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Assessment of Theoretical and Test Performance Considerations of Concentrated Solar Water Purification System "Parabosol" in Underserved Regions

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Abstract: Water is a fundamental human right and a prerequisite for sustainable development because it is an essential element of existence. Notwithstanding, a huge part of the world's population continues to face challenges in accessing clean and safe drinking water. This situation is particularly pronounced in arid and underdeveloped regions where there is a global water crisis that is a huge threat to human health, economic development, and environmental stability. Designed with solar energy, the award-winning "Parabosol" enhances water evaporation and purifies it simultaneously. Parabosol does not require any expensive machines or complicated infrastructural frameworks, making it both cost-effective and efficient for such vulnerable communities. Transporting it easily allows for quick deployment in remote areas during emergencies, ensuring a clean, dependable water supply for basic household use. This innovative measure, which reduces the risk of waterborne diseases and increases access to safe water resources within communities, could greatly contribute to public health promotion efforts. It is intended for daily performance that corresponds to the minimum needs of one family unit (no less than 35 L per person). The processing capacity of each station varies between 120 and 180 L of water per day (depending on geographical and environmental conditions), depending on geographical and meteorological (solar radiation values) factors. However, experimental values are around 250 L. Parabosol illustrates a novel model with its distinctive design and functionality, highlighting the critical role of clean energy in the development of a more sustainable and resilient future. Additionally, unlike macrosystems that require a substantial initial investment and ongoing operating costs, Parabosol is a portable solution that has the potential to address the issue of clean water scarcity in the future.

Keywords: solar energy; water purification; arid environment; sustainability; SODIS; design; water treatment

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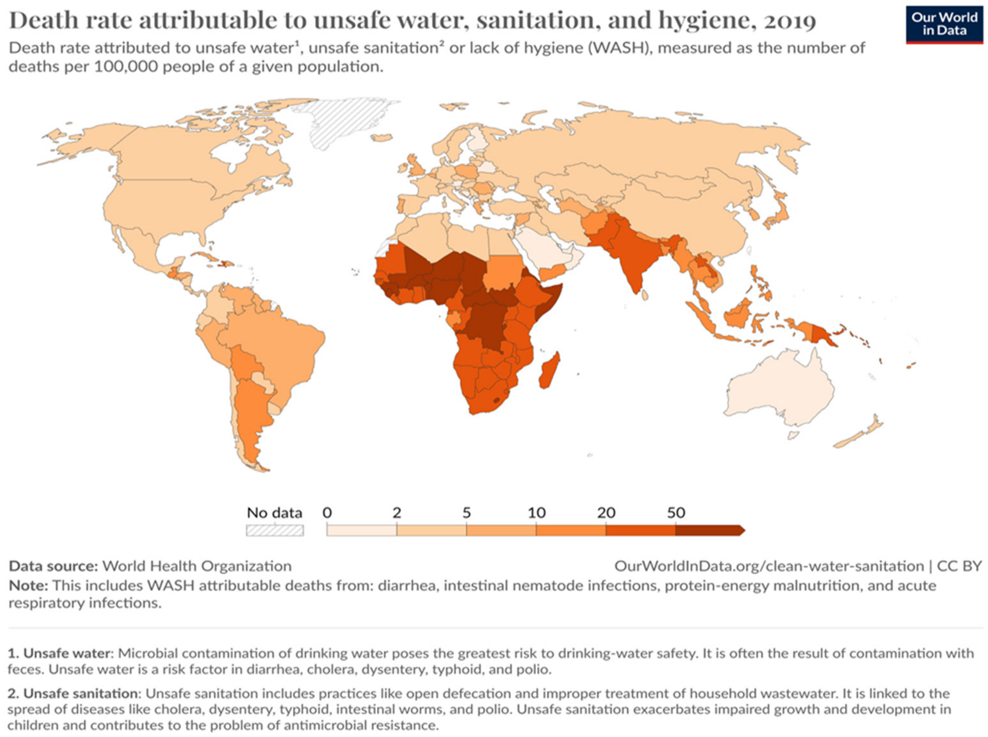
Citation: Gürsu, H. Assessment of Theoretical and Test Performance Considerations of Concentrated Solar Water Purification System "Parabosol" in Underserved Regions. *Sustainability* **2024**, *16*, 6611. https://doi.org/10.3390/su16156611

Academic Editor: Kian Jon Chua

Received: 22 May 2024
Revised: 23 July 2024
Accepted: 29 July 2024
Published: 2 August 2024

1. Introduction

The global water crisis is a pressing issue affecting arid regions and underdeveloped areas, leading to health risks and water scarcity. Over 2 billion people worldwide lack access to clean drinking water, resulting in a higher prevalence of waterborne diseases and mortality rates [1,2], and the United Nations Children's Fund [3–5] has stated that approximately 2 billion people lack access to safely managed drinking water globally: "The Water Project (2023) estimates that waterborne diseases claim the lives of a child every two minutes. This shocking statistic exemplifies the dire consequences of water scarcity and contamination, particularly in underdeveloped regions with limited access to sanitation and healthcare". These data underscore the magnitude of the water crisis and its impact on human well-being [2–4]. The United Nations (UN) has declared" access to clean water and sanitation a fundamental human right" [3]. This declaration emphasizes the international community's commitment to addressing the water crisis and ensuring equitable access to water resources (Figure 1) [2].



Death rate attributable to unsafe water, sanitation, and hygiene, 2019

Death rate attributed to unsafe water[1], unsafe sanitation[2] or lack of hygiene (WASH), measured as the number of deaths per 100,000 people of a given population.

Data source: World Health Organization OurWorldInData.org/clean-water-sanitation | CC BY

Note: This includes WASH attributable deaths from: diarrhea, intestinal nematode infections, protein-energy malnutrition, and acute respiratory infections.

1. **Unsafe water**: Microbial contamination of drinking water poses the greatest risk to drinking-water safety. It is often the result of contamination with feces. Unsafe water is a risk factor in diarrhea, cholera, dysentery, typhoid, and polio.

2. **Unsafe sanitation**: Unsafe sanitation includes practices like open defecation and improper treatment of household wastewater. It is linked to the spread of diseases like cholera, dysentery, typhoid, intestinal worms, and polio. Unsafe sanitation exacerbates impaired growth and development in children and contributes to the problem of antimicrobial resistance.

Figure 1. World Health Organization—processed by Our World in Data. "3.9.2—Mortality rate attributed to unsafe water, unsafe sanitation and lack of hygiene from diarrhea, intestinal nematode infections, malnutrition and acute respiratory infections (deaths per 100,000 population)—SH_STA_WASHARI" [datast]. World Health Organization [original data] [4].

The global water crisis demands a multifaceted approach that includes the following:

1. Investment in infrastructure: building sustainable water collection, storage, and distribution systems in arid and underdeveloped regions;
2. Water conservation: promoting water-efficient practices in agriculture and industry to reduce water consumption;
3. Innovation: encouraging the development and deployment of cost-effective water purification technologies which utilize renewable energy sources and require minimal infrastructure maintenance and cost.

Surface water is scarce in arid places due to little rainfall. Risen temperatures and evaporation worsen these situations, reducing water availability. The lack of infrastructure and resources for water management and distribution systems in underdeveloped countries causes leaky pipelines and poor irrigation. Poverty hinders access to advanced water filtration and sanitation technology. Another major cause of starvation is the rapid contamination of scarce water supplies owing to reckless use and pollution [3]. Water scarcity in desert places can be natural or man-made [6,7].

4. Natural Factors
    a. Climate change: Rising temperatures and changing precipitation patterns can exacerbate water scarcity in arid regions [7];
    b. Topography: Geological features such as deserts or arid landscapes naturally limit water availability [8];
    c. Droughts: Periods of extended drought can further deplete already limited water resources in arid regions [9].

5. Human-Made Factors
    a. Deforestation: Clearing of forests can disrupt local water cycles and reduce groundwater recharge rates [9,10];
    b. Overexploitation of water resources: Unregulated extraction of water for agricultural or industrial purposes can lead to depletion and contamination of water sources [11];
    c. Poor water management practices: Inadequate infrastructure, inefficient irrigation methods, and lack of water reuse strategies contribute to water scarcity issues in arid regions [12].

Water scarcity and waterborne diseases disproportionately affect vulnerable groups, especially children and the elderly. Water scarcity also has a significant impact on economic development and social inequality of underdeveloped societies. Urgent action is needed to achieve sustainable water management and prevent waterborne diseases.

2. The Problem and Aim of the Study

The study aims to investigate the theoretical possibilities and test the performance characteristics of the "Parabosol" solution, a concentrated solar water purification system, in the field. The study also aims to identify design criteria and areas for improvement and to examine the potential effects of the system for future opportunities. "Parabosol" is a practical water purification device that uses concentrated solar energy to provide an alternative solution to the lack of clean water access in disadvantaged communities, particularly in underserved areas. The objective of the study is to collect data and evaluate whether the product meets the performance target of providing sufficient clean water (sterilized) to meet the daily needs of a nuclear family (two adults + two adults and two children) in impoverished regions. Initially, we set the product's daily performance target at 150–180 L of water per station. This target is based on the standard values set by the UN and WHO [2,4]. To reach high temperatures, the target product employs a parabolic steel mirror, primarily to evaporate dirty water and subsequently condense it, which can enhance purification efficiency while minimizing operational costs. Based on portable principles, the product can adapt for both residential use and deployment in remote areas and in emergencies. We have made efforts to ensure user-friendly operation, long-term durability, and low maintenance and operational expenses. In addition to design considerations, the functionality of water sterilization is essential for improving performance metrics and expanding applicability. To obtain performance data that could facilitate system improvements during field work, the study implemented a two-way control system. In some cases, the target process involved building models and calculating theoretical techniques to determine the performance results of the systems. On the other hand, the experimental methodology always involved subjecting the target system to real-life conditions by performing tests on the model and then collecting empirical data. Comparisons between these two methodologies aim to evaluate the accuracy of the theoretical systems and performance models. This study, within the scope of the principles, also covers both micro and macro sterilization methods commonly used in regions with high solar energy efficiency. Additionally, the study aims to include a comparative table of commonly used sterilization approaches, along with worksheets that compare the results of using the Parabosol system. Finally, this study also highlights the potential consequences of the investigated parabolic system and offers suggestions for its further development.

2.1. Method

This study aims to comprehensively validate the effectiveness of the Parabosol solar water purification system. The two verification methods consist of three different stages.

2.1.1. Literature Review

The first stage involves a comprehensive review of the existing research on solar-powered water filtration methods. The aim is to identify specific groups of microorganisms posing threats to human health and develop a plan to eliminate them. This will facilitate the collection of current information, identify potential obstacles, and evaluate the effectiveness of the parabolic system.

2.1.2. Acquisition of Field Data and Comparison with Calculated Values of the Theoretical Model

The second stage is dedicated to the initial field trial of the Parabosol prototype. The study was conducted in Konya, Turkey, on 20 May 2023, with specific environmental conditions carefully evaluated. The collected data, including temperature measurements and water quality characteristics, were compared with theoretical calculations obtained from mathematical models. This comparison is important as an early assessment of the performance of the parabolic system and will identify areas requiring further research. The calculation process focuses on two main stages. The first stage involves measuring the thermal energy present in the transfer tube at the focal point of the parabolic mirror. The next stage entails achieving the desired levels of speed, quantity, and efficiency in the consistent transfer of thermal energy to the flowing water through the pipe. The Stefan–Boltzmann method is used to calculate the amount of heat. To obtain accurate data on the working prototype, temperature is systematically measured at four specific points at the parabolic focus and at two points on the mirror at regular intervals, and the water cycle is tracked according to a predetermined schedule. All these measurements are then transferred to a table for analysis (data sheets 1 and 2). (See Tables 1 and 2).

Table 1. Theoretical calculation data (Data sheet 1).

Time (Hour)	Solar Radiation (G) (W/m^2)	Heat Flux (Q) (W)	Theoretical Focal Line Temperature (°C)	Estimated Water Treatment Capacity (L/h) (+/−5%)
9:00 a.m.	600	368	128.1	21.6
10:00 a.m.	700	420	228.8	32.1
11:00 a.m.	800	491	238.3	41.0–43.0
12:00 p.m.	800	491	273.1	49.0–52.0
13:00 p.m.	700	420	227.1	37.1
14:00 p.m.	600	368	201.1	32.3
15:00 p.m.	500	306	195.4	27.1
16:00 p.m.	400	244	134.4	22.6
17:00 p.m.	300	182	119.4	14.1
Total				277.2–290.7

Table 2. The prototype values (data sheet 2) (real-time measurements).

Time (Hour)	Solar Radiation (G) (W/m^2)	Heat Flux (Q) (W)	Measured Focal Line Temperature (°C)	Measured Water Treatment Capacity (L/h)
9:00 a.m.	580	338	110.1	12.80
10:00 a.m.	700	401	160.8	18.10
11:00 a.m.	800	461	212.3	31.85
12:00 p.m.	800	491	224.2	39.26
13:00 p.m.	700	390	218.1	30.47
14:00 p.m.	600	338	181.1	28.62
15:00 p.m.	500	286	160.4	19.70
16:00 p.m.	400	241	140.4	10.92
17:00 p.m.	300	162	101.4	7.07
Total				198.78

2.1.3. Comparative Evaluation

The results of the initial field test will be compared with the theoretical models developed. This will facilitate further optimization of the system's design and operation. This three-part approach provides a systematic and comprehensive framework for validating the performance of the parabolic system. Integrating theoretical models with experimental data collection allows for a comprehensive and unbiased assessment of the system's heat transfer capabilities and limitations. This research's findings will contribute to the development of the parabolic system. Overall, it provides a structured and comprehensive approach to evaluating the performance of Parabosol, encompassing theoretical calculations, real-world data analysis, and comparative analysis. The combination of these stages allows for a thorough assessment of the system's effectiveness and identification of opportunities for refinement, and it prioritizes improvement areas based on their impact on the system's overall performance and economic viability.

2.2. Introduction to Parabosol as a Solar-Powered Water Purification System

The time has come for novel and sustainable water purification solutions as the global population grows, climate change worsens, and water resources become scarce. Academic research indicates that sustainable and efficient solutions are crucial to protect human health, agricultural productivity, and desert ecosystems [13]. Integrating clean and efficient water purification systems in poorer nations is a crucial step toward achieving the United Nations' Sustainable Development Goals, particularly Goal 6 about clean water and sanitation. Innovative environmental solutions have the potential to change dryland socioeconomics, improve communities, and promote sustainable development [14]. Given the challenges of climate change and increasing water demand, sustainable and effective solutions in dry regions are not optional but essential. Innovative technologies, renewable energy sources, and water purification processes offer a sustainable solution to water scarcity and build environmental resilience [12,15]. For example, solar-powered water purification systems are a strategic investment in human health and the future well-being of populations and ecosystems. These new methods could improve water quality, reduce dependence on traditional water sources, and mitigate the health and environmental impacts of water scarcity [15]. It is imperative to develop sustainable, clean, and efficient solutions given the worldwide water crisis and its disproportionate effects on desert and poor countries. Failure to act will lead to dire consequences. Therefore, investing in sustainable water purification systems like Parabosol in arid regions is not a choice but a necessity [16]. As we strive toward a more sustainable future, revolutionary technologies like Parabosol have the power to transform water availability, boost resilience, and promote equitable development in some of the most vulnerable regions of the world. This study tackles the complex issue of water scarcity head-on, exploring its environmental, social, and economic dimensions. Innovative and practical technologies such as Parabosol can help establish a more equitable, sustainable, and secure water future. The initial section sheds light on the global water scarcity crisis, while the second section examines its detrimental impact on public health, especially waterborne diseases. The report puts forth sustainable water and energy solutions for arid regions. It includes a comprehensive analysis of Parabosol's solar-powered water purification system that requires no infrastructural support. The study presents Parabosol as a sustainable water solution, highlighting its environmental benefits, cost-effectiveness, and long-term viability. It underscores the need for renewable energy solutions to tackle water scarcity. In conclusion, the paper highlights Parabosol's potential to address water scarcity issues and recommends further research and applications for solar water purification systems, as well as its invaluable role in providing clean water to water-stressed regions.

3. Exploring Water Purification

Water scarcity is a major obstacle to public health, economic growth, and environmental sustainability in underdeveloped arid regions. Sustainable, clean, and effective water scarcity solutions in sensitive environments are essential. The lack of potable water in developing countries affects daily living, spreads waterborne diseases, and perpetuates poverty [11]. Waterborne diseases kill millions worldwide, especially youngsters. Waterborne infections are costly, emphasizing the need to improve water quality and sanitation. Waterborne infections kill 3.575 million people globally, according to (Table 3). The WHO estimates 2.66 million of these deaths are under 5s. The Centers for Disease Control and Prevention (CDC) estimates that waterborne infections cost the US USD 1 billion annually [14]. Waterborne infections cost over USD 12 billion annually globally [14]. Ingestion, inhalation, or contact with contaminated water can spread bacteria, viruses, protozoa, and helminths that cause waterborne infections [17,18]. Lack of clean water and sanitation increases waterborne disease risk. An estimated 780 million people lack clean water, and 2.5 billion lack improved sanitation [19]. Addressing these issues and improving access to safe water and sanitation can reduce waterborne infections and improve public health. Clean water and sanitation are crucial to global well-being. Waterborne diseases demonstrate the need for better water quality, sanitation, and access to clean water worldwide. Comprehensive public health treatments, legislative measures, and sustainable water management practices can reduce waterborne illness burdens and improve health outcomes for at-risk communities. Public health initiatives to prevent waterborne infections and mitigate their socioeconomic implications include improving water quality, cleanliness, sanitation, and access to safe drinking water [15,20]. Governments, international organizations, non-governmental organizations, and local communities must work together to solve waterborne sickness in vulnerable populations. To achieve Sustainable Development Goal 6 of providing clean water and sanitation to all, we must prioritize infrastructure investments, strengthen regulatory mechanisms, and promote sustainable practices that protect water resources and public health [15,21].

Table 3. Waterborne diseases: global burden and age distribution by region (2022). Data source: World Health Organization (WHO), year: 2022 [20,22,23].

Region	Estimated Deaths	Children under 5	Adults (65+)	Total (%)
Africa	2.2 million (%62)	1.3 million (%59)	575,000 (%26)	4.075 million (%114)
Southeast Asia	1 million (%28)	600,000 (%60)	250,000 (%25)	1.85 million (%52)
Eastern Mediterranean	175,000 (%5)	105,000 (%60)	45,000 (%26)	325,000 (%9)
Western Pacific	100,000 (%3)	60,000 (%60)	25,000 (%25)	185,000 (%5)
Americas	100,000 (%3)	60,000 (%60)	25,000 (%25)	185,000 (%5)
Total	3.575 million (%100)	2.66 million (%74)	920,000 (%26)	7.62 million

3.1. Relationship between Clean Water Access and Disease Prevention

Access to clean water is fundamental to human health and plays a critical role in preventing a wide range of diseases, but waterborne pathogens are still a global concern for public health worldwide. There is an urgent need to implement better controls, monitoring, and regulations to ensure water quality as pathogens in contaminated water continue to be a significant cause of serious illness and death due to deficiencies in underdeveloped regions today. “Pathogenic microbes in water are of greatest concern in terms of human health, as they can cause significant illnesses and even fatalities when ingested”—World Health Organization (WHO) [24]. Sterilization of daily water needs (based on eating and drinking) is of vital importance for children and the elderly: “Efficient water sterilization methods are essential for protecting vulnerable populations, particularly children and the elderly, from waterborne diseases”—Centers for Disease Control and Prevention, CDC (2015) [20]. This section explores this relationship, highlighting possibilities and limitations (Table 4).

Table 4. Examples of waterborne diseases and their modes of transmission * (WHO, 2022) [23]. * Adapted from Centers for Disease Control and Prevention.

Disease	Pathogen	Mode of Transmission
Africa	Bacteria (e.g., *E. coli*), Viruses (e.g., rotavirus)	Contaminated water, food, or fecal–oral transmission
Southeast Asia	Salmonella Typhi bacteria	Contaminated water or food
Eastern Mediterranean	Vibrio cholerae bacteria	Contaminated water or food
Western Pacific	Hepatitis A virus	Contaminated water or food, Fecal–oral transmission
Americas	Roundworms, hookworms	Contaminated water or soil

3.1.1. The Link between Clean Water and Disease

Contaminated water harbors various pathogens (disease-causing microorganisms), like bacteria, viruses, and parasites. When consumed or used for hygiene, these pathogens can cause illnesses such as the following:

- Diarrheal diseases: the leading cause of death from waterborne illness, responsible for an estimated 3.575 million deaths globally in 2022 (Table 3) [23];
- Typhoid fever: a bacterial infection causing fever, diarrhea, and weakness;
- Cholera: an acute diarrheal illness caused by ingestion of contaminated water or food with Vibrio cholerae bacteria;
- Hepatitis A: a liver infection caused by the hepatitis A virus, transmitted through contaminated water and fecal matter [23];
- Helminth infections: infections caused by parasitic worms, like roundworms and hookworms, transmitted through contaminated water and soil [20].

3.1.2. Mechanisms of Disease Prevention

Clean water access enables several key practices that prevent these diseases:

- Drinking: Safe drinking water directly reduces the ingestion of pathogens. Contaminated water often harbors harmful bacteria, viruses, and parasites that can cause various illnesses when consumed. “Unsafe drinking water, sanitation and hygiene” are a major cause of diarrheal diseases, accounting for an estimated 3.575 million deaths globally in 2022 [22];
- Hygiene: Handwashing with clean water and soap is a simple yet highly effective practice for preventing the spread of diseases [2]. A 2008 review published in the *American Journal of Public Health* by Esham et al. highlights that handwashing with soap can significantly reduce the risk of diarrheal disease by 47% [23]. Also, the WHO underlined the persistent health risks of inadequate water, sanitation, and hygiene (WASH). The WHO estimates that up to 1.4 million deaths annually could be averted with better access to these essential services. Contaminated hands can easily transfer pathogens to food, surfaces, and other people, leading to infections. Washing hands with clean water and soap after using the toilet, before eating, and after handling potentially contaminated materials (like raw meat) significantly reduces the risk of infection [22];
- Food preparation: Clean water is essential for washing fruits, vegetables, and utensils. Foodborne illnesses can occur when fruits and vegetables are contaminated with pathogens from irrigation water or improper handling. Similarly, unclean utensils can harbor pathogens and transfer them to food during preparation or consumption. It is also essential for cooking and ensuring food safety. Contaminated water used in food preparation can lead to foodborne illnesses and infections. The Centers for Disease Control and Prevention (CDC) recommends using clean water to wash fruits and vegetables “just before eating, preparing or serving them” [20]. “Access to clean water for food preparation and cooking is crucial for preventing waterborne diseases associated with unsafe food practices” [10];

- Sanitation: Adequate sanitation facilities and proper wastewater disposal are crucial in preventing fecal contamination of water sources [4]. The WHO and UNICEF jointly state that improved water supplies and sanitation are essential to break the transmission cycle of fecal–oral diseases [22,23,25]. Open defecation or inadequate sanitation systems can lead to the contamination of nearby water sources with fecal matter. This contamination can then spread a variety of waterborne diseases when the water is used for drinking, hygiene, or food preparation [26]. Regular access to clean water is necessary to maintain personal hygiene and prevent water-related diseases that can result from poor sanitation practices [22,23];
- Combined effect: These practices, when implemented together, create a powerful barrier against the spread of waterborne diseases. Access to clean water is the foundation for all these practices, making it a critical factor in ensuring public health and well-being.

3.2. Clean Water Access and Possible Practices in Underserved Communities

As previously said, numerous marginalized populations worldwide continue to have difficulties in locating secure water sources because access to uncontaminated water is essential for various crucial aspects of good health and overall well-being. Additionally, it serves as a preventive measure against a diverse array of illnesses. Here is a more comprehensive exploration of these activities, substantiated by evidence and remarks from credible sources. Marginalized communities often lack the necessary infrastructure for a clean water supply, leading them to rely on contaminated sources, such as rivers and wells. This increases the risk of waterborne diseases, hampers efforts to improve public health in these regions, and ultimately results in widespread health issues [26].

3.3. Minimum Water Consumption in Underserved Communities

The daily water consumption of an individual living in underserved communities varies based on factors such as climate, access to clean water, living conditions, and personal habits. According to various sources and references, the average daily water consumption per person in arid environments (Africa, South Asia, Middle East) varies significantly based on climate, access to clean water, living conditions, and individual habits for drinking and basic hygiene purposes, which can be estimated as follows:

- Drinking water needs: The WHO [4] recommends a minimum of 7.5 L per person per day for basic hydration needs. UNICEF [17] suggests a broader range of 20–50 L per day;
- Basic hygiene needs: Additional water is required for basic hygiene activities, like handwashing, bathing, and cleaning. UNICEF [17] estimates a total of 50–100 L per person per day for both drinking and hygiene;
- Total consumption range: combining drinking and hygiene needs, the total daily water consumption in Africa ranges from 57.5 L to 150 L per person [2,4,14];
- Individual variations: age, gender, physical activity, health conditions, and cultural practices can further influence individual water needs.

Therefore, the total daily water consumption per person in Africa, considering both drinking water and basic hygiene needs, can range from 57.5 L to 150 L, depending on the specific sources and guidelines followed. It is important to note that individual water consumption may vary based on factors such as age, gender, health conditions, physical activity, and cultural practices. Access to clean and safe water sources is crucial for meeting daily water needs and maintaining good health and hygiene practices [4].

3.3.1. Boiling Water

This traditional technique is highly efficient in eliminating all types of microbial infections. Although the heating process generally takes place during household cooking, it can nevertheless be demanding in terms of fuel consumption in warmer areas and contribute significantly to a large carbon footprint. Furthermore, the boiling process can emit indoor air pollutants and pose potential health hazards. According to references [27,28], the approximate yearly expense of boiling disinfection amounts to USD 10.56 per individual.

3.3.2. Chlorination

Chlorine inhibits the proliferation of pre-existing bacteria in water. Nevertheless, it exhibits reduced efficacy against certain viruses and lacks effectiveness against prevalent protozoa. Although chlorine is a naturally occurring substance, it can lead to significant adverse reactions in humans when they come into contact with it or inhale it. The taste and odor of treated water limit its widespread use beyond pandemic periods. In the long run, "chlorine" in water combines with natural organic compounds to yield substances such as trihalomethanes, halo acetic acids, and chlorophenols that exhibit potentially carcinogenic, teratogenic, and mutagenic activities. In addition, the operation and accessibility of chlorine in underdeveloped locations are difficult because of the need for the regular replacement of consumables and infrastructure. However, the fact that chlorine is readily available in liquid or tablet form makes it a convenient and cost-effective approach, with an approximate yearly expense of USD 0.66 per individual [28,29].

3.3.3. Filtration

As filtration technologies progress, their operational expenses also increase. Filters generally fail to completely eradicate diseases because of their larger pore diameters compared to microorganisms. Nevertheless, ceramic filters have the capability to capture protozoa, are highly efficient in combating bacteria, and have shown effectiveness in dealing with viruses (the tiniest disease-causing agents). Users rely on filters because of their ability to purify water, and ceramic filters also have the capacity to lower water temperatures through evaporation. However, ceramic filters are prone to breaking easily and require careful handling, resulting in costly maintenance. The estimated annual cost of maintaining these filters is USD 3.03 per person [29].

3.3.4. Solar Water Disinfection

Solar water disinfection (SODIS) offers a compelling approach to household water treatment (HWT) in underserved regions. This method leverages the synergistic germicidal effects of ultraviolet (UV) radiation and elevated water temperatures [24,30–32]. Notably, SODIS boasts significant advantages in terms of cost-effectiveness and user-friendliness. The SODIS process is remarkably simple. Solar disinfection (SODIS) utilizes ultraviolet radiation (UV) from sunlight to inactivate harmful bacteria and viruses in water [28]. Transparent containers, such as glass or plastic bottles, are filled with the water to be treated and exposed to direct sunlight for an extended period. This straightforward procedure eliminates the need for complex equipment or additional consumables. Furthermore, SODIS does not adversely affect the taste of the treated water, enhancing its user acceptance; however, it is crucial to acknowledge the limitations of SODIS [24]. Water turbidity acts as a significant barrier to UV penetration, necessitating longer treatment times. Additionally, proper storage practices are essential to prevent recontamination. Treated water should be stored in clean, covered containers to minimize the risk of microbial regrowth. Studies estimate the annual cost of SODIS to be a mere USD 0.63 per person, highlighting its economic viability [30]. The germicidal efficacy of solar radiation can be further differentiated based on wavelength [32]. UVA radiation emitted by the sun is primarily responsible for bacterial inactivation, while UVB light demonstrates broader spectrum activity, eliminating bacteria, viruses, and protozoa [32]. Nevertheless, it is noteworthy that bacteria can resume growth in the absence of light during storage and cooling. To safeguard against this potential health risk, consumption of treated water within 24 h of exposure is recommended. Despite its merits, the standard application of SODIS using 1.5 or 2 L PET bottles presents scalability limitations. Considering the daily water requirement estimates of 50–100 L per person, a family would necessitate a substantial number of bottles (25–35 bottles per person) to meet not only drinking water necessities but also their basic needs [33]. This sheer volume of containers can render the method impractical for large-scale household use.

SODIS offers a promising yet limited solution for HWT in underserved regions. Its ease of use, affordability, and minimal impact on water taste are undeniable advantages. However, factors such as extended treatment times due to turbidity, the potential for recontamination, and scalability limitations with conventional bottle use necessitate further research and development efforts to maximize SODIS's potential as a sustainable HWT solution [34,35]. This analysis emphasizes the urgent requirement for cost-effective, easily accessible, and environmentally viable household water treatment (HWT) solutions in communities that lack adequate access to such services. Hydrological water treatment (HWT) has the potential to have a significant impact on enhancing public health and promoting sustainable development by tackling the obstacles of scarce resources, insufficient infrastructure, and varied water sources. It is evident that solar energy is the most convenient method for disinfection despite its lengthy process and short expiration period. All these analyses indicate a growing demand for innovative solutions that might enhance the speed and usability of the process [36–38].

3.4. Waterborne Diseases Transmission and Prevention Methods

Not all waterborne diseases are listed here. To choose the best method, consultancy is always necessary for different regions as types of pandemics can have different for precautions (Table 5).

- Boiling is a simple and effective way to kill most waterborne pathogens, which can also be used at the household level for emergencies or in areas without reliable water treatment. Boil water for at least 1–5 min at a rolling boil.
- Filtration offers a portable option for individual use, but filter selection and maintenance are crucial. Filtration systems can be effective in removing some parasites and bacteria, but not all. Choose a filter certified to remove specific contaminants.
- Chemical disinfection tablets or drops can be used for emergency purification, but proper dosage and limitations should be understood. Not all chemicals are effective against all pathogens.
- SODIS (solar water disinfection) involves exposing clear plastic bottles filled with water to sunlight for an extended period. Its effectiveness can be limited by factors like water clarity and sunlight intensity [36].
- SODIS and chemical disinfection can be used in limited situations, but their effectiveness can vary and limitations exist [38].
- Public water treatment plants are generally considered the most reliable and cost-effective method for large communities.

Solar-powered water purification systems powered by clean energy offer a promising path toward achieving sustainable water security in underdeveloped areas. By addressing challenges through innovative solutions and capacity building, solar power can illuminate a brighter future where clean water is accessible to all.

Table 5. Waterborne diseases transmission and potential prevention methods [26,30,38] *.

Disease	Causative Agent	Mode of Transmission	Boiling	Filtration	Chlorination	Water Treatment Plants	Public Education	SODIS	Chemical Disinfection	Best Performance Value
Cholera	Vibrio cholerae bacteria	Contaminated water and food; fecal–oral route	Yes	x	Public water supply	Public water system	Yes	Yes	Yes (limited availability)	Boiling (simple, effective)
Typhoid Fever	Salmonella typhi bacteria	Contaminated water and food; fecal–oral route	Yes	x	Public water supply	Public water system	Yes	Yes	Yes (limited availability)	Boiling (simple, effective)
Giardia	Giardia lamblia parasite	Contaminated water (including untreated surface water); fecal–oral route	Yes	Yes	-	Public water system	Yes	Yes	Yes	Filtration (effective, portable options)
Cryptosporidiosis	Cryptosporidium parasite	Contaminated water (including untreated surface water); fecal–oral route	Yes	Yes	-	Public water system	Yes	Yes	Yes (limited availability)	Filtration (effective, portable options)
E. coli infections	*E. coli* bacteria	Contaminated water and food; fecal–oral route	Yes	x	Public water supply	Public water system	Yes	Yes	Yes	Public water treatment (reliable, cost-effective)
Viral gastroenteritis (rotavirus, norovirus)	Viruses	Contaminated water and food; fecal–oral route	Yes	x	Public water supply	Public water system	Yes	Yes	Yes (limited availability)	Public water treatment (reliable, cost-effective)
Amoebic dysentery	Entamoeba histolytica parasite	Contaminated water and food; fecal–oral route	Yes	x	Public water supply	Public water system	Yes	Yes	Yes (limited availability)	Public water treatment (reliable, cost-effective)

* Yes—indicates the method is effective for preventing most of the disease. (x)—indicates the method may be partially effective or require specific filter selection. Public water supply—refers to chlorine added to drinking water by municipal treatment facilities. Public water system—refers to the infrastructure for delivering treated water to consumers. SODIS—solar water disinfection. Best performance-value—considers effectiveness, ease of use, and cost.

4. "Parabosol" Utilizing Solar Energy for Water Disinfection/Purification

The global water crisis is a growing concern, particularly in developing countries where access to clean drinking water is scarce. This problem is compounded by population growth and the increasing prevalence of waterborne diseases, which have worsened living conditions and human health, especially in Africa and South Asia. According to the United Nations (UN), waterborne infections cause outbreaks and lead to increased mortality, underscoring the need for innovative solutions [4]. Parabosol is an award-winning water purification technology that utilizes concentrated solar power (CSP) to provide clean drinking water in regions without centralized infrastructure. This innovative method essentially functions as a hybrid solution, using concentrated solar energy to heat the pre-treated water to over 250 °C, eliminating microbes and pathogens. The Parabosol system uses a parabolic linear steel mirror to concentrate solar energy and filters the water before and after treatment. It is user-friendly, cost-effective, and sustainable. As a novel innovative solution, it combines known HWT techniques, such as boiling, the UV effect of sunlight using the SODIS method, and filtration techniques, in a hybrid structure. It eliminates the need for fuel to boil water, making it a sustainable approach with significantly reduced carbon emissions. Since the water temperature reaches over 250 °C, it eliminates all pathogens and microorganisms [36]. It also has an additional secondary safety measure through bio-sand and carbon filters located at the inlet and outlet of the treatment tank. It is also suitable for emergency use in cases where solar energy is unavailable. Parabosol is a technologically producible and easy-to-use product with a simple interface. It can be easily transported and can provide long-term service in homes in underdeveloped and developing countries [38]. Parabosol has a performance capacity of treating an average of 150–180 L of water on a sunny day. It is designed to generate a volume that can meet the basic needs of a core family of 3–4 people. The Parabosol system was created to analyze and resolve issues that current systems cannot solve. It is designed to be user-friendly, durable, and cost-effective, with maintenance requirements. The parabolic mirror and evaporation pipe systems are made of steel, while the liquid transportation, processing, and clean water tanks are made of ultra-ABS material for long-lasting durability. Its modular and portable design allows for the repair and replacement of parts. Parabosol development is based on a problem-based approach with a focus on long-term sustainability, including the mechanical and storage components.

Parabosol is a scalable and low-cost alternative solution system that can improve quality of life and reduce waterborne infections. It is anticipated that practical solutions like Parabosol and the technologies provided can support the water purification systems of impoverished communities and demonstrate results that can change negative outcomes in impact analysis (Figure 2). This technology has the potential to play a significant role in addressing the global water crisis and improving the lives of millions of people. By providing access to clean drinking water, Parabosol can help to reduce the incidence of waterborne diseases, improve health outcomes, and promote sustainable development. Parabosol presents a promising alternative to existing HWT methods by overcoming limitations in technological complexity, economic accessibility, resource dependence, and sustainability. However, further research and development efforts are needed to optimize its scalability and cost-effectiveness for widespread adoption in arid regions.

Figure 2. Parabosol system.

4.1. Concentrated Solar Power System (CSP)

Concentrated solar power (CSP) is a renewable energy technique that harnesses sun rays to generate thermal energy. Unlike photovoltaic (PV) solar panels that directly convert sunlight into energy, CSP systems utilize parabolic mirrors or Fresnel lenses to concentrate the sun's beams, producing heat that is then converted into electricity. Parabolic mirrors can concentrate sunlight onto a receiver tube to produce high temperatures. This heat can be used to run steam turbines, store thermal energy, or provide heating and hot water in industries and homes. CSP systems mostly used to generate electricity from solar energy using parabolic mirrors are called "parabolic trough solar collectors" (PTSCs). Parabolic mirrors are optical systems that are used to collect or distribute (wave) energy. They have a wide range of applications, from solar collectors for water heating systems to microscopes, telescopes, and everyday flashlights. The most common way to understand parabolic mirrors is that a bundle of light beams parallel to the optical axis will reflect from the curved mirror surface and will focus on a single point (Figure 3a,b). A parabolic mirror differs from a spherical mirror in that it greatly reduces spherical and coma aberrations. PTSC systems heat receiver tubes by concentrating sunlight. The tube's heated fluid or gas powers steam turbines to create electricity. These collectors maximize energy gathering by following the sun's path and focusing sunlight over a smaller area. CSP systems can efficiently capture the sun's rays even in low light, storing heat at higher temperatures than PV systems [39]. The CSP technique is used in most solar power plants to generate thermal power by focusing sunlight on heat pipes, which generate electricity through turbine operation. CSP uses clean, limitless solar energy in various industries that need high temperatures and energy density. The Paris Agreement UNFCCC (2015) noted that this reduces fossil fuel use and greenhouse gas emissions, which is the main goal for the future [40].

- The efficiency of a CSP system is gauged by the concentration ratio, which signifies the ratio of sunlight to the receiver area. Higher concentration ratios lead to elevated temperatures and improved solar energy conversion efficiency.
- Heat diagrams play a crucial role in the design and operation of CSP systems, as they depict temperature distribution and energy flow, optimizing system performance and ensuring consistent efficiency.
- The types of mirrors, their geometrical structures, and the overall placement of the reflective units within the system directly affect the performance of the CSP solutions.

These systems typically achieve temperatures in the range of 300 °C to 400 °C according to the National Renewable Energy Laboratory, 2020. Concentrated solar power (CSP) offers a promising solution for generating clean and reliable electricity from the sun. Although challenges exist regarding costs, land use, water consumption, and geographic limitations, technological advancements and strategic planning can help address these concerns. As research and development progress, CSP has the potential to have a significant impact on a sustainable energy future, providing a clean and reliable source of energy to meet the increasing global demand for humanity [40]. The actual performance data for a particular CSP system can vary based on factors like collector design, heat transfer fluid, and geographic location with its specific solar irradiance levels. Research and development efforts are continually pushing the boundaries of CSP efficiency. Advancements in materials, heat transfer fluids, and system design aim to improve efficiency even further.

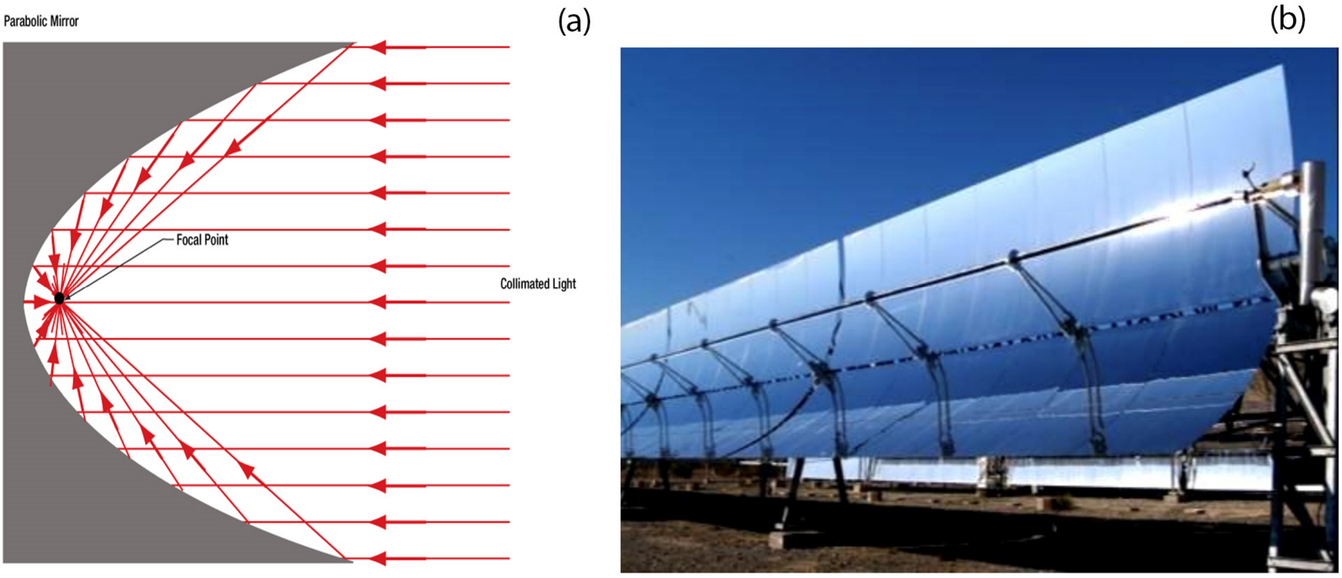


Figure 3. (**a**) Working principles of CSP; (**b**) linear parabolic mirror CSP systems.

4.2. The Working Principle of Parabosol

Parabosol is a cutting-edge product that implements the basic concepts of the CSP system used to quickly clean contaminated water by generating excess heat using solar energy (Figures 2, 4 and 6). The processing capacity of each station varies between 120 and 180 L of water per day (depending on geographical and environmental conditions), depending on geographical and meteorological (solar radiation values) factors. Average values are around these limits.

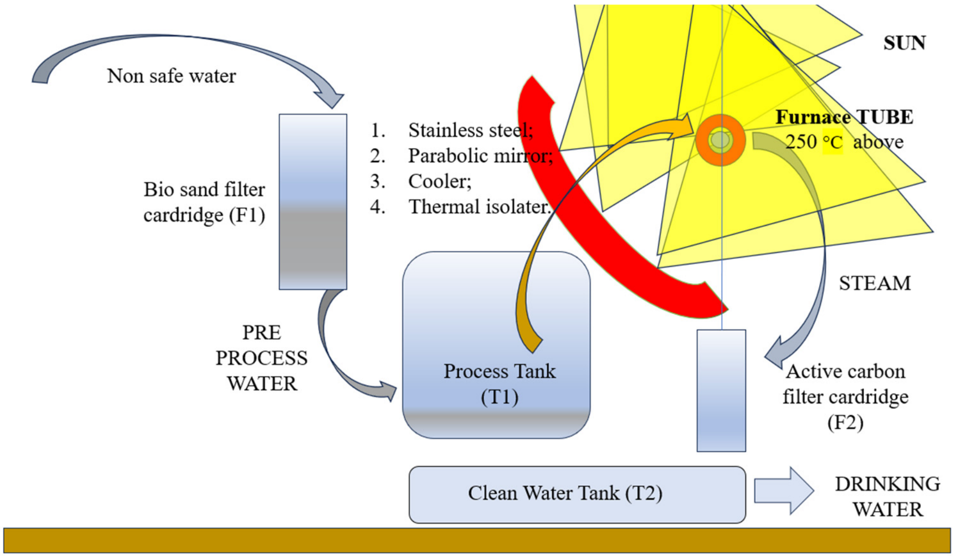


Figure 4. Working principle of Parabosol system.

Experimental values are, however, around 250 L. Just like other solar systems, although the geographical data of the region in which it is used affect the performance values of the system, the focusing feature of the parabolic mirror prevents the efficiency from falling below a certain line. Therefore, it can be predicted that the system will be able to capture target data in every region of the world by increasing the number of stations or scaling. Parabosol is a small-scale personal mobile CSP station due to its system capacity and production outputs. The system consists of three different types of containers, with five in total. The purification process is carried out using a steel parabolic linear mirror with a very high surface temperature range (due to direct beam solar radiation (G)). The product sterilizes water and makes it drinkable in a three-stage process. It takes untreated liquid from unsafe water sources, filters it through a sand filter, and collects it in a storage tank. It is then evaporated at an average temperature of 250 °C in a specially coated tube placed on the focal line of a steel parabolic mirror and transferred to a carbon filter. The third stage involves transferring the steam to the clean water tank. The external filling process is always provided by the clean water tank. If necessary, the nutrients can be added to drinking water tanks. The mirror surface is rising to high temperatures with the effect of solar beams. For protection of the system's performance, strong isolation and metal mirror cooling are always necessary for the protection of the blow molding process tank (T1). For support of these necessities, the mirror is reinforced by steal-corrugated coolers and non-flammable textiles, which are fully recyclable, and water tanks T1 and T2 are produced by blow molding PP (polypropylene) material, which is also fully recyclable. Filter cartridges F1 (for bio-sand) and F2 (carbon or ceramic base) are made of PE (polyethylene), both of which are transparent materials for additional UV benefits. In underdeveloped or undeveloped regions, filters are easily accessible. Additionally, their design ensures easy production and filling. We can also consider the selected sand filter (F1) and activated carbon filter (F2) as practical, useful, and economical solutions as additional measures for a high-temperature water purification system. Thanks to these filters, the Parabosol system can continue to operate at low capacity even when there is no sun.

Production Principles

The current design criteria for the Parabosol system prioritize ease of production and maintenance without the need for special population training, particularly in underdeveloped regions. This aims to meet the needs of the nuclear family in a self-sufficient manner without requiring minimal intervention and maintenance, in line with current user experiences and the requirements of extraordinary situations (such as disaster, emergency, epidemic, or infrastructure deficiencies). The authorities approved the design, which won the Energy Globe Award and the Green Dot Award. Manufacturers of low-performance plastics can produce plastic parts using injection, blow molding, or rotational molding technologies, whichever is more available, and all stainless steel parts are designed to be formed using conventional methods at similarly low technological levels. Therefore, it is not just a design solution but also one that takes sustainability and manufacturability into account. The manufacturing process is engineered to deliver durable, high-quality products to users. Utilizing medium-class production facilities and common plastic and assembly techniques, both the product and system components are designed for longevity. The blow molding tanks are constructed from polyethylene, while the accessories are made from recyclable polypropylene materials. The primary parabolic mirror and metal cooler are crafted from sturdy 0.5 mm stainless steel sheet components, selected to ensure the product's long-term resilience. The Parabosol system is engineered to be exceptionally efficient and environmentally sustainable. Maintenance is streamlined via the use of replaceable sand and carbon filters. However, the lifespan of these filters may be influenced by water quality, including the presence of contaminants like dirt, microorganisms, chemicals, and pesticides. Protective and insulating "felt" covers both sides of the parabolic steel mirror. Chosen for its environmental friendliness and suitability for diverse regions, this material can be easily replaced by users. The system's binding belts are standard, cost-effective accessories, while the focal heater comprises a pre-treated, coated steel tube designed for easy replacement. Moreover, the flexible water-carrying pipes are made from temperature-resistant elastomer materials to ensure durability and functionality under varying conditions. This meticulous design approach ensures the Parabosol system offers efficient, sustainable, and user-friendly water purification solutions (Figures 5 and 6).

- Assembly process: Figure 5 presents the mobile compact station assembly process.
- Technical specifications: The draft weight of a unit with filters is around 12 kg. The compact size of a standard unit is 65/65/120 cm. The overall volume is around 0.5 m^3. for transportation tanks, a two-unit tank is 25 lt. The average temperature output is around 250–272 °C.
- The cost: The estimated cost per unit is around USD 65 per filter set (one bio-sand filter and two carbon filter set totals USD 12/year).
- Performance: The "best performance hours" in a day for the system depend on the location and solar irradiance patterns. However, generally, Parabosol systems perform best during peak sunlight hours, typically between 10:00 a.m. and 4:00 p.m.
- Overall system efficiency: As stated earlier, the current Parabosol systems boast overall efficiencies ranging from 25–35% (on a yearly basis).

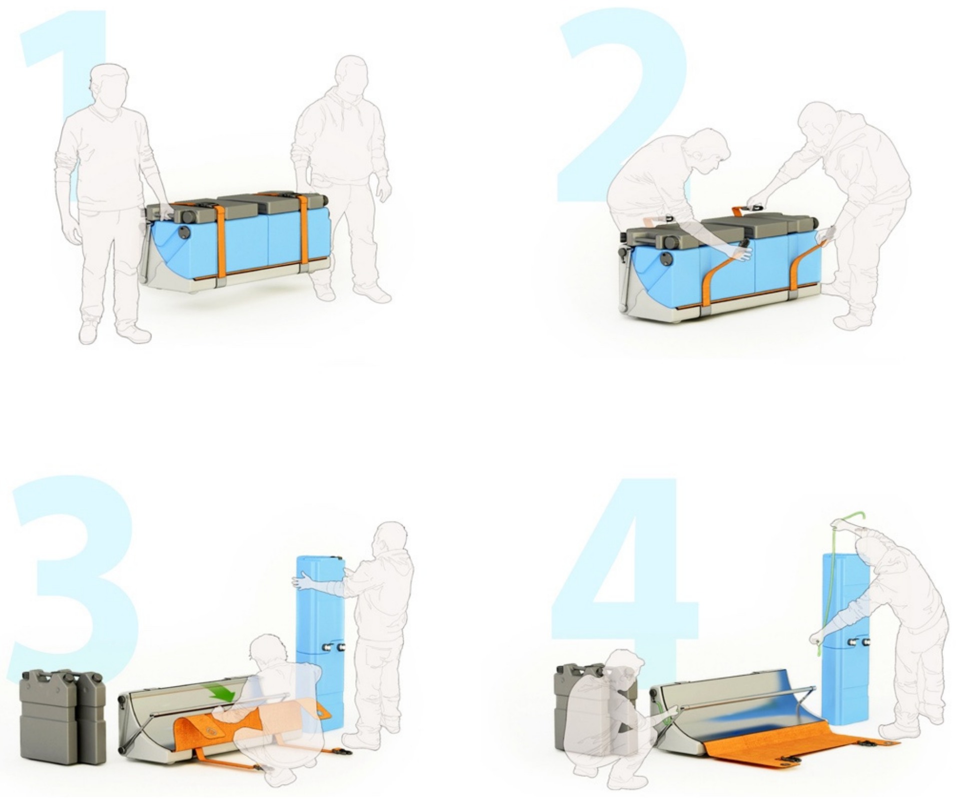


Figure 5. Parabosol CSP system station assembly.

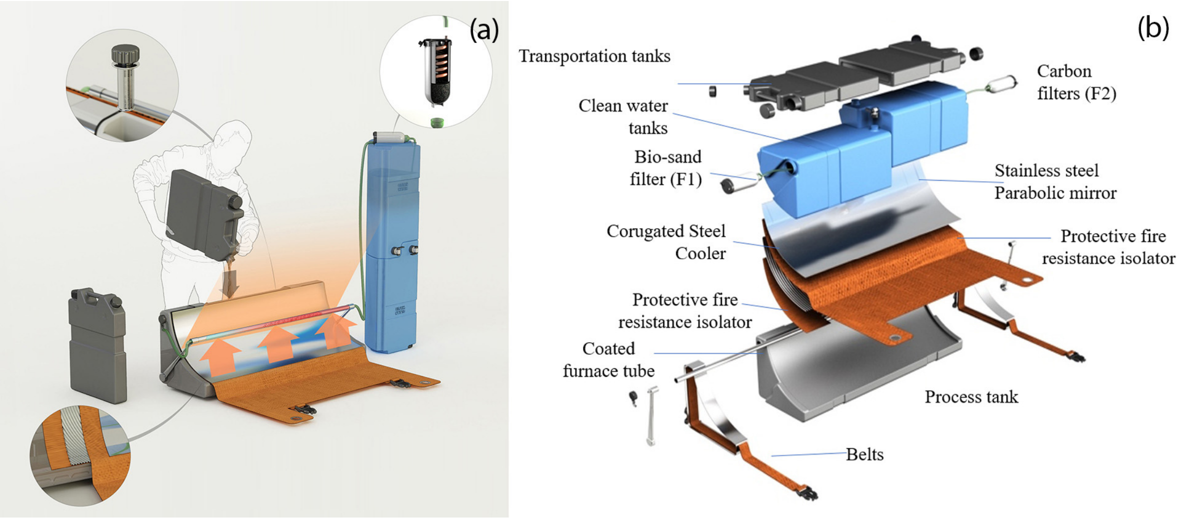


Figure 6. (**a**) The working stages; (**b**) Parabosol CSP system exploded.

4.3. Monitoring the Parabosol Prototype

4.3.1. Test Area

The initial field trial of the Parabosol prototype occurred in Konya, Turkey (Cihanbeyli, 35.65.488° N, 33.16194° S) on 20 May 2023, at 11:00 a.m. The test took place on a clear, sunny day in a rural area with a temperature of 24–27 °C, and dry weather conditions and measurement continued for around a week. Previous test results provided some of the information in this section. The main criteria for location selection were to choose a region with optimum solar performance values, which can be considered the geographical middle of Turkey. We paid attention to the proximity of this region to Salt Lake (Tuz Gölü), the low plant density around it, and the absence of trees to provide shade. We wanted the land to have values like desert conditions (high temperature, very low humidity, and high ETo values). We took care to create physical conditions close to the intended geographical conditions of inadequacy and underdevelopment. We collected water samples from Salt Lake and a stream flowing into this lake. Salt Lake samples were largely used to conduct an alternative study to demonstrate that the Parabosol system could also clean seawater. At the beginning of this study, we conducted the necessary laboratory examinations on water samples taken from the source and then took samples from the treated water.

Despite a loss and theft rate of approximately less than 30%, the prototype test successfully achieved its objectives. Experimental data and theoretical analysis can validate the results. It was determined that the targeted results were achieved; the water was cleared of biological life forms and cleaned of salt and metals. This study presents both sets of results. We used the following real parameters to estimate the surface temperature on the focal tube of the parabolic mirror system and cross-checked them with the prototype real values. In the next stage, we will repeat the tests on the sea and in more extreme conditions, using more polluted water sources and sea water.

4.3.2. Parabolic Mirror Specifications of the Parabosol First Prototype

- Parabolic mirror section length: 60 cm;
- Parabolic mirror length: 120 cm;
- Focal point length (f): 130 cm (20 mm ceramic tube);
- Stainless steel mirror: reflectivity (0.6–0.75);
- Solar radiation (G): used a solar radiation calculator to determine the direct beam solar irradiance (G) for Konya, Turkey, on May 20 at 11:00 a.m. Approximate value $\approx 700\ \mathrm{W/m^2}$.

4.3.3. The Heating/Boiling/Cooling Tube Sections

- Tube outer diameter: 24 mm (Figure 7a);
- Tube inner diameter: 14.2 mm (designed section tube with inner ribs);
- Tube material: industrial ceramics (emissivity (ε): 0.7–0.9 processed surface quality);
- Thermal conductivity to be specified: k = 50–70 W/(m·K); 50 for steel and 70 for ceramic;
- Ambient temperature (T_a): 20–25 °C (assumed).

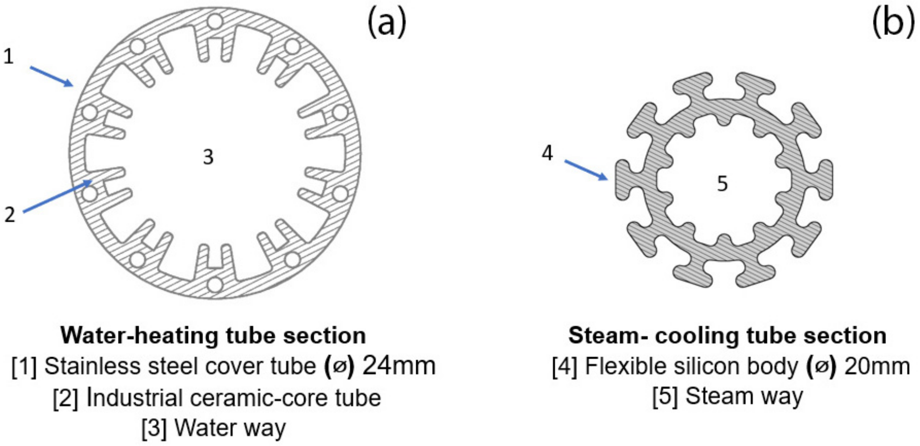


Figure 7. (**a**) Parabosol water-heating tube section; (**b**) steam-cooling tube section.

4.4. Calculating the Heat Transfer (Data 1 Settings)

This study targets the two variables set:

1. The level of the temperature on the focal tube, which is the result of condensation from the solar energy collected and reflected with the parabolic steel mirror;
2. The heat transfer performance of the tube to the water in seconds (Figure 7a).
   Heat flux at focal point (Q):

- $Q = (\pi * d^2 * \varepsilon * G)/(4 * f)$;
- d: mirror diameter (0.6 m), ε: emissivity (0.9), G: solar radiation (800 W/m^2), f: focal length (1.3 m);
- $Q \approx 630\ \mathrm{W/m^2}$;
- Heat transfer coefficient (h): (This will depend on convection and radiation at the outer surface. Specify h value or method for calculating h)
  Convection heat transfer from outer surface:
- $Q\_conv = h * A\_s * (T\_s–T\_a)$;
- h: convection heat transfer coefficient (W/(m^2·K)), A_s: outer surface area of the tube ($\pi * D\_o * L$), T a: ambient temperature (20 °C).
  Net heat transfer rate to the tube (Q_net):
- Q_net = Q—Q_conv.
  Heat transfer within the tube:
- Apply thermal conductivity (k) of the tube material;
- Use appropriate heat transfer equation (e.g., one-dimensional conduction for a simplified model) to determine the temperature distribution along the tube length.

Calculation Steps

a. Calculate heat flux (Q):

$$Q = (\pi * d^2 * \varepsilon * G)/(4 * f)\ \text{Heat flux calculation (Q):}$$

d: mirror diameter (60 cm), ε: emissivity (0.7), G: solar radiation (700 W/m^2), f: focal length (130 cm)

$$Q \approx 630\ \mathrm{W/m^2}$$

b. Calculate tube outer surface area (A):

$$A = \pi * (D/2)^2$$

D: tube outer diameter (210 mm)

$$A \approx 11078.5 \text{ mm}^2 \approx 0.01108 \text{ m}^2$$

c. Calculate heat flux density (q):

$$q = Q/A$$

$$q \approx 56.9 \text{ W/m}^2$$

d. Calculate tube outer surface temperature (T)

Temperature calculation (T):

$$T = \sqrt{}\,(4 * Q * \varepsilon/(\pi * \sigma * A))$$

σ: Stefan-Boltzmann constant (5.67×10^{-8} W/(m^2·K^4))

A: area considered for heat concentration at the focus (approximated as a circle)

$$A = \pi * (d/2)^2 \approx 0.283 \text{ m}^2$$

Calculate heat flux (Q):

σ: Stefan-Boltzmann constant (5.67×10^{-8} W/(m^2·K^4))

T ≈ 237.7 °C (the experimental temperature is in the field measured max. 243.2 °C +/− %5)

4.4.1. Theoretical Calculation Parameters of (Focal Water Tube)

- Tube outer diameter (D_o) = 0.21 m;
- Tube length (L) = 1.2 m;
- Thermal conductivity (k) = 50–70 W/(m·K) (50 for steel and 70 for ceramic);
- Emissivity (ε) = 0.7–0.9;
- Stefan–Boltzmann constant (σ) = 5.67×10^{-8} W/(m^2·K^4);
- Ambient temperature (T_a) = 20 °C = 293.15 K;
- Convection heat transfer coefficient (h) = 0.8 W/(m^2·K) (assuming laminar flow);
- Number of nodes (N) = 20.

a. Discretization

Node spacing (dx) = L/N = 0.06 m

b. Boundary conditions

Inlet temperature (T_1) = T_a = 293.15 K

c. System of equations

We will create a tridiagonal matrix equation (A ∗ T = b) to represent the heat transfer at each node:

A = [

[2*k/dx^2, −k/dx^2, 0, 0,. . ., 0],

[−k/dx^2, 2*k/dx^2, −k/dx^2, 0,. . ., 0],

[0, −k/dx^2, 2*k/dx^2, −k/dx^2,. . ., 0],

. . .,

[0, 0, 0, 0, 2*k/dx^2, −k/dx^2],

[0, 0, 0, 0, −k/dx^2, 2*k/dx^2]

```
]
b = [
−k/dx^2 ∗ T_a,
0,
0,
. . .,
0,
−k/dx^2 ∗ (h ∗ (T_N-T_a) + ε ∗ σ ∗ (T_N^4 − T_a^4))
]
```

d. Solution with Python (using Gauss–Seidel iteration)

Here is a Python code snippet demonstrating the iterative solution using the Gauss–Seidel method:

```
Define parameters.
k = 50 # W/(m*K)
dx = 0.06 # m
h = 0.8 # W/(m^2*K)
eps = 0.7
sigma = 5.67 × 10^−8 # W/(m^2*K^4)
Tamb = 293.15 # K
# Number of nodes
N = 20
# Initialize temperature array
T = np.ones (N + 1) ∗ Tamb
# Convergence tolerance
tol = 0.1 # K
# Iteration loop
while True:
T_old = T.copy()
for i in range (1, N):
T[i] = (T_old[I − 1] + T_old[i + 1])/2
# Boundary condition at outlet (node N)
T[N] = (T[N-1] + k ∗ dx/(h ∗ dx + eps ∗ sigma ∗ (T[N]**4—Tamb**4)))
# Check convergence
if np.max (abs (T-T_old)) < tol:
break
# Tube outer surface temperature
Tout = T[N]
```

Print (“Tube outer surface temperature:”, Tout—273.15, “°C”)

This code iteratively updates the temperature at each node using the temperatures from neighboring nodes until convergence is achieved within the specified tolerance. The final value of Tout represents the calculated tube outer surface temperature in Kelvin. Converting it to Celsius using Tout·273.15 °C provides the result. Running the code will give the approximate calculated tube outer surface temperature.

Important note:

This model neglects factors like variations in convection along the tube and assumes constant material properties. For a more accurate representation, consider using more sophisticated heat transfer models and potentially incorporating computational fluid dynamics (CFD) simulations.

4.4.2. The Daily Processed (Purified) Water Volume in Parabosol System Step 2 (Heat Transfer)

Operational time (total): 7 h (3.5 h peak, 3.5 h nonpeak time)

Dirty water process tank inner temperature 41 °C (measured)

Desired water temperature increase (ΔT_w): 75 °C (maintained) (process water temperature expected more than) 41 °C + 75 °C =106 °C. Minimum +/− %5 error

Tube properties: thermal conductivity (k) ≈ 70–90 W/(m·K)

Sectional open area in the tube (A_tube): 150 mm^2 (designed and protected section)

External temperature (T_out): 25 °C

Minimum inner tube temperature (T_in_min): 100 °C (for microorganism inactivation)

Calculation: determine water mass processed per Holkur

Water mass (peak hour) = 35 L ∗ 1000 kg/m^3 ∗ 1/1000 m^3/L ≈ 35 kg

Calculate required heat transfer:

Q_l_h_peak = water mass (peak hour) ∗ cp_w ∗ ΔT_w

Q_l_h_peak = 35 kg ∗ 4180 J/(kg·K) ∗ 75 °C

Q_l_h_peak ≈ 1.125 × 10ˆ7 J/h

Determine required heat transfer coefficient (h_i):

h_i = Q_l_h_peak/(π ∗ D_i ∗ L ∗ ΔT_w)

h_i = 1.125 x 10ˆ7 J/h/(π ∗ 0.015 m ∗ 20 m ∗ 75 °C)

h_i ≈ 18000 W/(m^2·K)

Solve for flow rate (ṁ_w_peak):

h_i = Nu ∗ k_w/D_i

Nu = h_i ∗ D_i/(k_w ∗ T_in_mean)

Assuming a mean inner tube temperature (T_in_mean) of +50 °C (the dirty water tank relative temperature slightly higher than the 40 °C) (halfway between the inlet and outlet temperatures), we can solve for the Nusselt number (Nu) and then for the flow rate (ṁ_w_peak) using the Dittus–Boelter correlation:

Nu = 18000 W/(m^2·K) ∗ 0.024 m/(70 W/(m·K) ∗ 50 °C) ≈ 76.5

ṁ_w_peak = ϱ_w ∗ A_tube ∗ v_w

v_w = Re ∗ μ_w/(ϱ_w ∗ D_i)

$$\mathrm{Re} = \mathrm{Nu} \ast D\_i/\mathrm{Pr} \ast k\_w$$

Substituting the values and solving for $\dot{m}\_w\_peak$, we obtain

$$\dot{m}\_w\_peak \approx 0.049\ \mathrm{kg/s}\ \text{(slightly higher than the experimental results)}$$

Results:

Flow rate ($\dot{m}\_w\_peak$): 0.049 kg/s (+/−5%) (highest daily value at 12:00 p.m.)

Heat transfer coefficient (h_i): 18,000 W/(m^2·K)

Nusselt number (Nu): 76.5

4.4.3. Real Time Measurement Data from Prototype Set and Environmental Inputs

The first prototype critical measurement points are as follows (Figure 8):

1. Four heat sensors on the focal hybrid tube (40 × 4) 160;
2. Four on the mirror surface (two on surface, two on the back side of the mirror);
3. Direct temperature monitoring in the dirty water tank (inner water temperature);
4. Measurement of the water flow (after the condensation);
5. Measurement of the process water amount in clean water tank (purified water);
6. Environmental data measurement (temperature, humidity, solar radiation, not wind speed).

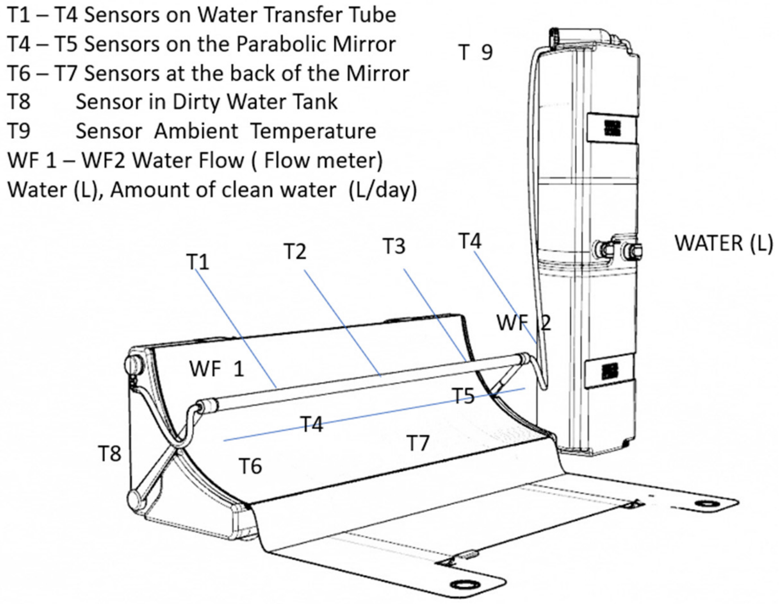


Figure 8. The critical measurement points on the prototype model during the test.

4.5. Comparison of Theoretical (Data 1) and Prototype Performance (Data 2)

Theoretical calculations show a slightly higher flow rate of 0.049–0.054 kg/s (peak hour values). The adjusted heat transfer coefficient (h_i) and Nusselt number (Nu) indicate changes in thermal conductivity. In field studies, prototypes process 37.8–42.2 L per hour of water with a 75 °C temperature increase (same peak values). Actual performance may vary due to product materials and field conditions. Field testing and monitoring are crucial to meeting water-processing targets while maintaining temperature requirements.

$$\text{Percentage difference} = (\text{theoretical—prototype performance})/\text{theoretical} \ast 100\%$$

$$\text{Percentage difference} = (277.20\ -198.78)/277.20 \ast 100\%$$

$$\text{Percentage difference} \approx 0.288\%\ (+/-3\%)$$

4.5.1. Considerations

It is important to note that experimental error margins are used to account for uncertainties in measurements and calculations. While the observed difference lies within the assumed error margin, it is still worth investigating the potential sources of errors to further refine the model and improve the accuracy of the predictions.

4.5.2. Additional Factors

Apart from the inherent uncertainties in measurements and calculations, other factors could contribute to the difference between the theoretical and the prototype performance. These factors may include the following:

- Variations in real-world conditions, such as solar radiation intensity, ambient temperature, and water flow rate, which may not perfectly align with the assumptions used in the theoretical model;
- Imperfections in the prototype system, such as manufacturing tolerances or material properties, which could affect the heat transfer efficiency;
- Limitations of the theoretical model itself, which may not fully capture all the complex physical phenomena involved in the water treatment process;
- The observed difference between the theoretical and the prototype performance falls within the assumed error margin; thus, it is crucial to continue investigating potential sources of error and refining the model to improve its predictive accuracy. Additionally, considering the factors that could contribute to the performance gap can provide insights for further optimization of the prototype system.

4.5.3. Estimating Heat Loss

Heat loss is a natural consequence of any solar energy concentration system. By understanding the different sources and implementing strategies to minimize them, the system can optimize the efficiency of the parabolic mirror and achieve higher achievable temperatures at the focal line. Remember, the actual heat loss will depend on the specific conditions of setup. Quantifying the exact percentage of heat loss is complex and depends on various factors such as the following:

- Cloud transients: This refers to the rapid changes in solar radiation intensity that occur due to the passage of clouds across the sun. These fluctuations can cause sudden drops in the amount of solar energy reaching the Parabosol system, leading to temporary decreases in its water treatment capacity;
- Mirror quality: The quality of the mirror surface significantly impacts scattering losses. Higher-quality mirrors with smoother surfaces minimize scattering and improve overall efficiency;
- Atmospheric conditions: Dust, haze, and cloud cover can significantly attenuate solar radiation, leading to higher heat loss. Clear skies will result in lower atmospheric losses;
- Wind speed: higher wind speeds can increase heat loss due to increased convection;
- Focal line design: if the focal line is not well insulated from the surrounding environment, conduction losses can increase;
- Reservoir tanks: materials and geometry affect the overall heat performance like "heat pumps".

4.6. Evaluation of Test

1. Using field data, the values obtained through theoretical calculations, assuming ideal conditions including solar radiation values, wind, humidity, and other variables held constant, were calculated to be on average 21.5% higher than the values from the prototype. Although a theoretical margin of error of +/−3% was anticipated, the deviation between the theoretical and experimental data occurred in the range of 25–30%. In other words, the observed deviation in water purification capacity (prototype performance) from the theoretical water purification capacity is 21.5%

lower. This difference remained below the anticipated 30% margin of error before the experiment. It has been observed that changes in weather conditions (such as light, wind, and humidity) affect the output data of the parabolic system.

2. Additionally, it is anticipated that the performance of the parabolic mirror (reflectivity) and the desired emissivity of the evaporation tube not being at ideal levels significantly contribute to the deviation in results. Variability in data, such as cloud cover, ambient temperature, and the temperature of the dirty water reservoir, also affects performance. Therefore, the observed difference may be attributed to the experimental margin of error and may not necessarily indicate a significant discrepancy between the theoretical model and the actual performance of the prototype. Although differences have emerged between the initial predictions and calculations made with field data, it is believed that the targeted threshold of 35–40 L per person per day can still be achieved. (But in Africa, considering both drinking water and basic hygiene needs, needs can range from 57.5 L to 150 L per person depending on the specific sources and guidelines followed). That means that the first prototype's performance just closed the Africa target, but still needs to improve. Hence, it has been determined that experiments need to be repeated in different regions, and further tests and measurements need to be conducted under various weather conditions (both open and closed environments).
3. Based on the results of this field study, we anticipate further quantitative improvements on the performance values achieved at this stage, which were initially based solely on prototype measurements. Expanding the mirror, enhancing the evaporation tube, and quantitatively refining the model are necessary to meet more demanding goals, such as increasing the intended daily water volume to acquire or treat. Moreover, enhancing the efficiency of the industrial ceramic boiling tube at the focal line is achievable. Furthermore, we assume that the margin of error primarily concentrates on these two specific spots. The parabolic mirror surface quality and reflectivity are also critically important for the overall performance of the solar radiation condensation and reflection on the focus line. Finally, this test revealed that the inner temperature of the dirty water tank is a crucial factor for the subsequent stage, as it directly impacts the heat transfer performance.
4. These field tests and theoretical calculations using field values provided insight into the possibility of realizing Parabosol performance values at the anticipated level:
    a. The parabolic mirror kept the concentrated radiation for heat generation continuously at the test value above the boiling point of water, which is also crucial for sterilization (7 h a day);
    b. This product's daily targets (water quantity) tend to meet these inadequate test conditions;
    c. This stage is crucial for identifying potential areas for product improvement;
    d. It has been shown that the product seems suitable for a structure that can be developed and used widely.

4.7. Possible Filters Options in Parabosol System

Recent advancements in household water treatment (HWT) technologies have focused on enhancing drinking water safety. Several extensively studied and implemented techniques include safe storage combined with chlorination, combined coagulant–chlorine disinfection systems, solar water disinfection, natural coagulation, reverse osmosis, ceramic filtration, bio-sand filtration, and slow and rapid sand filtration, all of which are effective in eliminating waterborne disease-causing microorganisms [32]. The Parabosol solution, which utilizes concentrated solar energy, presents a novel hybrid approach. Compared to the SODIS method, Parabosol operates at a higher temperature (1000 °C) in test conditions, and it incorporates a parabolic boiling system with changeable physical filters at the inlet and outlet. The system design allows for the use of various filter types, depending on availability and local conditions. (Figure 9a,b). The first proposed process stage incorporates a low-cost and effective bio-sand filter suitable for local and sustainable use. This filter can effectively remove protozoa with an efficiency of up to 100% [39]. The second stage utilizes a carbon filter (active carbon filter) or, depending on availability, a ceramic water filter, which operates by passing the water through a porous material. Local sourcing and cost-effectiveness make ceramic water filters a promising approach to reduce the burden of waterborne diseases [31]. The system design incorporates boiling and evaporation to shock the water at a high temperature. The inlet changeable sand filter and the outlet graphite, graphene, or industrial ceramic filters provide a second layer of security. The refillable design allows for multiple uses of the filters. Parabosol can produce an average of 150–180 L of drinking water per day at a cost of USD 0.24 per day using clean energy.

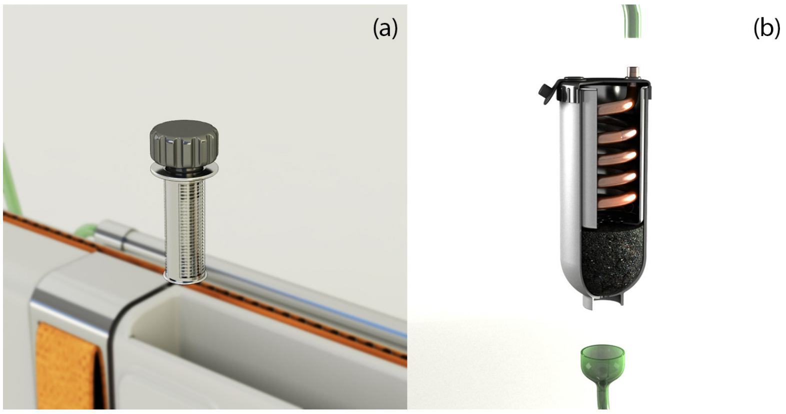


Figure 9. (**a**) Bio-sand filter; (**b**) carbon filter and cooling system.

- Material Alternatives

1. Ceramic filters: Explore alternative materials like porcelain or metal alloys for increased durability and potential for self-cleaning properties. They are highly effective at removing bacteria, protozoa, and some viruses, and they have a long-life span [32].
2. Bio-sand filters: Investigate the use of locally available sand and optimize biological layer development for improved efficiency. They remove bacteria, protozoa, and some viruses and reduce organic matter and improve taste [30].
3. Membrane filters: Research the development of more affordable and durable membranes, potentially from bio-based materials. They are highly effective in removing bacteria, viruses, and some parasites, and can also be expensive. They may require a pressurized water source and require regular replacement of the membranes [29,41].
4. Activated carbon filters: Explore the use of renewable or recycled materials for activated carbon production. They remove chlorine, taste, and odor contaminants and can also reduce some organic chemicals [29].
5. Graphene filters: Graphene has a unique property for water HWT. Graphene, a single layer of carbon atoms arranged in a hexagonal lattice, possesses remarkable properties that make it highly attractive for water filtration. Each molecular body has a high surface area. Graphene boasts an exceptional surface area, allowing for greater interaction with water molecules and the efficient capture of contaminants. Owing to its selective permeability, tailored graphene membranes can potentially allow the passage of clean water molecules while effectively blocking contaminants like bacteria, viruses, and heavy metals. With respect to durability, graphene's robust structure translates to a highly durable water filter material [42].

- Additional considerations:
    a. Combined filtration: combining different filter types can provide broader spectrum removal of contaminants;
    b. Local context: selecting the most suitable HWT solution depends on factors like water quality, resource availability, and user needs;

c. The study provides a general overview of common HWT filter solutions and material alternatives. Their specific effectiveness and limitations may vary depending on the design and implementation.

4.8. Harnessing the Sun's Power for Clean Water: "Parabosol" CSP System

While conventional water purification systems rely on substantial energy, infrastructure, and maintenance, Parabosol emerges as a promising alternative hope for underserved regions, offering independent solutions. Leveraging CSP technology, Parabosol stands out as a rapidly scalable water filtration solution for underserved regions. The system utilizes solar energy harnessed from a parabolic mirror to sterilize water, providing an environmentally friendly service that eliminates the need for electricity or chemicals. For areas with inadequate infrastructure, Parabosol's modularity, mobility, and affordability make it an exceptional solution. Notably, its potential as a practical and independent household product to combat waterborne illnesses and fatalities is significant. Larger communities and urban areas can quickly implement the Parabosol system, which uses durable and long-lasting steel mirrors and offers ease of use and maintenance. This system, as a quick, economical, and rational result, can stand out as a preferable solution with its low upfront costs, low operating expenses, easy-to-use interface, portability, high water safety standards, and scalability. These features are included in the Parabosol system, making it a logical and safe choice for developing regions, emergencies, and natural disasters.

Finally, all thermal systems that use concentrated solar energy, such as Parabosol, may have dimensions that pose some risks to the user, especially contact with surfaces having high temperatures, concentrated sunlight potentially being harmful to the human eye, and newly sterilized hot water carrying a risk when used unconsciously. To mitigate these potential risks, it could be beneficial to situate the parabolic system in elevated areas, like roofs and walls, particularly in areas that children cannot access, to minimize the risk of contact with hot surfaces and potentially harmful rays being reflected from the parabolic mirror into the human eye. To reduce these risks, informing and educating user groups can be beneficial for occupational safety and performance improvement.

4.8.1. Benefits for Underserved Regions

- Improved health outcomes: Clean drinking water plays a critical role in reducing waterborne infections, a major health concern in developing communities. By providing access to clean water, Parabosol can significantly improve public health [43];
- Enhanced water security: Remote communities often rely on unreliable sources like polluted rivers or stagnant pools. Parabosol empowers communities to produce clean water without relying on infrastructure, leading to enhanced water security;
- Environmental sustainability: Parabosol utilizes renewable solar energy with minimal maintenance requirements. Unlike other purification techniques, it produces minimal byproducts, making it a sustainable solution;
- Economic opportunities: Access to clean water can unlock economic potential. Time saved from water collection can be dedicated to income-generating activities or education. Clean water also supports agriculture and food production;
- Emergency response: Parabosol's mobility and modularity are crucial in emergency response situations;
- Elimination of complex infrastructure needs: Parabosol facilitates rapid and high adaptability;
- Ease of use: Parabosol is a user-friendly solution that adapts to urban and rural settings, catering to household use as well.

4.8.2. Challenges and Considerations

- Water production capacity: despite its portability and mobility, Parabosol's water production capacity (120–180 gallons per day) may be insufficient for large groups;

- Weather Dependency: Parabosol relies on sunlight for operation. Its effectiveness can be reduced during cloudy or rainy days [44];
- Maintenance: Replacing sand and carbon filters is essential for optimal performance. Ensuring accessibility to these replacement parts in remote areas is crucial. DIY principles can offer significant advantages in this regard. Parabosol represents a promising technology with the potential to revolutionize clean water access in underserved regions. Addressing concerns such as water production capacity, weather dependency, and spare part accessibility will pave the way for widespread adoption of this innovative solution.

4.9. Social Impact Analysis of Parabosol CSP Water Purification Systems

This analysis explores the potential social impacts of implementing Parabosol, a portable, concentrated solar-powered water purification system, in underserved regions facing water scarcity. Key areas of social impact are as follows:

1. Empowering women and girls: Collecting water is often a time-consuming task, especially for women and girls. Parabosol's portability potential can significantly reduce the time spent collecting water, freeing up time for numerous benefits, such as those which follow below;
2. Education: girls can attend school more regularly, potentially leading to higher literacy rates and improved educational attainment;
3. Income Generation: women can engage in income-generating activities, fostering economic empowerment and poverty reduction;
4. Hygiene, potentially leading to better health outcomes;
5. Education and opportunity: Better access to clean water, through access to easy-to-use systems like Parabosol can have a ripple effect on education. Reduced waterborne illnesses lead to better attendance rates, allowing children to focus on learning. User training on issues such as the use of the Parabosol system, maintenance of mirrors, and avoiding contact with hot areas are important for human health, efficiency and sustainability;
6. Additionally, the time allocated to women may enable them to prioritize their children's education;
7. Health and welfare: Safe drinking water is essential for preventing waterborne diseases such as diarrhea, cholera, and typhoid. By providing clean water [45]. Parabosol can significantly reduce the burden of these diseases and lead to
    a. Improved health outcomes: reduced disease rates mean a healthier population with fewer doctor visits and increased overall well-being;
    b. Increased productivity: a healthier workforce can contribute more effectively and potentially boost local economies;
    c. Community cohesion: Common access to a reliable source of clean water can foster a sense of community cooperation and social cohesion. Communities working together to maintain and manage Parabosol systems can strengthen social ties;
    d. Improvement of health and hygiene: more time can be devoted to household chores and personal hygiene.

4.9.1. Analysis Framework

- Baseline data: gather data on current water collection practices, time spent, waterborne illness rates, and educational attainment in the target region;
- Potential impact assessment: analyze how the Parabosol system implementation can affect these metrics, considering factors like time saved, reduced illness rates, and potential for increased school attendance;
- Case studies: if available, incorporate case studies from similar interventions to showcase real-world social impacts;

- Stakeholder involvement: consider perspectives of women, girls, community leaders, and educators to understand how Parabosol can best address their needs and empower them.

4.9.2. Challenges and Considerations

- Social norms and practices: Water collection might be deeply ingrained in social practices. Consider how to introduce Parabosol while being sensitive to existing cultural norms;
- Community Engagement: Successful implementation requires community buy-in. Develop strategies for community participation in planning, training, and maintenance of Parabosol systems;
- Long-term sustainability: Social impact is sustainable if communities can manage and maintain Parabosol systems. Analyze potential training programs and support structures to ensure long-term success.

Parabosol has the potential to create a significant social impact by empowering communities, improving health and well-being, and fostering educational opportunities. By addressing potential challenges and ensuring community engagement, Parabosol can be a powerful tool for social transformation in underserved regions.

5. Possible Water Purification Systems Comparison

Choosing an appropriate water purification system depends on several factors, including the quality of the source water, the desired level of treatment, and economic considerations (Table 6). While boiling stands as a straightforward and efficient method for eradicating most pathogens, it necessitates access to a heat source and fuel. Filtration systems, whether equipped with activated carbon or ceramic filters, can effectively eliminate particulates and certain microbes, but they may fall short of removing viruses or dissolved contaminants.

Municipal water treatment plants and reverse osmosis systems furnish high-quality treated water, although they might not be universally accessible and could entail substantial investment and maintenance expenses. UV light irradiation is effective for inactivating microorganisms, but it does not address dissolved solids. Portable chemical disinfection tablets offer effectiveness against select microbes, though their suitability for all water sources remains uncertain. Solar-powered disinfection systems such as solar water disinfection (SODIS) and Parabosol offer cost-effective options for clean water supplies dependent on sunlight exposure, but their effectiveness may vary depending on different climatic conditions. In summary, it is imperative to carefully evaluate water quality, resource availability, and treatment requirements to select the most appropriate water treatment system. When considering on-site water treatment alternatives, a delicate balance often arises between simplicity, effectiveness, and resource demands. For example, although solar-powered water disinfection (SODIS) seems to be the most economical solution for clean water resources, its use outside of emergencies may be problematic as it has been scientifically proven that it does not serve human health. Additionally, unfavorable weather conditions and variables may reduce the effectiveness of SODIS. Moreover, because it produces low heat, it may not be able to comprehensively address all contaminants. In contrast, the portable concentrated solar water purification system Parabosol represents an emerging technology with significant promise. By concentrating solar energy, this system can reach high temperatures and effectively destroy a wide range of microorganisms, including bacteria, viruses, and some parasites. Additionally, these systems can reduce heavy metals through processes such as precipitation. Although they require a high initial investment and slightly more complex installation than SODIS, parabolic mobile systems such as Parabosol have great potential to provide potable water, especially in places where there is no easy access to a conventional purification infrastructure. They can get rid of a wide range of contaminants, including heavy metals.

Table 6. Possible water purification systems comparison table [46–50].

System	Disease Prevention	Investment Cost	Service Cost	Maintenance	Availability	User-Friendly	Portability	Energy Dependency
Boiling	Effective against most pathogens	Low (pot/stove needed)	Low (fuel for stove)	Low (minimal cleaning)	Easy (widely available)	High	High	High (firewood or stove fuel)
Filtration	Moderately effective (depends on filter type)	Variable (low to high)	Low (replacement filters)	Variable (depends on filter type)	Easy (widely available)	Moderate	Moderate	Low (some require gravity, some pump-based)
Chlorination (public water supply)	Effective against most pathogens	N/A (public infrastructure)	N/A (part of water bill)	Low (public maintenance)	Easy (public infrastructure)	High	Low	Low (public infrastructure)
Water treatment plants	Highly effective (multi-barrier approach)	Variable (low to high)	N/A (part of water bill)	Low (public maintenance)	Easy (public infrastructure)	High	Low	Low (public infrastructure)
UV (ultraviolet light)	Effective against most pathogens	Variable (low to high)	Low (replacement bulbs)	Moderate (bulb replacement)	Moderate (commercially available)	High	High	Low (electrical outlet or solar panel)
Chemical purification tablets	Moderately effective (depends on type)	Low	Low	Low (minimal)	Easy (widely available)	High	High	Low (no external power source)
SODIS (solar water disinfection)	Moderately effective (works on some bacteria and viruses)	Low (clear plastic bottles needed)	Low (no additional costs)	Low (minimal)	Easy (widely available)	Moderate	High (lightweight, readily available)	High (sunlight)
Parabosol (concentrated solar)	Highly effective (research suggests effectiveness)	High (specialized equipment)	Low (no additional costs)	Moderate (cleaning mirrors, filters)	Moderate (testing phase, not widely available)	High	Moderate (requires transport and setup)	High (sunlight)

The operating costs and logistical sustainability of most possible water treatment systems (except SODIS) are quite high (Table 6). Despite the seemingly free nature of SODIS, its long-term health risks should only justify its use in extreme cases. Advanced filtration, such as ceramic filters with carbon and powder technology, is the most expensive in water purification systems and incurs additional costs for users. Large areas, like chemical applications (chlorination) commonly used in water treatment systems, are their focus, and they can be more effective in structures with distribution networks. In disasters and extraordinary situations, if the network is damaged, system performance may decrease. In addition, although the amount of water purification performance depends on the sun, Parabosol has emerged as a solution with low operating costs and high sustainability, while each station offers a solution that can meet the vital need for clean water for a family. It is thought that it will provide better results in terms of performance than the current treatment systems used in the medium and long term. Table 7 also examines the comparison of possible disease prevention methods with the Parabosol system. We have determined that the Parabosol system, when treated with a temperature above 100 °C for an average performance value of 180 L per day, allows water to evaporate even at the lowest performance and prevents any microorganisms from surviving in field tests.

Table 7. Daily performance data of Parabosol system output comparison (data 1 and data 2).

Time (Hour)	Solar Radiation (G) (W/m^2)	Theoretical Focal Line Temperature (°C) (Data 1)	Measured Focal Line Temperature (°C) (Data 2)	Theoretical Water Treatment Capacity (L/h) [Data 1]	Measured Water Treatment Capacity (L/h) [Data 2]
9:00 a.m.	600	128.1	110.1	21.6	12.8
10:00 a.m.	700	180.8	160.8	32.1	18.1
11:00 a.m.	800	238.3	212.3	41.0	31.85
12:00 p.m.	800	273.2	224.2	49.0	39.26
13:00 p.m.	700	227.1	218.1	37.1	30.47
14:00 p.m.	600	201.1	181.1	32.6	28.62
15:00 p.m.	500	195.4	160.4	27.1	19.7
16:00 p.m.	400	134.4	140.4	22.6	10.92
17:00 p.m.	300	119.4	101.4	14.1	7.07
Total				277.2	198.78

Based on the data in Table 6, when comparing various methods for sterilizing water like SODIS, filtration, chlorine, and UV with the Parabosol system, SODIS emerges as the most convenient and cost-effective option in terms of initial investment, operational expenses, effectiveness, and overall impact. However, there are concerns about the transfer of BPA from PET bottles exposed to sunlight in SODIS setups, which could lead to health issues. The use of chlorine also poses health risks. While filtration can enhance water quality, it may pose challenges in areas with high operational costs and limited long-term sustainability. Using UV light for water treatment raises questions about energy consumption and processing time. On the other hand, the parabolic system presents itself as a promising solution to address these issues. The upfront costs and operational expenditures involve basic filtration components, such as sand, ash, and carbon filters, if needed. The Parabosol system offers a compact alternative with potential for further development due to its durability, portability, and widespread accessibility.

5.1. Future Possibilities of Parabosol

Parabosol presents a promising approach to clean water production in water-scarce regions. Future studies should delve into expanding upon the initial research, exploring the possibilities for enhanced scalability, seawater purification, and the creation of an open system that integrates seamlessly with additional treatment methods.

5.1.1. Enhancing Scalability and Expanding Reach

- Modular (station) design: By developing Parabosol units as mobile and modular components, the system's capacity can be easily scaled to meet the specific water demands of a particular region. The system can scale by adding or removing modules to achieve the desired output performance.
- Reflector field optimization: Research can also focus on optimizing the layout of the Parabosol reflector field to maximize sunlight capture for target-scale systems. This will involve exploring concentrator technologies to gather sunlight from a wider area, which can significantly increase the water production capacity.
- Conquering salinity and unhealthy compounds: seawater purification potential

1. Brine management: Seawater desalination using Parabosol produces brine concentrate as a byproduct. Future research must address effective brine management strategies. This could involve developing solar-driven salt production plants or implementing mineral recovery techniques to minimize environmental impact;
2. Pre-treatment for seawater: Adapting Parabosol for seawater necessitates investigating compatible pre-treatment methods to address coagulation and flocculation requirements for effective desalination. This could involve developing solar-powered pre-treatment stages or adapting existing techniques for integration with the system. Imagine Parabosol seamlessly working with pre-treatment units powered by the sun itself, transforming seawater into clean drinking water.

5.1.2. Open System Design: Embracing Collaboration for Enhanced Purification

- Multi-stage purification: Parabosol's capabilities can be extended by integrating downstream filtration technologies like membrane filtration (reverse osmosis or ultrafiltration). This creates a multi-stage system capable of removing dissolved salts and contaminants beyond the reach of evaporation alone. Additionally, Parabosol can be used in tandem with other purification methods to deliver exceptionally high-water quality in the future.
- Chemical disinfection: Integration with chemical disinfection methods, like chlorination using solar-generated electricity, ensures the microbiological safety of purified water. This complements the disinfection achieved through high temperatures during evaporation.
- Real-time monitoring and control systems: Sensor-based monitoring systems can track operating parameters, like solar radiation, water temperature, and condensate quality, in real time. These data can be used to optimize performance and efficiency. By focusing on these expanded areas of research and development, Project Parabosol can evolve into a highly scalable, open-system solution for clean water.

5.1.3. Deployment Strategies

- Community ownership and participation: To ensure long-term sustainability, fostering community ownership and participation in Parabosol projects is crucial. This could involve training residents on system operation and maintenance, empowering them to manage their own water security.
- Integration with existing infrastructure: Parabosol should be designed for compatibility with the existing water infrastructure in underserved regions. This could involve developing modular units that can be integrated with existing storage tanks and distribution networks.
- Public–private partnerships: Facilitating public–private partnerships can leverage government funding with private sector expertise to accelerate Parabosol deployment at scale. Imagine governments collaborating with water technology companies to bring clean water to millions.

5.1.4. Measuring Success and Impact

- Improved water quality and access: The primary measure of success is the delivery of clean, safe drinking water to communities in need. Regular water-quality testing and monitoring access rates are essential to tracking Parabosol's impact.
- Socioeconomic benefits: Access to clean water can have a ripple effect on communities. Improved health, increased educational opportunities, and economic growth are potential benefits that should be tracked and measured. Imagine healthy children attending school and families lifted out of poverty thanks to the clean water provided by Parabosol.
- Environmental sustainability: As a renewable energy-powered system, Parabosol's environmental footprint should be continuously monitored. Life cycle assessments can be used to identify areas for improvement and ensure Parabosol remains a sustainable solution.

By focusing on these implementation strategies and impact measurements, Project Parabosol has the potential to become a transformative force in the fight against global water scarcity. Imagine a world where clean water is a basic human right, accessible to all, and powered by the sun. Project Parabosol represents a step toward that future, a future where innovation and sustainability converge to bring life-giving water to those who need it most.

6. Conclusions

The Parabosol Energy Globe award-winning water purification system, with its utilization of concentrated solar power (CSP), emerges as a beacon of hope for underdeveloped communities struggling with water scarcity. This innovative technology builds upon the established potential of solar disinfection for water treatment, as explored in recent advancements, but takes a crucial step forward by demonstrating its practicality in real-world situations.

The growing urgency for rapid response systems, particularly during outbreaks, underscores the strategic importance of such deployable solutions. By harnessing solar energy, Parabosol offers a sustainable and environmentally friendly approach to delivering clean water, fostering public health improvements, and promoting economic growth—all without dependence on the existing infrastructure. While the current scope of Parabosol's impact is primarily limited to household-level deployment with a defined capacity, its potential for broader-scale implementation holds immense promise. Parabosol, with its meticulously designed implementation strategies, has the potential to make a significant and lasting contribution toward achieving the UN's Sustainable Development Goal (SDG) of universal access to safe and affordable drinking water (SDG 6). The system's autonomous nature and user-friendly characteristics present a compelling solution for resource-limited settings, particularly in developing regions. Ongoing research and development efforts are actively addressing areas for improvement, focusing on enhanced energy storage capabilities, increased efficiency in low-light conditions, and the development of cost-effective filter replacements. To ensure the successful and sustained implementation of Parabosol systems in areas of greatest need, a collaborative approach involving governmental, non-governmental, and private sector organizations is crucial. By leveraging their combined resources and expertise, these stakeholders can work together to overcome existing challenges and expedite the widespread adoption of parabolic technology. This collaborative effort has the potential to unlock a new era of water security for vulnerable communities, paving the way for a healthier and more prosperous future.

Parabosol represents a groundbreaking advancement in solar-powered water purification. By harnessing the power of the sun and addressing the limitations of existing technologies, Parabosol offers a promising solution for tackling the global water crisis. Parabosol, with its potential for scalability, sustainability, and user-friendliness, has the potential to transform the lives of millions by ensuring access to clean drinking water, a fundamental human right and a cornerstone of sustainable development.

Funding: No funding was received.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data related to this article are available in this manuscript.

Acknowledgments: The authors would like to thank Gemini, a large language model from Google AI, for its assistance with this paper. Gemini was used for research, editing, and proofreading. The authors are grateful for Gemini's help in improving the quality of this paper.

Conflicts of Interest: The author declares no conflicts of interest.

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