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Assessment of High-Volume SODIS Reactor under Sub-Tropical Climate Conditions in Bangladesh.

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[A Thesis Submitted for the Degree of Bachelor of Science in Civil Engineering in Partial Fulfillment of the Requirements to the Department of Civil & Environmental Engineering]

Supervised by

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DECLARATION

It is hereby declared that the thesis, "Assessment of High-Volume SODIS Reactor under Sub-Tropical Climate Conditions in Bangladesh," submitted to the Department of Civil & Environmental Engineering is an original work accomplished under Prof. Dr. Md. Rezaul Karim's supervision and has not been handed in for credit toward a degree or diploma elsewhere.

Every source of data included in the thesis is properly referenced, and all ethical research techniques and standards of academic integrity were maintained throughout this work.

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DEDICATION

This thesis is dedicated to our parents and our family, whose unwavering support and encouragement have been my guiding light throughout this journey. To our friends, who have provided us with the strength and companionship needed to complete this research.

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ABSTRACT

In the present time, 98% of the Bangladeshi population is under basic water coverage and approximately 97% rural population and 82% urban population use ground water for drinking purpose (Khan, 2019; Hasan et al., 1999; Zuthi et al., 2009) . However, according to the latest Joint Monitoring Programme (JMP) report of 2022, with 86% of the poorest households showing E. coli contamination which has become a particular concern (Wateraid Bangladesh). Considering Bangladesh's subtropical climate, this research investigates the efficacy of Solar Water Disinfection as a sustainable and cost-effective method for purifying untreated large volume of groundwater to meet up the daily consumption (Kremere et al., 2019).. The importance of this topic lies in its potential to address the pressing public health crisis caused by untreated and contaminated water, which contributes to approximately 1.5 million deaths annually (Meierhofer & Wegelin, 2002). Despite existing studies on SODIS, there remains a significant gap in understanding its effectiveness for large volumes of E.coli contaminated water under varying environmental conditions, particularly in regions with high temperatures and seasonal fluctuations. The objective of this study is to investigate the appropriate exposure times and circumstances for SODIS, including salinity, pH fluctuation, and approximate H2O2 levels, in order to guarantee effective water purification. Furthermore, the study evaluates microbial reduction rates and the practical use of SODIS in local communities. By aligning with the targeted Sustainable Development Goals (SDGs) of 2030, the research aims to contribute to the development of sustainable water treatment solutions, particularly in some areas of Bangladesh where traditional water treatment methods may be unavailable or too costly and also other sub-tropical regions facing challenges associated with waterborne diseases. Altogether this research emphasizes the feasibility of SODIS as a practical solution for improving water quality and public health in Bangladesh, recommending for its broader implementation as part of integrated water management strategies.

CHAPTER 1: INTRODUCTION

1.1 General

Access to clean, uncontaminated water sources is a fundamental human right but millions of people still struggle to achieve this nationwide. Drinking untreated water exposes people to a variety of pollutants, such as chemical pollutants and infections carried by the feces (World Health Organization, 2023). As a result, drinking contaminated water that has been left untreated or improperly treated can lead to the spread of diseases like cholera, polio, and diarrhea, which can be extremely deadly (McGuigan et al., 2012). At least 1.8 billion individuals drank water tainted with feces in 2015, and 663 million people were reported to have utilized untreated water sources (WHO & Fund, 2021). Approximately 780 million people lack access to clean, safe water for cleaning, cooking, or drinking worldwide (Chan, 2019). Consequently, the yearly mortality rate from drinking untreated or polluted water is estimated to be 1.5 million (WHO, 2023). Availability to clean, safe water would avoid these deaths, but large-scale treatment systems have prohibitive upfront costs and ongoing maintenance needs that make their implementation difficult in dispersed or isolated populations (UNICEF, 2023). Finding inventive and durable solutions in this challenging scenario is essential to ensuring that everyone has access to clean drinking water. There are various conventional methods for treating water that can be used to deactivate microbes. Developed countries are typically able to afford to use complex systems that rely on chemical processing and filtering. These systems ensure that the water supply meets all national and international standards. However, the costs of infrastructure, operations, maintenance, and supplies are quite high in many poor countries. (Parvin et al., 2022). The current focus is on developing a powered by solar energy passive system that does not rely on chemical, mechanical, or electrical inputs. One such option that has developed is Solar Water Disinfection (SODIS) (McGuigan et al., 2012). Heat, UV radiation, and visible light combine to eliminate microorganisms in filled polyethylene terephthalate (PET) water bottles in the sun for around six hours (typically for 1.5L to 2 L), making the water safe to drink (Moreno-SanSegundo et al., 2021). For treating microbiologically polluted water at the house level, SODIS is an easy, economical, and ecologically friendly solution. SODIS improves the quality of drinking water by efficiently eliminating waterborne pathogens through the utilization of solar radiation (Stefan, 2017). It presents a very promising strategy to lessen the dearth of resources for clean water. Because the system is modular, it may be used in conjunction with other systems to enhance the capacity of water treatment as needed (Meierhofer & Landolt, 2009). Besides, PET containers ensure the efficacy of photo inactivation by efficiently penetrating the visible and UVA (400nm-750mm) light spectrums, killing bacteria without directly affecting genetic material and enabling the water safe to drink (Meierhofer & Wegelin, 2002).

1.2 Background

Solar Disinfection (SODIS) is a low-cost, effective method for disinfecting drinking water using sunlight (*UNICEF Water and Sanitation Activities*, 1984). SODIS has been extensively researched and implemented, particularly in regions with limited access to clean drinking water (Bryjak et al., 2016). The technique relies on the UV-A component of sunlight to inactivate microorganisms, which are damaged by UV-A radiation when exposed to clear plastic bottles (Tyrrell & Keyse, 1990). PET bottles are particularly effective for SODIS, as they do not leach harmful chemicals under sunlight exposure and allow sufficient UV-A penetration to achieve effective disinfection (Meierhofer & Wegelin, 2002) (Meierhofer, 2009). A research reveals that SODIS can reduce infant diarrhea by up to 45%, demonstrating its potential as a vital public health intervention in areas lacking access to clean water (McGuigan et al., 2012). The effectiveness of SODIS is influenced by environmental factors such as solar intensity and water turbidity (García-Gil et al., 2020). High solar intensity and clear skies are optimal for SODIS, while rainy seasons and cloudy conditions can reduce its effectiveness. Turbid water, with high levels of suspended particles, can hinder UV penetration, necessitating pre-treatment steps like filtration to enhance SODIS efficacy (García-Gil et al., 2020).

1.3 Mechanism of SODIS

Water that has been contaminated can be purified using the Solar Disinfection (SODIS) process, which uses UV light from the sun. The primary mechanisms of SODIS involve the direct and indirect effects of UV-A (320-400 nm) and UV-B (280-320 nm) radiation, as well as the synergistic effect of thermal heating (Santos et al., 2012). These mechanisms collectively inactivate pathogenic microorganisms through various photochemical and photo biological processes.

Photochemical Reaction

- **Direct UV Inactivation**: UV-A and UV-B radiation can directly damage the DNA and RNA of microorganisms. When UV radiation is absorbed by the nucleic acids, it causes the formation of pyrimidine dimers (thymine-thymine or cytosine-cytosine dimers), which are lesions that distort the DNA structure and inhibit replication and transcription (Polo-Lopez et al., 2019) (Kehoe et al., 2012).

$$\text{DNA} + \text{UV radiation} \rightarrow \text{DNA lesions (pyrimidine dimers)}$$

- **Indirect Inactivation through Reactive Oxygen Species (ROS):** When dissolved oxygen is present in water, reactive oxygen species (ROS) can also be produced by UV radiation. Hydrogen peroxide ($H2O_2$), hydroxyl radicals (•OH), and superoxide anions ($O_2\,\bullet^-$) are examples of these ROS. Because ROS is extremely reactive, it can harm lipids, proteins, and nucleic acids, among other biological constituents. (Rodrigues et al., 2016) (Garcia-Arman et al., 2020) (das & Soares, 2021).

The reactions are as follows:

$$O_2 + \text{UV radiation} \rightarrow O^{2-} + e^-$$

$$O^{2-} + H_2O \rightarrow H_2O_2 + O_2$$

$$H_2O_2 + \text{UV radiation} \rightarrow 2\bullet OH$$

This reaction can cause oxidative stress, leading to cellular damage and death of the microorganisms.

In addition to the photochemical effects, the thermal heating of water due to sunlight exposure can enhance the inactivation of microorganisms. Elevated temperatures can denature proteins, disrupt cell membranes, and accelerate the inactivation processes initiated by UV radiation (Tyagi et al., 2017) (Sharma et al., 2022).

$$\text{Heat} + \text{Proteins} \rightarrow \text{Denatured Proteins}$$

The combined effects of UV radiation and thermal heating result in a synergistic inactivation of microorganisms. The effectiveness of SODIS is maximized when both UV-induced damage and heat-induced damage occur simultaneously, leading to higher rates of microbial inactivation than either process alone (Fernandez et al., 2023).

In some cases, the addition of small amounts of hydrogen peroxide can enhance the SODIS process. H_2O_2 acts as a source of hydroxyl radicals when exposed to UV radiation, thereby increasing the oxidative stress on microorganisms (Patel et al., 2021) (Meierhofer & Wegelin, 2002).

$$H_2O_2 + \text{UV radiation} \rightarrow 2{\bullet}OH$$

The enhanced generation of •OH radicals significantly boost the disinfection efficacy of SODIS (Marugán et al., 2011).

1.4 Objectives

The following are the study's objectives:

- To assess how well the system produces drinking water that is safe for microbes.
- To determine how reactor efficiency is affected by subtropical climate conditions.
- To look at if the reactor can still produce enough treated water even after a shorter exposure period.
- To contrast conventional small-batch SODIS techniques with high-volume SODIS reactors.
- To fulfill SODIS's potential as an affordable point-of-use water treatment technique in subtropical areas.
- Examines whether the high-volume SODIS technology can be scaled up for centralized community water treatment plants.

1.5 Scope

The specific scope of the research is as follows:

- The research will focus on the field-level feasibility of a high-capacity SODIS reactor, targeting rural and semi-urban areas where affordable water treatment solutions are essential.
- By studying the reactor's performance in Bangladesh's subtropical climate, where temperatures reach 35-40°C with moderate UV radiation during summer, the study aims to provide guidelines for large-scale implementation.
- The research will assess how the SODIS process reacts under varying conditions, such as different pH levels and the required H_2O_2 concentrations in large water reactors.
- A modified SODIS process will be developed using two types of bacteria and integrating H_2O_2 to enhance its disinfection capabilities.
- A comparative analysis will be conducted between the effectiveness of the bacteria and evaluate which one is more convenient for the modified SODIS method.
- The potential for microbial regrowth after the SODIS treatment will be studied, comparing the modified process with conventional SODIS methods.
- A strategy will be developed to promote the modified SODIS for field applications in rural and urban areas with unsafe water supplies for the sub-tropical regions like Bangladesh.
- The research will provide a detailed analysis of how real-world solar radiation and temperature conditions influence the performance of the SODIS reactor in treating water to acceptable drinking standards.

CHAPTER 2: LITERATURE REVIEW

2.1 General

Numerous studies have been carried out since the 1980s to discover more about SODIS's operation, safety, and efficacy in various settings. This synthesis of the research examines important studies on SODIS, including its historical application, water disinfection capabilities, and how advancements in materials and techniques have increased its efficacy. Along with innovative ideas to improve the process, it also tackles issues such as the effects of environmental conditions and water quality. With all factors considered, this evaluation provides an easy-to-understand overview of SODIS and its potential that guarantee large amount of safe water to consume, particularly in resource-poor locations.

2.2 Introduced by Aft in ACRA (UNICEF)

Since SODIS with PET bottles was first developed in 1984 and does not release harmful chemicals when exposed to heat or sunlight in typical environmental circumstances, they can be used as a widely available material that is safe to distribute among populations without fear of chemical toxicity (Wegelin et al., 2012). The presence of this element was exceptional and provided a solution to the safety risks emanating from chemical contamination by PET bottles. This consensus was subsequently supported by other studies that found the materials used in SODIS treatment were durable and did not negatively affect long-term water quality (Larlee, 2017).

2.3 Disinfection Mechanism

The reason why PET bottles are so efficient in SODIS is that they have a big UV treatment due to the fact cell penetrate bacteria very well using such UV-A light (Polo-Lopez et al. Saito et al. (2019b)). UV-A radiation could pass an effectively PET bottle and inactivated harmful bacteria to have the safe quality of treated water / Water Analysis for Effective Team-Based Research Collaborations (Brizhik et al., 2003) (Islam & Smith, 2019). With this discovery, that then put us in a position of having good solid scientific information backing the use of PET bottles saying they do indeed work for bacterial disinfection.

2.4 Diarrhea Reduction

SODIS use reduces infant diarrhea by up to 45% and is among the most important public health interventions (McGuigan et al., 1998). Thus, they advocated for the widespread use of SODIS as a low-cost measure that can significantly reduce diarrhea prevalence in infants and thus improve public health status in water-deficient settings (Burchhardt et al. 2012). The fact that cases of diarrhea were fewer after use by the child illustrates why in developing countries, there needs to be a promotion of SODIS as an effective and affordable water treatment method**.**

2.5 Large-volume Potential

Studies have shown that SODIS may be efficiently scaled up with larger containers, increasing its usefulness in various settings. Larger amounts of water could be treated without lowering the disinfection process' efficacy (Keogh et al. 2015). Because of its scalability, SODIS may be implemented in bigger communities or households, offering a more flexible approach to providing clean drinking water.

2.6 History

The history of SODIS began in the 1980s when a Swiss NGO called Aktion Weltweiter Wassertag started looking into its possibilities. The foundation for SODIS's development and application was laid by early research that validated the concept (Various sources, 1980s) (*Eawag - Swiss Federal Institute of Aquatic Science and Technology - Eawag*, n.d.). These early investigations played a critical role in laying the scientific groundwork for SODIS and encouraging additional study and implementation.

2.7 Field Application

In 1988, SODIS began its field application, providing actual implementation to validate laboratory results (Meierhofer & Wegelin, 2002). Early field research proved the method's usefulness in practical settings, which aided in SODIS's wider acceptance (Acra & Centre, 1990). One of the most important steps in demonstrating the applicability and dependability of SODIS was its shift from laboratory to field application.

2.8 Environmental Impact

The climate and environment have an impact on SODIS's effectiveness. Research has indicated that the reliability of the disinfection process can be affected by weather patterns and solar intensity. Reduced solar intensity, cloud cover, and seasonal variations can lower the disinfection efficacy of SODIS, limiting its reliability during overcast or rainy periods (McGuigan et al. 2012). Higher temperatures and strong UV-A radiation enhance bacterial inactivation, but low sunlight and cold temperatures can significantly slow down the disinfection process (Ubomba-Jaswa et al. 2010). Solar intensity boosts SODIS efficiency, but in areas with lower sunlight, optical aids like lenses can improve outcomes; however, SODIS is less effective in cloudy or low-sun environments (Sommer, Marino, & Wegelin 1997). Loud cover, turbidity, and reduced solar radiation can limit SODIS effectiveness, necessitating pre-treatment for cloudy water and longer exposure times during low-radiation days (Luzi et al. 2016). Comprehending these environmental variables is crucial to maximizing the application of SODIS and guaranteeing its efficacy in various locations and seasons.

2.9 UV Radiation Range

The effectiveness of UV light in inactivating microorganisms primarily lies within the 200–400 nm wavelength range, with UV-C (200–280 nm) being the most effective for damaging the DNA and RNA of pathogens, leading to their inactivation (Santos et al., 2012). Research has shown that UV-B (280–315 nm) and UV-A (315–400 nm) also contribute to disinfection, but UV-C is especially potent because it directly disrupts nucleic acids. While UV-C is blocked by the atmosphere and is not available naturally in sunlight, UV-A (315–400 nm) is the key component in Solar Water Disinfection (SODIS), as it penetrates the Earth’s atmosphere and is effective in damaging the cellular structures of microorganisms, leading to their inactivation over extended exposure times. (Marugán et al., 2011) .

2.10 Geographical Impact

The UV radiation intensity and sunlight angle are influenced by latitude. Because of the stronger UV rays near the equator, SODIS is often more effective there. On the other hand, UV radiation is weaker at higher latitudes, which could lower SODIS's disinfection effectiveness. Higher altitudes have thinner atmospheres, which allows more UV light to reach the surface of the Earth. This could make SODIS more effective. However, additional variables like temperature and atmospheric conditions can distort this effect. Because UV exposure varies depending on location and climate, SODIS must be customized to the local environment in order to be effective. Depending on the UV radiation levels in the area, this may need modifying the application technique or exposure durations (García-Gil et al., 2020).

2.11 Material Influence

Because of the exceptional UV light transmission qualities, PET (polyethylene terephthalate) plastic bottles are particularly effective for Solar Water Disinfection (SODIS). Because PET is transparent, UV-A rays can pass through the bottle and get to the water within, which is crucial to the disinfection process(Conroy et al.2001). Because of its high UV transparency, the pathogens in the water can be effectively inactivated by the UV light. Furthermore, PET's strength and resilience to breakage make it a sensible option for SODIS applications under a range of environmental circumstances. PET bottles are an excellent choice for SODIS because of their affordability and wide availability, particularly in environments with limited resources. Research has indicated that PET bottles, in comparison to alternative materials with lower UV transmission rates, greatly increase the efficacy of SODIS (García-Gil et al., 2020).

2.12 Enhanced Methods of SODIS

Studies have shown that incorporating reflective materials such as mirrors and aluminum foils can significantly enhance the effectiveness of Solar Water Disinfection (SODIS) by increasing UV exposure. These reflective surfaces help direct additional UV light onto the water, improving the disinfection process. Research indicates that while mirrors and aluminum foils notably boost SODIS efficiency, lenses have a relatively minor impact. Reflective materials direct additional UV light onto the water, increasing the total UV exposure. This enhanced exposure improves the ability of UV rays to penetrate the water, leading to more effective inactivation of pathogens. The increased UV dose can reduce the time required for disinfection and ensure higher levels of pathogen removal. (Acra & Centre, 1990). Reflective materials can improve the performance of SODIS in environments where UV radiation is suboptimal. By increasing the amount of UV light available for disinfection, SODIS can operate more effectively in areas with high cloud cover or during shorter daylight hours (Heidarinejad et al., 2020) (Tsekeri et al., 2021).

2.13 Pathogenic Targets

SODIS (Solar Water Disinfection) has proven effective in minimizing various pathogens, including protozoa and viruses. SODIS is effective against viruses, highlighting its effectiveness in inactivating viral pathogens through UV exposure (Rodrigues et al. 2016). Similarly, (Kehoe et al. 2012) focused on Cryptosporidium parvum oocysts, a common protozoan parasite, and demonstrated that SODIS is capable of significantly reducing these oocysts, which are known for their resistance to many conventional disinfection methods. These studies underscore the broad-spectrum effectiveness of SODIS, making it a valuable tool for ensuring the safety of drinking water against a range of microbial threats. The ability of SODIS to address both viral and protozoan contaminants showcases its versatility and importance in providing safe drinking water, particularly in areas where traditional water treatment infrastructure is lacking.

2.14 Temperature Impact

Ambient temperature significantly impacts the effectiveness of Solar Water Disinfection (SODIS). A study on 3-liter PET bottles revealed that temperature variations can alter disinfection times, with higher temperatures generally enhancing the disinfection kinetics due to increased UV-A effectiveness. In contrast, lower temperatures slow down the process, requiring longer exposure to achieve the same level of pathogen inactivation. A comprehensive study emphasized the need for climate-specific adjustments to optimize SODIS performance, such as extending exposure times or using additional reflective materials in cooler climates. (Sharma et al.'s2022).

2.15 Water Turbidity

Increased turbidity levels can significantly reduce the effectiveness of Solar Water Disinfection (SODIS) by obstructing UV light penetration and thus impairing pathogen inactivation. A study found that pre-treating turbid water before applying SODIS can enhance its efficacy. This pre-treatment is crucial in locations with high concentrations of particulate matter, as it helps clear the water of suspended particles that would otherwise block UV rays and reduce the overall disinfection performance (Patel et al. 2021). High turbidity levels can significantly decrease the penetration of UV light through water, which impairs the disinfection process. Studies have shown that even moderate turbidity can lead to incomplete pathogen inactivation. For instance, a research demonstrated that turbidity levels above 30 NTU can reduce the effectiveness of SODIS by as much as 50% (Ochieng, J., et al. 2012). To counteract the effects of turbidity, pre-treatment techniques such as sedimentation and filtration are recommended. A study found that using a simple sedimentation process to remove particulate matter before applying SODIS can improve pathogen inactivation rates significantly (Mendoza, M., et al. 2015).

2.16 User Acceptance

The successful adoption of large-volume SODIS systems, such as 10-liter PET bottles, in community settings hinges on assessing both its feasibility and user acceptance. A study highlighted that community approval is essential for the effective implementation of SODIS. Their research underscores that the success of SODIS initiatives is significantly influenced by involving community members in the planning and execution phases. By addressing local needs and preferences, the likelihood of sustained use and acceptance of SODIS solutions is greatly improved. This community-centered approach ensures that the systems are not only technically effective but also aligned with the practical and cultural requirements of the users, thereby enhancing the long-term viability of SODIS programs (Fernandez et al. 2023) .

2.17 Global Use

More than 4.5 million people in 55 countries throughout Asia, Latin America, and Africa used SODIS on a daily basis by 2009 (WORLD HEALTH STATISTICS 2008, n.d.). This broad adoption highlights SODIS's potential to serve millions of people with safe drinking water and illustrates its influence and reach on a worldwide scale. One of the key reasons for SODIS’s global success is its simplicity and cost-effectiveness. The method uses readily available materials, such as PET bottles and sunlight, making it an accessible solution for communities with limited resources. This practicality is crucial for widespread use, particularly in low-income areas where traditional water treatment infrastructure may be lacking (Lytle, D. A., & Olson, B. H. 2001) . The extensive use of SODIS has been linked to improved health outcomes by reducing waterborne diseases. The method’s effectiveness in pathogen inactivation contributes to significant public health benefits, especially in regions with high incidences of waterborne illnesses (Olivier, J., & Clasen, T. 2006).

2.18 Improvement of H_2O_2

The combination of hydrogen peroxide H_2O_2 with the Solar Disinfection (SODIS) process is indeed a powerful modification. By adding H_2O_2 to SODIS, hydroxyl radicals (•OH) are generated when exposed to UV light. These radicals are highly reactive and possess strong oxidizing properties, making them capable of more effectively inactivating pathogens compared to UV light alone. This process enhances the efficacy of SODIS, making it a more comprehensive method of water disinfection. Research highlights that the combination of H_2O_2 and UV light produces these highly reactive radicals, significantly improving pathogen inactivation compared to UV light alone (Sciacca et al., 2011). This modification enables SODIS to be more effective against a broader spectrum of infections, thereby increasing its efficiency. Furthermore, the synergistic effects of combining solar UV rays with H_2O_2 have been demonstrated to improve bacterial inactivation. A study showed that integrating these methods enhances the overall effectiveness of the SODIS process, providing a more reliable water disinfection solution (Vidal and Diez 2005). The use of H_2O_2 with SODIS can thus provide a more resilient approach to water disinfection in various environmental and microbiological conditions. This combined approach results in a more robust and dependable strategy for ensuring safe drinking water, especially in challenging conditions where traditional SODIS might be less effective.

2.19 Chemical Safety

Water safety was ensured by investigations on the non-leaching nature of compounds found in PET bottles during SODIS. In response to worries about chemical pollution, Schmid et al. (2008) confirmed that, in SODIS settings, PET bottles do not emit any hazardous materials. This discovery is essential to guarantee the security and reliability of water treated with SODIS.

2.20 Water Quality

Organic matter and pH are two examples of water quality characteristics that can affect SODIS efficacy. Dejung et al. (2007) discovered that the SODIS process's efficiency might be impacted by a few water quality characteristics. Comprehending these factors is crucial for enhancing SODIS's performance and guaranteeing its efficacy in various water sources and circumstances.

Despite some initial challenges, the larger volume SODIS implementation was feasible and contributed to a reduction in waterborne diseases.

Since 2L PET bottles effectively inactivate microorganisms and have significant health benefits, most research on solar disinfection (SODIS) has concentrated on their use. Although investigations in the field and experimentation have shown that this level of water purification works well, there are substantial drawbacks for everyday practical application. A household of four would need twenty liters of potable water per day, as the World Health Organization (WHO) estimates that the average person uses five liters of water each day. In addition to being logistically difficult, SODIS's reliance on multiple little bottles is ineffective for households who require larger amounts of cleaned water.

Greater containers for SODIS have been investigated in recent research to overcome this constraint. The use of 19L polycarbonate (PC) containers and 10L to 20L plastic jars and buckets has been studied in Kenya, Africa, and India (S. Brockliss et al., 2022). (Keogh et al., 2015). These investigations have had uneven results, though, highlighting a few concerns including fluctuating UV penetration, problems with water turbidity, and logistical difficulty when managing larger containers. These discrepancies draw attention to a significant vacuum in the research on the viability and effectiveness of scaling up SODIS for higher water quantities.

To close this gap in the literature, investigating the usage of 8L PET bottles for SODIS has been conducted. The goal of this research is to assess the behavior and efficacy of these intermediate-sized containers in disinfecting water. The 8L PET bottles are a compromise between small-scale 2L bottles and larger containers, which have produced variable outcomes. This size is meant to give a more practical and manageable alternative for households that must disinfect huge amounts of water on a daily basis.

CHAPTER 3: METHODOLOGY

3.1 General

The conventional experiment for Solar Water Disinfection (SODIS) followed the guidelines and methodologies outlined in the World Health Organization (WHO) "Guidelines for Drinking-Water Quality" and the Swiss Federal Institute of Aquatic Science and Technology (Eawag) "SODIS Manual".

The WHO guidebook provides comprehensive guidelines for measuring water quality, covering physicochemical characteristics, turbidity, and levels of bacterial contamination. Two types of test water—one with low turbidity and the other with high turbidity—were prepared in accordance with WHO guidelines. Known bacterial counts were added to both kinds of water. For eight hours, the water samples in eight-liter PET bottles were exposed to direct sunshine. During this time, hourly observations of physicochemical parameters such temperature, pH, and turbidity were made. Bacterial counts were assessed at the end of the exposure, and further testing was conducted 12 and 24 hours later to assess regrowth.

3.2 Materials and Reagent Used

Here is the list of materials and reagent used in our experiment:

- Two types of E. coli bacteria (Normal E. coli and ATCC 25922 E. coli)
- Sterile distilled water
- 8-liter PET bottles
- Black Enamel Paint
- Loop
- mTec agar
- Autoclave machine
- Ethanol
- Filter paper
- Aluminum foil paper
- Hydrogen Peroxide
- NaOH, NaCl, HCl and others

Figure 1: Equipment used in the experiment.

3.3 PET Bottle Selection Process

First the 8L PET bottles were obtained from the local market having a thickness of 2.5 mm each and had been sterilized with distilled water.

3.4 Bacteria Collection and Preparation

The bacteria were collected from iccddr b Mohakhali. They have provided two types of bacteria one was the strongest among all E. coli bacteria ATCC 25922 and another one was normal E. coli bacteria. Both the bacterial strains of E. coli were obtained and cultured on appropriate agar media (mTec agar for E. coli). After collecting the bacteria, they were brought it to IUT Environment lab and was kept it at 4°C so that the cultures were incubated at the optimal temperature for each strain for 24 hours to ensure the growth of the bacteria.

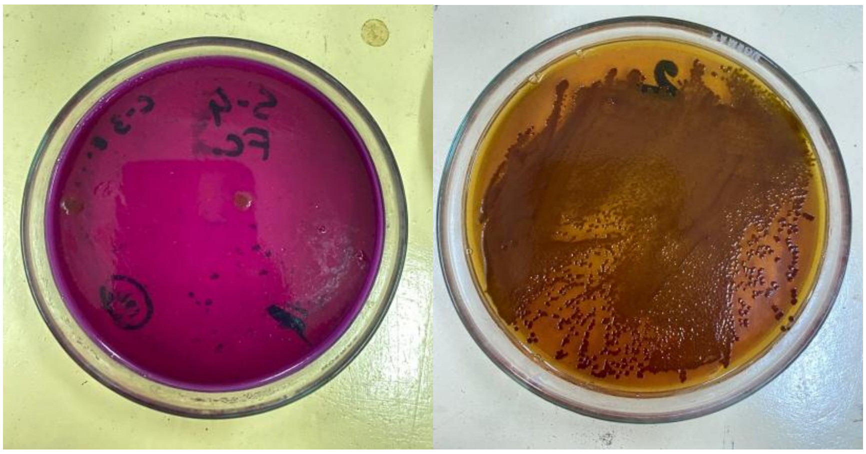

Figure 2: Normal E.coli and ATCC25922 E.coli Bacteria

For further culture process the serial dilution process was enacted where both bacteria were diluted for 4 times to ensure the optimum growth for our SODIS experiment.

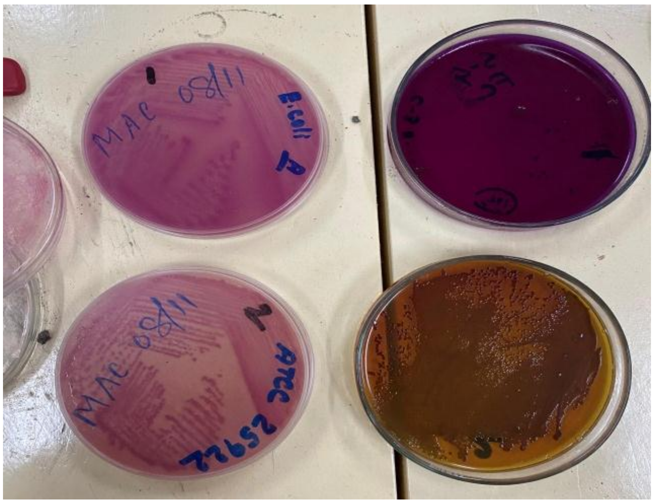

Figure 3: Cultured Normal E.coli and ATCC25922 E.coli Bacteria.

After incubation, a loop was sterilized and used to transfer individual colonies of each bacterial strain into separate sterile distilled water solutions. 85% normal saline solution with a pH of 7.8-8 was prepared and both saline solutions were prepared.

3.5 SODIS Setup

8-liter PET bottles were sterilized using ethanol before filling them with sterile distilled water to the 8-liter mark. Two bottles were prepared for the experiments for both bacteria.

Figure 4: Two types of setup for SODIS

3.6 Sterilization of Containers

The two 8-liter containers were washed, rinsed, and sterilized with absolute ethanol. The containers were air-dried to ensure complete ethanol evaporation. The sterilized 8-liter containers were filled with the prepared Test water 1 and Test water 2.

3.7 Preparation of 8-liter PET Bottles

8-liter PET bottles were sterilized using ethanol. In the SODIS treatment group, 26.78 ml of Normal E. coli suspension and 6.25 ml of ATCC 25922 E. coli bacterial suspension were added to separate PET bottles, ensuring an airtight seal. Additionally, to deactivate the functions of bacteria 10 mg/L hydrogen peroxide (H_2O_2) was added to each PET bottle and was mixed properly with the filled water. Moreover, to determine the appropriate amount of hydrogen peroxide (H_2O_2) 2.5 mg/L and 5 mg/L were added to each bacterial setup and have been overserved the bacterial growth.

3.8 Testing Procedure

Table 1: Testing Procedure of Test water 01 & Test water 02

	Test Water 01	**Test Water 02**	**Reference**
Description	High-quality groundwater, surface water, caught (newly harvested) rainwater or other water free of disinfectant residual	High-quality groundwater, surface water, rainwater or other water free of disinfectant residual with 20% by volume primary wastewater effluent or 1% by volume untreated raw sewage, sterilized or pasteurized	WHO
Turbidity	< 5 NTU	> 30 NTU	WHO
pH	7.0–9.0	6.0–10.0	WHO
Temperature	20 °C ± 5 °C	4 °C ± 1 °C	WHO
E. coli	1 x 10^5 CFU/100 mL	1 x 10^5 CFU/100 mL	Mwabi et. al 2011

3.8.1 Test Water 01:

An 8-liter container was filled with groundwater. The turbidity was adjusted to <5 NTU using a turbidimeter. The pH was adjusted to 7-9 using a pH meter. The temperature was adjusted to 20°C±5°C using a thermometer. The groundwater was spiked with the E. coli bacterial suspension to achieve a concentration of at least 10^6 CFU/100 ml.

Figure 5: Test Water 01

3.8.2 Test Water 2:

An 8-liter container was filled with groundwater. The groundwater + 1% sewage water mixture was autoclaved to sterilize it. The turbidity was adjusted to >30 NTU by adding sieved clay. The pH was adjusted to 6-10 using a pH meter. The temperature was adjusted to 4°C±1°C using a thermometer. The autoclaved groundwater + sewage water mixture was spiked with the E. coli bacterial suspension to achieve a concentration of at least 10^6 CFU/100 ml.

Figure 6: Test Water 02

3.9 SODIS Experiment

The filled PET bottles were placed on a flat surface in direct sunlight from 9 AM (+/- 30 min) to 5 PM for a total of 8 hours. The bottles were left undisturbed during the experiment, with an air space of about 15% of the container's volume for aeration.

3.10 Sampling

After each hour of solar exposure, water samples were collected from both the SODIS-treated and control group PET bottles for analysis. The physicochemical parameters such as turbidity, pH, UV, temperature, Fe, DO and Electric conductivity of the water samples were measured using appropriate instruments.

3.11 Bacterial Analysis

At the end of the 8-hour exposure, bacterial counts (colony-forming units per 100 ml) were determined for both E. coli in the SODIS-treated and control group samples using appropriate agar media.

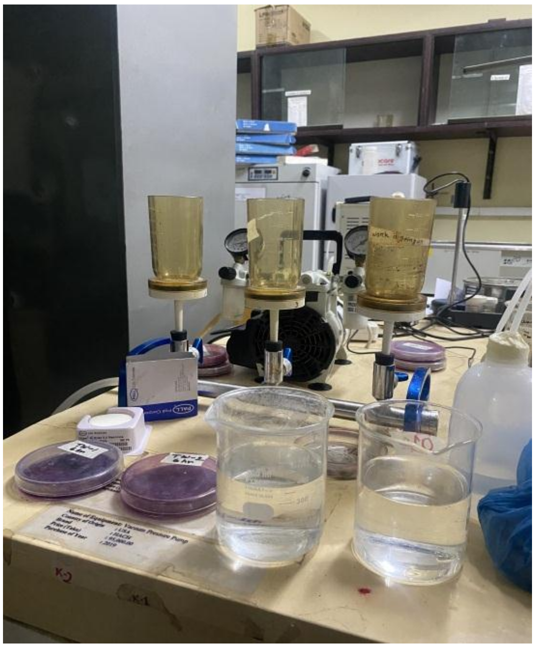

Figure 7: Multimedia Filter for Bacterial Analysis

3.12 Bacterial Regrowth Assessment

200 ml of each sample was filtered through filter paper to check for bacterial regrowth after 12- and 24-hours post-exposure.

CHAPTER 4: RESULTS & DISCUSSION

This chapter provides the experimental data of the research where various comparisons has been done to observe the bacterial growth and to finalize whether this method of water purification can be safe or not to provide drinking water and also the exact amount of H2O2 has also determined by conducting different experiments. Moreover some exceptional has been observed and their causes has also been described in this section. The results are shown below:

4.1 Test water 01 (a)- Normal E.coli Bacteria, Turbidity < 5 NTU

Table 2: Test Water- 01(a), Normal E.coli Bacteria (Turbidity<5NTU)

Parameters	Unit	Initial	1st hour	2nd hour	3rd hour	4th hour	5th hour	6th hour	7th hour
Temperature	°C	28	28.2	29	32	36.5	38	37.2	36.8
Ambient Temperature	°C	35.5	36.4	43	51.2	55	52	48	46
UV	W/m²	334	365	428	591	626	650	491	298
pH		7.39	7.61	7.57	7.33	7.48	7.55	7.64	7.68
Turbidity	NTU	1.4	1.48	1.43	1.03	1.32	1.06	1.02	0.8
DO	mg/L	12.29	21.4	18.76	15.93	14.92	15.28	15.02	14.1
EC	µS/cm	447	459	470	554	555	565	569	476
Fe	mg/L	1.2	1.12	1.3	0.92	1.2	1.93	1.74	1.65
E. coli	(CFU/100 ml)	4000000000	36	4	1	0	0	0	0

In this study, water sample 01 (a) was subjected to a comprehensive water quality analysis which was intentionally contaminated with normal E. coli bacteria and maintained at a turbidity level below 5 NTU. Parameters were monitored hourly over a seven-hour period to assess the effectiveness of treatment and disinfection processes.

It is found that the temperature gradually increases from 28°C to a peak of 38°C in the 6th hour before slightly dropping to 36.8°C in the 7th hour. While there are fluctuations, the temperature remains within acceptable ranges for water quality standards, as there is no specific WHO or ECR guidelines for water temperature in this regards. Ambient temperature rises steadily, peaking at 55°C in the 5th hour before decreasing to 46°C in the 7th hour. However, extreme temperatures can affect water chemistry and biological processes and high ambient temperatures can accelerate bacterial growth and chemical reactions. UV intensity fluctuates throughout the test, reaching a peak of 650 W/m^2 in the 6th hour. WHO guidelines recommend a minimum UV dose of 40 mJ/cm^2 (equivalent to 40,000 $\mu Ws/cm^2$) for the disinfection of drinking water. The pH fluctuates within a narrow range between 7.33 and 7.68, indicating stability close to neutral. WHO recommends a pH range of 6.5 to 8.5 for drinking water, and these results fall well within that range. Turbidity decreases gradually from 1.4 NTU to 0.8 NTU by the 7th hour, remaining consistently below the WHO and ECR guideline of 5 NTU for clear water. Low turbidity indicates fewer suspended particles, which can harbor pathogens and interfere with disinfection processes. According to WHO and ECR 2024 recommendation of Drinking water quality the range of standard DO level in drinking water is 6.5- 8.5. However, High DO levels are essential for supporting aquatic life and preventing anaerobic conditions. Here the result of DO exceeds the WHO and ECR guidelines. EC gradually increases from 447 µS/cm to 569 µS/cm in the 6th hour, showing slight fluctuations. EC is often used as an indicator of the total dissolved solids (TDS) in water. Higher conductivity generally indicates higher levels of dissolved minerals such as dissolved salts or ions, which may affect taste and corrosion. According to WHO there is no specific guideline for electrical conductivity, but the TDS level (which is related) is recommended to be less than 500 mg/L. Also there is no specific guideline in ECR for electrical conductivity, but the TDS level is recommended to be less than 1000 mg/L. WHO and ECR guideline for Fe is both of less than 0.3 mg/L. Unfortunately, the Fe level of examined water exceeds the standards. The E. coli count decreases rapidly from 4 billion CFU/100 ml to 0 CFU/100 ml by the 4th hour, meeting WHO and ECR's drinking water standards. WHO and ECR both guidelines specify that drinking water should contain 0 CFU/100 ml of E. coli, indicating successful disinfection or removal of bacteria from the water sample.

4.2 Test water 01 (b)- ATCC 25922 E. coli, Turbidity < 5 NTU

Table 3: Test water 01(b), ATCC25922 E.coli (Turbidity<5 NTU)

Parameters	Unit	Initial	1st hour	2nd hour	3rd hour	4th hour	5th hour	6th hour	7th hour
Temperature	°C	28	28.2	29	32	36.5	38	37.2	36.8
Ambient Temperature	°C	35.5	36.4	43	51.2	55	52	48	46
UV	W/m²	334	365	428	591	626	650	491	298
pH		7.49	7.75	7.63	7.48	7.79	7.75	7.53	7.62
Turbidity	NTU	1.38	1.45	1.39	1.02	1.12	1.3	1.37	1.37
DO	mg/L	10.98	20.6	17.62	15.84	11.54	11.2	10.95	12.43
EC	µS/cm	452	462	484	502	511	514	503	494
Fe	mg/L	1.07	1.46	0.95	0.94	1.19	1.07	0.87	0.25
E. coli	(CFU/100 ml)	4000000000	28	2	0	0	0	0	0

In this study, various water quality parameters were monitored hourly over a seven-hour period for water contaminated with ATCC 25922 E. coli and low turbidity (<5 NTU).

The results show that the water temperature started at 28.0°C, peaked at 38.0°C in the fifth hour, and then slightly decreased to 36.8°C by the seventh hour. Temperature is not specifically regulated by WHO or ECR, but significant temperature changes can impact microbial growth and chemical reactions in the water. The ambient temperature ranged from 35.5°C to a peak of 55°C in the fourth hour, reflecting external environmental conditions. UV radiation levels started at 334 W/m², peaked at 650 W/m² in the fifth hour, and decreased to 298 W/m² by the seventh hour. The pH values began at 7.49, fluctuated slightly, and ended at 7.62 by the seventh hour. These values fall within the WHO and ECR recommended range of 6.5 to 8.5, indicating suitable water for drinking in terms of acidity/alkalinity. Turbidity remained low, starting at 1.38 NTU and fluctuating slightly, ending at 1.37 NTU. The low turbidity levels are well within the WHO and ECR guidelines of below 5 NTU, indicating clear water that poses less risk of harboring pathogens. According to WHO and ECR 2024 recommendation of Drinking water quality the range of standard DO level in drinking water is 6.5- 8.5. DO levels increased significantly from 10.98 mg/L to a peak of 20.60 mg/L in the first hour and varied throughout the experiment, ending at 12.43 mg/L. EC values increased from 452 µS/cm to a peak of 514 µS/cm and ended at 494 µS/cm. These values are within acceptable limits for drinking water, as values below 1000 µS/cm are generally considered safe. Iron levels showed fluctuations, starting at 1.07 mg/L, peaking at 1.46 mg/L in the first hour, and significantly dropping to 0.25 mg/L by the seventh hour. Both WHO and ECR recommend iron levels below 0.3 mg/L. The initial levels exceed these limits, which could affect water taste, color, and cause staining, but the final level is within acceptable limits. E. coli levels started extremely high at 4 billion CFU/100 ml but dropped significantly to 28 CFU/100 ml in the first hour and reached 0 CFU/100 ml by the third hour which has meet WHO and ECR guidelines that require E. coli be totally absent in drinking water though initial contamination poses a significant risk.

4.3 Comparison of normal E. coli and ATCC 25922 E. coli in Test Water 01

4.3.1 pH value Comparison

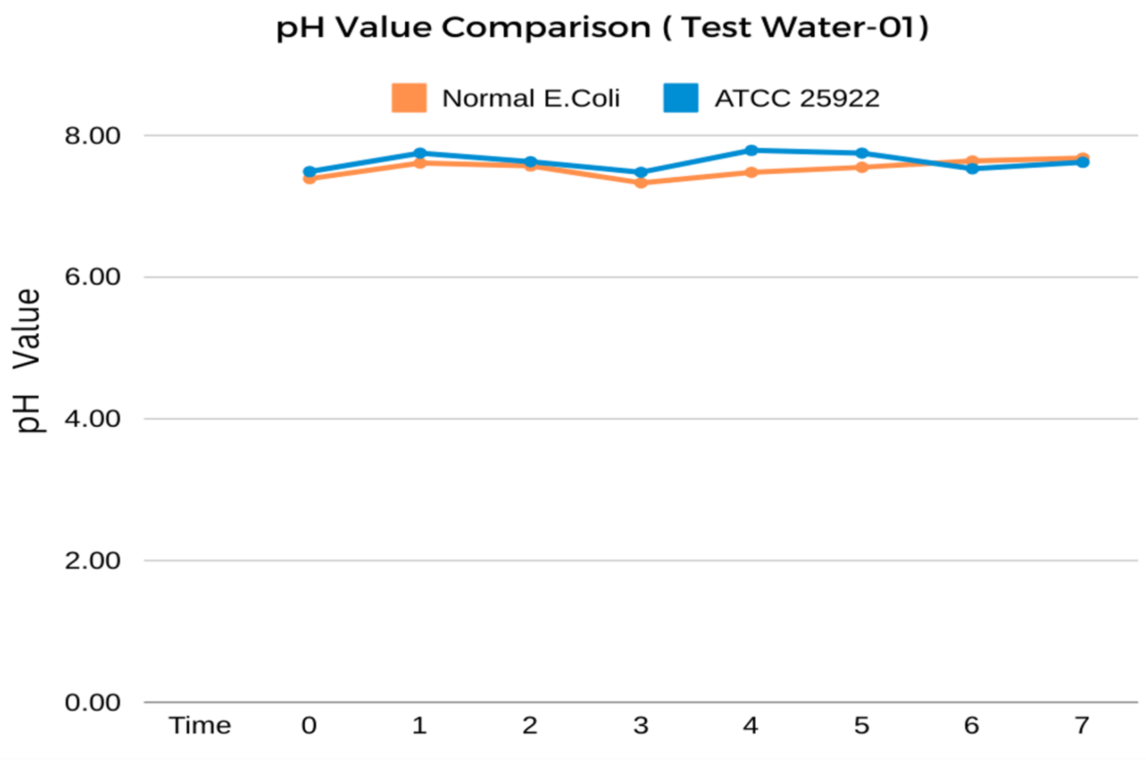

Figure 8: pH value comparison of Test water 01

This is a graphical observation of comparing the pH results of Test Water 01 with Normal E. coli Bacteria to Test Water 01 with ATCC 25922 E. coli where Turbidity of both water is less than 5 NTU. The initial pH values of both types of water samples were similar. Both kinds of water samples showed a progressive drop in pH over the course of the six-hour investigation. In both situations, these values fall within the WHO and ECR recommended range of 6.5 to 8.5, indicating suitable water for drinking in terms of acidity/alkalinity. The two varieties of bacteria had a similar rate of pH change over time, consistently lowering their pH values from the first measurement to the last hour.

4.3.2 Dissolved Oxygen Comparison

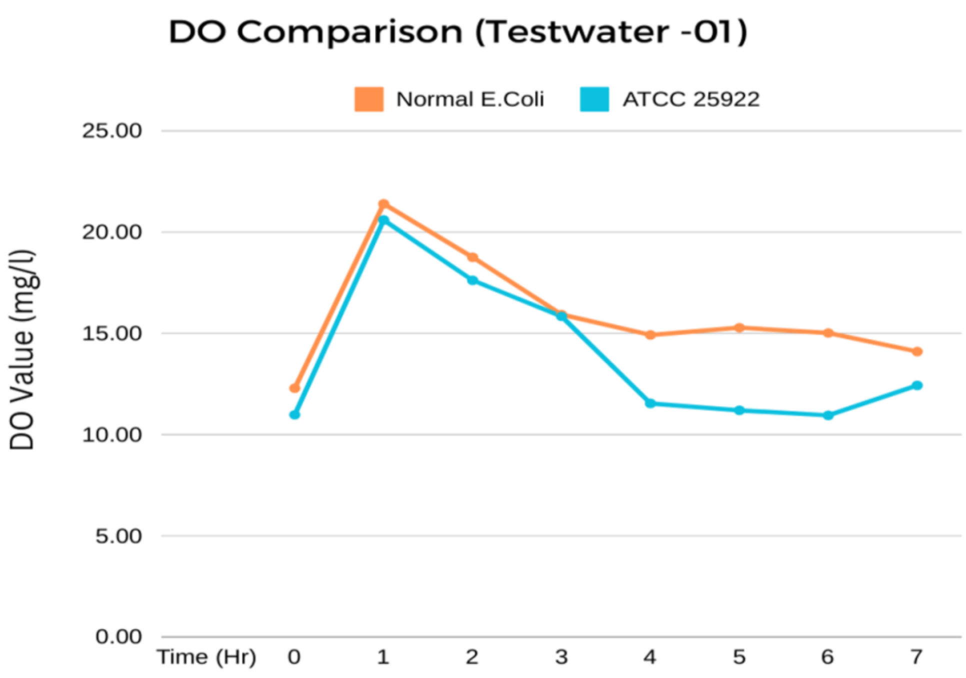

Figure 9: DO comparison of Test water 01

Here the graphical observation presents a comparison of Dissolved Oxygen (DO) levels over time for Test Water 01, specifically analyzing the behavior of Normal E. coli and ATCC 25922 E. coli in water with turbidity below 5 NTU tracking changes over a 7-hour period. Initially, Normal E. coli shows a higher DO level of approximately 12.29 mg/L, which peaks at 21.4 mg/L in the first hour, followed by a gradual decrease, stabilizing between 14 and 15 mg/L towards the end of the experiment. In contrast, ATCC 25922 E. coli starts with slightly lower DO levels but follows a similar trend, peaking early before declining and stabilizing around 12 mg/L by the 7th hour. Both strains exhibit a rapid initial increase in DO, followed by a steady decrease, indicating oxygen consumption during bacterial activity.

4.3.3 Turbidity Comparison

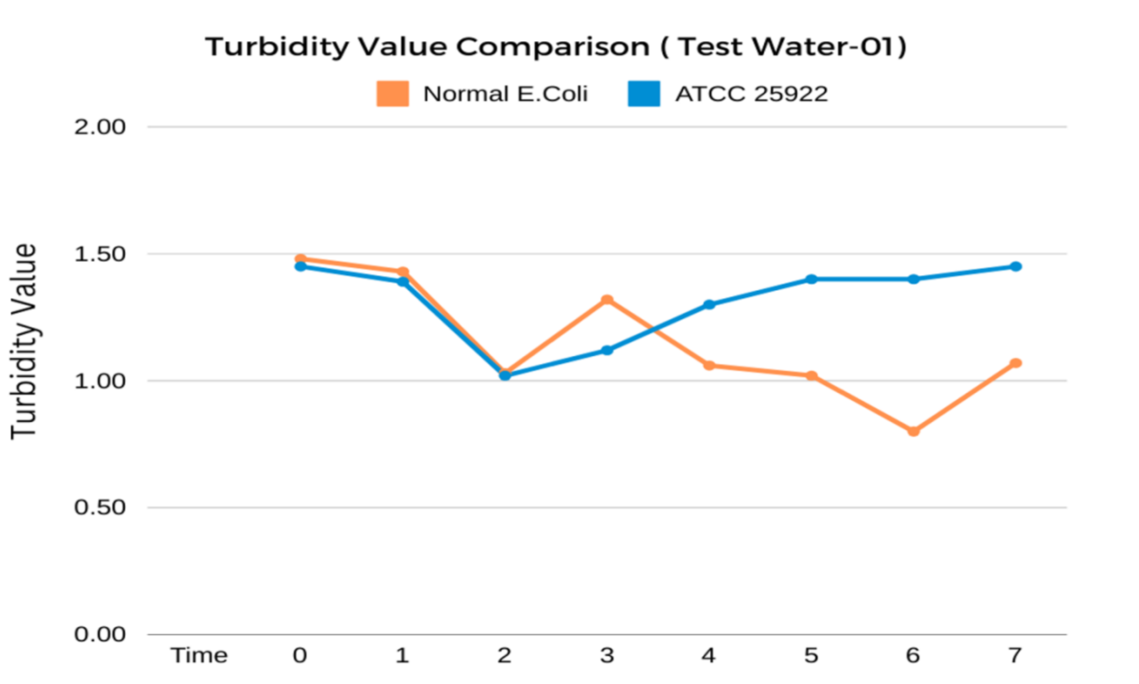

Figure 10: Turbidity comparison of Test water 01

This graph compares the turbidity levels of the water with two types of E. coli (Normal E. coli and ATCC 25922) with turbidity < 5 NTU over a period of 7 hours. At the start, both types of E. coli have a turbidity value of around 1.5. For normal E. coli, the turbidity value slightly decreases and then drops significantly at 2^{nd} hour. It then fluctuates around 1.0 to 1.2 until the end of the observation period, with some increase towards the end. For ATCC 25922 E. coli, the turbidity value decreases at first but then starts to increase from around 2 hours onward. It continues to increase gradually, reaching a value close to 1.8 by the end of the observation period.

4.3.4 E. coli count Comparison

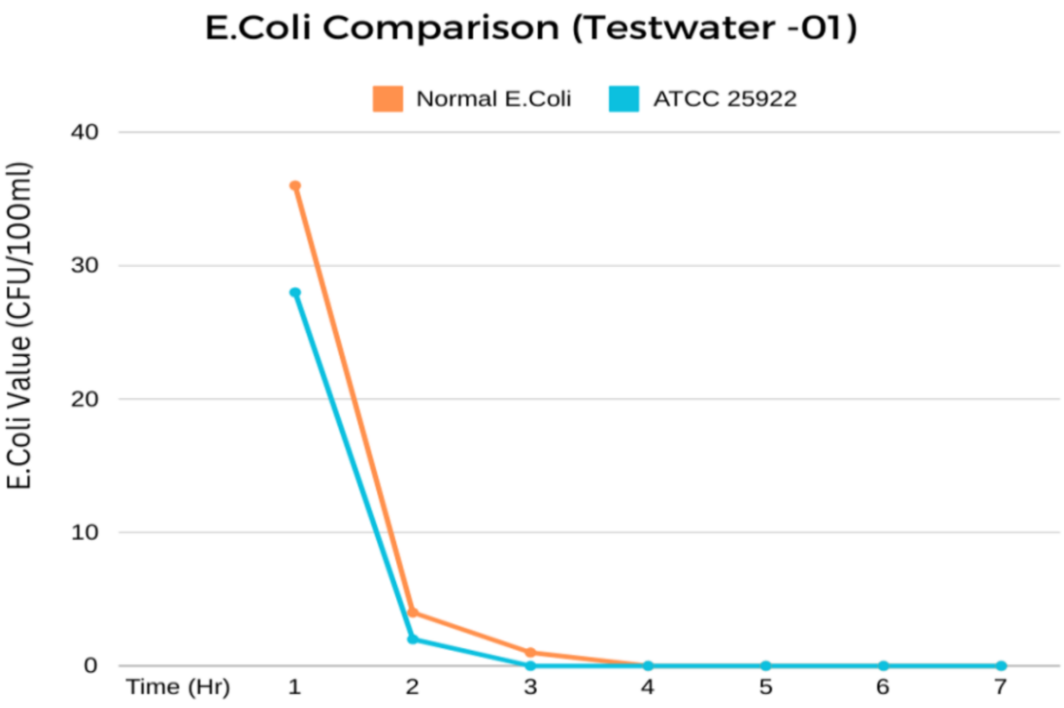

Figure 11: E.coli comparison of Test water 01

This graph compares the E. coli levels in Test Water 01, focusing on two strains: Normal E. coli and ATCC 25922 E. coli, both in water with turbidity levels below 5 NTU. At the beginning of the experiment (0 hours), Normal E. coli shows a higher concentration, around 35 CFU/100 ml, compared to ATCC 25922, which starts at 30 CFU/100 ml. Both types of E. coli experience a rapid decline in the first two hours, with their concentrations nearing 0 CFU/100 ml by the third hour. From the third hour onwards, the E. coli counts remain consistently low, indicating that both strains are effectively inactivated and remain at or near zero for the remainder of the 7-hour observation period.

4.4 Test Water 02 (a)-Normal E. coli Bacteria, Turbidity > 30 NTU

Table 4: Test water 02(a), Normal E.coli (Turbidity>30 NTU)

Parameters	Unit	Initial	1st hour	2nd hour	3rd hour	4th hour	5th hour	6th hour	7th hour
Temperature	°C	28.5	29.9	32	38.7	43.2	44.8	39.2	37.6
Ambient Temperature	°C	35.3	37.2	48	53.7	61	56	51.1	49.4
UV	W/m²	437	526	749	820	774	648	413	402
pH		7.47	7.56	7.42	7.45	7.57	7.45	7.46	7.65
Turbidity	NTU	54.9	46.8	44.6	43	46	38.1	40.4	42.4
DO	mg/L	13.07	15.89	17.22	18.26	19.36	15.52	13.46	10.93
EC	µS/cm	557	566	579	587	594	596	535	505
Fe	mg/L	1.65	1.8	1.67	1.5	1.32	1.09	0.75	0.9
E. coli	(CFU/100 ml)	4000000000	50	2	0	0	0	0	0

This table monitored several water quality measures hourly for water contaminated with normal E. coli and high turbidity (>30 NTU) during a seven-hour period.

The water temperature increased from an initial 28.5°C to a peak of 44.8°C at the fifth hour, then decreased to 37.6°C by the seventh hour. Although temperature is not specifically regulated by WHO or ECR, cooler water is generally preferred for consumption. The ambient temperature ranged from 35.3°C initially to a high of 61°C at the fourth hour, reflecting the external conditions impacting the water sample. UV levels started at 437 W/m² and peaked at 820 W/m² in the third hour, then decreased to 402 W/m² by the seventh hour. The pH values began at 7.47 and showed slight fluctuations, ending at 7.65 by the seventh hour. The observed pH values are within the acceptable range of 6.5 to 8.5 recommended by WHO and ECR, indicating the water's acidity/alkalinity is suitable for drinking. Turbidity started high at 54.9 NTU, decreased to 38.1 NTU by the fifth hour, then slightly increased to 42.4 NTU. WHO and ECR guidelines recommend turbidity levels below 5 NTU for drinking water. The consistently high turbidity indicates the water is not clear, which can significantly impact the efficacy of disinfection and pose a risk to water safety. According to WHO and ECR 2024 recommendation of Drinking water quality the range of standard DO level in drinking water is 6.5- 8.5. In this experiment the DO levels increased from 13.07 mg/L initially to a peak of 19.36 mg/L at the fourth hour, then decreased to 10.93 mg/L by the seventh hour which exceeds the standards limit. EC values increased from 557 µs/cm to 596 µS/cm, then decreased to 505 µS/cm by the seventh hour. EC values below 1000 µS/cm are generally acceptable for drinking water, indicating the observed values are within acceptable limits. Iron levels fluctuated significantly, starting at 1.65 mg/L, peaking at 1.8 mg/L at the first hour, and then dropping to 0.9 mg/L by the seventh hour. Both WHO and ECR guidelines recommend iron levels below 0.3 mg/L. The observed levels exceed these limits, which can affect taste, color, and cause staining of plumbing fixtures. E. coli levels started extremely high at 4 billion CFU/100 ml but dropped to 50 CFU/100 ml in the first hour and eventually to 0 CFU/100 ml by the third hour. WHO and ECR guidelines require that E. coli be absent in drinking water due to the risk of waterborne diseases. The rapid reduction to zero indicates effective disinfection over time, but the initial levels pose a significant contamination risk.

4.5 Test Water 02 (b)- ATCC 25922 E. coli, Turbidity > 30 NTU

Table 5: Test water 02(b), ATCC25922 E.coli (Turbidity>30 NTU)

Parameters	Unit	Initial	1st hour	2nd hour	3rd hour	4th hour	5th hour	6th hour	7th hour
Temperature	°C	28.5	29.9	32	38.7	43.2	44.8	39.2	37.6
Ambient Temperature	°C	35.3	37.2	48	53.7	61	56	51.1	49.4
UV	W/m²	437	526	749	820	774	648	413	402
pH		7.3	7.62	7.41	7.31	7.4	7.35	7.43	7.55
Turbidity	NTU	51	48	45.3	45	47.2	46	49.9	45.3
DO	mg/L	12.35	16.67	18.93	19.38	21.12	20.3	19.08	18.76
EC	µs/cm	468	487	492	495	499	510	475	462
Fe	mg/L	1.2	1.6	1	1.67	1.8	0.97	0.3	0.8
E. coli	(CFU/10 /0 ml)	400000 0000	30	4	0	0	0	0	0

This study monitored various water quality parameters hourly over a seven-hour period for water contaminated with ATCC 25922 E. coli and high turbidity (>30 NTU).

It is found that the water temperature increased from an initial 28.5°C to a peak of 44.8°C at the fifth hour, then decreased to 37.6°C by the seventh hour. Although temperature is not specifically regulated by WHO or ECR, cooler water is generally preferred. The ambient temperature ranged from 35.3°C initially to a high of 61°C at the fourth hour, reflecting the conditions affecting the water sample. UV levels started at 437 W/m^2 and peaked at 820 W/m^2 in the third hour, then decreased to 402 W/m^2 by the seventh hour. The pH values began at 7.3 and fluctuated slightly, ending at 7.55 by the seventh hour. Which was within the acceptable range of 6.5 to 8.5 recommended by WHO and ECR, indicating the water's acidity/alkalinity is suitable for drinking. Turbidity started high at 51 NTU, decreased slightly to 45 NTU, then varied between 45 NTU and 49.9 NTU. WHO guidelines recommend turbidity levels below 5 NTU and ECR guidelines recommend turbidity levels below 30 NTU for drinking water. According to WHO and ECR 2024 recommendation of Drinking water quality the range of standard DO level in drinking water is 6.5- 8.5. The above table shows that the DO levels increased from 12.35 mg/L initially to a peak of 21.12 mg/L at the fourth hour, then decreased slightly to 18.76 mg/L by the seventh hour. EC values increased from 468 µS/cm to 510 µS/cm, then decreased to 462 µS/cm by the seventh hour. EC values below 1000 µS/cm are generally acceptable for drinking water for ATCC 25922 E. coli, indicating the observed values are within acceptable limits. Iron levels fluctuated significantly, starting at 1.2 mg/L, peaking at 1.8 mg/L at the fourth hour, and then dropping to 0.8 mg/L by the seventh hour. Both WHO and ECR guidelines recommend iron levels below 0.3 mg/L. The observed levels exceed these limits, which can affect taste, color, and cause staining.

E. coli levels started extremely high at 4 billion CFU/100 ml but dropped to 30 CFU/100 ml in the first hour and eventually to 0 CFU/100 ml by the third hour FOR ATCC 25922 E. coli. WHO and ECR guidelines require that E. coli be absent in drinking water due to the risk of waterborne diseases.

4.6 Comparison of Normal E. coli and ATCC 25922 E. coli in Test Water 02

4.6.1 pH Value Comparison

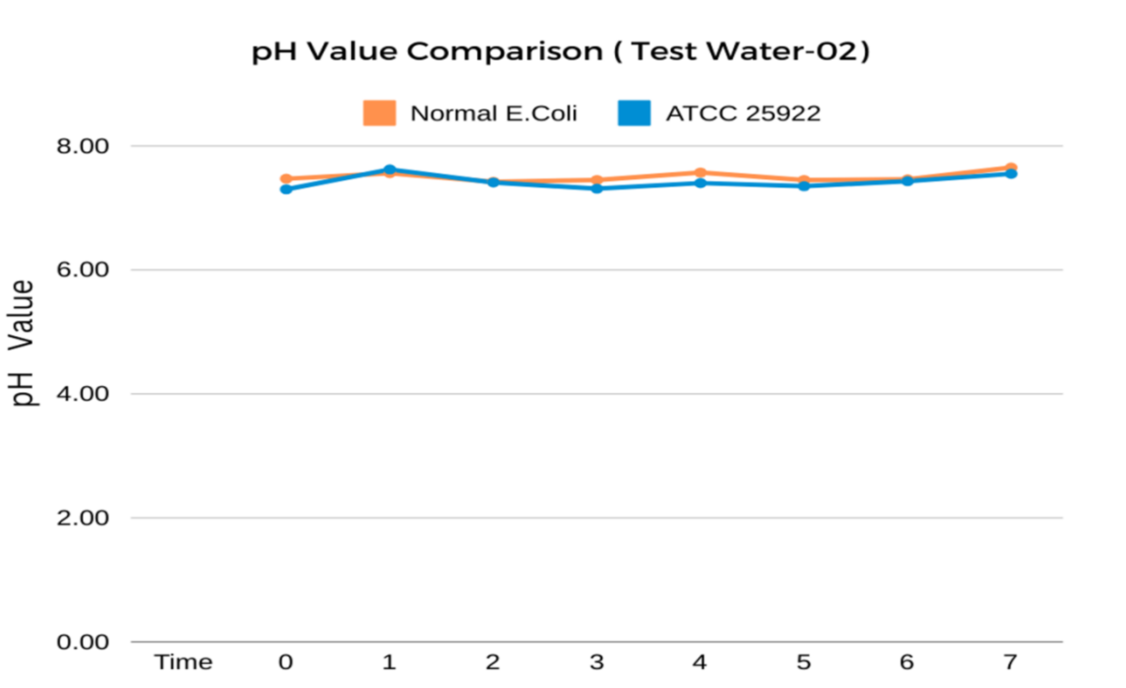

Figure 12: pH value comparison of Test water 02

The graph, pH Value Comparison (Test Water-02) shows the pH values over time for two different types of E. coli: Normal E. coli and ATCC 25922 E. coli. Both lines follow a similar trend, indicating that the pH values for Normal E. coli and ATCC 25922 are quite close throughout the time. The pH values remain around 8.00, with slight variations observed at different time points.

4.6.2 Turbidity Comparison

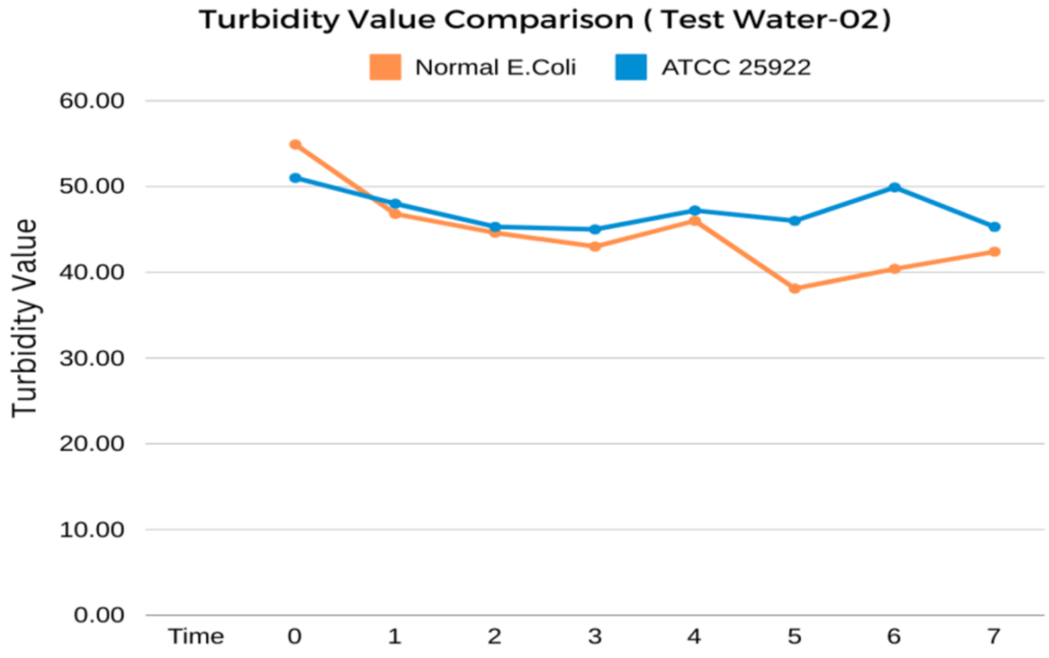

Figure 13: Turbidity comparison of Test water 02

The graph shows a comparison of turbidity values over time for two types of E. coli: Normal E. coli and ATCC 25922 E. coli for Test water-02 (>30 NTU). Both Normal E. coli and ATCC 25922 E. coli start with high turbidity values, with Normal E. coli slightly higher than ATCC 25922 E. coli. The graph also indicates that both E. coli experiences a decrease in turbidity over time. However, after the initial drop, the turbidity values stabilize and fluctuate within a similar range, with ATCC 25922 E. coli showing a bit more variability than Normal E. coli. After stabilization, the turbidity values for both strains fluctuate slightly but remain close to each other.

4.6.3 Electric Conductivity Comparison

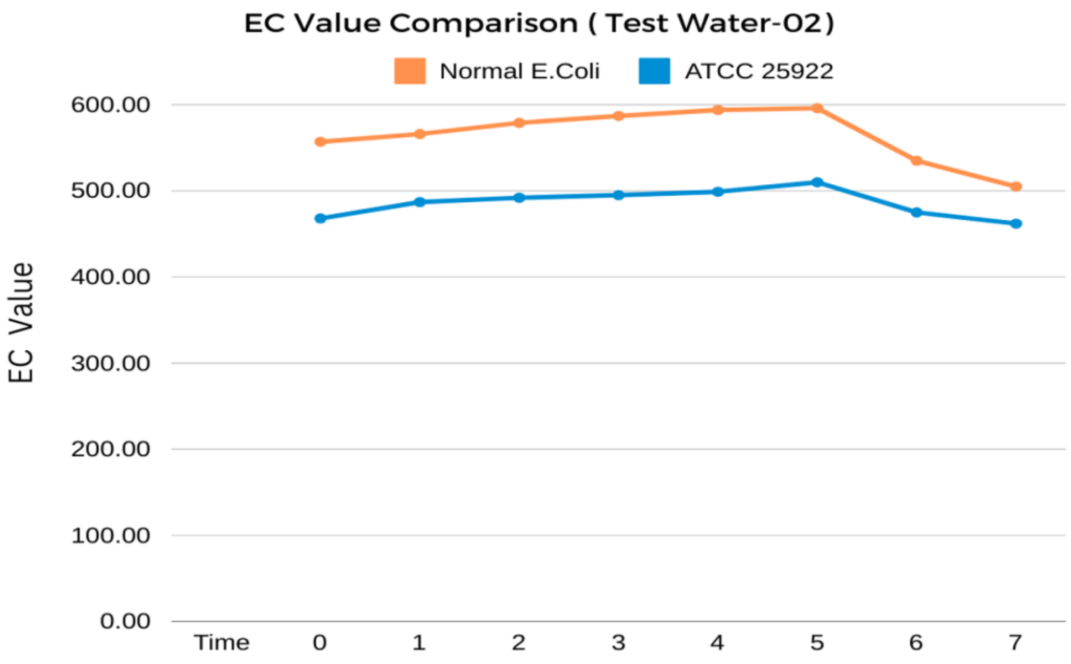

Figure 14: EC comparison of Test water 02

The graph shows the comparison of Electrical Conductivity (EC) values over time for two types of E. coli: Normal E. coli and ATCC 25922 E. coli for Test water-02 (>30 NTU). For Normal E. coli it starts with an EC value of about 525 initially. The value then remains relatively stable between 550 and 575 until 5th hour. After 5th hour, there is a noticeable decrease in EC value, dropping back to around 525 by 7th hour. For ATCC 25922 E. coli it starts with an EC value of about 475 at initial period. From 2th hour to 5th hour, the EC value remains relatively stable, fluctuating slightly around 500. After 5th hour, the EC value decreases slightly, ending at about 475 by 7th hour. Here, the EC values for both Normal E. coli and ATCC 25922 E. coli initially increase slightly, stabilize for a period, and then decrease back to their starting values by the end of the observation period. Normal E. coli consistently shows higher EC values than ATCC 25922 E. coli throughout the time intervals. The EC value trends to change the conductivity of the Test water-02 (>30 NTU) over time, potentially due to the metabolic activities or the growth patterns of both E. coli.

4.6.4 Dissolved Oxygen Comparison

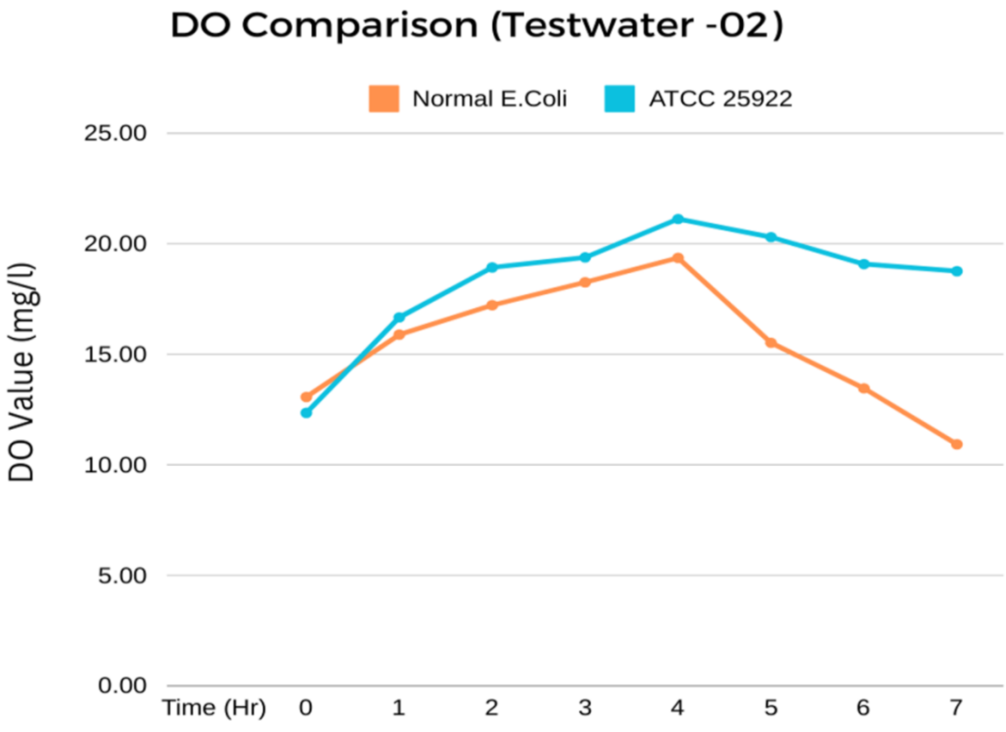

Figure 15: DO comparison of Test water 02

The graph displays the Dissolved Oxygen (DO) values over time for Normal E. coli and ATCC 25922. For Normal E. coli it starts with a DO value of around 14 mg/L initially. The DO value increases steadily, reaching just above 18 mg/L by 4th hour. After 4th hour, the DO value decreases sharply, dropping to around 10 mg/L by 7th hour. For ATCC 25922 E. coli starts slightly below 15 mg/L. It peaks at around 20 mg/L by the 4th hour to 5th hour. Here, ATCC 25922 E. coli maintains higher dissolved oxygen levels over time compared to Normal E. coli. This indicates the differences in their metabolic processes, with ATCC 25922 E. coli potentially having higher oxygen production or lower consumption. The sharp decline in DO for Normal E. coli after Hour 4 suggests a significant change in its increase in oxygen consumption.

4.6.5 E. coli count Comparison

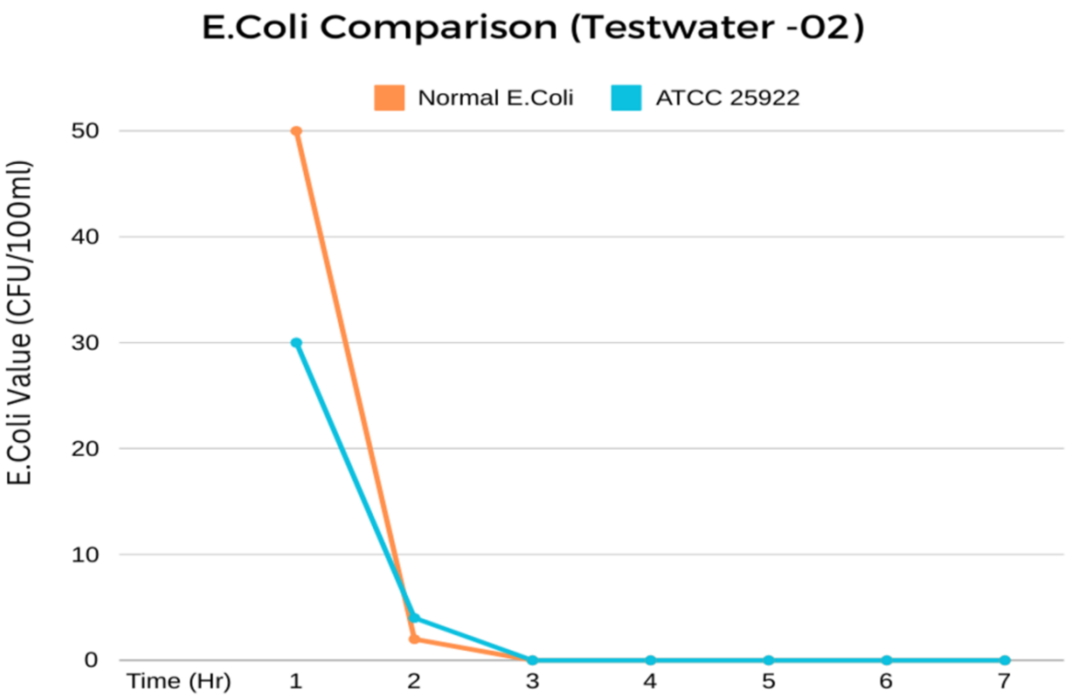

Figure 16: E.coli comparison of Test water 02

Here at the start, Normal E. coli has a higher count (around 50 CFU/100ml) compared to ATCC 25922 E. coli (around 30 CFU/100ml). By the 3rd hour, the count for both types of E. coli is very low (near 0 CFU/100ml). From the 3rd hour onwards, the E. coli count remains at or very near zero for both types. The graph focused the E. coli levels drop significantly in the first few hours and stay low for the rest of the observation period.

4.7 Test water 01(a,) Normal E.coli Turbidity < 5NTU. H_2O_2= 2.5 mg/L

Table 6: Test water 01(a), Normal E.coli (Turbidity<5 NTU), H2O2= 2.5 mg/L

Parameters	Unit	1st hour	2nd hour	3rd hour	4th hour	5th hour	6th hour
Temperature	°C	26.7	29.3	33.5	33.7	34.7	34.6
UV	W/m²	328	487	565	443	338	215
pH		7.68	7.69	7.67	7.51	7.34	7.32
Turbidity	NTU	1.1	1.03	0.98	1.01	0.87	0.84
DO	mg/L	9.77	9.64	8.58	7.86	7.9	7.54
EC	µS/cm	486	491	486	496	498	503
Fe	mg/L	0.58	0.47	0.68	0.52	0.62	0.56
E. coli	(CFU/100 ml)	146	123	56	33	22	14

In this experiment, water quality parameters were monitored hourly over a six-hour period, with initial conditions including a hydrogen peroxide concentration of 2.5 mg/L and turbidity maintained below 5 NTU.

The water temperature increased from 26.7°C to a peak of 34.7°C at the fifth hour, then slightly decreased to 34.6°C by the sixth hour. UV levels ranged from 328 W/m² to a peak of 565 W/m² in the third hour, then declined to 215 W/m² by the sixth hour. The pH values started at 7.68 and gradually decreased to 7.32 by the sixth hour, within a range of 6.5 to 8.5 for drinking water according to WHO & ECR guidelines. Turbidity values fluctuated slightly but remained well below 5 NTU throughout the experiment, with values ranging from 0.84 NTU to 1.1 NTU, which is below 5 NTU according to both WHO and ECR guidelines. Dissolved oxygen (DO) levels decreased from 9.77 mg/L initially to 7.54 mg/L by the sixth hour. High levels of dissolved oxygen are generally favorable for water quality, although WHO and ECR standards for DO is 6.5-8.5 for drinking water. Here it is found that the DO levels of both of the examined water is within the standard range. Electrical conductivity (EC) values increased slightly from 486 µS/cm to 503 µS/cm by the sixth hour. While there is no direct guideline for EC, values below 1000 µS/cm are generally preferred for drinking water, indicating the observed values are well within acceptable limits. Iron levels fluctuated, ranging from 0.47 mg/L to 0.68 mg/L. Both WHO and ECR guidelines recommend iron levels below 0.3 mg/L, and the observed values exceed these limits, which may affect the taste and color of the water and stain plumbing fixtures. Also, it is observed that the concentration of E. coli dropped dramatically over time, from 146 CFU/100 ml to 14 CFU/100 ml by the sixth hour. According to WHO and ECR guidelines, E. coli should not be present in drinking water since it indicates fecal contamination and a high risk of waterborne illnesses. Even though the pattern is declining, the observed values nevertheless demonstrate contamination, showing that while disinfection was effective, it did not completely eliminate E. coli within the six-hour observation period.

4.8 Test water 02(a), ATCC 25922 E. coli Turbidity < 5NTU. H_2O_2= 2.5 mg/L

Table 7: Test water 02(a), ATCC259922 E.coli (Turbidity<5 NTU), H2O2= 2.5 mg/L

Parameters	Unit	1st hour	2nd hour	3rd hour	4th hour	5th hour	6th hour
Temperature	°C	26.7	29.3	33.5	33.7	34.7	34.6
UV	W/m²	328	487	565	443	338	215
pH		7.46	7.47	7.39	7.3	7.11	7.12
Turbidity	NTU	1.02	0.94	0.92	1.1	0.87	0.79
DO	mg/L	7.56	7.32	7.3	7.23	7.06	6.91
EC	µS/cm	472	476	473	478	480	485
Fe	mg/L	0.7	0.6	0.7	0.7	0.8	0.7
E. coli	(CFU/100 ml)	103	78	27	21	13	8

In this experiment, water quality parameters were monitored hourly over a six-hour period, with initial conditions including a H_2O_2 concentration of 2.5 mg/L and turbidity maintained below 5 NTU.

Here, the water temperature increased from 26.7°C to a peak of 34.7°C at the fifth hour, then slightly decreased to 34.6°C by the sixth hour. UV levels ranged from 328 W/m² to a peak of 565 W/m² in the third hour, then declined to 215 W/m² by the sixth hour. The pH values started at 7.46 and gradually decreased, reaching 7.12 by the sixth hour which are within both the WHO and ECR guideline range, indicating acceptable acidity/alkalinity for drinking water. Turbidity values fluctuated slightly but remained well below 5 NTU throughout the experiment, with values ranging from 0.79 NTU to 1.1 NTU. WHO and ECR guidelines suggest turbidity levels below 5 NTU for effective disinfection, while the observed values suggest the water is relatively clear and within acceptable limits. Dissolved oxygen levels decreased from 7.56 mg/L initially to 6.91 mg/L by the sixth hour. EC values increased slightly from 472 µS/cm to 485 µS/cm by the sixth hour. According to WHO and ECR guidelines the observed values exceed these limits. E. coli concentrations decreased significantly over time, starting at 103 CFU/100 ml and dropping to 8 CFU/100 ml by the sixth hour which may have a high risk of waterborne diseases, although the observed values showed improvement time by time.

4.9 Test water 01(a), Normal E.coli Turbidity < 5NTU, H_2O_2= 5 mg/L

Table 8: Test water 01(a), Normal E.coli (Turbidity<5 NTU), H2O2= 5 mg/L

Parameters	**Unit**	**1st hour**	**2nd hour**	**3rd hour**	**4th hour**	**5th hour**	**6th hour**
Temperature	°C	26.3	29.9	31.2	32.4	31.8	31.3
UV	W/m²	328	497	445	367	338	215
pH		7.38	6.98	7.02	6.92	6.79	7.02
Turbidity	NTU	1.07	0.96	1.1	0.85	0.84	0.74
DO	mg/L	13.64	17.93	18.56	15.67	13.33	16.42
EC	µS/cm	503	516	531	538	527	510
Fe	mg/L	1.02	0.9	0.68	0.75	0.96	0.7
E. coli	(CFU/100 ml)	52	44	20	4	0	0

Here, water quality parameters were monitored hourly over a six-hour period, with a H_2O_2 concentration of 5 mg/L and turbidity maintained below 5 NTU.

The table illustrates that the water temperature increased from 26.3°C to a peak of 32.4°C at the fourth hour, then slightly decreased to 31.3°C by the sixth hour. UV levels ranged from 328 W/m² to a peak of 497 W/m² in the second hour, then declined to 215 W/m² by the sixth hour. The pH values remained relatively stable, ranging from 6.79 to 7.38 which is in the limit of WHO and ECR guidelines. Turbidity values fluctuated with values ranging from 0.74

NTU to 1.1 NTU which indicate that the water is relatively clear and within acceptable limits. Dissolved oxygen levels varied, starting at 13.64 mg/L and peaking at 18.56 mg/L in the third hour before decreasing to 16.42 mg/L by the sixth hour exceeding the limit of both WHO and ECR recommendation. EC values increased slightly from 503 µS/cm to 538 µS/cm by the fourth hour and then decreased to 510 µS/cm by the sixth hour. Iron levels decreased from 1.02 mg/L initially to 0.7 mg/L by the sixth hour. It is also observed that the E. coli counts dropped significantly from 52 CFU/100 ml to 0 CFU/100 ml by the fourth hour, and no E. coli was detected thereafter, meeting WHO and ECR standards for drinking water (0 CFU/100 ml). So, the use of 5 mg/L hydrogen peroxide in combination with UV exposure proved effective in eliminating E. coli by the fourth hour of the experiment.

4.10 Test water 02(a), ATCC 25922 E. coli Turbidity < 5NTU. H_2O_2= 5 mg/L

Table 9: Test water 02(a), ATCC25922 E.coli (Turbidity<5 NTU), H2O2= 5 mg/L

Parameters	Unit	1st hour	2nd hour	3rd hour	4th hour	5th hour	6th hour
Temperature	°C	26.3	29.9	31.2	32.4	31.8	31.3
UV	W/m²	328	497	445	367	338	215
pH		6.83	6.98	6.84	6.92	6.79	7.02
Turbidity	NTU	1.02	0.94	0.92	1.1	0.87	0.79
DO	mg/L	14.57	18.58	16.81	10.45	12.76	11.09
EC	µS/cm	498	510	509	512	521	525
Fe	mg/L	0.9	0.7	0.6	0.85	0.8	0.56
E. coli	(CFU/100 ml)	57	35	12	0	0	0

The table presents the results of an experiment evaluating the effect of H_2O_2 at 5 mg/L concentration on water quality parameters in water contaminated with ATCC 25922 E. coli with Turbidity < 5 NTU over a six-hour period. Here, The water temperature increased from 26.3°C to 31.3°C, and UV levels ranged from 328 W/m² to 215 W/m². The pH values remained stable, indicating acceptable acidity/alkalinity according to the ECR and WHO established guidelines for the quality of drinking water.. The turbidity values fluctuated slightly but remained below 5 NTU, indicating clear water within acceptable limits. Dissolved oxygen levels varied, starting at 14.57 mg/L and peaking at 18.58 mg/L in the second hour before decreasing to 11.09 mg/L by the sixth hour. EC values increased slightly, but values below 1000 µS/cm are generally preferred for drinking water. Iron levels decreased from 0.9 mg/L initially to 0.56 mg/L by the sixth hour. E. coli counts dropped significantly from 57 CFU/100 ml at the first hour to 0 CFU/100 ml by the fourth hour, and no E. coli was detected thereafter. This indicates successful disinfection, meeting WHO and ECR standards (0 CFU/100 ml for drinking water).

4.11 DO Comparison for different amount of H_2O_2 in Normal E. coli spiked Water

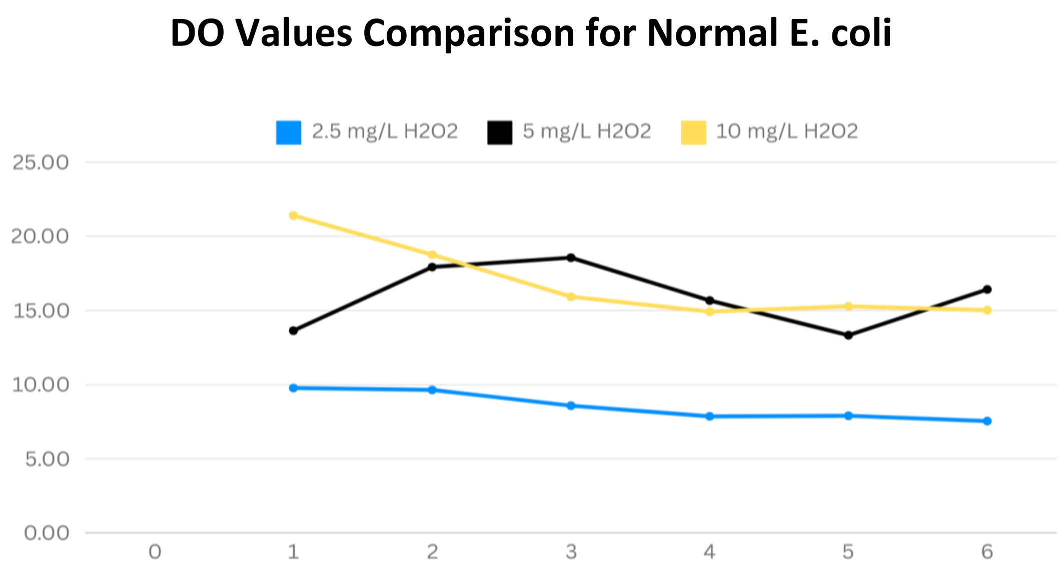

Figure 17: DO comparison of Normal E.coli for various dosage of H2O2

This graph analyzes the effectiveness of different H_2O_2 concentrations (2.5 mg/L & 5 mg/L & 10 mg/L) in maintaining DO levels over a time period for Testwater-01 (Turbidity <5NTU). For 2.5 mg/L H_2O_2, the value of DO starts with the lowest value (around 10 mg/L). Then, it shows a steady decrease over time, reaching below 10 mg/L by the last time point. For 5 mg/L H_2O_2, it is slightly higher than the 2.5 mg/L H_2O_2 line which is around 14 mg/L. And it initially increases to about 18 mg/L before gradually decreasing and stabilizing around 16 mg/L. On the other hand, for 10 mg/L H_2O_2, the DO value is the highest which is around 21mg/L. It gradually decreases and stabilizes around 15 mg/L. So, it can be concluded from the graph that the DO levels for 5 mg/L and 10 mg/L H_2O_2 show fluctuations but generally stay higher than the 2.5 mg/L concentration of H_2O_2.

4.12 DO Comparison for different dosage of H_2O_2 in ATCC 25922 E. coli spiked Water

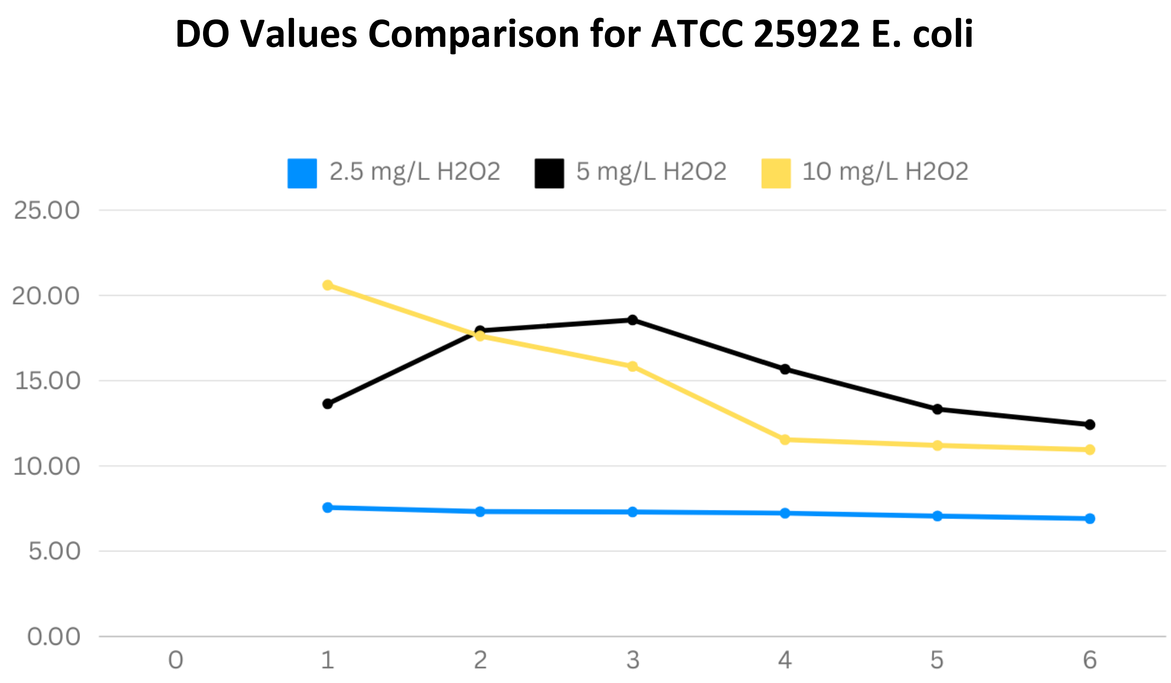

Figure 18: DO comparison of ATCC25922 E.coli for various dosage of H2O2

The graph shows the DO (Dissolved Oxygen) values comparison for Testwater-01(<5 NTU) with ATCC 25922 E. coli under different concentrations (2.5 mg/L & 5mg/L & 10 mg/L) of H_2O_2. For 2.5 mg/L concentration of H_2O_2 the DO values remain relatively constant around 7 mg/L throughout the time. For 5 mg/L concentration of H_2O_2, the DO values start at around 14 mg/L, increase slightly to about 19 mg/L at 3rd hour, then decrease gradually over time, ending at about 12 mg/L. On the other hand, for 10 mg/L concentration of H_2O_2 the DO values start at around 21 mg/L at 1st hour, then decrease over time, ending at about 10 mg/L.
It is analyzed that higher concentrations of H_2O_2 initially lead to higher DO values, which then decrease over time. And the 2.5 mg/L H_2O_2 concentration shows the least variation in DO values for Testwater-01 with ATCC 25922 E. coli.

4.13 E. coli count Comparison for different dosage of H_2O_2 in Normal E. coli spiked Water

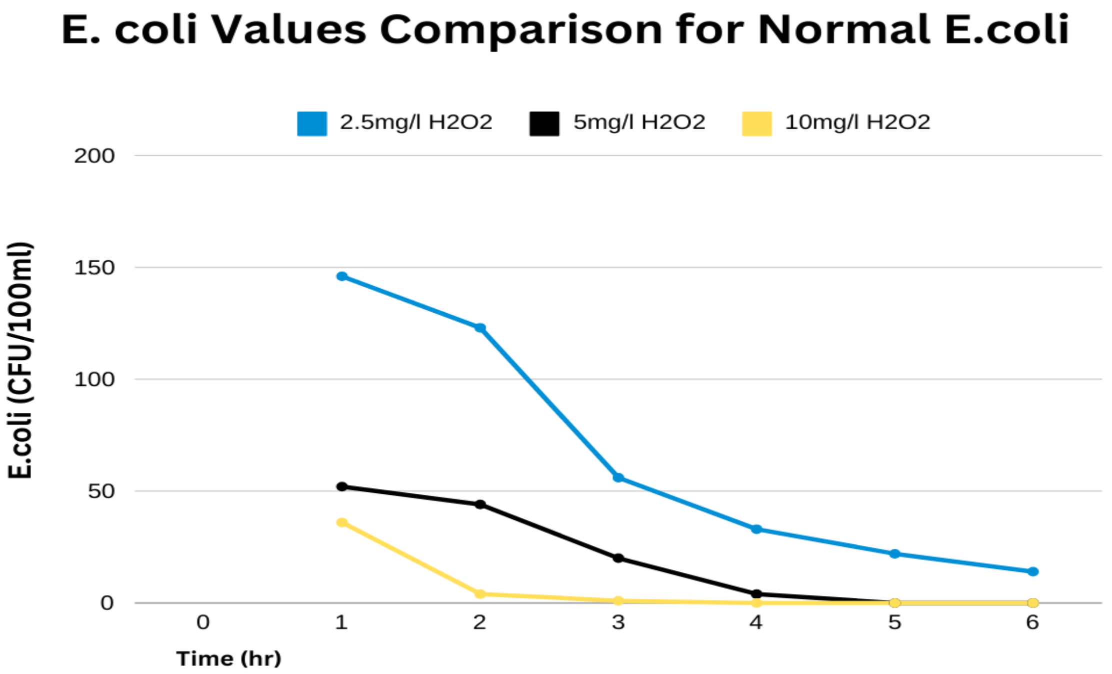

Figure 19: E.coli comparison of Normal E.coli for various dosage of H2O2

This graph displays the E. coli values over time for different concentrations of H_2O_2 for Testwater-01(<5 NTU) with Normal E. coli. For 2.5 mg/L concentration of H_2O_2, the E. coli concentration is around 146 CFU/100 ml at first hour. There is a steep decline in E. coli concentration during the first 2 hours, reaching around 123 CFU/100 ml. The concentration continues to decrease, reaching about 22 CFU/100 ml at 5th hours, and further down to nearly 14 CFU/100 ml by 6th hours. The Normal E. coli doesn't die off during the 6 hours observation period with the 2.5mg/L H_2O_2 concentration. And for 5 mg/L concentration of H_2O_2, the E. coli concentration is about 52 CFU/100 ml at 1-hour. The concentration steadily decreases over time, reaching approximately 4 CFU/100 ml by 4-hour. By 5th hour, the E. coli dies off and the concentration drops to 0 CFU/100 ml and remains at that level for the rest of observation time. And The 10 mg/L H_2O_2 concentration shows the quickest reduction, reaching 0 CFU/100 ml within 3 hours. At 1-hour, the value of E. coli is 36 CFU/100ml. The E. coli dies off at 4th hour and no regrowth of bacteria is shown during the observing period. Here, higher concentrations of H_2O_2 of 10 mg/L lead to a faster reduction in E. coli concentration. The 2.5 mg/L H_2O_2 concentration shows a slower reduction and reduces the E. coli concentration to nearly 0 CFU/100 ml for more than 6 hours. The 5 mg/L H_2O_2 concentration is intermediate in effectiveness, reducing the E. coli concentration to 0 CFU/100 ml by 4 hours which meets the standard recommendation of WHO and ECR. It demonstrates that increasing the concentration of H_2O_2 leads to a more rapid and effective reduction in E. coli levels for Testwater-01 (<5NTU).

4.14 DO Comparison for different dosage of H_2O_2 in ATCC 25922 E. coli spiked Water

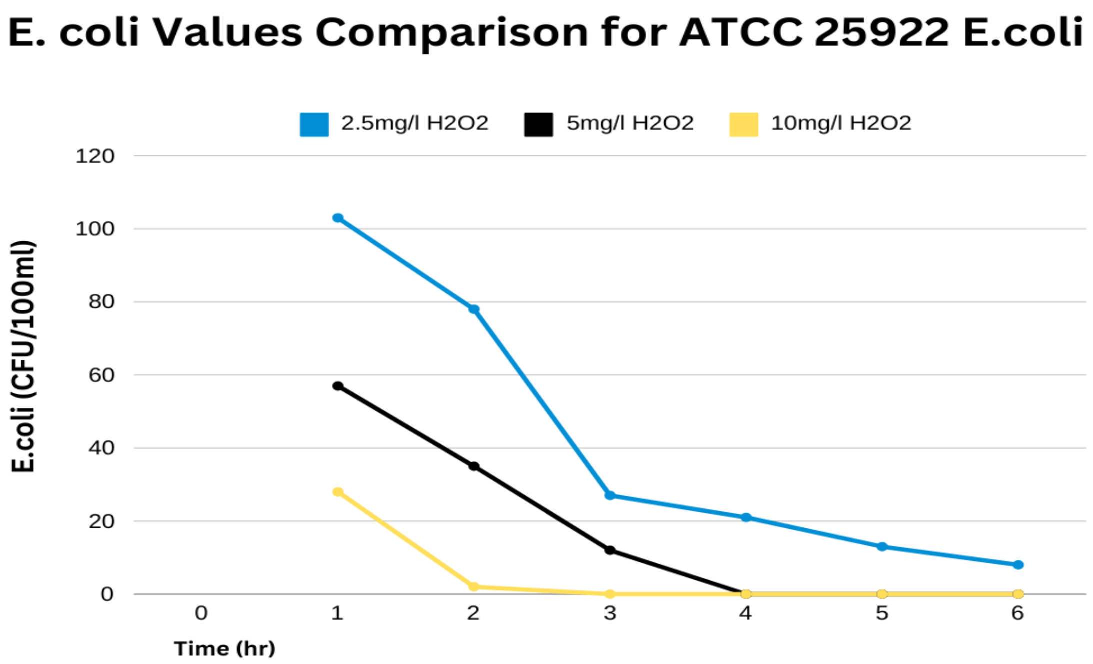

Figure 20: E.coli comparison of ATCC25922 E.coli for various dosage of H2O2

The graph shows a comparison of E. coli values over time for ATCC 25922 E. coli under different concentrations of H_2O_2 for Testwater-01(<5 NTU). For 2.5 mg/L H_2O_2, the E. coli concentration is around 103 CFU/100 ml at 1-hour. The concentration decreases steadily over time, reaching approximately 13 CFU/100 ml by 5-hour, and further dropping to nearly 8 CFU/100 ml by 6th hour. The ATCC 25922 E. coli takes time and doesn't die off within the 6 hours of observation period with the 2.5mg/L H_2O_2 concentration. And for 5 mg/L H_2O_2, the bacteria die off sooner. The E. coli concentration is about 57 CFU/100 ml at 1-hour. The concentration steadily decreases over time and reaching approximately 12 CFU/100 ml by 3 hours. By 4th hour, the E. coli concentration drops to 0 CFU/100 ml and remains at that level. And no regrowth of the bacteria is shown for the use of 5 mg/L H_2O_2 concentration in Testwater-01 (<5NTU). On the other hand, the E. coli concentration is about 28 CFU/100 ml for using 10 mg/L H_2O_2 at 1-hour. There is a rapid decline to 2 CFU/100 ml at 2nd hour. The E. coli concentration reaches 0 CFU/100 ml by 3 hours and remains at that level for the rest of the observation period. It is observed that higher concentrations of H_2O_2 lead to a faster reduction in E. coli concentration. The 10 mg/L H_2O_2 concentration shows the quickest reduction of the E. coli, reaching 0 CFU/100 ml within 3 hours. But The 2.5 mg/L H_2O_2 concentration shows a slower reduction and reducing the E. coli concentration to nearly 0 CFU/100 ml takes more than 6-hour. The 5 mg/L H_2O_2 concentration is intermediate in effectiveness, reducing the E. coli concentration to 0 CFU/100 ml by 4 hours.

4.15 Test water for increased pH (ATCC 25922 E. coli), Initial pH =10.11

Table 10: Test water 01(a), ATCC25922 E.coli, Initial pH= 10.11

Parameters	Unit	Initial	1st hour	2nd hour	3rd hour	4th hour	5th hour	6th) hour
Temperature	°C	27.2	28.9	29.3	31	33	35	34.2
Ambient Temperature	°C	31	34.7	39	41.2	53	55	49
UV	W/m²	297	356	487	662	587	490	363
pH		10.11	9.96	9.73	9.2	9.18	9.15	8.69
Turbidity	NTU	5.57	5.56	5.02	4.59	4.93	5.33	6.61
DO	mg/L	13.87	20.78	17.84	16.77	19.06	20.09	20.64
EC	µS/cm	878	854	872	889	892	882	850
Fe	mg/L	0.7	0.4	0.34	0.2	0.6	0.51	0.1
E. coli	(CFU/100 ml)	4000000000	67	48	22	8	0	0

The table of result describes as follows: The water temperature ranged from 27.2°C to 34.2°C, with the ambient temperature reaching a maximum of 55°C. UV levels ranged from 297

W/m² to 662 W/m², with a peak of 662 W/m² in the third hour. The pH ranged from 10.11 to 8.69, with pH values above this range, indicating high alkalinity. Turbidity values fluctuated, with a low of 4.59 NTU in the third hour and a high of 6.61 NTU in the sixth hour. Dissolved oxygen levels increased from 13.87 mg/L to 20.64 mg/L by the sixth hour, with EC values ranging from 850 µS/cm to 889 µS/cm. Iron levels fluctuated, with a peak at 0.7 mg/L and decreasing to 0.1 mg/L by the sixth hour. E. coli concentration was high, indicating severe contamination. The presence of E. coli decreased significantly, reaching zero by the third hour and remaining undetectable thereafter. The WHO and ECR guidelines emphasize the importance of avoiding E. coli in drinking water.

4.16 Test water for decreased pH (ATCC 25922 E. coli), Initial pH =4.99

Table 11: Test water 01(a), ATCC25922 E.coli, Initial pH= 4.99

Parameters	**Unit**	**Initial**	**1st hour**	**2nd hour**	**3rd hour**	**4th hour**	**5th hour**	**6th hour**
Temperature	°C	26.1	26.3	29.9	31.2	32.4	31.8	31.3
Ambient Temperature	°C	31	34.7	39	41.2	53	55	49
UV	W/m²	287	328	497	445	367	338	215
pH		4.99	4.2	4.21	4.12	4.18	4.16	4.02
Turbidity	NTU	1.23	1.45	1.39	1.02	1.12	1.3	1.37
Dissolved Oxygen	mg/L	12.31	19.29	17.84	14.37	15.25	17.49	19.81
EC	µS/cm	612	625	638	655	654	649	641
Fe	mg/L	0.97	1.02	1.1	0.92	1.2	0.93	0.74
E. coli	(CFU/100 ml)	4000000000	7	0	0	0	0	0

The experiment measured water quality parameters over a six-hour period, starting with an initial pH of 4.99. The water temperature increased from 26.1°C to 32.4°C, and the ambient temperature followed a similar trend. The WHO suggests that cooler temperatures are generally more acceptable for drinking. UV levels ranged from 287 W/m² to 497 W/m², which is more relevant to disinfection processes than to direct water quality concerns. The pH values were significantly below the WHO and ECR guidelines, indicating high acidity, which can lead to corrosion of pipes and leaching of metals into the water. Turbidity values varied, with a low of 1.02 NTU in the third hour and a high of 1.45 NTU in the first hour. Both WHO and ECR guidelines recommend turbidity levels below 5 NTU, preferably much lower to ensure effective disinfection. Dissolved oxygen levels increased from 12.31 mg/L initially to 19.81 mg/L by the sixth hour. EC values increased from 612 µS/cm initially to 655 µS/cm in the third hour, then slightly decreased to 641 µS/cm by the sixth hour. While there is no direct guideline for EC, values below 1000 µS/cm are generally preferred for drinking water. Iron levels varied, starting at 0.97 mg/L and fluctuating throughout the experiment which is within recommended iron levels below 0.3 mg/L. The experiment begins with an extremely high E. coli concentration of 4,000,000,000 CFU/100 ml, indicating severe fecal contamination. After just one hour, the E. coli count drops dramatically to 7 CFU/100 ml, showing that the combination of acidic conditions (pH 4.99) and solar disinfection (SODIS) has an immediate and highly effective impact on the bacterial population. By the second hour, the E. coli concentration reaches 0 CFU/100 ml, meaning all detectable bacteria have been completely eliminated, making the water microbiologically safe according to WHO and ECR standards, which require 0 CFU/100 ml of E. coli for safe drinking water. Over the next four hours, the E. coli count remains at 0 CFU/100 ml, indicating that no bacterial regrowth occurs, and the disinfection is not only effective but also sustained throughout the six-hour period.

4.17 Comparison for different pH water with Test Water 01

4.17.1 DO Comparison

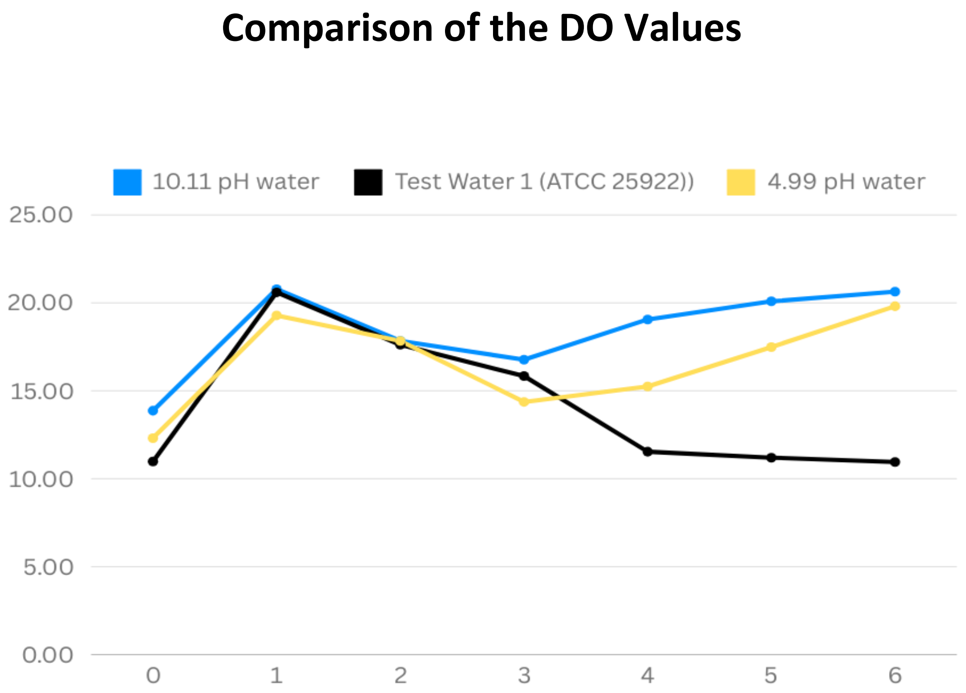

Figure 21: Do Comparison among Test water 01(b), increased and decreased pH water.

This figure compares the pH values over time for Test Water 01(b), which was subjected to both increased and decreased pH. In this scenario, For the water of pH 10.11, the initial pH was raised like NaOH, making the water more alkaline. Again for the water of pH 4.99, the initial pH was lowered, potentially using an acid like HCl, making the water more acidic.

The comparison between these two lines demonstrates the impact of pH adjustments on the disinfection process and on the overall water quality. The pH is a critical factor for microbial activity, water chemistry, and the effectiveness of disinfection. Monitoring how pH changes during the solar disinfection (SODIS) process helps determine whether the reactor works more efficiently under alkaline or acidic conditions.

4.17.2 EC Value Comparison

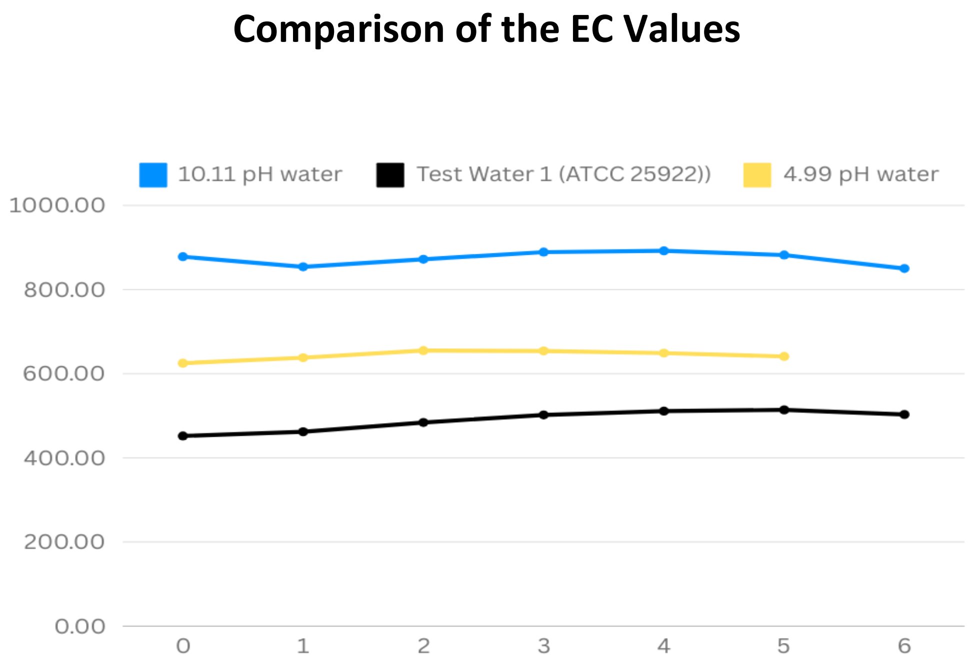

Figure 22: EC value comparison among Test water 01(b), increased and decreased pH water

4.17.3 E. coli count Comparison

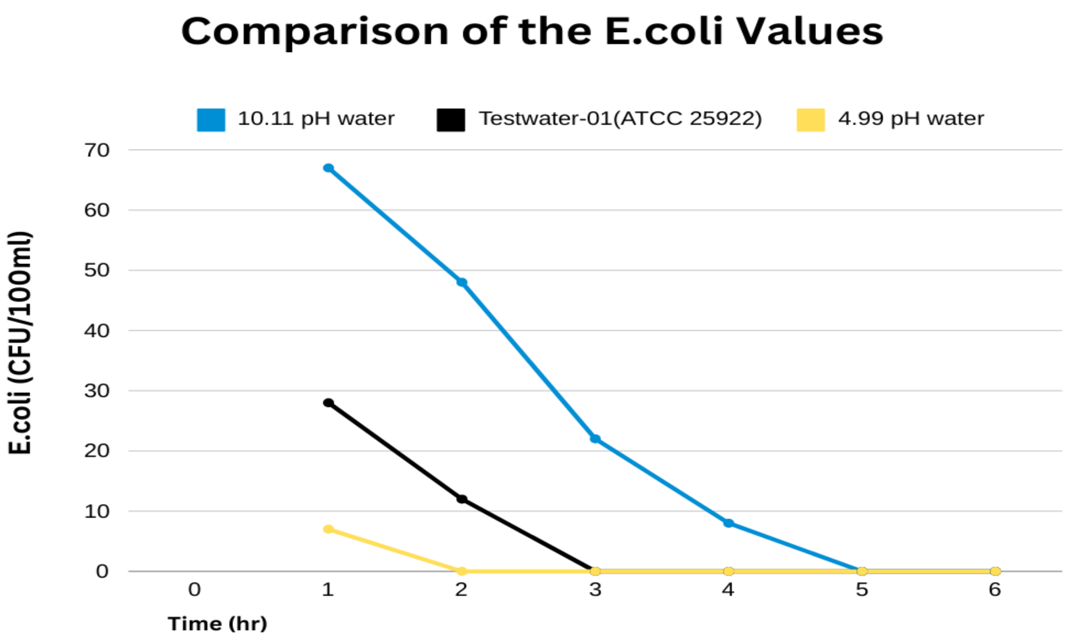

Figure 23: E.coli comparison among Test water 01(b), increased and decreased pH water

4.18 Test water for increased Salinity to 1%

Table 12: Test water 01(b) for increased Salinity to 1%

Parameters	Unit	1st hour	2nd hour	3rd hour	4th hour	5th hour	6th hour	7th hour
Temperature	° C	28.9	29.3	31	33	35	34.2	33.7
UV	W/m²	356	487	662	587	490	363	312
pH		7.29	7.45	7.74	7.58	7.56	7.69	7.59
Turbidity	NTU	1.02	1.13	1.57	1.33	1.29	1.38	1.38
DO	mg/L	21.44	20.89	20.2	18.29	19.27	17.58	17.22
EC	µS/cm	2189	2147	2128	2100	2075	2116	2110
Salinity	%	1.03	1.05	1.05	1.08	1.1	1.08	1.07
TDS	mg/L	1093	1088	1076	1068	1091	1069	1047
Fe	mg/L	1.26	1.21	1.1	0.4	0.35	0.2	0.15
E.coli	(CFU/100 ml)	11	3	1	0	0	0	0

The experiment involved monitoring water quality parameters for seven hours. The temperature rose from 28.9°C to a maximum of 35°C at the fifth hour, then dropped to 33.7°C by the seventh hour. UV radiation levels dropped to 312 W/m² from a peak of 662 W/m² in the third hour. pH levels varied from 7.29 to 7.74, reaching their maximum in the third hour. Measurements of turbidity began at 1.02 NTU and rose to 1.57 NTU in the third hour, then settled at 1.38 NTU in the last hour. Dissolved oxygen levels dropped from 21.44 mg/L to 17.22 mg/L by the seventh hour. Electrical conductivity values decreased from 2189 µS/cm to 2075 µS/cm during the fifth hour, followed by a minor rise to 2110 µS/cm in the following hours. Salinity levels rose from 1.03% to 1.10%, then decreased to 1.07% by the seventh hour. Total dissolved solids (TDS) showed a downward trend, and iron concentrations significantly decreased by the seventh hour. E. Coli was first detected at 11 CFU/100 ml, but dropped to zero by the fourth hour.

4.18.1 pH Value Comparison with Test Water 01

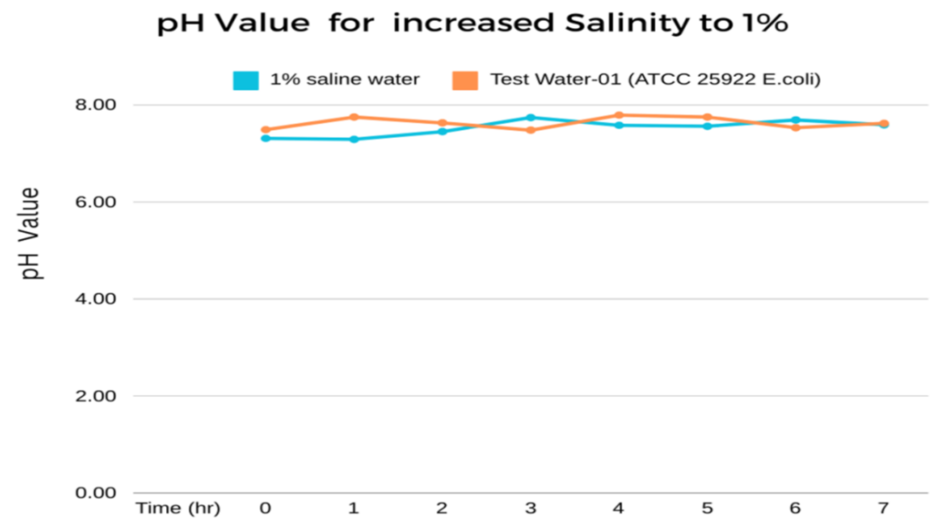

Figure 24: pH value comparison between Test water 01(b) and increased saline water

The graph displays the pH value for increased Salinity to 1% showing the variation in pH value over time for test water-01 with ATCC 25922 E. coli. For 1% saline water, the pH value starts at around 7.5 and remains consistent, with minor fluctuations between approximately 7.4 and 7.6 over the 7-hour period. The pH value for Test Water-01 (ATCC 25922 E. coli) follows a similar pattern to the 1% saline water with slight variations between approximately 7.4 and 7.6. Both water samples show a relatively stable pH value which is in the range over time, indicating that increasing salinity to 1% does not significantly affect the pH levels within the observed time frame.

4.18.2 DO Value Comparison with Test Water 01

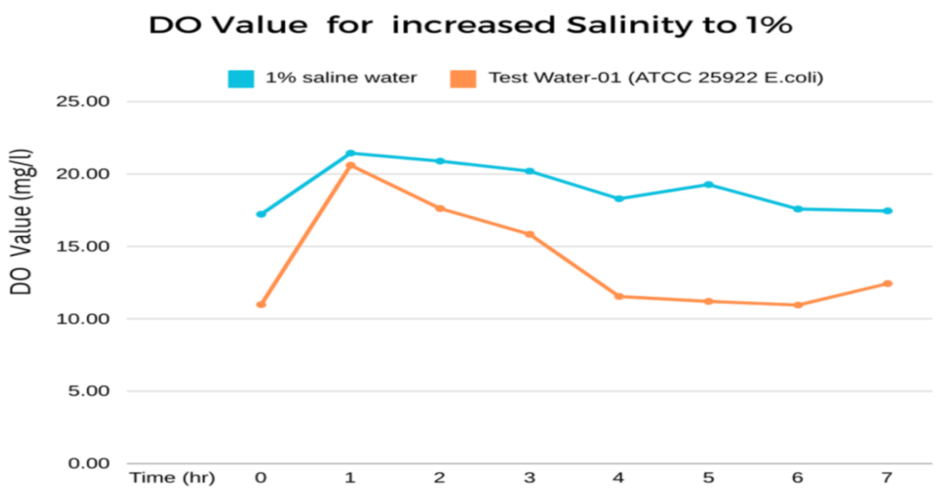

Figure 25: DO comparison between Test water 01(b) and increased saline water

The graph displays the DO Value for increased Salinity to 1%" showing the dissolved oxygen (DO) levels in mg/L over time (hours) for Test water-01 with ATCC 25922 E. coli. 1% saline water maintains higher DO values compared to Test Water-01 (ATCC 25922 E. coli) throughout the 7-hour period. The DO values for Test Water-01 decrease more sharply compared to 1% saline water, possibly due to the biological activity of E. coli, which may consume more oxygen. This indicates that increased salinity affects the dissolved oxygen levels differently in saline water and water containing E. coli.

4.18.3 EC Value Comparison with Test Water 01

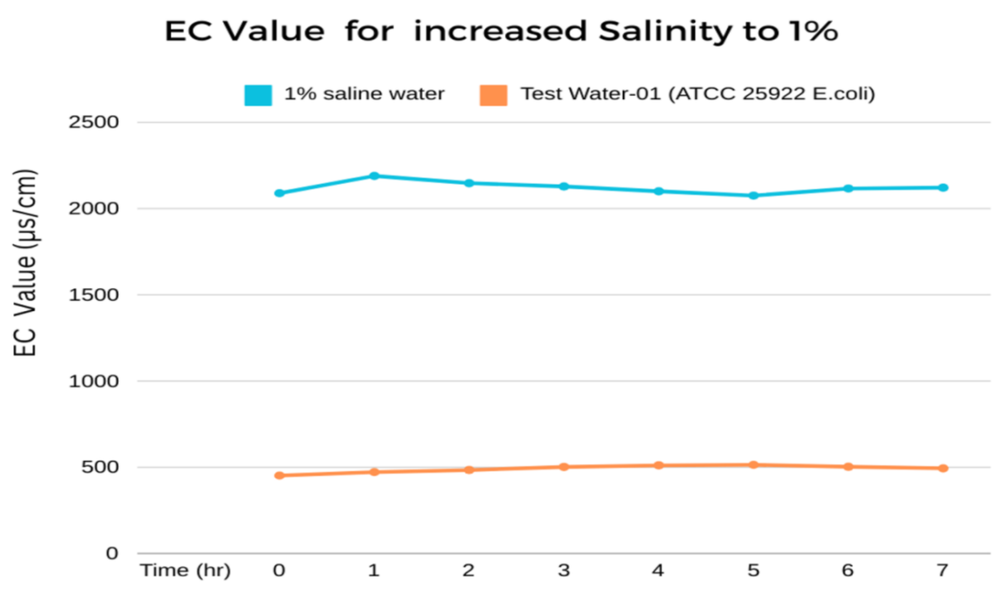

Figure 26: EC comparison between Test water 01(b) and increased saline water

The comparison of EC Value for increased Salinity to 1% shows the Electrical Conductivity values of for Test water-01 with ATCC 25922 E. coli. The relatively high and stable EC values indicate consistent salinity levels in the 1% saline water sample over the 7-hour period. The EC value for the 1% saline water is consistently higher (around 2000 µS/cm) compared to the test water with E. coli (around 500 µS/cm). This stability in EC values describes that the salinity levels in both samples are maintained throughout the experiment, indicating no significant changes in the water's salinity over time.

4.18.4 E. coli count Comparison with Test Water 01

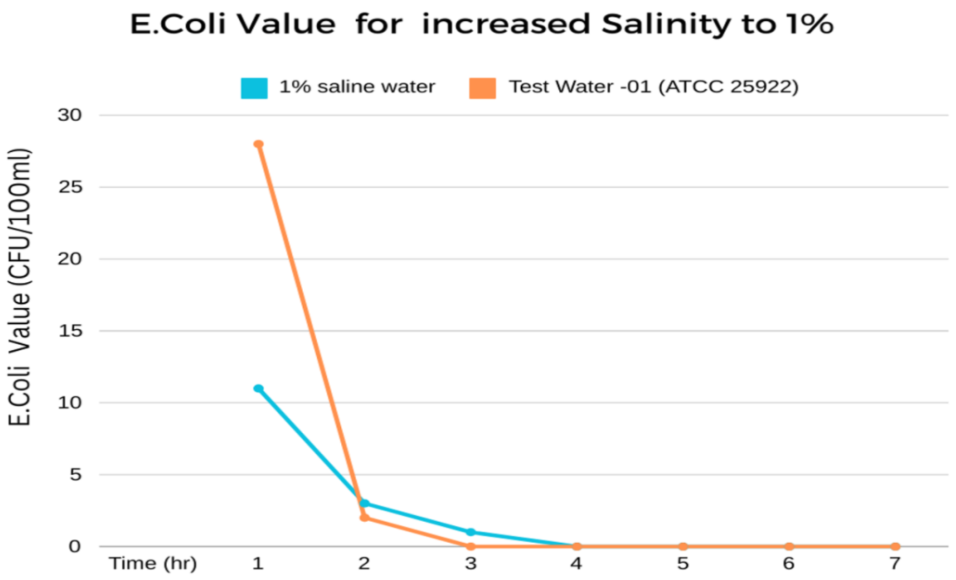

Figure 27: E. coli comparison between Test water 01(b) and increased saline water

The graph displays the E. coli value for increased Salinity to 1% for test water-01 with ATCC 25922 E. coli. The graph shows that the E. coli counts in both the 1% saline water and the test water with E. coli decrease sharply over the first few hours of the experiment. By the 3-hour mark, the E. coli counts in both samples are near 0 CFU/100ml, indicating a significant reduction in bacterial concentration. This suggests that the SODIS process is effective in reducing E. coli levels in water with increased salinity to 1% over a relatively short period.

4.19 Cost Estimation

The entire cost of initially configuring the SODIS system is displayed in this table. It covers the cost of labor, supplies, and other things required to construct the system.

Here are our expenses and costing for the experiment:

Serial Number	Particulars	Cost (in BDT)
1	Wood, Tin, Labor cost	2500
2	Pin + Rope + Pressure Pipe	500
3	8L PET Bottle	330
4	Tap	200
5	Gas Valve	500

6	Battery	240
7	Foil paper, Tissue paper, Glue	700
8	Black Enamel Paint	500
9	Hydrogen peroxide	1800
Total		7270 Taka

The annual costs for those utilizing the technique with tin sheets are listed in this table. It covers the price of paint, hydrogen peroxide, PET bottles, and foil paper. In comparison to other methods of cleaning water, this approach is inexpensive and simple to use, making it appropriate for low-income families in Bangladesh.

Here is the cost analysis for consumers with corrugated tin sheets:

Materials	**Unit**	**Unit price**	**Cost in BDT/ year**
8L PET Bottle	2	110 for each	220
Aluminum Foil paper	1 roll	250	250
Black Enamel Paint	1 liter	170	170
Hydrogen peroxide	1 liter	150 per 100 ml	1500
Total			2140

When compared to more expensive filtration systems such as RO purifiers, which cost BDT 5,000–20,000 annually or more traditional water purifying techniques like boiling which requires gas or electricity, the annual cost of BDT 2,140 is far lower. According to a previous analysis, boiling requires constant fuel such as gas, firewood or electricity, which costs about BDT 10,800 a year for an 8L daily water requirement. Fuel expenses are already a problem for many low-income households, so this method may offer a practical and affordable substitute maintaining the health protection from water-borne diseases.

CHAPTER 5: CONCLUSION & RECOMMANDATION

5.1 General

The final section of this study examines the conclusions drawn from the results and discussion sections. Furthermore, recommendations for implementing SODIS in the subtropical climate of Bangladesh are outlined based on WHO guidelines.

5.2 Conclusions

The conclusions of the experiments are given below-

1. SODIS is effective in reducing microbial contamination from water by killing or inactivating bacteria, viruses, and other pathogens that could cause waterborne diseases by only using the sunlight, heat and no chemicals. By providing microbiologically safe drinking water, SODIS contributes to improved health outcomes by reducing the pathogens from the water.

2. In subtropical climate like Bangladesh where temperatures can be relatively high, SODIS can achieve effective microbial reduction within the recommended exposure time (typically 6 hours or more). This makes it a viable and efficient method for purifying water and improving its microbiological safety. But because of seasonal variations, the effectiveness of SODIS can increase or reduce such as in summer days, temperature around 35-40 degrees, typically 4 hours of exposer time is viable to purify the water according to the WHO and ECR guidelines including microbial reduction.

3. Though because of seasonal variations, the effectiveness of SODIS can reduce. Eventually it takes a little more time to disinfect the water. Also, in areas with poor water quality, combining SODIS with pre-filtration or other water treatment methods (e.g., flocculation or filtration etc.) may improve overall water quality before disinfection, ensuring better effectiveness of SODIS.

4. In regions with varying weather patterns or seasonal changes, shorter exposure times could increase the reliability of SODIS as a water treatment method. Understanding the minimum effective exposure time for SODIS under different environmental conditions can optimize its effectiveness.

5. These experiments refer to the larger-scale systems designed to treat a higher volume of water compared to traditional small-batch methods. The SODIS method is effective and safe even for larger amount of water (8 liter of test water) for both type of E. coli bacteria (Normal E. coli & ATCC 25922 E. coli). It could also inform recommendations for optimizing SODIS implementations to maximize its impact on public health and water safety.

6. Using different amounts of H_2O_2 (2.5mg/l, 5mg/l, 10mg/l) shows that it effects the efficiency and reliability of SODIS as a water treatment method. Both type of E. coli (Normal E. coli & ATCC 25922 E. coli) dies off after 3rd hour for using 2.5mg/l of H_2O_2 for TW-01 and TW-02 samples in summer season unless like using of 5mg/l and 10mg/l H_2O_2.

7. By increasing 1% of the salinity level for TW-01 sample with ATCC 25922 E. coli it is observed that the inactivation of E. coli is approximately same as testwater-01. In summary, SODIS is effective for saline water and safe method for coastal areas.

8. Experimenting by decreasing and increasing the pH level, some variations are observed in the dissolved oxygen & EC values and in the inactivation of E. coli (ATCC 25922 E. coli). But after 4th hour no regrowth of E. coli shows back during the observation period.

9. Even after 6hr and 12hr and 24hr of SODIS with different concentration of H_2O_2 and different level of pH, no microorganisms grow back in either of the test water samples (TW-01 & TW-02) for both E. coli (Normal E. coli & ATCC 25922 E. coli).

10. According to the WHO and ECR guidelines, the turbidity, DO and electric conductivity values are under the standard range. But under some conditions, the values are higher than the permissible range and still no regrowth are found.

11. SODIS is extremely cost-effective because it requires minimal infrastructure and materials. The main components are transparent PET bottles and sunlight, both of which are widely available and inexpensive. Even it doesn't cost much for large amount water to disinfect. This affordability makes it accessible to communities with limited financial resources. As well as implementing SODIS is simple and does not require technical expertise.

12. SODIS is environmentally sustainable as it does not produce waste or emissions. It utilizes renewable energy (solar radiation) and promotes green environment by reducing the use of disposable plastic bottles through reuse.

Despite its benefits, challenges such as variability in sunlight intensity, seasonal changes, and water turbidity in subtropical regions can affect the efficiency of SODIS. Addressing these factors through community education, monitoring, acknowledgement and adaptation strategies in the community is necessary for maximizing its effectiveness as this contributes to improved public health outcomes and supports sustainable development goals related to water and sanitation (SDGs).

5.3 Future Scopes

The future outlook for the SODIS experiment for large amount of water can be explored through sustainable applications, technological innovations and efficiency improvements in Bangladesh. Here's a perspective on the future recommendation:

1. Investigating new materials like bitumen etc that can enhance UV penetration and improve the effectiveness of SODIS application for larger volumes of water.
2. Laboratory experiments can require to determine the effectiveness of SODIS under the previous conditions in the seasonal variations to find out if SODIS is safe or not.
3. Future studies can explore adding TiO_2 as a photo catalyst in SODIS experiment and investigate how well it works compared to the weather conditions in Bangladesh.
4. Some future designs such as passive solar thermal heating systems that can help in raising water temperature and enhancing pathogen kill rates and improving efficiency of SODIS for larger water volumes.
5. For environmental sustainability, future researches can focus on developing eco-friendly, biodegradable, or reusable container materials according to the guidelines that are safer and less harmful to the environment than the PET plastics.
6. Developing affordable, easy-to-use water quality testing kits to assess turbidity, Fe, bacteria levels, and overall water safety comparing with the standards which can help the communities to monitor water quality before and after SODIS treatment.

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