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SOLAR TECHNOLOGY AS AN INNOVATIVE ALTERNATIVE FOR QUALITY WATER CONSUMPTION: THE HONDURAN EXPERIENCE IN RURAL COMMUNITIES

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SUMMARY

Incorporating innovative solutions that facilitate access to water quality for the population is a worldwide standard. For the first time in Honduras, this project aimed to evaluate the portable solar water heating system called "Solvatten" in two rural communities in the Department of La Paz, Honduras, with complementary initiatives to optimize its use. For the baseline survey and monitoring of the adoption of the proposed technology, semi-structured interviews, household observation, and focus groups with beneficiaries were conducted. The water's physical, chemical, and microbiological characteristics for human consumption were evaluated and compared to the Honduran government's current "Basic Analysis Program." The water used in households complies with the turbidity parameters required for using the Solvatten technology. In addition, the results showed a reduction in the positive sample percentage of E. coli collected from beneficiary households after using the Solvatten unit. This intervention, which included integrative actions such as training and delivery of complementary inputs, is considered positive, sustainable, and scalable to regions with similar conditions.

Introduction

Access to water for human consumption is a global issue. According to the World Health Organization (WHO, 2017), about 3 in 10 people (2100 million people) lack access to safe water at home, and 6 in 10 people lack basic sanitation services worldwide. This situation leads to more than 1.1 billion people at risk of becoming infected with pathogens commonly found in untreated water (Manzolillo, 2019). In addition, it is a potential vehicle for microorganisms that can directly affect health (causing diarrhea) and well-being (Assunta *et al*., 2016), mainly in children, making it the second leading cause of infant mortality. Furthermore, frequent diarrhea is a cause of malnutrition, increasing the risk of infectious or acute respiratory diseases (Dhrifi, 2018).

Access to potable water is effective in reducing the risk of diarrhea. Therefore, it is essential to develop innovative initiatives seeking access to safe and low-cost drinking water, contributing to public health (Graf *et al*., 2010). The use of solar technology has proven to be efficient in reducing microorganisms, which the WHO recognizes as one of the most appropriate methods for producing drinkable water in developing countries (Pichel *et al*., 2019). For example, SODIS technology uses solar radiation to increase water temperature, removing 98-99% of total and fecal coliforms after solar exposure (Okurut *et al*., 2013; Marobhe and Sabai, 2021). In addition, a study conducted in rural areas over a three-week

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TECNOLOGÍA SOLAR COMO ALTERNATIVA INNOVADORA PARA EL CONSUMO DE AGUA DE CALIDAD: LA EXPERIENCIA HONDUREÑA EN COMUNIDADES RURALES

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RESUMEN

Incorporar soluciones innovadoras que faciliten el acceso a agua de calidad a la población es un estándar mundial. Por primera vez en Honduras, este proyecto tuvo como objetivo evaluar el sistema portátil de calentamiento de agua con energía solar denominado "Solvatten" en dos comunidades rurales del Departamento de La Paz, Honduras, con iniciativas complementarias para optimizar su uso. Para la encuesta de línea de base y el seguimiento de la adopción de la tecnología propuesta, se realizaron entrevistas semiestructuradas, observación domiciliaria y grupos focales con los beneficiarios. Se evaluaron las características físicas, químicas y microbiológicas del agua para consumo humano y se compararon con el "Programa de Análisis Básico" vigente emitido por el gobierno de Honduras. El agua utilizada en los hogares cumple con los parámetros de turbidez requeridos para el uso de la tecnología Solvatten. Además, los resultados mostraron una reducción en el porcentaje de muestras positivas de E. coli *recolectadas de los hogares beneficiarios después de implementar la unidad Solvatten. Esta intervención, que incluyó acciones integradoras como capacitación y entrega de insumos complementarios, se considera positiva, sostenible y escalable a regiones con condiciones similares.*

A TECNOLOGIA SOLAR COMO ALTERNATIVA INOVADORA PARA UM CONSUMO DE ÁGUA DE QUALIDADE: A EXPERIÊNCIA HONDURENHA EM COMUNIDADES RURAIS

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RESUMO

A incorporação de soluções inovadoras que facilitem o acesso da população a água de qualidade é uma necessidade mundial. Pela primeira vez em Honduras desenvolveu-se um projeto visando a implementação do sistema portátil de aquecimento solar de água denominado "Solvatten" em duas comunidades rurais do Departamento de La Paz, com iniciativas complementares para otimizar a sua utilização. Para o levantamento de base e monitorização da adoção da tecnologia proposta, foram realizadas entrevistas semi-estruturadas, observação doméstica, e grupos focais com os beneficiários. As características físicas, químicas e microbiológicas da água para consumo humano foram avaliadas e comparadas com o "Programa de Análise Básica" emitido pelo governo hondurenho. A água utilizada nos lares cumpre com os parâmetros de turbidez necessários para a utilização da tecnologia Solvatten. Além disso, os resultados mostraram uma redução na percentagem de amostras positivas de E. coli recolhidas após a implementação com o Solvatten. Esta intervenção, que incluiu ações integrativas como formação e fornecimento de insumos complementares, é considerada positiva, sustentável e escalável para regiões com condições semelhantes.

period, which implemented three water purification methods (chlorine tablets, silver-infused ceramic tablets, and SODIS), reported that all water samples tested negative for *Escherichia coli* during the last week of testing for all methods (Ngasala *et al*., 2020). These results encourage the use of this type of technology for the benefit of the population.

In 2019 Zamorano University proposed implementing the "Solvatten" technology (a portable water heating unit, Solvatten AB, Sweden https://solvatten.org/) in Honduran rural communities, with training and water analysis to supply drinking water to beneficiary families. The water placed in the unit must be exposed to the sun for 2 - 6hours for its treatment, which complies with the WHO Guidelines for drinking water (<1 *Escherichia coli* / 100ml of water) (Jönsson *et al*., 2011). Solvatten is easy to operate, causing positive environmental impacts (Jönsson *et al*., 2011, Isberg and Nilsson, 2011). Solvatten is a portable dispositive that combines water treatment (solar radiation) and a water heating system to inactivate microorganisms that cause diarrhea or other diseases (Hagström and Lundström 2012). The equipment has a black hue to absorb more sunlight and thus raise the temperature to inactivate microorganisms. It has dimensions of 49 × 36 × 13cm, with the capacity to process 10,000mL of water (Solvatten 2019). When pouring the water into the Solvatten equipment, it passes through a cheesecloth filter which can be replaced by cloth garments, maintaining the economic stability of the users (Hagström and Lundström 2012). The entire assembly is designed to be durable and maintenance-free. Furthermore, it is friendly to people of all ages since it is designed so that everyone can understand when the water finishes its processing through visual indicators (indicator changes from a sad red face to a green happy face (see https://www.zamorano.edu/2019/11/14/corredor-seco-93-hogares-consumiran-agua-segura-partir-de-2020/). This paper aims to evaluate the Solvatten system implementation, used for the first time in Honduras, and provide recommendations for its performance on a larger scale.

Materials and Methods

The study was conducted with 100 families from Cedritos and La Laguna (Santiago Puringla municipality, department of La Paz), located between 1400 - 1500 meters above sea level and benefiting from the Rauteca micro-watershed (10 kilometers away). The water source of these communities is managed by a local water administration (LWA) board but without drinking water purification systems. The project was executed from March to September 2020, in which: 1) water quality was evaluated; 2) training was delivered on the use of the technology; 3) follow-up visits were conducted for evaluation of the implementation; 4) support to the LWA.

Community water evaluation

Water samples were collected in March 2020: 13 from random households, one from the water source, one from the storage tank, one from the Nutritional Training Center (NTC), and one from the Health Center (HC). Water samples were taken during morning hours (between 8:00-10:30) in sterile bags and maintained refrigerated for further microbiological analysis at the Food Microbiology Laboratory within 24h after collection. The presence of *Escherichia coli* and *Salmonella* spp. was determined by the membrane filtration technique (APHA 2017). Additionally, 3L samples were submitted to a private laboratory for physicochemical analysis according to Standard Methods for Examination of Water and Wastewater (APHA 2017): aluminum (method 3500-Al), calcium (method 3500 Ca B), chlorides (method 4500-Cl B), true color measurement (method 2120 C), hardness (method 2340 C), total iron (method 3500-Fe B), manganese (method 3500-Mn B), sulfides (4500-S2- F). The *in situ* analyses were carried out with a pocket tester (OAKTON PCTS tester 5) to measure conductivity, pH, total dissolved solids (TDS), salinity, and temperature. The National Technical Standard for the Quality of Honduran Drinking Water (1995) was used as a reference (Republic of Honduras, 1995).

Delivery of the technology

The HC and the municipality organized the participating households according to the LWA. A complimentary kit (funnel, bucket with lid and water outlet tap, cheesecloth filter, canteen, and training handouts) was provided to each family. The design and validation of the flyers served as training and reinforcement material for three key concepts: 1) use and handling of the Solvatten, 2) safe water consumption, and 3) environmental impact (see https://www.zamorano.edu/2020/09/17/agua-segura-cambiando-vidas-y-fortaleciendo-la-salud-de-familias-rurales-en-honduras/).

A training sessions program was developed starting in March (2020). Three stations were designed simultaneously for a dynamic approach to the three key concepts for half an hour each. They received the Solvatten and a complimentary kit and signed a commitment to its proper use. During the COVID-19 pandemic, following biosafety protocols, starting in July (2020), the investigators adapted the training to short videos with 15-person sessions to complete the delivery (see https://www.youtube.com/watch?v=lLyMXRJFo90).

Evaluation of the technology's implementation

Follow-up visits were carried out in August - September (2020) with a survey, an interview, and direct observation in 58 households. A structured questionnaire was used for the interviews (questionnaire available from the corresponding author upon request). In addition, three focus groups were conducted to assess the degree of adoption of the Solvatten and any limitations or difficulties in its use. A semi-structured questionnaire was used in groups of 5 to 8 participants; members of the LWA and women mothers of families were included. Seventeen treated water samples were randomly collected directly from the Solvatten and the treated water storage container for physicochemical and microbiological evaluation. Three additional samples were collected for microbial analysis from Solvatten units, where the treatment still needed to be completed since the families were using the under-processed water. All samples were collected during morning hours and kept refrigerated until analysis within 24h from the collection. The data was analyzed in the statistical program SAS v. 9.4 for the Chi-square test of equal frequencies to compare frequencies of *E. coli* positive samples between visits ($P<0.10$).

Support to the LWA

The development of a plan to improve water quality in the communities was defined for early implementation. While evaluating the impact of the use of the portable water purifier, at the same time, we worked with the water board to improve the water supply's benefits to their homes. The members of the Board received technical training on the use of the tablet chlorinator, proper maintenance of the community water repository tank, and managing the water system. As a result, the water distribution pipeline from the tank to the communities' homes was improved, as well as the household sanitation services, to prevent open defecation.

Results

Community Water Profilin

Regarding the treatment of drinking water before the distribution of Solvatten, 25% of the families indicated that they boiled it, 27% chlorinated it, 19% filtered it, 10% exposed the water to sun radiation, 6% applied combined treatments, 2% buy bottled water, and 10% did not apply any treatment. Information about chlorination and filtration methods was not collected. The results show that eight indicators were within typical values for the ranges established by the Honduran Technical Regulations (conductivity, total dissolved solids, temperature, aluminum, calcium, chlorides, and hardness) in the community's water sources. However, one sample showed a 6.1 value for the pH parameter, slightly below the recommended value of 6.5 (Republic of Honduras, 1995). For true color, nine samples were found to be above the permissible value of 15 Pt-Co, and in the case of iron, six samples were found to be above the allowable value ($0.3 mg \cdot l^{-1}$). Of the 17 samples, in the case of turbidity, 15 were below the maximum permissible limit (15 NTU) (Table I).

The absence of *Salmonella* spp. was reported in all samples. However, *E. coli* was present in 14/17 samples (82%) (Figure 1). These positive samples were from water sampled at the source, storage tank, HC, NTC, and households.

Follow-up visit and evaluation of the implementation of the technology

The microbiological results of household water after the supply of the Solvatten were negative for the presence of *Salmonella* spp. In addition, a reduction in the frequency of positive samples for *E. coli* 9/20 (45%, $P<0.1$) was observed (Figure 1). However, their presence (1 - 79 CFU/100ml) in the Solvatten-treated water samples may be attributed to incomplete device cycling (some users reported insufficient solar radiation because of cloudy days and no change of the color indicator), use of turbid water (turbidity values > 5 NTU), or post-treatment contamination. Collivignarelli *et al*. (2018) compared conventional disinfectants' advantages and disadvantages, including solar energy. They pointed out the weakness: it is not suitable for waters with high levels of suspended solids, turbidity, color, or soluble organic material.

In a separate study conducted by the authors, Solvatten's efficiency was evaluated by introducing purified water inoculated with bovine feces to reach 5 logs CFU/100ml of coliforms and *E. coli*. The equipment, when properly

TABLE I
PHYSICAL AND CHEMICAL CHARACTERIZATION OF COMMUNITY WATER

Parameter	Recommended value	Max. Allowed value	Average ± std dev (Visit 1, n= 17)	Average ± std dev (Visit 2, n= 17)
Aluminum ($mg\cdot l^{-1}$)	–	0.2	0.05 ±0.03	0.15 ±0.07
Calcium ($mg\cdot l^{-1}$)	100	–	11.53 ±2.70	6.88 ±0.44
Chlorides ($mg\cdot l^{-1}$)	25	250	2.74 ±0.82	4.72 ±1.89
True color measurement (Pt-Co)	1	15	23.94 ±19.48	< 1
Hardness ($mg\cdot l^{-1}$ $CaCO_3$)	400	–	< 0.01	25.55 ±0.89
Total iron ($mg\cdot l^{-1}$)	–	0.3	0.29 ±0.19	< 0.1
Manganese ($mg\cdot l^{-1}$)	0.01	0.5	0.05 ±0.02	< 0.05
Sulfides ($mg\cdot l^{-1}$)	—	0.05	< 0.04	< 0.04
Conductivity ($\mu S\cdot cm^{-1}$)	400	–	69.36 ±3.06	7.23 ±1.12
pH	6.5-8.5	–	6.77 ±0.21	7.13 ±0.22
Total dissolved solids ($mg\cdot l^{-1}$)	–	1000	34.83 ±1.46	3.58 ±0.57
Turbidity (NTU)	1	15	1.43 ±0.49	12.61 ±3.89
Temperature (°C)	–	–	18.73 ±1.15	20.59 ±0.98

Recommended and Maximum values established by Honduran technical regulation.

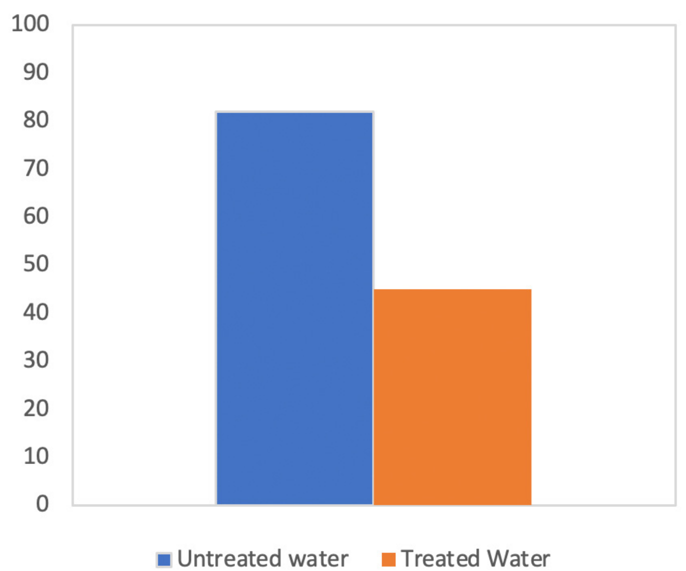

Figure 1. Microbiological water quality results. Untreated water shows the percentage of positive *E. coli* (≥ 1 CFU/100 ml) of water sampled before implementation of the Solvatten technology. Treated water refers to water collected from households after being treated with the Solvatten unit.

operated, reduced the concentration of total coliforms and *E. coli* up to 99.9% with an average exposure time of 4.62 ±0.86 hours, in which the water reached a temperature of 56.5 ±5.0°C (results obtained from five independent trials). Upon these findings, water would comply with the *E. coli* limit (<1 CFU/100ml) when the concentration of the water to be treated is less than 1000 CFU/100ml and the equipment is used correctly (water filtered through a cotton cloth and waiting until the color indicator changed to green, see supplementary material S1) (Fajardo *et al*., 2021). The treated samples that met the microbiological criteria were collected directly from the Solvatten units and the container for treated water storage. These findings confirm no immediate deterioration of water quality when filling the collection containers, consistent with other studies (Trevett *et al*., 2005).

Like others in developing countries, the communities in this study are forced to use any water available, even from unprotected sources, which leads to increased diseases (Ngasala *et al*., 2018). Unfortunately, shared experiences on the implementation of Solvatten are scarce. However, some techniques with proven efficacy using solar energy (Zaman *et al*., 2019) contribute to public health. They can play a prominent role in reducing the water-borne disease burden in rural communities (Chu *et al*., 2019), upon which this project was based.

Use of Solvatten

Unlike other studies that reported only partial adoption of solar SODIS technology (Islam *et al*., 2015; Rainey and Harding, 2005), all families said no problems or difficulties were addressed using Solvatten. In addition, the investigators observed the correct use of the technology during the visits. During the interviews, Solvatten users reported that in most cases, the water takes between 2 and 6 hours to purify, depending on the sun's intensity. Sometimes it takes up to 8 hours to purify their water, especially on cloudy days. Regarding the number of times, they use Solvatten per day, users use it according to their needs and the sun's intensity. Some use it one time a day, and others two times. They use it 3 to 8 times a week and an average of 2 times a day. Participating families expressed satisfaction with Solvatten, one of them indicated "that her young daughter has not been sick with diarrhea since they have been using the Solvatten." Also, 66% of those interviewed believe that "good health" is a benefit of using this innovative solution, 14% associated it with improving life quality, and the remaining 5% with ease of use.

Initiatives for Sustainability

The main problems identified by the LWA regarding access to quality water were weak water system management and homes with limited sanitation services infrastructure. As a result, a water quality improvement plan was developed and implemented that included five components: installation of a chlorinator and provision of portable equipment; training; improvement of the water pipeline; supply and installation of latrines; and inter-institutional coordination.

Conclusions

The beneficiaries widely adopted the Solvatten units, and their use was facilitated by a kit and training sessions. The results showed that the water is safe for human consumption after being exposed to this technology, guaranteeing compliance with the storage and hygienic practices. However, for future experiences, it is important to consider weather conditions and use a water filtering system to reduce dissolved solids.

The difficulties that families faced were that the water came with residues during the rainy season, for which they were provided with cheesecloth filters. Another area for improvement was the intensity of solar energy; the process is not complete during cloudy days. Therefore, other water treatments, such as boiling or chlorination, should be applied when the process is incomplete.

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