

Solar water disinfection in Kiribati

Assessment and implementation of solar water disinfection systems



Dr Christian Stärz



SPC
Secretariat
of the Pacific
Community

Solar Water Disinfection in Kiribati

Assessment and implementation of solar water disinfection systems

Dr Christian Stärz

©Copyright Secretariat of the Pacific Community (SPC) 2015

All rights for commercial / for profit reproduction or translation, in any form, reserved. SPC authorises the partial reproduction or translation of this material for scientific, educational or research purposes, provided that SPC and the source document are properly acknowledged. Permission to reproduce the document and/or translate in whole, in any form, whether for commercial / for profit or non-profit purposes, must be requested in writing. Original SPC artwork may not be altered or separately published without permission.

Original text: English

Secretariat of the Pacific Community Cataloguing-in-publication data

Programme: Global Climate Change Alliance: Pacific Small Island States

Cover design: Sailesh Kumar Sen

Pictures: Dr Christian Stärz

SPC Technical Report SPC00028

March 2015

SPC DISCLAIMER

While care has been taken in the collection, analysis, and compilation of the data, they are supplied on the condition that the Secretariat of Pacific Community shall not be liable for any loss or injury whatsoever arising from the use of the data.

Secretariat of the Pacific Community
Geoscience Division (GSD)
Private Mail Bag, GPO Suva, Fiji Islands
Email: christians@spc.int
www.spc.int
www.sopac.org

This report has been produced with the financial assistance from the Secretariat of the Pacific Community and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

Contents

Acknowledgements.....	1
Introduction	2
1.1. Background	2
1.2. Objective	3
2. Solar energy for water disinfection	3
2.1. Materials and methods	3
2.1.1. SODIS reactor experiments	3
2.1.2. Solar radiation and cloud cover	5
2.1.3. Geographical and statistical analysis	5
2.2. Results and discussion	5
2.2.1. Quality of drinking water sources in Bairiki, South Tarawa	5
2.2.2. Solar radiation and water temperature	6
2.2.3. Inactivation of bacteria	10
2.2.4. Reflection and transmission.....	11
2.3. Conclusion.....	13
3. Summary	15
Contact.....	15
References	16
Appendix	18

Figures

Figure 1: Drinking water quality in Bairiki, Tarawa	6
Figure 2: Global (left) and UV radiation (right) in South Tarawa, Kiribati.....	9
Figure 3: Annual mean UV-B radiation in J/m ² /day between the years 2004 and 2013.	8
Figure 4: Water temperature in PET batch reactors.....	10
Figure 5: Inactivation of total coliforms and E. coli in PET batch reactors	11
Figure 6: Reflection of UV radiation (left graph) on corrugated iron (a) and aluminium foil (b) and transmission of UV radiation (right graph) of PET batch reactors	12

Acknowledgements

The research was funded by the Global Climate Change Alliance: Pacific Small Island States programme (GCCA:PSIS), SPC's Water and Sanitation Programme and the German Agency for International Cooperation (GIZ). The GCCA: PSIS project in Kiribati is managed by Dr Gillian Cambers and coordinated by Juliana Ungaro (both SPC). Nicol Cave (SPC) coordinated the SODIS behaviour change campaign and Larissa Leben (WHO) assisted in research and analysis. The GCCA: PSIS project is grateful for the organisational and logistical support from Rhonda Robinson, David Hebblethwaite (both SPC), Dr Wulf Killmann (GIZ), Dr Teatao Tiira, Dr Patrick Timeon, Tebikau Tibwe, Tianuare Taeuea, and Kiatoa Tio (all Ministry of Health, Kiribati), David Teaabo (Ministry of Foreign Affairs, Kiribati), Choi Yeeting (Office of the President) and for the input from all members of the Kiribati National Experts Group (KNEG).

Introduction

Solar water disinfection (SODIS) is an effective, environmentally sustainable, low-cost solution for drinking water treatment at household level for people consuming water that is microbiologically contaminated. The process of SODIS uses solar energy to destroy pathogenic micro-organisms that cause water-borne diseases, thereby improving the quality and safety of drinking water.

Increased awareness of the hazardous by-products of chlorination of drinking water has led to more attention being paid to UV irradiation. Furthermore, chemical disinfection with chlorine is not effective against all kind of protozoa, such as *Cryptosporidium* and *Giardia* (Hijnen et al. 2006). Laboratory studies have shown that UV disinfection processes are effective against broadly all water-borne microbial species of pathogenic interest. Clinical trials of the technique in the developing world clearly indicate that, when implemented correctly and used regularly, SODIS can significantly reduce the rate of childhood dysentery and infantile diarrhoea up to 75% (Du Preez et al. 2010; Rai et al. 2010; Du Preez et al. 2011; McGuigan et al. 2011).

The application of SODIS has spread throughout the developing world and is in daily use in more than 50 countries in Asia, Latin America and Africa. Although more than five million people worldwide disinfect their drinking water with SODIS, this technique is hardly known in the Pacific region. Many studies and numerical models of solar irradiation suggest, however, that solar water purification is ideal in near-equatorial and tropical areas, where intense solar radiation is available throughout the year. The islands of Kiribati, especially, indicate perfect environmental conditions for solar disinfection systems. Kiribati ranks as the country with the second highest ultraviolet (UV) radiation in the world (WHO 2004).

1.1. Background

Kiribati is highly vulnerable to the impacts of climate change due to the low elevation of the islands and the lack of secure water supply. The limited freshwater resources are easily contaminated because of the high water table and certain soil characteristics. Increasing population pressure and limited available land for settlement in South Tarawa contribute to the pollution of groundwater, which is the main source of water. South Tarawa's population of around 50,000 lives on an area just over 15 km². Residents receive piped water for only two hours every alternate day because of high leakage from the system and limited freshwater supplies. Poorly functioning sanitation systems and inadequate sanitation practices among the local population contribute to the pollution of the groundwater.

To respond to these health risks, the Secretariat of the Pacific Community (SPC) in partnership with the European Union (EU) under the Global Climate Change Alliance: Pacific Small Island States project, launched the Solar Water Disinfection Project (SODIS) in Bairiki (South Tarawa) in October 2014. Part of the project is this research study, which assesses solar radiation for drinking water treatment.

As a consequence of consuming contaminated drinking water, childhood mortality from diarrhoea is more common in Kiribati than in other Pacific Island countries. Health officials report an average of three outbreaks of acute diarrhoeal disease in South Tarawa every year.

1.2. Objective

The overall objective of the study in Kiribati was to reduce the incidence of water-borne diseases such as diarrhoea. The research consisted of testing, evaluating and optimising the implementation of a sustainable technique for purification of drinking water using solar energy.

The approach to improve disinfection of water using renewable energy focuses on:

- assessing the environmental conditions and in particular the solar radiation;
- modelling a disinfection rate for contaminated water;
- optimising SODIS, especially for the environmental conditions in this region;
- reducing treatment duration and user maintenance (compared to the global standard);
- enhancing the disinfection efficiency against water-borne pathogens;
- using, where possible, cheap, local materials for low-cost systems; and
- developing the capacity to plan for drinking water safety .

2. Solar energy for water disinfection

Based on experience in near-equatorial regions, the islanders of Kiribati are likely to benefit from SODIS due to their geographical location but, in order to make an informed choice of SODIS as the appropriate technology, they need information. Global and UV irradiation need to be recorded in order to calculate the mean exposure time for sufficient disinfection under different weather conditions. Thermal inactivation of pathogens through infra-red radiation of the solar spectrum must also be assessed. A combined approach with both UV and infra-red radiation would be ideal, due to a remarkable synergistic effect in the treatment process. Therefore, various reactor types and reflecting applications were tested to intensify the efficiency of solar disinfection and to inactivate pathogens within a shorter time.

2.1. Materials and methods

2.1.1. SODIS reactor experiments

As Kiribati is among the least developed countries in the world and is also an island state, the aim was to come up with a cost-effective, simple and, most importantly, sustainable solution for drinking water treatment in rural areas and remote islands. It must be a solution that does not require long supply chains, expensive resources and materials, or complicated knowledge for set-up and usage; and it must be cheap to maintain. With all this in mind, polyethylene terephthalate batch reactors (PET bottles) and corrugated iron as the reflective surface were chosen. They have been successfully used in remote areas in the world (SANDEC and EAWAG 2002) and are available in, or can be delivered to, most remote islands of Kiribati at low cost.

All the field measurements and tests were conducted in Bairiki, Tarawa (latitude: 1.330636, longitude: 172.974426, altitude: 0–2 m) from 7–26 October 2014, which was the end of the dry season. For solar water disinfection, the solar reactors were filled with samples of water from different sources and placed on a rack exposed to direct sunlight at an angle of 10°–20° from 9 a.m. to 5 p.m. (UTC/GMT +12) every day.

a) Reactor and reflection materials

In order to quantify how much of the total UVA and UVB radiation reaches the water for photo-inactivation of pathogens, a variety of PET batch reactors were tested. Transmission rates vary because of particles added to the plastic during the manufacture of the bottles.

UVA and UVB transmittance by the transparent reactors was tested using UVA and UVB handheld solar meters.¹ For each reactor, a 2 cm² piece of PET material from an identical bottle was cut out and placed on top of the solar meter sensor facing the sun. UVA+B and UVB were measured with and without the square from the PET bottle, and the difference was calculated as a percentage of the total irradiation received.

As well as transparent reactors, reactors that were partly or completely painted black were tested in order to measure the effect of an increase in the temperature of the water on inactivation of *E. coli* and other coliforms, compared to the reflection from corrugated iron and aluminium foil boards, which were also tested.

In order to quantify the intensity of reflection, handheld solar meters measured UVA+B and UVB radiation at an angle between 45° and 90° to both corrugated iron and aluminium foil 12 times. The average intensity was then calculated.

b) Water sources

All water sources in the area were monitored; rainwater (stored in a tank) and tap water (groundwater treated by chlorination and provided by the Public Utilities Board) were tested. For the daily test, groundwater from an unprotected well was used, as this was the most contaminated water source. Consequently, the results could be generalised to the water from the other sources.

c) Water temperature

The temperature of the water in the bottles was measured by a thermal data logger² every minute during the time they were exposed to the sun, from 9 a.m. to 5 p.m. (UTC/GMT +12) every day. The sensors were placed in the water through a hole in the bottle top, and pushed down two-thirds the length of the bottle.

d) Microbiological analysis

E. coli is a widely used indicator micro-organism for faecal contamination (WHO 2001) and was therefore tested every day. Out of each bottle, a 1 ml sample was withdrawn every hour from 9 a.m. to 5 p.m. every day and placed on a petri dish.³ The medium on the petri dish contained chromogenic enzyme substrate, Magenta-GAL and XGLUC. The first samples of each day, containing more than 200 colony forming units (CFUs), were diluted by a factor of 1:10. In order to verify results of the 1 ml samples, especially the last ones, where less than 20 CFUs were detected, a 50 ml sample was tested for quality control each time, using filters.⁴ All the petri dishes were placed in an incubator immediately after sampling and were incubated for 24 hours at 35±1 °C.

¹ Model 5.0 UVB and 6.2 Total UV (A+B) SOLARMETER®, Michigan, US

² Model: 296-151 [TDFC], Electronic Temperature Instruments Ltd, West Sussex, England

³ EC Compact Dry™, Nissui Pharmaceutical Co. LTD

⁴ PALL Life Sciences, Nylon membrane filters, 47 mm 0.45 µm

CFUs were visually counted: a red/pink colour indicated coliforms, while a blue/blue purple colour indicated *E. coli* bacteria. All the equipment (petri dishes, etc.) were sterilised in boiling water for 15 minutes after every set of tests and all surfaces were regularly cleaned with a 1:10 bleach dilution.

2.1.2. Solar radiation and cloud cover

Solar radiation was monitored with a UV-Radiometer for UVA (spectral range: 315–400 nm) and UVB (spectral range: 280–315 nm) radiation measurements in W/m^2 ⁵ and a pyranometer measuring global solar exposure in the spectral range 285–2800 nm⁶ every minute from sunrise to sunset every day. The devices were placed on a roof with no trees or other buildings around it to avoid false results due to interfering shade. Data were logged using the logbox SD.⁷

Cloud coverage is the main parameter affecting treatment time for the solar disinfection process. This is particularly relevant for setting up the SODIS guidelines. The cloud cover conditions were classified as shown below.

Classification	Description
Clear sky, cloudless	The sky has no clouds or clouds cover less than 1/10 of the sky
Some scattered cloud	Between 1/10 and 1/2 or less than one half of the sky is covered with clouds (on average during the day)
Very cloudy	Between 1/2 and 9/10 of the sky is covered with clouds
Overcast	More than 9/10 of the sky is covered with clouds

2.1.3. Geographical and statistical analysis

Quantum GIS (Dufour 2.0) was used for geographical analysis. Data for UV radiation was obtained by Beckmann et al. (2014) and NASA (2005). Statistical analysis and evaluation was carried out using Excel and SPSS (version: 15.0).

2.2. Results and discussion

2.2.1. Quality of drinking water sources in Bairiki, South Tarawa

All drinking water sources were tested to get an overview of the overall microbial contamination and to set up a baseline in order to assess the SODIS process. Figure 1 shows that all water samples contained high concentrations of coliform bacteria. Further, the presence of *E. coli* indicates contamination by faecal bacteria which could be a severe health risk. According to the *WHO bacteriological quality of drinking water guideline* (WHO 1996), Coliform bacteria and *E. coli* **must not be detectable** in any 100 ml sample (0 CFU/100 ml). Even the tap water, which was supposed to be chlorinated by the Public Utilities Board (PUB), was highly contaminated with *E. coli* on six out of 14 test days (Max: 2,500 CFU/100 ml). Possible reasons for this result are unsafe water storage

⁵ Broadband UV-Radiometer UV-S-AB-T, Kipp&Zonen, Delft, Netherlands, calibration date: 23 June 2014, expected daily inaccuracy: <5%

⁶ (model CMP21; Kipp&Zonen, Delft, Netherlands, ISO-classification: Secondary Standard, sensitivity: 7–14 $\mu\text{V/W/m}^2$, calibration date: 01 May 2014, expected daily inaccuracy: <2%)

⁷ Kipp&Zonen, Delft, Netherlands

practices and contamination of supply from external pollution sources. Some sections of the PUB transmission line are below the groundwater table, and hence the system is unpressurised, so there is a high likelihood that infiltration from local groundwater is occurring at these locations (GHD 2015). Rainwater samples contained *E. coli* bacteria with a medium value of 150 CFU/100 ml (Max: 1,500 CFU/100ml) on nine out of 15 test days. The highest microbial contamination was found in the well water samples. All 13 samples tested positive for *E. coli* with a medium amount of 2,420 CFU/100 ml (Max: 8,750 CFU/100ml). Consequently, it is absolutely necessary for all households in Bairiki (and probably in Tarawa) to disinfect their drinking water at the point-of-use, regardless of the water source.

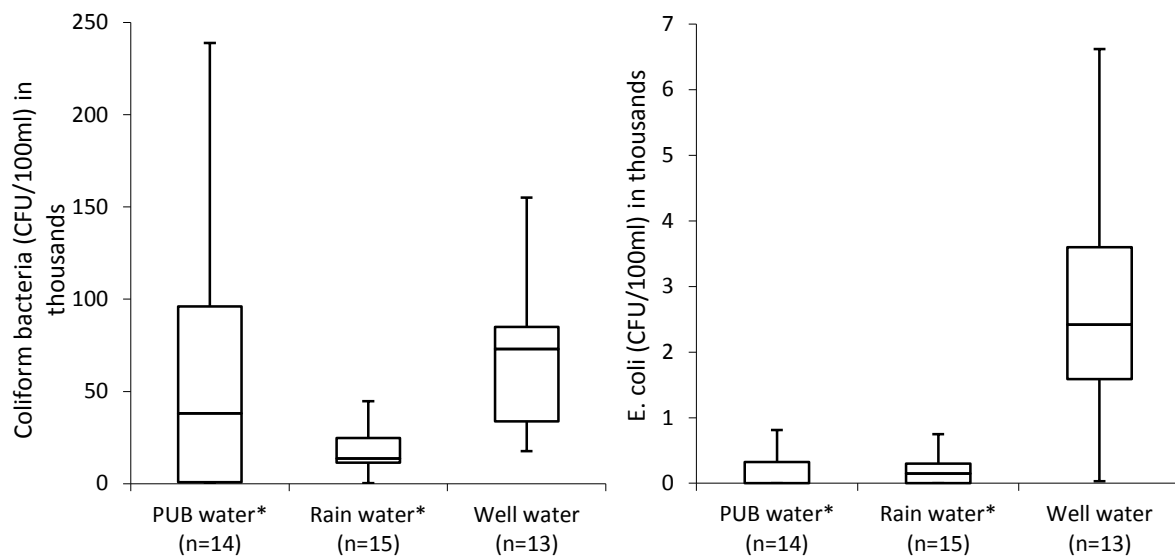


Figure 1: Drinking water quality in Bairiki, Tarawa

Water samples from end-of-use points tested on coliform bacteria and *E. coli* of the study site Bairiki for the period of the field study from 7 to 26 October 2014

*stored in 200 litre tanks

2.2.2. Solar radiation and water temperature

Many studies have been conducted worldwide to define a minimum irradiation time or a minimum UV intensity for SODIS. However, microbial inactivation by natural sunlight is a complex interaction of physical, chemical and biological processes, which depend on several parameters such as pathogen turbidity, temperature, UV and solar radiation, geographical location, climate and weather, reactor material and exposure time. Using only one parameter, such as an exposure time of six hours on a sunny day, which was initially promoted by SANDEC and EAWAG (2002), does not seem to be sufficient to define a general SODIS criterion for every location. Regardless, for practical reasons there is a need to describe simple indicators to keep the method appropriate for users. Once the environmental conditions are assessed on a mesoscale, local guidelines and thresholds based on weather conditions and treatment time can be defined.

a) Global and UV radiation

A certain amount of solar energy is needed to achieve microbial inactivation. Solar radiation is the driver of the disinfection process and thus needs to be measured for all SODIS-related approaches.

The global radiation measured during the field study can be seen as representative for the study area, as the values for Bairiki from 7 to 26 October are almost the same as the 22-year average data for Tarawa (Figure 2). The slight left shift of the grey graph occurs due to seasonal differences. Measured global radiation counts a total dose of 19.56 MJ/m^2 with a maximum of 854.59 W/m^2 as the daily average. The highest value of $1,357.74 \text{ W/m}^2$ was measured at 11:33 a.m. on 17 October 2014.

Ultraviolet (UV) light is the most important wavelength for the disinfection process. The only existing UV data for the Pacific region (except Hawaii) are estimates from satellite images presenting a global overview of their spatial-temporal distribution. According to WHO (2004), the islands of Kiribati experience the second highest amount of erythemal UV light worldwide.

Although the UV-A wavelengths bordering on visible light are not sufficiently energetic to directly modify DNA bases, they play an important role in the formation of reactive oxygen species (ROS) in water, such as singlet oxygen, superoxide, hydrogen peroxide and hydroxyl radical. Once formed, these ROS can cause damage to DNA, oxidations of amino acids in proteins, and oxidations of polyunsaturated fatty acids in lipids (Reed et al. 2000). In particular, UV-B radiation (about 0.5% of solar radiation) is responsible for most of the germicidal effects of sunlight on pathogens by directly destroying their DNA. Figure 3 shows the spatial distribution of UV-B doses for a ten-year average in the Pacific region. The islands of Kiribati are located in an area with the highest UV-B doses in the region, which suggests this country as a hot-spot of erythemal UV light and hence ideal for UV-driven applications such as SODIS.

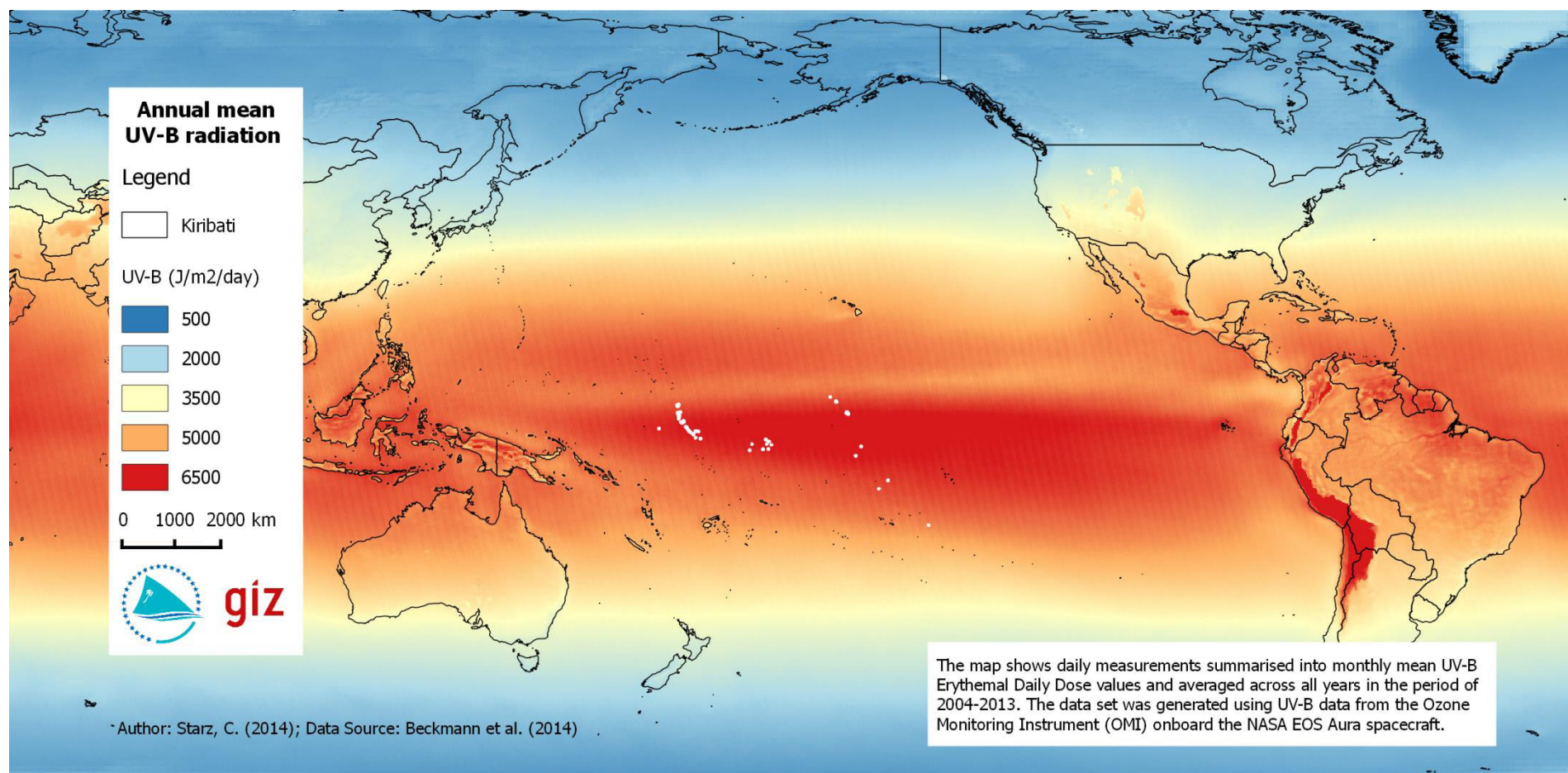


Figure 3: Annual mean UV-B radiation in J/m²/day between the years 2004 and 2013.

Due to seasonal patterns and daily changing weather conditions, however, it is necessary to assess the UV radiation on the ground before this method can be properly implemented. The right graph in Figure 2 shows ground-based average values of UV-A and UV-B radiation for Bairiki from 7 to 26 October. On average, the total UV-A radiation is 1.61 MJ/m²/day (UV-B = 42.66 kJ/m²/day) with a maximum of 73.32 W/m² (UV-B = 2.21 W/m²) at noon. The highest UV-A value of 89.61 W/m² (UV-B = 2.60 W/m²) was measured at 11:34 a.m. on 17 October 2014. This is equal to a UV-Index of 14, which is classified by WHO as extreme (highest level).

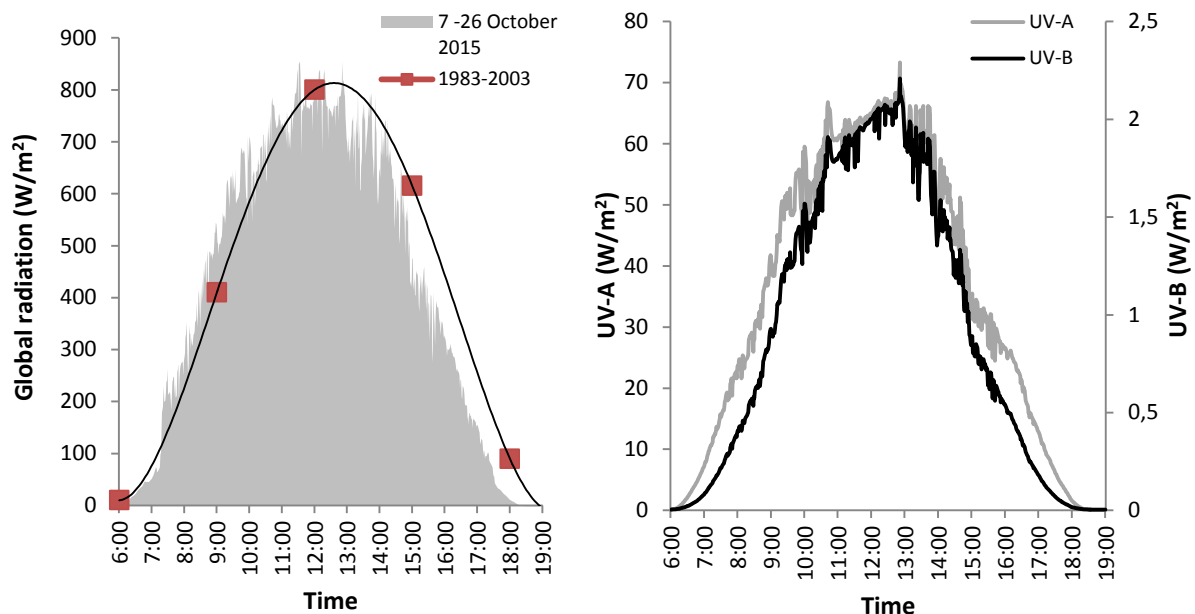


Figure 2: Global (left) and UV radiation (right) in South Tarawa, Kiribati.

Global and UV radiation are average data for the period of the field study from 7 to 26 October 2015. The graph on the left shows the 22-year average global radiation data for comparison (source: NASA 2005)

b) Water temperature

Pathogenic micro-organisms are vulnerable to two effects of sunlight: UV light and infra-red radiation. A synergy of these two effects occurs, and their combined effect is more than double than the sum of the single effects (SANDEC and EAWAG 2002). This means that the mortality of the pathogens increases if they are exposed to UV light and the water temperature reaches 45°C or higher at the same time (Wegelin et al. 1994). Thermal disinfection of liquids is termed pasteurisation, which can take place at much lower temperatures than boiling, depending on how long the water is held at the pasteurisation temperature. For solar pasteurisation, temperatures need to be > 50°C (Ray and Jain 2014). Maintaining a water temperature of 50°C requires only one-third of the typical solar irradiation intensity needed for inactivation (Oates et al. 2003). Therefore, SODIS systems, which increase the water temperature within a short time without reducing the transmission of UV-radiation, are recommended.

The effect of various reflecting materials and colours was also tested and assessed. Figure 4 shows the global radiation during an average sunny day with a clear sky in Tarawa and its effect on the water temperature in two different SODIS batch reactors: a clear reactor and a reactor that had been painted half black. The threshold for the synergistic effect of UV light and temperature was

reached in the clear PET batch reactor after 170 minutes of exposure time. The half-black PET batch reactor reached 45°C already after 95 minutes and even exceeded the threshold for pasteurisation after 145 minutes. Both reactor types recorded maximum temperatures of 58.4°C (02:13 p.m., half-black PET) and 49.2°C (12:58 p.m., clear PET) on 14 October 2014. The application of aluminium foil, to enhance the receiving solar radiation in the reactor had no positive effect on the water temperature.

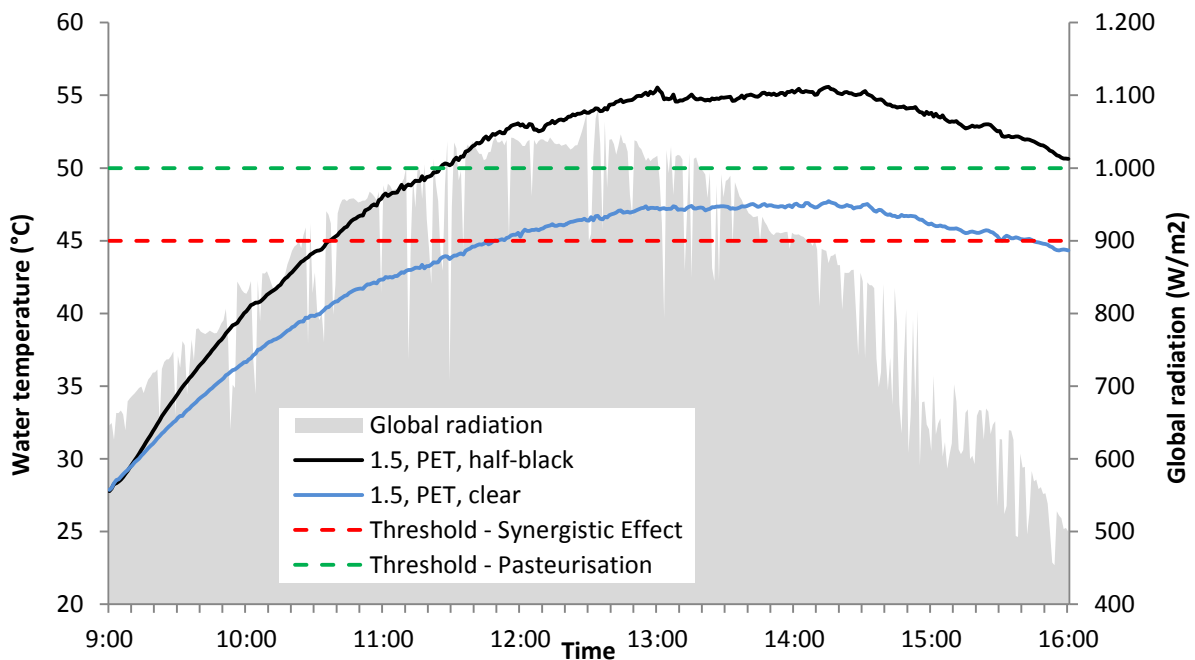


Figure 4: Water temperature in PET batch reactors

Global radiation and water temperature average data for five sunny days with clear sky at 12.10., 14.10., 18.10., 21.10., and 24.10.2014 in Bairiki, South Tarawa. Threshold for SODIS synergistic effect: 45°C. Threshold for pasteurisation is 50°C.

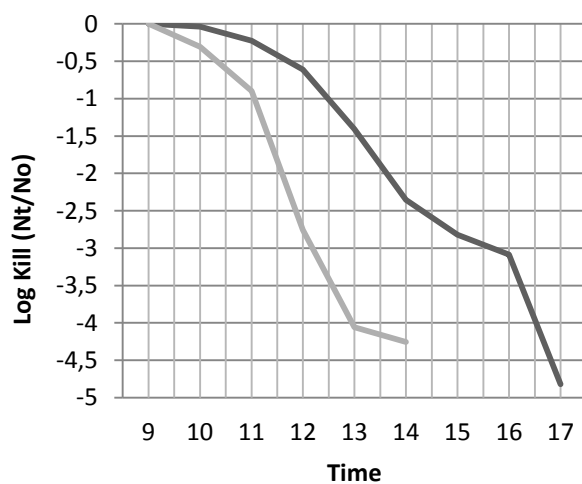
2.2.3. Inactivation of bacteria

The main criteria for safe drinking water with SODIS are a combination of time and weather parameters, including global and UV irradiance and water temperature. The SODIS guidelines by SANDEC and EAWAG (2002) recommend treating the water for six hours on a sunny day and for two to three days if it is cloudy.

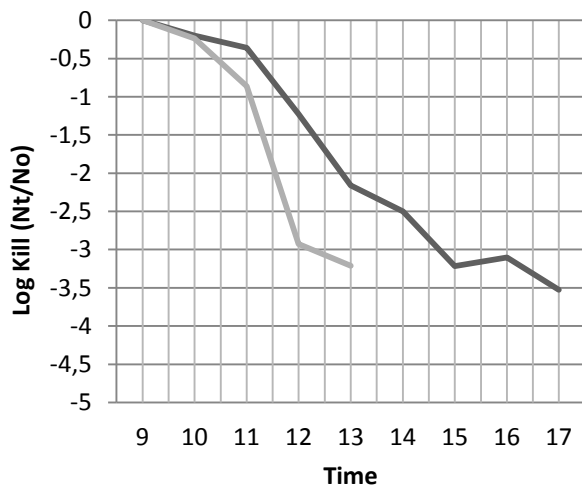
The research results of this study indicate that much less treatment time is needed in Tarawa. Figure 5 shows that, even on days with an overcast sky, more than 99.9% of *E. coli* and total coliforms could be inactivated in normal PET bottles in one day (total coliforms: ~6.5 hours; *E. coli*: ~5.5 hours). These very good results can be explained by the high UV doses in Tarawa and the synergistic effect of water temperature and solar radiation in sunny conditions.

In clear bottles, a 3-log reduction of all tested bacteria occurred after three hours on clear days and days with scattered cloud. The inactivation of bacteria was enhanced by applying black paint lengthwise on half of the surface of the bottle. These half-black reactors increased the water temperature faster than the clear bottles and thus supported the synergistic effect (see previous section). Consequently, the treatment time could be reduced by around half an hour on these days. On very cloudy or overcast days, however, no positive effect of applying black paint could be proven.

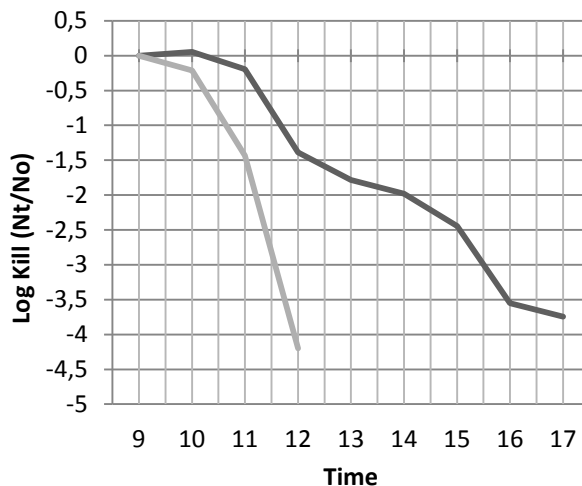
Moreover, a medium increase of water temperature in black bottles (below the pasteurisation level) even caused a multiplication of pathogens on cloudy days. Martin-Dominguez et al. (2005) reported similar results: bottles painted black achieved different degrees of success with respect to enhancing the heat transfer to the contaminated water. However, UV radiation is still available on cloudy days for optical inactivation of pathogens, but totally blackened reactors are unable to raise the temperature of water up to the pasteurisation level on such days.



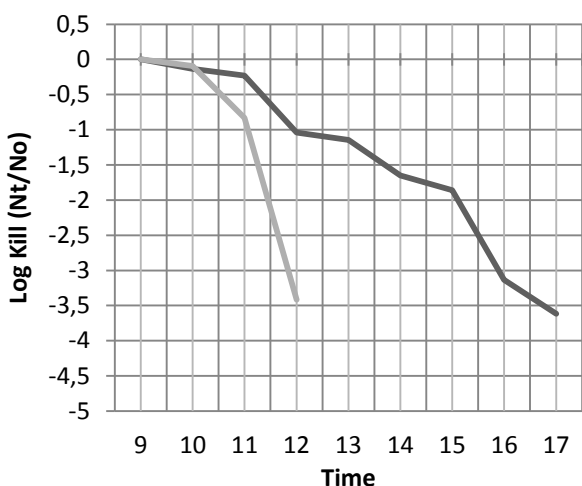
(a) Total Coliforms; **clear** PET batch reactor



(b) E. Coli; **clear** PET batch reactor



(c) Total Coliforms; **half-black** PET batch reactor



(d) E. Coli; **half-black** PET batch reactor

— very cloudy to overcast — clear sky to some scattered clouds

Figure 5: Inactivation of total coliforms and E. coli in PET batch reactors

2.2.4. Reflection and transmission

The SODIS bottles are usually only illuminated on the upper side of the reactor that faces the sun. There have been various attempts to concentrate solar radiation using solar mirrors or reflective

materials to increase the radiation in the bottles. According to Hindiyeh and Ali (2010) and Kehoe et al. (2001), aluminium foil attached to the back of the bottles increases the disinfection rate by a factor of 1.85 to 2.

The PET bottles can be placed on top of a sheet of corrugated iron or aluminium foil, and both were tested. Both materials increased the UV radiation – by ~50% using corrugated iron and by ~60% using aluminium foil (see Figure 6). This research focused on SODIS bottles in combination with corrugated iron because almost all roofs in the study site were made of this material, which ensures local availability and acceptance.

PET seems to be a suitable reactor material for SODIS processes but the results of this and other research suggest that there is potential for improving the SODIS system. Transparent PET bottles are opaque below wavelengths of 320 nm, and transmittance of UVA radiation can reach as high as 85–90% (McGuigan et al. 1998). The tested PET bottles from shops in Tarawa averaged 70% less transmissive than those in the study of McGuigan et al., which may be explained by the use of different colours in the bottle manufacturing process. UVB radiation is as much as two to three orders of magnitude more effective than UVA radiation for microbial inactivation (Setlow 1974) but PET reduces the transmission of UVB radiation by around 60%. Introducing reactors using other materials that are more transmissive (e.g. borosilicate glass) could be considered, as UVB radiation is very high in Kiribati and this would greatly improve the disinfection process. However, as PET bottles are locally available and affordable for everyone in Tarawa and Kiribati, PET bottles for SODIS are recommended, as their performance in drinking water disinfection has been proved in the environment of Tarawa.

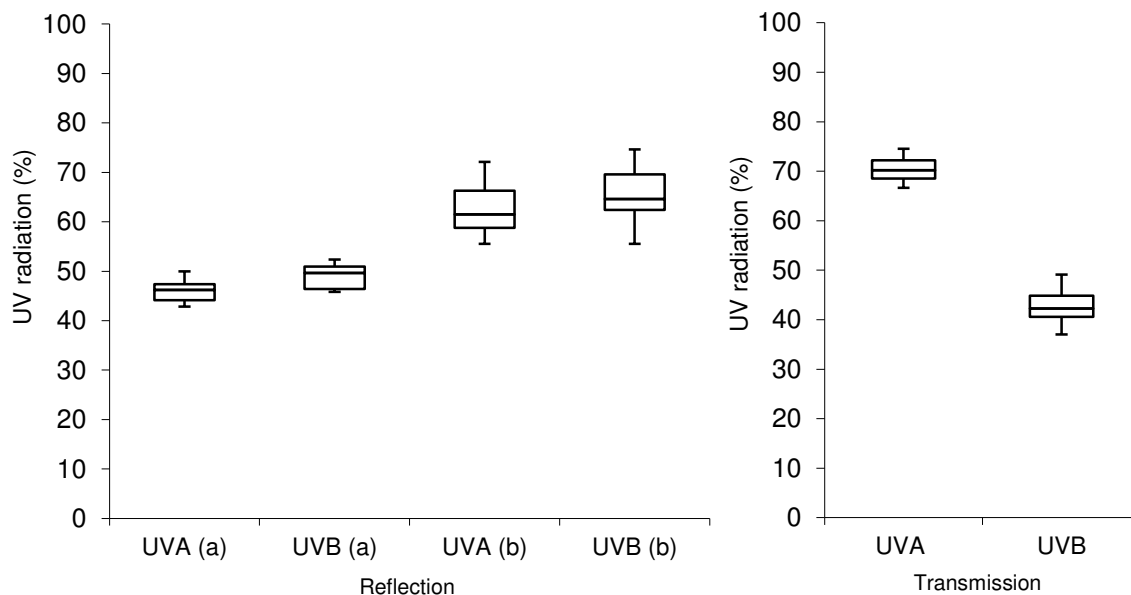


Figure 6: Reflection of UV radiation (left graph) on corrugated iron (a) and aluminium foil (b) and transmission of UV radiation (right graph) of PET batch reactors (n=12).

2.3. Conclusion

This study shows that SODIS is a very effective, sustainable and inexpensive method of disinfecting microbiologically contaminated drinking water in Tarawa. After filling transmissive batch reactors (e.g. PET bottles) with contaminated water and exposing them to sunlight, SODIS produces pathogen free drinking water. Health impact assessment studies in other regions in the world have reported 75% reductions in the incidence of diarrhoea in regular users of SODIS (Du Preez et al. 2010; Rai et al. 2010; Du Preez et al. 2011; McGuigan et al. 2011).

SODIS in South Tarawa, Kiribati

Kiribati is a country with one of the highest UV doses in the world; it receives many sunshine hours and shows hardly any seasonal changes of radiation rates due to its close location to the equator. The environmental conditions in South Tarawa are considered ideal for SODIS. The results of this research demonstrate that treatment time of contaminated water can be reduced to three hours on clear days and days with scattered clouds, and it is even possible to inactivate all the bacteria on cloudy, overcast days, although according to the literature, exposure time is six hours on a sunny day or between two and three days if it is cloudy. In order to include a safety buffer, however, it is recommended to increase treatment time and set up the following guidelines (Box 1).

The way forward

Taken as absolute values, the number of deaths of children under-five years old due to diarrhoeal diseases exceeds 1,000 each year in the Pacific region. The highest rates occur in Kiribati and Papua New Guinea (WHO and UNICEF 2015).

It is expected that SODIS is feasible on all islands of Kiribati and rolling it out on a national level could be done by promoting this method and considering it in plans relating to drinking water safety. Nevertheless, it is suggested the local conditions be screened before implementing SODIS in locations other than Tarawa in order to reduce the risk of underestimating the treatment time.

After Kiribati, there is a huge potential to roll out SODIS to other Pacific Island countries as they also have a lot of sunshine hours throughout the year. Many of these islands are close to the equator, which guarantees a high dose of UV-radiation.

This method could be implemented wherever the environmental conditions meet the criteria for SODIS, and where the use of the SODIS methodology complements local domestic drinking water management and drinking water safety practices. The climate and solar environment on site need to first be assessed to ensure a proper disinfection process. The SODIS guidelines (see Box 1) can be adapted to local conditions.

According to existing health impact assessment studies on SODIS, under five mortality from currently 57/1,000 (WHO 2013) to 14/1,000 per year could be potentially achieved by implementing SODIS in Kiribati.

Box 1: SODIS Guidelines

1. Start SODIS in the morning before 10 a.m. Fill the bottle two thirds full of water, shake it for ten seconds and then fill the bottle to the top.
Why? Shaking increases the creation of reactive oxygen species (ROS), which improve the disinfection process.
2. Put the bottle on an elevated surface (e. g. table or roof) which is ideally reflective (e.g. corrugated iron or aluminium foil).
Why? This keeps the reactor away from faecal contamination by animals. Reflective materials increase the reception of solar energy in the bottles.
3. Ensure that there is no shade (e.g. from surrounding trees) on the SODIS spot all day.
Why? Shade decreases the disinfection process by reducing the received solar energy.
4. Finish SODIS in the evening after 5 p.m. Remember the cloud cover conditions from this day.
 - a) If the sky was clear or a little cloudy, the water is safe to drink and should be directly consumed out of the bottle.
Why? Consuming the water directly out of the bottle reduces the risk of recontamination through dirty containers.
 - b) If the sky was very cloudy, the water should not be consumed today. Start with step 2 tomorrow.
Why? There is a risk that there are still pathogens in the water due to an insufficient dose of solar radiation.
5. If the bottle was not opened before consumption, properly treated SODIS water (see 4a) can be stored in a dark place but only for up to three days.
Why? Theoretically, SODIS water can be stored for a very long time, but if there are any bacteria still in the bottle, they could reproduce and reach a health-risk concentration.
6. Once the bottle has been opened, the water should be drunk soon after to prevent secondary contamination.

Sunshine duration solely is not sufficient to ensure a proper disinfection of all pathogens in drinking water. From the findings of this research and reviewed studies, a combination of criteria and limits can be suggested for safe and sustained implementation of SODIS⁸ (Box 2).

There is further potential to benefit from the environmental conditions in Kiribati and other Pacific Island countries and territories by increasing the treatment volume with innovative applications such as flow-through systems, which can disinfect up to 500 litres a day for schools, hospitals and communities. These systems are inexpensive and easy to maintain but should be implemented initially as a pilot in order to assess performance and acceptance.

Indeed, compliance must be high to effectively reduce diarrhoea with SODIS. People must consume the solar treated water habitually and without interruption to supply. Moreover, it requires behaviour change, since users must organise bottles, wash and fill them with water, put them in the sun for an appropriate length of time, collect them, and use them as recommended. All these steps require changes in behaviour and in the daily routine of SODIS users (McGuigan et al. 2012).

⁸ Under natural sunlight conditions on days with clear or scattered clouds; 1.5 litre PET bottles on corrugated iron

Box 2: SODIS criteria

- Water turbidity > 30 NTU
- Global irradiation > 10 MJ/m²/day **or**
UVA radiation dose > 750 kJ/m²/day **or**
Water temperature > 50°C for one hour

3. Summary

Contaminated drinking water leads to a high risk of water-borne diseases such as diarrhoea, cholera and typhoid fever. Amongst the poor and especially in developing countries, diarrhoea is a major killer. Kiribati shows the highest rate of deaths of children under five from diarrhoea in the Pacific Island region. This rate could be significantly reduced by sustainable treatment of contaminated water with SODIS.

The weather conditions in Tarawa are ideal for implementing SODIS. This study proves that water from all sources (groundwater, tap water and rainwater) can easily be disinfected. On days with a clear sky, a much shorter treatment time (less than three hours) is needed, compared to other tropical regions where the average recommended disinfection time under similar weather conditions is six hours. Further, the research study demonstrates that SODIS works even on very cloudy days. However, in order to reduce the risk of some pathogens remaining in the drinking water, this treatment method should not be used on days when the sky is overcast or it rains all day.

Considering SODIS as a treatment method within Kiribati's approach to Drinking Water Safety Planning, as well as in emergency response planning, is highly recommended. Further, this method contributes to energy security: SODIS is a zero-cost method that uses renewable energy and thus reduces CO₂ emissions, unlike disinfecting drinking water by boiling it using firewood or fossil fuels.

Many other Pacific countries and territories are located close to the equator and receive a lot of sunshine hours all year round (e.g. Tuvalu, Papa New Guinea, Marshall Islands and Palau). There is a huge potential for these countries to benefit from solar water disinfection techniques.

Contact

Dr Christian Stärz

SPC/GIZ Coping with Climate Change in the Pacific Island Region (CCCPIR)

Secretariat of the Pacific Community (SPC)

Geoscience Division | Water and Sanitation Programme

Private Mail Bag, GPO, Suva, Fiji

Email: christian.staerz@gmx.de

References

- Beckmann M., Václavík T., Manceur A.M., Šprtová L., von Wehrden H., Welk E., and Cord A.F. (2014). glUV: A global UV-B radiation dataset for macroecological studies, *Methods in Ecology and Evolution*. 5: 372–383.
- Du Preez M., Conroy R.M., Ligondo S., et al. (2011). Randomized intervention study of solar disinfection of drinking water in the prevention of dysentery in Kenyan children aged under 5 years. *Environ Sci Technol*; 45:9315–9323.
- Du Preez M., McGuigan K.G. and Conroy R.M. (2010). Solar disinfection of drinking water in the prevention of dysentery in South African children aged under 5 years: the role of participant motivation. *Environ Sci Technol*. 44:8744–8749.
- GHD (2015). Report for Ministry and Foreign Affairs and Trade – Kiribati Water and Sanitation Sector Situational Analysis and Scoping Mission, 23/15369
- Hijnen, W.A.M., Beerendonk E.F. and Medema G.J. (2006). Inactivation credit of UV radiation for viruses, bacteria and protozoan (oo)cysts in water: A review. *Water Research* 40: 3–22.
- Hindiyeh M. and A. Ali (2010). Investigating the efficiency of solar energy systems for drinking water disinfection. *Desalination* 259: 208–215.
- Kehoe S.C., Joyce T.M., Ibrahim P., Gillespie J.B., Shahar R.A. and McGuigan K.G. (2001). Effect of agitation, turbidity, aluminium foil reflectors and container volume on the inactivation efficiency of batch-process solar disinfectors. *Water Res.* 35 1061–1065.
- Martin-Dominguez A., Alarcón Herrera M.T., Martin-Dominguez I.R. and Gonzalez-Herrera A. (2005). Efficiency in the disinfection of water for human consumption in rural communities using solar radiation. *Sol. Energy* 78: 31–40.
- McGuigan K.G., Joyce T.M., Conroy R.M., Gillespie J.B. and Elmore-Meegan M. (1998). Solar disinfection of drinking water contained in transparent plastic bottles: characterizing the bacterial inactivation process. *J Appl Microbiol* 84:1138–1148.
- McGuigan K.G., Samaiyar P., Du Preez M. and Conroy R.M. (2011). High compliance randomized controlled field trial of solar disinfection of drinking water and its impact on childhood diarrhea in rural Cambodia. *Environ Sci Technol*. 45:7862–7867.
- McGuigan K.G., Conroy R.M., Mosler H.J., Du Preez M., Ubomba-Jaswa E. and Fernandez-Ibañez P. (2012), Solar water disinfection (SODIS): a review from bench-top to roof-top. *Journal of Hazardous Materials* 235-236: 29-46
- Oates P.M., Shanahan, P. and Polz M.F. (2003). Solar disinfection (SODIS): simulation of solar radiation for global assessment and application for point-of-use water treatment in Haiti. *Water Res.*, 37pp. 47–54.
- Rai B., Pal R., Kar S. and Tsering D.C. (2010). Solar disinfection improves drinking water quality to prevent diarrhea in under-five children in Sikkim, India. *J Glob Infect Dis*. 2:221–225.
- Ray C. and Jain R. (2014). Low cost emergency water purification technologies. *Integrated Water Security Series*. Elsevier, USA. ISBN: 978-0-12-411465-4.

Reed R.H., Mani S.K. and Meyer V. (2000). Solar photo-oxidative disinfection of drinking water: preliminary field observations. *Lett. Appl. Microbiol.* 30: 432–436.

SANDEC & EAWAG (2002). Solar water disinfection—A guide for the application of SODIS. Duebendorf, SANDEC Report No 06/02. ISBN: 3-906484-24-6.

Setlow, R.B. (1974). Wavelengths in sunlight effective in producing skin cancer – theoretical analysis. *Proceedings of the National Academy of Sciences of the United States of America* 71 (9): 3363-3366.

Wegelin et al. (1994). Solar water disinfection: scope of the process and analysis of radiation experiments. *Journal of Water SRT-Aqua* 43 (3) 154-169.

WHO and UNICEF (2015, in preparation): Sanitation, drinking-water and health in Pacific Island countries: Progress and ways forward. WHO Western Pacific Regional Publications.

WHO (2000), Global Water Supply and Sanitation Assessment. World Health Organization. Geneva (http://www.who.int/docstore/water_sanitation_health/Globassessment/GlobalTOC.htm)

WHO (2001). Water quality: Guidelines, standards and health. Edited by Lorna Fewtrell and Jamie Bartram. Published by IWA Publishing, London, UK. ISBN: 1 900222 28 0.

WHO (2004). World health statistics 2004. Geneva, Switzerland, World Health Organization (http://apps.who.int/gho/athena/data/download.xsl?format=xml&target=GHO/UV_1&profile=excel&filter=COUNTRY:*;REGION:AFR;REGION:AMR;REGION:SEAR;REGION:EUR;REGION:EMR;REGION:WP R)

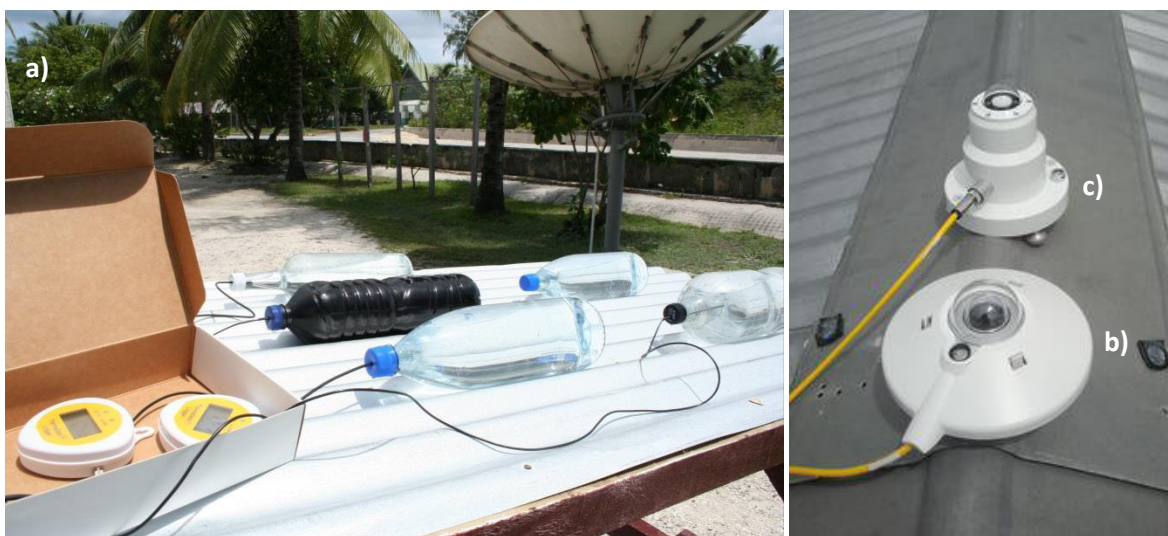
WHO (2013), World health statistics 2013. Geneva, Switzerland, World Health Organization (http://www.who.int/gho/publications/world_health_statistics/2013/en/).

Appendix

A 1: Water sources in Bairiki, South Tarawa: a) tap water (provided by the Public Utilities Board), b) rain water c) well water

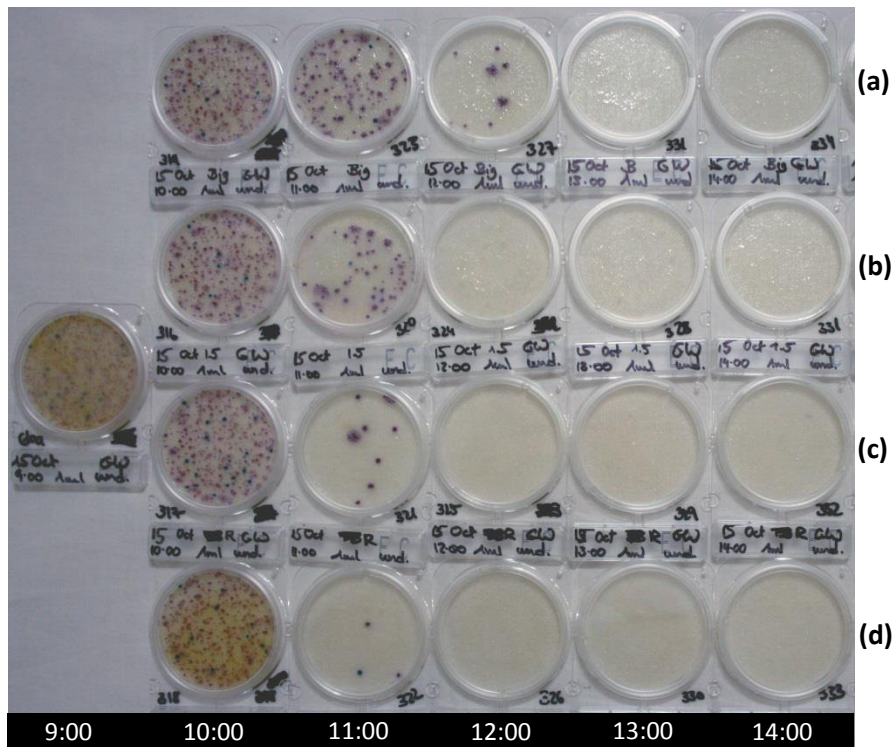


A 2: Recording of a) water temperature, b) global radiation and c) UV-A+B radiation

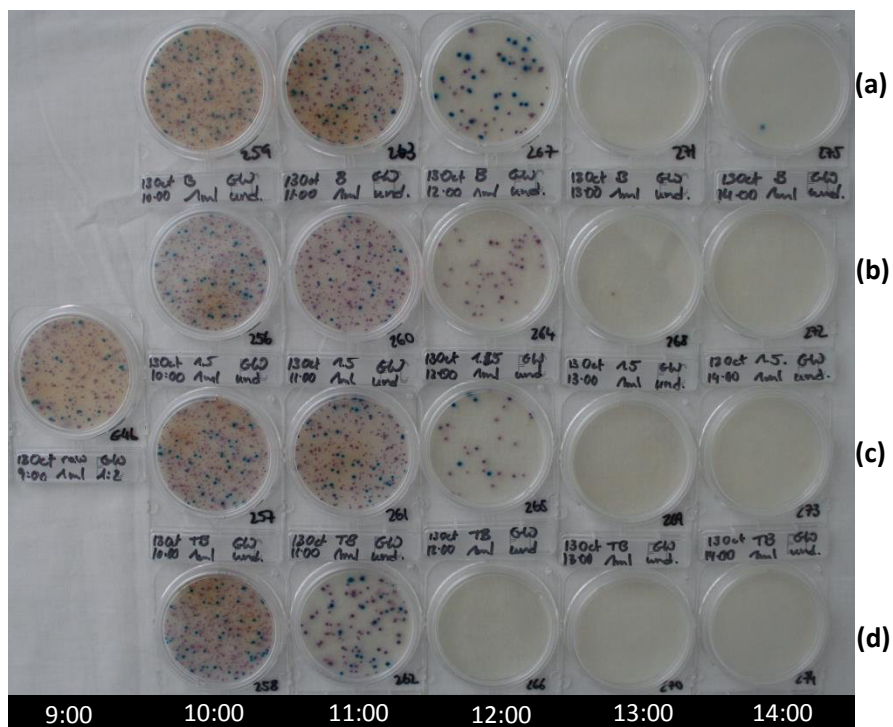


A 3: Time series of microbial inactivation by SODIS during different cloud cover conditions

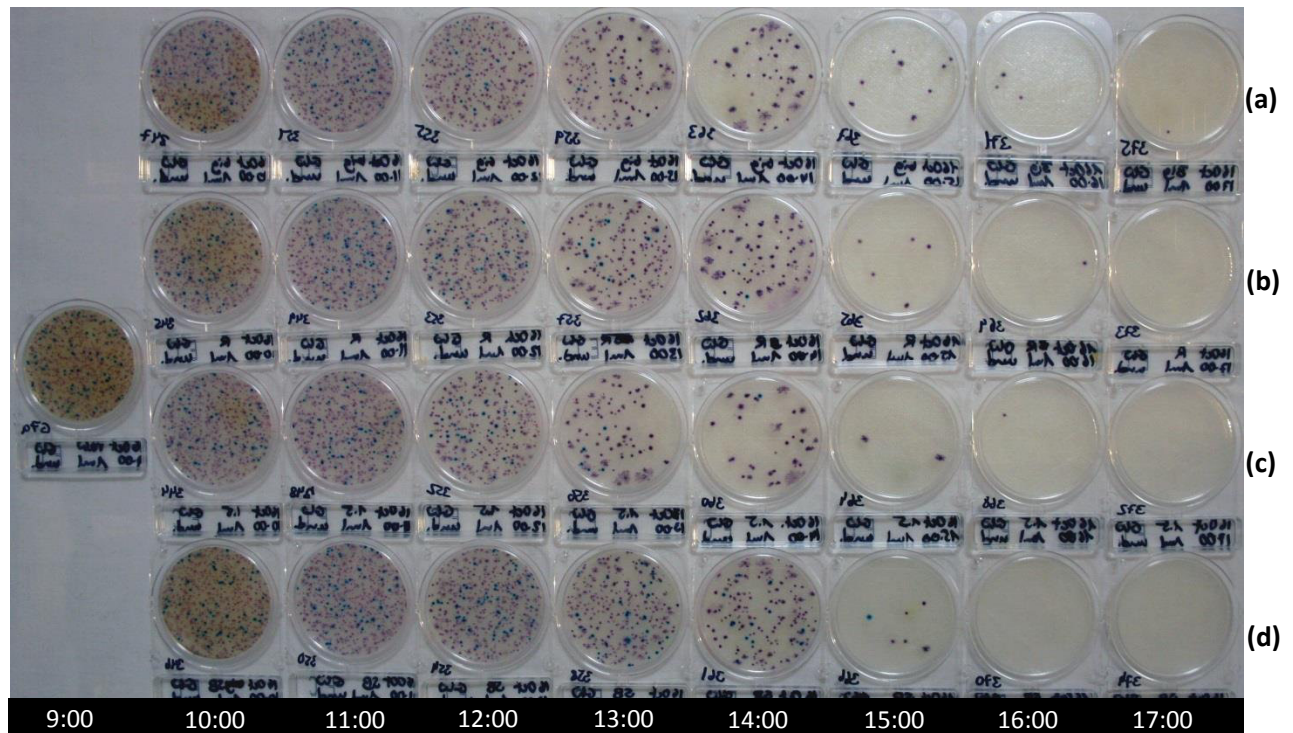
October 15, 2014: **Clear sky** from 9:00 to 14:00. a) 2.25 litre PET; b) 1.5 litre PET; c) 1.5 l PET + foil; d) 1.5 litre PET + lengthwise black



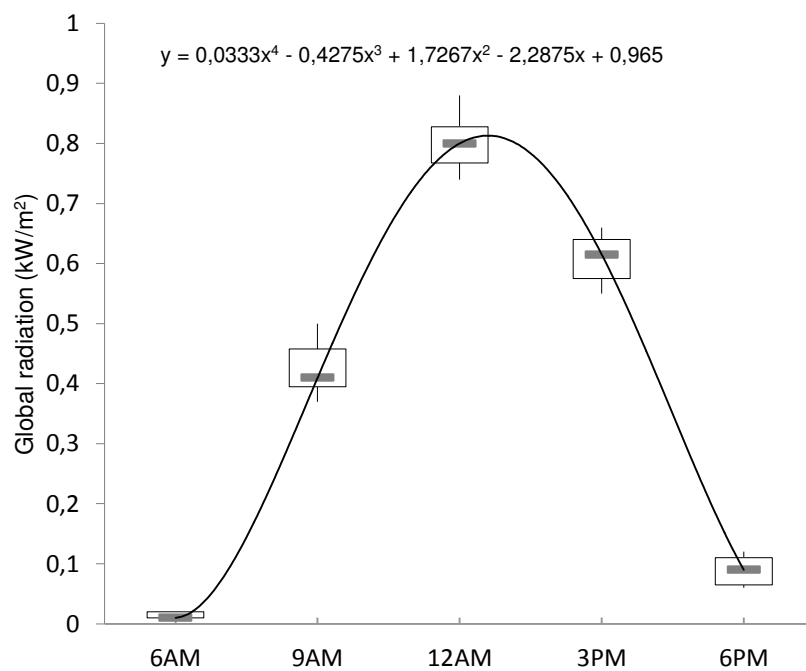
October 10, 2014: **Some scattered clouds** from 9:00 to 16:00. a) 1.5 litre PET black; b) 1.5 l PET; c) 1.5 litre PET + top black; d) 1.5 litre PET + lengthwise black



October 16, 2014: **Overcast** from 9:00 to 14:00 and from 15:30 to 17:00; **clear sky** from 14:00 to 15:30. a) 2.25 litre PET; b) 1.5 litre PET + foil; c) 1.5 litre PET; d) 1.5 litre PET + lengthwise black



A 4: Mathematical model of global radiation in Bairiki, Kiribati. Derived from the period July 1983 to June 2005; Data source: NASA (2005)





CONTACT DETAILS
Secretariat of the Pacific Community

SPC Headquarters
BP D5,
98848 Noumea Cedex,
New Caledonia
Telephone: +687 26 20 00
Fax: +687 26 38 18

SPC Suva Regional Office
Private Mail Bag,
Suva,
Fiji,
Telephone: +679 337 0733
Fax: +679 337 0021

SPC Pohnpei Regional Office
PO Box Q,
Kolonia, Pohnpei, 96941 FM,
Federated States of Micronesia
Telephone: +691 3207 523
Fax: +691 3202 725

SPC Solomon Islands
Country Office
PO Box 1468
Honiara, Solomon Islands
Telephone: + 677 25543 /
+677 25574
Fax: +677 25547

Email: spc@spc.int
Website: www.spc.int