



The Effect of Bottle Scratches On SODIS Water Disinfection

A Field Test on how bottle scratches affect the
quality of Solar Water Disinfection

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Abstract

Over one billion people on Earth do not have access to clean drinking water. Several nonprofit and government organizations are promoting low-cost, household methods for water purification¹. One method that has been promulgated for many years is called solar water disinfection or SODIS. The SODIS method includes placing low turbidity, biologically contaminated, water into a clear bottle and placing the bottle in bright sunlight for six hours². Disinfection is achieved via solar UV-A radiation penetrating the bottle and disrupting bacteria, virus, and helminth reproduction and respiration³. Concerns have recently been raised about the possible degradation in SODIS disinfection effectiveness due to surface scratches that accumulate on the bottles during routine, daily, handling.

This paper addresses the hypothesis that, if SODIS water disinfection is related to bottle scratches, then increased bottle scratch density will result in decreased solar disinfection quality.

Three tests were conducted using plastic bottles of varying size and density of scratches. The first two tests were conducted in the summer when ambient temperatures exceeded 35°C. Pre-SODIS water e-coli contamination exceeded 30,000 cu/100ml (much greater than we typically find in remote villages and urban slums in Africa and South America). Disinfection was found to be complete after six hours of exposure to direct sunlight regardless of scratch density. However, the bottle water temperatures in the summer tests exceeded 50 °C for several hours of the six hour exposure to sunlight. In such circumstances, pasteurization would have been the driving force for disinfection regardless of scratch intensity⁴.

A third test was conducted in cold weather with ambient temperatures above freezing and below 20°C. Bottle water temperatures never exceeded 27°C. Complicating the third test however, was a transition in sky conditions from clear to hazy, three hours into the initial six hours of sunlight exposure. Although samples were drawn for analysis after six hours of sunlight exposure, the bottles were left outside for 30 consecutive hours. The last six hours of sun exposure were under clear skies. E-coli and other fecal coliforms were found to be present in all bottles regardless of scratch density after the initial six hours of exposure. Although E-coli were no longer present after thirty hours, other fecal coliforms were still present.

Our conclusion from all scratched bottle tests is that bottle scratches do not influence the quality of SODIS disinfection, however the SODIS disinfection is greatly influenced by ambient temperature and bottle diameter.

In addition, a darkened-room “control” test was conducted, over four days, simultaneously to the above tests to measure the effect of time on bacterial reduction at summer and winter ambient temperatures in non-sunlight conditions. The test results indicated a 98+% reduction in E-coli over a four day period by simply placing contaminated water in a darkened-room at ambient conditions for four days.

Introduction

In 2005 the World Health Organization (WHO) reported that diarrheal disease claims the lives of over 1.2 million children each year; most less than the age of five⁵. WHO states that diarrheal incidents in a community can be reduced by 88% if the community is provided with access to clean water, effective sanitation practices, and proper hygiene⁶. One method to clean water that is being widely promoted⁷ and used in developing countries is solar water disinfection or SODIS. The technique utilizes filling clear plastic or glass bottles with relatively clear yet biologically contaminated water and then placing these bottles in bright sunlight for six hours. The UV-A radiation from sunlight interferes with the reproductive and respiratory capabilities of bacteria, viruses, and helminths, greatly reducing their efficacy after six hours of exposure⁸.

Two of the authors were conducting water sanitation and hygiene activities in Togo, Africa in the spring of 2009. It came to our attention that a respected nonprofit organization, that had been promoting SODIS, was no longer doing so because they noticed many of the plastic bottles being used for SODIS were noticeably scratched after six months of use. They hypothesized the scratches would interfere with UV transmission and thus the effectiveness of purification.

Nature Healing Nature has been promoting SODIS for many years in Africa and South America. Rather than ignore their hypothesis, we decided to conduct several tests investigating the hypothesis that, **if SODIS water disinfection is related to bottle scratches, then increased bottle scratch density will result in decreased solar disinfection quality.**

Method

Plastic Bottles

The same six plastic bottles were used for each of three SODIS tests.

- Test Bottle T (not pictured): A 2-liter clear plastic cola bottle was used to measure water temperature during the solar exposures. This bottle was placed adjacent to the other bottles. The cap was periodically removed and a thermometer inserted for a direct measure of water temperature within ± 1 °C.
- Test Bottle CB: A clear 1.5-liter plastic water bottle was used as a control. This bottle was new and did not have any visible scratches.
- Test Bottle LSB: A 1.5-liter plastic water bottle was lightly scratched with



Figure 1 - Photo of four test bottles (three scratched)

sandpaper (these bottle scratches are typical of those we have witnessed in Africa and South America).

- Test Bottle CSB: A 2-liter plastic cola bottle was heavily scratched by scraping the bottle on concrete.
- Test Bottle SSB: A 1.5-liter plastic water bottle was thoroughly scratched with sandpaper (Nature Healing Nature has not witnessed bottles this heavily scratched being used for SODIS in Africa or South America).
- Test Bottle LRB (not shown): A 2-liter clear plastic cola bottle was filled with contaminated water and placed in a darkened outdoor room for four days. It was used to monitor bacterial reduction due to time only (no UV benefit) and at ambient temperature.

Table 1 - Diameter and material of each plastic test bottle

Bottle Tag	Description	Diameter (cm)	Material
T	Temperature monitoring bottle	10.7	2 liter cola bottle without recycling designation
CB	Clear Bottle	8.9	PET
LSB	Lightly-Sanded Bottle	8.9	PET
CSB	Moderately-Sanded Bottle	10.7	2 liter cola bottle without recycling designation
SSB	Heavily-Sanded Bottle	8.9	PET
LRB	Bottle placed in a dark room	10.7	2 liter cola bottle without recycling designation

Protocol common to each test

Three tests were conducted on separate days in Houston, Texas, USA. Each test followed the same procedure for contaminated water collection, bottle preparation, sampling technique (except sample quantity), bacterial incubation, and counting.

A four gallon sample of water was extracted from White Oak Bayou in Houston, Texas between 8:00 and 8:30 AM on each day of testing. The visibly clean, five gallon, plastic bucket used for extraction was rinsed twice with bayou water before a final sample was drawn. The four gallon sample was filtered twice through a cotton cloth to remove debris.

The filtered bayou water was added to within 4 cm of the top of each SODIS test bottle (household tap water was used for the temperature monitoring bottle T). Each bottle was shaken vigorously 20 times to oxygenate the water then filled to within 1 cm of the top.



Figure 2 – Collecting Water



Figure 3 – Filtering Water

Ambient conditions differed between tests

Three tests were conducted on separate days in Houston, Texas. The first test was conducted on July 23, 2009. Skies were clear throughout the duration of the test. The ambient temperature reached 41°C, and the internal temperature of the test bottles reached 57°C (for full temperature data, see Graph 1). Samples were drawn after 6 hours of bright sunlight exposure.



Figure 4 – Hand lines visible through water

The second test was conducted on July 26, 2009. Skies were clear. The ambient temperature reached 41°C and the internal bottle temperature reached 58 °C. Samples were drawn after 6 hours of bright sunlight exposure.

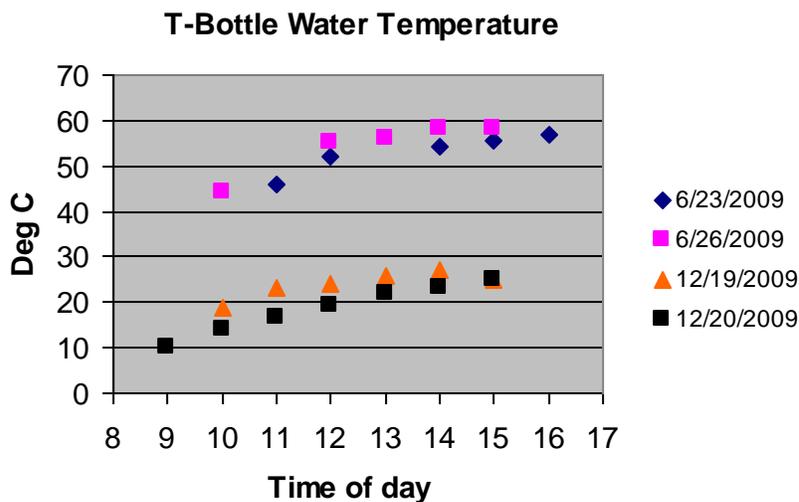


Figure 5 - Bottles placed on a hot tin roof

The third test took place on December 19th and 20th, 2009. Ambient temperatures on the first day reached 20°C and internal bottle temperatures peaked at 27 °C. Ambient temperatures on the second day reached 19°C and internal bottle temperatures reached 25°C. Skies were clear for the first three hours of testing, but hazy for the second three (see photo). In accordance with SODIS/EAWAG recommended methods, the bottles were left out for an additional 24 hours. Samples were drawn at 6 hours and again at 30 hours.



Figure 6 – Winter-sky hazy after 3 hr of exposure



Graph 1 - Test water temperatures

Sample Testing

One pipette was used to draw a sample from each bottle for bacteriological testing. The pipette was flushed with distilled water ten times between uses.¹ For summer tests, sample sizes were between 0.5 ml and 8.0 ml. All winter test samples were 1.0 ml. Each sample was placed in a 10 ml bottle containing Micrology Labs Easygel[®] and gently inverted 30 times to mix. Easygel is a pectin-gel testing method which comes as a sterile 2-part test unit consisting of a 10ml bottle of liquid medium and a Petri dish that is pretreated with a special formulation: the gel stains E-coli and fecal coliform according to species for easy identification.⁹ Samples from all tests were placed in a Hova-Bator Incubator at 35 °C within 2 hours of extraction from the bayou. Incubation time was in 24 hours increments in all sample sets.



Figure 7 - Easygel samples and Hova-Bator incubator

SODIS Test Results

Summer test results

The first summer test was conducted on June 23, 2009. Disinfection was complete after six hours of exposure to direct sunlight regardless of scratch density. However, the bottle water temperatures exceeded 50 °C for five of the six-hour exposure to sunlight. In such circumstances, pasteurization would have been the driving force for disinfection regardless of scratch intensity.

¹ The validity of this method of pipette disinfection was confirmed by testing the pipette after use. The test showed no bacterial cross contamination between pipette usages.

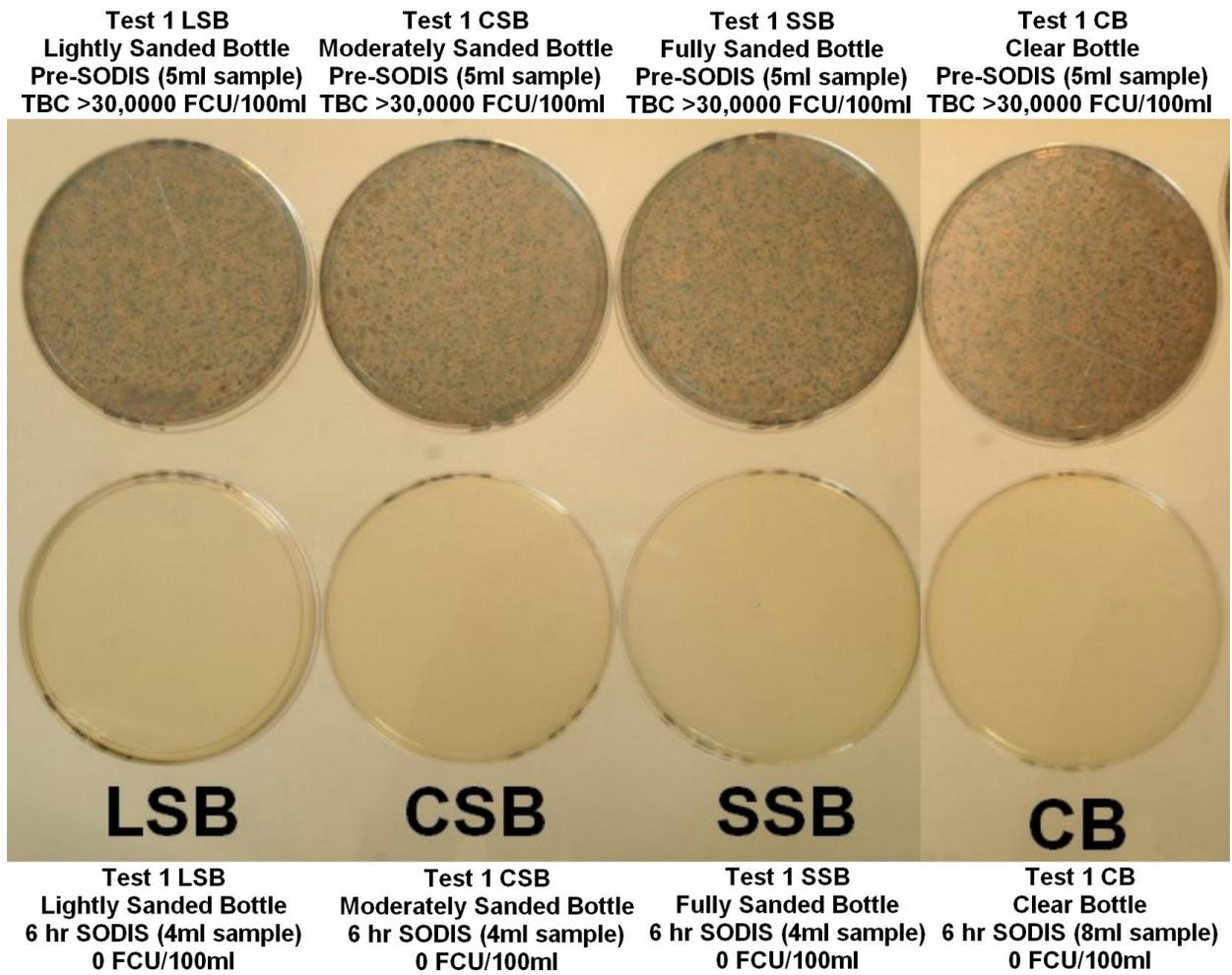


Figure 8 - Summer Test-1 Results

Top row is as collected and bottom row is post SODIS

The second summer test conducted June 26, 2009 indicates disinfection was complete after six hours of exposure to direct sunlight regardless of scratch density. However, the bottle water temperatures exceeded 50 °C for four of the six hour exposure to sunlight. As in test 1, in such circumstances pasteurization would have been the driving force for disinfection regardless of scratch intensity¹⁰.

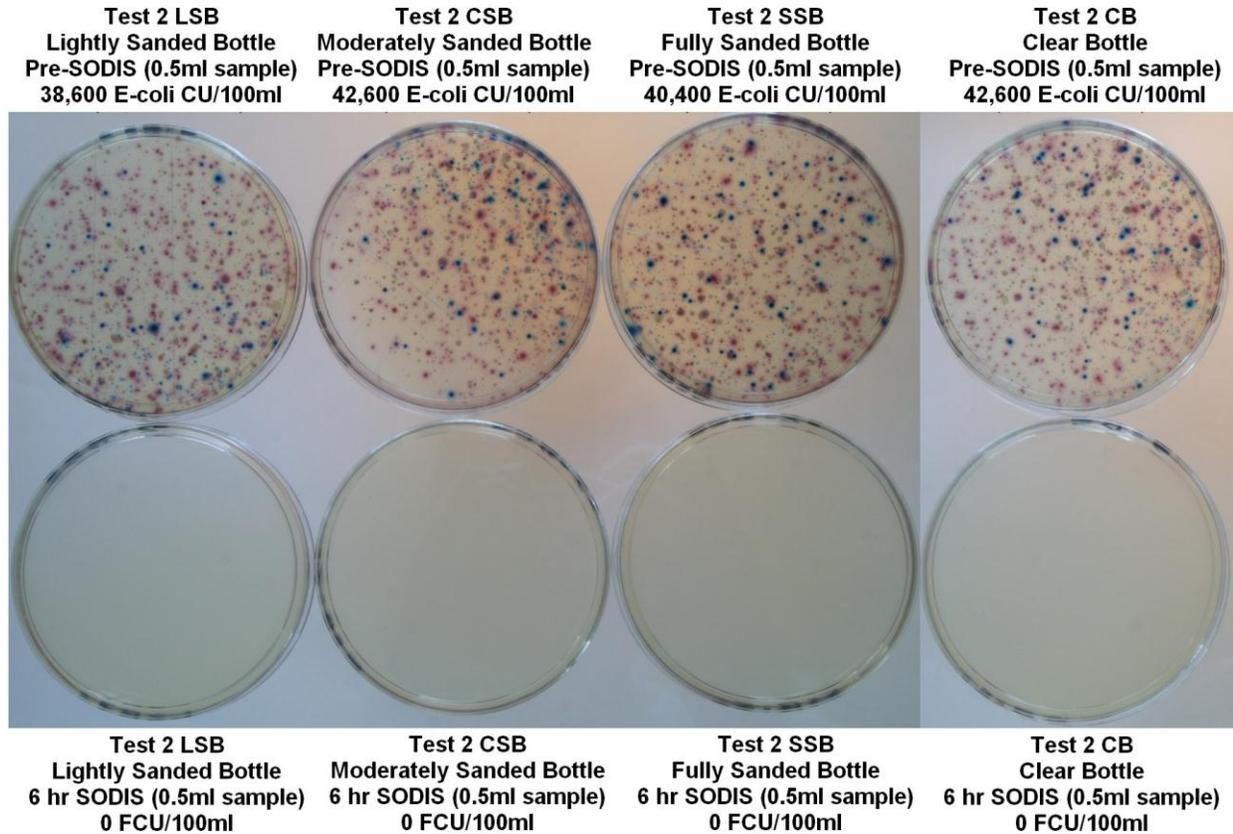
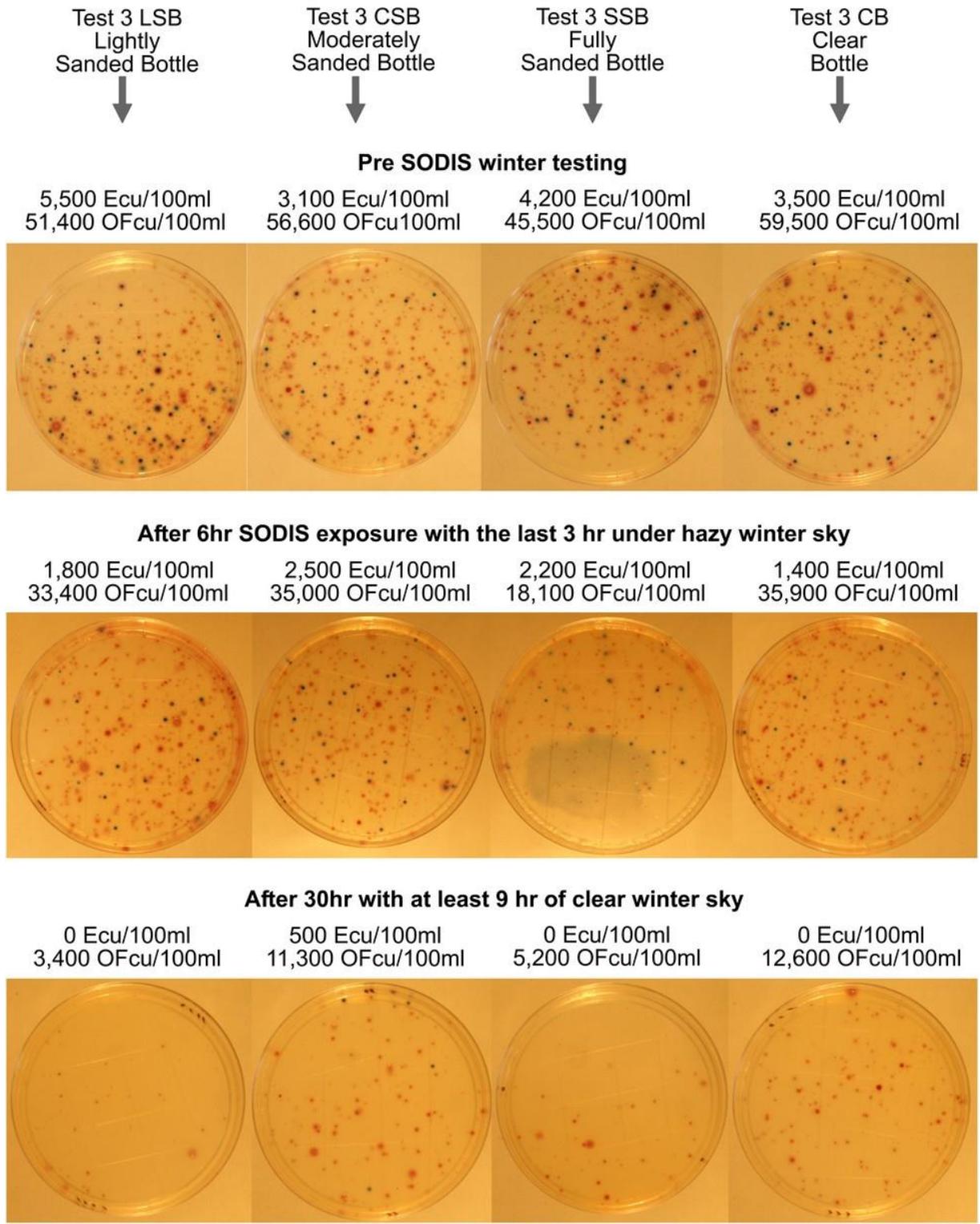


Figure 9 - Summer Test-2 Results

Top row is as collected and bottom row is post SODIS

Winter test results

The third test was conducted in winter on December 19, 2009. During the winter tests, ambient temperatures were above freezing and less than 21 °C. Water temperature did not exceed 27 °C. Due to hazy skies during the last three hours of the first day exposure, the bottles were left outside for a total of thirty hours. This is recommended by SODIS/EAWAG protocol¹¹. One milliliter samples were drawn at 0, 6, and 30 hours. Petri dish photos and counts are given below. The units of measure are E-coli colony units per 100ml (Ecu/100ml), and Other Fecal coliform colony units per 100/ml (OFcu/100ml). The reader may note that as-drawn bayou water E-coli concentrations were approximately ten times higher in the summer.

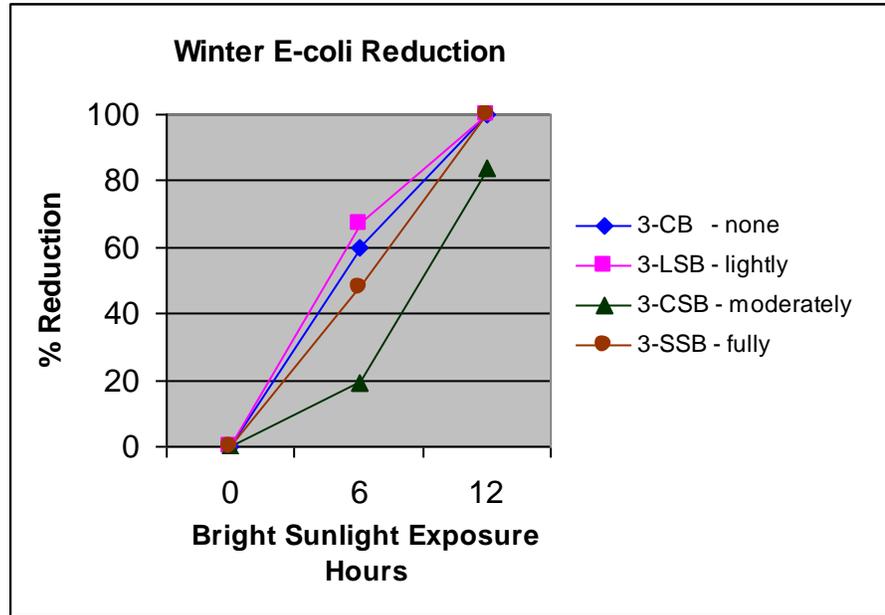


*The units of measure are E-coli colony units per 100ml (Ecu/100ml),
and Other Fecal coliform colony units per 100/ml (OFcu/100ml)
(Post SODIS test results are ± 100Ecu/100ml)*

Figure 10 - Winter Test Results.

E-coli were present in all bottles after 6 hours of exposure regardless of bottle scratch density (see graph 2).

Of note is the lower quality of disinfection in the moderately scratched bottle (CSB). Differences between this bottle and the others include its larger diameter, unknown plastic, (see table 1) and the depth of its scratches, which were approximately twice that of the other bottles.

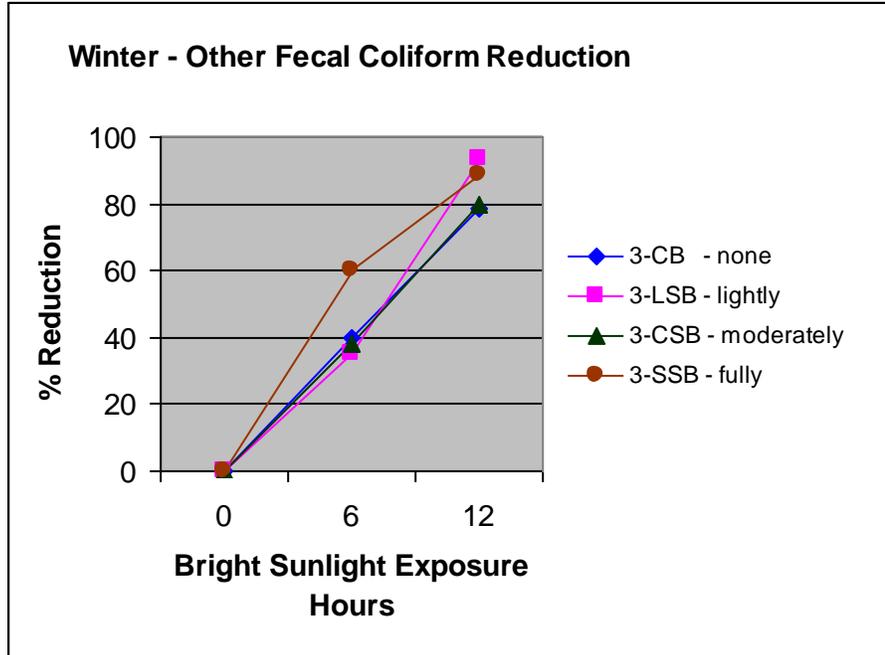


Graph 2 – Winter E-coli Reduction Effectiveness

Note: The exposure hours of the X-axis are hours in full overhead sunlight. The 12 hour data points are those sampled at 30 hours, i.e. at least two 6-hour overhead sunlight exposures.

Although E-coli were reduced to zero in three of the four test bottles after two days of SODIS, other fecal coliforms were persistent.

Other Fecal Coliform (OFC) reductions are depicted in Graph 3. OFC were present in all bottles after 6 hr and 12 hours of exposure regardless of bottle scratch density. The non-scratched control bottle (CB) fared about the same as the scratched bottles.



Graph 3 - Winter Other Fecal Coliform Reduction Effectiveness

Note: The exposure hours of the X-axis are hours in full overhead sunlight. The 12 hour data points are those sampled at 30 hours, i.e. at least two 6-hour overhead sunlight exposures.

SODIS Test Conclusions

None of the summer SODIS tests bottles (sets 1 and 2) showed any active bacteria after six hours of exposure regardless of bottle scratch density. **These results suggest that scratches on 1.5 to 2-liter plastic bottles do not decrease SODIS bacterial disinfection in hot weather where pasteurization is a contributing factor.** The bottled water temperatures in the summer tests exceeded 50°C for four hours of the six hours of overhead sunlight exposure. In such cases, pasteurization would have been the principal factor in bacterial disinfection.

Our results also suggest that although SODIS disinfection effectiveness is reduced when ambient temperatures are between 10°C and 20°C, bottle scratches are not a factor. In fact, the lightly scratched LSB bottle performed slightly better in percent e-coli and other fecal coliform reduction than the unscratched CB bottle (see Graphs 2 and 3).

Nature Healing Nature's field experience in Africa and South America indicates drinking water from hand-dug wells is typically contaminated with 100 to 1,500 E. coli per 100ml^{xiii}. This far exceeds the WHO guidelines of 0 ECU/100ml and no more than 10 FCU/100ml^{xiii}, however, from a practical standpoint, most adult remote villagers and urban slum dwellers are able to cope with more than 0 FCU/100 (50 FCU/100ml may be considered a mild contamination)^{xiv}. Therefore SODIS should be an effective method for household water disinfection at temperatures as low as 20°C irrespective of bottle scratch density.

Darkened-Room “Control” Test

Introduction

A darkened-room “control” test was done at the same time as the summer and winter testing. The purpose of the dark-room “control” testing was to compare the SODIS disinfection effectiveness to simply leaving contaminated water in a darkened-room for several days at ambient temperature. The World Health Organization (WHO) suggests a 3-Jar method^{xv} for emergency water cleaning that relies on the natural reduction of biologicals in water when their food source is eliminated. The method also takes advantage of particulate settling over a three day period^{xvi} which can correspond to 50% reduction in thermotolerant bacteria^{xvii}. Bacteria tend to favor particulate as a platform for habitation and even mineral compounds such as Arsenic will tend to accumulate on particulate, especially when iron is present, which, when allowed to settle over time, can reduce arsenic by 50%^{xviii}. The Bengali term for this is ‘bashi pani’ or “drink water after a while”.

Darkened-room protocol

A 2-liter, clear plastic cola bottle was filled with bayou water and labeled LRB, at the same time and on the same days as those filled for the summer and winter tests. Samples were periodically drawn for testing over a four day period.

In both the summer and winter tests the LRB bottle was filled with cloth-filtered bayou water, not shaken (which would have contributed to a disinfecting effect of oxygenation), and placed in an outside shaded building. The temperature inside the building approximated the ambient temperature outside. The temperature of the water in the summer test did not exceed 42 °C. The temperature of the water in the winter test did not exceed 20°C. Samples were drawn, tested, and counted using the same protocol as the other water tests described above. Some daily samples were not taken due to a lack of Easygel testing kits.

Darkened-room summer test results

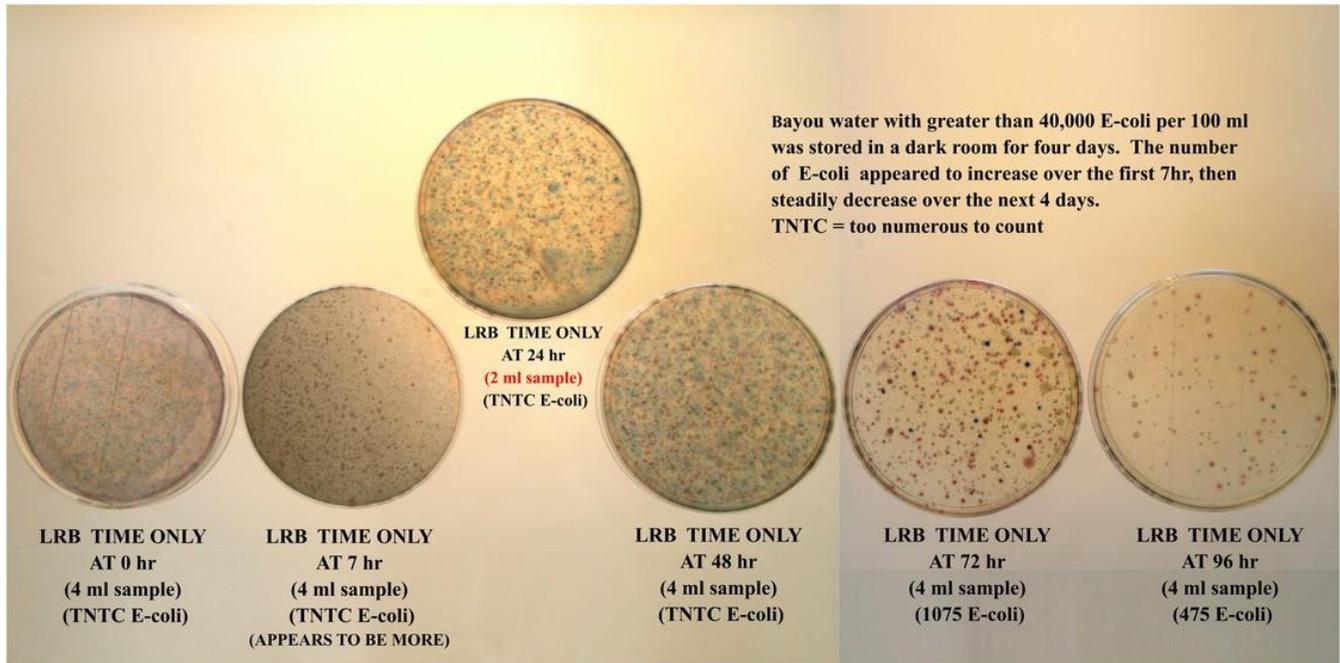


Figure 11 – Darkened-Room Summer Test Results

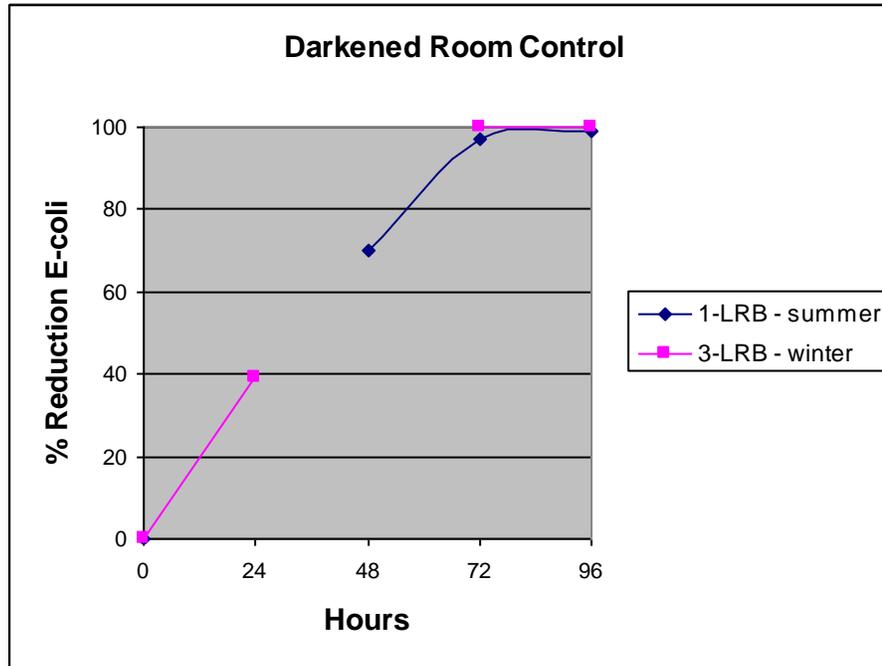
Note: The 24-hour test dish photo is elevated to distinguish it from the rest due to the use of a 2ml sample rather than 4ml sample.

Darkened-room winter test results



Figure 12 - Darkened-room winter test results.

Darkened-room graphical test results



Graph 4 - Darkened-room test results

Note: The summer, 24-hour, data point is not indicated because the E-coli were too numerous to count. The winter, 48-hour data point is missing due to a lack of an Easygel testing kit.

Darkened-room Test Conclusions

Our darkened-room “control” bottle tests (see Graph 4) verify water quality can be improved by simply waiting to drink it. This is referred to by WHO as the 3-Jar, emergency water treatment method (transferring by decantation from jar to jar over a three day period). Although the WHO procedure implies the water can be consumed on the third day, our test results indicate that it is strongly advisable to wait for a full three days before consumption (consume on day four). We refer to this technique as the 4-Jar method. Our 4-Jar method differs from the WHO 3-Jar in two ways:

- 1) **Filter through a clean cloth:** We ask the beneficiaries to filter their collected water through two layers of cloth while pouring it into their household storage container rather than decanting each day. This filtration greatly reduces sediment and eliminates the risk of guinea worm^{xx}. It also eliminates the need to lift and pour from the in-house storage container which is usually much larger and heavier than the containers used to transport water to the household.
- 2) **Use multiple storage jars:** We find that villagers typically use a different container for fetching water than for storing it^{xx}. Since there is little likelihood of sedimentation after filtration, we do not suggest they decant the water daily. We suggest they add three storage jars to their home (they already have one) and use water from the jar that has sat undisturbed for a full three

days, being careful not to use water at the bottom of the jar where there might be a small amount of sediment. Jars should be cleaned before refilling.

The 4-Jar method is not as effective as SODIS, however the concept of time being a mitigator of bacterial contamination offers certain synergies when combined with SODIS. In circumstances when the effectiveness of SODIS is compromised, such as cold weather, it may be beneficial to lengthen the SODIS exposure to two days thus taking advantage of the time dependent reduction in bacterial contamination.

Field-Practice Recommendations

Our recommendation to people that promote SODIS is to suggest that the beneficiaries:

- Keep the bottles as clean as possible, but it is “OK” if the bottles are scratched.
- Use the newest and cleanest bottles for SODIS and older, heavily scratched bottles for storage and daily use.
- Use bottles less than 10 cm in diameter (typically 1.5 liter or less).
- Do whatever possible to increase the bottled water temperature during SODIS (orientation, placement on a hot surface, painting one side of the bottle black, etc.).
- In winter time with temperatures between 0 - 20°C, increase the exposure to two days (as on cloudy days).
- If the beneficiaries can not find enough bottles to supply their daily needs, suggest they store drinking water for a full three days and begin drinking it on the fourth.

Further Research Recommendations

Conduct studies on the effect of filtration versus decantation while using the 3-Jar or 4-Jar method to clean water.

Conduct studies on waiting an additional twenty-four hours to improve the 3-Jar method efficacy (confirms our 4-Jar recommendation).

Conduct more tests to verify the effect of bottle scratches on SODIS efficacy.

Endnotes

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