Assessment of the Potential for Solar Disinfection (SODIS) in Kapingamarangi, Pohnpei State, Federated States of Micronesia and in Ailuk Atoll, Republic of the Marshall Islands

on behalf of the EU - North Pacific – Readiness for El Niño (RENI) Project

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1. Introduction

Poor or unacceptable drinking water quality is a growing concern not only among community members in the Republic of Marshall Islands (RMI) and in the Federated States of Micronesia (FSM), but also among sector professionals due to its direct influence on peoples' health. Though a variety of techniques are practiced throughout the Pacific Region, the search for better solutions is still a continuous effort. This is in one part due to the affordability of the technologies available and to the remote and isolated character of the Pacific Island countries, and in another part due to the un-comparable and unpredictable nature of the behaviours of these communities.

The Solar Water Disinfection (SODIS) process is a simple and low-cost technology used to improve the microbiological quality of drinking water. SODIS uses solar radiation to destroy pathogenic microorganisms which cause waterborne diseases. The use of this process is ideal in treating small quantities of water in areas without access to a central water treatment system, e.g. in remote communities on scattered islands. Furthermore, SODIS is especially designed for use at a small-scale level because it relies solely on locally available resources, such as PET reactors and sunlight. Sunlight treats the contaminated water through two synergetic mechanisms: radiation in the spectrum of UV-A and UV-B, and increased water temperature.

This study aims to assess the solar irradiation for a sustainable implementation of SODIS in Ailuk Atoll (RMI) and Kapingamarangi in Pohnpei State (FSM) to improve the water quality for residents and thereby reduce the incidence of waterborne diseases, including diarrhoea, typhoid and cholera.

2. Assessment of the potential of SODIS

SODIS uses solar radiation, UV-A and UV-B radiation in particular, as the media for deactivating or destroying bacteriological pathogens. Therefore, a look at global solar radiation levels can be used as a first indicator when assessing the potential of SODIS on RMI and FSM. The global solar radiation (or global horizontal irradiation) is the sum of direct and diffuse components of solar radiation (in kWh/m2). Research at the Swiss Federal Institute of Aquatic Science and Technology (EAWAG) revealed that at 30°C water temperature, a daily solar radiation dose of at least 2,50 kWh/m2/day (global irradiation) is required. A similar threshold, 2,78 kWh/m2 (or UV-A radiation dose > 750 kJ/m2/day or water temperature > 50°C for one hour), was defined by Stärz (2015) as the sufficient dose for SODIS applications in the Republic of Kiribati.

2.1. Republic of Marshall Islands, Ailuk Atoll

Ailuk Atoll, located at 10.3422° N, 169.9125° E, is a low-lying atoll with a rural environment and a population of 338 people. Residents rely on rainwater catchment systems and water extracted from shallow wells, which access the shallow freshwater lens beneath the island, for their drinking water supply. The community and household rainwater catchment systems are poorly maintained, rarely cleaned and have not been fitted with water quality accoutrements like first flush diverters. Some of the wells are located close to household septic tanks.

From 2007 to 2015 an average global irradiation of **5.77 kWh/m2 per day** was recorded on Ailuk, which is almost double the amount of the required threshold dose for SODIS. The northern islands of RMI like the Bokak or Bikar Atolls reach average doses of more than 6,2 kWh/m2 per day and prove to have the best solar conditions for SODIS in RMI. However, even atoll islands in the south of RMI like Majuro (RMI's capital), Jaluit or Mili witness average irradiation doses of up to 5,0 kWh/m2 per day and would be suitable locations for SODIS (see Fig 2).

2.2. Federated States of Micronesia, Kapingamarangi Atoll

Kapingamarangi is a remote, low lying atoll near the equator (1.0786099° N, 154.8075256° E) in Pohnpei State, with 474 residents. It is similar to the Ailuk environment, although more remote. In regard to the drinking water, most of the houses have thatched roofs, so they cannot act as water catchments. Therefore, most of the drinking water supply is obtained from specially built small catchments and the limited access residents have to well water. The result is both a scarcity of water supply and contamination in what is available.

From 2007 to 2015 an average global irradiation of **5.36 kWh/m2 per day** was recorded on Kapingamarangi, which also exceeds the required threshold dose for SODIS. Similar to the results for Ailuk, this is due to its very southern location close to the equator. Although the northern islands of FSM reach lower doses of solar radiation, all locations should be applicable for SODIS (see Fig 1).

2.3. Estimation of treatment time to disinfect drinking water

According to the general SODIS guideline of EAWAG (2016), the PET reactor needs to be exposed to the sun for six hours if the sky is clear (i.e., 0%-50% cloud cover). If there is 100% cloud cover, the bottles need to be exposed to the sun for two consecutive days. During days of continuous rainfall, SODIS does not perform satisfactorily. Rainwater harvesting is recommended during these days. Alternatively, if a water temperature of at least 50°C is reached, an exposure time of one hour is sufficient.

According to the recorded data in RMI and FSM, an average treatment time of 2,5h (Ailuk)/ 3h (Kapingamarangi) of sunlight with a clear sky would be sufficient. A similar disinfection rate was observed in Tarawa, Kiribati (Stärz, 2015): A 3-log reduction (99,9%) of all tested bacteria occurred after three hours on clear days and days with scattered clouds.

3. Recommendations

3.1. Behaviour change campaign design recommendations

Community promoters, called “water champions” in Kiribati, play 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 are influential to the people in charge of drinking water in individual households. The amount of motivation and enthusiasm in serving the community is a key criterion in the recruitment of these promoters. These criteria often apply to people who have been previously enrolled in SODIS trainings and integrated research projects. Promoters should have a solid understanding of WASH to prevent infections with waterborne diseases, a comprehensive knowledge of the application guidelines of SODIS 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 takes 1-2 days, depending on the tasks which promoters are expected to do. Refresher trainings throughout the course of the project are recommended.

It is recommended to roll out a **research integrated** behaviour change campaign, by which community promoters are actively involved in the research process, thereby increasing their engagement and ownership in the project. Solar radiation is the driver of the disinfection process and thus should be measured and its “high” values proved to the community. Quantitative bacteriological water quality tests indicate the concentration of pathogens in the water and visualize the contamination of drinking water before and after treatment. Test results showing zero contamination after SODIS treatment strengthens the community’s beliefs that the method works effectively and yields the benefits associated with safe drinking water consumption. Therefore, water quality tests 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. Such a research takes 5 to 7 days and can be combined with a training of the promotors and an official launch of the SODIS campaign, during which the research results can be revealed.

Information, Education and Communication (IEC) materials used in behaviour change campaigns should be attractive, adapted to the local context, and designed 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 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.

3.2. Technical recommendations for SODIS

On days with a clear or scattered sky, a much shorter treatment time (2.5 to 3 hours) should be needed in both atolls, compared to other tropical regions where the average recommended disinfection time under similar weather conditions is six hours. Nevertheless, it is recommended to increase treatment time (e.g., by a factor of two) to include a **safety buffer** due to various seasonal factors and weather patterns, unknown water sources or types of pathogens. Once the environmental conditions are assessed (e.g., through the research integrated approach), guidelines and thresholds based on weather conditions and treatment time can be amended for both locations.

Polyethyleneterephtalate (PET) has proven to be a suitable reactor material for SODIS processes, but there is potential for improvement of the SODIS system by using a different reactor material. Both UV-A and UV-B radiation are responsible for water disinfection, with UV-B being more effective than UV-A. UV-B radiation is responsible for most of the germicidal effects of sunlight on pathogens by directly destroying their DNA (Jagger, 1985). However, in past cases where SODIS was used, the geographical areas in which the countries were located did not receive sufficient UV-B radiation, so the reactor material chosen (PET) did not take UV-B radiation into account. Consequently, PET reduces the transmission of UV-B by around 60% (Stärz, 2015). However, the RMI and FSM atolls receive high amounts of UV-B radiation, which can be taken advantage of. Introducing reactors using other materials that are more UV-B transmissive (e.g., borosilicate glass), could be considered. This would greatly improve the disinfection process and the treatment time could be reduced to even one hour. Yet, the affordability and accessibility of the material chosen must be taken greatly into account.

Reactors used for SODIS should not exceed **two litres**, as suspended solids block UV radiation. At a water depth of 10cm and moderate turbidity of 26 NTU (Nepherometric Turbidity Units), UV-A radiation is reduced to 50%. Containers with a larger exposed area per water volume would be more efficient (Sommer et al., 1997).

Oxygen plays an important role in killing the pathogens. Sunlight produces highly reactive forms of oxygen (oxygen free radicals and hydrogen peroxides) in the water. These reactive molecules contribute to the destruction process of the microorganisms (Whitlam & Codd, 1986). At 100% oxygen saturation, the disinfection rate for E.coli and Enterococcus Faecalis is approximately double the rate compared to that of 50% oxygen saturation (Reed, 1997). The bottles should be shaken to aerate the water before the application of SODIS to ensure that the water contains a sufficient amount of oxygen (more than 3 mg oxygen per litre).

Preliminary treatment is necessary, such as sedimentation, flocculation, and filtration, if turbidity exceeds 30 NTU. This treatment should be considered if **groundwater** is used as a water source. Rainwater should be applicable for SODIS without prior treatment.

4. Conclusion

The SODIS technique is hardly known in the Pacific region, even though a large body of microbiological research has assessed and demonstrated the its effectiveness in destroying diarrhoea-causing bacteria and other parasites (e.g. Berney, et al., 2006; McGuigan, et al., 1998; Smith, et al., 2000; Wegelin, et al., 1994). In the year 2014, SODIS was tested in the Pacific region for the first time and successfully introduced to the Republic of Kiribati (Stärz, 2015). Similarly, the biggest challenge of this research was not the efficiency of the technology but to see how the technology could be best integrated in the daily lives of the Kiribati people.

It is expected that **SODIS would be very effective on both Atoll islands in RMI and FSM**. Nevertheless, compliance must be high to effectively reduce waterborne diseases with SODIS. People must consume the solar treated water habitually and exclusively. Moreover, it requires a **behaviour change**, since users must obtain 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. The biggest challenge in changing the behaviour of water users in the case of Kiribati was the acceptance of the method itself. SODIS was misunderstood as being too simple to destroy pathogens like bacteria and parasites.

In line with the successful implementation of a behaviour change campaign in Kiribati, it is crucial to show **evidence of the applicability of SODIS** to decision makers and to water users in the community. Campaigns are considered to be most effective when they address the behaviour change process holistically and employ a combination of promotional tools addressing the following factors: risk, attitude, norm, ability and self-regulation (see Appendix).

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GLOBAL HORIZONTAL IRRADIATION

FEDERATED STATES OF MICRONESIA

Kapingamarangi Atoll

Location
1.0786099° N, 154.8075256° E

Global horizontal irradiation
5.364 kWh/m^2 per day

Direct normal irradiation
4.732 kWh/m^2 per day

Diffuse horizontal irradiation
1.989 kWh/m^2 per day

Optimum tilt to maximize SODIS effect
3 ° / 180 °

Air Temperature
28.3 °C

Description:
This solar resource map provides a summary of the estimated solar energy available for Solar Water Disinfection (SODIS) and other energy application. It represents the average daily/yearly sum of global horizontal irradiation, covering a period from 2007 to 2015. The underlying solar resource database is calculated by a model from atmospheric and satellite data with 30-minute time step. The effects of terrain are considered at nominal spatial resolution of 250m. There is some uncertainty in the yearly GHI estimate as a result of limited potential for regional model validation due to lack of high quality ground measurement data, which is estimated to vary regionally from approx. 5% to 7%.
Author: Stärz, C. (2018)
Data Source: GSA (2016), owned by the World Bank

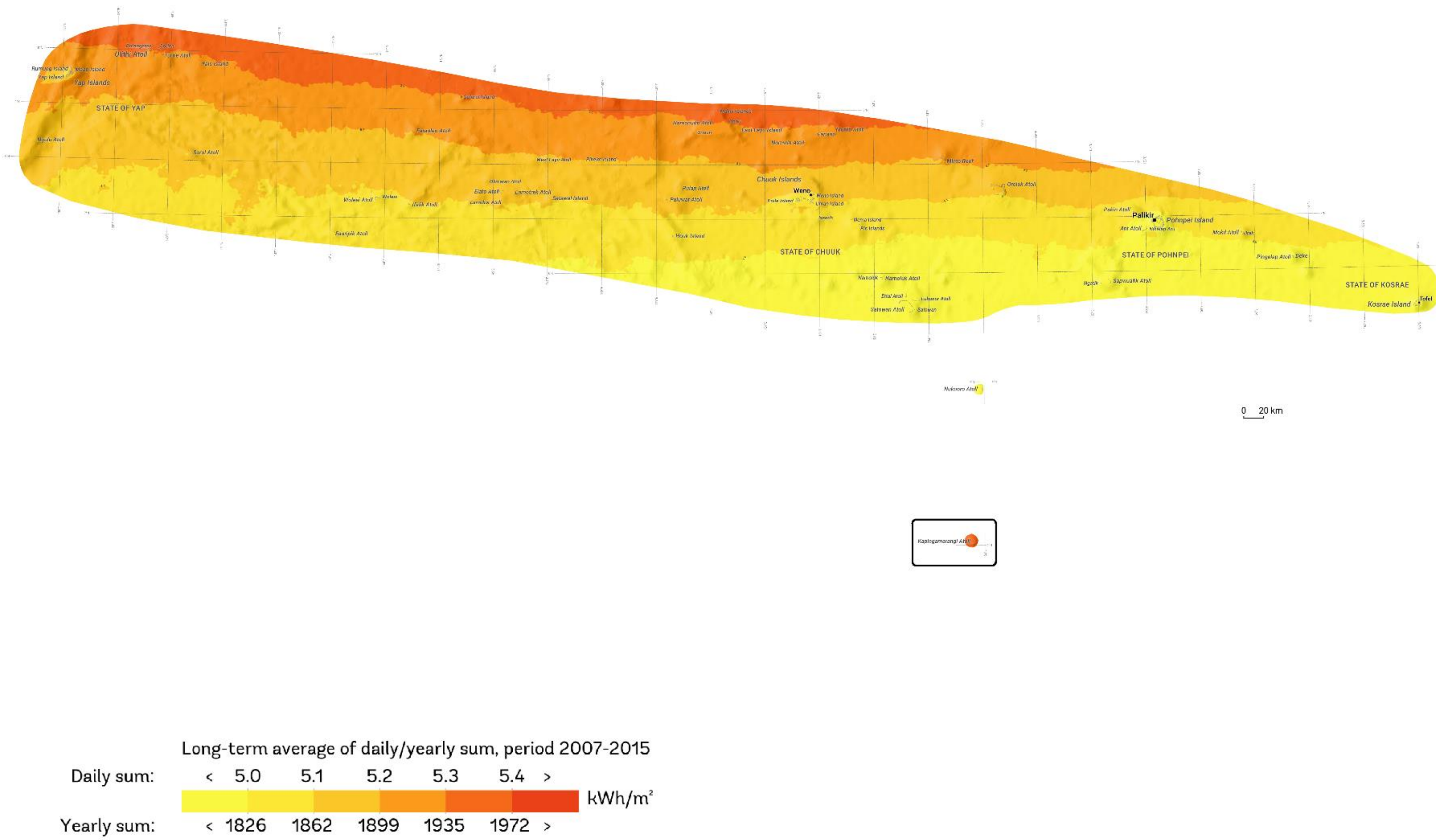

Fig 1: Global horizontal irradiation in the Federated States of Micronesia (2007-2015)

GLOBAL HORIZONTAL IRRADIATION

MARSHALL ISLANDS

Ailuk Atoll

Location
10.3422° N, 169.9125° E

Global horizontal irradiation
5.77 kWh/m² per day

Direct normal irradiation
4.907 kWh/m² per day

Diffuse horizontal irradiation
2.241 kWh/m² per day

Optimum tilt to maximize SODIS effect
12 ° / 180 °

Air Temperature
27.7 °C

Description:
This solar resource map provides a summary of the estimated solar energy available for Solar Water Disinfection (SODIS) and other energy application. It represents the average daily/yearly sum of global horizontal irradiation, covering a period from 2007 to 2015. The underlying solar resource database is calculated by a model from atmospheric and satellite data with 30-minute time step. The effects of terrain are considered at nominal spatial resolution of 250m. There is some uncertainty in the yearly GHI estimate as a result of limited potential for regional model validation due to lack of high quality ground measurement data, which is estimated to vary regionally from approx. 5% to 7%.
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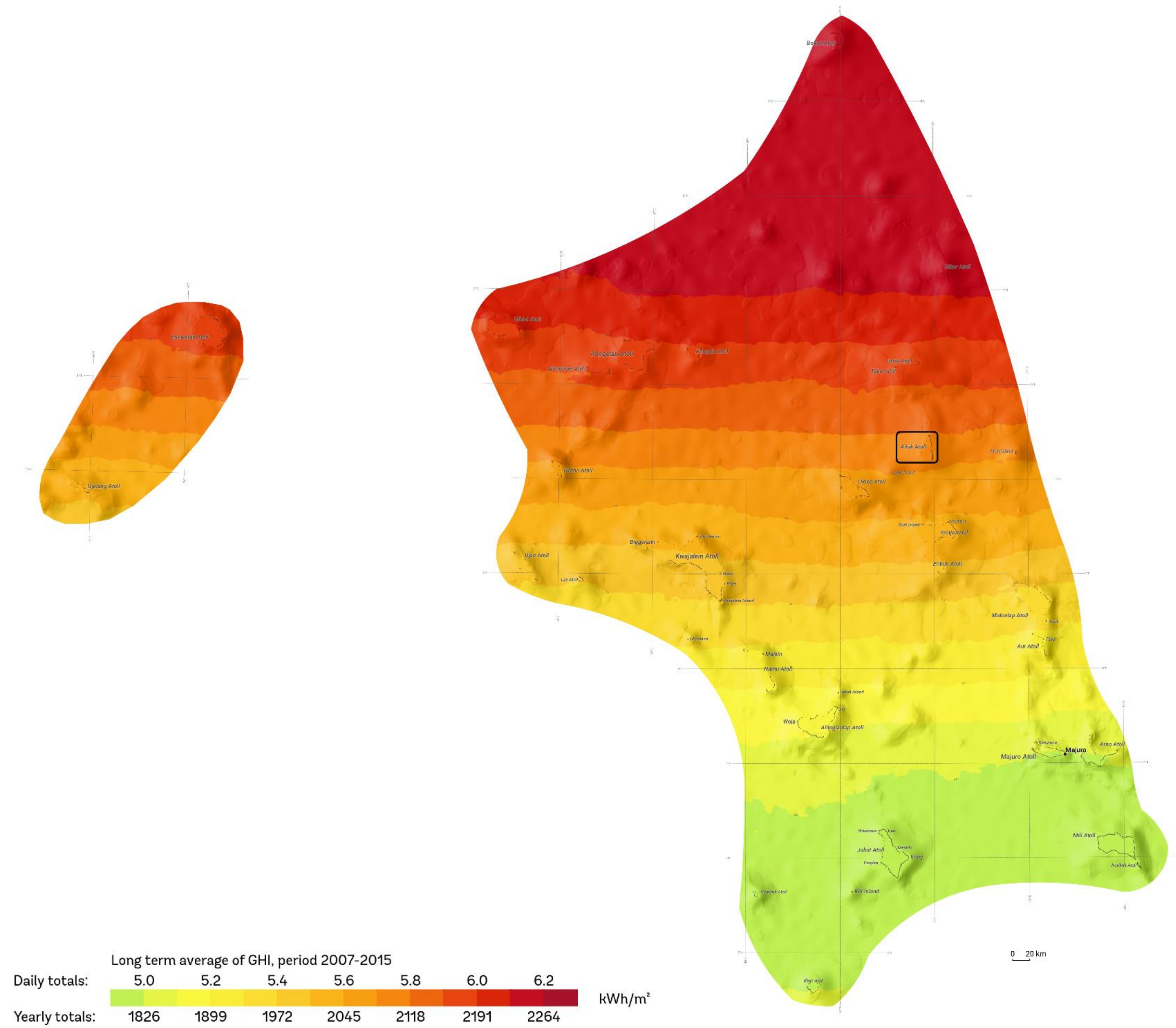

Fig 2: Global horizontal irradiation in the Republic of Marshall Islands (2007-2015)

Appendix

Promotion tools addressing behaviour change factors (according to EAWAG, 2016)

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.)

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

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%).

<u>**Addressing ability factors**</u> **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
<u>**Addressing self-regulation factors**</u> **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