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Effect of enhanced ultraviolet solar radiation on acceleration of contaminated water disinfection

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ABSTRACT

Significant water scarcity in the Middle East severely restricts resources for both domestic and agricultural sectors. Although reclaimed wastewater is currently mostly used for agricultural purposes, increasing the supply of clean, drinkable water is crucial. This study offers a practical method of using ultraviolet (UV) solar radiation to purify and disinfect water. To evaluate the effectiveness of this sustainable approach in generating high-quality, drinkable water. Wastewater samples from the South Amman Water Authority and spring water from Yajooz were exposed to solar disinfection treatments utilizing Concave mirror and without concave mirror. Tests showed that turbidity and electrical conductivity were improved, and that concentration of total dissolved solids was decreased. In addition, total coliform, E. coli, and P. aeruginosa decreased in all water samples with time of exposure to solar radiation. In addition to physical/chemical/microbial properties of treated wastewater, and treated spring water were also improved through exposure to enhanced UV of solar radiation. In comparison to the control group, the use of a concave mirror led to consistently lower final microbial counts and higher water temperatures (up to 39 °C). The resulting microbial levels were well within the regulatory limits for both restricted and unrestricted agricultural irrigation (JS 893/2021), even though the treatment did not completely eliminate all pathogens needed for drinking water under Jordanian standards (JS 286/2015). These results imply that, in water-scarce areas, solar intensification with concave mirrors is a very efficient and sustainable method of treating wastewater for safe irrigation reuse. In addition, this study shows effectiveness of a low-cost, low-tech, and basic design for solar water disinfection (SODIS) that employs mirror reflectors.

Keywords: solar radiation, microbial parameters, physical/chemical parameters, wastewater treatment.

INTRODUCTION

The issue of securing a potable water supply to meet human demand is difficult for those communities with increasing population [1-3], especially those communities in water-poor countries with decreasing supply. There is a crucial need for simple but effective system for improvement of water quality and specifications [4]. Jordan has an arid climate, so unfortunately, fresh water is very scarce. There is growing concern about water quality, especially for environment and for health, calling for comprehensive understanding of innovative disinfection methods to reduce microbial pollutants. Indeed, need to provide potable water has increased as population has increased [5], with recent influx of human refugees causing more pressure on this issue. Several attempts have been made to ameliorate this pressure; for example, through desalination of salt water, but this demands high energy input. Therefore, alternative energy-efficient methods for enhancing both supply and quality of drinking water are highly sought after in Jordan. As energy sector accounted for about 72.9% of total GHGs emission of Jordan in 2006 [6], solar energy is an attractive alternative renewable energy source that is recommended to combat greenhouse gas emissions. Enhanced ultraviolet (UV) light offers a potentially revolutionary method of cleaning contaminated water, and use of solar radiation as main source for UV disinfection mechanism would reduce demand for energy from fossil fuels. In addition to ability of UV to inactivate a broad range of microorganisms, UV radiation is useful in a number of settings including those of inorganic impurities [7].

Thus, alternative solutions for water disinfection involving solar energy will be investigated to reduce effects resulting from use of conventional energy from fossil fuels. The primary goal of work described here is to find an efficient solution to produce clean water using clean energy, thereby reducing GHG emissions which cause climate change, ozone layer depletion, and pollution of environment. Need is urgent for such simple and cost-effective system for water disinfection instead of using a capital-intensive system that requires sophisticated equipment, and demands skilled operators and advanced biological and chemical materials. Also, at customer/household circles/levels, the implementation of some procedures such as boiling of water for 10–15 minutes or use of specific chlorine compounds in form of tablets consumed in water tank to keep disinfection working for water, turns difficult and invisible with old network system and insufficient infrastructure of distribution systems and water network [8].

Studies have indicated that attaining successful disinfection results may depend on a certain UV radiation dosage. For instance, a dosage of 30 mJ/cm^2 was successful in bringing bacterial and virus contamination down to sanitary standards, confirming UV as a dependable wastewater disinfection technology [9]. This result is consistent with research [10] on use of pulsed UV light, which has demonstrated promising results in inactivating a variety of pathogens. Nevertheless, effectiveness of pulsed UV light in different settings is still poorly understood because there is a lack of information on how well UV works when inorganic contaminants are present. Also, disinfection and treatment of water with UV has natural and environmental benefits [11-12] of system processes and operations, in addition to reducing cost of treatment by using natural solar radiation system. Further, UV treatment is a good substitute for conventional chemical disinfectants and eliminates hazards of chemicals and by-products that are frequently found in chlorinated water treatments [13-14]. In addition to altering some physicochemical characteristics [15-16], UV treatment will result in lower bacterial populations related to high UV radiation intensity [10,17], which increases disinfection capacity overall [18].

Insufficient water supply and sanitation facilities causes serious health problems and exposes large populations to waterborne diseases [19]. WHO estimates that 4 billion instances of diarrhea occur annually, of which 2.5 million result in mortality, primarily in children under five. Waterborne pathogens include bacterial/viral/parasitic organisms, that spread by fecal contamination in water. Two most frequent causes of diarrhea in underdeveloped nations are rotavirus and Escherichia coli [20]. This requires researchers to work on new technologies to purify water at low cost. In this work, solar energy will be investigated for water disinfection. Here we are looking at low-cost technology that can be applied by individuals, households, and small communities such as refugee camps during normal or emergency situations. Consequently, this project is expected to increase availability of clean drinking water and reduce risks of water-related health problems. This work demonstrates efficiency of a simple design for solar water disinfection (SODIS) using mirror reflectors. Moreover, application of nanoscale clay minerals in SODIS was also demonstrated.

The current work aims to test physical/chemical/biological properties of treated wastewater and spring water and then to disinfect this water using UV solar radiation and test water to show enhancement in water and wastewater characteristics.

One interesting development in environmentally friendly water treatment techniques is disinfection of contaminated water using increased ultraviolet (UV) sun radiation. This method makes use of UV radiation's disinfecting properties as well as plentiful energy that comes from exposure to sun. Optimizing this approach to guarantee drinking water safety while reducing need for chemical disinfectants requires a thorough grasp of factors influencing disinfection efficacy. Objectives of this study are:

- To design a unit for reflecting solar radiation.
- To investigate other parameters that would influence treatment (optimization phase) light intensity, light exposure time, UV radiation and temperature.
- To test water quality after solar treatment (pH, EC, turbidity, total coliform, *E. coli*, *P. aeruginosa*).

SODIS is used as an active photo-catalytic, hybrid, or intensified systems in this research, also it has the following novelties, aspects and advantages:

- A simple accelerates for microbial destruction.
- Sunlight shows a significant decrease in time required for inactivating pathogens like *E. coli*.
- Small-scale bottle treatment toward continuous flow reactors allows for faster, larger-scale decontamination.
- Reduced treatment time, enhanced efficiency for turbid water, low cost, and sustainable resource of energy.
- The shortcoming in this system that it needs to be implemented on an industrialized scale and need a filtration unit to decrease turbidity in order to increase the efficiency.
- Tt uses a clean recycled glass bottles of 2 to 5 or 10 liters and simple collected concave mirrors to concentrate solar radiation.

This research presents a low maintenance and effective procedure in disinfection procedure and system for enhancement of water quality.

MATERIALS AND METHODS

The methodology used in this work was employed to assess effectiveness of solar radiation in enhancing disinfection of water samples through development of a portable, low-cost system that uses solar radiation to improve efficiency of water treatment in southern Amman community. Assessment methodology includes microbiological and physicochemical testing of water samples collected from wastewater treatment plant of community.

The research design involves a combination of experimental and laboratory-based techniques to examine impact of solar radiation on microbial contamination and physical properties of water. Experimental setup, sampling procedures, and instruments used for microbial and chemical testing that are described in detail. Analysis includes testing for total coliform, *E. coli*, *P. aeruginosa* concentrations, as well as measuring key physicochemical parameters such as turbidity/electrical conductivity/total dissolved solids (TDS)/ph.

An essential part in disinfecting wastewater contaminated with dangerous microbes like *Pseudomonas aeruginosa*, *Escherichia coli*, and total coliform is ultraviolet (UV) sun radiation. In addition to turbidity, electrical conductivity, total dis,0solved solids (TDS), and pH levels, other physicochemical characteristics also affect effectiveness of UV disinfection. In addition to being efficient, UV-based disinfection techniques are also environmentally friendly because they don't produce hazardous by-products that come with conventional chemical disinfection techniques.

Numerous pathogens are successfully rendered inactive by UV light, especially in UV-C spectrum, which damages their genetic material and stops them from replicating. UV-C light is most effective against microorganisms because it can cause DNA base dimerization, particularly thymine dimers, which hinder microbial growth and viability. Germicidal spectrum for UV disinfection goes from 200 to 280 nm [21-22]. Since late 19th century, UV technology has been used in water treatment systems. Its adoption has developments in UV lamp technology and an increasing amount of evidence demonstrating been made easier by its effectiveness against a variety of pathogens, such as bacteria and viruses [23-25].

The UV conditions are classified into the following characteristics:

- Wave length – the most effective disinfection occurs in UVC range (200–280 nm), which matches maximum DNA/RNA absorption spectrum of microorganisms.
- Optimal exposure time – study shows that specific, controlled exposure times (as presented in tables 1 and 3) are required for effective inactivation of contaminants.

Water apparatus

Laboratory bottles of 500 ml were used as "BOECO GERMANY" boro 3.3. with blue screw cap, able to withstand steam sterilization up to 140°C. In addition to, a glass bottle is used because it is transparent, available and resistant to high temperature (whether it is sun temperature or autoclave vapor). Also, a paragraph film was used to cover bottles instead of blue screw cap to obtain highest solar radiation.

Wastewater was collected from southern region of Amman after filtration and before chlorination (the turbidity was about 13–23 NTU units). Also, another sample was collected from Yajooz spring (low turbidity water sample).

Enzyme substrate coliform test

Total coliform, *E. coli*, and *P. aeruginosa* were confirmed by IDEXX setup. Along with quality/quantity tests, this method is regarded as certified, quick, simple and accurate.

Hydrolysable substrate is utilized in enzyme substrate tests for detection of total coliform and *E. coli* enzymes. Total coliform group is characterized as all microscopic organisms having chemical ß-D-galactosidase, which separates chromogenic substrate, resulting in chromogenic release. *E. coli* is characterized as microorganisms giving a positive total coliform reaction and having chemical ß-glucuronidase. Which separates a fluorogenic substrate, bringing fluorogen. Test can be utilized as a part of either a multi-tube and multi-well or a presence and absence (for 100-mL sample) format. A quanti-tray, sealer, UV lamp, UV viewing cabinet, sterile vessel containing sodium thiosulfate, incubators, anti-foam, chemicals (for particular testing) make up IDEXX setup.

To remove the impact of residual chlorine in water samples, 100 milliliters of sample were put on a sterile container with sodium thiosulfate. Colisure reagent was utilized for total coliform and *E. coli* tests, while pseudalert was utilized for *P. aeruginosa* test.

Appropriate reagent powder was then added to water sample and manually dissolved using a swirling vessel – if foam formed in water samples, we had to add five drops of anti-foam. Water samples were then put on quanti-tray/2000 to be sealed and incubated for 24 hours at 35±0.5 °C for total coliform, *E. coli* and *P. aeruginosa*. Then, total coliform-positive cells take on a magenta or red color. Trays containing *E. coli* and *P. aeruginosa* were subjected to UV light; after UV exposure, cells containing *E. coli* will appear luminous red and magenta, whereas cells positive for *P. aeruginosa* will show a blue, fluorescent color. MPN number/100 ml was determined by counting the number of positive tubes in each tray.

IDEXX setup was used to test for *P. aeruginosa, E. coli* and total coliform. Along with quality and quantity tests, this method is regarded as certified, quick, simple and accurate (Fig. 1). Figure 2 presents reagent bottles colisure reagent and pseudalert reagent. Figure 3 presents quantity-tray/2000 results.

Physiochemical water testing

The following physical and chemical parameters were investigated in this project: turbidity, electrical conductivity, total dissolved solids, and pH. Water turbidity, which influences penetration and efficacy of UV light, is a crucial factor in UV treatment. Increased turbidity can reduce disinfection effectiveness by protecting microorganisms from UV light [26]. Implementing sedimentation procedures can greatly lower turbidity,

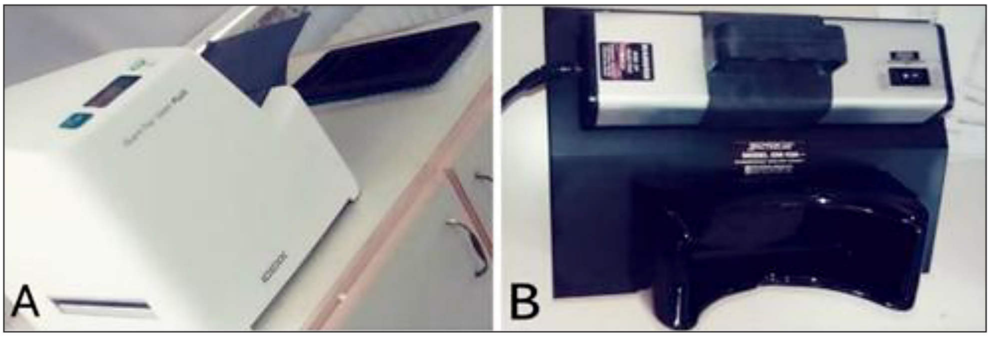

Figure 1. IDEXX system, with being the Quanti-Tray sealer (A), the cabinet with UV lamps (B)

Figure 2. Bottles of reagents: colisure (A), and pseudalert agent (B)

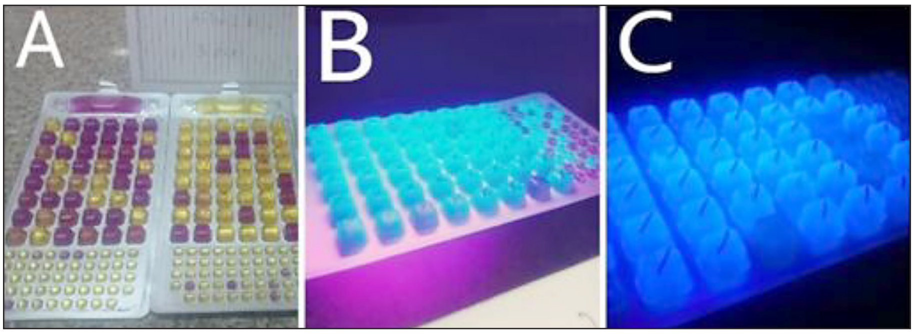

Figure 3. Quanti-tray/2000 outcomes: A – yellow for negative total coliform and magenta and red for positive; B – fluorescent, magenta wells for positive *E. coli* and inflorescent wells for negative; C – blue, fluorescent wells for *P. aeruginosa* that is positive, and inflorescent wells for those that are negative

improving effects of following UV treatment on microbiological organisms, such as *E. coli* and total coliforms, according to a study by [27].

Turbidity, which is measured in NTU (nephelometric turbidity units), is a measure of a liquid's optical characteristics that result in light rays being scattered or absorbed rather than passing through a sample in straight lines. According to EN ISO 7027, the unit measures dispersed light at a 90° angle and ranges from 0.01 to 1100 NTU. The TB 210 IR compact infrared turbidity meter is shown in Figure 4.

Electrical conductivity is a measure of facility with which electrical current can pass through water. And is measured in microseconds (μS/cm). Handheld SD 70 (Lovibond), as shown in Figure 5, was used to measure electrical conductivity.

Figure 4. Turbidity meter

Figure 5. EC meter

Figure 6. TDS meter

Figure 7. pH meter

The concentration of all dissolved materials in water, including inorganic salts and trace amounts of organic compounds, is known as total dissolved solids. TDS is measured in ppm (mg/L). Figure 6 presents TDS meter used, Handheld SD 80 TDS (Lovibond).

Although pH measures the potential activity of hydrogen ions (H+) in a sample, it also reveals how acidic the sample is. 7.0 is regarded as neutral on the pH scale, which runs from 0 to 14. Acids are defined as solutions with a pH of less than 7.0. Basic solutions have a pH of 7.0 to 14.0. Pen-type pH meter, with measurements ranging from 0 to 14 pH, with 0.01 resolution and ± 0.05 accuracy is shown in Figure 7.

RESULTS AND DISCUSSION

The experimental setup, which is essential to optimization stage, includes techniques that specify application of different environmental circumstances in treatment scenarios. For example, exposure duration and light intensity can have a big impact on how well solar disinfection procedures work. A thorough evaluation of these characteristics shows how important they are for improving disinfection capabilities against microbiological pollutants. In particular, research shows that continuous exposure to different UV wavelengths significantly reduces bacteria count. Furthermore, temperature during treatment affects rates of chemical reactions involved in degradation processes as well as microbial survivability [28].

Two experimental setups were conducted; first experimental setup was used a water sample from southern Amman wastewater treatment plant, and second setup was conducted by using a water sample from Yajooz spring. Figures 8 and 9 show experiment setup. Samples were collected from wastewater treatment plant and spring water according to plant and procedure that are followed usually in water and wastewater treatment [29]. Also, statistical calculations and parameters were prepared [30]. Table 1 presents parameter results for wastewater that exposed to solar radiation.

The results in Table 1 revealed that direct solar radiation affected the physical and biological characteristics of wastewater, both with and without the use of a concave mirror (C.M.). A temperature of 25.2 °C, a pH of 7.3, and

Figure 8. Concave mirror experiment setup

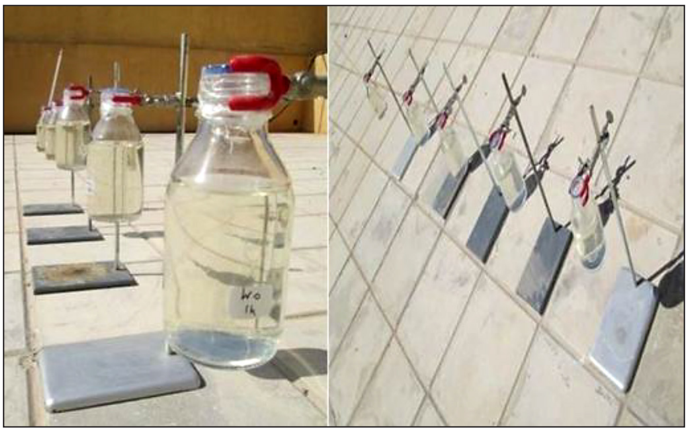

Figure 9. Base samples without concave-mirror experiment setup

Table 1. Microbial parameters results when wastewater samples are exposed to direct solar radiation by concave mirror (C.M) and without concave mirror (W.M) [30-34]

Group	Time period (h)	Sample temp. (°C)	Air temp. (°C)	Solar radiation (W.h/m²)	Cloud cover	pH	Turbidity (NTU)	TDS (ppm)	Conductivity (µS/cm)	Total coliform (MPN/100ml)	*E. coli* (CFU/100ml)	*P. aeruginosa* (CFU/100ml)
Base	0	25.2	23.7	8.5	90% clear	7.3	37.7	582	859	>2419.6	1119.9	248.1
W.M	1	33	31	8.6		7.3	37.4	583	866	1553.1	436	172
	1.5	36	33.8			7.2	37.2	588	876	770.1	43.9	58.3
	2	37	35.4			7.2	37.1	594	884	387.3	26.6	48
	2.5	37.3	36.4			7.2	36.8	587	870	98.7	12	24.3
C.M	1	34.3	28	8.7		7.1	37.3	580	862	1203.3	298.7	122.3
	1.5	37.2	29			7.1	37	587	874	272.3	21.1	28.5
	2	38	29			7.1	36.9	592	874	222.3	20.9	20.3
	2.5	39	31			7.2	36.7	592	878	95.9	8.5	14.6

Note: Number of repetitions is 3 for each category, and the value calculated is the average value.

high concentrations of biological contaminants >2419.6 MPN/100ml for total coliform, 1119.9 MPN/100ml for *E. coli*, and 248.1 MPN/100ml for *P. aeruginosa* were recorded at 0 hours for the untreated water. Moreover, the temperature in the C.M. group increased to 39 °C concurrently with these biological changes, surpassing the W.M. group's recorded temperature of 37.3 °C.

All bacterial concentrations in the W.M. and C.M. groups significantly decreased after being exposed to solar radiation for 2.5 hours. In contrast to the W.M. group, the group treated with the concave mirror (C.M.) consistently showed lower microbial counts at every time interval. The W.M. group measured 98.7 MPN/100 ml, while the C.M. group reduced total coliform to 95.9 MPN/100 ml by the end of the 2.5-hour period (Fig. 10). *E. coli* and *P. aeruginosa* showed a similar pattern, reaching final concentrations of 8.5 MPN/100 ml and 14.6 MPN/100ml, respectively, in the C.M group as opposed to 12 MPN/100ml and 24.3 MPN/100 ml in the W.M group (Fig. 11). Figure 12 shows the concentration of Pseudomonas for treated wastewater.

Figure 13 shows the turbidity of W.M and C.M samples considering the exposure time using linear regression. Figure 14 presents the linear and logarithm regression. The microbial total coliform in C.M. and W.M. with the time of exposure to solar radiation. Linear regression shows a strong relation for turbidity with time as shown in Figure 13. While in Figure 14, linear regression is better than logarithm regression in C.M. total coliform (R^2 = 0.8337). But, for W.M. logarithm regression (R^2 = 0.9889) is better than linear regression. Also, Figure 15 presents the *E. coli* on exposure time for W.M. and C.M. and it is seen that logarithm regression is better than linear regression depending on the R2 adjusted in the figure for booth.

The observed microbial inactivation is consistent with previous research on solar water

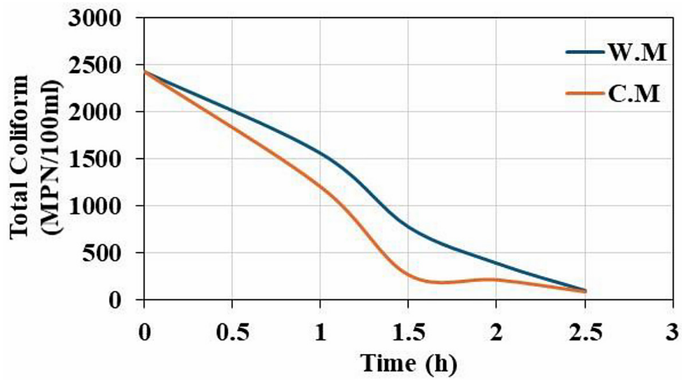

Figure 10. Concentration of total coliform for treated wastewater

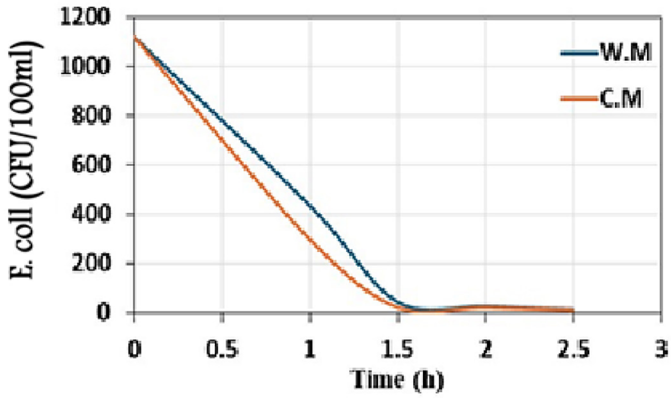

Figure 11. Concentration of *E. coli* for treated wastewater

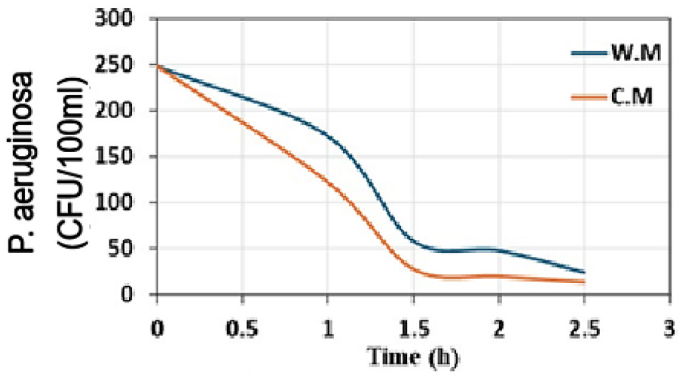

Figure 12. Concentration of *P. aeruginosa* for treated wastewater

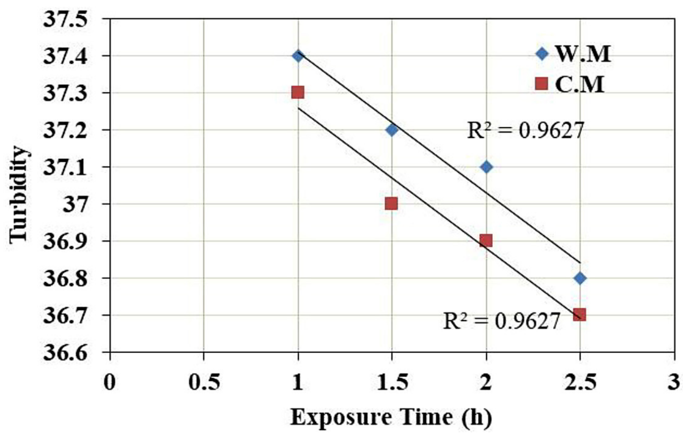

Figure 13. Turbidity for W.M and C.M upon time of exposure

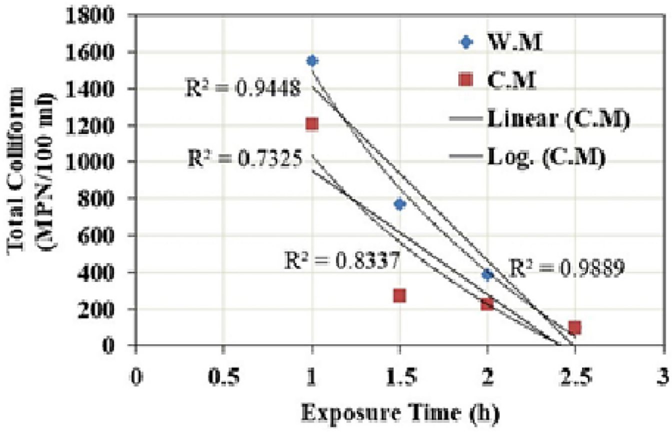

Figure 14. The total coliform upon time of exposure

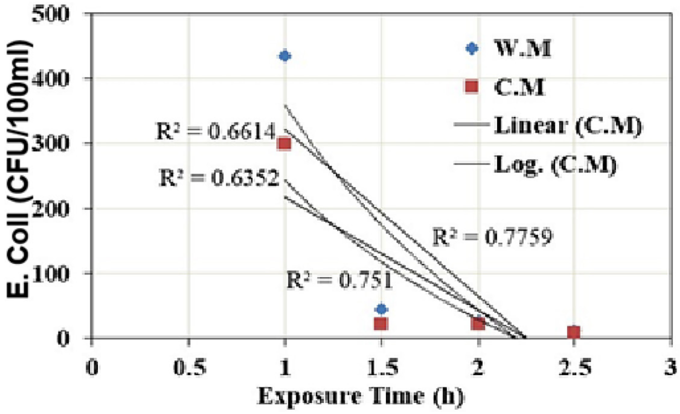

Figure 15. *E coli* with time of exposure (MPN/1000 ml)

disinfection (SODIS). UV-A radiation, which directly damages pathogen DNA and RNA through oxidation, and thermal effects, which alter cellular protein structures, work together to drive the inactivation mechanism [35-37]. In line with earlier research, the concave mirror accelerated this process by raising solar flux and raising the temperature in the C.M group to 39 °C, which is known to hasten the thermal inactivation of bacteria such as *P. aeruginosa* and *E. coli* [38, 39]. While traditional SODIS frequently necessitates longer exposure times (up to 6 hours) in PET bottles, this study indicates that significant reductions can be achieved with refractive intensification in as little as 2.5 hours.

The Jordanian Standard for Reclaimed Domestic Wastewater [40] and the Jordanian Standard for Drinking Water [41] must be compared to the treated wastewater quality in order to assess its potential for reuse. Depending on the type of crop, this standard sets stringent limits for *E. coli*. For example, the limit is 100 MPN/100 mL for cooked vegetables and 1,000 MPN/100 mL for fruit trees. According to our findings, the C.M.-treated water had an *E. coli* level of 8.5 MPN/100 mL after 2.5 hours. This shows that solar treatment with a concave mirror is very successful in preparing wastewater for safe agricultural reuse, as it is well within the regulatory limits for both restricted and most unrestricted irrigation categories.

Jordanian drinking water standards [41] mandate that total coliforms, *E. coli*, and *P. aeruginosa* be completely absent (0 MPN/100 mL). The water does not satisfy the stringent microbiological requirements for potable use, despite the notable decrease the C.M group's final *E. coli* count was 8.5 MPN/100 mL. As a result, even though this solar disinfection technique works well for irrigation, it is insufficient on its own for producing drinking water and would need additional multi-stage treatment (such as filtration or chlorination) to satisfy JS 286/2015's zero-pathogen requirement [42].

Statistical analysis on data of wastewater treated by solar radiation

Through statistical analysis using one-way ANOVA analysis on treatment of water (wastewater and common water), it is shown that difference of water characteristics is not significant depending on the ANOVA analysis and p-value that is greater than 0.05. That means thus that effect of solar radiation on different water type is same on water disinfection treatment. Table 2 presents characteristics of treated water and p-value upon one-way ANOVA analysis.

Water sample from Yajooz spring

The findings in Table 3 assessed the effects of direct solar radiation on the physical and biological characteristics of spring water samples from Yajooz, both with and without the use of a concave mirror (C.M.). With total coliform >2419.6 MPN/100 ml, *E. coli* at 816 MPN/100ml, and Pseudomonas at 114.5 MPN/100 ml, the initial baseline parameters showed high microbial contamination.

Figures 16, 17, and 18 show that both treatment approaches showed a significant decrease in all observed microbial populations after being exposed to solar radiation for three hours. In comparison to control, and W.M., the C.M. group attained faster microbial inactivation at temperatures of 37 °C. In particular, both techniques successfully decreased total coliform and *E. coli* to less than 1 MPN/100 ml by the end of the 3-hour period. Both groups' physical characteristics, such as turbidity and pH, stayed largely constant during the exposure period. Also, Figure 19 presents the turbidity for W.M and C.M samples using linear regression for data.

The synergistic effect of thermal energy and ultraviolet (UV) radiation is the main cause of the observed rapid disinfection. The addition of a concave mirror increases the solar flux and concentrates energy to raise the water temperature, whereas UV-A and UV-B radiation directly damages DNA and causes oxidative stress in pathogens.

Table 2. Characteristics of waste water and statistical analysis (ANOVA)

Turbidity (NTU)	Total coliform (MPN/100ml)	*E. coli* (MPN/100ml)	*P. aeruginosa* (MPN/100ml)
37.4	1553.1	436	172
37.2	770.1	43.9	58.3
37.1	387.3	26.6	48
36.8	98.7	12	24.3
37.3	1203.3	298.7	122.3
37	272.3	21.1	28.5
36.9	222.3	20.9	20.3
36.7	95.9	8.5	14.6
DF = 1, 4, 5 p-value = 0.233 F value = 1.25 Effect size = 0.56 (large)	DF = 1, 4, 5 p-value = 0.306 F value = 1.213 Effect size = 0.55 (large)	DF = 1, 4, 5 p-value = 0.464 F value = 1.112 Effect size = 0.53 (large)	DF = 1, 4, 5 p-value = 0.273 F value = 4.267 Effect size = 1.03 (large)

Table 3. Microbial parameter results when Yajooz spring water samples are exposed to direct solar radiation by concave mirror (C.M) and without concave mirror (W.M)

Group	Time period (h)	Sample temp. (°C)	Air temp. (°C)	Solar sadiation (W.h/m^2)	Cloud cover	pH	Turbidity (NTU)	TDS (ppm)	Conductivity (µS/cm)	Total coliform (MPN/100ml)	*E. coli* (CFU/100ml)	*P. aeruginosa* (CFU/100ml)
Base	0	26	25	8.5	90% clear	7.6	1.21	529	804	>2419.6	816	114.5
W.M	1	32	26	8.6		7.5	1.15	553	820	>2419.6	233.3	53
	2	33	26			7.6	1.07	552	820	81.3	17.3	8.4
	3	34.2	27			7.7	1.06	559	818	<1	<1	1
C.M	1	34	26	8.7		7.6	1.11	529	816	>2419.6	214.2	23.1
	2	35.4	26			7.7	0.97	547	717	9.8	1	1
	3	37	28			7.6	0.9	543	816	<1	<1	<1

Note: Number of repetitions is 3 for each category, and the value calculated is the average value.

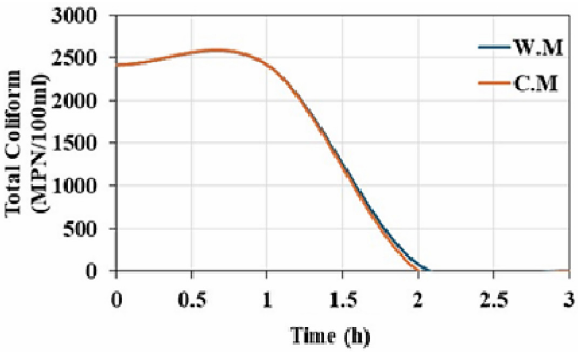

Figure 16. Concentration of total coliform for spring water

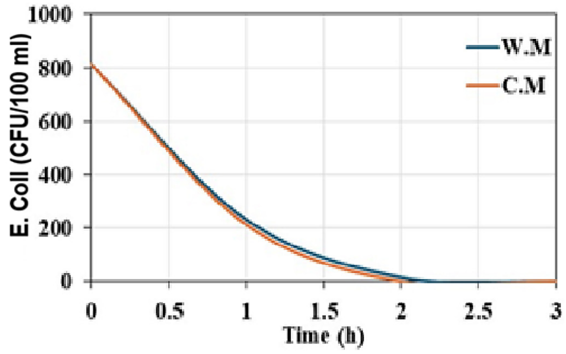

Figure 17. Concentration of *E. coli* for spring water upon time of exposure to solar radiation

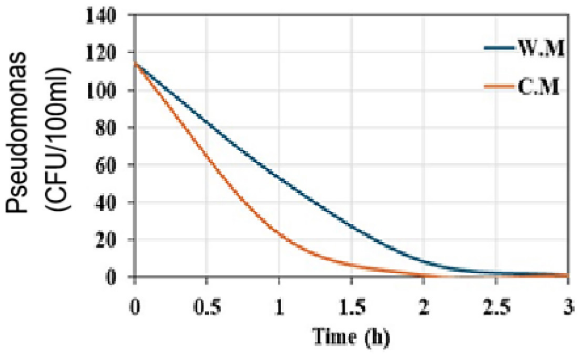

Figure 18. Concentration of *P. aeruginosa* for spring water upon time of exposure to solar radiation

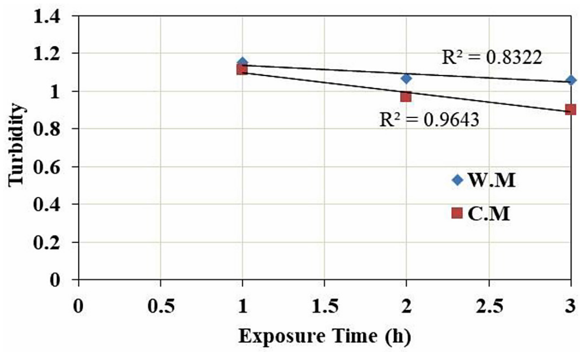

Figure 19. Turbidity for W.M and C.M upon time of exposure

By weakening cellular membranes and making them more vulnerable to UV-induced photolysis, research demonstrates that even slight temperature increases (such as reaching 37 °C) dramatically increase the death rates of *E. coli* and *P. aeruginosa*. According to recent research, concentrating solar collectors – like parabolic or concave systems – improve microbial kill rates and shorten exposure times when compared to conventional SODIS [43].

Statistical analysis on data of water treated by solar radiation

Through statistical analysis using one-way ANOVA analysis on treatment of water (Yajouz spring water water), it is shown that difference of spring water characteristics is not significant depending on ANOVA analysis and p-value that is greater than 0.05. That means thus that effect of solar radiation on different water type is same on water disinfection treatment. Table 4 presents

Table 4. Characteristics of Yajooz spring water and ANOVA analysis

Turbidity sample (NTU)	Total coliform (MPN/100 ml)	*E. coli* (MPN/100 ml)	*P. aeruginosa* (MPN/100 ml)
1.15	2420	233.3	53
1.07	81.3	17.3	8.4
1.06	1	1	1
1.11	250	214.2	23.1
0.97	9.8	1	1
0.9	1	1	1
DF = 1, 4, 5 Effect size = 0.74 (large) p-value = 0.215 F value = 0.785	DF = 1, 4, 5 Effect size = 0.47 (large) p-value = 0.404 F value = 0.8778	DF = 1, 4, 5 Effect size = 0.057 (small) p-value = 0.914 F value = 0.0131	DF = 1, 4, 5 Effect size = 0.35 (large) p-value = 0.507 F value = 0.486

characteristics of Yajouz water and p-value upon one-way ANOVA analysis

With a percentage reduction of 96%, 99.2%, and 95% in the counts of total coliform, *E. coli*, and *P. aeruginosa*, respectively, after 150 minutes of exposure, it was discovered that the disinfection unit with CM was more effective at disinfecting water. With a percentage decrease in total coliform, *E. coli*, and *P. aeruginosa* levels of 95.9%, 97.2%, and 90%, base unit was the least effective.

The Jordanian Standard for Drinking Water [43], which serves as the region's benchmark for groundwater and potable water safety, validates the efficacy of this approach. According to the standard, there must be no detectable levels of *P. aeruginosa*, *E. coli*, or total coliform in a 100-milliliter sample. The solar disinfection process, especially when enhanced by the concave mirror, successfully brought the contaminated Yajooz spring water into compliance with national safety requirements by reaching levels of <1 MPN/100ml within 3 hours.

These results demonstrate that incorporating inexpensive concave mirrors into point-of-use (POU) water treatment is a practical and sustainable approach. Solar-based systems provide a high-performance, carbon-neutral alternative in Jordan's rural or water-scarce areas where traditional chemical disinfection (like chlorination) is frequently unavailable or produces hazardous byproducts.

CONCLUSIONS

Concave mirrors are an inexpensive, environmentally friendly way to improve solar disinfection. It successfully lowers microbial loads to levels appropriate for a variety of irrigation applications, helping to achieve water conservation goals in water-scarce regions like Jordan, even though it is insufficient to make wastewater drinkable by Jordanian standards.

According to the study, solar water disinfection (SODIS) is a very efficient and reasonably priced way to treat tainted spring water in the Yajooz region. By concentrating solar flux and raising water temperatures to 37 °C, the integration of a concave mirror speeds up the process of reducing microbial loads, even though standard solar exposure still significantly reduces them. As shown in results, solar radiation has an effective impact in reducing the biological parameters for water and wastewater such as total coliform, *E. coli*, and *P. aeruginosa* in all samples and it is clear in the figures prepared. Also, ANOVA analysis results showed significant effect or difference in treatment level of samples tested in the current research.

The system effectively satisfies the strict Jordanian Standard (JS 286/2015) for drinking water by achieving the <1 MPN/100ml threshold for total coliform, *E. coli*, and *P. aeruginosa* in just three hours. In rural or water-scarce areas where conventional chemical disinfection is not available, this method offers a viable and practical substitute for point-of-use water treatment. Also, ANOVA analysis give the evidence on the success of the treatment using C.M. in simple SODIS system as applied in current research.

Despite the study's revealed strong potential of biological disinfection efficacy, a number of issues still exist. First, seasonal and diurnal variations can affect the system's performance because it is inextricably linked to solar intensity. Second, even though concave mirrors improve UV concentration, maintaining efficiency in arid Middle Eastern climates requires managing the practical problem of mirror soiling, or dust accumulation. Lastly, even though the procedure greatly decreased microbial loads, but the traditional (classic) SODIS here need to use a filtration unit to decrease turbidity of water to increase the efficiency of the system in water treatment. Also, more time is needed for water treatment to increase the efficiency of the system.

Further research is needed to determine whether it can also eliminate non-biological and chemical pollutants like heavy metals, and micro-plastics well as drugs, hormones, and pesticides residue. Moreover, the need for complete and comprehensive research is needed to cover the treatment of biological, physical, and may be chemical pollutants to be included in the system.

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