Sandec: Sanitation, Water and Solid Waste for Development

SODIS manual

Guidance on solar water disinfection

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aquatic research

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Sandec is the Department of Sanitation, Water and Solid Waste for Development at Eawag. It develops new concepts and technologies adapted to the physical and socio-economic conditions in low- and middle-income countries to improve sustainable access to safe drinking water and environmental sanitation.
>>www.sandec.ch

Eawag
P.O. Box 611
8600 Dübendorf
Switzerland
Phone: +41 (0)58 765 52 86
Fax: +41 (0)58 765 53 99
Email: info@sandec.ch

Authors: Samuel Luzi, Monika Tobler, Fabian Suter, Regula Meierhofer

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Text editing: Paul Donahue, Anna Muntwyler

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Pupil collects SODIS bottles at a rural school in Bolivia

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R. Meierhofer

Regula Meierhofer
Head of SODIS Reference Centre

Christoph Lüthi
Head of Sandec

Acronyms

Eawag	Swiss Federal Institute of Aquatic Science and Technology
HWTS	Household Water Treatment and Safe Storage
LRV	Log reduction value: used to specify by what order of magnitude concentrations of pathogens are reduced (1 log = factor 10, 2 log = factor 100, etc.)
POU	Point of use, also referred to as point of consumption
SDG	Sustainable Development Goal
SODIS or SODIS method	Standard water treatment method based on the principle of solar (water) disinfection
Solar water disinfection	Inactivation of pathogens in water caused by irradiation of sunlight through direct and indirect mechanisms
SODIS Reference Centre	Program of Eawag to support the research and promotion of SODIS
UNICEF	United Nations Children's Fund
WASH	(Drinking) Water, Sanitation and Hygiene
WHO	World Health Organization

Mother and child in Cameroun

About this manual

This manual presents an overview of the SODIS method based on 20 years of research and practice. It is structured into three parts:

1. SODIS at a glance
The first part presents the basic facts about solar disinfection and the SODIS method, gives information about the history of the SODIS method and highlights its benefits. It also discusses the niche of SODIS in the context of HWTS and WASH and the potential impact and role of SODIS in relation to programs aiming at reducing the prevalence of diarrheal disease.



SODIS users in Laos, India and Bolivia

2. Technical aspects of the SODIS method
The second part addresses the technical aspects that influence the efficacy of the SODIS method in removing pathogens from water. This information aims at providing a solid understanding of the correct application of SODIS in the field, and of the expected outcomes under various conditions.



Water quality testing in Guinea, Switzerland and Laos

3. Promotion of the SODIS method
The third part reviews specific approaches and tools used to promote the SODIS method to target populations. It aims at supporting experts with the integration of the SODIS method into HWTS, WASH and health projects.



Promotion in Togo, Bolivia and India

1 SODIS at a glance

1.1 The SODIS method

The SODIS method is a water disinfection method, making use of the sun's energy and using PET bottles. It exploits the germicidal effect of solar radiation – especially UV-A radiation - on diarrhoea causing pathogens.

The SODIS method consists of the following simple steps:

1. **Wash a plastic bottle:** The bottle must be clean, transparent, colourless, 2l in volume or smaller, and have all plastic or paper labels removed. We recommend using PET bottles and to wash them with soap before the first usage.

2. **Fill bottle with water:** Potentially contaminated water is filled into a PET bottle. The water should not be very turbid.

3. **Expose bottle to the sun:** The bottle is exposed to direct sunlight for one full day (at least 6 hours including noon hours) on mostly sunny days, or 2 days when the sky is more than 50% clouded. On days of continuous rainfall, SODIS should not be used.

4. **Store water:** The treated water is stored in the bottles until consumption in order to avoid re-contamination.

Figure 1: SODIS steps

The SODIS methd has specific comparative advantages and drawbacks:

Specific comparative advantages of SODIS

- Effectiveness against pathogenic bacteria
- Easy to understand and to apply
- Zero or very low cost
- Independent from energy sources other than sunlight
- Independent from supply chains for products other than PET bottles
- Integrated protection from re-contamination if water is stored in the SODIS bottles
- No adverse effect on the water's taste

Specific comparative drawbacks of SODIS

- Limited effectiveness against certain pathogenic viruses and protozoa
- Dependent on access to sufficient numbers of PET-bottles
- Dependent on sufficient sunlight
- Relatively high daily labour demand
- Relatively high treatment time
- Limited aspirational appeal (poor people's method)

Children in Nepal drinking SODIS water

SODIS bottles in India

1.2 Niche of SODIS in the context of HWTS and WASH

SODIS is recognized as one of several viable methods for household water treatment. It has been promoted, both as a stand-alone intervention and as one component in broader HWTS (Household Water Treatment and Safe Storage) or WASH (Water, Sanitation & Hygiene) programs. Different HWTS methods have existed for years (SODIS and biosand filtration), decades (chlorination and ceramic filtration) or even longer (boiling). New technologies are being developed and introduced into the market. And yet, the principle of water treatment at the household level is still not a mainstream practice. All common HWTS methods have disadvantages and have so far failed to achieve large scale uptake.

The niche for the SODIS method can only be evaluated in the context of other HWTS technologies, and the benefits it offers can vary significantly from one location to another. As a low-cost method that is independent from supply chains for products other than PET bottles, SODIS has comparative advantages particularly among the poorest segments of the population, and in areas where no other HWTS technologies are marketed. As only sunlight and PET bottles are required for the application of the method, SODIS promotion mainly consists of measures aiming at a behaviour change in the target communities. Therefore, the promotion of SODIS is more rapidly scalable compared to the promotion of HWTS methods that require the establishment of supply chains for specific products. As new affordable HWTS technologies that are superior to SODIS in terms of convenience, efficacy, and aspirational appeal become available in a given location, the niche for SODIS is expected to shrink. The same is true when income levels increase in a community.

This manual advocates an integrated HWTS promotion approach that enables water users to make informed choices among a range of technology options. The promotion of a range of HWTS methods can more effectively address the diverse needs, capacities, and preferences of water users.

Beyond the integrated promotion of different HWTS technologies, it is important to understand HWTS as one element in broader strategies of diarrhoea prevention that also include the improvement of water supply and sanitation systems, and the promotion of improved hygiene practices. A holistic perspective on all these issues allows HWTS interventions to be targeted specifically at areas of greatest potential, and can exploit the synergies available by integrating HWTS promotion within broader WASH and health programs.

SODIS and other HWTS methods are particularly relevant in areas where universal household connections, offering reliable supplies of good quality water are not available in the short and mid-term. HWTS is seen as an effective complementary strategy to accelerate the progress towards universal safe water consumption. However, the provision and maintenance of functional and reliable water supply systems is - and continues to be - the central pillar of most national programs to increase safe water consumption.

Box 1: Key criteria of HWTS-methods

- high effectiveness against the full range of pathogens (and possibly chemical contaminants) under a wide range of conditions
- affordable cost
- low labour inputs for operation and maintenance
- high productivity (litres/day)
- positive effects on water aesthetics and taste
- high robustness and user safety
- attractive design
- automatic shut-down mechanism if treatment effectiveness is compromised
- integrated safe storage
- local availability of product and replacement parts

1.3 Health benefits of SODIS

The main purpose of SODIS and other HWTS methods is to reduce the risk of infection from diarrheal disease by improving drinking water quality.

Safe drinking water is recognized as a basic requirement for healthy development and a dignified life. Despite significant progress in reducing the consumption of contaminated water in low- and middle-income countries during the last decades, more than 748 million people still lack access to an improved source of drinking water (WHO/UNICEF 2014). This means that they have to rely on drinking water from rivers or ponds, unprotected springs or dug wells, or water transported by trucks. Moreover, many people with access to improved water sources (i.e., household connections, public standpipes and tube wells, protected springs or dug wells, and rainwater harvesting) are still exposed to contaminated water. This is the case because either their source does not supply pathogen free water, or the water is re-contaminated during transport from the source to the household, or it is stored and handled under unhygienic conditions.

Drinking water contaminated with pathogens is a major transmission route for diarrheal disease. 1.7 billion cases of diarrheal disease occur every year, and around 760’000 young children die annually from the symptoms of diarrheal disease, most of them in low- and middle-income countries. It is estimated that approximately 88% of infections from diarrheal diseases could be prevented by interventions to improve drinking water quality, sanitation, and hygiene practices (Black et al. 2003).

Evidence indicates that water quality improvements at the point of consumption are more effective in reducing diarrheal disease than both increased access to clean water sources or quality improvements at the source. However, it is important to note that health benefits only accrue if SODIS and other HWTS methods are applied correctly, consistently, and sustainably.

1.4 History of SODIS

The principle of water disinfection by solar radiation was first discovered in 1984 by Prof. Aftim Acra of the American University in Beirut.

In the 1990s, researchers at Eawag/Sandec launched extensive laboratory studies to evaluate the potential of solar radiation to inactivate bacteria and viruses. Based on the findings of these experiments, they designed a standard procedure – the SODIS method. After successful field testing, Eawag initiated a program in 2001 to disseminate the SODIS method through promotion projects in more than 25 low- and middle-income countries to ensure that the SODIS method becomes available to the people most in need. In 2011, Eawag und the Swiss NGO Helvetas Swiss Intercooperation entered into a partnership with the goal to jointly promote the SODIS method worldwide. In the context of this partnership, various projects supporting the promotion of household water treatment, including the SODIS method, are being carried out by Helvetas.

Today, the SODIS method is recognized as one viable HWTS option. According to monitoring data from projects supported by Eawag, at least 5 million people have started using the method to improve the quality of their drinking water.

Martin Wegelin receiving the Red Cross Price for SODIS at the Swiss parliament (2006)

2 Technical aspects of the SODIS method

This chapter explains the disinfection mechanism of solar water disinfection (chapter 2.1) and the various factors influencing the pathogen removal capacity of the SODIS method, such as irradiation intensity, material of bottles or water turbidity (chapter 2.2). It also presents the most important advanced designs that have been proposed to improve the SODIS method (chapter 2.3) and summarizes the key implication for the application of the SODIS method in the field (chapter 2.4).

2.1 Mechanism of solar water disinfection

The term solar water disinfection describes the process of inactivation of pathogens in water through the direct effects of solar irradiation. It takes place in the top layer of surface water bodies, and is harnessed for drinking water disinfection. The spectrum of solar radiation reaching the Earth's surface consists of radiation of different wavelengths, i.e., ultraviolet, visible, and infrared radiation. The main mechanism of pathogen inactivation during solar disinfection is direct or mediated damage to proteins and the DNA of the organisms, induced by radiation in the UV-B, UV-A, and possibly the lower visible range.

The relatively small fraction of solar UV-B radiation that reaches the earth's surface can inactivate pathogens by degrading the organisms' DNA or RNA (Jagger 1985). This direct inactivation mechanism is of minor importance to the SODIS method based on the use of PET bottles, however, because PET absorbs most of the UV-B radiation.

The UV-A fraction of the solar spectrum does not directly affect the DNA or RNA in pathogens. It does, however, cause the formation of reactive oxygen species (ROS, e.g., singlet oxygen, superoxide, hydrogen peroxide, and hydroxyl radical), which then react with and damage the DNA or proteins of microorganisms (Whitlam & Codd 1986). ROS formation can be mediated by organic photosensitizers dissolved in the water, such as organic molecules or iron (exogenous mechanism), or by molecules of the pathogenic organisms themselves (endogenic mechanism).

The observed - though relatively small - germicidal effect of radiation in the lower range of the visible spectrum is mediated by sensitizers rather than by direct absorption (Rincon & Pulgarin 2004c).

Heat also damages the molecular structure of pathogenic organisms, a mechanism known as thermal inactivation or pasteurization. Thermal inactivation sets in at temperatures as low as 40°C degrees for Vibrio Cholerae (Berney et al. 2006). During solar exposure, the water is typically heated up by solar infrared radiation, depending on the irradiation intensity, ambient temperature, and location (wind cooling, heat absorbing background). At temperatures above 45-50°C, a synergistic effect of thermal inactivation and UV-A radiation occurs which strongly enhances the inactivation rate of solar disinfection (see chapter 2.2.7).

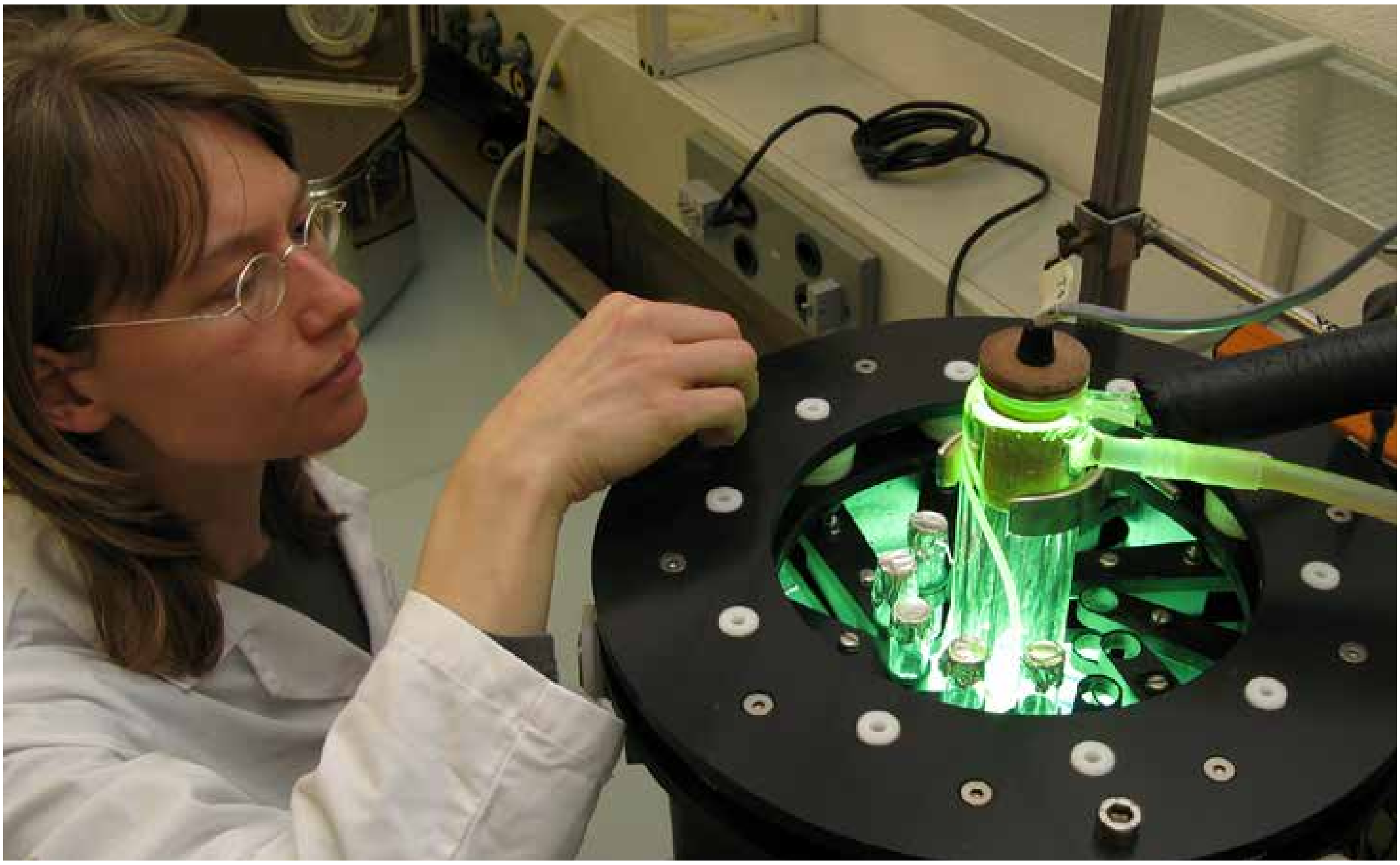
In the case of bacteria, membrane enzymes, e.g., enzymes of the respiratory chain and the F1F0-ATPase, are the likely first targets of ROS (Bosshard et al. 2010). With continued irradiation, structural proteins and enzymes responsible for different cellular functions (e.g., the transcription and translation apparatus, transport systems, amino acid synthesis and degradation, respiration, ATP synthesis, etc.) are damaged as well, leading to cell inactivation and death (Bosshard et al. 2010).

The disinfection mechanism during solar disinfection is less understood for viruses and protozoa than for bacteria. Viruses do not have a cell membrane, which means that the endogenic inactivation process is less important than for bacteria. Virus inactivation during SODIS, thus, likely occurs through the exogenous production of reactive oxygen species - mediated through photosensitizers dissolved in the water – which then damage the viruses' genome and/or capsid shell, while direct inactivation is of minor importance in PET bottles because they block most of the UV-B radiation. Virus inactivation in PET bottles is, therefore, typically slower and more dependent on water composition than the inactivation of bacteria. Many protozoa that can form cysts or spores are particularly resistant to environmental stress, including solar UV radiation. As a consequence, most pathogenic protozoa are less removed efficiently by the SODIS method, or require higher irradiation doses for complete inactivation (see chapter 2.2.1).

Box 2: Terminology Solar Water Disinfection vs. SODIS

- The term solar water disinfection describes the process of the inactivation of pathogens in water through the direct effects of solar irradiation.
- The term SODIS or SODIS method commonly refers to the standard method formulated for household use with PET bottles and one to two days of solar exposure.

SODIS bottles on a corrugated iron sheet in Togo



Laboratory tests at Eawag

2.2 Factors of pathogen removal capacity

Numerous studies under laboratory and field conditions have documented the pathogen removal capacity of solar water disinfection in general, and of the SODIS method using PET bottles in particular. According to the findings of these studies, the disinfection efficacy of the SODIS method depends on a number of factors:

- Type and origin of pathogenic organism
- Irradiation intensity
- Material and size of bottles
- Place and position of bottle exposure
- Turbidity and dissolved organic matter
- Oxygen content
- Water temperature
- Re-growth

The available data do not allow for a complete and systematic understanding of the influence of all of the above different factors, or for the construction of predictive models that show the combined effect of these factors on the disinfection effectiveness.

For practical applications, standard recommendations are applied that reduce the complexity for the users, but which allow for satisfactory pathogen inactivation results most of the time under most circumstances. Some of these recommendations were formulated somewhat heuristically based on the limited available data (e.g., the thresholds for turbidity level, bottle volume or geographical latitudes where SODIS can be applied), and substantiated by the results of field tests.

This section postulates the typical pathogen removal levels in tropical/subtropical countries at temperatures up to 45°C, assuming that SODIS has been correctly applied. Higher reduction rates are possible for strong irradiation conditions or water temperatures above 45°C, and lower rates occur especially if several unfavourable conditions co-exist (i.e., winter season, cloudy weather, turbid water, scratched bottles, etc.). These values are based on published results of field and lab studies. Note that the measured 'reduction' in pathogen concentrations always depends on the method of analysis. There is evidence that the assessment of viability/cultivability of pathogens can lead to overestimations of the actual infectivity (Smith et al. 2000; McGuigan et al. 2006), or underestimations, i.e., if re-growth occurs.

Box 3: Measuring disinfection effectiveness

- The pathogen removal capacity of a technology is often described in units of 'log reduction values' (LRV). A log reduction value of 1 corresponds to a reduction in pathogen concentrations by 90%, a LRV of 2 to a reduction by 99%, etc.
- Another common measure for the pathogen removal efficiency is the inactivation rate coefficient k. The inactivation rate can be calculated from the ratio of the start and end concentration of pathogens, and the treatment time (t) or received irradiation dose (Fluence, F), respectively, assuming first order inactivation kinetics: $\ln[C/C0]=-k*t$
- The extent of pathogen removal for the SODIS method is often specified as a function of the received dose of solar radiation - or the exposure time at a specific irradiation intensity required to reduce the pathogen concentrations by a certain factor, e.g., by 3 LRVs (99.9%). The fact that different SODIS studies measured the intensity of solar radiation (real or simulated) for different wavelength ranges (e.g., full spectral light, UV-A: 320-400nm, or arbitrary range: e.g., 350-450nm) makes the comparison of results across studies difficult.

2.2.1 Type and origin of pathogenic organisms

The resistance to UV-A irradiation varies considerably between different types of pathogens. Generally, pathogenic bacteria are less capable of withstanding the effects of solar UV radiation compared to most viruses and spore or cyst forming protozoa. Many viruses are strongly affected by UV-B radiation, which plays a minor role in the SODIS process with PET bottles. Differences in terms of resistance to solar radiation are observed also between different species of pathogenic bacteria, though the variance is smaller than for different viruses and protozoa.

Tables 1-3 provide log reduction values of SODIS for different pathogens. These figures are based on published studies. Log reduction values relate to the solar exposure of water in PET bottles or comparable lab experiments (UV-B cut off for studies with viruses) and temperatures below 40°C (i.e., no synergistic effect of radiation and temperature). These results are believed to be representative of the efficacy of SODIS under typical field conditions in tropical countries, assuming the correct application of SODIS according to the standard recommendations. For particularly favorable or unfavorable conditions (in terms of water composition, solar intensity and temperature) the inactivation rates may also be higher or lower than specified here.

Bacteria

Bacteria cause some of the most dangerous diarrheal diseases, including cholera and bacterial dysentery. None-spore forming diarrhoea-causing bacteria are among the pathogens that are most effectively inactivated by solar irradiation. SODIS typically reduces the concentrations of these pathogens by several orders of magnitude on a typical day in tropical or subtropical regions. Inactivation rates vary from species to species. For example, the dose and solar exposure time required to reduce the concentration of Vibrio Cholerae by 90% [165 kJ/m2 in the range of 350-450 nm corresponding to 24 minutes of exposure in the experiment conducted by Berney (2006)] is substantially lower than the required dose and exposure time for E.coli (1210 kJ/m2, 182 minutes, respectively). Table 1 presents the typical removal rates for different types of pathogenic bacteria that have been reported in scientific literature.

Evidence from E.coli studies suggest that bacteria extracted from wastewater are more resistant to solar radiation than bacteria cultured in the laboratory (see Fisher et al. 2012 and references cited therein). It is, thus, likely that SODIS experiments with lab-cultured organisms somewhat overestimate the disinfection efficacy of SODIS in field applications, and the results of these studies must be interpreted cautiously.

The disinfection efficacy of SODIS was investigated for a number of different pathogenic organisms. The majority of scientific studies on SODIS focus on pathogenic bacteria, indicator bacteria like E.coli, or indicator groups (total coliforms, thermotolerant coliforms), because the analytical procedures to quantify viruses and protozoa are more difficult and costly. However, SODIS efficacy results for E.coli cannot be directly extrapolated to other pathogen types. And the SODIS efficacy for E.coli underestimates the efficacy for less resistant pathogens (e.g., Vibrio Cholerae), but overestimates the efficacy for most spore-forming bacteria, viruses, and protozoa. Inactivation studies for SODIS based on the concentration of total coliforms likely underestimate the effectiveness for pathogenic bacteria, as some coliforms adapt to environmental stress and are, therefore, more resistant to solar radiation.

Pathogen	Log reduction value (6h)*	Reduction of pathogen concentration (6h)*	Approx. time required for 3 log reduction*	Reference
Escherichia coli	2-5	99 – 99.999%	1 day	(McGuigan et al. 1998; Kehoe et al. 2001; Fujioka & Yoneyama 2002; Berney et al. 2006; Boyle et al. 2008; Fisher et al. 2008; Fisher et al. 2012; Kruti & Shilpa 2012)
Vibrio cholera	3-5	99.9-99.999%	3h	(Kehoe et al. 2004; Berney et al. 2006)
Salmonella spp.	2-4	99 – 99.99%	1 day	(Smith et al. 2000; Kehoe et al. 2004; Berney et al. 2006; Bosshard et al. 2009)
Shigella flexneri	2-4	99 – 99.99%	1 day	(Kehoe et al. 2004; Berney et al. 2006; Bosshard et al. 2009)
Shigella dysenteriae	>4	>99.99%	< 1day	(Kehoe et al. 2004)
Campylobacter jejuni	>4	> 99.99%	< 1 day	(Boyle et al. 2008)
Yersinia enterocolitica	>3	> 99.9%	1 day	(Boyle et al. 2008)
Enterococcus feacalis	2-5	99 – 99.999%	1 day	(Reed 1997; Fujioka & Yoneyama 2002)

Table 1: Inactivation of bacteria
**estimations for irradiation intensities in tropical countries, for mostly sunny weather, i.e. for average daily UV-doses of 1MJ/m2.*

Water quality tests in Laos

Viruses

Major waterborne viruses include Rotavirus, Caliciviruses, Coxsackievirus, Enterovirus (e.g., Poliovirus, Echovirus), Adenovirus, Hepatitis A and E virus, Coronavirus and Astrovirus (SuSanA 2009). Viruses are responsible for a substantial share of total infections with diarrheal disease. However, evidence suggests that rotavirus - which causes most virus-related diarrhoea cases in children - is mainly transmitted via contaminated hands or other surfaces (Percival et al. 2004), though drinking water is also a possible transmission route.

As infective viruses are often more difficult to quantify than bacteria, there is less data available on the inactivation efficacy of SODIS for viruses than for bacteria. Furthermore, some of the available SODIS studies used bacteriophages as models for human viruses, instead of actual pathogens, and used experimental set-ups that are not representative for the standard SODIS method in PET bottles (i.e., not cutting off the radiation in the UV-B range). Table 2 presents only data that are believed to be representative for the standard SODIS method.

An early study on solar disinfection found that solar radiation affects the encephalomyocarditis virus, bacteriophage f2 and bovine rotavirus in approx. in the same rate as bacteria, i.e. 3-4 log removal for 6 hours, (Wegelin et al. 1994). This was also confirmed in later studies for poliovirus (Heaselgrave et al. 2006), coxsackievirus, poliovirus and hepatitis A virus (Heaselgrave & Kilvington 2012), as well as for echovirus, coxsackievirus and poliovirus (Fujioka & Yoneyama 2002). However, this high observed inactivation rate was probably caused mainly by the small fraction of UV-B radiation in sunlight that reaches the earth's surface.

Studies with SODIS using PET bottles (which block most of the UV-B radiation) yielded far lower inactivation rates (> 30 hours exposure time needed for 3 LRV for Rotavirus, corresponding to only 0.5 LRV in 6 hours (Fisher et al. 2012)). A recent study investigating virus removal in PET containers indicates that the inactivation rate strongly depends on the type of virus, and on the water composition (Dionisio Calado 2013). Inactivation rates were higher in Swiss tap water than in tap and groundwater from Chennai, indicating that the higher levels of dissolved organic material in the Indian groundwater hinder the production of reactive oxygen species. Viruses that are more susceptible to oxidants (bacteriophage MS2 and echovirus) were inactivated effectively in Swiss tap water (4 log removal in 6 hours), while inactivation was much slower in water samples from India (1 log removal in 6 hours). More resistant viruses (bacteriophage Phi X174, adenovirus) were inactivated at even lower rates in all water samples. The disinfection of viruses in this study was significantly faster at higher temperatures, but more research is required to determine which viruses are efficiently inactivated at temperatures typically reached in SODIS bottles in tropical countries (i.e., around 40°C) for different water compositions.

The values presented in Table 2 are derived from studies using PET bottles or other set-ups that cut off UV-B radiation. Higher inactivation rates observed for the full solar spectrum are not shown as they are not representative of the standard SODIS method using PET bottles.

Based on these findings, it is difficult to postulate one single approximate log-reduction value for viruses in real world SODIS applications. Under favourable conditions in terms of water composition and temperature, inactivation rates greater than 3-4 LRV can be expected for the more susceptible viruses. Some virus concentrations may be hardly affected by SODIS (LRV < 1), especially under unfavourable conditions (e.g., in water with much organic material and low temperatures), and for the more resistant types.

Pathogen	Log reduction value (6h)	Reduction of pathogen concentration (6h)	Time for 3 log reduction (h)	Remarks	Reference
Bovine rotavirus	0.5-1	70% - 90%	>20	Lab experiments with cut off filter for UV-B	(Wegelin et al. 1994)
Coliphage f2	1	90%	>15	Lab experiments with cut off filter for UV-B	(Wegelin et al. 1994)
EMCV	>0.5	Very low	>50	Lab study with cut off filter for UV-B	(Wegelin et al. 1994)
Wild coliphages	<1	50%	>30	Field study with PET bottles	(Dejung et al. 2007)
Polio Virus	Very low	Very low	>50	Lab study with cut-off at 360nm or UV-B	(Fujioka & Yoneyama 2002; Silverman et al. 2013)
Murine norovirus	1.3	95%	1.8	PET bottles	(Harding & Schwab 2012)
MS2 coliphage	1-4	90-99.99%	<6 - 33	PET bottles. High values for swiss tap water, low values for Indian tap and groundwater in the study by Caldao	(Fisher et al. 2012; Harding & Schwab 2012; Dionisio Calado 2013)
Echovirus	1	90%	>12	PET bottles. Indian groundwater.	(Fujioka & Yoneyama 2002; Dionisio Calado 2013)
Coxsackievirus	Very low	Very low	>50	Cut-off at 360nm	(Fujioka & Yoneyama 2002)
PhiX174 bacteriophage	0-0.5	0 – 70%	>12	PET bottles	(Dionisio Calado 2013)
Adenovirus	Very low	Very low	>40	PET bottles (Dionisio Calado 2013)	(Gall 2010; Dionisio Calado 2013; Silverman et al. 2013)

Table 2: Inactivation of viruses

Protozoa

The most important-diarrhoea causing protozoa are species of Giardia, Cryptosporidium, and Amoeba. Protozoa can form cysts or oocysts that are typically very resistant to environmental stress, including chemical drinking water treatment in some cases. While the symptoms of diarrheal disease caused by protozoa are often less acutely live-threatening compared to infections with viral or bacterial pathogens, Cryptosporidiosis is a serious health threat for immunocompromised persons, e.g., for people living with HIV/Aids.

Table 3 shows inactivation rates for protozoa. Cysts of Giardia species and other types of protozoa are inactivated by SODIS at approx. the same rate as diarrhoea causing bacteria (Table 1). Cysts of Cryptosporidium species require a significantly higher irradiation dose than E.coli. Amoeba are only significantly affected by solar UV radiation at temperatures above 50°C.

Pathogen	Log reduction value (6h)	Reduction of pathogen concentration (6h)	Approx. time for 3 log reduction (h)	Reference
Giardia spp	2 - >3	99 – >99.99%	< 6 - 9	(McGuigan et al. 2006; Heaselgrave & Kilvington 2011)
Cryptosporidium spp.	0.3 - >0.4	45- >92%	>10 - 70	(Mendez-Hermida et al. 2005; McGuigan et al. 2006; Mendez-Hermida et al. 2007; King et al. 2008; Gomez-Couso et al. 2009; Heaselgrave & Kilvington 2011)
N.Guberi	3.6	> 99.99%	< 6	(Heaselgrave & Kilvington 2011)
Entamoeba invadens	1.9	< 99.99%	> 9	(Heaselgrave & Kilvington 2011)
Acanthamoeba polyphaga / histalogica		Inactivation only > 50°C		(Lonnen et al. 2005; Heaselgrave et al. 2006; Mtapuri-Zinyowera et al. 2009)
Acanthamoeba castellanii	>2	> 99%	< 9	(Heaselgrave & Kilvington 2011)

Table 3: Inactivation of protozoa

Examining petri dishes

Other micro-organisms

The effectiveness of SODIS against other pathogenic organisms was investigated in several studies. The results for the inactivation of helminth eggs (Ascaris suum) and two types of fungi are listed below.

The reported results suggest that expected removal values are in the range of 1LRV only under typical SODIS conditions, though the results for fungi are somewhat inconclusive, i.e., in Lonnen (2005) vs. Haeselgrave (2010). Compared to bacteria, viruses, and protozoa, these microorganism contribute only marginally to the health burden of waterborne diseases.

Pathogen	Log reduction value (6h)	Reduction of pathogen concentration (6h)	Approx. time for 3 log reduction (h)	Reference
Ascaris suum	1	90%	>15	(Heaselgrave & Kilvington 2011)
Fusarium solani	0.7	70%	>20	(Heaselgrave & Kilvington 2010)
Candida albicans	1	90%	>15	Heaselgrave 2010 (Heaselgrave & Kilvington 2010)

Table 4: Inactivation of helminths and fungi

Box 4: Pathogen removal capacity of SODIS

- The SODIS method, if applied correctly, substantially increases the safety of drinking water. Substantial reduction of pathogen concentrations can be expected for pathogenic bacteria and for certain types of protozoa. For Cryptosporidium, Amoeba and most viruses, a substantial inactivation can only be expected under favourable conditions (high water temperatures for protozoa, high steady state concentration of reactive oxygen species for viruses, and high irradiation dose).
- The inactivation rate for bacteria in real field applications of SODIS is comparable to chlorination and ceramic filtration. In the classification of HWTS systems based on performance targets proposed by the WHO (2011), SODIS would likely be ranked as an 'interim' solution, though this depends on the specific indicator organisms selected for the evaluation.
- The exponential relationship between irradiation dose and log removal value means a fraction of the pathogen population - also bacteria - may survive the SODIS treatment if initial concentrations are very high. SODIS does not completely sterilize the water. Many non-pathogenic microorganisms and algae are not affected by solar radiation, and survive the SODIS treatment.

Box 5: UV-Index

The UV-Index is an indicator designed to inform the public about UV intensity and to help them choose the appropriate protection from sunburn and skin cancer. The UV-index is calculated from the UV-radiation intensity in a given location weighted for the damaging effect of different wavelengths on the human skin. Radiation in the lower wavelength range (UV-B) is more harmful than radiation of longer wavelengths (UV-A), and, therefore, has a greater weight in the UV-index. The intensity of UV-B varies more strongly than visible light and UV-A radiation depending on, e.g., season, altitude, ozone layer, and zenith angle. This means that the UV-index is not an ideal proxy for the potential efficacy of SODIS, and is not reliable as a guide for SODIS users to adapt exposure times. Local weather conditions (sunny/cloudy) is a better guide for practical purposes in most cases.

2.2.2 Irradiation intensity

The most important determinant of the rate of pathogen inactivation in the process of solar disinfection is the intensity of solar UV radiation. Figure 1shows a typical inactivation curve for E.coli concentrations as a function of the cumulative irradiation dose, also called fluence. After a shoulder or lag period during which the concentration of viable cells remains more or less constant, the concentrations of viable cells drop exponentially as a function of the received UV dose.

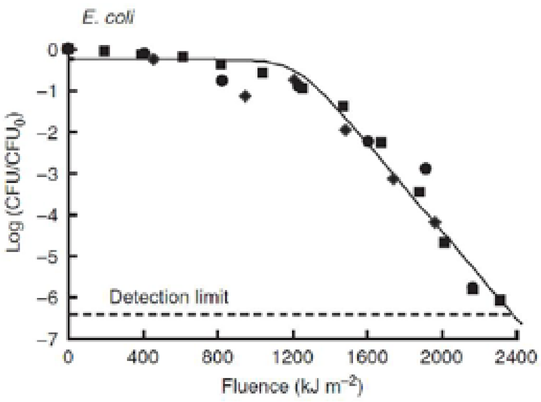


Figure 1: Inactivation curve of Escherichia coli exposed to sunlight (350–450 nm) on three different days at a constant temperature of 37°C (Berney et al. 2006)

In spite of the critical importance of the irradiation dose for the efficacy of SODIS, it is difficult to postulate a minimum dose required for effective disinfection. On the one hand, this is because different additional factors influence the treatment efficiency, including type, origin and physiological state of pathogens, water temperature, and water composition. On the other hand, different experimental setups applied in available studies on SODIS make it difficult to directly compare observed inactivation rates.

For example, studies were conducted with natural sunlight (varying according to season, location, and time of the day) or artificial lamps and filters with different radiation spectrums. Irradiation doses are reported either for the full solar spectrum or only for part of the spectrum (e.g., UV, UV-A), or as an intensity (average, peak, or range) for a certain treatment time. A comprehensive model for the efficacy of SODIS in relation to the irradiation dose and other influence factors does not exist.

In the absence of such a model, this manual aims at providing a differentiated picture of the dose-response relationship by listing the range of inactivation rates reported in SODIS studies. The log reduction values postulated and minimal exposure time for effective treatment (3 log reduction for pathogenic bacteria) in Chapter 2.2.1 above are based on these data, assuming typical irradiation intensities in tropical and subtropical (up to 35˚ latitude) countries.

Wegelin et al. (1994) postulated a threshold dose for 3 log inactivation of bacteria of 555 Wh/m2 in the range of 350-450nm. Table 5 presents corresponding doses for different wavelength ranges calculated using a model spectrum (ASTMG173). The table also provides corresponding values for average irradiation intensities to reach the required dose, assuming an exposure time of five or six hours, respectively. Note that the fraction of UV radiation as part of the full spectrum may deviate significantly from this model spectrum depending on location and season. Threshold irradiation doses presented below are, thus, only rough estimates.

	350-450 nm	UV	UV-A	UV&Vis	200-1100 nm	Full spectrum
Dose (Wh/m2)	555	270	263	2816	4764	5667
Dose (MJ/m2)	2.00	0.97	0.95	10.14	17.15	20.40
Dose (J/cm2)	199.8	97.4	94.7	1013.8	1715.0	2040.0
Intensity (6h) W/m2	93	45	44	469	794	944
Intensity (5h) W/m2	111	54	53	563	953	1133

Table 5 Estimated threshold irradiation dose (and corresponding irradiation intensity values for a 5 or 6 hours exposure period), for different wavelength ranges

The exposure time required to reach the threshold dose of solar radiation mainly depends on the location and weather conditions. Average daily doses of UV radiation are displayed on the map below. Between 30 degrees latitude North and South, the average daily UV doses are > 1.3 times higher than the required threshold dose for SODIS, except for regions with frequent cloudy or rainy weather.

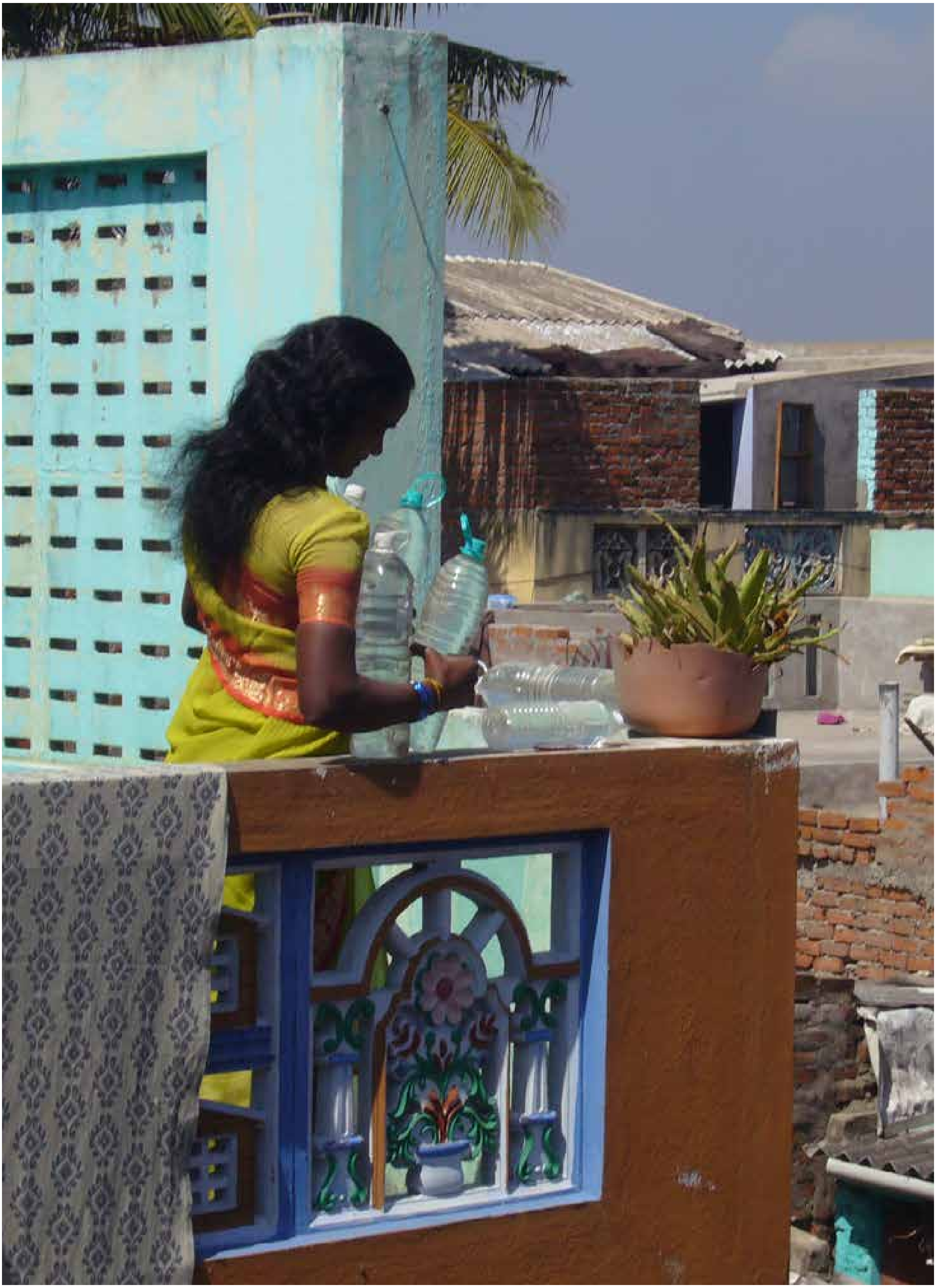
Table 6 presents SODIS efficacy results for bacteria, and E.coli in particular, as a function of the irradiation dose. Note that different studies report doses or irradiation intensities for different wavelength ranges, which means that the results cannot be directly compared. This table aims to provide a better idea of the efficacy results that can be expected in practical applications based on the available studies, rather than the definition of a single 'true' threshold value, though most studies suggest that the recommendation of at least 6h exposure in tropical countries for 3 log reduction of bacteria is realistic. Possible reasons for the observed differences other than irradiation dose in the cited studies may relate to factors that are discussed in the following sections. Lab studies relying on irradiation intensities much greater than those occurring naturally may produce results that are not representative for real life SODIS applications (Bosshard et al. 2009).

Box 6: Recommended exposure time

- Based on the data inTable 5, a recommendation for minimal exposure time of 6 hours on sunny days in tropical countries was formulated. In order to increase the safety margin, and to prevent impatient SODIS users from shortening the exposure time to less than 6 hours, we recommend the promotion of a minimal exposure for a full day even under sunny weather conditions.
  - 1 day of exposure to direct sunlight on mostly sunny days (less than 50% cloud cover)
  - 2 full consecutive days of exposure to direct sunlight on mostly cloudy days (more than 50% cloud cover)
  - On days of continuous rainfall, SODIS is not performing effectively and should not be used
- Given the key role of radiation intensity for a high disinfection rate, it is very important to adhere to the recommendations for the duration of solar exposure. In locations closer to the equator and in summer months, the solar irradiance can easily exceed the required intensity. This represents a safety margin that ensures effective disinfection even for shorter exposure times. In winter months and in locations further away from the equator, this safety margin becomes smaller. In this case, the temptation to shorten the exposure time, e.g., to drink treated water after lunch or to treat two batches of water in a day with the same bottles, holds a high risk of infection because the water is only partially disinfected. Adherence to the application guidelines is, thus, critically important and must be stressed in the promotion.
- Note that these guidelines do not apply to regions beyond 30 degrees latitude North and South, where solar intensity can be much lower, particularly in winter.

Author	Irradiation type	Wavelength range reported	Dose	Intensity	Result (selected pathogens)	Remarks	Comparison with Wegelin 1994
(Wegelin et al. 1994)	Simulated sunlight	350-450nm	555 Wh/m2	111 W/m2	3- 4 LRV in five hours for E. coli and St. faecalis,		=
(Heaselgrave & Kilvington 2010)	Simulated sunlight	Wavelength range not specified		150W/m2	E.coli: 5.7 log reduction after 4h	wavelength range unclear	Not comparable, wavelength range not specified
(Bosshard et al. 2009)	Simulated and natural sunlight	350-450nm		various	E.coli: Loss of culturability (0.1 % survival) at 1700kJ/m2		=
(Dejung et al. 2007)	Natural sunlight	UV-A (320-400nm)		UV: 16.9Wm2 (average day)	Postulated minimum UV-A dose for 3LRV vegetative bacteria incl. E.coli: 60Wh/m2 (4h on average days)	Mean water temperature 44 degrees	++
(Fisher et al. 2012)	Natural sunlight	UV-A (320-400nm)		73W/m2 (calculated)	3 log reduction of lab cultured E.coli in 3h, 3 log reduction of wastewater derived E.coli in 7h		Lab cultured: = W-derived: -
(Reed 1997)	Natural sunlight	Not specified: Full spectrum?		600-750W/m2 (full spectrum?)	E.coli: 6log inactivation in 3h under aerobic conditions Enterococcus feacalis: similar	Temperature < 28 degrees	Not comparable, wavelength range not specified
(McGuigan et al. 1998)	Simulated sunlight, 300-1020nm:		20200 KJ/m2 11500 KJ/m2 2900 KJ/m2	700 W/m2 (corresp. sunny weather) 400 W/m2 (corresp. to partly cloudy weather) 100 W/m2 (corresp. to overcast conditions	3 log inactivation 2.5 log inactivation 2 log inactivation		-
(Lonnen et al. 2005)	Simulated sunlight	300-400nm		200W/m2	E.coli: 5.5 log inactivation in 2.5h		Higher intensity than Wegelin
(Berney et al. 2006)	Natural sunlight	350-450nm	2400 KJ/m2 in 6-7h		E.coli: 3 log reduction requires 2000kJ/m2		=
(Boyle et al. 2008)	Natural sunlight	295-385 nm		Maximum noon intensity: >1000 W/m2 (full spectrum)	Dose of 125 kJ/m2 (295-385 nm) required for 2 log inactivation of E.coli Time for 4-log-unit reduction: C. jejuni, 20 min; S. epidermidis, 45 min; enteropathogenic E. coli, 90 min; Y. enterocolitica, 150 min.		+
(Ubomba-Jaswa et al. 2009)	Natural sunlight	295-385 nm			Complete inactivation at 108 KJ/m2 (UV)		++
(Kehoe et al. 2001)	Natural sunlight	300-20000nm			Full inactivation at 4-5 Mj(m2	High water temperature!	Not comparable due to synergistic effect

Table 6: SODIS efficacy as a function of irradiation dose



2.2.3 Place and position of bottle exposure

The penetration depth of UV-light depends on the position of the bottle in terms of exposure to sunlight. Penetration depth is minimal - and treatment efficacy maximal - if the bottles are placed lying down, and at a slight incline so that the sunlight hits them at a favourable angle (ideally 90 degrees). As the position of the sun shifts during the day, the bottles should be placed so that the penetration depth is low on average throughout the course of the day, which is usually the case if the bottles are placed horizontally. Readjusting the inclination of the bottles during the day is neither practical, nor necessary.

SODIS bottles in Cameroun

More important than the inclination is that the bottles receive direct sunlight during the entire exposure time and are not shaded by houses, trees or other objects when the sun's position shifts during the day. Finding such suitable places can be a challenge, especially in densely populated urban areas or in villages with dense vegetation cover, but the exposure to direct sunlight is not an application factor that can be compromised or relaxed.

The surface on which bottles are placed is of secondary importance. Treatment efficiency can be slightly increased if bottles are exposed in a warm place, i.e., protected from wind cooling or on a dark background, or on a reflective surface, such as a metal sheet. The accelerating effect of dark or reflective backgrounds is in the range of <30% (e.g., Mani et al. 2006) and, thus, not high enough to justify a reduction of the recommended exposure time. Due to the limited increase of disinfection efficacy relative to a substantial increase in the complexity of the SODIS method, an early recommendation to paint the back side of the bottles black is no longer promoted.

More sophisticated technical systems to increase radiation dose or temperature, e.g., solar collectors, may significantly increase the treatment efficacy and shorten the required exposure time. None of the devices designed so far have been promoted at scale at this point (see chapter 2.3).

2.2.4 Material and size of bottles

Due to the wide availability of PET bottles in low- and middle-income countries, the SODIS method was specifically designed and widely tested with this type of container. Other types of containers can also be used for solar disinfection for drinking water purposes as long as they fulfil two key requirements: high transmittance for UV radiation and no migration of potentially harmful substances into the water.

As the UV transmittance and safety cannot be easily evaluated by the water users themselves, we generally do not recommend using containers made of other materials, especially plastic bottles not made from PET, unless they have been certified and specifically approved for SODIS use. UV irradiation intensity decreases significantly with penetration depth in the water column, even in clear water. SODIS efficacy is, thus, higher in smaller bottles (Dessie et al. 2014). This effect is all the more important if the water contains suspended particles or dissolved organic material that absorb UV radiation (see below). For this reason, it is recommended to use bottles that are not larger than 2l in volume, with a maximum penetration depth of 10cm.

PET (Polyethylene terephthalate) is an inert plastic material that is widely used for food packaging. 'Plastic' bottles used for water and soda are almost exclusively made of PET. Only a small fraction of the widely available transparent 'plastic' bottles are made of other materials, such as PVC, and these bottles are mostly used for liquids such as edible oil rather than for water and soft drinks. PET bottles are labelled with the symbol "1", though this label is sometimes missing on bottles of local brands of bottled water. PVC (Symbol 3) can be distinguished from PET Bottles through a flame test: PET burns more easily and produces a sweet smoke, while the smoke of PVC is pungent. Bottles made of polycarbonate (PC: a durable sturdy plastic typically used for feeding milk bottles, Symbol 7) must not be used for SODIS because they potentially release BPA, a carcinogenic compound not found in PET.

Box 7: SODIS with glass bottles

- Different types of glass have different chemical and physical properties. Certain types (e.g., quartz glass) have a very high transmittance for UV radiation, while other types (e.g., window glass) effectively filter out this part of the solar spectrum. All commercial glass bottles used for beverages that were tested so far at Eawag had a UV transmittance comparable to PET bottles, and were, thus, suitable for SODIS. No differences were found in studies of glass and PET bottles that compared their SODIS effectiveness ((Asiimwe et al. 2013).
- It is possible, however, that certain glass bottles available in target countries have different UV transmittance properties, and we recommend testing UV transmittance of locally available bottles before promoting them widely for SODIS use. Glass bottles also have certain disadvantages compared to PET bottles which include their greater weight and risk of breaking, limited availability in suitable sizes, and the lack of reusable caps.

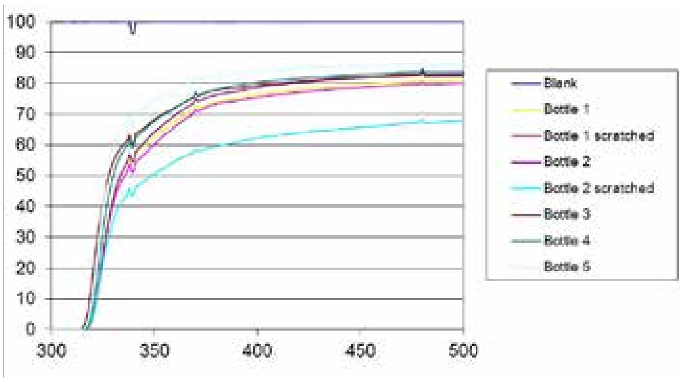


Figure 2: Typical transmittance spectrum for PET bottles

SODIS bottles in India

The transmittance of PET for UV-A radiation is relatively high, especially in the longer wavelength range (see Figure 2). The absorption of most of the UV-B radiation by the bottle material is a limitation to the effectiveness of SODIS, especially in regard to the inactivation of viruses. However, the use of containers with a higher UV-B transmittance rate (e.g., bags made of PE) for solar water disinfection at large scale would require a supply chain build-up of for new products, such as containers made from properties that are not yet widely available.

Colorants in PET bottles can decrease the transmittance of UV-A radiation. While some blue colorants only insignificantly affect the UV-transmittance, brown or green colour additives effectively block most UV radiation. As a general recommendation, only colourless, transparent bottles should be used for SODIS. All bottles with a light blue tint tested by Eawag exhibited a high UV-transmittance, and these bottles can, thus, be used for SODIS. Chemical UV-blockers are sometimes added to PET for the purpose of protecting sensitive contents, such as cosmetic products, fruit juice, or beer. However, high costs and problems with the recyclability of PET bottles that contain additives have so far limited the use of UV-blockers even for these liquids. There is no reason to assume that UV-blockers will ever be added to bottles used for water or soda.

Box 8: Safety of using PET bottles

- Certain types of plastics contain and leach chemical compounds that are harmful to human health, such as Bisphenol-A, that leaches from rigid plastic bottles made of polycarbonate. It is, thus, important to carefully evaluate all potential health concerns associated with the (re-)use of PET bottles for SODIS. Nobody wants to substitute one serious health risk - from infection with diarrheal disease - with another related to chemicals leaching from bottles into the water.
- Available data indicates that there is no significant health risk related to the release of chemicals from PET bottles. E-mails warning of health risks related to the consumption of water from ‘plastic’ bottles left in the sun have been circulating for years and will probably continue to do so. Compounds like Bisphenol A or dioxin that are sometimes associated with ‘plastic bottles’ in these e-mails are not used in the production of PET. The claim that the consumption of water stored in PET bottles (new, re-used, or exposed to sunlight) causes cancer is not supported by any scientific evidence.
- The available scientific studies show that solar exposure and the corresponding increase of water temperature can slightly increase the rate of migration of organic substances into water. However, the concentrations of these substances after SODIS treatment were still in the same order of magnitude as were the controls in dark storage, and well below WHO drinking water guideline values. This was shown for two compounds suspected of leaching into the drinking water from PET bottles [two plasticizers: DEHA and DEHP; (Schmid et al. 2008)]. A similar study conducted in India by IIT Chennai found the same results for different PET bottles used for SODIS (new bottles and bottles used previously for SODIS, big brands and local brands, unpublished report), and in Pakistan (Mustafa et al. 2013). Other studies investigating the migration of organic compounds from PET also did not find any reason for concern (Franz & Welle 2009; Ubomba-Jaswa et al. 2010; Guart et al. 2011; Bach et al. 2013, 2014) though uncertainties remain related to analytical procedures and the quality of PET raw materials (Keresztes et al. 2009; Bach et al. 2012). Antimony, a catalyst in the PET production process, migrates into the water at significant rates only in the case of very high temperatures (> 60 degrees Celsius) and/or long storage times (Westerhoff et al. 2008; Andra et al. 2011; Welle & Franz 2011; Rungchang et al. 2013; Sanchez-Martinez et al. 2013).
- Overall, the scientific evidence indicates that the health risk for SODIS users from using PET bottles is very low, and in the same order of magnitude as the risk to people from consuming beverages from regular PET bottles without solar exposure.

2.2.5 Turbidity and dissolved organic matter

Suspended particles in the water absorb and scatter radiation in the visible and UV range and can, thus, reduce the disinfection effectiveness of solar radiation. Sommer, Marino et al. (1997) found that at a turbidity level of 26 NTU (Nepherometric Turbidity Units), the intensity of UV radiation is decreased by approx. 50% after 10 cm penetration depth, compared to 25% reduction in clear water. The part of radiation that is scattered by the suspended particles is not lost, and can still produce reactive oxygen species that inactivate pathogens. Other studies also showed that the pathogen removal rate of SODIS decreases with the increasing turbidity of water (McGuigan et al. 1998; Kehoe et al. 2001; Gomez-Couso et al. 2009). The high disinfection efficacy in highly turbid water observed in some cases may be attributable to thermal inactivation as a result of the absorption of IR radiation and not due to photochemical reactions.

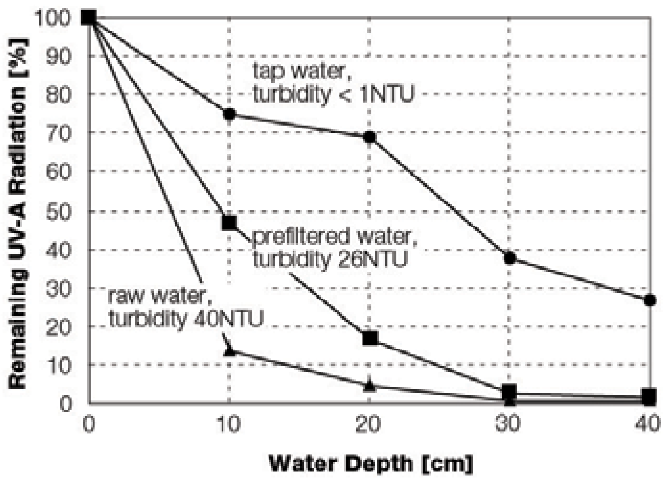


Figure 3: Effect of turbidity on radiation intensity, for different water depths. Source: (Sommer et al. 1997)

Based on these studies a turbidity level of 30 NTU was postulated as a threshold for the upper limit for effective SODIS treatment. Water with higher turbidity should be pre-treated, e.g., through settling and decanting, cloth or sand filtration, or flocculation. In areas where drinking water is turbid – both below or above 30 NTU – the use of alternative water treatment methods, which also improve water aesthetics, should be considered, as these are likely to appeal to users and hence would have higher uptake and sustained use.

The threshold turbidity value of 30 NTU can be estimated using a simple test: if the font of a typical newspaper headline is still readable vertically looked at through the mouth of a full bottle, the turbidity is lower than 30 NTU.

Dissolved organic material, i.e., large molecules, such as humic acids, can also decrease the potential disinfection efficacy of SODIS. Dissolved organic matter can both directly absorb UV-A radiation, acting as an internal UV filter, and quench reactive organic species (ROS) that cause damage to the pathogenic organisms. The opposite effects of dissolved organic matter - i.e., producing and quenching ROS - are not fully understood and may vary considerably depending on the type and concentration of the organic material (Wilson & Andrews 2011). Some dissolved organic compounds absorb light in the visible range and, thus, act as colorants in the water, while others do not change the water's appearance.

There is no simple indicator available to SODIS users to determine the level of organic material in water. Dissolved organic material can be removed to some degree by coagulation/filtration processes, but this relies on the availability of coagulants and requires an additional treatment step.

Estimating the water turbidity

2.2.6 Oxygen content

The damaging effect of UV-A radiation to cell structures is mediated by the reactive oxygen species (ROS) that are produced by photosensitizers. Photosensitizers are either dissolved organic compounds (exogenous pathway), or molecules of the pathogenic cell itself (endogenous pathway). Due to the critical role of ROS, the SODIS process does not perform efficiently in anaerobic (oxygen free) water. At 50% oxygen saturation, the disinfection rate for E.coli and Enterococcus faecalis is approximately half the rate at full oxygen saturation (Reed 1997). Early SODIS application guidelines recommended shaking partly filled bottles for oxygen saturation before solar exposure. This recommendation is no longer upheld as shaking the bottles complicates the process and water is oxygenated during the process of filling the bottles prior to solar exposure.

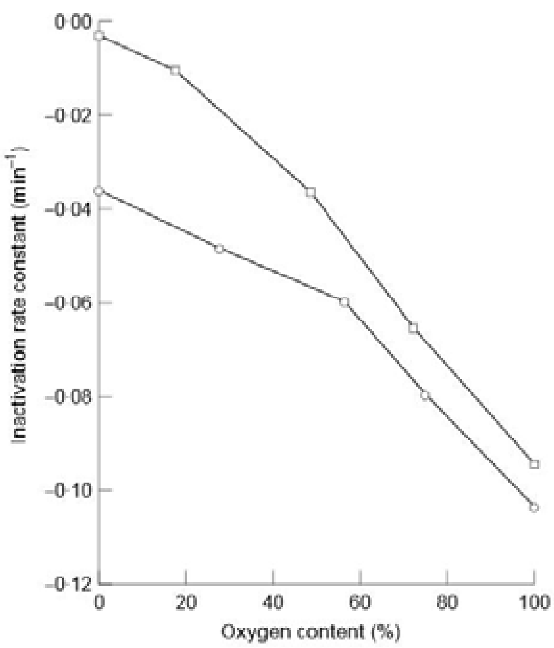


Figure 4: Effect of oxygen concentration on the rate of inactivation of Escherichia coli (o) and Enterococcus faecalis (▯). Air-equilibrated water (100%) contained oxygen at 8.4mgL-1 Source: (Reed 1997)

2.2.7 Water temperature

Pathogenic microorganisms are inactivated by high temperatures in the absence of UV radiation (pasteurization). The temperatures at which pathogens are killed within 60 minutes vary between species and are in the range of 45°C (Vibrio cholerae) to 63°C (Enteroviruses) (Berney et al. 2006). Even below pasteurization temperatures, the efficacy of SODIS significantly increases with higher temperatures. Below approximately 45°C, the temperature dependency of inactivation rates is weak and approximately linear (Wegelin et al. 1994; Fisher et al. 2008). At 50°C, the required irradiation dose and/or exposure time are reduced by as much as two thirds (Wegelin et al. 1994), or a 3 log difference of pathogen reduction compared to the calculated sum of the individual effect of radiation and heat (Theitler et al. 2012). This means that at favourable conditions - hot weather, strong irradiation – complete disinfection can be achieved faster than within the recommended exposure time of one day (6 hours minimum).

However, water users cannot easily determine the water temperature inside SODIS bottles. Therefore, it is not recommended to shorten the exposure time even if irradiation conditions and temperature seem favourable. We also do not recommend shortening the exposure time if bottles are placed on a dark surface to maximize the thermal effect.

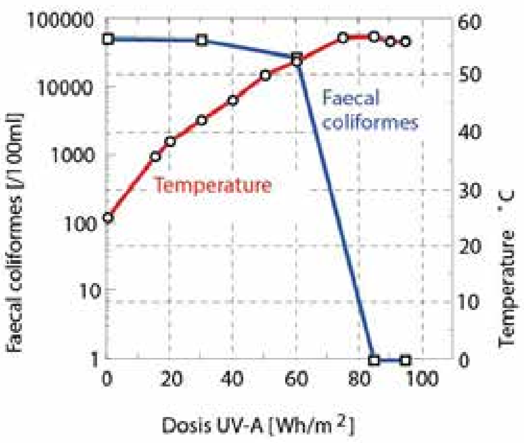


Figure 5. Inactivation curve of faecal coliforms in glass bottles, water turbidity 17 NTU display synergistic effect of UV-irradiation and temperature above 50°C. Source: (Sommer et al. 1997)

Family applying SODIS in Laos

2.2.8 Re-growth

The available literature does not provide a conclusive picture as to whether pathogens do recover from the effects of solar radiation or increase in number after solar exposure, and under which conditions this could be expected. Based on lab experiments, Bosshard et al. postulate that the damage done to the cell as an effect of UV-A radiation is irreversible. Several studies found no re-growth after SODIS treatment (McGuigan et al. 1998; Boyle et al. 2008; Bosshard et al. 2009; Dessie et al. 2014). Wegelin at al. (1994) observed a regrowth of E.coli to original concentration within one week after a short (32 min) irradiation with artificial light, but no re-growth after 3 hours of irradiation with sunlight. Amin and Han (2009) observed only very limited regrowth of E-coli and total coliforms even for moderate treatment efficacy under weak sunlight conditions. Rincon and Pulgarin (2004a) observed re-growth of E-coli to initial levels within 24 hours after irradiation. Gelover, Gómez et al. (2006) found moderate re-growth of total coliform within the first day after SODIS treatment. Sciacca, Rengifo-Herrera et al. (2010) observed re-growth of Salmonella sp. reaching initial concentrations within 18 hours after treatment, and further growth by about 1 log thereafter. AL-Gheethi, Norli et al. (2013) found decreasing concentrations of bacteria when the SODIS treated water was stored at room temperature, but re-growth if the treated water was stored at 37°C. The presence of nutrients in the water and the origin (wild vs. laboratory cultured) and physiological state (steady state or exponential growth state) of pathogens are believed to influence if and to what extent bacteria populations can recover from solar irradiation. As E.coli and other faecal bacteria do not typically multiply in the environment (except, e.g., Salmonella), the apparent re-growth in water samples could indicate an incomplete inactivation and sub-sequent repair of cells or could relate to the analytical procedures overestimating the inactivation effect (Reed 2004; Khaengraeng & Reed 2005).

Re-growth or recovery as reported in some of these studies would seriously compromise the viability and potential health impact of the SODIS method. Water quality tests conducted in many SODIS promotion projects did not produce evidence for considerable re-growth, and instead indicate a substantial improvement of water quality. And yet, based on the inconclusive evidence, the re-growth of bacteria in SODIS treated water must be considered as a potential limitation to the efficacy of SODIS and could have health impacts in real life applications. While the reasons and conditions for re-growth or revival are not yet completely clear, it is advisable to store SODIS treated water in a cool place and to consume it within a short time (a few hours up to one day) after treatment.

Proposed measures to inhibit re-growth, e.g., adding H_2O_2 or TiO_2 to the water (Rincon & Pulgarin 2004b) may be technically viable, but do not seem realistic in practice due to the increased complexity of the treatment process, and the need to establish supply chains for such additives. If a chemical substance is added to the water, it may as well be one that disinfects the water without creating an additional need for irradiation (e.g., chlorination).

2.3 Advanced designs

A number of technological designs have been proposed to increase the technical efficacy or practical aspects related to the SODIS method. As none of these designs have yet to evolve into widely promoted commercial products, they are only briefly addressed in this manual (for a review, see McGuigan et al. 2012). While potentially more effective and attractive than PET bottles, the marketing of advanced SODIS products will have to address several challenges, including higher costs for water users and the need to establish sustainable supply chains and business models in target areas. Advanced designs based on solar disinfection, thus, do not share two of the main comparative advantages of the standard SODIS method, i.e., the very low or zero cost and the wide availability of required materials. The potential uptake of an advanced SODIS container in relation to other water treatment products is at present unknown.

Generally, five types of technical advances can be distinguished.

1. Simple local modifications for SODIS use in bottles

Different simple modifications have been proposed to increase the efficiency of SODIS, including self-made solar reflectors to concentrate sunlight, or boxes/covers for additional heating effects. While such modifications can somewhat accelerate the treatment process, the magnitude of this effect is usually in the range of less than 50%. Effectively motivating water users to construction and maintain such systems is considered challenging, and not justified given the limited effect. No commercial product has emerged so far.

2. Bottle and bag designs

New types of containers for solar water disinfection could provide different types of benefits compared to regular PET bottles. First, a higher transmittance for UV radiation would increase treatment efficacy (especially for viruses if transmittance for UV-B is high). Second, less bulky containers, e.g., collapsible bags, could be transported to target areas much more easily than empty bottles. This would increase the scope of potential use for, e.g., disaster relief operations, and makes business models for sales potentially more profitable. Third, an attractive commercial product that offers advantages compared to regular PET bottles (e.g., larger volume, convenient outlet/tap, aesthetical appeal) is likely to be more valued and more consistently used by target households. Designs for SODIS bags are currently being field-tested.

3. Solar disinfection reactors

The idea of using solar radiation for the treatment of larger water volumes – typically a few hundred litres a day – for sale or distribution at the communal level has been pursued in a number of research groups (e.g., Gill & Price 2010; Kalt et al. 2014) The design of a reliable solar disinfection reactor system (batch or continuous-flow) is technically challenging for a number of reasons, including cleaning. The material and construction cost of solar reactors and the need for operation and maintenance may also be significant and, thus, limit the cost-effectiveness of solar reactors compared to other technologies used to treat large volumes of drinking water (including chlorination).

4. Additives

A number of additives have been studied that can enhance the treatment efficacy of SODIS, including TiO_2 or H_2O_2 (Byrne et al. 2011). Some of these additives substantially enhance the treatment effectiveness. There are two major constraints, however, to their being widely promoted and used in target countries. First, the addition of a substance to the water significantly complicates the process for the user, while the additional benefit is limited. Even if exposure times can be reduced to only one to two hours, the labour input remains the same or even increases, and exposing the bottles for one to two (midday) hours is still a practical challenge for people who work outside their homes. Second, the regular and consistent use of a SODIS catalyst depends on the existence of reliable supply chains for such a product, and relies on recurring purchases. There is no compelling reason for water users to buy and use a catalyst for solar disinfection, if they could just as well buy and use a chemical disinfectant, e.g., chlorine, which directly kills pathogens.

5. Indicators

One disadvantage of the SODIS method is that there is no visual indication for water users to know when the water is ready for consumption. Technologies that measure UV radiation and that produce a signal when the required dose has been received can help to mitigate this constraint. Both electronic and chemical indicators are being designed and field tested. In addition to increasing users' confidence in the effectiveness of SODIS, such indicators may add a certain modern or 'high tech' appeal to the method and counteract the perception of SODIS as a poor man's solution.

2.4 Implications for the application of the SODIS method

The SODIS method, if applied correctly, substantially increases the safety of drinking water. It can effectively inactivate diarrhoea causing bacteria and - to a lesser extent - pathogenic viruses and protozoa. The following list summarizes the key implication for the application of the SODIS method.

Irradiation intensity

- Expose bottles for a full day (minimum of 6 hours including noon hours) on sunny days (less than 50% cloud cover). Expose bottles for 2 consecutive days during mostly cloudy days (more than 50% cloud cover). Do not use SODIS on days of continuous rainfall, or in very foggy conditions.
- Make sure bottles are exposed to direct sunlight during exposure and are never shaded by trees, houses or other objects. Expose bottles horizontally, or slightly inclined, so that the penetration depth for radiation is minimized (long side facing the sun).

Material and size of bottles

- Use bottles made of PET (other containers should be used only if they are specifically approved for solar disinfection)
- Use only bottles up to 2l of volume, i.e., that allow for a short penetration depth for UV radiation

Turbidity and dissolved organic matter

- Use SODIS for water with no or very low turbidity (maximum 30 NTU)
- Pre-treat turbid water before SODIS, e.g., by filtration, flocculation or settling.

Water storage

- Store SODIS water in the SODIS bottles themselves, as this reduces the risk of re-contamination.
- Water should not be stored for long periods to minimize the risk of bacterial re-contamination or re-growth. Consumption within a day or two is recommended.
- Water should be consumed directly from the bottles, or poured into a clean cup or glass. If another container is used for storage and/or cooling, the guidelines for safe storage must be followed: clean container, narrow opening, lid to cover the opening, water stored away from animals and small children, and withdrawal through a tap/spigot integrated in the storage container or with a clean ladle.

Application of SODIS in India

3 Promotion of the SODIS method

This chapter addresses key factors contributing to the successful promotion of the SODIS method and it highlights lessons learnt from SODIS projects in more than 30 countries in Africa, Asia and Latin-America. It does not prescribe a specific one-size-fits-all approach.

The chapter presents: evidence of uptake, the sustainability of the health impact of SODIS projects (chapter 3.1), the important elements of the planning phase of a SODIS project (chapter 3.2), how behaviour change factors can be addressed (chapter 3.3) and the promotion tools that were applied successfully (chapter 3.4).

3.1 Evidence on uptake, sustainability, and health impact

The studies related to uptake, sustainable use and the health impact of SODIS show that the challenges faced by SODIS users are not unique, but are rather typical for the most common HWTS methods.

3.1.1 Evidence on uptake

Most of the available information about the uptake of SODIS stems from monitoring data from promotion projects that were typically collected by the implementing organizations at the end of a promotion phase. This monitoring data, however, has to be carefully interpreted as the reporting biases because of the water users, field workers, and implementing agencies could affect the quality of the data by exaggerating the impact of the project. Also, the monitoring data only provides an understanding of the situation over a short-term and does not allow for extrapolations concerning long term use rates.

In projects supported by Eawag, application rates ranged from very low uptake in some areas (particularly when SODIS was promoted along with other HWTS options) to nearly 100% SODIS use in pilot projects with a high promotion intensity and favourable conditions. The average adoption rates were in the range of 30-60% at the end of a promotion phase, and typically dropped after promotion activities were discontinued.

The following table summarizes the adoption rates published in scientific articles. Note that many of these results were generated in the context of SODIS promotion research projects where the main objective was to assess the effectiveness of promotion tools and the relevance of different influencing factors. The promotion methodology and resulting outcomes are not necessarily representative for promotion campaigns implemented by governments or NGOs.

One important finding is that neither the adoption, nor the relapse, are homogeneous processes, but that distinct patterns occur for early, middle, and late adopters, and that different motivational factors are particularly relevant for each of these groups (e.g., Moser & Mosler 2008; Tamas & Mosler 2011).

Study	Adoption rate	Remarks
(Rainey & Harding 2005)	10% routine adoption (n=40 HHs)	Very small sample
(Christen et al. 2011)	32% compliance (total sample: 216 HHs)	Multi-parameter indicator for SODIS compliance used
(Heri & Mosler 2008)	60% self-reported SODIS users (n= 644HHs)	SODIS water amounted for only 33% of the water, many SODIS users also used boiling
(Mosler et al. 2013)	65% SODIS use if household training were conducted (n= 364 HHs)	Data collection six months after the promotion, adoption lower in areas with other promotion strategies
(Tamas & Mosler 2009)	45-59% SODIS water consumption (n=337 HHs)	Adoption depending on promotion strategy, 32% SODIS water consumption in the control group
(Graf et al. 2008)	69% of children consume SODIS water (n=717)	Multiple answers possible: 53% also reported consumption of boiled water, 23% reported raw water consumption

Table 7: Uptake of SODIS

Scientific studies testing the effect of different promotion approaches on uptake yielded valuable insights:

- Altherr, Mosler et al. (2008) highlight the importance of a favourable attitude, while the intention to use also depends on perceived social pressure and actual use on action knowledge.
- Christen, Pacheco et al. (2011) reported that the frequency of promotional interactions, the gender of household members, ownership of a latrine, and the presence of malnourished children correlated with higher SODIS uptake.
- The study of Heri and Mosler (Heri & Mosler 2008) highlighted the importance of frequent promotional interactions, and found statistically significant correlations with SODIS use for the following behaviour change factors: daily tasks and habit, the descriptive norm (practice by relevant peers), perceived threat of diarrhoea, perceived benefits of SODIS (cost savings, better taste) and the availability of PET bottles in sufficient numbers. The intention to use SODIS was strongly determined by affective beliefs in this study.
- Kraemer and Mosler (2010) found that the intention to use SODIS increases if it is easier for people to remember to use SODIS, if they are convinced that untreated water is unhealthy, and if people believe that others think positively about them when they use SODIS (Kraemer & Mosler 2010).
- Moser and Mosler (2008) found that the involvement with the issue of safe water is particularly relevant for early adopters, while middle adopters are influenced by different factors including opinion leaders, and late adopters are more strongly influenced by the behaviour of the majority (Moser & Mosler 2008).
- Graf, Meierhofer et al. (2008) found that biomedical knowledge of the causes of young children’s diarrhoea, increased knowledge of the proper handling of water, stronger beliefs about the important role of water in causing diarrhoea, and higher social norms concerning water treatment were associated with the use of SODIS.
- Two studies investigated how psychological factors change from initial uptake to long term use (or relapse), and suggested the fol-

lowing recommendations for successful promotion: increase visibility in the community, include daily routine planning as part of household trainings and fostering remembrance of SODIS use by distributing stickers and posters (Tamas & Hans-Joachim 2011 ; Mosler & Kraemer 2012).

- A study in Bolivia found that household visits by promoters were more effective than promotion through opinion leaders or events like health fairs (Tamas et al. 2009).
- A study in Zimbabwe tested the effectiveness of different promotion strategies, and found that interventions involving household trainings through promoters were much more effective than campaigns without promoters (Mosler et al. 2013).
- Tamas and Mosler (2009) compared different promotion approaches and found that, including public commitments and prompts for remembering as promotion tools in the promotion conducted by health volunteers, schools and radio had a positive effect on uptake.
- Meierhofer and Landolt (2009) and Gurung, Grimm et al. (2009) highlight key success factors for SODIS uptake based on non-research SODIS projects, including the commitment and authority of promoters, promotion frequency, the visibility of SODIS used in the community, bottle availability, appropriate promotion materials, and an enabling environment.

3.1.2 Evidence on sustainability

Sustained application of SODIS is a necessary condition for its health impact. It can be considered as the first step in the potential health impact of a project.

A research project conducted by Eawag systematically addressed the long term application of SODIS use in different countries (Tamas et al. 2011).

- In Nepal, long term SODIS user rates have been about 60% lower two to four years afterwards than at the immediate end of the promotion (21% vs. 60% SODIS users in the promotion areas). About two thirds of the people in these areas treat their water with one or several HWTS methods, ceramic filters being the most common technology. 50% of the households reported that they still mostly or occasionally consumed untreated water.
- In Indonesia, an average of 21% of the people were found to still use SODIS (thereof: 2/3 daily users) up to five years after the promotion, but with high local variation. The application of SODIS was only sustained in areas with continued promotion, while in other former project areas, all former SODIS users reverted back to boiling, which was common in the area already before the SODIS project. The highest long-term application rates of SODIS were found in Bolivia with an average use of 62% several years after the promotion, whereas many households use both SODIS and boiling.
- A study in rural Peru reported between 32% (observed) and 42% (self-reported) SODIS use seven years after the promotion project (Halperin et al. 2011)

Pupils in Bolivia learning how to treat their water with SODIS

3.1.3 Evidence on health impact

The ultimate goal of every SODIS or HWTS promotion activity is to reduce the health risks associated with diarrheal disease in the target population. Impact studies of HWTS projects mainly focus on the reduction of diarrhoea incidence or infection risk ratios, either before and after an intervention, or by comparing the intervention population to a control group.

A meta-analysis of high quality studies found an average 44% risk reduction of diarrhoea disease due to interventions to improve water quality at the household level [95% confidence interval: 0,48–0,65 (Waddington & Snilstveit 2009)]. However, the observed health impact varies considerably across the different studies. SODIS health impact studies yielded risk reduction values in a similar range, with studies measuring no statistically significant effect (Mausezahl et al. 2009) to studies showing more than 80% risk reduction for cholera among children below 5 drinking SODIS treated water (Conroy et al. 2001). An overview of results from SODIS health impact studies is summarized in Table 8: Results from health impact studies in SODIS promotion areas.

There are different reasons for the large observed variance. First, pathogens that can cause diarrheal disease in humans are transmitted through different pathways. The relative dominance of the different transmission routes can vary substantially from one location to the next, and is typically neither known, nor easily measurable. SODIS (and other HWTS methods) can only prevent infections with diarrheal disease that are caused by contaminated water. The greatest health impact resulting from SODIS promotion can, thus, be expected in areas where diarrhoea is mainly transmitted by drinking water. In contrast, in a location with relatively good raw water quality, but widespread open defecation and inadequate hygiene, the potential health impact of SODIS is limited. Another reason for the variable health impact findings relates to the technical limitations of different methods for different pathogen types. Technologies with a limited pathogen removal capacity for certain pathogens (e.g., SODIS and ceramic filtration for viruses, chlorination for certain protozoa) will yield a lower health impact in area where these pathogens are responsible for a large share of the infections. The third - and very important - determinant of the health impact of a HWTS intervention like SODIS is the consistent and correct application of the method (including safe storage), as well as the consequent safe water consumption by the water users. Studies show that the consumption even of small quantities of contaminated water in the range of 5-10% of the total consumption can practically nullify the health effect of water treatment (Brown & Clasen 2012). Achieving such high consistency of safe water consumption is a major challenge in pilot projects, and even more so in large scale promotion programs.

Beyond their limited generalizability due to variable local influence factors, health impact studies for HWTS interventions have been criticised for methodological weaknesses. Most of the published health impact results for HWTS interventions are based on randomized controlled trials and rely on diarrhoea incidence data provided by the water users themselves. Such data are prone to bias (see Box 9). The assessment of clinical data or anthropometric changes of height and weight in children arguably yields more objective results. A first study assessing weight-for-age and height-for-age measures in a SODIS intervention area reported that children aged six months to five years were 0.8 cm taller on average in households using SOIDS compared to children in the control group (95% confidence interval: 0.7 to 1.6 cm, P = 0.031) after one year of intervention (Du Preez et al. 2011). The same study also found a tendency that children from SODIS households were heavier than those drinking raw water on average (Median weight-for-age: higher by average of 0.23 kg over a 1-year period in the SODIS group (95% confidence interval: 0.02 to 0.47 kg, P = 0.068).

Considering the methodological challenges in assessing and interpreting health impact data, it is recommended that health impact studies be conducted only by professional epidemiologists. Quantitative studies that do not effectively control for bias or qualitative health impact studies conducted as part of the monitoring and evaluation process of promotion projects are likely to produce distorted and unreliable results. Data on diarrhoea cases from health centres and hospitals are less bias-prone than self-reported diarrhoea incidence, but are also limited as indicators for the health impact of a project (inconsistent data quality, mismatch between areas reported to be covered by the health centre and the project, and normal seasonal and inter-year fluctuations that need to be considered in longitudinal comparative analyses).

Box 9: Measuring health impact

- Health impact studies aim to measure the extent of the reduction in disease incidence or in the risk of infection that results from an intervention, e.g., the promotion of SODIS. The main challenge in health impact studies is to collect reliable, representative, and robust data, and to statistically isolate the effect of the intervention from other intervening variables.
- Most existing studies on the health impact of SODIS (or WASH interventions in general) are designed as 'randomized controlled trials' that compare the diarrhoea incidence in an intervention group vs. a control group. Diarrhoea incidence data are typically collected from water users directly through surveys. Self-reported diarrhoea incidence is a problematic indicator for different reasons:
- The recall period of respondents is typically very short, which means that the user data are only reliable for a short time, typically 48h prior to the data collection.
- Data collection through surveys is prone to bias at different levels. Water users, data collectors and data evaluators tend to exaggerate the effect of an intervention, often unconsciously. This can influence the way they answer question, ask questions, or analyse data, respectively. This is particularly problematic if health data are collected by project staff that were also involved in the promotion. Hunter (2009) postulates that the reported health benefit in many HWTS studies is as least in part - if not entirely – explained by responder and reporting bias.
- More reliable results can be gained from blinded studies (i.e., placebo-controlled), double-blinded studies (placebo-controlled, data collectors do not know if the surveyed household used the real product or the placebo), or objectively verifiable indicators (e.g., clinical diarrhoea data, effect on growth and weight gain).

Author, year	Con-try	Study group	Type/indicator	Result	Remark
(Conroy et al. 1996)	Kenya	Children 5-16y	Odds ratio for all diarrhoe episodes, and 'severe' diarrhoe	Diarrhoea (odds ratio 0·66 [0·50–0·87]), severe diarrhoea (0·65 [0·50–0·86])	
(Conroy et al. 2001)	Kenya	Children < 5y	Odds ratio for infections with cholera	Odds ratio 0.12, 95% CI 0.02 to 0.65 81% less cholera cases among children <5	No significant effect for older children and adults
(Conroy et al. 1999)	Kenya	Children < 6y	Odds ratio for diarrhoe	Odds ratio 0.69, 95% CI 0.63 to 0.75	High turbidity water
(Rose et al. 2006)	India	Children < 5y	Incidence rate ratio, duration, severity	IRR 0.64 (40% reduced risk of infection)	86% also consume other type of water
(Arnold et al. 2009)	Guatemala	Children <5y		No difference between the intervention and control villages in the prevalence of child diarrhoe or child growth	Post intervention study; very low compliance for HWTS (8.7% confirmed HWTS use in control group vs. 3.3% in interv. group)
(Mausezahl et al. 2009)	Bolivia	Children < 5y	Self-reporte diarrhoe (diarrhoe diary)	Relative rate of diarrhoe: 0.81 (95% CI 0.59–1.12)	Statistically not significant, low compliance with SODIS (32.1%)
(du Preez et al. 2010)	South Africa	Children < 5y	Dysentery, non-dysentery type diarrhea	Dysentery: IRR 0.64, 95% CI 0.39-1.0, P 0.071) Non-dysentery: no statistically significant effect	IRR for dysentery statistically only significant for households with "high motivation"
(Du Preez et al. 2011)	Kenya	Children 6 months – 5y	Incidence rate ratio Height to age Weight to age	Dysentery IRR = 0.56 (95% CI 0.40 to 0.79) Dysentery episodes IRR = 0.55 (95% CI 0.42 to 0.73) nondysentery days IRR = 0.70 (95% CI 0.59 to 0.84) nondysentery episodes IRR = 0.73 (95% CI 0.63 to 0.84). Median height-for-age: higher by average of 0.8 cm over a 1-year period in SODIS group (95% CI 0.7 to 1.6 cm, P = 0.031). Median weight-for-age: higher by average of 0.23 kg over a 1-year period in the SODIS group (95% CI_0.02 to 0.47 kg, P = 0.068).	Difference in weight for age indicator not statistically significant
(Graf et al. 2010)	Cameroon	Children < 5y	Odds ratio	OR (intervention group vs control group) : 0.63 OR (SODIS users vs none-users) : average 0.45	
(McGuigan et al. 2011)	Cambodia	Children 6 months – 5y	Dysentery, non-dysentery type diarrhoe	Dysentery: IRR 0.50 (95% CI 0.27_0.93, p = 0.029) Non-dysentery: IRR of 0.37 (95%CI 0.29_0.48, p < 0.001)	

Table 8: Results from health impact studies in SODIS promotion areas

Explanations:
Measures for the magnitude of the effect of an intervention:

- *Incidence rate ratio (IRR): Ratio of the incidence rates (% of population with disease) between the intervention and control group. An IRR of 0.50 means that the incidence rate of diarrhoe cases in the intervention group was half that of the control group.*
- *Odds Ratio (OR): Ratio between the odds of infection between different groups (the odd is the ratio between people with and without disease). An OR<1 means that the odds of infection with diarrhoe are lower in intervention households (e.g., 5 times lower for an =R of 0.20).*
- *Relative risk: Ratio of the probability of the event occurring in the intervention group versus a control group.*

3.2 Elements to consider during the planning phase

3.2.1 Planning a behaviour change intervention

The SODIS method, and HWTS in general are practices that bring about the reduction in health risks. As such, they are comparable to other preventive health practices, such as physical exercise, dental hygiene, healthy diet, safer sex, non-smoking, etc. The potential health impact of these practices critically rely on instituting an effective and sustainable behaviour change among the target population. Such transformations are typically difficult to achieve, take much time, and require concerted and coordinated campaign efforts through different promotion channels.

Health programs often concentrate on the educational aspects to persuade people to adopt a healthy practice. And yet, many examples show that increased awareness alone is seldom sufficient to change a behaviour across the target population. Successful behaviour change promotion requires a more comprehensive approach. According to the RANAS model (see Fig. 10), behaviour change depends on factors relating to risks, attitudes, norms, ability, and self-regulation, all of which can be influenced by targeted interventions.

A behaviour change campaign should always start with the definition of the target group (e.g., all people of municipality X, all teachers in district Y, all women of the city X, all children under five years in region Y), the behaviour to be changed in the target population (e.g., people drink contaminated water -> people drink exclusively safe water), followed by the determination of the factors steering the targeted behaviour. The factors can be defined based on evidence or estimation (see Box 10). Based on these factors, promotion tools (e.g., community trainings, household visits, etc.) can be selected and designed.

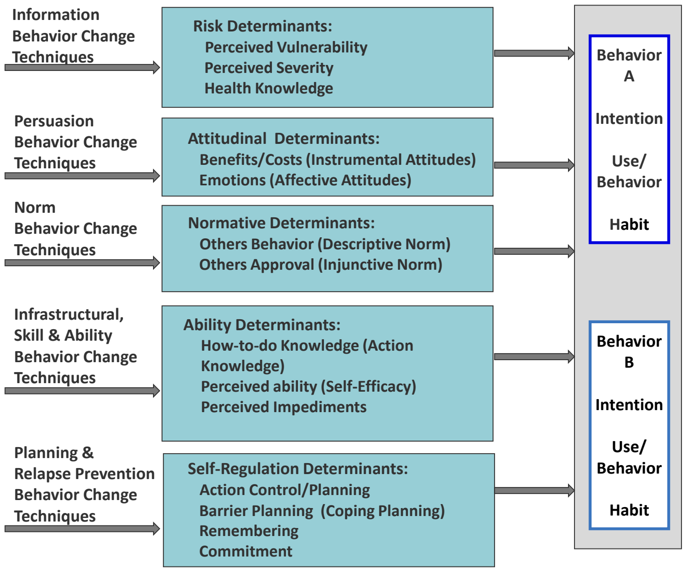


Figure 10: RANAS model (for details, see Mosler (2012))

Wall sticker in India

Box 10: How to apply behaviour change models in the planning of projects

Few non-governmental organizations are in a position to implement a large-scale and evidence-based behaviour change campaign due to limited financial and human resources. It is, therefore, important to note that behaviour change models are also useful if the importance of critical factors can only be estimated or as a source for inspiration.

- **Behaviour change campaign based on evidence:** A behaviour change model can be the conceptual framework for data collection to assess the relative importance of different psychological and practical factors by baseline surveys. Such an assessment can provide the basis to design behaviour change campaigns that are evidence-based and tailored to the specific context. The requirements (expertise, time, budget, etc.) for a quantitative study are substantial, and may exceed the capacities of most small organizations. More information on conducting comprehensive behaviour change assessments can be found at: http://www.eawag.ch/fileadmin/Domain1/Abteilungen/ess/schwerpunkte/ehpsy/behavioural_march_2013.pdf

- **Behaviour change campaign based on estimation**: The RANAS model can influence project planning by providing a systematic understanding of the critical factors that may have to be addressed, even if their relative importance can only be estimated, e.g., based on previous experiences, expert opinion or qualitative data.

- **Behaviour change model as inspiration:** Organizations that promote health practices without the capacity or ambition to implement evidence-based behaviour change campaigns may find specific ideas in the behaviour change models on how to strengthen their promotion approaches by integrating new promotion tools to influence previously neglected parameters.

3.2.2 Selection of intervention area

The prioritization and selection of target areas for SODIS or HWTS promotion should be based on a needs assessment and the potential impact of the intervention. Key factors determining the potential impact include the extent of consumption of contaminated water and the applicability of different HWTS methods in view of different context-specific factors, including physical, economic, and psychological aspects. Analysis of the potential impact can draw from available data, water quality tests, surveys, and/or through participatory appraisals with experts and local stakeholders.

HWTS promotion can only yield health benefits if the target population actually consumes water contaminated with pathogens, and consequently suffers from diarrheal disease. This is more likely in areas where the water is contaminated by pathogens at the source level, and/or is at a high risk of secondary contamination during collection, transport and storage. Water quality tests can be used to estimate the typical level of contamination from faecal pathogens at the point of consumption, and possibly to identify the critical points where the contamination occurs. Note that drinking water contamination may vary considerably from one source to the next, and from one day to the next.

In areas where one or several HWTS methods are already widely used, the promotion of a new technology only makes sense if it offers additional benefits - e.g., higher disinfection efficacy, lower costs, convenience and, therefore, potentially more consistent use - or if they can reach population segments that are not yet benefiting from the available HWTS systems.

Box 11: SODIS/HWTS promotion in areas affected by chemical water pollution

- Special criteria apply to areas where chemical contaminants - e.g., arsenic, fluoride, or organic pollutants - are present in the drinking water in potentially harmful concentrations. The most common HWTS technologies - boiling, chlorination, ceramic, biosand or membrane filtration, and SODIS - do not eliminate these contaminants from the water. Additional or alternative treatment technologies must be employed to remove these compounds. While such technologies exist for use at the household level, their relatively high cost and requirements in terms of operation and maintenance render centralized applications more cost-effective in many circumstances. Unlike for microbial contaminants, re-contamination from chemical pollutants in the water supply system or during handling and storage by water users is not a major concern.

- Areas affected by chemical water contamination should receive priority with regard to the improvement of centralized water supply and treatment. The application of SODIS or other HWTS methods is nevertheless advisable, if:
  - no treatment facilities to remove the chemical contaminants are available, at least not in the short term -> HWTS at least reduces the risk of infection from diarrheal disease, while the need to improve chemical water quality remains urgent.
  - treatment technologies to remove chemical pollutants are available, but only remove chemical contamination and not pathogens, and do not reduce the risk of microbial re-contamination during transport and storage -> HWTS closes the remaining gap to safe water consumption.
  - alternative water sources are available that are free from chemical pollutants, but are potentially contaminated with pathogens -> HWTS lowers the risk of using chemically safe sources as alternative options.

Woman applying SODIS in India

The applicability of a HWTS system typically depends on specific local conditions. For the SODIS method, the following factors must be considered:

- Irradiation: The SODIS method should only be promoted in areas where solar radiation is strong enough year round for effective reliable disinfection, i.e., in tropical and sub-tropical regions up to 35 degrees latitude with only limited foggy or rainy periods. The applicability of SODIS can be limited for people residing in multi-story buildings or in areas with dense vegetation due to their limited access to places that receive at least 6 hours of direct sunlight each day.
- Water turbidity: As suspended particles absorb solar radiation, SODIS is unsuitable for areas with turbid water supply (>30 NTU), unless a pre-treatment method can be successfully promoted.
- Bottle availability: Targeted water users in SODIS promotion areas must be able to collect or buy bottles for SODIS in sufficient quantities. If water or soda bottles are not readily available, the potential to set up a sustainable bottle sourcing system must be evaluated based on realistic assumptions (see Chapter 3.2.6).

Beyond these 'external' conditions determining the applicability of SODIS, the potential uptake and impact also depends on a number of factors related to people's economic capacities, perceptions, attitudes and habits. The reasons why people do or do not consume untreated water or use HWTS methods should be assessed at least qualitatively before defining the range of HWTS technologies to be promoted and the set of promotion tools. Furthermore, the assessment should cover the conditions in which the promotion takes place, including political, legal, institutional, economic, and socio-cultural factors (see Chapter 3.2.7). Note that many factors influencing the potential uptake of a new practice like SODIS, including attitudes towards the technology (e.g., preferences in terms of taste, look and temperature of treated water, and willingness to invest labour) are difficult to assess before the method has been introduced and applied in the community. A pre-test at a small scale can help to evaluate these issues and plan the intervention more specifically.

Tools for the selection of an intervention area inlcude:

- The review of available data on water quality at different points and times, diarrhoea incidence, water supply, water quality, water consumption and treatment practices, climatic conditions, and household income
- Doing water quality tests to assess the extent of water contamination
- Surveys, expert consultations, focus group discussions or observations to assess factors relating to the applicability of the SODIS method, to patterns and habits of water collection, transport, storage and consumption, current HWTS use, as well as people's perceptions, attitudes, preferences, and needs.
- Expert consultation and community or group meetings for a qualitative participatory assessment of potential impact

Box 12: SODIS in disaster situations

- The availability of safe drinking water and the prevention of epidemics are key concerns in the aftermath of many natural disasters, including earthquakes, floods, or storms that destroy the water supply infrastructure. The focus of disaster response efforts often is on the centralized treatment and distribution of treated drinking water. In recent years, disaster relief agencies have evaluated the use of HWTS systems as a complementary strategy with varying success (Lantagne & Clasen 2012). Promotion of SODIS in the aftermath of a disaster may be less suitable than, e.g., chlorine tablets, for a number of reasons:
  - The capacities of local and external disaster relief agencies to conduct trainings on the correct application of a practice like SODIS is limited.
  - The people affected by a disaster have more urgent priorities than attending a SODIS training.
  - The logistics of distributing empty bottles are not favourable (refer to SODIS bags, chapter 2.3), especially compared to chemical disinfectants.
  - SODIS may not be applicable due to cloudy or rainy weather.
- However, the promotion of SODIS can be beneficial in the context of disaster preparedness programs. If people have been trained on how to use SODIS and do have access to PET bottles, they can start treating their water before relief activities reach them.


SODIS bottles in Bolivia

3.2.3 Development of a monitoring and evaluation scheme

An effective monitoring and evaluation scheme should be part of every SODIS/HWTS promotion project. This subchapter highlights specific SODIS-related parameters and indicators that can be integrated into a monitoring and evaluation-scheme. A standard scheme differentiates between outputs, outcome and impact parameters. Comprehensive guidelines on appropriate indicators and implementation aspects for the monitoring and evaluation of HWTS projects are provided in a toolkit developed by WHO and UNICEF (2012).

Output level

The main output monitoring parameters in SODIS projects are the number and coverage of promotion events, user trainings, follow up visits, the production and distribution of IEC materials and, if necessary, the establishment of bottle supply.

Outputs are typically monitored through records of field workers, and are cross-checked by supervisors and verified through (random) field visits. The quality of the training can be monitored by joining promoters during field work, and qualitatively assessing the know-how of randomly selected target households.

Outcome level

The outcome is defined as the immediate effects resulting from project activities. It can be monitored continuously, or evaluated at a specific point in time. The key outcome parameter for the success of a SODIS project is the level of consistent water treatment and the related rate of safe water consumption. Outcome data are typically analysed in relation to the situation at the beginning of the intervention (baseline data), and are typically generated from surveys, observations, or analysis of physical parameters (e.g., water quality).

If the promotion relies on regular visits, outcome data can be collected through monitoring forms used each time the promoter visits the users. Continuous outcome monitoring allows projects to identify challenges and adapt the promotion methodology during the course of the implementation. In small projects, data for project evaluation can be collected from all trained users. In larger projects, data are typically collected through surveys covering a random sample of the trained users (see Box 13). As for the output monitoring, data collected and reported by the promoters should be verified through spot checks by project supervisors or external partners mandated with project monitoring.

Safe water consumption depends on water treatment and consumption patterns, as well as on the effectiveness of the water treatment itself on the water quality. SODIS can only contribute to reducing infection risks if users exclusively consume safe drinks (correctly treated water, bottled water, tea, soft drinks, etc.). It is, therefore, important to also include indicators about the consumption of safe drinks to the monitoring and evaluation scheme.

The selection of indicators should be adapted to the data collection framework. Several simple indicators should be selected for regular monitoring, while multiple and more refined indicators are adequate for evaluations.

NGO member in Togo explaining transmission routes of diarrheal diseases

Box 13 – List of questions to assess outcome on household level

Consumption of safe drinks

The level of safe water consumption is difficult to assess. Direct questions on whether and how much raw water is consumed by the family members are likely to produce differing answers. A detailed account of all drinks consumed by the family members may produce a more accurate picture, but is also time consuming and, thus, more appropriate as part of an outcome survey than as parameters for the continuous monitoring framework. In spite of the expected bias, changes in self-reported raw water consumption can be used as a first approximation for project outcomes:

- Do some household members regularly/occasionally consume potentially contaminated water (e.g., untreated water from potentially unsafe sources or water stored with a risk of re-contamination)?

HWTS application

For most families, treated drinking water potentially constitutes an important share of their safe drinks. It is advisable to evaluate the uptake and use of all methods in an integrated manner using method-specific indicators. The most basic indicator is the use or non-use of a HWTS system for the treatment of water. Furthermore, it is relevant if the users have the capacity to meet the entire drinking water demand

- Is any method for water treatment used at the household? Which one(s)?
- How many litres of water are treated every day, using which HWTS method(s)? For consistent safe water consumption, the total volume of treated water must be sufficient for the number of people living in the household (at least 1-2 litres per person per day), taking into account other safe drinks consumed, and consumption outside the household, e.g., at school or at work.
- How is the treated water stored?

SODIS application

The correct and consistent use of SODIS should be assessed in more detail through a combination of indicators and observations, such as:

- Can the person in charge of drinking water supply correctly explain the application steps for SODIS -> colourless PET-bottles are exposed horizontally to the sun for at least 6 hours on a sunny day, or 2 days if the sky is mostly overcast, safe storage in bottles, etc.)?
- How frequently is SODIS practiced (-> daily, almost daily, occasionally, rarely) ? On which day was SODIS last done? On days when SODIS is not used, does the household use another method for drinking water treatment, and which one?
- How many SODIS bottles are exposed daily?
- Is there an adequate access (in terms of access, prize, type, quality) to bottles?

The credibility of the provided answers can be checked with observations, such as the following:

- How many bottles are exposed to the sun?
- How many bottles with treated water are stored?
- Are the bottles exposed to the sun correctly (-> no shade during entire day, colourless bottles, labels removed, clean and not heavily scratched bottles)?
- Do the bottles show signs of regular use (scratched and slightly milky surface due to regular solar exposure)?
- Does the household have a sufficient number of bottles? (enough to meet the drinking water demand of the household, plus to possibly store water treated the previous day)
- Is the water in the bottles warm (indicating that the bottles were exposed for some time before the visit)?
- Is the treated water stored safely? (If treated water is transferred to another container for storage, are precautions taken for safe storage -> container covered, withdrawal through a spigot, narrow mouth, or with a ladle)?
- The correct use of SODIS can also be assessed through water quality tests of the treated drinking water. Due to high costs and logistical challenges, water quality tests are typically employed in outcome evaluation studies among a sample of households rather than as an integrated element of monitoring frameworks. Note that positive test results can have other causes besides incorrect SODIS use (incomplete disinfection due to very high raw water contamination, re-contamination after treatment or during analysis).
- The different indicators for consistent SODIS use and safe water consumption can be aggregated into an index to classify households as 'regular' and 'irregular' SODIS users, or 'regular' or irregular' safe water consumers. For example, households may be counted as 'regular SODIS users' if the data indicate correct methodological know-how, sufficient number of bottles, and evidence of their regular use. A household can be considered a 'regular safe water consumer' household if monitoring data indicate that only water from safe sources, treated water, or other safe drinks are consumed.

Reasons for using/not using SODIS

The following questions can yield qualitative insight regarding the effectiveness of the deployed promotion tools:

- How did you learn about the SODIS method (e.g., household visits, radio campaigns, promotion through health professionals, street theatre, etc.)?
- For users: What convinced you to start using SODIS (knowledge about germs in the water, fear of disease, promoter's advice, doctor's advice, example of neighbours, etc.).
- For non-users: Why do you not practice SODIS, or treat your drinking water? (promotion not convincing, no time, neighbours also do not do it, doctor does not recommend it, government does not recommend it, not enough bottles available, etc.)

Hygiene application

Hygiene education is a component integrated in most HWTS promotion projects, and indicators for hygiene practices can also be included in the monitoring and evaluation. Specific indicators for hygiene practices and use of other HWTS methods are described in other manuals (UNICEF 2013). A more in-depth assessment of how the different promotion tools influenced behaviour change factors (e.g., based on the RANAS model) requires a more stringent methodology in terms of sample size, sampling procedure, formulation of questions, etc., and should be conducted by professional social scientists.

3.2.4 Impact evaluation

Impact refers to lasting changes of key target parameters (e.g., health, wealth) that are often difficult to accurately assess, and depend on a multitude of influencing factors. In SODIS projects, the main targeted impact are health benefits, i.e., a reduction of diarrhoea incidence or infection risk in the target community.

Self-reported diarrhoea incidence data can be collected through questionnaires or diarrhoea diaries in which households note the occurrence of diarrhoea each day for each family member. Children below the age of five are most vulnerable to infection with diarrhoea, and are, thus, often the focus of health impact studies. The recommended recall period for diarrhoea incidence are the 48 hours prior to the interview. If a longer reference period is chosen, interviewees are less likely to correctly remember diarrhoea incidences (Zafar et al. 2010). One particular challenge in health impact studies based on self-reported diarrhoea data is responder bias. Surveyed households in non-blinded studies tend to over-estimate the health impact either because they genuinely hold an overly positive view of the effects, or because they adjust their answer to what they think the interviewer wants to hear.

If reliable data on diarrhoea incidence is available, e.g., from health centres, these data can be used to document the health effects of the intervention. As seasonal and inter-year variations of diarrhoea incidence can be substantial, diarrhoea data from the intervention should be analysed relative to a control group not receiving intervention, but otherwise living in similar conditions. Measurements of anthropometric changes, such as weight for age or eventually height for age among children, is considered a more reliable indicator or health impact than self-reported diarrhoea incidence.

Assessing the magnitude of the health impact resulting from a SODIS or HWTS project is a non-trivial task that usually exceeds the capacity of implementing organizations (see chapter 3.1.3). In order to gain statistically significant results on health impact, the study design, sample and the data analysis need to meet scientific standards. Health impact studies should, thus, always be planned and implemented by experienced epidemiologists. Given the methodological challenges of health impact assessments and the fact that numerous scientific health impact studies for SODIS and HWTS interventions already exist, it is neither feasible nor necessary to conduct a health impact study in every SODIS promotion project.

Mother and child in Kenya

Box 14 Methodological aspects of monitoring and evaluation

The following sections provide some guidance on the collection of reliable monitoring and impact data and point to specific weaknesses often found in semi-scientific studies.

Reference data

- Outcome and health impact data must be evaluated relative to a reference. In longitudinal studies, the same indicators are assessed before and after an intervention in the target area. The data in the baseline survey must be of the same type and format as the data collected in the monitoring or end line evaluation. For new technologies like SODIS that have been introduced in a community by a project, detailed indicators regarding correct and consistent use obviously cannot be collected at baseline. If no comprehensive baseline study can be conducted, at least a basic set of household data (i.e., prevailing HWTS practices) should be recorded during the initial promotion at the group or household level. This approach is bias-prone, but still allows for a simple outcome evaluation.
- Alternatively, an outcome or impact can be evaluated through comparison with the same indicators assessed in a control group. Control groups need to be as similar to the intervention group as possible (e.g., with regard to age, ethnic background, education, income level, water source, etc.) but unaffected by the project intervention.

Random sampling

- If only a part of the entire target population can be included in the outcome evaluation, it is important to choose these households randomly in order to minimize selection bias. For example, households close to the main road are more likely to be included in the survey in a non-randomized selection procedure than households at the far end of the village, which could distort the results. One way to conduct a random sampling is to assign a number to each household and to use a random number generator for the selection. If this is not possible, walking transects (e.g., selecting every 5th household while walking along randomly selected roads in the target area) is a viable substitute method if it is assured that all households in the area have the same chance to be selected (Tamas et al. 2009).

Sample size

- If the sample size of an outcome or impact evaluation is too small, statistical analysis cannot determine whether the observed results actually reflect significant differences between the control and intervention groups (longitudinal studies: differences before/after the intervention) or could also be explained by chance (i.e., due to random selection among two populations with internal variance).
- For a non-scientific project evaluation, at least a hundred households should be covered in each intervention and control group. The minimal sample size required for statistical analysis depends on the expected frequency of the target parameter (e.g., safe water consumption, diarrhoea incidence). For health impact studies, several hundred or more households must be included so that at least a few dozen diarrhoea cases are recorded. The minimal sample size is larger if diarrhoea prevalence is low, and if a short recall period is applied (which is recommended).

Data collection

- In order to minimize responder and reporting bias, data should be collected by external and independent persons who the interviewees do not associate with the intervention. If data are collected by the promoters themselves, it is more likely that the interviewees exaggerate the effect of the project. For the same reason, questions that specifically relate to the promoted behaviour change (SODIS/HWTS) should be asked at the end of the questionnaire.
- A standardized data collection methodology - how questions are asked, observations made, answers recorded, etc. - has to be used consistently by all interviewers, which requires thorough training of the interviewers. Questionnaires must be pre-tested to make sure that the questions and the local language translations for terms, such as microorganisms, disinfection or diarrhoea, are understood by responders in the same way.

Statistical analysis

- Descriptive statistics are used to characterize the sample population and to summarize the data of the key target parameters. Typical descriptive indicators in health impact studies include percentages of different variables (e.g., HWTS users, diarrhoea cases, etc.) for the intervention and the control groups. For statistically significant conclusions regarding differences in diarrhoea incidence or infection risks between intervention and control groups, inferential statistics have to be applied using appropriate software and in-depth statistical expertise.

3.2.5 Definition of project scope

SODIS projects should not be conceptualized as a stand-alone intervention. Potential synergies with other programs and campaigns can be explored during the planning phase. If conditions vary widely across the project area, a segmentation of different target groups and a tailored promotion approach for each segment should be considered.

The most basic level of integration relates to different HWTS technologies, as opposed to single-technology promotion. An integrated HWTS promotion approach is strongly recommended, as a range of methods to choose from is more likely than a single technology to meet the needs, preferences, and needs of all the population in a given area, and result in a more consistent water treatment practice.

On a second level, HWTS promotion can be integrated with other interventions that also target a reduction of diarrheal disease. The rationale and the awareness component of HWTS promotion campaigns – i.e., information on diarrhoea causing pathogens and the barriers to their transmission routes – directly relate to the issues of personal and environmental hygiene, as well as sanitation. Promotion of hand washing can and should always be integrated with HWTS promotion. Vice versa, HWTS can be integrated as a component in ongoing or new hygiene and sanitation promotion programs. The potential synergies between public water supply programs and HWTS promotions are somewhat more difficult to address in practice. Water supply agencies may be hesitant to actively promote household water treatment because this implicitly means that public supply fails to achieve safe water consumption. Water supply agencies, thus, are more likely to support HWTS campaigns if the focus is on mitigating the problem of re-contamination at the household level, rather than source contamination.

On a third level, HWTS can be integrated within other health and development programs and campaigns, in particular with programs that already have a focus on behaviour change, i.e., maternal and child health, malaria, nutrition, etc.

While the integration of HWTS within other programs can help the HWTS promotion reach a large population faster, the trade-off is that the HWTS issues could get diluted among the other promoted messages, and the promotion intensity might not be high enough for an effective behaviour change to take root.

Box 15: Single-method vs. multi-barrier approach

- None of the common low-cost HWTS methods - except boiling – can effectively remove or inactivate all types of pathogens that can cause diarrhoea. Moreover, the effectiveness of most technologies is reduced for water with high turbidity. A multi-step approach consisting of pre-treatment, e.g., sedimentation, filtration, and disinfection, allows for a more effective removal of both turbidity and pathogens. However, each additional treatment step complicates the process and increases the time and labour demand and, therefore, is also likely to decrease user acceptance and uptake. Considering the limited and slow uptake for single-step HWTS technologies (e.g., boiling, chlorination, filters, SODIS, etc.) observed in many promotion projects, it seems unlikely that a multi-step treatment approach will be adopted at large scale. Advanced technologies that combine multiple treatment steps inside a single device ('multi-barrier systems') can be both highly effective and perceived as attractive and convenient by water users. To date, such integrated multibarrier systems' are typically more expensive than single step treatment systems, and are mostly marketed towards middle-class populations.
- Safe water storage to avoid secondary contamination after water collection and/or treatment is a practice that most households can easily improve on with already available resources and, hence, is probably a more promising target behaviour than combinations of treatment methods. Several HWTS methods also provide protection from recontamination (SODIS bottles, residual chlorine, and closed storage compartment of filters).
- To avoid project implementations that are too complex, a manageable number of HWTS methods can be pre-selected. The key criteria determining their selection are the potential of the method to meet the people's needs and preferences, affordability, and local availability of products. This should also allow for flexibility to expand the range of promoted methods if new products and/or financing mechanisms (e.g., micro-credits) become locally available.

Box 16: Pilot project vs. large scale promotion

- So far, most SODIS promotion projects were implemented in a 'pilot mode'. This means that the promotion approach was designed with the main purpose to establish the practice of water treatment using SODIS in a geographically limited target area. The same is true for most projects that promote other HWTS technologies, though the marketing of filters or of chlorine has expanded to a national scale in some countries (private sector and social marketing programs). The recommendation to boil drinking water has been promoted by national health authorities for decades.
- Both small and large scale promotion approaches offer specific advantages. Small scale projects typically allow for a high level of promotion intensity though interpersonal communication - considered to be very effective for successful behaviour change. Many SODIS projects have relied on paid 'SODIS promoters' to do trainings at the community, group and household level on information dissemination through IEC materials, and on regular household visits for follow up. In pilot projects, promotion tools can be tailored specifically for the local target population. At the same time, a new practice like SODIS may be viewed rather sceptically if it is only promoted at pilot scale, i.e., when the target households realize that the practice is neither widely known, nor used by people outside the project area, and is not actively promoted by influential institutions, e.g., the Ministry of Health or the water supply agencies.
- Large scale health campaigns are typically coordinated by national health authorities. National health campaigns often have fewer financial resources per target family compared to pilot projects, but have privileged access to existing institutions for the promotion activities, e.g., the education and health extension system or mass media. Messages endorsed by the government and transmitted through these channels have high credibility and potentially impact societal norms more effectively than small NGO projects. The downside is that the promotion intensity may not be very high if HWTS is merely integrated in the curriculum of teachers or health workers and risks to be marginalized among all the other educational messages which they are expected to transmit.
- For example, SODIS use at the end of pilot projects in Pakistan relying on paid promoters was around 50%. When SODIS was promoted at the district level as one additional message in the curriculum by "Lady Health Workers" working for a national health program , uptake was only 5-10% - though at a much larger scale.

3.2.6 Assessment of bottle supply

The existence of functional and sustainable supply chains is not a dominant constraint to the application of SODIS in many locations. In most urban and peri-urban settings, used PET bottles are widely available, and are often also collected for recycling. In many rural areas, empty bottles are available, but are considered a valuable resource that can be used for different purposes in households, and are sold in local markets at a price of around 2-20 US$ cents per bottle. Wherever possible, water users should be advised and motivated to collect or buy bottles for SODIS use from existing sources. In some rural and remote areas, however, PET bottles may not be available in the quantities required for consistent SODIS use. In these areas, the promotion of SODIS is not recommended unless effective measures can be adopted to strengthen the bottle supply. The present bottle availability and the potential to strengthen the bottle supply should be carefully evaluated before initiating a SODIS promotion program. The design of a sustainable bottle supply system must be based on a thorough and realistic assessment of both the availability of bottles in sufficient quantities from potential sources, such as local shops, hotels or restaurants, and the viability of possible distribution channels. In particular, project planners must be careful to not overestimate the willingness of SODIS promoters or local entrepreneurs to collect and sell bottles unless they can receive an adequate profit.

Pilot projects that have strengthened bottle availability for SODIS have yielded the following insights:

- Free distribution of bottles is not conducive to the sustainable practice of SODIS. Though free distribution often results in a high initial adoption rate, it also creates dependency and expectation for a continued bottle supply, preventing water users from developing their own strategies to find and collect enough bottles. Once free distribution stops, most former SODIS users are likely to abandon the practice. Free or highly subsidized distribution of bottles is also not recommended because it distorts people's perception of the value and cost of PET bottles, which can negatively affect their willingness to invest their own resources to have PET bottles and their motivation to use a 'cheap' product for water treatment.

- There is only little room - if any - for the generation of sufficient profits from the sale of empty bottles as an economically viable entrepreneurial activity to sustain the bottle supply. Their bulky volume makes the transport of PET bottles logistically challenging and expensive, and people's willingness to pay for empty bottles limits the potential sales price and related profit margins. Bottle supply schemes that are financially or logistically dependent on the project and the implementing organization are likely to collapse after the support ends.

- In some cases, the sales or distribution of bottles through the project created the wrong impression among the target population that these bottles had special properties which make them particularly effective for SODIS. If people fail to realize that other locally available PET bottles are also suitable for SODIS, they are likely to abandon the practice when the bottle supply stops.

- Most bottle supply systems established in rural areas as part of SODIS promotion projects did not last in the long run. The low cost of a PET bottle and the low willingness to pay for empty bottles made it impossible to generate income sufficient to cover the collection, transport and distribution expenses, and to render bottle sales as an attractive long-term business opportunity for local entrepreneurs.

In the absence of a viable bottle supply scheme, only the most committed households in remote areas usually invest the efforts and resources necessary to source the required amount of bottles (e.g., organizing transport through visitors from urban centres, purchasing soft drinks in suitable bottles for subsequent SODIS use). Unfortunately, the local availability and affordability of products is also typically limiting for other HWTS methods (chemical disinfectant, filters, etc.) in remote areas. A pragmatic HWTS strategy for remote areas is, thus, to focus on the promotion of HWTS technologies for which sustainable supply systems can be established (products that are affordable and easy to transport, and which generate reasonable profits), and to reinforce safe storage and already known, but inconsistently practiced, water treatment methods (e.g., boiling). SODIS can be promoted as an option if at least part of the population can source bottles on their own.

Given limited global success in the promotion of low tech HWTS methods (SODIS, chlorination, ceramic filters, etc.) through behaviour change campaigns, some experts believe that a breakthrough towards large scale HWTS adoption will more likely be achieved through the marketing of new and attractive commercial HWTS products by the private sector. Commercial HWTS devices are successfully marketed in middle-income segments of the population in many countries. New financing mechanisms, e.g., micro-credit schemes, are increasingly applied to make HWTS technologies affordable also to the lower income segments of the population. The incentive for the private sector to engage in the promotion of SODIS is limited by the low potential profit margins that can be derived from the sales of empty PET bottles. Advanced SODIS systems that are being developed - such as SODIS bags, UV indicators, or reactor systems (see chapter 2.3) – are potentially more attractive to private enterprises as they could yield higher profits that would sustain the promotional activities.

Box 17: Bottle supply schemes applied in SODIS promotion projects:

- Collection of bottles from urban centres, hotels/restaurants/party-venues, etc., by promoters, paid bottles collectors or other local institutions.
- Bulk purchase of new bottles from bottle manufacturers.
- Distribution/sale to SODIS users
- Free distribution by promoters and health centres (not recommended)
- Direct sales with a profit margin through promoters and health workers
- Retail sales with a profit margin through local shops, health centres, etc.

3.2.7 Creation of an enabling environment

The enabling environment is a key determinant for successful project interventions. The following six elements that define the enabling environment and that need to be pro-actively fostered are:

1. Socio-cultural Acceptance
2. Legal and Regulatory Framework
3. Institutional Arrangements
4. Financial Arrangements
5. Government Support
6. Skills and Capacity

Most of the elements critical to support an enabling environment should be identified or become evident during the planning process (for a more detailed definition, see Eawag-Sandec/WSSCC/UN-HABITAT (2011)). Some elements of the enabling environment can be influenced by local level stakeholders and institutions, while aspects at higher levels, such as national policies, are more difficult to influence. The following activities are recommended to increase the likelihood of successful implementation:

- Make sure that the promoted methods and the promotion activities conform with the applicable legal and regulatory frameworks.
- Establish a solid evidence base and documentation to justify the promotion of HWTS. This includes information on water quality and diarrheal disease - including water quality tests from local water sources and household storage containers.
- Establish contacts with local authorities, political, and health professionals, and religious and informal leaders, and convince them of the benefits of HWTS for the local population. Gain their formal or informal endorsement and/or active support. Relevant government agencies should be consulted at the appropriate level (local, district, province, national) before starting a project. This may include the agencies responsible for water supply and sanitation, health, development, housing, poverty alleviation, and education.
- Identify potential opposition to the promotion of HWTS, e.g., private entrepreneurs selling bottled water or other HWTS products who may fear lower profits, or public water suppliers who react defensively against the inherent criticism of existing water supplies. Try to convince them that the goal of the project is universal safe water consumption, and that public supply, private sector and HWTS promotion can play complementary roles towards this end, with low tech HWTS being an intermediary solution.
- Make sure the prerequisites for a rapid uptake are in place when the promotion starts. This particularly applies to the local availability of SODIS bottles, or other HWTS products, respectively. If measures to strengthen supply chains are planned as part of the project, this activity should be launched ahead of the main behaviour change campaign. Promoting the use of a method or product that is not available to people is a futile exercise.
- In many countries, comprehensive national HWTS strategies are under discussion. In order to support this process, organizations implementing SODIS/HWTS projects are encouraged to engage in advocacy activities, which can include:
- Active participation in WASH expert meetings and HWTS working groups
- Sharing of experiences and results from projects with relevant stakeholders, particularly with government water and health authorities
- Active lobbying for the integration of HWTS in the activities of organizations having national outreach
- Contributions to the integration of HWTS in the activities of other organizations: e.g., during the formulation of a strategy and or of regulations, capacity building, coordination among different institutions, design and co-funding of HWTS programs, and integration of a HWTS component in existing programs.
- Establishment of partnerships with like-minded organizations to enhance the scope and scale of HWTS projects
- Share the experience of the project through media channels to generate broad awareness
- Seek or facilitate collaboration with academic institutions to broaden the evidence base of HWTS

In order to pro-actively foster the activities of an enabling environment, sufficient resources in terms of budget and personnel need to be earmarked in the planning phase. Successful activities may require the active and continuous involvement of high level representative of the organization, as lower level project staff may not have the necessary access to key stakeholders.

SODIS bottles in Togo

3.3 Addressing behaviour change factors

SODIS and HWTS campaigns are considered to be most effective if they address the behaviour change process holistically and employ a combination of promotion tools addressing the following factors: risk, attitude, norm, ability and self-regulation. This subchapter shows how these factors can be addressed. Tools that have been effective in past SODIS projects are highlighted in the next subchapter.

3.3.1 Addressing risk factors

Despite the heavy toll in terms of mortality and morbidity, diarrhoea is often not recognized as a preventable disease among the most vulnerable populations of low-income countries. Without the knowledge about disease vectors and infection routes, and without the means to adopt preventive measures, communities have learned to accept diarrhoea as a part of life, or as fate. WASH programs and the promotion of boiling by health authorities have increased people's understanding about the causes and effects of diarrheal disease, but low awareness continues to be a limiting factor to behaviour change in many places. The insight that HWTS use is typically highest among the more educated people confirms the critical importance of awareness. As the with the results of many health programs (e.g., anti-smoking campaigns) show, disseminating information about health risks is often not sufficient to trigger a rapid and far-reaching behaviour change.

As a driver of behaviour change, the fear of the harmful health effects from a certain behaviour is most effective if these effects are grave, likely, immediate, and linked to the behaviour through simple cause-effect relationships (e.g., drunk driving or ingestion of poisonous substances). Health threats are less deterring if the health effects are mild, uncertain, occur in the far future, or if the link between behaviour and effect is complex or stochastic (e.g., cancer). As diarrhoea is mostly non-fatal for adults, fear of pathogens in drinking water may not be powerful enough to change people's behaviour – while for families with small children, the fear of infection from potentially fatal diseases can act as a very potent motivation.

Although the fear of diarrheal disease may not be the most important driver of behaviour change in many cases, information about diarrhoea causing pathogens and the different transmission routes should feature as one element of a SODIS promotion campaign. Practices to block pathogen transmission routes other than HWTS – i.e., personal and environmental hygiene or improved sanitation - should at least be mentioned, or can be promoted prominently as integral parts of the campaign, depending on the defined scope of the project and available resources.

The concept of the preventability of diarrheal disease is comparatively easy to understand, when based on the information about germs and transmission routes. This is even the case with people who have the long standing perception that diarrhoea is a normal part of life. The same is true for the severity of diarrhoea disease. Most people have experienced diarrhoea first hand, and can understand the serious health effects that the disease can have, especially on infants.

In contrast, it is difficult to communicate information about infection risk for different reasons. Firstly, it is typically not possible to assess the infection risk due to drinking water contamination for the target population in absolute terms, nor relative to other transmission routes. Secondly, personal experiences may seemingly contradict objective risks: a person can consume untreated water for months without any health problems, but suffer from diarrhoea – e.g., from pathogens being transmitted through contaminated food - shortly after adopting the practice of drinking water treatment. A SODIS campaign should, therefore, avoid raising unrealistic expectations by suggesting that diarrhoea infections can be completely prevented by HWTS, but instead transmit the message that infection risks can be significantly reduced if the practice is consistently applied.

The consumption of treated water can effectively prevent infection from diarrhoea disease, but only if the level of safe water consumption is consistently high. Brown and Clasen (2012) concluded that a reduction from 100% to 90% in safe water consumption would decrease its protection from infection by up to 96% based on a theoretical model of infection risks. Therefore, it is extremely important to stress the importance of consistent safe water consumption in promotion campaigns and to integrate this point among the key promotion messages, e.g., in training curricula and on IEC materials. Especially for the most vulnerable household members, i.e. young children or people with compromised immune systems, zero-tolerance of the consumption of unsafe drinks (including untreated water) should be propagated. The level of consistent safe water consumption should also be integrated as a monitoring parameter.

Box 18: Addressing risk factors

Target behaviour

- People drink exclusively safe water.

Promotion target

- The targeted population should know that the consumption of contaminated water puts them at risk of infection from diarrheal disease (perceived vulnerability), should know that diarrheal disease can have severe consequences, such as suffering, absence from school or work, medical expenses and may cause death (perceived severity), and should know that diarrheal disease is transmitted by germs of faecal origin (factual knowledge).

Potential promotion components

- Household visits by promoters (e.g., with information flyers)
- Training event for the community (e.g., through street theatre)
- Mass media campaign via local radio or national TV (e.g., interviews with experts, statements of celebrities, etc.)

3.3.2 Addressing attitude factors

Numerous examples show that health programs that focus only on risks and adverse health effects may be less effective than campaigns that portray the target behaviour as a desirable and overall beneficial practice. Examples of health campaigns in which positive persuasive messages were employed – instead of or along with deterring messages focusing on health threats - include non-smoking, healthy diet, physical exercise, dental hygiene, or hand washing.

Generally, promotion tools for SODIS should focus not only on prevention of the adverse effects of diarrheal disease, but should frame safe water consumption as part of a happier, modern, more healthy lifestyle. If a campaign can associate safe water consumption – or the use of SODIS - with positive notions, such as happiness, empowerment, financial savings, and gain of social status, positive attitudes are created that are conducive to behaviour change. The availability and consumption of safe drinking water becomes desirable in its own right, with health benefits being only one of several underlying motivations.

Positive attitudes can be constituted both at the rational (instrumental beliefs) and emotional (affective beliefs) level. At the rational level, a SODIS promotion project should create awareness about the tangible benefits of SODIS, including:

- Improved water quality and health
- Empowerment of mothers to control factors that impact family health
- Reduced absence from school and work
- Financial savings (increased productivity, reduced treatment costs, and reduced treatment costs compared to the boiling or purchase of bottled water)
- Time savings (relative to boiling)
- Social status gain from having safe water in the household for themselves and visitors
- The better taste of water (compared to boiled and chlorinated water)

The conclusion that the benefits outweigh the investment, despite the investment required to collect bottles and daily labour input, constitutes the rational component in the intentions of water users to try out this new practice.

Instead of simply focusing on rational arguments, promotional tools can also be designed specifically to strengthen positive affective beliefs in the target population. This relates to the tone of inter-personal communication, the formulation of the campaign slogan ("SODIS for happy families" instead of "SODIS to prevent disease"), the design of posters, etc. Generally, it is easier to create positive emotional associations for a modern looking high-tech water treatment device than for a low-tech system like SODIS, boiling or chlorination. Low-cost technologies are even at risk of being perceived negatively if their use is associated with poverty and with the inability to purchase a more sophisticated technology. For SODIS, the use of a waste product (empty bottles) may be a stigma in some locations and may have to be actively countered with messages to improve the method's reputation . If water users expect to lose rather than gain social status from adopting SODIS, they might decide against it even if they believe in its positive effects in terms of water quality and health.

The most important advantages of SODIS– the simplicity and use of a widely available inexpensive 'waste' product – can also work as a disadvantage unless a positive emotional association with SODIS use is established. If several HWTS methods are promoted in parallel, it may be necessary to put special emphasis on creating positive attitudes for each individual technology. Failing that, only the most attractive option(s) may be considered viable by the target households even though they may not be affordable or locally available, leaving the potential of other methods untapped.

Box 19: Addressing attitude factors

Target behaviour
- People drink exclusively safe water.

Promotion target
- The targeted population should believe that water treatment will result in the improved health of family members and that the costs and labour inputs are worthwhile (instrumental beliefs), and should feel positive about consuming treated water and providing treated water to family members (affective beliefs).

Potential promotional components
- Involvement of celebrities in the promotion campaign
- Painting of murals in the community
- Distribution of IEC materials and key messages via social media

3.3.3 Addressing norm factors

Very few people base their intentions to adopt a new behaviour solely on the rational weighing of costs and benefits, or due to their affective beliefs. Most people look to other members in their community and are influenced by their example, advice, and by what they think others expect them to do. A water user may be more easily convinced to adopt a HWTS method if it is already widely practiced in the community (descriptive norm) and recommended/endorsed by local authorities and important peers (injunctive norm). In addition, most people have a sense of what is 'the right thing to do' (personal norm) that may or may not differ from societal norms.

For projects introducing a new HWTS technology, it is crucial to inform and persuade local leaders and influential figures in order to secure their endorsement, and possibly their active involvement in the promotion. The same is true for practices that are already known but not widely adopted, such as boiling water or hand washing. Influential figures can include political and religious leaders, teachers, local doctors, nurses, or community health workers. With the support of these opinion leaders, a project is more likely to trigger a favourable social dynamic, resulting in universal adoption and sustained use of the practice. Local opinion leaders should be involved in the early preparatory steps, i.e. before the start of the promotion at the household level. Note that it is often easier to secure the endorsement and support of health professionals than of the authorities in charge of water supply, because for them the promotion of HWTS means admitting that the public supply is not safe. The promotion of SODIS through schools or mass media channels also contributes to strengthening norms and a common perception of SODIS as a mainstream practice.

Once promotion is ongoing and the first households have started using SODIS, the project should aim at increasing the visibility of the early adopters and capitalize on their experience to convince other households to change their behaviour. Visibility can be enhanced, e.g., by asking SODIS user households to display stickers outside of their homes. Interactions between users and non-users can be actively supported to trigger a self-reinforcing social dynamic towards widespread SODIS use. If the promotion fails to establish a solid base of SODIS users relatively fast, and if early adopters are seen relapsing towards raw water consumption, it can become very difficult to convince the more hesitant water users to adopt SODIS use.

People's perception of whether SODIS is – or could become - a mainstream practice also depends on the extent to which these practices are promoted at a larger scale, e.g., through national level policy campaigns or as part of the curriculum in schools and health programs. If SODIS is promoted only in small pilot areas, the fact that friends and relatives in neighbouring areas are not aware of the method can potentially limit the trust of people in the method. Promotion through mass media also strengthen the perception of SODIS/HWTS as a trustworthy practice. National policies and programs are often beyond the control of organizations implementing SODIS projects, however, and the integration of HWTS promotion at the national level is commonly a long term goal. In some cases, it may be possible to leverage the support of national authorities for pilot projects that establish norms, e.g., by asking permission to conduct promotional activities through health centres or schools, and/or to use government logos on IEC materials.

3.3.4 Addressing ability factors

Educating the people on how to apply the SODIS method correctly and sustainably, i.e., the transfer of action knowledge, is a key component of every SODIS promotion campaign. Although the application procedures for SODIS - as for most other HWTS methods - are relatively simple, there is still considerable room for misunderstanding that can result in incorrect use. Targeted water users must be able to correctly perform all the steps of the SODIS method. Furthermore, they must be aware of the conditions that potentially limit the effectiveness of SODIS (e.g., cloudy or rainy weather, high water turbidity, and scratched bottles), and must know how to mitigate these challenges in order to achieve satisfactory results. The promotion must also assist targeted water users in developing strategies on how to deal with the potential challenges to the long term application of SODIS (see chapter 3.3.5).

Successful transfer of know-how regarding the correct application of SODIS is more likely if communication employs different promotion tools (oral, visual, hands-on training, etc.), and is repeated at different points in time. SODIS communication channels are similar to those promoting sensitization about diarrheal disease and transmission routes: group trainings, household visits, street theatre, written materials, and/or mass media. Practical demonstrations of the SODIS methods should be part of group or household trainings. Household visits offer the opportunity for promoters to answer queries, correct mistakes, provide advice on specific challenges, and to discuss strategies on how to sustain the practice and avoid relapses (see also chapter 3.3.5) For the sustained use of SODIS, it is important that the promotion strengthens people's self-efficacy, i.e., their confidence and ability to overcome challenges that may prevent them from applying SODIS. These challenges may apply to entire communities (e.g., bottle supply), in which case they should be addressed during community trainings. Challenges that are very specific to individual households (e.g., access to suitable places for bottle exposure) are best addressed during household visits.

Box 20: Addressing norm factors

Target behaviour
- People drink exclusively safe water.

Promotion target
- The targeted population should perceive water treatment as a mainstream practice (descriptive norms), should perceive water treatment as a practice that is approved and viewed favourably (injunctive norms) and think of water treatment as the right thing to do (personal norm).

Potential promotion components
- SODIS-stickers placed outside of the homes of SODIS-users
- Training events at schools
- Endorsement of respected opinion leaders
- Establishing a 'safe water zone', i.e., declaring an area a safe water zone once a threshold of safe water households are recorded (e.g., 80%).

Box 21: Addressing ability factors

Target behaviour
- People drink exclusively safe water.

Promotion target
- The targeted population should know the correct application for water treatment (action knowledge), should know how they can successfully deal with barriers that arise during the maintenance of the behaviour (maintenance self-efficacy) and should know how they can successfully recover from setbacks and failure (recovery self-efficacy).

Potential promotion components
- Community or group trainings, including practical demonstrations
- Household visits by promoters, including practical demonstrations
- Written IEC materials with application guidelines, e.g., for distribution to households or for display in the community

3.3.5 Addressing self-regulation factors

Addressing people's awareness, motivation, and ability to use SODIS is expected to translate into an initial uptake of the practice in a community. This does not mean, however, that the project has already succeeded in establishing sustainable behaviour change. New habits are formed through regular practice over several weeks or months, and the risk of relapsing to old habits persists even after that. The following subchapters describe approaches and tools that help to transform the new practice of water treatment into a sustainable habit and prevent relapsing to the consumption of raw water.

Planning routine and coping activities

Many people are quick to make room in their daily routines for a newly advertised technology or practice in the short term. This applies to the use of a new household water treatment method or to putting new running shoes to the test. However, as the practice loses novelty and excitement, it risks being marginalized in relation to the former older routine activities. Relapse is all the more likely if the new practice is time-consuming and tedious. For this reason, forming the habit of regular SODIS use may be even more challenging than achieving the sustained use of a filter, considering the multiple routine tasks that are required (periodic collection of bottles, daily filling and exposure at least six hours waiting period, possibly cooling of water, etc.).

In order to prevent relapsing from the consistent application of SODIS, potential priority conflicts with other activities should be permanently resolved. While some households find it easy to integrate SODIS in their daily activities, others may need external support and advice. SODIS/HWTS promotion programs should be prepared to provide this kind of support. Concretely, this means discussing the daily household routine with the person in charge of drinking water, and assigning responsibilities and time slots for each task. Advice on how to integrate SODIS/HWTS into household routines must relate to the individual situations of each household, and promoting a participatory approach is essential. General suggestions can be provided during community and group trainings. Stimulating interactions between households to share experiences and best practices is another approach. It can be useful to write down the outcomes of these discussions, i.e., the individual solutions in each household, to help water users better remember the plan.

Ideally, routine activities and coping strategies can be implemented by household members themselves without relying on external support. Collective solutions, e.g., households supporting each other with bottle supply or surveillance of exposed bottles can be considered to mitigate certain challenges, but such arrangements are often fragile and prone to failure if one of the involved parties does not do his/her assigned role for some reason.

Remembering and reminders

In order for a practice to become a routine habit, it is important that people remember the behaviour, particularly at the specific time when it has to be performed. Remembering is especially important in the early stages of the habit formation process, and when the practice is interrupted for some reason, e.g., during rainy periods in the case of SODIS.

Different strategies can be employed to support remembering in the target households. One key task for promoters during follow-up visits to households is to remind people to apply and to practice the water treatment and/or safe storage. Printed materials distributed to households as prompts - e.g., stickers or posters put on display in the place where water treatment is done – can positively impact the habit formation process. Such prompts are more likely to be used and to remain visible in households if they are integrated around other useful things, i.e., a calendar. Reminders such as banner or posters can also be distributed for display in the community at strategic locations. Another channel to disseminate reminders is mass media, i.e. radio and TV programs. School promotion can support remembering if children learn about SODIS/HWTS and remind their parents back home about the practice.

Commitment

People are more likely to follow through with a behaviour change if they consciously commit to do so. This can be a private commitment, a declaration made to friends or family members, or a public pledge. The promotion can try to motivate the people to make a commitment and to communicate it to others. Promoters can ask people directly if they are willing to treat their drinking water (applying caution not to pressure them into making false commitments), and invite them to share their commitment with others, either bilaterally or during group meetings. This declaration can be formalized as a public pledge or by signing a written declaration of intent. Stickers or posters put up outside the house or compound also represent the commitment of the household and can, as such, reinforce their motivation to keep up the behaviour.

Institutionalization

The experience from SODIS promotion as with other health-related behaviour change, campaigns is that sustainable habit formation depends on a long-term promotion effort. Any SODIS or HWTS project should, thus, adopt strategies aimed at institutionalising the promotion activities (both in terms of education and product availability) beyond the actual project period. In the long term, central governments are expected to play a large role in HWTS promotion through national programs. In individual projects, institutionalisation mainly relies on local institutions. Local health centres or community health workers, schools, self-help groups, etc., can continue education activities if they have been properly trained and equipped with the necessary materials (e.g., manuals and promotion guidelines). Newly formed local groups for the specific purpose of HWTS promotion, e.g., HWTS committees, are at a high risk of disintegrating without project support compared to pre-existing institutions. Supply chains for required HWTS products (including consumables and spare parts) are preferably transferred to private entrepreneurs on a commercial basis. For the

Pupil in Bolivia explaining different water treatment methods

successful institutionalisation of subsidised business models, the long-term availability of funds for subsidies must secured.

Efforts to achieve institutionalization can be started early in the project cycle, though the local institutions may want to see that HWTS promotion is effective before they commit to engaging in such projects in the long run. Institutionalization should be a main focus of phasing-out activities towards the end of a project.

Box 21: Questions to address self-regulating factors for SODIS application

The following issues should be addressed:

- When and how do we collect bottles? Who is responsible?
- Which person is in charge of filling, placing, and – if necessary - watching over the bottles?
- At what time, after and before what other activities, do we fill and expose the bottles?
- Which water do we use for SODIS? Water from a source, or household storage?
- Where in the household do we fill the bottles, using what equipment?
- Where do we expose the bottles to the sun? Is there a risk that the bottles could be tampered with while we are away, and how can this be prevented?
- Do bottles need to be moved during the day to receive enough sunlight? Who is responsible?
- How do I ensure that the required exposure time is adhered to, i.e., that water is not consumed too early in the day by some family members?
- Where do I store the treated water? In the bottles themselves? Do I need a second set of bottles for exposure for the next day? Or in a storage container? How do I keep it clean and prevent re-contamination?

Furthermore, potential challenges and barriers to the application of SODIS that may arise should be discussed, e.g.:

- What other activities could conflict with the application of SODIS? What can be done to resolve these conflicts?
- Who applies SODIS when the person in charge is (temporarily) unavailable?
- What adaptations are needed when the weather is cloudy and the bottles need to be exposed for two consecutive days (e.g., use of another HWTS method)?
- What alternative methods can I use if SODIS is not applicable for some reason, or if the volume of safe water is insufficient to meet the demand?
- What options do I have in case the regular source of new bottles becomes inaccessible?

Box: 22 Addressing self-regulation factors

Target behaviour

- People drink exclusively safe water.

Promotion target

- The targeted population should have a clear understanding of where, when and how to treat water (action control/planning), should be aware about potential barriers to the application and know strategies to overcome them (coping planning), should regularly be reminded to treat water before consumption (remembering) and should commit publicly or privately to treat water consistently (commitment).

Potential promotion components

- Household visits with structured discussions to plan routine activities and protocols of the coping strategies
- Follow-up community trainings
- Prompts for the households or for display in the community (e.g.,: sticker, poster, calendar)
- Statements of intent made in front of promoters or friends/neighbours

3.4 Recommendations for the promotion

This manual does not prescribe a specific one-size-fits-all approach for the promotion of SODIS but rather provides a series of recommendations that have been effective in past SODIS projects.

3.4.1 Use multiple promotion channels

The use of multiple promotion channels will reach more members of the target population, and allow the promoted messages to be conveyed from different angles.

The promotion channels used in previous SODIS projects can be grouped into the following four categories:

- Individual visit or meeting: This promotion channel is mainly used during household visits and during meetings with local opinion leaders, such as doctors, political leaders, religious leaders or entrepreneurs in the health sector.
- Training or information events: This channel is ideal to reach a specific group within a community, such as women groups, teachers or members of an association.
- Traditional mass medias: Television, radio and print media are mostly used to complement the personal promotion channel and reach a wide range of users.
- Internet: The Internet is mainly used to provide information on the web and to interact with target groups via social media.

Implementing agencies are encouraged to evaluate and select a suitable set of channels according to the target groups, the local context, the duration of the intervention, as well the financial and personal capacity.

3.4.2 Engage community promoters

In most SODIS promotion projects supported by Eawag, community promoters played a crucial role in the training and follow up of water users. They can address all key factors influencing behaviour change by organizing trainings, engaging local authorities, and regularly visiting individual households. Effective promoters enjoy respect and credibility in the community and can get easy access to the people in charge of drinking water inside households (usually women). The level of motivation and enthusiasm to serve the community is a key criterion in the recruitment of promoters. These criteria often apply to people who had been previously enrolled in community training or outreach projects, or people who occupy influential positions in the target area (community health workers, staff of health centres, and self-help group leaders).

Studies show that inter-personal communication is often the most effective promotion tool, and that the effectiveness critically depends on the rapport between the promoters and the target population.

3.4.3 Integrate water quality tests to the promotion campaign

Water quality tests to demonstrate the contamination of drinking water before and after treatment are a powerful persuasive promotional tool. Tests at source or at the household storage level raise awareness about the presence of germs in the water and can inform about related health risks. Test results showing zero contamination after SODIS treatment strengthen beliefs that the method works effectively and yields the benefits associated with safe drinking water consumption. Water quality tests as a tool to influence attitudes (instrumental as well as affective beliefs) are most effective if they are performed and interpreted in the presence of the water users so that they can see the results with their own eyes.

The number and frequency of water quality tests in a SODIS/HWTS promotion project is typically limited by cost and the demand for skilled labour. Water quality tests can be conducted either through field test methods or at a local lab. There are two different types of faecal pathogen tests:

- quantitative methods indicating the concentration of either pathogens or indicator organisms in the water
- presence/absence tests showing a positive result if any number of pathogens or indicator organisms above a (very low) threshold concentration are present in the water.

The most common example of presence/absence tests are H2S vials that are filled with water and indicate contamination through a colour change. Presence/absence tests are less expensive and easier to process than quantitative tests, but cannot show differences in contamination levels. Presence/absence tests also do not evaluate and prioritize sources with different contamination levels. Furthermore, they fail to demonstrate a substantial improvement in water quality if a few indicator organisms survive the treatment process and produce a positive result. Water quality tests that indicate contamination for both untreated and treated water – even if pathogen concentrations were in fact substantially reduced – will negatively affect people's belief in the treatment method and their motivation to adopt it. Quantitative tests provide a more differentiated picture of varying contamination levels. Quantitative test methods include membrane filtration for coliform counts and most probable number methods and typically require more costly materials and labour inputs (including possibly a filtration step to detect pathogens in low concentrations) compared to presence/absence tests.

Most common field testing methods require an incubation period of at least 24 hours. The gap between sampling and results somewhat limits the persuasive effect of water quality testing, and project staff may need to go to the field site twice to conduct the test and present the results. Field test materials, including vials and plates, can remain with the water users during the incubation period. However, qualified personnel is needed to interpret and discuss the results and to safely dispose of the materials.

The volume of water used in different analytical methods determines the reliability of test results. Test methods using small sample volumes (e.g., 1ml) cannot produce reliable results in the low concentration range, especially for concentrations below 100

CFU/100ml) . Processing larger water samples - e.g., filtering 100ml samples for the subsequent detection of coliforms on the filter paper - is often a time-demanding and error-prone step, and requires additional material and skilled labour.

Due to their costs and demand for skilled labour, water quality tests are usually employed at specific times - e.g., to establish an evidence base to persuade local opinion makers before the start of a promotion campaign, at community trainings, or at a limited number of households - rather than as a regular activity in all households.

Examples of water quality test methods are:

- Local lab: mostly membrane filtration or most probable number method, multi-parameter analysis if required, usually expensive (> 5USD per test)
- Field test kits for quantitative tests (e.g., Delaqua, Hach): prices typically > 1000 USD, heavy if including a battery powered incubator
- Disposable plates and trays for quantitative tests: e.g., 3M Petrifilms, Compact Dry plates, IDDEXX Quanty-Tray : cost typically 1-2 USD per test, and may require additional materials that complicate field testing (filtration unit of 100ml samples, and an incubator if ambient temperature is not high enough)
- Vials for presence/absence tests: e.g., H2S vials - their cost can be <1 USD per test

Water quality tests in Guinea

3.4.4 Develop comprehensive and attractive IEC materials

Information, Education and Communication (IEC) materials used in behaviour change programs should be attractive, adapted to the local context, designed specifically to influence one or several specific behaviour change factors.

There is a wide range of IEC materials that can be used in a promotion campaign, such print-materials (e.g., stickers, leaflets, posters, handbooks, manuals), paintings (e.g., murals), audio-material (e.g., radio ads) or video-material (e.g., TV ads).

A comprehensive IEC strategy defines a series of parameters and design features for all the materials. Materials used in the training of trainers or distributed to promoters for their own reference are typically more detailed and technical, while materials distributed to target households or displayed in public places typically concentrate on simple, clear, factual or emotional messages. Examples for promotion materials used in SODIS promotion projects are available on the SODIS webpage: www.sodis.ch.

Box 24:: Examples of key messages addressing different risk factors:

- "Diarrhoea is severe, but is a preventable disease!" (risk factor)
- "Safe water is good for you!" (attitudinal factor)
- "Everyone in the community drinks safe water!" (norm factor)

Box 25: Parameters and design features of IEC materials

For all IEC materials, the following parameters should be defined:

- Type (poster, leaflet, sticker, radio spot, puppet theatre, etc.)
- Purpose, i.e., which behaviour change factor will be addressed (multiple purposes possible)
- Target audience
- Main message
- Content
- Format
- Distribution channel
- Number of copies

To maximize the effectiveness of IEC materials, the following design features should be applied:

- Adapted to the purpose
- Adapted for the target audience (e.g., adults, children, illiterates, decision makers, etc.)
- Adapted to local contexts (i.e., in terms of language, appearance of people in illustrations, and cultural sensitivities)
- Clear and catchy key message
- Aesthetic and attractive design
- Simple where possible (not too much text), comprehensive where necessary (e.g., user instructions must be complete)

Wall painting in India

3.4.5 Promote an integrated HWTS approach

An integrated HWTS approach enables water users to make informed choices among a range of technology options about what more effectively addresses the diverse needs, capacities, and preferences of water users.

Therefore, promoting several methods is challenging and may overwhelm the target water users. The following strategies can be applied:

- Avoid overloading target water users with technical details during the first promotion event, focus on the importance of safe drinking water and the existence of technological solutions.
- Make sure that people can easily access detailed information about the different technologies after the promotion, both to support their selection among the different HWTS methods, and to resolve questions regarding the application of their chosen method. Easy access to relevant information can be achieved through training and capacity building of local resource persons (health workers and group leaders), household visits after the initial training, or IEC materials displayed in the community or distributed to each household.

Woman applying SODIS in Nepal

Box 23: Essentials: What promoters need to know

SODIS promoters must have a solid understanding of the rationale of household water treatment to prevent infections with diarrhoea, a comprehensive knowledge of the application guidelines of SODIS and possibly of other HWTS methods, and should be able to advise water users on how to overcome challenges to the correct and sustained application of SODIS. An initial training of promoters typically takes 1-3 days, depending on whether or not other HWTS methods are integrated in the promotion, and the tasks which promoters are expected to do. Refresher trainings during the promotion period are recommended.

A promoter should have knowledge of:

- Diarrhoea: pathogens, health effects, mortality risk, and productivity loss
- Transmission routes of pathogens through drinking water, hygiene, food, and the environment
- Strategies to prevent transmission of pathogens: water treatment, improved personal and environmental hygiene, and improved sanitation
- Drinking water contamination: possible source, and critical points for recontamination
- Importance of consistent safe water consumption for effective prevention of infection
- Household water treatment: different options
- Solar disinfection: principle (UV radiation in sunlight)
- SODIS steps: exposure of water in clean PET bottles to direct sunlight, and storage in bottles
- Weather dependence: 1 day (min. 6 hours) for sunny weather; 2 days when the sky is more than 50% cloudy; not applicable on rainy days
- Limitations of the SODIS method: not effective for turbid water, not effective during rainy days, and does not remove chemical pollutants, such as arsenic and fluoride.
- Bottle types: water and soda bottles made of PET, colourless, maximum 2 litres and labels removed
- Suitable places to expose bottles: no shade during the entire exposure time (possibly: reflective surface)
- Quantity: sufficient to allow for consistent safe water consumption for all family members
- Storage: ideally in the bottles, alternating 2 sets of bottles for daily exposure and storage
- Replacement of bottles: when the outer surface becomes opaque from scratches or solar radiation, which happens typically after a few months
- Bottle availability: points of access, and strategies to collect bottles
- Strategies to integrate water treatment into daily household routines
- Promotion skills: effective use of persuasion, communication, and monitoring tools
- Depending on scope of the project: application guidelines of other HWTS methods, specific information and application guidelines for hygiene and sanitation

4 Appendices

4.1 References

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Eawag
Überlandstrasse 133
P.O. Box 611
8600 Dübendorf
Switzerland
Phone: +41 (0)58 765 52 86
Fax: +41 (0)58 765 53 99
info@sandec.ch
www.eawag.ch, www.sandec.ch, www.sodis.ch

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