Effectiveness of Solar Water Disinfection - "SODIS method", for the removal of total coliforms in municipal surface waters.

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ABSTRACT
According to the new UNICEF/WHO report, about 2.2 billion people worldwide lack safe drinking water services, 4.2 billion people lack sanitation facilities and 3 billion lack basic hand washing facilities. The objective of this study is to evaluate the effect of the SODIS method for the removal of total coliforms in surface water. For this purpose, surface water samples were taken, avoiding exposure to sunlight during storage. Subsequently, total coliforms were isolated from the samples, which were used to make controlled contamination of the experiments, to apply the SODIS method, three ranges were established for turbidity (99, 40 and 16 NTU) and thickness (0.0140, 0.0113 and 0.0110 cm/ml) and were subjected to radiation of 1182 ± 122 W/m^2 and 955.1 ± 425 w/m$^{2.}$ respectively. As a result, a pattern was observed in which the lower the turbidity and thickness, the higher the percentage of removal. For a low turbidity (16 NTU) a removal of 99.7 ± 0.2% was obtained and for a thickness of 0.0110 cm/ml a removal of 99.9%. Based on this, it is concluded that the SODIS method is a viable alternative for water purification and that it can be improved by reducing turbidity and increasing thermal heating and UV radiation.

Keywords: Solar disinfection; bacterial inactivation; ultraviolet rays, PET.

Introduction

Water is essential for the development of human physiological processes; therefore, it is the most abundant component in the body with an average of 60% (Salas et al., 2020); due to its importance and the scarcity of this resource in different regions, surface water is often used as an alternative supply of drinking water. These waters do not have any type of treatment and consumers are exposed to drinking water contaminated with various microorganisms such as total coliforms; because raw water is their only source of supply, cases of intoxication occur frequently in rural areas (Feria et al., 2020). In Colombia, a significant number of people consume water contaminated with feces, affecting their health and well-being; according to a study by Vargas (2020), approximately 5 million Colombians in rural and urban areas have limited access to safe drinking water, resulting in a high risk of waterborne diseases, being a serious problem in regions such as La Guajira and Chocó, where sanitation infrastructure is deficient and communities face high rates of water contamination (Vargas, 2020).

It is known that not all the population in rural areas has access to drinking water and the SODIS method responds to this situation by being an alternative used for water disinfection that consists of using Luzsolar together with glass bottles commonly made of polyethylene terephthalate containing the water to be treated, allowing the elimination of pathogenic agents due to the germicidal effect of the UV radiation emitted by the sun (Oviedo, 2023; Aquinaga & Medeiros, 2022).. The effectiveness of the method depends on several factors such as the physical and chemical characteristics of the water to be treated, the intensity of solar radiation and even the exposure time together with the type of container. Likewise, the geographical location and climate can directly influence the effectiveness of the treatment (Feria et al., 2020). This method is an easy and low-cost solution for populations that do not have the resources to purchase drinking water (Santos and Tirira, 2020).

The application of the SODIS method removes total and fecal coliforms which are Gram-negative bacilli that grow in aerobic environment (Gianoli, et al., 2018) Total coliforms are a group of bacteria commonly found in the environment, including soil, vegetation and surface water; these bacteria are used as indicators of water quality and the possible presence of pathogens therefore the presence of total coliforms in water may suggest microbiological contamination and the need for further treatment or investigation of the source of contamination (Ashish et al., 2023). These microorganisms include several species of bacteria, such as Escherichia coli and other related genera, which are capable of fermenting lactose producing gas and acid. Detection of total coliforms is commonly carried out by methods such as membrane filtration and the multi-tube technique, which allow enumeration and confirmation of the presence of these bacteria in water samples (Ashish et al., 2023).

Therefore, it is important to evaluate whether the effect of the SODIS method is significant and what variables influence its effectiveness in removing total coliforms in surface water samples. This study focused on evaluating the turbidity and thickness on the total coliform removal effect of the SODIS method in a jagüey in the municipality of Pijiño, department of Magdalena.

Materials and Methods

Study location and sampling

The research was conducted on a farm in the municipality of Pijiño del Carmen, Magdalena with an average annual temperature of 24 °C to 37 °C and clear weather condition (Weather Spark, 2018).

The samples were taken from the surface water of a jagüey from which the farm is supplied. Sampling was carried out by collecting the water in a sterile glass container, storing it under refrigeration and transferring it to the Biotechnology and nanotechnology laboratory of the technopark network (SENA) (Infante et al., 2016).

Isolation and identification of total coliforms and Escherichia coli.

The strains of total coliforms and Escherichia coli were obtained from a sample of well water from the jagüey; 1 ml of the sample was taken and inoculated in Chromogenic medium which was incubated at 37ºC for 24 hours. After this time, the blue colonies showed the presence of E. coli and the pink colonies showed the presence of total coliforms (Quintero et al., 2021; Chiquito et al., 2020).

Preparation of inoculums for controlled contamination

Total coliforms and E. coli previously identified were cultured in nutrient medium and incubated at 37 °C for 24 hours. Once the pure colonies were obtained, controlled inoculation was performed in tubes with 10 ml of sterile saline solution until reaching a concentration of 5.0 McFarland degrees (6x108 CFU/ml), once the concentration was known, it was adjusted to 5000 CFU/ml, using the formula $C1 \times V1 = C2 \times V2$, where C1 is the initial concentration, C2 is the desired concentration, V1 is the initial sample volume and V2 is the volume required to obtain the desired concentration (Navarro et al., 2010). This concentration was chosen because it was the average concentration of total coliforms contained in the water sample.

Sampling and turbidity analysis

Three samples of water from the jaguey were taken for turbidity analysis in the Hach 2100N equipment, for which the sample was initially homogenized and 1 ml was taken and placed in the equipment cell without generating bubbles. Three levels of turbidity were determined: high, medium and low, corresponding to 99 NTU, 40 NTU and 16 NTU, respectively. From these data, the percentage removal of turbidity and total and fecal coliforms was determined by applying the SODIS method using the equation (Cifuentes, 2022; Feria et al., 2020).

Establishment of the water layer of samples to be subjected to the SODIS method

The samples were sterilized and added in PET bottles, taking into account three water film thicknesses: 0.0140, 0.0110 and 0.0113, which were calculated under the following formula **Z=L/V** where **Z:** Water thickness (mm/ml) **L:** Water film (mm) **V:** Water volume (ml). Based on these data, the percentage removal of turbidity and total and fecal coliforms was determined by applying the SODIS method. (Adolfo-Chávez, 2021).

Average hourly irradiance

The SM 206 solar radiation measuring equipment was used to measure irradiance during each hour during the exposure of the samples. The unit of measurement of irradiance is given in units of W/m^2, the average of hourly measurements was taken according to the exposure time to determine the value of $W*h/m^2$, applying the following formula (Alfares, 2017):

$$\text{Hourly Average Irradiance} = \frac{(\text{Measurement 1}+\text{Measurement 2}+\text{Measurement 3}+\cdots.\text{n})}{(\text{number of measurements taken})} = (\frac{\text{W}}{\text{m2}})$$

Submission of the sample to the solar disinfection method SODIS

Initially, water was added from the jaguey with high, medium and low turbidity levels previously sterilized in PET bottles up to ¾ of its capacity and the bacterial inoculum was added, homogenized for 20 seconds and more water was added until the capacity was completed; subsequently, the PET bottles were taken with the three thicknesses of water sheet and the bacterial inoculation was performed and homogenized for 20 seconds.

Each treatment consisted of three replicates and were exposed to the sun on the roof for 5 to 6 hours during two days. For the controls, the same procedure was carried out without sun exposure.

For the determination of the efficiency of the SODIS method, the analysis of total and fecal coliform removal was carried out by taking 1 ml of the treatments and inoculating them in 20 ml of molten medium, which was homogenized with rotary movements. Once the medium solidified, it was incubated at 35°C for 48 hours. In addition, 1 ml of the treatments was taken to measure turbidity removal.

The following formula was taken into account:

$$\%\text{removal turbidity} = \frac{\text{Turbidity after SODIS treatment}}{\text{Turbidity before SODIS treatment}} \text{ x } 100$$

$$\% \text{ coliform removal} = \frac{\frac{\text{UFC coliform}}{\text{ml}} \text{ after SODIS treatment}}{\frac{\text{UFC coliform}}{\text{ml}} \text{ Before SODIS treatment}} \text{ x } 100$$

Application of sodium hypochlorite at a concentration of 1.5 mg/liter.

In a PET bottle, 225 ml of sample + 1.5 mg/l of sodium hypochlorite were added, the sample was homogenized and completed with 75 ml of sample for a total of 300 ml. The sample was sealed and stored at room temperature without direct sunlight, this was done in order to compare the SODIS method with the natural disinfection method used in treatment plants.

Statistical analysis

The data were tabulated and processed in the SPSSS version 27 program, applying mean comparison by means of ANOVA of one factor and Tukey's post-hoc test with Alpha of 0.05. The results were obtained and an exploratory analysis was carried out.

Results and discussion

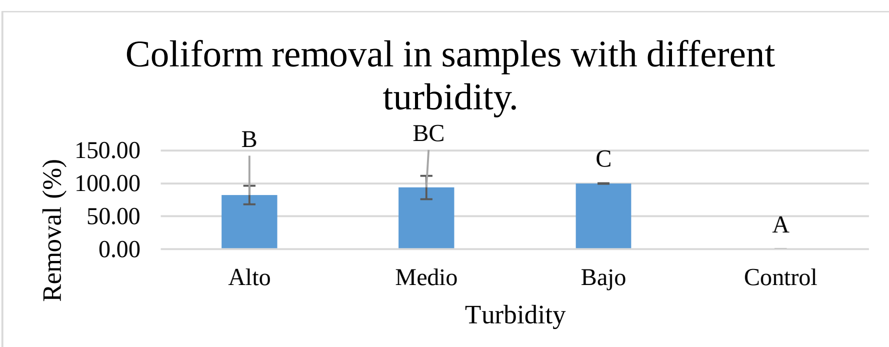
Determination of the effect of radiation and organic matter content in contaminated water samples on the reduction of total coliforms.

Once the samples with different turbidity levels were prepared, they were exposed to an average radiation of 1182 ± 122 W/m2 and after the exposure time, the coliform count was carried out to determine the percentage of removal (Figure 1).

The removal of coliforms is mediated by turbidity, as evidenced by the 82.3 ± 5.6 % removal rate at high turbidity and 99.7 ± 0.2 % at low turbidity. Likewise, the ANOVA analysis of variance shows that in at least one of the treatments the average percentage of removal is different, with 95% reliability, according to Tukey's test (letters above the bars) the percentage of removal of the treatments (high turbidity and low turbidity) are statistically different, also all treatments were different from the control (Figure 1), with low turbidity being the treatment with the best results, suggesting that the sodis method is more effective when there is a lower concentration of undissolved organic matter in the samples. (This suggests that a physical pretreatment of the water should be done to remove these particles, since they can be used as a protective barrier and a source of nutrients and energy for coliform bacteria).

Dessie et al. (2014), among the variables that have the greatest impact on the correct operation of the SODIS method are: water turbidity, temperature and the type of container to be used, therefore, the control of these variables can generate the optimization of the result of this study.

Figure 1. Coliform removal in samples with different turbidity.

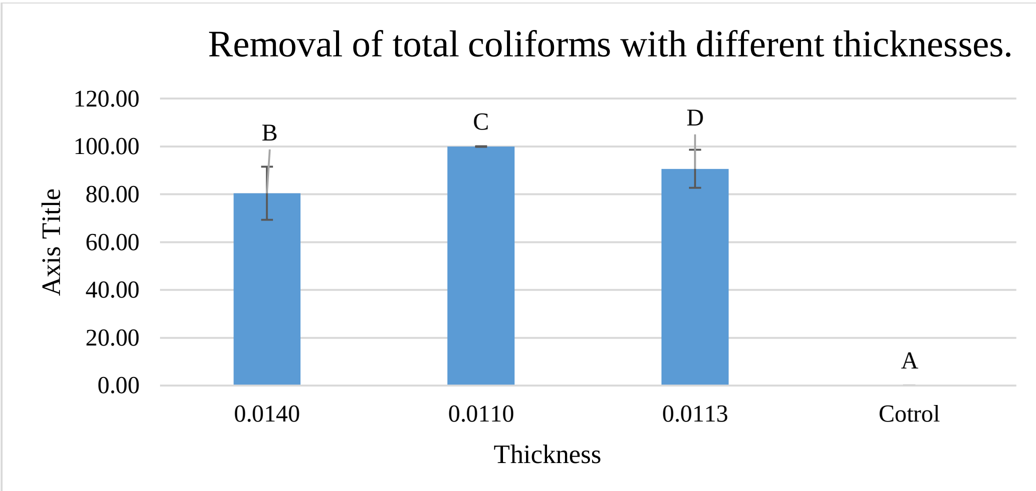


Note: Turbidity: high = 99 NTU, medium = 40 NTU and low = 16 NTU. Own source.

Determination of the effect of radiation and water layer thickness in contaminated water samples on the reduction of total coliforms.

Samples with different thicknesses and low turbidity (16 NTU) were exposed to an average radiation level of 955.1 ± 425 w/m2 at an average radiation level of 955.1 ± 425 w/m^2.

Figure 2. Removal of total coliforms according to the thickness of the water sheet.



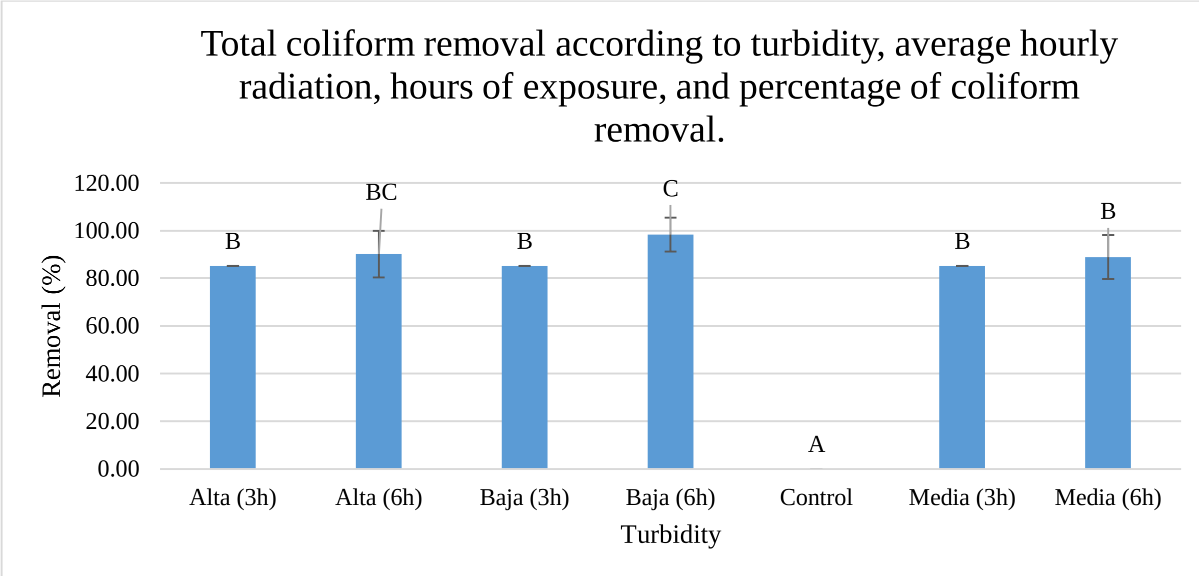
There is evidence of an increasing removal percentage as the thickness decreases, obtaining a removal of 80.4 ± 4.5 % for the thicker sample and 99.9 % for the thinner sample. In addition, graph 2 shows that the three treatments show significant differences, with the thinner treatment showing the lowest dispersion. The ANOVA analysis of variance shows that in at least one of the treatments the average percentages of total coliform removal are different, with 95% reliability, according to the Tukey test (letters above the bars) all treatments are statistically heterogeneous, indicating that the thickness has a direct influence on the solar disinfection process.

According to García et al. (2021), having greater thickness decreases the passage of UV-A radiation, which conditions the efficiency of disinfection, which tends to make it a slow method, with low performance and a high level of uncertainty with respect to the radiation received.

Establishment of the effect of radiation and exposure time in contaminated water samples on the reduction of total coliforms.

Figure 3 shows that the effect of the exposure time of the samples to solar radiation corresponding to 955.2 ± 425 w/m^2 is not notable, observing that the removal for high and medium turbidity is statistically similar, and that at low turbidity there is a significant increase in the removal of total coliforms with longer exposure time;

Figure 3. Graph of total coliform removal according to exposure time.



Source: own

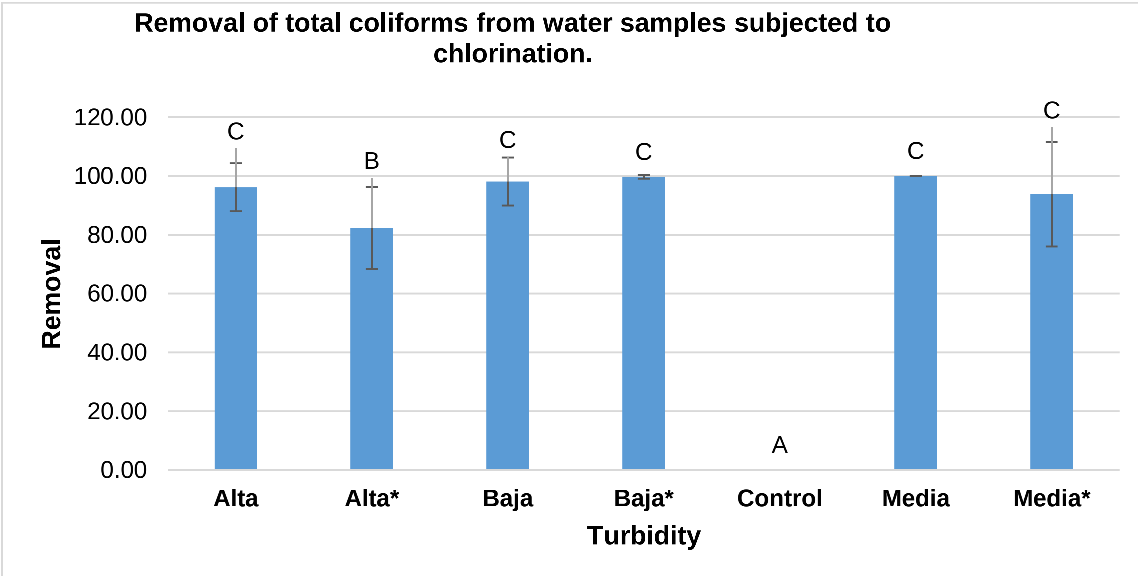
To compare the results of total coliform removal between the solar irradiance method and the traditional method (chlorination).

Samples subjected for 45 minutes to 1.5 ppm chlorine showed a better total coliform removal rate reaching 100 % at medium turbidity, although in an exploratory analysis a removal pattern like that of radiation can be inferred in which the treatment efficiency is limited to the turbidity of the water.

As observed in Figure 4 there is not a wide range of difference between treatments, (However, it is observed that at high turbidity there is a significant statistical difference between treatment with SODIS treatment and treatment with chlorine, at medium and low turbidity there is no significant statistical difference between treatment with chlorine and SODIS treatment, suggesting that turbidity is the limiting variable for the effectiveness of the method, in each treatment the removal of total coliforms was greater than 95 % in low turbidity conditions (16 NTU); Benabbou et al. (2024) and Garcia et al. (2021) emphasize turbidity as a factor of reduced effectiveness and increased exposure time, hence the difference between direct contact of chlorine with the sample and indirect contact of radiation on the sample; Martinez et al. (2019) refers to turbidity as a limiting factor in the drinking water treatment process, because microorganisms can be protected by suspended solids in the water where disinfection agents such as radiation cannot enter , therefore if we analyze the advantage that exists in the direct action of homogeneity between two liquids and the range of contact that derives from this, the efficiency of chlorine can be understood.

Likewise, Feria et al. (2020) describes that the germinicidal effect of the SODIS method is mediated by thermal heating and UV radiation; in turbid waters, suspended solids adsorb and retain solar heat (HANNA Instruments, 2024), which supports the removal pattern of the SODIS method being higher the lower the turbidity.

Figure 4. Graph of total coliform removal from water samples subjected to chlorination.



Note. the * refers to treatments with mean radiation of 1182 ± 122 w/m2 and the * refers to treatments with 1.5 ppm chlorine. the letters above the error bar indicate whether there is a significant difference: different letters = significant difference between the groups evaluated, identical letters = no significance.

Dessie et al. (2014) makes the adjustment of the SODIS method based on their research managing to optimize the method by achieving the removal of 99.99 % of coliforms, this in radiation conditions of 166.2 w/m^2, turbidity of 2 NTU, pH 7, OD of 6.52 mg/L, black colored PET bottle with half surface area and water depth of 10 cm.

The modification of the SODIS method allows water purification to be of higher quality without losing the concept of easy and economical, and this can be seen in graph 2 in which the modification of the thickness is a factor that increases or decreases the removal. This is similar to the studies carried out by Aquinaga and Medeiros (2022) and Cifuentes (2022) who determine the variation in the removal according to the depth, surface and storage element used.

Conclusion

The SODIS method is a viable and affordable alternative for the removal of total coliforms present in water. For its optimal application, variables such as turbidity and thickness must be taken into account, the lower the turbidity and thickness, the greater the removal of microorganisms mediated by exposure to the sun.

At a turbidity of 16 NTU and a thickness of 0.0110 cm/ml a better performance of the method was obtained, being the removal of 98.35 % and 99.9 % respectively , compared to methods such as the application of chlorine, there is no wide range of difference that indicates that the SODIS method has no potential. Also, it can be inferred that the SODIS method can be optimized by reducing turbidity and increasing the transfer of radiation to medium.

Based on the results obtained, the SODIS method can improve its effectiveness by implementing filtration systems prior to exposure in order to guarantee the reduction of turbidity, taking into account the permissible limit for human consumption established by Colombian regulations and the study to carry out studies with water film thickness <0.0110 cm/ml.

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