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Drinking water quality and solar disinfection: Effectiveness in peri-urban households in Nepal

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ABSTRACT

The study examined pH, turbidity and fecal contamination of drinking water from household water storage containers, wells and taps, and the Godawari River, and tested the effectiveness of solar disinfection (SODIS) in reducing levels of fecal contamination from household containers. The research was conducted in 40 households in a village 6 km outside the capital city of Kathmandu, Nepal. Three rounds of data were collected: a baseline in March 2002 followed by training in solar disinfection, and follow-ups in June and July 2002. Untreated drinking water was found to have levels of contamination ranging from 0 to too numerous to count fecal coliform CFU 100 ml^{-1}. Source water was significantly more contaminated than water from the household storage containers. Wells were less contaminated than taps. SODIS reduced the level of contamination under household conditions. Turbidity from taps was above 30 NTU in the rainy season, above the maximum for effective solar disinfection. SODIS was routinely adopted by only 10% of the participating households during the study.

Key words | drinking water, fecal contamination, Nepal, pH, solar disinfection (SODIS), turbidity

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INTRODUCTION

Water and sanitation have a major impact on health. Globally, lack of clean water and sanitation together are the second most important risk factors for ill-health (Murray & Lopez 1997). Lack of access to safe drinking water increases the risk of contracting waterborne diseases including diarrhoea, cholera, typhoid, hepatitis A and amoebic dysentery. Every year 4 billion cases of diarrhoea cause 2.2 million deaths, mostly among children under 5 years old, and in less industrialized countries (WHO/UNICEF 2000).

Nepal is a small Asian country located along the Himalayan mountain range between India and China. Nepal's 2003 Human Development Index rank was 143rd out of 175 countries, indicating a low life expectancy at birth, low educational attainment and low income (UNDP 2003). Many of Nepal's health problems, including high infant and child mortality and high incidence of fecal-orally transmitted disease, are related to contaminated water (UNDP 1995). The Asian Development Bank's (1998) Plan for Nepal stated that poor water supply and sanitation and unhygienic living conditions, especially in rural villages, remain among the major obstacles to improving health. The weak health infrastructure in rural areas contributes to high numbers of fatalities for many treatable illnesses, including dehydration due to diarrhoea. A joint study by His Majesty's Government (HMG) of Nepal and UNICEF found that water treatment in the home reduced the risk of diarrhoea in children by 1.5 times (HMG/UNICEF 1997). They concluded that inexpensive effective methods of home water treatment are urgently needed as a short-term and even long-term solution to the lack of community-level water systems.

There are many methods available for household-level disinfection of drinking water, including chlorination, iodine, filtering and solar disinfection. Each of these methods or combinations of methods has trade-offs in terms of effectiveness, convenience and cost (Sobsey 2002). Solar disinfection (SODIS) was recommended during

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World Water Day 2001 as a simple, low-cost method for water purification at the household level (WHO 2001).

SODIS uses solar energy in the form of ultraviolet radiation and, to a lesser extent, infrared heat, to inactivate or destroy pathogenic microorganisms in the water. The process has three main steps: (1) collect clear, empty 1.5 or 2 litre PET plastic bottles (mineral water or soda pop bottles) with labels removed; (2) fill with contaminated water, shake and close; and (3) place bottles on their sides in full sun for at least 6 hours during the middle of the day when the solar radiation is most intense. Actual exposure time required depends on latitude, altitude, season, weather and turbidity of the water (EAWAG/SANDEC 2002).

This technology has been tested under controlled conditions at a laboratory the Kathmandu Valley of Nepal, and has shown reductions of bacterial contamination in drinking water of over 90% (ENPHO 2002). It has been tested in households in the *Terai,* or lower elevations of Nepal near the Indian border, and was shown to be effective both in disinfecting water and in reducing diarrhoea (Moulton 1999). However, at the time there had been no research on effectiveness under household conditions in the Kathmandu Valley, which differs in culture, ethnicity and geography from the *Terai* region. This study tested the effectiveness of solar disinfection of drinking water in a peri-urban village in Kathmandu Valley, Nepal. Three parameters of drinking water quality (pH, turbidity and fecal contamination) were examined, and several null hypotheses were tested, including no difference in fecal contamination, turbidity and pH in water from different sources, and no difference in fecal contamination before and after SODIS treatment. Household variables that may affect the level of fecal contamination were also analysed.

This research was approved by Oregon State University's Institutional Review Board for the Protection of Human Subjects. The research also had the support of His Majesty's Government of Nepal's Drinking Water and Sanitation Section under the Ministry of Local Development, and of the Chairman of the Siddhipur Village Development Committee (VDC). One of the VDC Chairman's staff was assigned to the project as a translator and facilitator. The researcher and translator met with each potential participant to explain the study and to ask for her consent to participate. If she agreed to participate, the translator read the written informed consent form in Newari language, and the participant either signed her name or made a thumbprint to indicate consent on a form written in Nepali. A copy of the consent form was given to the participant and all originals will be kept by the researchers for three years before being pulped.

METHODS

The study was conducted from February to July 2002. The research site, Siddhipur Village, was selected on the basis of its location 6 km outside the capital city of Kathmandu, and because prior research indicated bacteriological contamination of the village water sources. There is no community-level drinking water treatment plant in this village, and household treatment is rare.

Selection of households

The sample of 42 households was randomly selected using stratification by ward, in order to use the existing village census as a sampling frame. Three of the nine village wards were selected using a random number generator. Fourteen households were randomly selected from each of those wards. The contact person was the primary food preparer in the selected household. All contacts were women.

After receiving voluntary informed consent, three cycles of data collection were performed. Baseline data were collected in March 2002, followed by data collections in June and July 2002. Two households dropped out of the study after the baseline data were collected, and were not included in the analysis. The final sample size was 40 households. During the baseline cycle, demographic data and information about drinking water sources and behaviours were collected on a survey form. Next, all household contacts attended a two-hour training session. The training included information and discussion about the ways water can become contaminated, the health effects of drinking or consuming contaminated water, and instructions on how to implement the SODIS method of solar disinfection of drinking water. Volunteers demonstrated the technique with feedback from the other participants, and the session ended with a discussion of the next steps of the study and how the results would be used.

After the training, all participating households were provided with two 1.5 litre clear PET bottles for each person in the household. This allowed for two sets of bottles, rotated so that half of the set of bottles were exposed on day 1 and consumed on day 2, while the second set was being exposed on day 2 and consumed on day 3 in an ongoing cycle. During each household interview session participants were asked if they had any questions or comments about using solar disinfection, about their drinking water quality, and about any aspect of the village environment they thought was significant. These comments were noted and analysed for themes in a separate part of the study.

Water sampling procedures

Water sampling was performed during the period of March to July 2002. In March, baseline samples were taken from the household water storage container (*gagri*) in each household, and from the primary drinking water sources used by the participating households. Households generally used the closest tap or well to the house, although some households preferentially used one type or another despite a slightly longer walk to reach the water source. Samples were also taken from the Godawari River, which is the source of the tap water in the village, and from exposed SODIS bottles during the follow-up sampling rounds. The water samples were tested for pH, turbidity and fecal contamination.

pH and turbidity measurements were taken on site in the field. pH, a measure of the concentration of hydrogen ions, was measured and recorded in the field with a Hach Pocket Pal pH tester. The pH meter was calibrated with standard solutions at the ENPHO laboratory before data collection. Raw water for use as drinking water usually has a pH in the range of 5.5 and 8.6, and in this range there is no immediate health effect in humans (DeZuane 1997). pH may, however, affect the rate of leaching of metals or minerals into water and the growth of microorganisms.

Turbidity is a measure of suspended solids in a solution, usually clay, silt, organic matter or microorganisms (*Standard Methods* 1998). Turbidity was measured and recorded in the field using a HACH DR/820 portable spectrophotometer (Hach 1997). The units are in formazin attenuation units (FAU), equivalent to nephelometric turbidity units (NTU) (Hach 1997). The United States Environmental Protection Agency has set the maximum contaminant level of turbidity in drinking water at 1 NTU, and it must not exceed 0.3 NTU in 95% of daily samples in any month (USEPA 2002). The WHO guidelines for routine monitoring are that the median level of turbidity should be less than or equal to 1 NTU, with a maximum of 5 NTU for any single sample (WHO 1993).

Fecal coliform bacteria were used as an indicator of fecal contamination (WHO 1993). Samples were collected directly from the taps and household containers into 120 ml Whirl-pak bags. Well water samples were collected by rinsing the researcher's bucket in the well to be sampled, then collecting a bucketful for sampling. Water was poured directly from the bucket into the Whirl-pak bag. Samples were transported on ice in a cooler back to the laboratory for processing. Processing occurred less than 8 hours after collection in accordance with handling times and temperatures for microbiological samples (Hach 1997).

The water samples were tested for fecal contamination using membrane filtration and incubation. The samples were processed using a Del Aqua membrane filtration kit and incubator loaned by the government's Drinking Water and Sanitation office. The samples were filtered through Millipore 0.7 μm membrane filters with grids. The Millipore M-FC fecal coliform media was prepared in small batches of 100 or 200 ml, on an 'as needed' basis, by the lab staff at the ENPHO laboratory facilities to ensure sterile conditions. The media was packaged in 24 ml sterilized glass tubes with lids, enough media for about seven samples. Any partially used tubes of media were discarded. After completing filtration of the day's samples, a blank sample with boiled water and then a spike with water known to be contaminated with fecal material were run to test for reliability and incubated along with the other samples. The lab procedures were carried out using quality control measures as specified by Hach for bacteriological testing, disinfection of the area and disposal of completed tests (Hach 1997).

Data analysis

The data from water testing were entered into Excel 2000 spreadsheets. The data were checked for input errors before importing into JMP (SAS, Institute 2001) and S + (Insightful Corp 2001) statistical software packages for analysis. Water samples with CFU recorded as TNTC (too numerous to count) in the data log were replaced with 1,000 CFU per 100 ml for the purposes of analysis, a slightly larger value than the highest actual count in the data. Samples with dried out pads were recorded with a dash to indicate that there was no result, and these samples were excluded from the analysis.

The data and residuals were examined for assumptions for normality and equal variances. Turbidity and fecal coliform data were transformed using a natural log transformation, then back-transformed for interpretation of results. Interpretation of the log-transformed data followed the guidelines in Ramsey and Schafer (1997). Differences in water quality parameters were tested by two-way ANOVA, followed by a Tukey HSD post-hoc test for significant results. The paired data examining the effectiveness of SODIS in reducing fecal coliform contamination were tested using a Wilcoxon Signed Rank test. A multiple regression was used to examine the contribution of variables that might explain the level of fecal contamination. Statistical significance was set at $P < 0.05$.

RESULTS AND DISCUSSION

The study examined water quality from households, wells, taps, SODIS bottles and the Godawari River for three parameters: level of fecal contamination, turbidity and pH. There were significant differences among the four sources for all three parameters tested. The unadjusted means and standard deviations of the parameters measured in the households, from the SODIS containers, and from wells, taps and the river are shown in Table 1. The adjusted means and results of the ANOVA tests for all parameters are summarized in Table 2.

Effectiveness of SODIS

The effectiveness of SODIS in reducing fecal contamination was tested with a one-sided paired samples Wilcoxon Signed-Rank test, comparing the average difference in level of contamination (measured in CFU) before and after SODIS exposure ($\mu = 152$ CFU, SE $= 68$), to a hypothesized mean of 0. The result $T(9) = 21.5, P = 0.014$, indicates that there is a reduction in fecal contamination after using SODIS under household conditions. The pre- and post-treatment levels of contamination are shown in Figure 1. The SODIS treatments in nine of the ten samples resulted in 0 CFU 100 ml^{-1}, so they are not visible on the graph.

SODIS successfully reduced the number of bacteria in water under the household conditions tested in this study. This is in agreement with other research in Nepal by the Environment and Public Health Organization (ENPHO), which reported a mean reduction of 89% in fecal coliform in 33 tests conducted over a period of six months, from January to July 2001, on the roof of their office in Kathmandu (ENPHO 2002). In 2002, from April to August, Shrestha his colleagues tested contaminated water at various altitudes in Nepal and found that clear SODIS bottles averaged 99.2% removal of fecal coliform (Shrestha *et al.* 2003). Both of these studies noted the need for research for a complete year, as did Khayyat (2000), who found that *E. coli* was reduced but not eliminated on days with morning fog, a frequent occurrence in the winter in the Kathmandu Valley.

In the second round of testing, there was one SODIS sample where the level of contamination increased compared with the control sample from that household (9 July 2002: household container 30 CFU, SODIS container 168 CFU). It is possible that this bottle had not yet been exposed. Another explanation is that the bottles might have been situated in an area where they did not receive full sunlight throughout the day. This raises the important issues of duration of exposure during cloudy weather, proper handling of the bottles to avoid recontamination, and correct placement of SODIS bottles to ensure maximum ultraviolet exposure.

In addition to testing water quality, variables that may affect water quality were also examined for their contribution to the level of fecal contamination. Age and number of years of formal education of the household contact, number of people in the household, and presence of latrine in household were not found to be significant predictors of bacterial contamination of water in the household storage containers.

Fecal contamination

Too numerous to count (TNTC) data points were replaced with 1,000 for this analysis. A natural log transformation

Table 1 | Means and standard deviations (SD) for drinking water quality parameters by water source

Water source	**Sampling round 1 (baseline) March 2002**	**Sampling round 2 (first follow-up) June 2002**	**Sampling round 3 (second follow-up) July 2002**	**Overall**
Household water storage containers (untreated)	Count Mean (SD) Range	Count Mean (SD) Range	Count Mean (SD) Range	Count Mean (SD) Range
pH	n = 40 7.8 (0.6) 6.9 to 8.9	n = 38 7.8 (0.6) 7.2 to 8.9	n = 38 7.8 (0.5) 7.1 to 9.4	N = 116 7.8 (0.6) 6.9 to 9.4
Turbidity[1]	n = 40 10.1 (15.0) 0.0 to 61.0	n = 38 7.3 (6.7) 0.0 to 29.0	n = 38 7.3 (8.5) 0.0 to 41.0	N = 116 8.2 (10.7) 0.0 to 61.0
Fecal contamination[2]	n = 40 67 (77) 0 to 348	n = 34 262 (272) 0 to TNTC[3]	n = 37 112 (136) 0 to 608	N = 111 140 (193) 0 to TNTC[3]
SODIS bottles (treated)	**Sampling round 1 (baseline) March 2002**	**Sampling round 2 (first follow-up) June 2002**	**Sampling round 3 (second follow-up) July 2002**	**Overall**
pH	–	n = 5 8.0 (2.5) 7.5 to 8.8	n = 8 8.4 (0.5) 7.5 to 8.8	N = 13 8.2 (0.5) 7.5 to 8.8
Turbidity[1]	–	n = 5 1.4 (1.7) 0.0 to 4.0	n = 8 3.3 (4.0) 0.0 to 11.0	N = 13 2.5 (3.4) 0.0 to 11.0
Fecal contamination[2]	–	n = 5 0 (0) 0	n = 7 24 (63) 0 to 168	N = 12 14 (48) 0 to 168
Wells (untreated)	**Sampling round 1 (baseline) March 2002**	**Sampling round 2 (first follow-up) June 2002**	**Sampling round 3 (second follow-up) July 2002**	**Overall**
pH	n = 8 7.2 (0.1) 7.1 to 7.5	n = 8 7.2 (0.1) 7.1 to 7.5	n = 8 7.3 (0.2) 6.9 to 7.5	N = 24 7.2 (0.1) 6.9 to 7.5
Turbidity[1]	n = 8 30.6 (27.2) 0.0 to 73.0	n = 8 17.6 (22.3) 0.0 to 73.0	n = 9 13.8 (21.4) 0.0 to 56.0	N = 25 20.4 (25.3) 0.0 to 73.0
Fecal contamination[2]	n = 8 124 (118) 6 to 380	n = 8 401 (308) 8 to TNTC[3]	n = 9 357 (191) 47 to 592	N = 25 297 (255) 6 to TNTC[3]
Taps (untreated)	**Sampling round 1 (baseline) March 2002**	**Sampling round 2 (first follow-up) June 2002**	**Sampling round 3 (second follow-up) July 2002**	**Overall**
pH	n = 1 7.7	n = 9 8.4 (0.0) 8.4 to 8.5	n = 9 8.3 (0.1) 8.1 to 8.6	N = 19 8.3 (0.2) 8.1 to 8.6
Turbidity[1]	n = 10 11.4 (5.9) 2 to 19	n = 9 16.9 (6.9) 1 to 24	n = 9 51.8 (9.4) 36 to 64	N = 28 26.1 (19.5) 1 to 64

Table 1 | (*continued*)

Water source	Sampling round 1 (baseline) March 2002	Sampling round 2 (first follow-up) June 2002	Sampling round 3 (second follow-up) July 2002	Overall
Fecal contamination[2]	n = 10 238 (279) 36 to TNTC[3]	n = 9 488 (108) 356 to 660	n = 8 598 (172) 232 to 760	N = 27 428 (250) 36 to TNTC[3]
Godawari River at diversion for Siddhipur taps (untreated)	**Sampling round 1 (baseline) March 2002**	**Sampling round 2 (first follow-up) June 2002**	**Sampling round 3 (second follow-up) July 2002**	**Overall**
pH	n = 1 8.9	–	n = 2 8.8 (0.0)	N = 3 8.8 (0.1)
Turbidity[1]	n = 1 7 7	–	n = 2 36.5 20 to 53	N = 3 26.7 (23.7) 7 to 53
Fecal contamination[2]	n = 1 TNTC[3]	–	n = 2 TNTC[3]	N = 3 TNTC[3]

[1]In formazin attenuation units (FAU), equivalent to nephelometric turbidity units (Hach 2003)
[2]In fecal coliform colony forming units (CFU) of fecal coliform bacteria per 100 ml sample
[3]Too numerous to count (TNTC), replaced with 1,000 CFU for analysis

was performed on the fecal contamination data so that it met the assumptions of normality and equal variance. Differences in the level of fecal contamination among the four untreated water sources were statistically significant, $F(5,161) = 15.0$, $P < 0.0001$.[1] The log-transformed means, back-transformed geometric means and standard errors are shown in Table 3. The mean difference in fecal contamination of the transformed data, backtransformed, gives the best estimate of the population mean differences in fecal contamination between the two sources, expressed as a ratio between the two sources in the original scale. The mean differences of the transformed data and the back-transformed means with their 95% confidence intervals are shown in Table 4.

Siddhipur's drinking water from all sources: households, taps, wells and the Godawari river, had levels of fecal coliform in excess of the World Health Organization's recommended guidelines of 0 CFU fecal coliform 100 ml^{-1} (1998). The mean household contamination was 140 CFU (SD 193), and wells had a mean of 297 CFU 100 ml^{-1} (SD 255). Taps had a mean of 428 CFU 100 ml^{-1} (SD 250), and the river, which is the source of the tap water, had a level of contamination that was too numerous to count in a 100 ml undiluted sample, but was higher than 960 CFU 100 ml^{-1}, the highest number of colonies counted during the water testing.

In contrast to previous research (Blum *et al.* 1990; Rijal *et al.* 1998) the level of fecal contamination in water from the household containers was lower than from the drinking water sources, either wells or taps, indicating that there is no fresh contamination occurring in the households. The lower levels in the household may be due to natural die-off of bacteria over time, or due to bacterial properties of the brass containers that are used for drinking water storage in the home. Brass is an alloy of copper and zinc, and copper is commonly used as a fungicide due to its phytotoxic properties (USEPA 2003). In addition, the shape of the traditional water storage containers may prevent in-house contamination because the narrow mouth discourages dipping or scooping water from the container. Further research is needed on holding water in household storage containers to see if this is a reliable method of reducing contamination without additional treatment.

Wells showed slightly less contamination than the taps. During the first two sampling rounds, the level of

[1] With log-transformed data, the anti-log of the transformed mean is the geometric mean of the data in the original scale. The geometric mean level of fecal contamination in household water storage containers is $e^{3.33}$, or 28 CFU per 100 ml sample. This is an estimate of the median of the data in the original scale.

Table 2 | Summary of adjusted means and ANOVA tests for all drinking water quality parameters

Water quality parameter	Household water storage containers	Wells	Taps	Godawari River	F test (degrees of freedom)	*P* value
pH	7.8	7.2	8.3	8.9	13.4 (5, 157)	< 0.0001
Turbidity (FAU)[1]	5.6	8.4	20.1	20.8	6.6 (5, 168)	< 0.0001
Fecal contamination (CFU 100 ml^{-1})[1]	27.9	82.8	169.1	607.1	15.0 (5, 161)	< 0.0001

[1]Data transformed using natural logarithm

contamination was very low (6 CFU 100 ml^{-1} in March and 8 CFU 100 ml^{-1} in June), but in July the level of contamination was 332 CFU 100 ml^{-1}. Future research on this well would be useful to identify the source of increase in contamination at the start of the rainy season. The taps, which are fed from the central reservoir that is filled with water from the Godawari River, have the next highest level of contamination.

The highest level of contamination (too numerous to count CFU for all three samples) was found in the Godawari River at the source where it is diverted to fill Siddhipur's central reservoir. The reservoir, in turn, feeds the system of taps in the village when the central faucet at the reservoir is turned on for several hours in the morning and evening.

The level of contamination varied significantly by sampling round, with more contamination in the sampling rounds during the rainy season of June and July than during the dry season in March. Households and wells had the highest mean level of contamination in June, at the start of the rainy season, but taps and the river reached the highest mean level in July, about a month after the start of the rains.

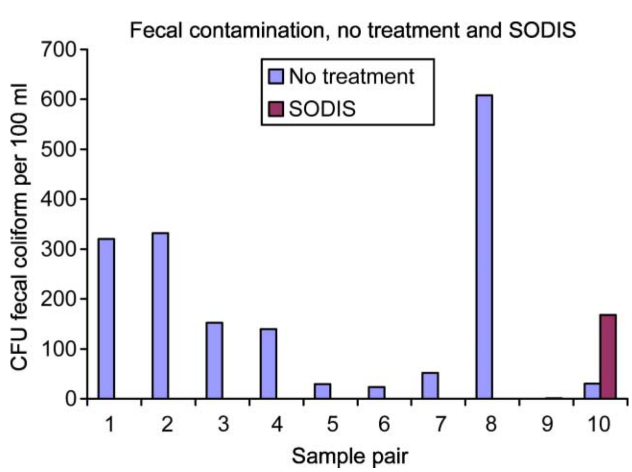

Figure 1 | Change in fecal contamination after SODIS treatment.

Turbidity

Turbidity should be less than 30 FAU or NTU for effective solar disinfection using SODIS (EAWAG/SANDEC 2002). The overall mean turbidity for each of the four water sources was less than 30 FAU. However, when examining the water sources by sampling round, several means were found to be above 30 FAU. Wells were just over this limit, with a mean of 30.6 FAU (SD 27.2) in the first round of sampling. Mean values for tap water and the river in the third round were also over 30 FAU. Overall, 17 samples out of 58 (29%) from water sources, and 4 samples out of 139 (3%) from households had FAU over 30.

The analysis controlled for effect of sampling round on turbidity, and found that it was not statistically significant. However, from a practical standpoint, the high levels of turbidity in the taps during the rainy season indicate that tap water is not appropriate to use for SODIS without first using some method of reducing turbidity. Settling in the household storage container, filtration, or some method of coagulation and flocculation are all options to reduce turbidity. Since the household samples were all under 30 FAU, filling the SODIS bottles from the household storage container rather than filling directly from the tap may be sufficient to lower the turbidity enough to use SODIS. Water with turbidity of 30 FAU is usually visibly discoloured, so it does not take any special equipment to test whether settling is required. Turbidity of the water from wells and from the household water storage containers during all three sampling rounds was low enough to use SODIS without any settling or filtering.

Table 3 | Fecal contamination (CFU 100 ml^{-1}) means and standard errors (SE) by water source

Water source	N	Mean contamination (SE)[1]	Geometric mean contamination (SE)[2]
Household	112	3.33 (0.20)	28 (1.2)
Well	25	4.42 (0.40)	83 (1.4)
Taps	27	5.13 (0.31)	169 (1.4)
River	3	6.41 (0.85)	607 (2.3)

[1]natural log transformed data
[2]antilog of mean of transformed data

pH

Significant differences were found in mean pH values among the untreated water sources, controlling for sampling round, $F(5,157) = 13.4$, $P < 0.0001$ (see Table 2). The mean differences and 95% confidence intervals (CI) between the pairs of sources are shown in Table 5.

The lowest mean pH was found in the wells, followed by household storage containers, taps and water taken directly from the Godawari River (Table 2). Although pH does not have a WHO health-based guideline, the means from all sources were under 11.0 where eye irritation and skin disorders have been reported (WHO 1993). No one in Siddhipur drinks directly from the river, although the river is the source of the water that is distributed through the system of taps in the village, so there is probably no, or very little, exposure to drinking water with pH levels above 8.5. Lower pH may not be desirable because water is stored in brass water containers, and acidity can cause copper to leach out of the brass.

CONCLUSIONS AND RECOMMENDATIONS

Fecal contamination of drinking water is a serious concern in Siddhipur, as research showed that all untreated water in Siddhipur is contaminated with fecal bacteria in excess of WHO guidelines (1993), and enteric pathogens may also be present.

The level of fecal contamination from household water storage containers was lower than the levels from wells, taps or the river, indicating that there is no contamination occurring within the household. All but two households used traditional brass containers for storing water in the household. The shape of these containers discourages dipping into the container and may limit in-house contamination of water, and exposure to the copper may reduce bacterial contamination of water in the containers.

All drinking water quality parameters tested (pH, turbidity and fecal contamination) differed among the sources sampled (household water storage containers, SODIS bottles, wells, taps and the Godawari River).

Table 4 | Ratio of mean differences and 95% confidence intervals (CI) for fecal contamination (CFU 100 ml^{-1})

Water sources	Mean difference[2]	Ratio of mean difference contamination[3]	Lower, upper limit 95% CI[3]
Households-Wells[1]	1.09	2.97	1.31, 6.71
Households-Taps[1]	1.80	6.06	2.75, 13.35
Households-River[1]	3.08	21.75	2.49, 190.18
Wells-Taps	0.71	2.04	0.73, 5.69
Wells-River[1]	1.99	7.33	0.76, 70.49
Taps-River	1.28	3.59	0.38, 34.31

[1]significant difference at $P < 0.05$ (Tukey HSD)
[2]natural log transformed data
[3]antilog of transformed data

Table 5 | pH mean differences and 95% confidence intervals (CI) for drinking water sources

Water sources	Mean difference in pH	Lower, upper 95% CI
Wells-Households[1]	0.56	0.28, 0.84
Wells-Taps[1]	1.09	0.70, 1.49
Wells-River[1]	1.61	0.84, 2.39
Households-Taps[1]	0.53	0.21, 0.85
Households-River[1]	1.05	0.31, 1.79
Taps-River	0.52	−0.27, 1.31

[1]significant difference at $P < 0.5$ (Tukey HSD)

SODIS was effective in reducing fecal contamination, but other technologies may be more attractive to women who feel their drinking water is dirty but have no other options for treatment. About 10% of the households in the study adopted SODIS on a routine basis during the study period. Other women used SODIS intermittently during the study period, or only when they had time, and some rejected it for aesthetic reasons. The timing of the data collection was delayed several times due to strikes in the Kathmandu Valley, and a lack of timely follow-up may have affected the rate of adoption of the technology. Despite the fact that the technology was not widely adopted, the experience can inform future efforts to improve water quality and reduce diarrhoea in Nepal. Key points from this study include emphasizing the links between water quality and health, educating about the sources of water contamination, and evaluating the perceptions of risks, benefits and barriers to SODIS. Future studies can include motivational visits to see how they affect the adoption rate.

There are still many gaps to fill in the understanding of SODIS as an effective household level water treatment before a blanket recommendation for adoption can be made. SODIS depends on ultraviolet radiation to disinfect pathogens, so these results can only be interpreted in the context of the weather and day length during the study period. Ultraviolet light also is a function of altitude, and Nepal has an enormous variation in topography. In addition to season and weather, the results only apply to areas of the same altitude as the study area. More research is needed to determine the effectiveness of SODIS during the winter when days are shorter and colder. A full year of data collection by a researcher living in the village would address this issue and also provide additional insight into the knowledge gaps in order to design better educational materials on water and health. Additional research is also needed on turbidity levels during the rainy season, along with simple, inexpensive methods of filtering or settling water.

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