas revealed that the understanding of diarrhoea as a frequent (at least three times in the last 24 h) passage of watery and possibly bloody stools was well established in the communities. Epidemiological studies widely use diarrhoea occurrence among children under five as an indicator for measuring the health outcome of water quality interventions (Fewtrell *et al.* 2005; Clasen *et al.* 2007). The same applies to the recall time of two weeks (period prevalence). Reports on diarrhoea incidence dating back to periods exceeding two weeks may not be remembered accurately (Blum & Feachem 1983).

A question pertaining to stomach pain incidence among members of the household in the last two weeks served as an additional indicator to evaluate the health gains from the intervention.

Compliance with the intervention: SODIS application

To assess household compliance with the intervention, we created a score of SODIS use. The score comprised the following five information components provided during the interview: one point was added to the score if SODIS water was mentioned by the respondents when describing the type of liquids consumed by their children under five. Another point was assigned if the respondents could at

least sufficiently describe how to prepare SODIS water. Another point was given if the respondents declared that they themselves (their household) were SODIS users. Another point was added if the interviewers observed bottles in the households (or exposed to the sun) which were obviously used for SODIS. And finally, the last point was attributed if the interviewers themselves regarded the households as SODIS users. This personal assessment allowed the interviewers to use their experience (they had worked as SODIS promoters before) and express their doubt if a household was merely pretending to use the method.

Hence, the minimum score value was 0 and the highest possible value 5. Finally, we used the score to assess SODIS application by the households. The score was rated as follows: 0–3 points = non-user, 4 points = irregular user, 5 points = regular user. All the questioned households in the intervention group were classified according to that ordinal rating.

Consumption of liquids

We assumed that SODIS use has no *direct* influence on health, but a rather mediated effect through the overall pattern of liquid consumption. Therefore, the respondents were asked about all the types of liquids normally consumed by their children under five. As the question was open ended, the interviewers did not suggest any answers and recorded all the answers in a table. Concerning water, the interviewers asked what source it was from, if the water was treated on household level and, in case of a positive answer, what method was used. If liquids like fruit juice or (powdered) milk were mentioned, the interviewers asked whether they were mixed with water and the kind of water used. Any drinks consumed regularly outside the home were also recorded as far as was known by the respondents. The respondents were subsequently asked to assess how many cups of the mentioned drinks each child consumed during a normal day. The quantity of drinks consumed on a regular basis (but not daily) was given as an approximate fractional amount (e.g. two cups a week is about 0.3 cup a day).

Later during data analysis, water not treated on household level was qualified as unsafe. Therefore, not

only was water collected from wells and springs categorized as potentially contaminated, but also rainwater and tap water as it can be (re)contaminated after collection in poor hygienic environments.

The information on liquid consumption allowed to determine whether the children under five in a given household consumed any untreated water. This was expressed by the variable '*consumption of unsafe water*' and was answered only by 'yes' or 'no'. Further, the data on the quantity of consumed liquids was used to calculate the variable '*percentage of unsafe drinks*'. It expresses the proportion (in per cent, 0–100) of potentially unsafe drinks as a portion of the total drinks consumed on average throughout a day by children under five in a given household. Drinks using water from various sources that had not been treated at the household level and liquids like juice and milk mixed with such untreated water were considered unsafe. The following drinks were classified as safe: water treated at the household level (SODIS, chlorination, filtration, boiling etc), bottled water, tea, breast milk, undiluted juice and undiluted milk.

Hygiene

To assess hygiene practices of individual households, we calculated an index containing four indicators: (1) reported frequency of hand washing of young children during a day, (2) reported regularity of using soap for hand washing and (3) reported situations in which children under five wash their hands. For this later indicator, given categories (e.g. before eating) were ticked according to the provided answers. The sum of the mentioned situations was subsequently calculated and then recoded to a 4-point scale. In addition, the last (4) indicator was cleanliness of the household. This was an observational item to be appraised by the interviewers (without questioning the household). This avoided mere reliance on self-reporting as hygiene behaviour is prone to be overstated by respondents (Manun'Ebo *et al.* 1997; Biran *et al.* 2008).

All four indicators, rated on a 4-point scale, were added up and divided by four (or three in the event of a missing value). The final hygiene index ranged from 1 to 4 (poor hygiene–good hygiene).

Cleanliness of surroundings

Young children spend a lot of time sitting, crawling, toddling and playing within the immediate environment of the households. Cleanliness of the immediate surroundings (e.g. free of rubbish and faeces) can therefore have an effect on the children's health. Interviewers rated the area in front and a few metres around each questioned household using a 4-point scale (very dirty–clean).

Socio-economic status

To assess the relative difference in socio-economic status of the interviewed households, we used an index based on the following five indicators (observed or reported): type of building, equipment in household, kind of energy used for cooking, number of people sharing one bed/mattress and interviewer's appraisal of the economic situation. Each indicator could assume a value between 1 and 4. The index was developed by adding the five items and dividing them by five (or four in the event of a missing value). The index for socio-economic status could finally reach a value between 1 (low) and 4 (relatively high).

Selection and training of field workers

Among all the SODIS promotion staff, 15 people were selected as interviewers and another six as supervisors. They received a four-day survey training covering topics such as household selection procedures (cf. below), interviewing technique, content and use of the questionnaire. A test run also formed part of the training. Focus was placed on the interviewers' correct understanding of their new data collectors' role, which differed totally from their former role as promoters. To reduce potential interviewers' bias, great effort was devoted so that everyone was aware that the objective of the evaluation survey was not to identify poorly working promoters but to learn general lessons for future implementation activities. After having familiarized the former promoters with these key issues and thanks to their advanced knowledge in the field of water and hygiene, they were ready to act as interviewers. Furthermore, owing to their work experience and background, they were well acquainted with the intervention areas, spoke

the indigenous languages common in the areas and could approach the dwellers in a culturally accepted way. Another training issue concerned the manner of conducting a standardized introduction when requesting participation of the households in the survey. The interviewers had to inform the households that they were conducting a non-profit survey on health and water. The main caretaker of the children was asked to participate. If possible, the interviews should be conducted inside the house without external disturbance (music, other people etc.).

Previous research experience with such surveys (Graf *et al.* 2008) suggested that households trained by promoters overstated their SODIS application and provided answers to please the survey staff, especially if they felt that the interview aimed at checking their compliance with the SODIS training. To minimize this problem, interviewers were not allowed to conduct the survey with households they had previously visited as promoters. Additionally, the interviewers were trained not to mention SODIS or the implementing NGO throughout the entire introduction. The interviewers only explicitly mentioned the method in the very last section of the questionnaire. Thus, the respondents should, up to that point, have been unaware of the relationship between the survey and SODIS. All these measures helped to minimize responder and observer bias as much as possible.

The supervisors received training on how to organize the survey in the slum areas. Their task was to look after the interviewers and ensure quality control by checking completed questionnaires, observing the performances of interviewers and providing feedback. Additionally, the supervisors randomly chose a number of completed questionnaires, visited the concerned households and validated that the interviews had taken place and had been conducted correctly.

Selection of intervention households

Households visited by promoters during the project implementation phase were all registered in a list. In each of the four study areas, 120 households were randomly selected from these lists. Assuming that a number of households would not be available for interviews (moved away, not willing to participate, not at home even after a revisit),

we expected to realize 80–100 interviews with intervention households in each of the four areas.

The interviewers conducted the survey in their own district; however, they did not question households they had previously visited as promoters. Therefore, they had to visit a promotion zone different from their own within the area. This would prevent the respondents and the interviewers from knowing each other from previous interactions.

Selection of control households

After completing each interview with an intervention household, the interviewers had to question a household that had not been preselected in the promotion list. These randomly selected households had probably never heard of SODIS before and had not been in contact with the intervention activities. They were selected by counting the neighbouring doors/houses of the intervention household. At the tenth household, the interviewers asked for survey participation (if not available at the 11th, 12th or 13th household). After completing the interview with a household selected by this method, the interviewers continued to question another intervention household preselected in the promotion list.

Some control households selected randomly may know of SODIS even though promoters had not visited them. In this case, the data of these interviewed households was excluded from the control group during data analysis. To allow for such dropouts, the interviewers were instructed to question in total about 400 control households.

Sample size

Based on the findings of the pre-intervention survey, the control households of the evaluation survey were assumed to reveal a diarrhoea prevalence of about 35%. Anticipating a 30% reduction in diarrhoea for the intervention households, a sample size of 316 was needed in each group (alpha = 0.05). We attempted to interview approximately 400 households in each group to allow for dropouts. By applying the aforementioned household selection procedure, we obtained a total sample of 783 interviewed households composed of 369 intervention households and

414 control households. However, during analysis, 112 households were excluded from the control group as they had already heard of the method from neighbours, friends or the mass media. Therefore, the final control group consisted of 302 households. Based on these figures, the final power was calculated as 0.82.

The intervention group was further subdivided in terms of compliance with the intervention activities (Figure 1).

Data analysis

All the data of the questionnaires were fed into an Excel file and converted into SPSS for statistical analysis. Missing values were replaced by average values found for that specific variable in the total sample. Quality control of the entered and transferred data was conducted by a third person who examined the files. A random sample of one-quarter of all cases was selected and checked for data accuracy by using the original questionnaires. Links between categorical variables were analysed with Pearson's chi-square test and Fisher's exact test; means of continuous variables were compared with *t*-tests. Multivariate analysis was conducted by calculating logistic regression models.

This research mainly aimed at assessing the health impact of the SODIS intervention. Therefore, we assumed that households being in the intervention group, or respectively using SODIS, would reveal less diarrhoeal diseases than the control households, respectively the non-users. Furthermore, we also assumed that diarrhoea would be associated with other health risk factors like hygiene and cleanliness of surroundings. We expected that SODIS use would still be linked to the health outcome when considering and controlling these factors. This assumption was tested with a logistic regression model. The role of potential mediator variables like percentage of unsafe drinks and socio-economic status was explored by including them subsequently into the model.

RESULTS

Characteristics of samples

The demographic profiles of the participants of the pre-intervention and evaluation survey are presented in Table 1. Statistical comparisons revealed that the respondents of the evaluation survey were significantly younger (averaging 2.8 years) than the respondents of the pre-intervention survey and more often female (85.8 vs. 69.8%). Concerning marital status, no significant difference between the
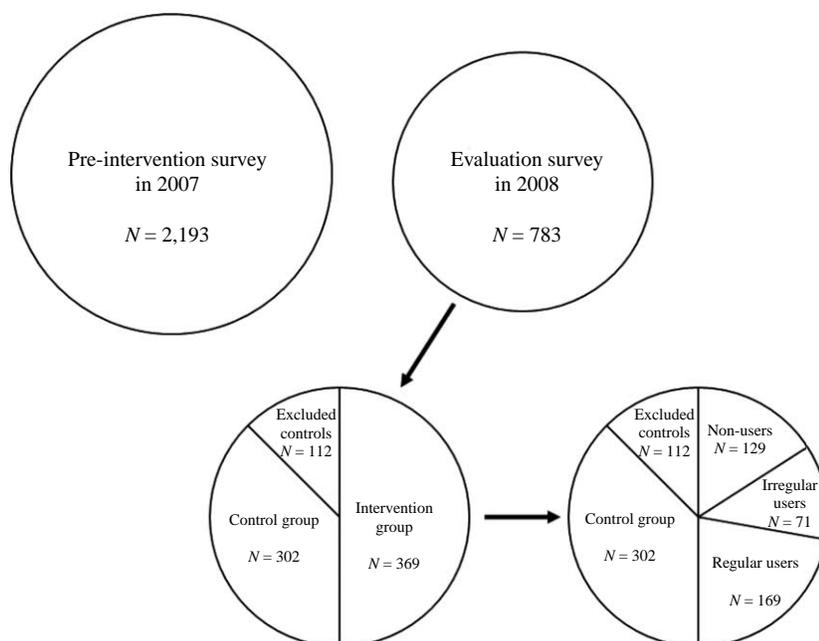

Figure 1 | Schematic illustration of study groups (not proportional).

Table 1 | Demographic profiles of the study participants

	N	Age of respondent (mean in years)	Sex of respondent (percent female)	Marital status (percent)				Number of people in household (mean)	Number of children under five (mean)
				Single	Married	Divorced	Widowed		
Pre-intervention survey (1)	2193	32.9 (SD = 11.5)	69.8%	25.8%	71.5%	0.3%	2.4%	6.5 (SD = 3.3)	1.7 (SD = 1.0)
Evaluation survey (2)	783	30.1 (SD = 9.4)	85.8%	23.0%	74.4%	0.1%	2.5%	6.3 (SD = 2.9)	1.6 (SD = 0.9)
p-value (1) vs. (2)	–	<0.001***	<0.001***	0.171	0.130	0.999	0.999	0.031*	0.344

* = significant ($p \leq 0.05$), *** = highly significant ($p \leq 0.001$).

two samples was found. A small but significant difference (0.2) in household size was detected between the two samples; however, no difference was found pertaining to the number of children under five.

The evaluation survey ($N = 783$) comprised three groups: intervention (47.1%), control (38.6%) and excluded controls (14.3%). Among the 369 households of the intervention group, the following SODIS application (compliance) was determined: 45.8% regular users, 19.2% irregular users and 35% non-users. The 112 excluded households had not received any SODIS training by promoters. However, they had already heard of the method through channels other than promoters (neighbours, friends, mass media). In fact, the data revealed that 25% of these households were using SODIS regularly and 6.5% irregularly. In the final control group of 302 households, no respondents knew SODIS and, thus, none applied SODIS.

The demographic and socio-economic characteristics of all groups are given in Table 2. Comparisons revealed that the excluded households did not differ in their profile from the control group. When the control group was compared to the intervention group, no statistical difference was found in the socio-economic status, household size or number of children under five. However, respondents of the intervention group differed in age, sex and marital status.

The control group was also compared with the different SODIS application groups of the intervention group. Compared to the non-users of the intervention group, the control group had a significantly lower socio-economic status. In addition, the regular users were more often married and less often single than the respondents of the control group. When comparing the three SODIS application groups (non-users, irregular users, regular users) of the intervention group, no difference was found in age, sex, household size, number of children under five or socio-economic status. The only significant difference between the three groups was their marital status. Participants of regular user households were more often married and less often single than the non-users of the intervention group.

Health impact of the intervention

The pre-intervention survey of the households revealed a 34.3% prevalence of diarrhoea among children under five.

Table 2 | Evaluation survey groups: demographic and socio-economic profiles

| | N | Age of respondent (mean in years) | Sex of respondent (percent female) | Marital status (percent) | | | | Number of people in household (mean) | Number of children under five (mean) | Socio-economic status (mean) |
				Single	Married	Divorced	Widowed			
Excluded controls (1)	112	29.4 (SD = 8.4)	86.6%	20.2%	78.0%	0.0%	1.8%	6.3 (SD = 3.1)	1.7 (SD = 0.9)	2.6 (SD = 0.5)
Control group (2)	302	28.5 (SD = 9.0)	88.7%	27.5%	69.4%	0.0%	3.1%	6.1 (SD = 2.9)	1.6 (SD = 0.9)	2.5 (SD = 0.6)
Intervention group (3)	369	31.5 (SD = 9.9)	83.1%	20.2%	77.3%	0.3%	2.2%	6.4 (SD = 2.9)	1.6 (SD = 0.9)	2.6 (SD = 0.5)
Intervention group further divided according to SODIS application (4-6)										
Non-users (4)	129	31.6 (SD = 9.6)	84.3%	26.4%	69.7%	0.0%	3.9%	6.4 (SD = 3.0)	1.6 (SD = 1.0)	2.7 (SD = 0.5)
Irregular users (5)	71	30.8 (SD = 9.4)	85.9%	21.4%	77.1%	1.5%	0.0%	6.2 (SD = 3.1)	1.6 (SD = 0.8)	2.6 (SD = 0.5)
Regular users (6)	169	31.7 (SD = 10.3)	81.1%	14.8%	83.3%	0.0%	1.9%	6.4 (SD = 2.7)	1.7 (SD = 0.9)	2.6 (SD = 0.5)
p-value pre-intervention vs. (2)	–	<0.001***	<0.001***	0.545	0.470	0.999	0.597	0.015*	0.239	NA
p-value pre-intervention vs. (3)	–	0.016*	<0.001***	0.023*	0.023*	0.374	0.724	0.430	0.618	NA
p-value (1) vs. (2)	–	0.383	0.550	0.136	0.092	0.999	0.734	0.503	0.385	0.263
p-value (2) vs. (3)	–	<0.001***	0.039*	0.030*	0.024*	0.999	0.503	0.178	0.541	0.129
p-value (2) vs. (4)	–	0.002**	0.201	0.814	0.955	0.999	0.768	0.276	0.769	0.046*
p-value (2) vs. (5)	–	0.067	0.510	0.303	0.205	0.192	0.216	0.707	0.664	0.237
p-value (2) vs. (6)	–	<0.001***	0.021*	0.002**	0.001**	0.999	0.552	0.209	0.278	0.764
p-value (4) vs. (5)	–	0.596	0.754	0.441	0.266	0.352	0.164	0.666	0.574	0.722
p-value (4) vs. (6)	–	0.936	0.476	0.014*	0.006**	0.999	0.473	0.987	0.562	0.110
p-value (5) vs. (6)	–	0.555	0.367	0.216	0.265	0.302	0.556	0.620	0.252	0.355

* = significant ($p \leq 0.05$), **/*** = highly significant ($p \leq 0.01$)/($p \leq 0.001$).

After the intervention, 31.8% of all households in the control group of the evaluation survey reported diarrhoea incidence. No statistical difference between these two prevalence rates was observed ($\chi^2 = 0.76$, $p = 0.383$). On the contrary, diarrhoea prevalence in the intervention group of the evaluation survey was lower and amounted to 22.8%. Compared to the pre-intervention survey, a significant difference in diarrhoea incidence was noted ($\chi^2 = 19.18$, $p < 0.001$, odds ratio = 1.77).

Direct comparisons of intervention and control group pertaining to diarrhoea occurrence also revealed a significant difference ($\chi^2 = 6.89$, $p = 0.009$, odds ratio = 1.58).

The intervention group was further divided according to SODIS application and compared concerning diarrhoea prevalence (Figure 2). The households of the control group and the non-users of the intervention group showed exactly the same diarrhoea rate (31.8%). They both differ significantly from the irregular users reporting diarrhoea in 16.9% of the cases (control group: $\chi^2 = 6.19$, $p = 0.013$, odds ratio = 2.29, non-users: $\chi^2 = 5.21$, $p = 0.022$, odds ratio = 2.29). The regular users with 18.3% reveal a slightly higher diarrhoea rate than the irregular users; however, the difference is insignificant ($\chi^2 = 0.07$, $p = 0.79$). Diarrhoea prevalence among regular users is significantly lower than among non-users of the intervention group ($\chi^2 = 7.21$, $p = 0.007$, odds ratio = 2.07) and the control group ($\chi^2 = 9.95$, $p = 0.002$, odds ratio = 2.07). The same is
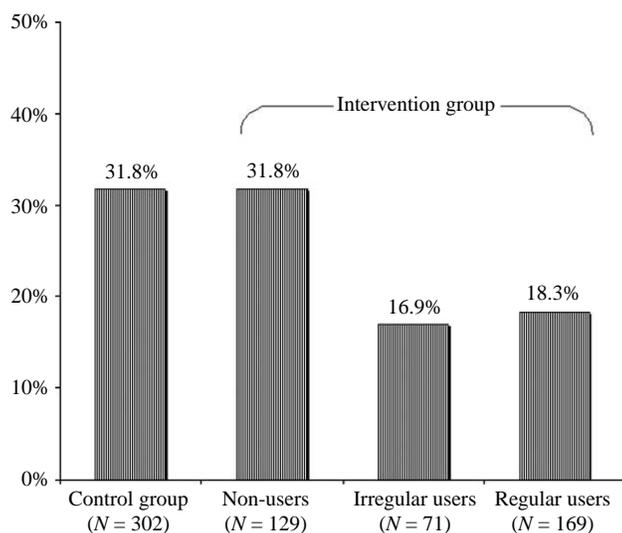
true for the irregular users when compared to the non-users of the intervention group ($\chi^2 = 5.21$, $p = 0.023$, odds ratio = 2.29) and to the control group ($\chi^2 = 6.19$, $p = 0.013$, odds ratio = 2.29).

The control group and the SODIS application groups of the evaluation survey were also analysed for the other health indicator, i.e. stomach pain among household members (Figure 3). Stomach pain among regular SODIS users was reported by trend less often than among irregular users ($\chi^2 = 3.26$, $p = 0.07$, odds ratio = 1.7), and significantly less often than among the non-users of the intervention group ($\chi^2 = 7.12$, $p = 0.007$, odds ratio = 1.93) and the control group ($\chi^2 = 11.33$, $p < 0.001$, odds ratio = 1.99). No significant differences in stomach pain were found between the irregular users, the non-users of the intervention group and the control group.

Consumption of liquids and SODIS application

Concerning *consumption of unsafe water*, the data in the pre-intervention survey indicated that 75.5% of all interviewed households consumed unsafe water. In other words, untreated water formed part of the young children's daily liquid intake. In the control group of the evaluation survey, the value was even higher at 86.4%. However, among the SODIS application groups, the consumption of unsafe
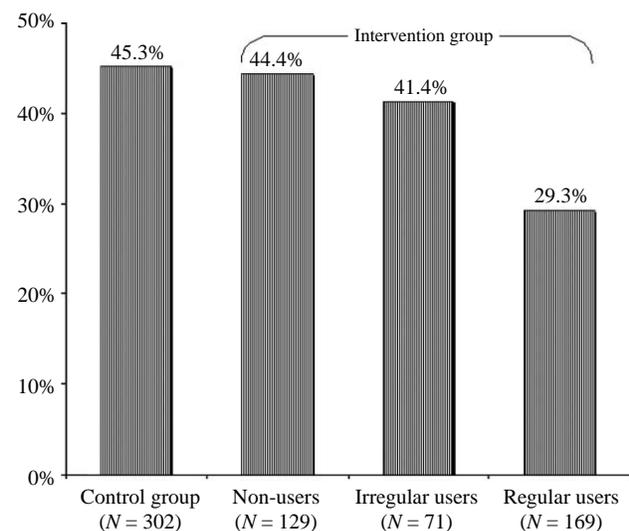
Figure 2 | Percentage of households reporting diarrhoea among children under five in the control group and SODIS application groups of the evaluation survey.

Figure 3 | Percentage of households reporting stomach pain among household members in the control group and SODIS application groups of the evaluation survey.

water decreased with increasing use of SODIS: 78.3% of non-users of the intervention group consumed unsafe water, 39.4% of irregular users and 21.3% of regular users. A similar trend was noted for the variable *percentage of unsafe drinks* (Table 3). The results of these two variables indicate that the non-users of the intervention group did not refuse SODIS because they preferred other point-of-use treatment methods instead. They plainly did not use any type of water treatment method. In fact, water purification methods like boiling, filtration and chlorination were rare in the overall data of the evaluation survey. In both the SODIS application groups and the control group, these methods were mentioned by less than 5% of the respondents. Households who used SODIS were also asked if they had applied other water treatment technologies before knowing SODIS. Irregular users answered positively in 25.4% of the cases and regular users in 18.3% ($\chi^2 = 1.41$, $p = 0.236$).

In the evaluation survey, respondents who gave untreated water to their children were asked why they did not treat it (with any method) prior to consumption. For 41% of the concerned non-users of the intervention group ($N = 100$), treatment was not necessary, 32% stated that they did not have time, for 10% it was a lack of money and for 3% no reasons were given. The remaining 4% gave several reasons. The number of irregular and regular users who replied to the question was too small for any reliable interpretation. However, the answers of the non-users of

the intervention group can be compared to those of the control group. For 43.4% of the households of the control group giving untreated water to their children ($N = 244$), treatment was not necessary, for 13.5% it was for lack of time, 16.4% had no money and 22.1% did not know why. The remaining 4.6% gave two or more of these reasons. Chi-squared tests revealed that the only statistically significant difference in reported reasons between non-users of the intervention group and the control group was lack of time ($\chi^2 = 15.80$, $p < 0.001$, odds ratio = 3.01).

Consumption of liquids and diarrhoea

The variables *consumption of unsafe water* and *percentage of unsafe drinks* were linked not only to the intervention and respective compliance, but also to diarrhoea. All households admitting to the consumption of unsafe water ($N = 441$) reported diarrhoea in 33.6% of the cases, whereas in only 15.6% of the households negating the consumption of unsafe water ($N = 250$), diarrhoea was reported among children under five ($\chi^2 = 26.07$, $p < 0.001$, odds ratio = 2.73). Furthermore, a significant difference (*t*-test, $p < 0.001$) was noted when comparing the *percentage of unsafe drinks* among households with ($N = 187$) and without ($N = 504$) diarrhoea: in households with diarrhoea, young children consumed on average 61.2% (SD = 37.1) unsafe drinks, whereas in households without reported illness, this figure totalled on average 46.5% (SD = 41.9).

Table 3 | Evaluation survey: consumption of unsafe water and percentage of unsafe drinks among children under five in the control group and SODIS application groups

	N	Consumption of unsafe water (percentage of affirming households)	Percentage of unsafe drinks (mean)
Control group (1)	302	86.4%	70.3% (SD = 33.7)
Intervention group (2–4):			
Non-users (2)	129	78.3%	64.1% (SD = 40.3)
Irregular users (3)	71	39.4%	27.5% (SD = 35.4)
Regular users (4)	169	21.3%	12.6% (SD = 21.0)
p-value (1) vs. (2)	–	0.035[*]	0.126
p-value (1) vs. (3)	–	<0.001[***]	<0.001[***]
p-value (1) vs. (4)	–	<0.001[***]	<0.001[***]
p-value (2) vs. (3)	–	<0.001[***]	<0.001[***]
p-value (2) vs. (4)	–	<0.001[***]	<0.001[***]
p-value (3) vs. (4)	–	0.004[**]	0.002[**]

[*] = significant ($p \leq 0.05$), [**]/[***] = highly significant ($p \leq 0.01$)/($p \leq 0.001$).

Hygiene, cleanliness of surroundings and SODIS application

Additional health risk factors were analysed after establishing some evidence that diarrhoea occurrence in the studied population was associated with SODIS intervention, especially with its compliance, as well as with the quality of the consumed water. One of the risk factors is hygiene. During the intervention phase, the promoters also tried to motivate the visited households to practise proper hygiene. Table 4 reveals that, compared to the control group, regular users exhibited significantly better hygiene values. Irregular users missed the 5% significance level just marginally.

Since the other risk factor, cleanliness of household surroundings, was expected to be in limited control of the households, the intervention activities may have no or only a small effect on that variable. However, Table 4 suggests that regular and irregular users tend to have cleaner surroundings than non-users of the intervention group and control group. The difference between regular users and non-users of the intervention group was statistically significant.

Hygiene, cleanliness of surroundings and diarrhoea

Since hygiene and cleanliness of surroundings are diarrhoea-causing risk factors, they were related to that health outcome. Table 5 shows that households without diarrhoea had better hygiene and cleaner surroundings than households with diarrhoea occurrence.

Multivariate analysis of diarrhoea-causing risk factors

Logistic regression models were calculated using the data of the evaluation survey to explore further the relationship between SODIS application and diarrhoea when including the influence of other factors. We progressed stepwise by calculating three models (Table 6 below). A stepwise approach was used first to test our assumption, that SODIS is related to the health outcome even if other risk factors are controlled, before exploring how the importance of the health predictors changes when potential moderator variables are integrated (second and third model). The first regression included the following three factors: SODIS application (non-users, irregular users and regular users; all households of the control group were additionally coded as non-users), hygiene and cleanliness of surroundings. All proved to be significant in predicting diarrhoea incidence, i.e. the better the hygiene and cleaner the surroundings, the less likely the occurrence of diarrhoea. Furthermore, diarrhoea occurrence was less likely among households using SODIS irregularly or regularly. Nevertheless, explanation of variance of the first model was rather limited with 6.8% (Nagelkerke's R^2).

In the second regression, the variable *percentage of unsafe drinks* was included. Hygiene and cleanliness of surroundings kept their predictive power. However, this time, SODIS application lost its statistical importance, whereas the newly included variable gained significance. This can be considered as a logical consequence, since

Table 4 | Evaluation survey: hygiene and cleanliness of surroundings in the control group and SODIS application groups

	N	Hygiene (mean)	Cleanliness of surroundings (mean)
Control group (1)	302	2.5 (SD = 0.6)	2.6 (SD = 0.7)
Intervention group (2–4):			
Non-users (2)	129	2.6 (SD = 0.6)	2.5 (SD = 0.8)
Irregular users (3)	71	2.7 (SD = 0.5)	2.7 (SD = 0.7)
Regular users (4)	169	2.7 (SD = 0.5)	2.8 (SD = 0.8)
p-value (1) vs. (2)	–	0.169	0.274
p-value (1) vs. (3)	–	0.058	0.278
p-value (1) vs. (4)	–	<0.001***	0.062
p-value (2) vs. (3)	–	0.510	0.079
p-value (2) vs. (4)	–	0.104	0.015*
p-value (3) vs. (4)	–	0.478	0.780

* = significant ($p \leq 0.05$), *** = highly significant ($p \leq 0.001$).

Table 5 | Evaluation survey: hygiene and cleanliness of surroundings as a function of diarrhoea occurrence

	N	Hygiene (mean)	Cleanliness of surroundings (mean)
Diarrhoea incidence (1)	187	2.5 (SD = 0.5)	2.5 (SD = 0.7)
No diarrhoea incidence (2)	504	2.7 (SD = 0.6)	2.7 (SD = 0.8)
p-value (1) vs. (2)	–	<0.001***	<0.001***

*** = highly significant ($p \leq 0.001$).

SODIS is an important method (among others) of providing safe water and is therefore possibly mediated through the variable *percentage of unsafe water*. However, such conclusions need to be interpreted with caution as the two variables are closely correlated ($r = -0.599$***), thus making interpretation of the model's coefficients problematic (multi-collinearity). The second model's explanation of variance was only fractionally better this time (7.9%).

Finally, the variable socio-economic status was added to the third regression model, as the households with diarrhoea incidence ($N = 187$) were lower in socio-economic status than households ($N = 504$) without diarrhoea (*t*-test, 2.5 vs. 2.6, $p = 0.005$). However, when socio-economic status was included in the model along with the other factors, it did not gain significant predictive power. After inclusion of the socio-economic status, the variables *percentage of unsafe drinks* and *cleanliness of surroundings* were still significant, but hygiene had slipped over the 5% level. Again, multi-collinearity makes interpretation of the coefficients difficult, as socio-economic status correlated with the two factors *cleanliness of surroundings* ($r = 0.324$***) and *hygiene* ($r = 0.270$***). Socio-economic status did not correlate significantly with *SODIS application* ($r = -0.009$) or *percentage of unsafe drinks* ($r = -0.032$). The explained variance of the third regression model amounted to 8.1%.

DISCUSSION

The objective of the present study was to assess the health gains from the implementation of the water treatment method SODIS in urban slums of Yaoundé, Cameroon, and to identify the conditions necessary for compliance with the intervention.

During the intervention phase, promoters visited 2,911 households on a regular basis and taught them how to use SODIS. The evaluation survey conducted shortly after the end of the promotional activities revealed that in a random sample of intervention households with young children, 45.8% were regular users, 19.2% were irregular users and 35% were non-users of the method. Since the large majority of all trained households had children under five, this compliance rate can be generalized and applied to the total group of 2,911 intervention households.

The major finding on the health gains was that after SODIS dissemination, households with young children were 1.77 times less likely to have childhood diarrhoea than before the intervention. In other words, diarrhoea prevalence in the pre-intervention survey amounted to 34.3%, whereas in the intervention group it totalled 22.8%. Thus, compared to the preliminary intervention situation, diarrhoea risk was reduced by 33.7% in households having received the intervention.

In contrast, the control households, which had not benefited from the intervention, revealed almost the same diarrhoea rate as the pre-intervention households. This indicates that in our settings, time effects like seasonal changes in diarrhoea prevalence can be largely ruled out when analysing the effects of intervention.

Direct comparison between intervention and control group of the evaluation survey revealed that households of the control group were 1.58 times more likely to report the occurrence of diarrhoea than households of the intervention group (diarrhoea prevalence: control 31.8% vs. intervention 22.8%; reduction of risk: 28.3%).

Within the intervention group, households were classified according to their level of SODIS application into regular users, irregular users and non-users. Regular users had significantly less diarrhoea occurrence among their young children than non-users of the intervention group or households of the control group. In fact, regular users had a 2.07 times smaller chance to contract childhood diarrhoea.

Table 6 | Evaluation survey: logistic regression analyses of diarrhoea incidence among children under five (0 = no incidence, 1 = incidence)

Factors	Regression 1					Regression 2					Regression 3				
	B	SE B	Exp(B)	CI 95%	p-value	B	SE B	Exp(B)	CI 95%	p-value	B	SE B	Exp(B)	CI 95%	p-value
Hygiene	−0.342	0.170	0.711	0.509–0.992	0.044*	−0.338	0.171	0.713	0.510–0.997	0.048*	−0.307	0.174	0.735	0.523–1.034	0.077
Cleanliness of surroundings	−0.364	0.130	0.695	0.539–0.897	0.005**	−0.350	0.131	0.705	0.545–0.911	0.008**	−0.314	0.135	0.731	0.561–0.952	0.020*
SODIS application	−0.337	0.115	0.714	0.570–0.894	0.003**	−0.155	0.141	0.856	0.649–1.129	0.272	−0.164	0.142	0.849	0.643–1.121	0.248
Percentage of unsafe drinks	–	–	–	–	–	0.006	0.003	1.006	1.001–1.012	0.029*	0.006	0.003	1.006	1.001–1.012	0.030*
Socio-economic status	–	–	–	–	–	–	–	–	–	–	−0.197	0.180	0.821	0.577–1.170	0.275
Constant	1.335	0.470	3.799	–	0.005**	0.683	0.556	1.980	–	0.219	1.026	0.639	2.791	–	0.108

* = significant ($p \leq 0.05$), **/*** = highly significant ($p \leq 0.01$)/($p \leq 0.001$).
Regression 1: Nagelkerke R^2 = 0.068***, N = 656; Regression 2: Nagelkerke R^2 = 0.079***, N = 655; Regression 3: Nagelkerke R^2 = 0.081***, N = 655.

Diarrhoea prevalence amounted to 31.8% in the control group and 18.3% among regular users. We can conclude that full compliance with the intervention reduced diarrhoea risk by 42.5%. These results are in line with findings of other SODIS health impact studies (Conroy et al. 1996, 1999, 2001; Hobbins 2003; Rose et al. 2006; Graf et al. 2008).

An interesting fact is that irregular users had almost the same level of diarrhoea as regular users. This is surprising as the variables on consumption of liquids revealed that irregular users gave unsafe water and drinks more often to their young children than regular users. This lack of difference in diarrhoea incidence between these two application groups can possibly be attributed to the influence of hygiene behaviour and cleanliness of the surrounding area. These variables did not differ significantly between irregular and regular users. Another explanation could be the applied methodology of classifying households as irregular and regular users. Maybe our approach in obtaining the SODIS application score was not optimal as we included the interviewers' judgements on the user status of the households. This was possibly vulnerable to subjectivity, and some regular users could have been wrongly classified as irregular users and vice versa. However, when the other health indicator, stomach pain, was analysed, irregular users tended ($p = 0.07$) to report more often the occurrence of that health problem than regular users. This supports the validity of the methodology of classifying SODIS application.

We examined whether SODIS application still had an impact on the health status when other diarrhoea risk factors were considered. To control for such confounding factors we calculated logistic regression models for diarrhoea incidence. By including the risk factors hygiene and cleanliness of surrounding in the model, SODIS application still had predictive power for reducing diarrhoea. However, when the variable *percentage of unsafe drinks* was included, SODIS application lost its significance. We believe that this is attributed to the mediating role of this variable: SODIS provides safe water and therefore reduces the value of *percentage of unsafe drinks*. The same applies to other water treatment methods. As a consequence, SODIS application affects diarrhoea incidence only indirectly. Socio-economic status was also integrated in the model but did not reach significance level. Thus, differences in wealth in the studied areas may not influence the health

outcome directly but are related to the diarrhoea risk factors. Interpretation of the regression models was limited by its small levels of explanation of variance and problems with multi-collinearity (correlations between outcome predictors).

Concerning identification of the conditions that may have been decisive when determining why some intervention households accepted and used the method while others refused or dropped it: in the intervention group, the regular, irregular and non-users did not differ in socio-economic status or in number of people and children under five in the household. These factors therefore seemed unimportant for SODIS uptake, at least when the study population comprises households with young children in urban slums.

Respondents were supposed to be the main caretaker of the children under five. Mostly they were the mothers of the children. In terms of age, they did not differ in these three SODIS application groups. However, respondents of regular user households were more often married and less often single than non-users of the intervention group. Therefore, marital status or, in other words, family structure could be an important factor for SODIS uptake. This may possibly be attributed to task and duty sharing in the marriage condition. In contrast, single mothers might be overtaxed with childcare, household work *and* money-generating activities and would, therefore, have more problems integrating SODIS as an additional routine in their daily life. This is supported by another finding in our study: when non-users of the intervention group were asked why they did not treat (with any method) the water on household level, they were three times more likely to refer to time problems compared to the control group.

Another reason why regular users were more often married than non-users could also be attributed to social pressure. Once the decision to test the method for a certain time was taken, it was more likely for married mothers to stick to the new behaviour if the husband had agreed to it or had at least been informed. He might have supported directly or indirectly the trial period, which could put the wife under real or felt pressure to continue with the behaviour. Naturally, further research would be needed to confirm these hypotheses.

The fact that we collected data on health and water consumption prior to the intervention can be rated as strength of our research. Although our limited financial resources did not allow conducting a fully randomized controlled trial, it was possible for our study to exceed a simple correlative design. Availability of pre-intervention data enabled us to compare diarrhoea prevalence not only after SODIS introduction between the different groups of the evaluation survey, but also within time. Another strong point is that we did not only analyse the data regarding having received intervention or not, but additionally split it into SODIS application groups using a multi-criteria assessment. The division in these compliance groups allowed a more accurate evaluation of health improvement and also supported analysis of factors facilitating the uptake of the method.

Concerning the weaknesses, there were differences between demographic profiles of the pre-intervention and the overall evaluation survey. Respondents of the evaluation survey were on average younger and more often female than in the pre-intervention survey. In retrospect, we believe that these dissimilarities can be explained by a methodological inattention: in the pre-intervention survey, emphasis to interview the main caretakers of the children had not been as strong as in the evaluation survey. This could possibly be the reason why in the pre-intervention survey, more male household heads and fathers had been interviewed. Since in many traditional (as well as modern) societies, husbands are often older than their wives, this could explain the age difference between the participants of the two surveys. However, this does not influence comparability of the two study groups.

The evaluation survey also revealed some differences in characteristics between the intervention and control group. Respondents of the intervention group were significantly older, less often female, more often married and less often single compared to the control group. This might be explained by a possible survey technique problem similar to the aforementioned one. As the intervention households had been preselected from promotion lists, the interviewers could have more readily accepted a respondent other than the mother if she was absent. Since the interviewers needed answers from that particular household, they might not have been as strict as when looking for interview partners in the control households. Therefore, we believe that interviewers tended to question more often fathers in

intervention households than in control households. As explained above, we expect the fathers of young children to be on average older than the mothers. We also believe that children raised by single mothers are far more common than children raised by single fathers. This would explain the difference in marital status between the intervention and control group. As there was no statistical difference in socio-economic status or in the number of household members and children under five in the two groups, we think that comparability is not critically affected.

Due to conflicts of interest, the use of former SODIS promoters as interviewers seemed to pose a further problem. However, we made sure to minimize any bias through proper training of the interviewers and by sending them to areas where they had not worked as promoters. Furthermore, inclusion of implementation staff in the research was also of great advantage as explained in the *Methods* section of this paper. Finally, as several variables were only collected in the evaluation survey and not in the pre-intervention survey, some relations between variables could only be correlated and not causally determined. For instance, the intervention also included certain training on hygiene. In fact, in the evaluation survey we found that the regular users had significant better hygiene values than the control group. This indicates that the training had some effect. However, as we did not collect data on hygiene in the pre-intervention survey nor follow up households, we were unable to dismiss the other causes in our interpretation. Therefore, we can not rule out that households with already better values on hygiene were more aware of health-related behaviour and thus adopted SODIS more readily and became regular users.

Based on the results obtained, we can conclude that SODIS introduction had positive health benefits among the target population of Cameroon. Our results are thus in line with findings of most previous SODIS health impact studies conducted in other regions of the developing world (Conroy *et al.* 1996, 1999, 2001; Hobbins 2003; Rose *et al.* 2006; Graf *et al.* 2008). Therefore, we recommend to further promote and disseminate SODIS as an effective water treatment method among poor populations in low-income countries. In our view, this recommendation can be provided also despite the recent study of Mäusezahl *et al.* (2009), which did not report a significant reduction in diarrhoea. The results of one case study revealing a rather low compliance are interesting and require further discussion. However, the results of a single study should not form the basis for general conclusions, as health impact is dependent on various factors like compliance, parallel consumption of untreated water, site-specific importance of drinking water as a transmission route for infection and other factors. However, we are looking forward to additional research on health benefits of SODIS and other household water treatment methods. Future studies could try to put even more attention to the observer/respondent bias and to the inclusion of objective health indicators as recently suggested (Clasen *et al.* 2009; Schmidt & Cairncross 2009*a*,*b*).

Aside from the health effects of SODIS, for which evidence is available, focus should be placed on other research scopes. Selection of appropriate strategies to inform beneficiaries about SODIS is one of them and the reasons why some households adopt the practice of water treatment and others not. These are issues pertaining to diffusion (how to reach people), promotion (how to convince them) and behavioural change strategies (how to break routines, introduce new behaviour). So far, only a few studies on these social aspects of SODIS have been published (Rainey & Harding 2005; Altherr *et al.* 2008; Heri & Mosler 2008; Moser & Mosler 2008; Tamas *et al.* 2009). Consequently, there is an enormous need for additional research. In this study, dissemination of the method was conducted by regular household visits of promoters. Previous experience and research (EAWAG/SANDEC 2002; Meierhofer & Landolt 2008) have shown that this generates the highest sustainable adoption, whereas a single information or training event is not sufficient to achieve a lasting behavioural change (Rainey & Harding 2005).

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REFERENCES

Altherr, A. M., Mosler, H. J., Tobias, R. & Butera, F. 2008 Attitudinal and relational factors predicting the use of solar water disinfection: a field study in Nicaragua. *Health Educ. Behav.* **35**(2), 207–220.

Biran, A., Rabie, T., Schmidt, W., Juvekar, S., Hirve, S. & Curtis, V. 2008 Comparing the performance of indicators of hand-washing practices in rural Indian households. *Trop. Med. Int. Health* **13**(2), 278–285.

Blum, D. & Feachem, R. G. 1983 Measuring the impact of water supply and sanitation investments on diarrhoeal diseases: problems of methodology. *Int. J. Epidemiol.* **12**, 357–365.

Clasen, T., Schmidt, W.-P., Rabie, T., Roberts, I. & Cairncross, S. 2007 Interventions to improve water quality for preventing diarrhoea: systematic review and meta-analysis. *Br. Med. J.* **334**(7597), 782–785.

Clasen, T., Bartram, J., Colford, J., Luby, S., Quick, R. & Sobsey, M. 2009 Comment on 'Household water treatment in poor populations: is there enough evidence for scaling up now?'. *Environ. Sci. Technol.* **43**(14), 5542–5544.

Conroy, R. M., Meegan, M. E., Joyce, T., McGuigan, K. & Barnes, J. 1996 Solar disinfection of drinking water and diarrhoea in Maasai children: a controlled field trial. *Lancet* **348**, 1695–1697.

Conroy, R. M., Meegan, M. E., Joyce, T., McGuigan, K. & Barnes, J. 1999 Solar disinfection of water reduces diarrhoeal disease, an update. *Arch. Dis. Child.* **81**, 337–338.

Conroy, R. M., Meegan, M. E., Joyce, T., McGuigan, K. & Barnes, J. 2001 Solar disinfection of drinking water protects against cholera in children under 6 years of age. *Arch. Dis. Child.* **85**, 293–295.

EAWAG/SANDEC 2002 Solar water disinfection: a guide for the application of SODIS. EAWAG/SANDEC, Dübendorf, Switzerland. Accessed 12 March 2009. Available from: http://www.sodis.ch/files/SODIS_Manual_english.pdf

Fewtrell, L., Kaufmann, R. B., Kay, D., Enanoria, W., Haller, L. & Colford, J. M. 2005 Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis. *Lancet Infect. Dis.* **5**, 42–52.

Graf, J., Meierhofer, R., Wegelin, M. & Mosler, H.-J. 2008 Water disinfection and hygiene behaviour in an urban slum in Kenya: impact on childhood diarrhoea and influence of beliefs. *Int. J. Environ. Health Res.* **18**(5), 335–355.

Heri, S. & Mosler, H. J. 2008 Factors affecting the diffusion of solar water disinfection: a field study in Bolivia. *Health Educ. Behav.* **35**(4), 541–560.

Hobbins, M. 2003 *The SODIS health impact study* (PhD Thesis). Swiss Tropical Institute, Basel.

Hunter, P. 2009 Household water treatment in developing countries: comparing different intervention types using meta-regression. *Environ. Sci. Technol.* **43**(23), 8991–8997.

Kosek, M., Bern, C. & Guerrant, R. L. 2003 The global burden of diarrhoeal disease, as estimated from studies published between 1992 and 2000. *Bull. World Health Organ.* **81**(3), 197–204.

Lantagne, D., Meierhofer, R., Allgood, G., McGuigan, K. G. & Quick, R. 2009 Comment on 'Point of use household drinking water filtration: a practical, effective solution for providing sustained access to safe drinking water in the developing world'. *Environ. Sci. Technol.* **43**(3), 968–969.

Manun'Ebo, M., Cousens, S., Haggerty, P., Kalengaie, M., Ashworth, A. & Kirkwood, B. 1997 Measuring hygiene practices: a comparison of questionnaire with direct observations in rural Zaire. *Trop. Med. Int. Health* **2**(11), 1015–1021.

Mäusezahl, D., Christen, A., Duran Pacheco, G., Alvarez Tellez, F., Iriarte, M., Zapata, M. E., Cevallos, M., Hattendorf, J., Daigl Cattaneo, M., Arnold, B., Smith, T. A. & Colford, J. M. 2009 Solar Drinking Water Disinfection (SODIS) to reduce childhood diarrhoea in rural Bolivia: a cluster-randomized, controlled trial. *PLoS Medicine* **6**(8), 1–13.

Meierhofer, R. & Landolt, G. 2008 Factors supporting the sustained use of solar water disinfection—experiences from a global promotion and dissemination programme. Water and sanitation in international development and disaster relief. *Proceedings of International Workshop in Edinburgh*, Scotland. 28–30 May 2008. Accessed 12 March 2009. Available from: http://www.sodis.ch/files/Meierhofer_08_WatSanWSProceedings_Factors%20supporting%20SODIS%20use.pdf

Moser, S. & Mosler, H. J. 2008 Differences in influence patterns between groups predicting the adoption of a solar disinfection technology for drinking water in Bolivia. *Soc. Sci. Med.* **67**, 497–504.

Nguendo Yongsi, B., Salem, G. & Bruneau, J.-C. 2008 Epidémiologie géographique des maladies diarrhéiques à Yaoundé (Cameroun). *M@ppemonde* **89**(1), 1–17, Accessed 26 June 2009. Available from: http://mappemonde.mgm.fr/num17/articles/art08102.html

Parrot, L., Sotamenou, J. & Dia, B. K. 2009 Municipal solid waste management in Africa: Strategies and livelihoods in Yaoundé, Cameroon. *Waste Manage.* **29**, 986–995.

Rainey, R. & Harding, A. 2005 Acceptability of solar disinfection of drinking water treatment in Kathmandu Valley, Nepal. *Int. J. Environ. Health Res.* **15**(5), 361–372.

Rose, A., Roy, S., Abraham, V., Holmgren, G., George, K., Balraj, V., Abraham, S., Muliyil, J., Joseph, A. & Kang, G. 2006 Solar disinfection of water for diarrhoeal prevention in Southern India. *Arch. Dis. Child.* **91**(2), 139–141.

Schmidt, W.-P. & Cairncross, S. 2009 Household water treatment in poor populations: is there enough evidence for scaling up now? *Environ. Sci. Tech.* **43**(4), 986–992.

Schmidt, W.-P. & Cairncross, S. 2009 Response to comment on 'Household water treatment in poor populations: is there enough evidence for scaling up now?'. *Environ. Sci. Technol.* **43**(14), 5545–5546.

Sobsey, M. D. 2002 *Managing Water in the Home: Accelerated Health Gains From Improved Water Supply*. World Health Organization, Geneva, Accessed 12 March 2009. Available from: http://www.who.int/water_sanitation_health/dwq/wsh0207/en/index.html

Sobsey, M. D., Stauber, C. E., Casanova, L. M., Brown, J. M. & Elliott, M. A. 2008 Point of use household drinking water filtration: a practical, effective solution for providing sustained access to safe drinking water in the developing world. *Environ. Sci. Technol.* **42**(12), 4261–4267.

Tamas, A., Tobias, R. & Mosler, H. J. 2009 Promotion of solar water disinfection: comparing the effectiveness of different strategies in a longitudinal field study in Bolivia. *Health Comm.* **24**(8), 711–722.

Tanawa, E., Tchapnga, H. B. D., Ngnikam, E., Temgoua, E. & Siakeu, J. 2002 Habitat and protection of water resources in suburban areas in African cities. *Build. Environ.* **37**, 269–275.

Trevett, A. F., Carter, R. C. & Tyrrel, S. F. 2004 Water quality deterioration: a study of household drinking

water quality in rural Honduras. *Environ. Health Res.* **14**(4), 273–283.

WHO 2004 Water, sanitation and hygiene links to health. Facts and Figures–updated November 2004. Accessed 27 March 2009. Available from: http://www.who.int/water_sanitation_health/factsfigures2005.pdf

WHO 2007 Combating waterborne disease at the household level. Accessed 1 November 2009. Available from: http://www.who.int/water_sanitation_health/publications/combating_disease/en/

Wright, J., Gundry, S. & Conroy, R. 2004 Household drinking water in developing countries: a systematic review of microbiological contamination between source and point-of-use. *Trop. Med. Int. Health* **9**(1), 106–117.