Design, construction and testing of an improved solar water disinfection system (SODIS)

Damiana A. Amatobi1 · Jonah C. Agunwamba2

Received: 7 January 2021 / Accepted: 20 October 2022 / Published online: 2 November 2022
© The Author(s) 2022

Abstract
This study improves on the conventional SODIS design to make it more effective and increase its acceptability. An improved SODIS was designed to allow polyethylene teraphalate (PET) bottles serving as reactors to be under approximately 97% sunrays’ cover, and with a provision for a heat absorber. The improved SODIS was tested for inactivation of microorganisms by loading it with eight PET bottles filled with water containing 10^5 to 10^7 CFU/100 ml of Escherichia coli. The test was conducted simultaneously with a conventional SODIS, consisting of an improvised rooftop arrangement, containing same quantity of water-filled bottles with same concentration of E. coli. The two systems were placed close to each other, and exposed to direct sunlight for seven hours each day, on six different days. Ambient temperature was measured with a general-purpose thermometer. The thermometer was inserted into one bottle on each system to measure (representative) temperature. At hourly time intervals, a bottle was taken out from each system for enumeration of E. coli concentration. Hourly ambient and bottle temperatures were read simultaneously. The improved SODIS achieved a temperature of 4 °C above ambient and 1 °C above the conventional SODIS. In all the experiment days, complete inactivation of E-coli below detectable limit (less than 1 CFU/100 ml) was achieved at the fourth hour of exposure to sunlight by the improved SODIS and sixth hour by the conventional SODIS. The inactivation rates, K, for E. coli were 0.53 and 0.46 for the improved SODIS and the conventional (rooftop) SODIS, respectively.

Keywords Acceptance · Disinfection · Households · Microbial · SODIS, Water

Introduction
The provision of accessible, affordable and sustainable safe drinking water for every household across the world can reduce the prevalence of gastrointestinal diseases. Globally, waterborne diseases claim over 3.4 million lives annually (Berman 2009). Majority of the world population reside at households, and many, especially in the developing countries, do not have reliable safe drinking water supply sources. Improving the microbiological quality of household water by point-of-use treatment can reduce the scourge of waterborne diseases (World Health Organization (WHO), 2007). According to the WHO (2013), most household water treatment intervention technologies focus on filtration, flocculation/disinfection, chlorination and solar water disinfection (also called SODIS). A study conducted on intervention efforts on these technologies found solar water disinfection technology to be the most cost-effective (WHO 2013). Extensive research reveals that solar water disinfection technology is a feasible and low cost option for household drinking water treatment, especially in tropical countries. SODIS application can reduce the prevalence of waterborne diseases: Perhaps, the reason SODIS is promoted in more than 30 countries of the world (Wikipedia 2019).

Most of the existing solar water disinfection system being promoted across the world consists of placing transparent PET or glass bottles containing untreated drinking water on rooftops or similar structures, so that sunrays can impinge on the upper side of the bottle. Exposure of contaminated clear potable water to ultraviolet radiation from sunlight for a reasonable length of time disinfects the water and makes it safe for drinking. The ultraviolet radiation penetrates the outer cell membrane of the bacteria or...
virus and reach the cell structure and disrupts its DNA, thereby preventing reproduction of the cells. At suitable water temperature of about 30 °C, a solar irradiance of at least 500 Wh/m² (all spectral light) for about 5 h for solar exposure can effectively purify water (Eawag 2002).

The performance of SODIS has been investigated for disinfection of major gastrointestinal waterborne pathogens, including Escherichia coli, Salmonella, Pseudomonas aeruginosa, Cryptosporidium parvum, Vibrio cholerae, Enterococcus faecalis, Norovirus and Hepatitis A virus (McGuigan et al. 2012; Gómez-Couso et al. 2009; Amin et al. 2014). These researches reveal that SODIS is able to deactivate a wide range of waterborne pathogenic microorganisms. Bitew et al. (2018) found that the application of SODIS reduced the incidence of diarrhea among a study group of under-five children in a rural community of Northwest Ethiopia from 15.3 episodes/100 person-week to 8.3 episodes/100 person-week. Hence, SODIS can play a significant role toward improving access to safe drinking water in rural communities in sub-Saharan African countries. SODIS can operate using either PET or glass bottles as reactors without loss in efficacy (Asiimwe et al. 2013).

However, some major drawbacks of SODIS system include high contact time (six or more hours), low output, and inability to track the sun, and constraints in the accessibility of rooftops. Other technical limitations include the dependence of SODIS on weather conditions and its inability to treat effectively water of turbidity above 30NTU. There are some studies aimed at addressing some of the limitations of the SODIS system. Painting of one side of the bottle black to improve heat absorbance was investigated and was found to be more inefficient during cloudy weather (Pandit and Kumar 2019). In addition, the use of parabolic mirror to focus solar radiation on SODIS bottles has also been examined. Navntoft et al. (2008) used compound parabolic collector (CPC) mirrors to enhance the efficiency of solar disinfection (SODIS) and achieved more than 5-log unit reduction in bacterial population one hour earlier than the system fitted with no CPC.

Polo-López et al. (2019) found that use of transparent polypropylene (PP) buckets of 5 L- and 20 L containers for SODIS reduced E. coli, MS2-phage and Cryptosporidium parvum concentrations with no significant statistical difference with the concentration achieved with PET bottles. However, the safety of using the polypropylene buckets exposed in the sun for treating drinking water has not been fully understood. The use of low-density polyethylene (LDPE) bags has also been investigated but was found to be degrading overtime (Danwittayakul et al. 2017). For high turbid water, pretreatment to reduce turbidity and dissolved solids such as sedimentation or filtration has been suggested (McGuigan et al. 1998).

The research efforts taken to improve SODIS are yet to make the system to be more effective and practicable as to gain wide acceptance among the rural and poor households in the developing countries. The output of many studies seem to offer more academic relevance rather than practical value. Therefore, there is still need to improve the conventional SODIS to make it more effective, affordable, easy to build and to operate by locals, and more acceptable to households. The aim of this study is to improve on the conventional SODIS design, to make it more effective, affordable and acceptable to households in Nigeria and other countries across the world. The specific objectives of the study are as listed below:

1. Provide an improved SODIS design for reducing the limitations of the conventional system
2. Construct the designed system
3. Investigate the performance of the designed SODIS system against the conventional SODIS system

Materials and methods

Design of an improved solar drinking water disinfection system

The improved SODIS design consists of solar collector with four basic components:

(a) an insulated wooden body
(b) a reflector which directs sunrays and heat to the bottom side of the containers
(c) an absorber which absorbs heat from solar radiation and transmits the heat to water containers via air circulation and
(d) a wooden frame for holding the water containers

To achieve the maximum UV radiation effect, the frame is arranged so that every water container can be placed in the sun with an inclination angle equal to the local latitude and facing the south. The transparent water bottles serve as glazing transmitting UV rays across the water for deactivation of microorganisms. UV radiation impinges unto the black absorber surface where the rays are converted into infrared radiation that is transmitted upwards to heat the underside of the bottles. The target is for the collector to achieve an average water temperature of above 40 °C in the PET bottles (reactor), within four hours of exposure to sun during clear sky (non-cloudy weather). With rise in water temperature above 40 °C, the inactivation rate of microorganisms, KT, due to thermal effects, increases (Siriwong and Holasut 2006).

Siriwong and Holasut (2006) assert that:
and

\[ K_T = 0, \quad \text{for} \quad t < 40^\circ C \]  

(1)

and

\[ K_T = 1.1036^{(t-44.6958)} \quad \text{for} \quad t > 40^\circ C \]  

(2)

where \( t \) is the deactivating temperature in °C.

**Working principles of the improved solar water disinfection system**

Figure 1 is a schematic diagram showing the working principle of the modified SODIS design. The reactor consisting of PET bottles containing drinking water to be disinfected are suspended on a support such that most parts of the bottle are free. The collector is placed in the North–South direction under full sunlight cover. Light rays are incident on top of the bottles facing the sky. Light rays also pass through the opening space by the side of the collector and are reflected upwards to the underside of the bottles with the aid of two aluminum foil reflectors. Thus, the bottles are under about 97% cover of incident ultraviolet radiation from the sun.

In order to increase the temperature inside the reactors, the body of the collector is insulated, and a black heat absorber surface is provided. The absorber surface transmits heat toward the reactors (filled PET bottles). Figure 2 is a 3-D diagram of the improved SODIS design, with basic dimensions in mm.

**Sizing of the improved SODIS**

In the current study, the improved SODIS was designed to produce enough fresh drinking water daily for an average family of six for a single run, which is about 10 L per day. This requires that the supports (panel) contain at least seven PET bottles of 1.5 L each. Average daily water consumption in Afikpo North Local Government Area where this study
took place was determined by survey to be about 1.54 L per person per day.

**Application of kinetic model for UV disinfection of drinking water**

This study applied a disinfection model developed by Luckiesh and Holladay (Agunwamba 2008).

This model expresses the kinetics of disinfection process as:

\[ N = N_0 e^{(-kt)} \]  

(3)

where: \( N_0 \) is the initial concentration of the microorganisms (organisms/100 ml); \( N \) is the concentration of microorganisms after irradiation (organisms/100 ml); \( I \) represents UV irradiation density (W/cm²); \( t \) denotes the time of exposure (seconds); \( k \) is the inactivation rate constant (cm²/Ws).

With \( I \) taken as the mean UV irradiation density during the period of exposure, then the inactivation rate constant \( K = kI \), and \( K \) can be determined from equation of the curve, by fitting the plot, of microorganism concentration (\( N \)) against time(\( t \)) into an exponential best fit (Marni, et al. 2013). Thus, \( N = N_0 e^{(-Kt)} \)

Hence,

\[ \ln \left( \frac{N}{N_0} \right) = -Kt \]  

(4)

Equation (4) is a linear decay curve, which can be used as the first-order approximation for the water disinfection process. With the inactivation rate constant determined from the plot, Eq. (4) can be rearranged to estimate the number of hours needed for disinfection, given the initial concentration of microorganisms and the desired (safe) detection limit.

Hence:

\[ t = \ln \left( \frac{N}{N_0} \right) / -K \]  

(5)

**Experimental investigation of the improved SODIS in comparison with the conventional SODIS**

**Bottle preparation**

The 1.5 L PET bottles for commercial drinking water (Eva Water) were purchased from the market. It was ensured that all the bottles had no scratches and were not leaking. The bottles were emptied and then refilled with about 100 mg/L sodium hypochlorite (Sigma-Aldrich, 7681-52-9) solution capped and allowed to stay for 12 h for disinfection. Then, the bottles were thoroughly rinsed (4 times) with distilled water and immediately filled with the prepared water for solar drinking water disinfection investigation.

**Bacterial preparation**

In this study, *E. coli* was used as the indicator organism because of its widespread use as an indicator of fecal contamination of drinking water. The presence of *E. coli* in water indicates fecal contamination. In addition, *E. coli* has guideline value for safe drinking water set by the WHO and the Nigerian Standards for Drinking Water Quality (NSDWQ).

Water sample for bacterial preparation was collected from water borehole identified to contain a mean *E. coli* concentration of about 9.5 CFU/100 ml. Escherichia coli in the sample was isolated following standard laboratory procedures (Bichi and Amatobi 2013). Confirmed *E. coli* colonies were stabbed in Mueller–Hinton agar and kept at room temperature for inoculation. From the *E. coli* isolated, a single colony was streaked onto stocks in 15 ml of quarter-strength Ringers solution of sterile nutrient broth (Conda Pronadisa 1340). The solution was then incubated at 37 °C for 24 h. Documentary evidence demonstrates that after 18 h of incubation, the bacteria would be in the stationary phase at a concentration of \( 10^9 \) CFU/mL (Asiimwe et al. 2013; Boyle et al. 2008). This phase was nevertheless confirmed by enumeration at this stage from two trial runs. Bacterial suspensions were harvested by centrifugation at 800 X g for 10 min and the pellet was re-suspended in 15 ml of quarter-strength Ringers solution. Centrifugation and re-suspension steps were repeated three times to remove all traces of the growth medium. The third step produced the stock solution for inoculation of prepared water samples.

Appropriate dilution was made from the stock solution directly into 2000 ml volumetric flask containing the borehole water sample to obtain seeded water having an initial concentration of \( 10^5 \) to \( 10^7 \) CFU/100 ml of *E. coli*. The seeded water was poured into the PET bottles and then the bottles were capped.

**Solar drinking water purification experimentation**

Seven PET bottles filled with the prepared *E. coli* suspension were labeled A0 to A6 and were loaded on the improved SODIS. An eighth filled bottle fitted with thermometer for measurement of temperature (Fig. 3) was also loaded. The system was then exposed to sunlight. At hourly time
intervals (0, 1, 2, 3, 4, 5, 6), a bottle was taken out for bacterial enumeration, starting from bottle A0. The enumeration was carried out within 24 h, using the standard plate count method (Bichi and Amatobi 2013).

Figure 4 shows a picture of the improved SODIS loaded for experimentation. The same procedure was repeated simultaneously using filled PET bottles labeled B0 to B 6 but the bottles were loaded on a rooftop arrangement.

From the picture in Fig. 4, it is noticeable that the PET bottles in the improved SODIS design are largely whitish under sunshine, whereas on the rooftop arrangement the bottles appear bluish, despite using new (shiny) corrugated roof material. This is the effect of the internal reflectors fitted into the improved SODIS design.

The enumerated concentrations were plotted against time and (bottle) temperature. The resulting curve was fitted into an exponential (bacterial decay) curve. The equation of the curve was obtained using Microsoft Excel 2007 software. The results obtained by the improved SODIS design were compared with the one obtained using conventional (rooftop) SODIS.

Results and discussion

Results

Figure 5 is a picture of the designed and constructed improved SODIS exposed to sunlight. “Appendix A”
Table 1 Variation in daily hourly water temperature of PET bottles of improved SODIS during the experiment

| Local time | A: Modified system temperature (°C) |
|------------|-------------------------------------|
|            | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Mean |
| 9:00       | 27    | 28    | 26    | 27    | 27    | 25    | 27   |
| 10:00      | 28    | 28    | 28    | 30    | 26    | 28    |     |
| 11:00      | 32    | 32    | 33    | 35    | 35    | 32    |     |
| 12:00      | 35    | 36    | 34    | 37    | 36    | 34    | 35   |
| 13:00      | 42    | 40    | 39    | 44    | 43    | 36    | 41   |
| 14:00      | 46    | 44    | 43    | 46    | 44    | 37    | 43   |
| 15:00      | 44    | 43    | 40    | 43    | 42    | 35    | 41   |
| 16:00      | 40    | 39    | 37    | 39    | 40    | 32    | 27   |
| Mean       | 37    | 36    | 35    | 37    | 37    | 32    | 35   |

Table 2 Variation in daily hourly water temperature of PET bottles of the rooftop SODIS during the experiment

| Local time | B: Rooftop system temperature (°C) |
|------------|------------------------------------|
|            | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Mean |
| 9:00       | 27    | 28    | 26    | 27    | 27    | 25    | 27   |
| 10:00      | 28    | 29    | 29    | 30    | 29    | 26    | 29   |
| 11:00      | 29    | 31    | 30    | 31    | 29    | 27    | 30   |
| 12:00      | 32    | 35    | 33    | 36    | 35    | 30    | 34   |
| 13:00      | 38    | 39    | 38    | 40    | 39    | 33    | 38   |
| 14:00      | 40    | 42    | 43    | 43    | 41    | 34    | 41   |
| 15:00      | 39    | 38    | 39    | 41    | 39    | 32    | 38   |
| 16:00      | 36    | 35    | 36    | 38    | 35    | 31    | 35   |
| Mean       | 34    | 35    | 34    | 36    | 34    | 30    | 34   |

Table 3 Variation in daily hourly ambient temperature during the experiment

| Local time | C: Ambient temperature (°C) |
|------------|----------------------------|
|            | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Mean |
| 9:00       | 27    | 28    | 26    | 27    | 27    | 25    | 27   |
| 10:00      | 28    | 28    | 27    | 27    | 28    | 26    | 27   |
| 11:00      | 29    | 29    | 29    | 30    | 29    | 27    | 29   |
| 12:00      | 32    | 32    | 33    | 33    | 32    | 28    | 32   |
| 13:00      | 35    | 33    | 35    | 35    | 34    | 31    | 34   |
| 14:00      | 36    | 37    | 35    | 35    | 33    | 32    | 35   |
| 15:00      | 32    | 32    | 31    | 34    | 32    | 30    | 32   |
| 16:00      | 30    | 30    | 29    | 33    | 30    | 27    | 30   |
| Mean       | 31    | 31    | 31    | 32    | 31    | 28    | 31   |
Fig. 7  a and b  Average deactivation curve of E. coli concentration in water samples inside PET bottles exposed to sunlight on the improved SODIS and the conventional SODIS, respectively. Note: N is in Log10 units.

**E. coli Concentration**

N = 7.814e^{-0.53t}  
R^2 = 0.940

**Water Temperature**

N = 8.491e^{-0.46t}  
R^2 = 0.951

(a) Modified Purifier Average Performance Result  
(b) Roof-top Purifier Average Performance Result

Fig. 8  a and b  Day 1: Side-By-Side Performance Curves of the Improved SODIS and the Conventional SODIS

**E. coli Concentration**

N = 8.431e^{-0.61t}  
R^2 = 0.930

**Water Temperature**

N = 8.869e^{-0.48t}  
R^2 = 0.922

(a) Modified Purifier Performance Curve: Day 1 (April 02, 2020)  
(b) Roof-top Purifier Performance Curve: Day 1 (April 02, 2020)

Fig. 9  a and b  Day 2: Side-By-Side Performance Curves of the Improved SODIS and the Conventional SODIS

**E. coli Concentration**

N = 13.88e^{-0.55t}  
R^2 = 0.939

**Water Temperature**

N = 8.209e^{-0.44t}  
R^2 = 0.955

(a) Modified Purifier Performance Curve: Day 2 (April 13, 2020)  
(b) Roof-top Purifier Performance Curve: Day 2 (April 13, 2020)
Fig. 10  a and b Day 3: Side-By-Side Performance Curves of the Improved SODIS and the Conventional SODIS

Fig. 11  a and b Day 4: Side-By-Side Performance Curves of the Improved SODIS and the Conventional SODIS

Fig. 12  a and b Day 5: Side-By-Side Performance Curves of the Improved SODIS and the Conventional SODIS
shows some pictures taking during the construction of the improved SODIS.

Figure 6 shows the mean variations in temperatures achieved by water in PET bottles exposed to sunlight placed on: (a) the Improved SODIS, and (b) the rooftop SODIS, and (c) the mean ambient temperature variations during the experiment period. Tables 1, 2 and 3 show the details of daily (experiment days only) temperature variations.

Figures 7, 8, 9, 10, 11, 12 and 13 present the experimental days’ side-by-side performance curves for the improved SODIS and the conventional SODIS.

Discussion of results

Temperature variation

The daily temperature (average for each day) of water inside the PET bottle placed on the improved SODIS ranged between 27 and 43 °C (mean = 35 °C, standard deviation = 6.6). For the conventional rooftop SODIS system, daily water temperature varied between 27 and 41 °C. (Mean = 34 °C, standard deviation = 5.4). The mean ambient temperature ranged between 27 and 35 °C (mean = 31, standard deviation = 3.1). Thus, the improved SODIS design achieved a temperature of about 4 °C above ambient and 1 °C above the conventional (rooftop) SODIS.

The relatively higher temperature of water observed in the PET bottles when exposed to sunlight above ambient temperature is attributable to heat trapping effect; whereby ultraviolet light of short wavelength easily passes across a transparent surface (PET bottles in this case) but on reaching an opaque wall (the absorber) is reflected out as a long wavelength. The long wavelength (infrared) does not easily escape the transparent surface, so heat is trapped. The increase in temperature of the improved SODIS over the conventional one is expected because of the provision of a black surface absorber, which absorbs and transmits heat across the water-filled bottles. Researchers in Spain obtained a maximum temperature of 42.5 °C for water in PET bottles exposed to natural sunlight (Danwittayakul et al. 2017). However, the temperature obtainable in reactors of solar water purification system depends on local weather conditions during the exposure period.

Response of E. coli in water inside PET bottles to solar water disinfection for the improved SODIS design and the conventional (rooftop) SODIS

The results show that the starting concentration of the seeded E. coli in the water samples was approximately 10⁶ CFU/100 ml. In all the experiment days, complete inactivation of the bacteria below detectable limit (less than 1 CFU/100 ml) was achieved at the fourth hour of exposure to sunlight for the improved SODIS and sixth hour for the conventional rooftop SODIS. From the average performance curves, the inactivation rates, K, were 0.53 and 0.46 for the improved SODIS and the conventional SODIS, respectively. The high R² (square of Pearson’s product moment correlation) values of above 0.9 for the fitted inactivation curves indicate that deactivation of E. coli in the water samples in the PET exposed to solar ultraviolet radiation followed natural decay process closely.

The absence of E. coli in drinking water sources is recommended as a standard for safe drinking water by both the World Health Organization Guidelines for Drinking Water Quality and the Nigerian Standards for Drinking Water
Quality. The six-hour time recorded for complete inactivation of bacteria in water inside the PET bottles exposed to sunlight on a rooftop or similar platforms conform with the rates suggested by other researchers (McGuigan et al. 2012). The six-hour period is a long lead-time and one of drawbacks of the conventional SODIS system. Obviously, the four-hour inactivation time achieved by the improved SODIS design reduces this drawback. There are other attempts at developing enhanced SODIS technologies for reducing the drawbacks of the conventional system, especially in terms of contact time and volume of water delivered. Examples of such attempts include painting of bottles and use of parabolic mirrors (Pandit and Kumar 2019). However, most of these attempts have more relevance for academic/laboratory studies rather than practical/field value. They are largely impracticable within household settings. The current research adopted a simple and practical technology and achieved above 30% reduction of time required by conventional SODIS system for purification of drinking water using natural sunlight.

**Conclusion and recommendations**

The improved SODIS designed in this study achieved a reduction in the contact time required to deactivate pathogenic microorganisms in water inside PET bottles exposed to solar radiation for purification from six hours to four hours (about 33% decrease). The design can provide daily drinking water for a family of six, which is the average size of family in Afikpo, South Eastern Nigeria. With the net weight of 20 kg, the improved SODIS design can be moved around to track the sunrays. It was constructed at a cost of less than 10,000 Naira (26USD). It is affordable to households in Nigeria and has a projected lifespan of a minimum of three years. It is recommended that the improved SODIS design be used for treating drinking water sourced from boreholes/wells and other household water supplies whose turbidity levels fall below 30NTU such as clear surface water and clear water from unprotected springs. Water of turbidity > 30NTU should be pre-filtered before disinfection.

**Appendix A**

Some pictures taken during the construction of the improved SODIS are shown in Fig. 14.
The authors confirm that the data supporting the findings of this study are available within the article. Further details of the data are available on request from the corresponding author.

Code availability Not applicable.

Conflict of interest The authors declare that they have no conflict of interest.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

Funding The authors received no specific funding for this work.

Availability of data and materials The authors confirm that the data supporting the findings of this study are available within the article.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

Agunwamba JC (2008) Water engineering systems. De-Adroit Innovation, Enugu
Amin MT, Nawaz M, Amin MN, Han M (2014) Solar disinfection of Pseudomonas aeruginosa in harvested rainwater: A STEP towards potability of rainwater. PLOS ONE 9(3):e90743
Asimwe JK, Quilty B, Muyanja CK, McGuigan KG (2013) Field comparison of solar water disinfection (SODIS) efficacy between glass and polyethylene terephalate (PET) plastic bottles under sub-Saharan weather conditions. J Water Health 11(4):729–737. https://doi.org/10.2166/wh.2013.197
Berman J (2009) WHO: Waterborne disease is world’s leading killer. Voice of America. https://www.voanews.com/archive/who-water-borne-disease-worlds-leading-killer. Accessed 10 December 2020
Bichi MH, Amatobi DA (2013) Assessment of the quality of water supplied by water vendors to households in Sabon-gari area of Kano, northern Nigeria. Int J Eng Sci (IJES) 2(7):9–17
Bitew BD, Gete YK, Andargie BGA, Adafrie TT (2018) The effect of SODIS water treatment intervention at the household level in reducing diarrheal incidence among children under 5 years of age: a cluster randomized controlled trial in Dabat district, northwest Ethiopia. Trials 19:412. https://doi.org/10.1186/s13063-018-2797-y
Boyle M et al (2008) Bactericidal effect of solar water disinfection under real sunlight conditions. Appl Environ Microbiol 74(10):2997–3001
Danwittayakul S, Songngam S, Phulua T, Muangsakem S, Sukkas S (2017) Safety and durability of low-density polyethylene bags in solar water disinfection applications. Environ Technol 38(16):1987–1996. https://doi.org/10.1080/09593330.2016.1244564
Eawag (2002) Solar water disinfection. In: A guide for the application of SODIS. Swiss Centre for Development Cooperation in Technology and Management (SKA), Switzerland
Gómez-Couso H, Fontán-Sain M,ichel C, Fernández-Ibáñez P, Ares-Mazás E (2009) Efficacy of the solar water disinfection method in turbid waters experimentally contaminated with Cryptosporidium parvum oocysts under real field conditions. Trop Med Int Health 14:620–627
Marni RK, Sisco TE, David LD, Surbeck CQ (2013) Solar disinfection water treatment for a community-scale system: an analysis of design parameters for humanitarian engineering projects. Int J Serv Learn Eng 8(1):88–101
McGuigan KG, Conroy RM, Mosler H, du Preez M, Ubomba-Jaswa E, Fernandez-Ibáñez P (2012) Solar water disinfection (SODIS): a review from bench-top to rooftop. J Hazard Mater 235–236:29–46
McGuigan K, Joyce T, Conroy R, Gillespie J, Elmore-Meeegan M (1998) Solar disinfection of drinking water contained in transparent plastic bottles: characterizing the bacterial inactivation process. J Appl Microbiol 84:1138–1148
Navntoft C, Ubomba-Jaswa E, McGuigan KG, Fernández-Ibáñez P (2008) Effectiveness of solar disinfection using batch reactors with non-imaging aluminum reflectors under real conditions: Natural well water and solar light. J Photochem Photobiol B 93(3):155–161. https://doi.org/10.1016/j.jphotobiol.2008.08.002
Pandit AB, Kumar JK (2019) Drinking water treatment for developing countries: physical chemical and biological pollutants. Royal Society of Chemistry, London
Polo-López M et al (2019) Microbiological evaluation of 5 l and 20 l-transparent polypropylene buckets for solar water disinfection (sodis). Molecules 24:2193. https://doi.org/10.3390/molecules24112193
Siriwong C, Holasut K (2006) The coupling effect between heat and UV irradiation in the solar disinfection for drinking water in the PET bottles. Conference proceedings of Technology and Innovation for Sustainable Development Conference (TISD2006) Faculty of Engineering, Khon Kaen University, Thailand. https://www.academia.edu/22458971/The_Coupling_effect_between_heat_Wikipedia (2019) Solar water disinfection. https://en.wikipedia.org/wiki/Solar_water_disinfection. Accessed 15 July 2020
World Health Organization (2007) Combating waterborne disease at the household level. https://www.who.int/household_water/advocacy/combating_disease.pdf. Accessed 02 May 2020.
World Health Organization (2013) Household water treatment and safe storage (HWTS): Manual for the participants. World Health Organization, Geneva

Publisher’s Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.