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# Design and Experimental Evaluation of passive Solar Still under hottest and driest climate condition of Ethiopia: A case of lake-Afdera saline water

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechanical Engineering

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Design and Experimental Evaluation of passive Solar Still under hottest and driest climate condition of Ethiopia: A case of lake-Afdera saline water

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## Declaration

I here declare that the thesis with a title of "*Design and Experimental Evaluation of passive Solar Still under hottest and driest climate condition of Ethiopia: A case of lake-Afdera saline water*" contains my own work. Wherever contributions others are involved, every effort is made to indicate clearly with reference to the literature and acknowledgement of collaborative research and discussion.

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__________________ _____June 21, 2025____________

Signature Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

Dr. Mulu Bayray (Asso. Prof)

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## ABSTRACT

Access to potable water remains a critical challenge globally, particularly in arid regions such as Ethiopia's Afar Region, where groundwater is often limited or contaminated with high levels of fluoride and salinity. This study investigates the design and performance of passive solar stills for desalinating saline water from Lake Afdera under extreme climatic conditions. The objective was to enhance the productivity of conventional single-slope, single-basin solar stills by incorporating black volcanic rocks as thermal energy-absorbing materials.

Two solar still configurations—a conventional design and a modified design with black volcanic rocks—were constructed and experimentally evaluated over two days in Afdera. Parameters such as ambient temperature, water temperature, and hourly yield were recorded. To validate the results, the modified still was later tested under different environmental conditions at Mekelle University using thermocouples, PicoLog software, a pyranometer, and measuring jars for precise data collection.

Results showed that the modified solar still significantly outperformed the conventional still in water yield, producing 3,482 ml and 3,800 ml over two days compared to 1,920 ml and 1,780 ml, respectively. It also demonstrated improved night-time performance, yielding 890 ml versus 340 ml, due to better heat retention from the black rocks. Correlation analysis from the Mekelle validation indicated strong relationships between water yield and solar radiation ($r = 0.60$), rock temperature ($r = 0.96$), internal temperature ($r = 0.85$), and ambient temperature ($r = 0.83$). The modified system achieved 32.87% higher efficiency in Afdera than in Mekelle, highlighting the role of environmental conditions.

The findings confirm that integrating black volcanic rocks into solar still design enhances efficiency and output, offering a cost-effective and sustainable desalination solution for arid, high-radiation regions like Afar.

**Keywords:** Desalination, solar still, thermal energy storage, volcanic rocks, water scarcity, passive systems

## Acknowledgment

The journey to completing this thesis has not been easy. The challenges of a COVID-19 lockdown that halted all movement, followed by a devastating war that disrupted everything, made resuming to research work and reconnecting with my university and advisor seem almost impossible. Yet, through the will of the Almighty God, the unwavering support of my advisor, Dr. Mulu Bayray (Associate Professor), and the dedication of Mekelle University, I was able to see this work through to completion.

I am profoundly grateful to my advisor, Dr. Mulu Bayray, for his invaluable guidance, patience, and encouragement throughout this journey. His deep insights and expertise not only shaped my research but also inspired me to persevere in the face of immense difficulties.

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I am also deeply thankful to the Institute of Energy at Mekelle University for their contributions and support during my validation tests on campus. Their collaboration played a key role in ensuring the accuracy and credibility of my findings.

Above all, I owe my deepest gratitude to my family, whose unconditional love, patience, and encouragement have been my greatest source of strength. Their belief in me never wavered, even in the most difficult times, and for that, I am forever grateful.

This work is a testament, not only to academic perseverance but also to the power of resilience, collaboration, and unwavering support.

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# CHAPTER ONE: INTRODUCTION

## 1.1. Background of the study

The exponentially growing demand of energy from one side, and the climate change caused by non-renewable energy sources, from another side, willingly or unwillingly compelled the world to focus on renewable energy sources. However, the world countries still, haven't agreed on the mechanisms how to eliminate the available non-renewable energy depend sources. But all agree to build future energy sources based on renewable energy. So it becomes necessary to use the renewable energy sources not only for huge industries, but also for various applications including water purification.

Solar energy is one of the renewable energy sources necessary to be utilized for the socio-economic development of a nation. Solar energy is clean, eco-friendly, inexhaustible, abundantly available and has the greatest potential of all the sources of renewable energy. Specially, the utilization of solar energy is of great importance to countries (like Ethiopia which is known by 13 months sun-gifted) where sun-light is abundant for major part of the year (Tiwari 2013).

Along with energy, pure water is also one of the major concerns of today. In most developing countries as well as in many developed countries, the supply of potable water is a major problem. Roughly 2.2 billion people of the earth's population still do not have access to clean, safe, drinkable water, and they are suffering from the incapability of supplying pure drinking water to their communities, especially in their arid regions. Globally, 200 million man-hours are spent each day, mostly by females, to collect water from distant, often polluted sources (UNICEF, 2023; World Vision, 2023). The same is true in Ethiopia, where 62% of rural households are traveling 30 minutes or more to fetch drinking water daily (USAID, 2023)

From another side, even though more than 70% of earth's surface covered by water; about 97.5% of all water on earth is salt water, leaving only 2.5% as fresh water. Of this about 70% is frozen in the icebergs in Polar Regions and the remaining present as soil moisture, or lies in deep underground aquifers as groundwater which is not accessible for direct human use. Only 1% of the world's fresh water is accessible for direct human uses which is regularly renewed by rain and snowfall, and is therefore available on a sustainable basis ( postel et al. 1996).

Freshwater resources are increasingly strained due to industrial activities, agricultural demands, and population growth. As of the latest data, global access to clean water has improved, yet population growth and climate change continue to exacerbate water scarcity issues. The contamination and depletion of freshwater resources persist, posing a significant threat to the availability of safe drinking water in the coming decades. Without significant improvements in water management and purification technologies, it is projected that safe freshwater may become critically scarce within the next 20-25 years (Ritchie 2023; Shatar 2023)

Even though, many methods and processes are used for pure purification, because of its cost and its expensive energy use, rarely used and not widely available. So, new ways of water purification at lower cost, with less energy consumption as well as eco-friendly method is badly needed (Shannon et al. 2008).

Distillation of unsafe water is one of the steps to get the clean water, which is affordable, reliable and technically, easy to construct, operate, maintain as well as environmentally friendly. Distillation has long been counted as a method of making saline or brackish water drinkable and purifying water in remote areas. Solar Energy could provide a sustainable alternative to drive the distillation plants, especially in the countries which lie on the solar belt such as Africa, the middle east and south Asian countries ( Muftah et al. 2014)

So, solar desalination plants (solar stills) are the feasible solution for providing sufficient amount of safe water for a small community or family in the region where sufficient amounts of solar energy and access to saline or brackish water is available.( Iqbal and Ahmed 2014).

Passive solar stills are simple in construction, operation, usually smaller in size, and less costly. Passive stills only utilize exorbitant available solar energy to remove the impurity in contaminated water, thus it is safe, clean, eco-friendly, and energy saving process. So, this papers focus will be on passive type which fit with our need.

The origins of the solar distiller can be traced back to 1551 when Arab alchemists used simple solar stills to keep mine workers hydrated during the work day (Al-Hayek et al. 2004). Designs similar to these ancient distillers still exist today. However, adaptations to that simple design now incorporate changing factors, such as sun position, geographical location, and weather conditions.

In many parts of the world, especially in sub-Saharan Africa, including Ethiopia, access to clean drinking water remains a significant challenge. Areas lacking clean water are often impoverished and do not have the infrastructure to support large-scale water purification systems. As of the latest data, an estimated 2 billion people globally do not have access to safely managed drinking water services. This situation leads to numerous avoidable deaths, including approximately 485,000 deaths annually due to diarrheal diseases caused by unsafe drinking water and inadequate sanitation (UNICEF, 2023; WHO, 2023) .

The most source of fresh water in Afar Region is the underground water which is either very limited and cannot meet the increasing demand or contaminated with fluoride or salt. High fluoride concentration in ground water in and around the Great Rift Valley is a natural phenomenon having a negative impact on public health (FAO). In addition, the salinity problem of the region is very high. Most lakes like Lake-Afdera, Lake-Dobie and Lake-As-ale contents are saline water as well as the around areas of the lakes. Being the region very hot and the people live nomadic way of life make the problem crucial.

From environment perspective, most dwells uses pump consuming oil and causing a dependency on fossil fuels, which is costly and unfriendly to the environment. Population in Afar over the last four decades has almost tripled and the available fresh water can no longer be enough without considering the water consumption due to the expansion in the industry. Not only that, one of the major regional transformation programs is to settle the pastoral community based on water sources.

One person’s daily water need depend on the climate condition of the areas. So, the solar stills to be launched in Afar region should have high amount of output to fit with water need of the people. Hence, the effect of hotness and dryness of the area on solar still output must be evaluated, as, priority should be given to this cost effective, easily transportable, and eco-friendly technology. In this research, the main questions to be answered are: what is effect of hot and dry climatic condition on the yield and efficiency of solar still? What is the effect of absorbing materials on the yield? By conducting field experiment and analyzing the result.

## 1.2. Problem Statement

Water is life, and the threat of unsustainable means of potable water supplies has led to the search of renewable energy sources to create a cleaner and more efficient solution for potable water supply. Various modular technologies existed, in which potable water can be produced, but these have proved to be quite expensive as large and very complex designs are involved. Because this problem is prevalent in the world's poorest countries, there is a need for the technology to be simple in design, affordable and sustainable.

Afdera, located in the north-eastern part of Ethiopia's Afar Region, is one of the hottest inhabited places on Earth. The scarcity of fresh water in the area remains a critical issue. Residents typically rely on groundwater from streams or wells, but these sources are often miles away, and the surrounding lake water is salty.

The community still faces significant challenges in accessing clean water. The local groundwater sources are often brackish, making them unsuitable for direct consumption. Water is sometimes trucked in from distant towns like Logia, but this option is expensive and unaffordable for many residents.

Due to the high salinity of available water, residents face numerous health issues, including kidney disease, swollen ankles, and hypertension. This situation underscores the urgent need for sustainable water solutions in the region, and specifically in Afdera. Efforts to address water scarcity in Ethiopia, including Afdera, are ongoing. Various organizations and projects are working to improve access to clean water and sanitation facilities. However, significant gaps remain, and many communities still rely on unsafe water sources, leading to widespread waterborne diseases and other health problems (Lifewater International)

From another hand, since the targeted communities are poor, and mostly illiterate, even there is advanced method of solar distillation, the complexity of design and cost of the system doesn't fit with fact on the ground. So, the best option is to use the simplest system, cheapest in cost and easiest in operation and maintenance with good yield and purification efficiency technology.

## 1.3. Objectives

### 1.3.1. General objectives

The general objective of this research is to design and experimentally investigate the yield and overall efficiency of passive solar still under the hottest and driest climate condition of Afdera, Ethiopia and validate in Mekelle environmental condition.

### 1.3.2. Specific objectives

- To design and fabricate passive type solar still prototype for Afdera climate condition using appropriate locally available materials.
- To investigate daily yield and purification quality of the prototype
- To investigate the effect of volcanic black rocks (as absorbing materials) on the overall efficiency and productivity of the distiller.
- To conduct validation test in Mekelle University, main campus

## 1.4. Significance of the Study

The significance of this study lies in its potential to address critical water scarcity issues in one of the hottest and driest regions of the world, Afdera, Afar, Ethiopia. By focusing on the design and experimental investigation of passive solar stills, the research aims to enhance the efficiency and yield of solar distillation systems using volcanic rocks as absorbing materials. After that, the result validate in different environmental condition of Mekelle which enable to evaluate the real performance of the modified still. This modification could provide a sustainable and cost-effective method for producing clean drinking water, crucial for improving the living conditions and health of local communities. Furthermore, the study's findings could offer valuable insights for similar arid regions globally, promoting the adoption of renewable energy solutions for water purification.

## 1.5. Scope and Limitations

The study focuses exclusively on a comparative analysis between two types of solar stills: conventional solar stills and modified solar stills utilizing volcanic rocks as absorbing materials to investigate in both Afdera and mekelle. The investigation does not encompass double-slope solar stills, which may exhibit the highest yield potential. Furthermore, the study is limited to assessing the impact of environmental factors such as wind, humidity, and temperature on the performance of the solar stills. It does not explore design-related parameters or other variables that could influence efficiency. Additionally, unlike the Mekelle test, the data related to wind and humidity utilized in Afdera, sourced from online databases, may be subject to accuracy and quality limitations, which could affect the overall findings and conclusions.

### 1.6. Organization of the paper

The organization of this paper includes five chapters; the first chapter is Introduction, which discusses the water scarcity problem in the Afar region and the potential of solar stills for desalination; the second chapter which is Literature Review, reviews existing studies on various solar still designs and identifies research gaps; the third chapter is Methodology, detailing the design, construction, materials, experimental setup, and data collection and analysis procedures for the passive solar still; the fourth chapter is present Results and Discussion, for experimental findings, comparing the performance of the designed solar still with conventional methods, and analyzing the impact of environmental factors on its efficiency; and the last chapter is Conclusion and Recommendations, summarizing key findings, discussing the effectiveness of the solar still in Afdera's harsh climatic conditions, and providing recommendations for future research and design improvements.

# CHAPTER TWO: LITERATURE REVIEW

## Solar desalination

Solar stills provide an easy solution of fresh water to most of the Earth’s Region. Different solar stills with designs and combination have been developed and tested over an age. Various

Researchers studied and reviewed different designs, performance factors, status and progress in solar stills.

The efficiency and distillate output of passive solar still is very less. There are numerous designs and operational parameters along with climatic conditions that affect the performance of a passive solar still. Due to the large scope of improvement in passive solar stills and for fulfilling the requirement of fresh potable water in an n economical and environment friendly way, it has been studied intensively by various researchers.

The process of water distillation involves heating water to the point of vaporization, at which point the water will undergo a phase change from liquid to vapor. The water vapor then condenses onto a cooler surface where it can be collected. Any contaminants contained in the original feed water (such as salt, silt, and heavy metals) will remain in the distiller basin. The collected water vapor is now free of all prior contaminants and is fit for consumption.

A solar powered distillation device contain three basic components: a basin in which the contaminated water is contained, a surface above said feed water for the water vapor to condense onto (i.e. a glass pane), and a catch basin for the distilled water to drain into.

During operation of the distiller, solar energy is collected by the feed water. When enough energy is absorbed by the water, the water undergoes a phase change. The water vapors then rises and comes into contact with the cooler transparent, inclined surface. Here the vapor once again goes through a phase change from vapor back to liquid. The water then condenses and runs off the transparent inclined surface into a collection bin. The distillation process rids the contaminated water of any impurities and most commonly found chemical contaminants within the environment. These contaminants are left behind in the basin.

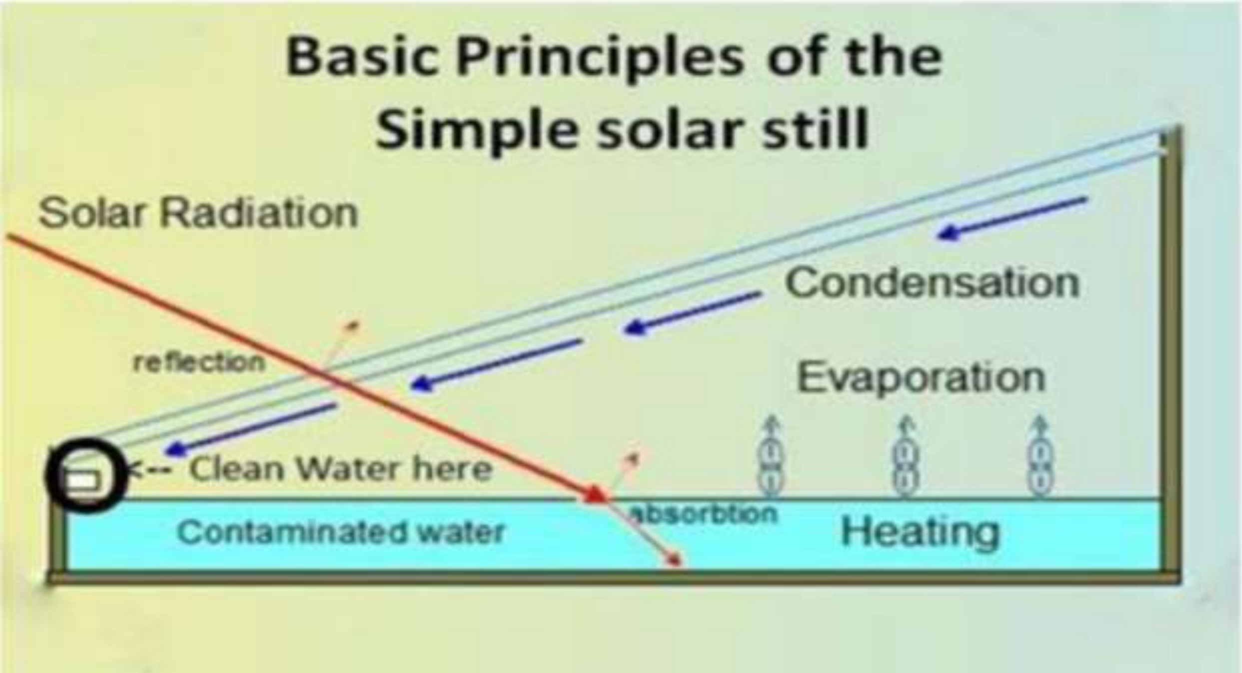

**Figure: 1 basic principles of solar still**

In general, desalination technologies are broadly classified into two categories based on the principle of separation of salts and fresh water from the saline water solution. In evaporative or thermal desalination technologies, the extraction of fresh water is obtained through phase change by the addition of heat to the saline water solution. It consists of alternate cycles of evaporation and condensation phenomenon. These technologies are of various types namely Multiple Effect Distillation (MED), Multi Stage Flash (MSF) desalination, Thermal Vapor Compression (TVC), Mechanical Vapor Compression (MVC) and others. In membrane desalination technologies, the salts are separated from the saline water solution by the aid of selective membranes. In these pressure driven membrane processes of desalination, fresh water is obtained without phase change.

Membrane desalination technologies are namely Reverse Osmosis (RO), Electro Dialysis (ED) and others. These conventional methods of producing fresh water are highly energy consuming techniques involving either requirement of heat and a kind of mechanical or electrical energy to separate salts in the case of thermal and membrane processes respectively (El-Dessouky HT and Ettouney HM 2002).

Solar desalination on the other hand proves to be the most economical and viable techniques of purifying the saline water solution. It uses the naturally available abundant supply of solar energy to evaporate the water and thus this method has zero operational cost (Naim M, Mervat A and El-Kawi Abd, 2003). The solar still is a very simple way of distilling the water. It consists of a container whose inner surfaces is coated with black paint and is fitted with a glass cover. The container is filled with saline or brackish water to be purified. The solar radiation gets transmitted through the glass cover and is absorbed by the basin liner which in turn heats the water. The evaporated water gets condensed underneath the glass surface and is collected in a trough fitted along the length side (Vinoth KK and Kasturi Bai R, 2008).

Solar stills are mainly classified into two categories namely single effect and multi-effect stills. Each of these stills are further classified as active and passive type depending upon the source of heat to evaporate water either directly through sun or using some external aid like solar collectors namely flat plate collectors, evacuated tube collectors and concentrating collectors which are coupled to the desalination unit. Single-effect solar still is the original solar still construction. These types of stills have only one layer of glazing over the water surface, thus a lot of heat energy becomes wasted through latent heat of condensation in the form of conduction through the glazing.

## 2.1. Overview of Solar Still Technology

Solar still technology has seen numerous advancements over the years, focusing on improving efficiency and productivity.

Younis et al. (2022) provide a comprehensive review of recent developments in solar still technology. Their study emphasizes the various types of solar stills, including passive and active systems, and highlights innovations such as the use of Nano fluids, phase change materials (PCM), and advanced geometries to enhance performance. They also discuss the environmental and economic benefits of these technologies, particularly in arid regions.

Shoeibi et al. (2021) delve into techniques for simultaneously enhancing heat and mass transfer in solar stills. The review covers hybrid techniques that integrate solar stills with other renewable energy technologies, such as photovoltaic panels and wind turbines. This integration helps increase the overall efficiency of water production, making solar stills more viable for large-scale applications in dry climates.

Mohammed et al. (2022) conducted a comparative study on the performance of different solar still designs, including conventional, PCM-enhanced, and other advanced models. Their research demonstrated that solar stills equipped with PCM and other modifications significantly outperformed traditional designs. The study's findings underscore the importance of thermal storage in improving the efficiency of solar desalination systems.

Mouhoumed et al. (2022) investigated various parameters affecting the productivity of basin-type solar stills under local climate conditions. Their study highlighted the critical role of factors such as basin water depth, solar intensity, ambient temperature, and the use of reflectors in enhancing the performance of solar stills. The findings suggest that optimizing these parameters can lead to substantial improvements in water yield.

An older study by Tripathi and Tiwari (2006) analyzed the performance of different solar still configurations based on various factors affecting productivity. They compared conventional passive solar stills, solar stills with enhanced heat absorption, and other advanced designs to determine the most efficient setups for hot and dry climates. The study provided valuable insights into the design and operational parameters that maximize the efficiency of solar stills.

A study by Velmurugan et al. (2008) examined the enhancement of solar still performance using different energy-absorbing materials. They tested materials such as black rubber, black granite gravel, and black pebbles in the basin of the stills. The results showed that these materials significantly improved the productivity of the solar stills by increasing the heat absorption and retention within the system .

Research by Tabrizi et al. (2010) focused on passive solar stills integrated with external condensers. Their study found that the inclusion of external condensers led to a significant increase in the freshwater yield of the solar stills. This improvement was attributed to the enhanced condensation process facilitated by the additional cooling surface area provided by the condensers.

Hansen et al. (2015) conducted a study on the use of Nano fluids to improve the thermal efficiency of solar stills. They explored various types of Nano fluids, such as Al2O3 and TiO2, and their effects on heat transfer within the stills. The findings indicated that Nano fluids could substantially enhance the evaporation rate, leading to higher water production rates compared to conventional water-based solar stills.

A study by Dev et al. (2011) focused on the performance of solar stills integrated with wick materials. They tested different wick materials, such as jute cloth and sponge, to enhance water transport and evaporation rates. The research demonstrated that using wick materials improved the overall efficiency of the solar stills by maintaining a continuous and uniform water flow across the evaporation surface.

Finally, research by Murugavel et al. (2010) explored the use of solar stills coupled with solar collectors. Their study aimed to maximize the thermal input to the solar stills by pre-heating the water using flat-plate or evacuated tube solar collectors. The results showed that coupling solar stills with solar collectors significantly increased the water production rates, highlighting the potential of hybrid systems for efficient desalination in arid regions.

## 2.2. Studies on Solar Stills in Hot and Dry Climates

Younis et al. (2022) provide a comprehensive review of recent developments in solar still technology, focusing on various types, including passive and active systems. They highlight innovations such as the use of Nano fluids, phase change materials (PCM), and advanced geometries that enhance performance. The review underscores the environmental and economic benefits of these technologies, particularly in arid regions where water scarcity is a critical issue.

Shoeibi et al. (2021) delve into techniques for simultaneously enhancing heat and mass transfer in solar stills. Their review covers hybrid techniques that integrate solar stills with other renewable energy technologies, such as photovoltaic panels and wind turbines. This integration increases the overall efficiency of water production, making solar stills more viable for large-scale applications in dry climates

Dawood et al. (2022) investigated the enhancement of freshwater productivity of solar stills through temperature difference management. They determined that increasing the temperature difference between basin water and glass cover enhances daily productivity. Their findings suggest that optimizing this temperature gradient is crucial for improving the efficiency of solar stills in hot and dry climate.

Abu-Arabi et al. (2020) examined three different types of solar stills: regenerative, conventional, and those with double glass cover cooling. Their study found that regenerative solar stills, which reuse heat within the system, offered superior performance in terms of water production efficiency. This research highlights the potential of regenerative designs in maximizing output in harsh climates.

Tripathi and Tiwari (2006) analyzed the performance of various solar still configurations based on factors affecting productivity. They compared conventional passive solar stills, solar stills with enhanced heat absorption, and other advanced designs to identify the most efficient setups for hot and dry climates. Their study provided valuable insights into design and operational parameters that maximize efficiency.

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## 2.3. Impact of Environmental factors

The performance of solar stills, essential devices for water purification in arid regions, is significantly influenced by various environmental factors. Key factors include ambient temperature, wind velocity, solar intensity, and humidity, all of which directly affect the efficiency and yield of the stills. Higher ambient temperatures enhance the evaporation rate, while wind velocity influences the condensation process by affecting the cooling of the condensation surface. Solar intensity, the primary energy source for solar stills, dictates the rate of water heating and evaporation. Humidity levels can impact the rate of evaporation and condensation, with lower humidity generally leading to higher evaporation rates. Understanding and optimizing these environmental parameters is crucial for improving the productivity of solar.

### 2.3.1. Impact of Wind Speed

Wind speed plays a significant role in the efficiency of solar stills by enhancing the evaporation and condensation processes. Chinchilla-Guarin et al. (2016) found that increased wind speeds can improve the yield of solar stills by facilitating better heat transfer and promoting more effective evaporation and condensation cycles. Another study highlighted that optimal wind speeds can significantly improve yield without causing excessive cooling, thereby maintaining efficient operation. Essa (2022) supports this finding, showing a direct correlation between higher wind speeds and increased productivity due to improved heat transfer rates.

Additionally, Maciejczak et al. (2020) observed that specific wind conditions, such as the Foehn wind, had a notable impact on environmental variables including wind speed, which consequently affected solar still performance.

### 2.3.2. Impact of Temperature on Solar Stills

Ambient temperature is a critical factor influencing the yield of solar stills. Higher temperatures enhance the evaporation rate, thereby increasing distillate output. Ayoub (2013) emphasized that temperature is a crucial variable, with yields increasing significantly at higher temperatures due to enhanced evaporation rates. Essa (2022) also observed a direct correlation between ambient temperature and solar still productivity, reinforcing the importance of this variable in optimizing performance. Chinchilla-Guarin et al. (2016) further noted that fluctuations in temperature directly affect the efficiency of solar stills, with higher temperatures leading to better performance. Bonkaney (2017) also supported these findings, indicating that elevated ambient temperatures boost evaporation rates, thus increasing yield.

### 2.3.3. Impact of Humidity on Solar Stills

Humidity has a complex relationship with the efficiency of solar stills. While moderate humidity levels can support the evaporation process, excessive humidity can hinder it by reducing the rate of evaporation. Bonkaney (2017) illustrated that while moderate humidity is beneficial, excessive levels can reduce overall efficiency by slowing down the evaporation process. Essa (2022) also found that high humidity levels tend to decrease the yield of solar stills due to the lower evaporation rate. Chinchilla-Guarin et al. (2016) observed that variations in humidity levels significantly impact the performance of solar stills, with higher humidity levels leading to reduced efficiency. Maciejczak et al. (2020) also analyzed the effects of environmental variables, including humidity, and confirmed that higher humidity levels negatively impact solar still performance.

## 2.4. Role of Absorbing Materials in Solar Stills

Panchal et al. (2017) analyzed the performance of solar stills utilizing various energy-absorbing materials such as marbles and stones. Their study found that these materials significantly enhanced the thermal performance of the stills by increasing the heat absorption and retention within the basin, leading to higher water evaporation rates and productivity.

Abdullah et al. examined the effects of different absorbing materials on the thermal performance of single basin single slope solar stills. They tested materials like black granite, charcoal, and metal shavings, finding that black granite provided the best performance due to its high thermal conductivity and heat retention properties, which enhanced the evaporation rate.

Younis et al. (2022) provided a comprehensive review of recent developments in solar still technology, focusing on various types and their enhancements. They highlighted the use of nanofluids and phase change materials (PCM) as effective means to boost the efficiency of solar stills. These advanced materials improve thermal performance by enhancing heat transfer and storage capabilities.

Kabeel et al. (2011) reviewed numerous studies on solar stills and evaluated the impact of different absorbing materials. They emphasized that materials with high specific heat capacity, such as sand and blackened surfaces, could significantly increase water yield by maintaining higher temperatures within the still.

Tony et al. (2024) explored recent advances in solar still technology, focusing on the incorporation of various absorbing porous materials. Their study found that materials like pumice stone and sponge significantly improved water production rates by enhancing surface area for evaporation and heat absorption.

Abdullah et al. (2023) conducted a comparative analysis aimed at enhancing the performance of tubular solar stills. They investigated the role of different absorbing materials, including black painted surfaces and metal meshes, finding that these materials could dramatically increase the efficiency of the solar stills by improving heat distribution and retention.

Murugavel et al. (2008) examined the performance of solar stills with different energy-absorbing materials, such as black rubber and black granite gravel. Their study concluded that these materials enhanced the heat absorption in the stills, leading to higher evaporation rates and increased freshwater output.

Tabrizi et al. (2010) investigated the use of energy-absorbing materials in passive solar stills. They tested materials like dark-colored gravel and heat-absorbing tiles, finding that these materials significantly improved the thermal efficiency of the stills by increasing the basin temperature and evaporation rate.

Dev et al. (2011) studied the impact of wick materials on the performance of solar stills. They found that using materials such as jute cloth and sponge as wicks improved the water transport and evaporation process, leading to higher efficiency and productivity of the solar stills.

Velmurugan et al. (2008) explored the effect of different energy-absorbing materials in enhancing solar still performance. They tested materials like blackened jute and charcoal, demonstrating that these materials significantly boosted the evaporation rates by increasing the absorption and retention of heat within the solar stills.

### 2.5. Case Studies Relevant to Afdera, Ethiopia

Chala Diriba, et al, (2017) presents a detailed study on using solar distillation for water purification in the Dubti region of Afar, Ethiopia. The research evaluates three types of basin-type solar stills: single slope, double slope, and a modified version. The study aims to address the challenge of purifying saline and fluoride-contaminated water. Results indicate that the solar stills effectively reduce salinity and fluoride levels, making the water safe for consumption. This research highlights the potential of solar still technology in providing a sustainable solution for clean water in arid regions.

This review has synthesized the fundamental principles, technological advancements, and performance-influencing factors pertinent to solar still desalination. It is established that solar stills offer a viable, low-cost, and environmentally sustainable solution for freshwater production, particularly crucial in arid and water-scarce regions like Afdera, Ethiopia. Significant progress has been made in enhancing efficiency through innovations such as the integration of phase change materials (PCMs), nanofluids, various energy-absorbing materials, wick structures, external condensers, and hybrid systems combining solar stills with collectors or other renewables. Research consistently underscores the critical impact of environmental parameters—specifically solar intensity, ambient temperature, wind speed, and humidity—on still productivity, along with design factors like basin water depth and the use of reflectors. While case studies, such as those in the Afar region, demonstrate the practical applicability and effectiveness of solar stills in reducing salinity and fluoride contamination in Ethiopian contexts, a distinct research gap remains. Specifically, there is a lack of comprehensive, localized studies focusing on the optimization of simple, low-cost, passive solar still designs specifically for the hyper-arid conditions and unique water contamination profile (high salinity combined with fluoride) prevalent in Afdera, Ethiopia, while considering the critical constraint of locally available materials and limited technical capacity. Most enhancement studies focus on complex or active systems, or single contaminants, potentially unsuitable for such remote settings. Therefore, this study aims to address this gap by investigating the performance optimization of readily constructible passive solar still designs in Afdera, evaluating the efficacy of locally sourced low-cost absorbing materials under its specific environmental conditions, and assessing their combined impact on the simultaneous removal of both salinity and fluoride to produce potable water.

# 3. CHAPTER THREE: METHODOLOGY

This chapter describes the practical steps taken to explore whether sunlight could be used to turn the salty water from Lake Afdera into safe drinking water for the nearby community. To test this idea, two different small-scale water purification devices, called solar stills, were designed and built. The designs were kept simple, aiming to use materials readily found locally to keep costs down and ensure the approach could be practical for the community. One device followed a common, basic design. The other was altered by adding naturally occurring volcanic rocks inside its main basin, based on the idea that these rocks might help the water heat up better. Both devices were carefully constructed in a university workshop, focusing on creating sturdy, water-tight units that could capture sunlight effectively.

Once built, both devices were taken to the edge of Lake Afdera itself. They were filled with lake water and set up under the sun. Over several days, the team carefully measured how much clean water each device produced throughout the daylight hours, while also noting how hot the water and the surrounding air became. To understand if the modified device with the rocks would work well in other sunny places, it was later moved to a different university location with a different climate. There, it was tested again in the same way, using more specialized tools to measure temperatures and sunlight strength very precisely. Finally, all the information gathered from both locations was carefully examined. The main goal was to compare how much water each design produced and how effectively they used the sun's energy to clean the water.

## 3.1. Study Area Description

Lake Afdera is located some 700 km north of Addis Ababa (12.6˚ N and 41˚ E) situated at 112 m sea level in the Danakil depression. The molten black rocks and graves around the area and the hot springs that drain the lake, the only source of water other than the scanty precipitation, witness the reality. It is a rainfall deficit area receiving an average annual rainfall of about 100mm (Wood and Lovet, 1979).

Lake Afdera is a hypersaline lake situated in a topographically unique and geologically active region. The lake fills a topographic depression created by tectonic activities within the Afar Rift, making it a part of a larger geological landscape characterized by volcanic and fault structures.

The maximum measured depth is 80 m, making Lake Afdera the deepest known lake in Afar and the lowest elevation of the Danakil Depression. Comparison with historical reports shows that the lake level did not fluctuate significantly during the last 50 years. (Schaegis J-C et al, 2021). The surface area of lake Afdera is 70 $km^2$; maximum depth is 80m; salinity is 160gram/liter; conductivity 250000 $k_{20}$ ($\mu cm^{-1}$); PH = 6.55 (Wood and Talling, 1988), the air, lake water and spring water temperature in November around noon were 40˚, 33˚ c and 50˚ c respectively. The very high salinity is accounted by the high evaporation concentration and the lakes geological history of having marine input from red sea (Giofiantini, et al, 1973)

### 3.1.1. Afdera Community

The socio-economic condition of the Afdera community is characterized by several challenges and vulnerabilities. The community in Afdera struggles with access to clean and sustainable water sources. The area is extremely arid, and the available water, primarily from wells and Lake Afdera, is often saline. This lack of fresh water leads to significant health issues, including kidney disease and hypertension, due to the high salinity of the water consumed (USAID, 2019).

Educational opportunities in Afdera are also limited, reflecting broader regional challenges. The region faces infrastructural deficits that hinder the establishment and maintenance of educational facilities. Consequently, school attendance rates are low, and literacy levels are significantly below the national average (UNICEF, 2022).

Health facilities are sparse and often under-resourced. The high prevalence of waterborne diseases exacerbates health conditions, particularly among children. The community is also affected by the recurrent droughts and harsh climatic conditions that impact overall health and wellbeing (IOM, 2022). The economy of Afdera largely depends on salt mining from Lake Afdera and pastoralism. However, these activities are highly vulnerable to climatic extremes, such as droughts, which are becoming more frequent due to climate change. This economic instability contributes to the persistent poverty in the region (UNICEF, 2022).

### 3.1.2. Climate and Environmental Conditions of Afdera

Afdera, located in the Afar Depression; experiences extreme climatic conditions typical of an arid desert environment. The region is characterized by scorching temperatures, particularly during the hottest months from May to September, where daytime temperatures often exceed 40°C. Nighttime temperatures also remain high, usually above 25°C, creating a consistently hot environment. Rainfall in Afdera is minimal, with annual averages of less than 200 mm. The primary rainy season occurs from March to April, with a secondary, less intense season from September to October (Meteoblue, 2024)].

Humidity levels are generally low due to the arid conditions, though localized increases can occur near Lake Afdera. The region also experiences strong winds, particularly in the afternoons, contributing to high evaporation rates and further influencing the arid climate. Geographically, Afdera is part of the Afar Depression, a significant geological feature formed by the junction of three tectonic plates. This area is characterized by flat plains, active volcanic regions, and expansive salt flats. Vegetation is sparse, consisting mainly of drought-resistant shrubs and grasses adapted to the harsh conditions. Wildlife is limited but includes species specifically adapted to arid environments, such as certain birds and small mammals (Getahun, 2001)

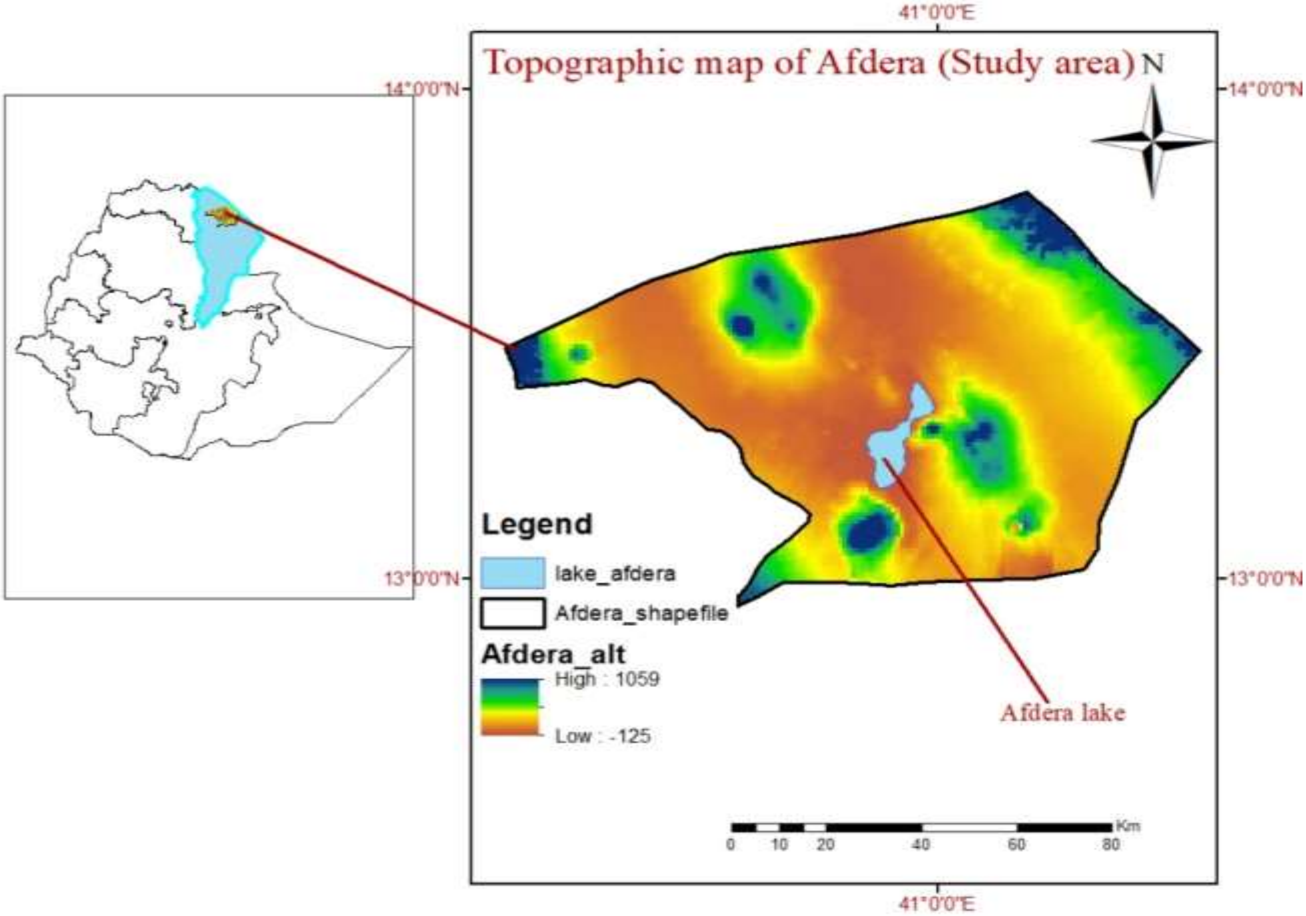


fig: 2 topographic map of Afdera

### 3.1.3. Characteristics of Lake Afdera Saline Water

Lake Afdera, also known as Lake Giulietti, is a highly saline lake located in the Danakil Depression. The lake's salinity levels are among the highest globally, making it an extreme environment primarily due to its position in an endorheic basin where water inflow does not drain out but evaporates, leaving behind high concentrations of salts. The water of Lake Afdera is rich in various salts, predominantly sodium chloride, but also contains significant amounts of magnesium, potassium, and calcium salts. This unique chemical composition makes the lake an important source of salt extraction for local industries (MedCrave, 2020)

The physical properties of the lake are also influenced by its high salinity. The water is denser and more buoyant than typical freshwater. It generally has a clear to slightly turbid appearance due to the suspended salts and minerals. Temperatures in the lake are typically warm, often surpassing

30°C, especially in shallow areas during peak sunlight hours. The extreme salinity limits the types of organisms that can survive in Lake Afdera. Only halophilic, or salt-loving, microorganisms such as specific bacteria and algae thrive in this environment. Higher aquatic life forms are virtually nonexistent due to the inhospitable conditions for most species (Elias Mamushet, 2023).

## 3.2. Design and Fabrication of the Prototype

The Afdera community in Ethiopia's Afar Region has been grappling with significant water shortages, leading to the prevalence of waterborne diseases. Addressing this issue is crucial for improving public health and enhancing the socioeconomic conditions of the local population. One viable solution is the desalination of Lake Afdera's saline water, which could provide a sustainable source of potable water. This study stands to assess the feasibility of harnessing solar energy in Afdera Woreda for desalination at the household level. The study focused on evaluating the solar energy potential in the woreda, which is known for its extreme climatic conditions. Specifically, it examined whether locally available materials could be utilized effectively in solar stills for desalination. Two types of solar stills were constructed for this purpose: a conventional solar still and a modified version incorporating volcanic rocks as absorbing materials. The performance of these solar stills was compared in terms of their production capacity and efficiency to determine the most effective design for providing clean drinking water to households in the Woreda.

Afdera is located in the northeastern part of the Afar Region, known for being the hottest inhabited place on Earth. The annual temperature in this region ranges from 21°C to 43°C, with an average annual temperature of 33°C. But, sometimes the area experiences up to 50°C. The area experiences relatively low wind speeds, ranging from 2.95 m/s to 4.5 m/s at a height of 10 meters.

Two solar stills were constructed in the mechanical engineering workshop at Samara University. The materials for the construction were sourced from local markets. Before manufacturing, critical design parameters such as material selection and appropriate manufacturing techniques were considered. The design aimed to produce a minimum of 2 liters of potable water per day, deemed sufficient for drinking needs. Based on calculations, a 1 square meter area was determined to be the optimal size for the solar stills. One of the solar stills was a conventional design, while the other was modified using volcanic rocks as absorbing materials to enhance efficiency. The data used for calculation was sourced from online sites and other research papers.

| PARAMETER | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Surface Pressure | 99.06 | 98.95 | 98.77 | 98.6 | 98.49 | 98.29 | 98.31 | 98.37 | 98.5 | 98.78 | 98.94 | 99.07 | 98.68 |
| Max. Temperature at 2 Meters © | 35.46 | 36.95 | 38.85 | 40.42 | 42.01 | 43.42 | 40.27 | 38.53 | 39.37 | 38.93 | 37.45 | 35.76 | 38.95 |
| Min. Temperature at 2 Meters (C) | 21.94 | 22.7 | 24.66 | 26.84 | 28.82 | 30.25 | 30.01 | 28.98 | 28.77 | 26.21 | 23.5 | 22.06 | 26.23 |
| Temperature at 2 Meters (C) | 28.2 | 29.33 | 31.29 | 33.32 | 35.2 | 36.47 | 34.85 | 33.47 | 33.74 | 32.3 | 30.13 | 28.48 | 32.23 |
| Earth Skin Temperature (C) | 31.25 | 32.84 | 34.95 | 36.75 | 38.91 | 39.79 | 37.11 | 35.23 | 36.31 | 35.35 | 32.76 | 31.06 | 35.19 |
| Wind Speed at 10 Meters (m/s) | 4.54 | 4.5 | 4.43 | 4.16 | 2.95 | 3.18 | 2.74 | 2.27 | 2.04 | 3.09 | 4.19 | 4.42 | 3.54 |
| Direct Normal Radiation (kW-hr/m^2/day) | 5.56 | 5.47 | 5.57 | 6.12 | 6.4 | 5.63 | 4.69 | 4.45 | 5.47 | 6.43 | 7.27 | 6.62 | 5.8 |
| Max. Direct Normal Radiation (kW-hr/m^2/day) | 7.94 | 8.43 | 7.27 | 8.09 | 8.27 | 6.54 | 5.46 | 5.21 | 6.09 | 7.81 | 8.31 | 8.45 | 7.32 |
| Min. Direct Normal Radiation (kW-hr/m^2/day) | 3.77 | 2.92 | 4.1 | 4.79 | 4.48 | 4.2 | 3.85 | 3.51 | 4.5 | 5.49 | 5.63 | 4.35 | 4.3 |

Table 1: NASA, 2015

### 3.3. Design calculations

In order to make a rough calculation for the expected efficiency and distillate output of the prototype units, some climatological data for the chosen area is necessary. Even though in Ethiopia the properly recorded solar radiation data is available only for Addis Ababa (NASA, 2010), the data used here is based on data recorded for more than 10 years by the NASA Surface meteorology and Solar Energy: ReT screen Data (Ansari and Mokhtar, 2005). Hence, the climatological data of Lake Afdera which accessed from NASA power data viewer is listed at the Table 1

#### A. Basin design

To estimate the output of a solar still, the following Equation (1) can be used (Twidell and Weir, 2006; Badran and Abu-Khader, 2007):

$$Q= \frac{E*G*A}{L}\text{……………….Equation (1)}$$

Where;

E = efficiency,

L = Latent heat,

A = area of still,

G= daily/annual global horizontal solar radiation (MJ/m2), and

Q is daily output of water from single slope solar still.

### B. Assumptions

Q =2 liter/day/capita (to meet for individuals daily need)

E =0.40 (40% is a common still efficiency) (Tiwari, Singh, H. N Tripathi, 2003)

### C. From the Table

G= 4.45 kw-hr/$m^2$ (minimum solar radiation of the location)

The total amount of energy required to change the water into vapour is termed as the latent heat of Vaporization (L).

Since the latent heat is vary with the amount of salt in the water, and the salinity of lake-Afdera is 160g/kg of water; the latent heat is then 2021 kJ/kg at 50 degree C from the table. ( Mostafa H., John Hm, and Syed M, 2010)

**Hence**;

To get the area of basin,

Useful solar radiation per day is (G) = 4.45*0.4 =1.78 kwh/$m^2$/day

1.78 kwh/$m^2$/day *3600s= 6408KJ/$m^2$/day

Then, calculated yield is = $\frac{6408KJ/m2/day}{2021KJ/KG}$ = 3.17kg/$m^2$/day

So, area of basin can be calculated by A= $\frac{2}{3.17}$ = **0.63 $m^2$**…. Here we can approximate the results into **1$m^2$**

### 3.3.1. Design details for both stills

Designing a solar still involves considering various factors to optimize its efficiency and performance in converting solar energy into purified water. In our case, we mainly consider the cost-effectiveness of materials and construction to achieve our goal; to make a balance between performance and affordability.

By carefully addressing these design considerations, we can create a solar still that efficiently utilizes solar energy to produce clean water. The specific requirements may vary based on the intended application and environmental conditions of the location. Below are estimated requirements for our applications and Afdera environmental conditions. Hence; two identical single slope solar stills were designed and manufactured using the following materials and design considerations.

**Specifications**

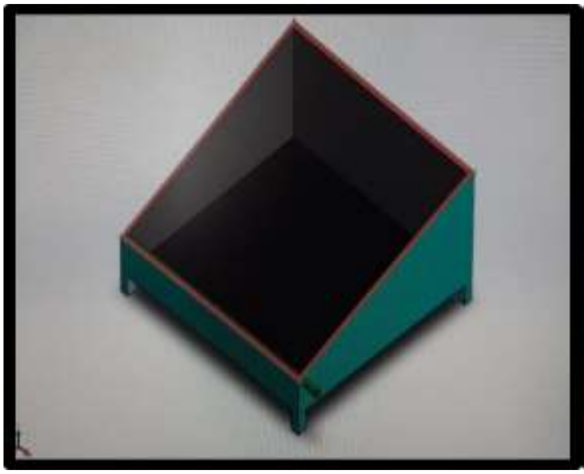
| **Items** | **Types** | | **Description** |
|---|---|---|---|
| | **Values**<br>**S1** | **Values**<br>**S2** | |
| | Single basin single slope | Single slope three sub basin | |
| Length and width | 100*102cm | 141.5*102cm | Based on calculation |
| Glazing material | Glass with 4mm thickness | Glass with 4mm thickness | Glass has a higher solar transmittance and a longer lifetime compared to plastic |
| Slope of the glazing | 15° | 15° | To place with an inclination equal to the latitude angle, to receive the sun rays close to normal throughout the year |

| | | | |
|---|---|---|---|
| Depth of basin | 15 | 15 | Based on calculations |
| Absorbing material | Conventional | Volcanic rock | To increase storage |
| Basin material | Aluminum | Aluminum With rocks separation | For being light in weight and easily available material with a high thermal conductivity of 205 W/mK at 25°C |
| Coating | Black | Black | |
| Sealing | Plaster joint tape and silicon | Plaster joint tape and silicon | |
| Pipes | Plastic pipe channel | Plastic pipe channel | |

Table 2: design consideration and specifications

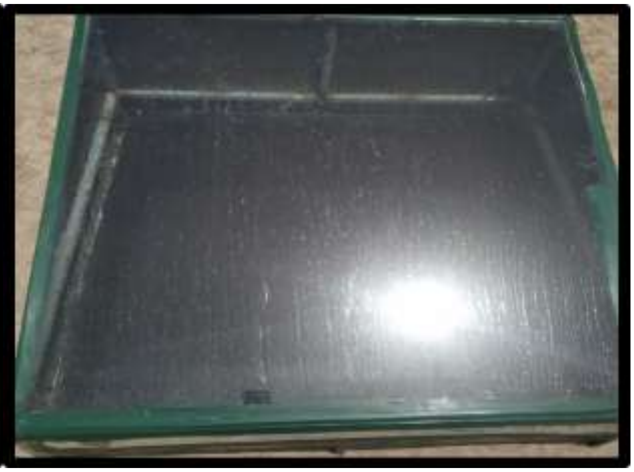
#### *3.3.1.1. Conventional solar still (SS1)*

SS1 is conventional mainly used as reference still which works based on basic principles of solar still. In our case, SS1 contains no phase changing or absorbing materials. The conventional still (SS1) made up of different materials. The basin of the still is made of the aluminum sheets and the structure of the still is made up of galvanized iron. It has an inclined top cover of 15° made of glass (4 mm thickness), and the cover sealed with plaster joint tape silicon to make airtight. The whole body of the still coated with black painting.



A

Fig3A: SS1 solid work



B

Fig3B: Conventional solar still manufactured

#### 3.3.1.2. Modified solar still (SS2)

SS2 is a modified solar still that incorporates volcanic rocks as absorbing materials in the basin. The design includes a specific arrangement of volcanic rocks below the basin, with two separations in the middle (5cm*100cm). The basin is constructed using aluminum sheet metal, and it is designed to be swiped out for easy removal of residuals and salts after the distillation process.

Volcanic rocks used to absorb and retain heat effectively. This property makes them preferable for enhancing the efficiency of solar stills by aiding in the evaporation and condensation processes. Creating a separate area of volcanic rocks in the middle of a basin designed in assumption to help several functions.

- ✓ Heat Retention: The rocks can release the stored heat gradually during the night, helping to maintain a relatively stable temperature in the basin area.
- ✓ Direct Sunlight Exposure: Placing the rocks in the middle of the basin ensures direct exposure to sunlight, maximizing their heating potential.
- ✓ Easy Accessibility to Heat: The close proximity of the rocks to the basin water allows for easy transfer of heat, promoting efficient heating of the water.

- ✓ The design takes into account the arrangement and size of the volcanic rocks to optimize heat absorption and distribution. Additionally, the depth and size of the basin, as well as the type of volcanic rocks used, will influence the system's effectiveness.

The aluminum sheet metal construction of the basin offers durability and the added benefit of easy maintenance. Being able to slide in and out the basin makes it convenient to remove any residuals or salts that may accumulate during the distillation process, ensuring the continued effectiveness of the solar still.

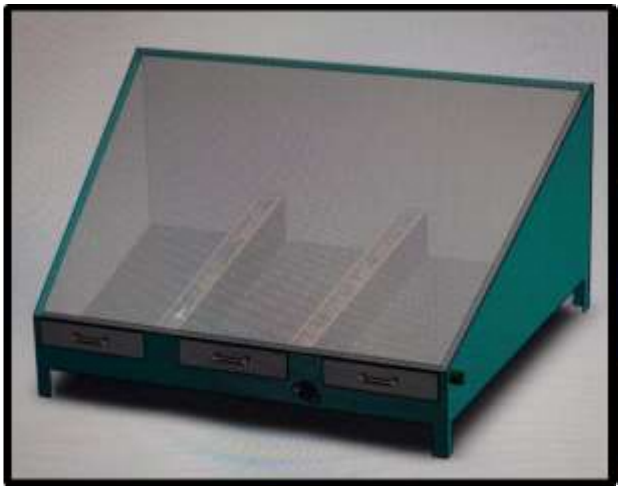
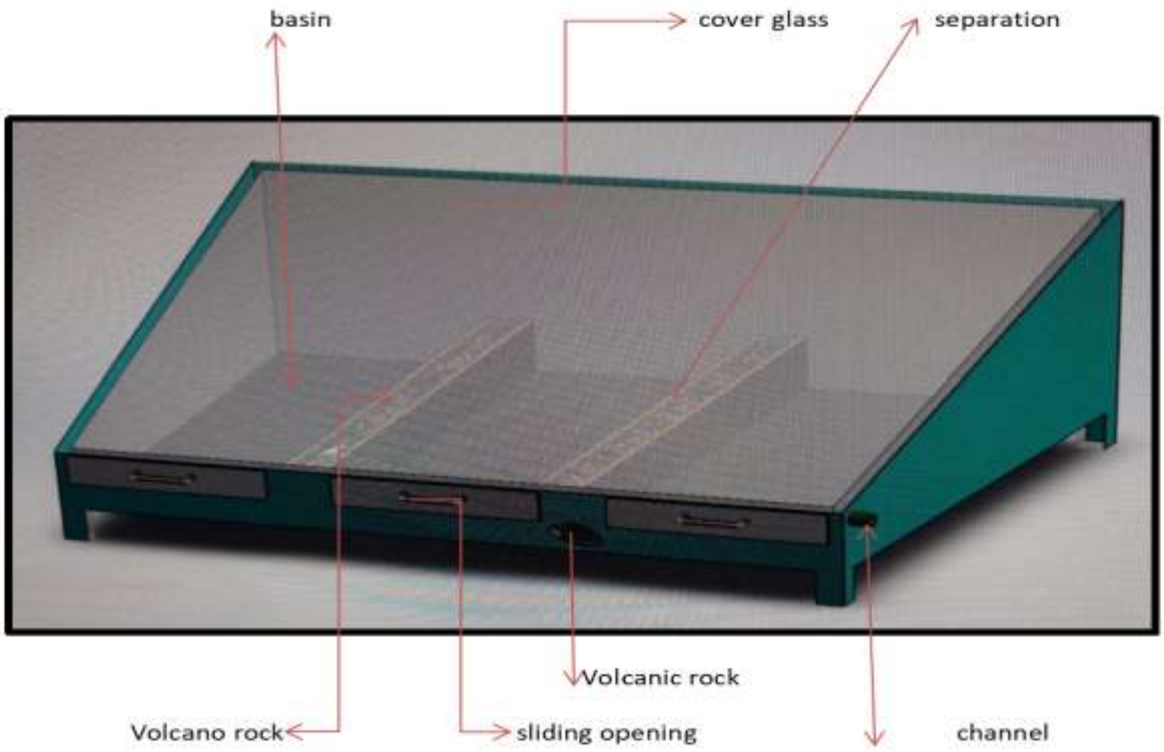


Fig 4A: SS2 solid work

fig 4B: modified solar under manufacturing

Fig3: modified solar still (solid work) part names



### 3.3.2. Construction Process

The construction of both solar stills was done manually in the workshop. The materials were sourced from local markets, ensuring cost-effectiveness and accessibility. After the manufacturing process, the stills were rigorously tested for any misalignments and leakages to ensure their structural integrity and functionality. Once confirmed to be in good working condition, the solar stills were transported to Afdera for experimental purposes. In Afdera, the stills were subjected to practical testing to evaluate their efficiency and effectiveness in real-world conditions. The performance of these stills was monitored and compared, particularly focusing on the conventional solar still and the modified version, which incorporated volcanic rocks as absorbing materials. This comparison aimed to determine the optimal design for maximum desalination efficiency, considering the unique climatic conditions of Afdera.

### 3.3.3. *Measuring instruments used during field experiment*

The Following measuring instruments used during experimental work in Afdera

| No | Instruments | Quantity | Range | accuracy | % error |
|---|---|---|---|---|---|
| 1 | Measuring jar | 2 | 0-500ml | ±1ml | 0.5 |
| 2 | Digital thermometer | 2 | -50℃ - 300℃ | ±1℃ | 0.5 |
| 3 | Measuring cylinder | 1 | 0-500ml | ±0.5 | 1 |

Table: 3 measuring instruments

**Digital Thermometer**: Used to measure the temperature of the environment, which is crucial for understanding the efficiency of the solar stills. Accurate temperature measurements help in correlating the ambient conditions with the distillate output and overall performance of the solar stills.

**Measuring Jars**: Employed to measure the hourly distillate output from the solar stills. This measurement is essential for determining the efficiency and productivity of the solar stills over a given period. Regular monitoring ensures that any variations in output can be accurately recorded and analyzed.

**Measuring Cylinder**: Used to measure the volume of distilled water produced with precision. This tool is important for conducting detailed and accurate performance evaluations of the solar stills, ensuring that all measurements are reliable and reproducible.

### 3.3.4. *Measuring instruments used during validation experiment*

After conducting experimental investigations on two solar stills in Afdera, the modified solar still was transported to Mekelle University to validate the results and assess its efficiency under different climatic conditions. The validation took place at Mekelle University's arid campus, specifically at the Institute of Energy building. The validation test utilized using a thermocouple with PicoLog software, a pyranometer, and a measuring jar to ensure accurate data collection and analysis.

Fig 6: Experimental setup

### 3.3.5. Experimental Procedure

After manufacturing the solar stills at Samara University, the devices were transported to Afdera, located 240 kilometers away. The solar stills were installed at the edge of Lake Afdera. On June 5, 2024, the devices were set up and filled with water early in the morning. Measurements of temperature, yield, and other important parameters began immediately. The same method was repeated on June 6 to ensure consistent data collection and validate the results.

Then the modified solar still device was transported to Mekelle, approximately 476 kilometers away. The solar stills were installed on the rooftop of the Institute of Energy building. On December 11, 2024, the device was set up and filled with water. Measurements included temperature readings using a thermocouple (TC-08) connected to PicoLog 6.2 software, yield measurements using a measuring jar, and solar radiation measurements using a pyranometer. The tests were conducted on December 12 and 13 to ensure consistent data collection and validate the results.

#### 3.3.5.1. Efficiency Calculation

The efficiency of a solar still can be calculated using several methods depending on the type of efficiency being measured. The two main types are thermal efficiency and overall efficiency. Here is a detailed explanation of how to calculate these efficiencies: Thermal Efficiency**:** The thermal efficiency of a solar still is defined as the ratio of the thermal energy used for water distillation to the total solar energy incident on the still. It is calculated using the following formula:

$\eta t = m \times hfg / A \times Ht$

Where:

$\eta t$ = Thermal efficiency

m = Mass of distilled water (kg)

hfg = Latent heat of vaporization (kJ/kg)

A = Area of the solar still ($m^2$)

Ht = Total solar insolation over a period of time ($kJ/m^2$) .

Overall Efficiency: The overall efficiency of a solar still considers the total energy input and the useful energy output. It is calculated as follows

$\eta = \frac{m*L}{A*I*t}$ ---------------------------------------------------------------- equation

where;

$\eta$ = Efficiency of the solar still

$m$ = Mass of distilled water (kg)

$L$ = Latent heat of vaporization (J/kg)

$A$ = Surface area of the solar still ($m^2$)

$I$ = Average solar irradiance ($W/m^2$)

$t$ = Time period (seconds)

#### 3.3.5.2. Comparison of Solar Still Yields

The yields of both the conventional solar still and the modified solar still were measured and compared during the initial experimental setup in Afdera. Following this, the modified solar still was transported to Mekelle to further assess its performance under different climatic conditions. The results obtained in Mekelle were compared with the yields recorded in Afdera to evaluate the impact of varying environmental factors. Additionally, the efficiency of the modified solar still was analyzed and compared in both locations to determine its adaptability and performance consistency across different climates.

### 3.3.6. Data Analysis Methods

To analyze the data from the experimental evaluation of both solar stills, the following data analysis techniques were used:

Descriptive Statistics: This technique was employed to summarize the data collected from the experimental evaluation. Key statistical measures such as mean, median, standard deviation, and range were calculated for various parameters including water yield and temperature. This provided a comprehensive overview of the central tendency and variability in the data.

Comparative Analysis: This method was utilized to compare the performance of the solar still designs or configurations. By examining the daily and hourly water yield, temperature variations, and efficiency of each design, insights were gained into which design was most effective under the given environmental conditions. This involved plotting and comparing the performance metrics over time to identify patterns and differences between the designs. Then compare both stills in Afdera and Mekelle.

Efficiency Calculations: Detailed calculations were performed to determine the efficiency of each solar still design. This included evaluating the amount of solar energy converted into usable water and comparing it across different configurations. The efficiency was assessed by considering factors such as the rate of evaporation and condensation, as well as the overall water output relative to the solar energy input. By these, data analysis techniques, the research was able to thoroughly evaluate the effectiveness and efficiency of the solar still types and designs.

# 4. CHAPTER FOUR: RESULTS AND DISCUSSION

The use of solar stills for water desalination is a critical technology in arid regions like Afdera, located in the Afar Depression in northern Ethiopia. This area is characterized by extreme climatic conditions, including high temperatures and minimal rainfall, which create a significant demand for efficient water desalination methods. In this context, two solar still devices, referred to as SS1 and SS2, were deployed to evaluate their performance in terms of daily water yield and efficiency.

Afdera's harsh environment provides a challenging but ideal testing ground for solar stills. The extreme heat and high evaporation rates necessitate robust and effective desalination technologies. The experiment aimed to compare the daily yield and efficiency of both solar stills to determine which design is more suitable for these conditions.

### 4.1. Daily Yield Data

Daily data were meticulously collected, focusing on key performance metrics such as the amount of desalinated water produced and the overall efficiency of each solar still. Yield was measured as the volume of water produced per day, while efficiency was calculated based on the amount of solar energy converted into desalinated water.

The findings from this experiment are crucial for understanding the practical applications of solar stills in similar arid environments. By analyzing and comparing the performance of SS1 and SS2, the study aims to provide insights into optimizing solar desalination technology to better meet the water needs of Afdera community.

The experiment conducted in Afdera, compared the performance of two solar still devices:

- SS1: Conventional passive single slope single basin solar still.
- SS2: Modified single slope single basin solar still with black rocks as absorbing materials

| | DAY-1 | | DAY-2 | | Remark |
|---|---|---|---|---|---|
| Time (hour) | SS1 (Yield in ml) | SS2 (Yield in ml) | SS1 (Yield in ml) | SS2 (Yield in ml) | |

| | | | | | |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 20 | 20 | |
| 2 | 20 | 30 | 40 | 40 | |
| 3 | 50 | 60 | 50 | 80 | |
| 4 | 210 | 300 | 140 | 220 | |
| 5 | 140 | 200 | 160 | 280 | |
| 6 | 220 | 450 | 200 | 480 | |
| 7 | 240 | 332 | 210 | 380 | |
| 8 | 200 | 320 | 200 | 370 | |
| 9 | 180 | 300 | 180 | 320 | |
| 10 | 140 | 220 | 120 | 260 | |
| 11 | 100 | 200 | 80 | 230 | |
| 12 | 80 | 180 | 80 | 200 | |
| Night | 340 | 890 | 300 | 920 | |
| Total | 1920 | 3482 | 1780 | 3800 | |

Table 4: daily yield data for both solar stills

Yield comparison

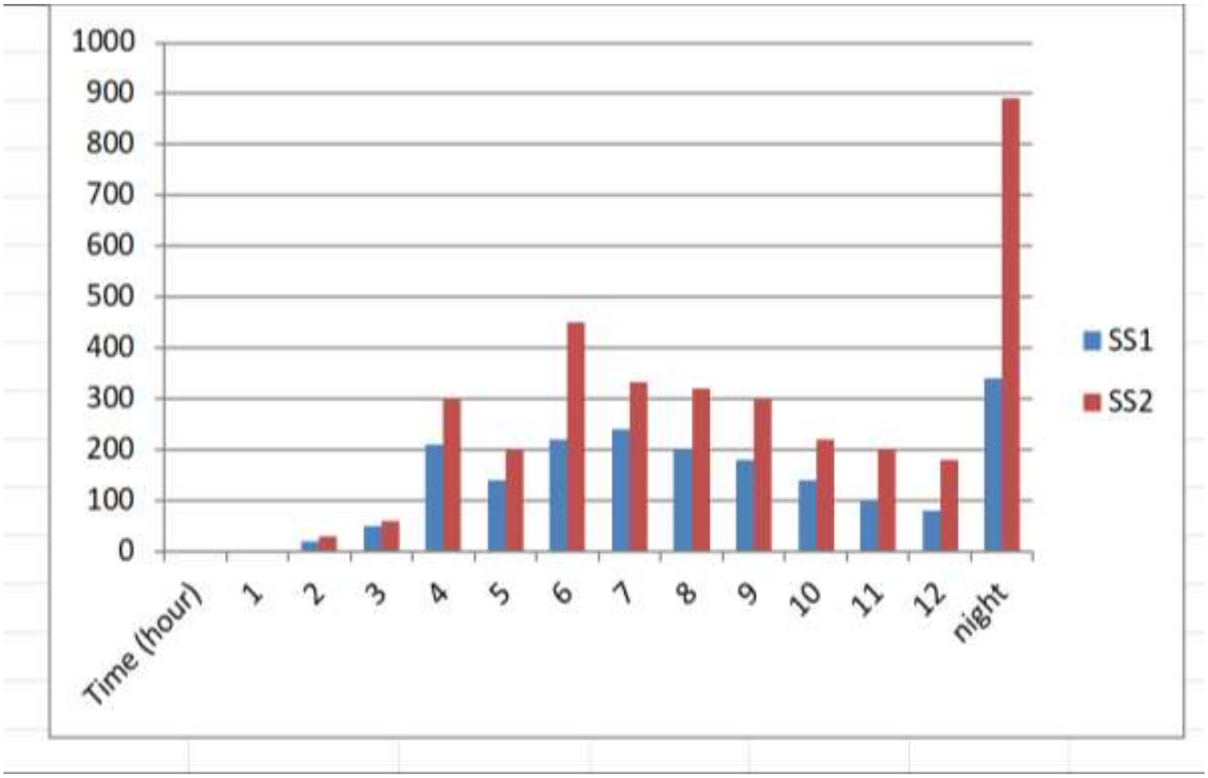


Chart 1: yield comparison; Day-1

Key observations indicate that SS2 consistently outperformed SS1 in terms of yield at nearly every measured time point. Both stills reached their peak performance at the 6th hour, with SS1 producing 220 ml and SS2 producing 450 ml. The cumulative yield at night was significantly higher for SS2 (890 ml) compared to SS1 (340 ml). A detailed analysis reveals that during the initial hours (1–3 hours), SS2 showed a slightly higher yield than SS1, suggesting a quicker start in absorbing and converting solar energy due to the presence of black rocks, which appear to enhance the initial heating phase. During midday performance (4–8 hours), SS2's yield substantially exceeded that of SS1, with the largest discrepancy observed at the 6th hour.

The design of SS2, incorporating black rocks as absorbing material, contributed to better heat retention and higher evaporation rates by absorbing more heat and releasing it gradually. During the later hours (9–12 hours), as solar intensity decreased, SS2 continued to maintain higher yields compared to SS1. This sustained efficiency can be attributed to the thermal mass provided by the black rocks, which kept the water temperature elevated for longer periods. The significant difference in nighttime yield (890 ml for SS2 vs. 340 ml for SS1) highlights the advantage of the black rocks in retaining and slowly releasing heat even after sunset. This indicates that the black rocks significantly improve latent heat storage, leading to prolonged condensation and yield. The use of black rocks as an absorbing material in SS2 resulted in faster initial heat absorption, enhanced peak performance during midday, sustained higher temperatures and evaporation rates into the later hours and night, and an overall increased daily yield compared to the conventional design. These findings align with studies suggesting that the inclusion of absorbing materials, such as black rocks, can significantly enhance the efficiency and yield of solar stills by improving heat retention and distribution.

On June 6 Considering June 5 Data to interpret the results of Day-2, let's first summarize and compare the yields for each solar still (SS1 and SS2) over the two days.

Day-1, Data Summary:

- SS1 Total Yield: 1920 ml
- SS2 Total Yield: 3482 ml

Day-2 Data Summary:

- SS1 Total Yield: 1780ml
- SS2 Total Yield: 3800ml

## 4.2. Comparison and Interpretation:

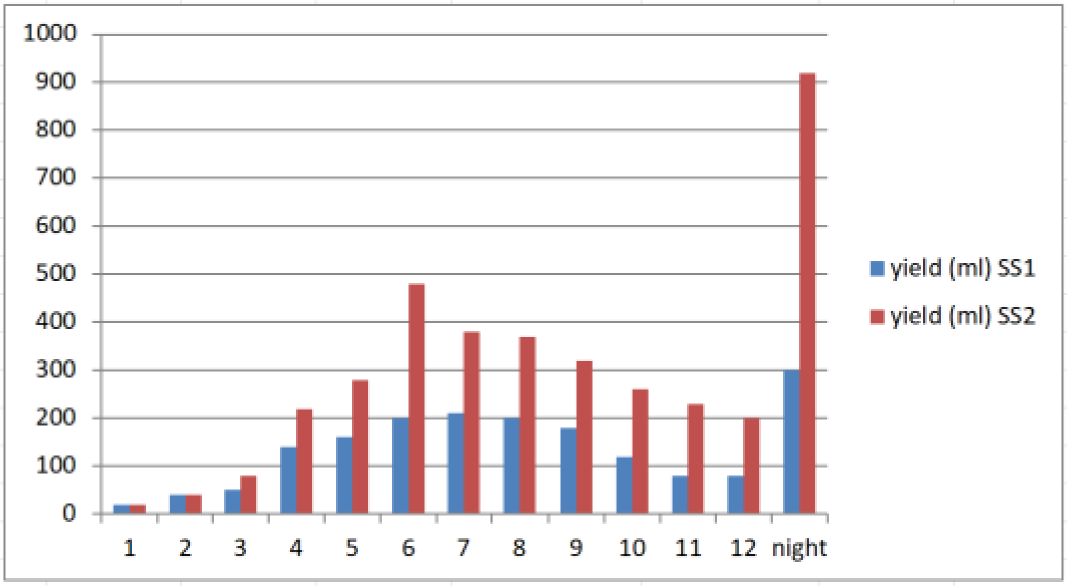


Chart 2: yield comparison Day-2

On Day-2, SS1 produced slightly less water (1780 ml) compared to Day-1 (1920 ml), with a difference of 140 ml attributed to the loosening of the sealing caused by high temperatures, allowing air to enter the system. In contrast, SS2 produced more water on June 6 (3800 ml) compared to Day-1 (3482 ml), showing an increase of 318 ml, which indicates improved performance due to insulation with silicon that ensured airtightness and better system optimization. In terms of efficiency comparison, SS2 continued to outperform SS1 significantly, producing more than double the amount of water. This consistent performance across both days highlights SS2's superior design and material efficiency. SS2 demonstrated a consistently higher yield compared to SS1, both during daylight hours and at night, indicating a more efficient solar still system. The results from Day-2 align with those from Day-1, reinforcing the reliability of SS2's enhanced performance.

### *4.1.1. ENVIRONMENTAL ELEMENTS*

Inside Temperature Results for SS1 and SS2

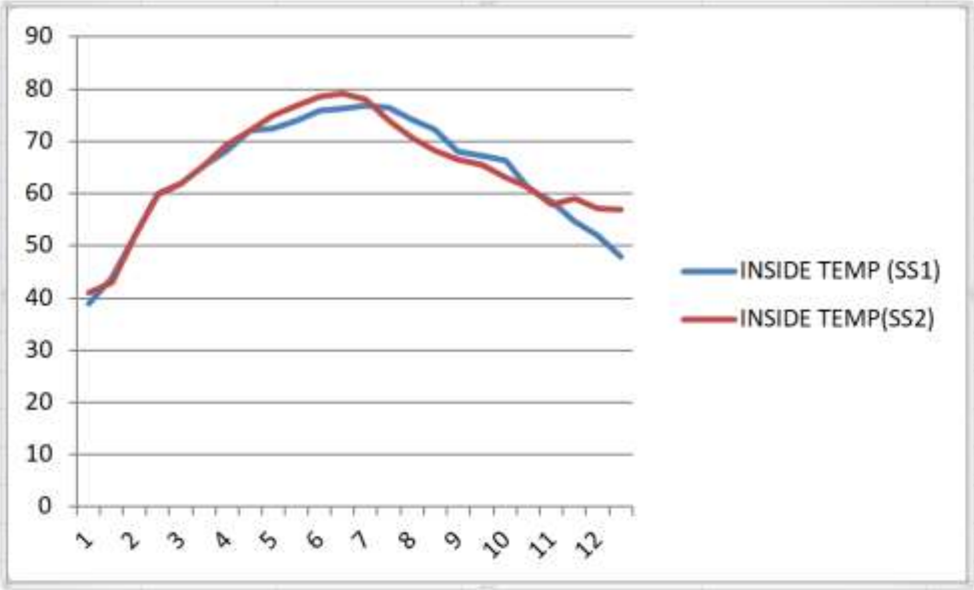


Chart 3: comparison of temperature differences

### 4.1.2. Efficiency and Yield Interpretation

Throughout the experiment, SS2 consistently maintained higher temperatures compared to SS1, particularly during the peak hours (1:30 to 7:00), where higher internal temperatures enhanced the evaporation rate, which is crucial for solar still efficiency. SS2 reached its peak temperature of 78°C at 7:00, while SS1 peaked at 76.7°C, demonstrating SS2's ability to achieve higher evaporation rates and, consequently, greater efficiency. The higher temperatures in SS2, especially during hours 3 to 7, resulted in increased evaporation rates, leading to higher water yield, as evaporation and subsequent condensation are directly related to internal temperatures. The outside temperature, peaking at 47°C, significantly influenced the internal temperatures of both SS1 and SS2, contributing to enhanced efficiency during the day. However, the drop in internal temperatures towards the later hours indicated thermal energy loss as outside temperatures fell, impacting evaporation. Despite this, SS2's higher internal temperatures and superior thermal performance demonstrated its greater efficiency and yield compared to SS1. SS2's ability to maintain elevated temperatures for longer periods was key to its improved performance, enabling it to utilize available solar energy more effectively for evaporation. The environmental variables recorded during the experiment, including wind speed, humidity, and temperature, had a significant impact on the daily yield of both SS1 and SS2.

|  | Day-1 |  |  | Day-2 |  |  | Remark |
|---|---|---|---|---|---|---|---|
| **Time (hour)** | Wind (km/hr) | Humidity | Temperature | Wind km/hr | Humidity | Temperature |  |
| **1** | 4 | 29 | 36 | 6 | 22 | 38 |  |
| **2** | 5 | 29 | 37 | 6 | 22 | 39 |  |
| **3** | 5 | 25 | 39 | 5 | 20 | 39 |  |
| **4** | 6 | 21 | 42 | 5 | 18 | 40 |  |
| **5** | 6 | 17 | 43 | 4 | 15 | 42 |  |
| **6** | 6 | 14 | 45 | 4 | 13 | 44 |  |
| **7** | 8 | 13 | 47 | 6 | 11 | 48 |  |
| **8** | 10 | 12 | 47 | 8 | 8 | 48 |  |
| **9** | 10 | 10 | 47 | 10 | 6 | 47 |  |
| **10** | 11 | 8 | 47 | 12 | 8 | 46 |  |
| **11** | 11 | 7 | 46 | 12 | 9 | 46 |  |
| **12** | 12 | 7 | 45 | 14 | 10 | 45 |  |

Table 5: environmental elements data

### 4.1.3. Daily Data and Comparison of Both Solar Stills in Terms of Yield and Efficiency

Investigation of the daily yield and efficiency of two solar stills, SS1 and SS2, under the extreme climatic conditions of Afdera, Ethiopia. Conducted over two consecutive days, the experiment aims to analyze the influence of environmental variables such as wind speed, temperature, and humidity on the performance of the solar stills. The data collected provides a detailed comparison of the distillate output of each still, thereby offering insights into their operational efficiency under varying conditions.

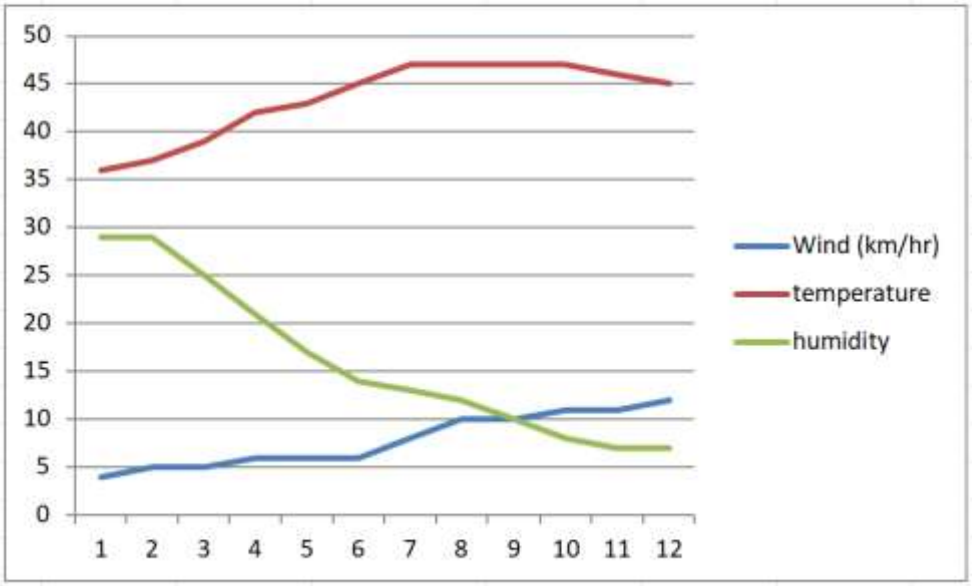


Chart 4: daily environmental elements correlation

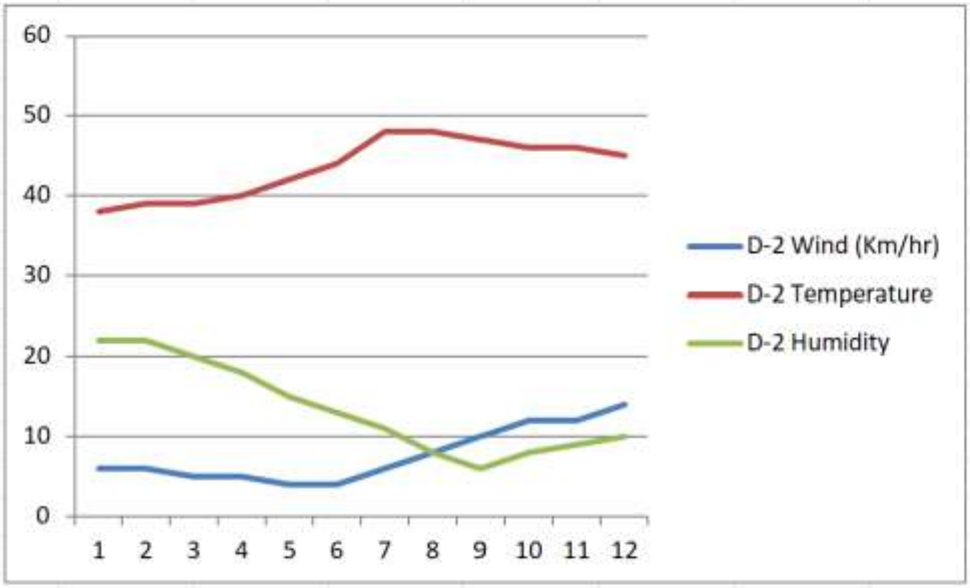


Chart 5: environmental elements correlation

## 4.2. Data Interpretation and Yield Comparison

Environmental Data for Day One and Day Two, Impact of Wind, Humidity, and Temperature on Yield

- Wind Speed:

Increased wind speeds generally enhance the condensation process by cooling the glass cover of the stills more effectively. This results in a higher temperature differential, boosting distillate yield.

SS2 consistently shows a higher yield compared to SS1, possibly due to better design or materials that take greater advantage of the wind cooling effect.

- Temperature:

Higher temperatures increase the evaporation rate within the stills. This effect is evident in the peak yields during the hottest parts of both days.

The significant yield difference between SS1 and SS2, especially during peak temperatures, suggests that SS2 might have a more efficient heat capture and retention mechanism.

- Humidity:

Lower humidity levels correlate with higher yields, as drier air promotes more efficient evaporation and condensation cycles.

The decreasing trend in humidity throughout both days aligns with increasing yields, particularly in SS2, indicating its superior efficiency in low-humidity conditions.

The data analysis reveals that SS2 outperforms SS1 in both yield and efficiency under the tested conditions. Environmental factors such as wind speed, temperature, and humidity significantly impact the performance of the solar stills. Understanding these influences can guide the design and optimization of solar stills for improved water distillation in arid regions like Afdera.

### *4.2.1.* Calculation of Efficiency of SS2 Compared to SS1

To calculate the efficiency of SS2 compared to SS1, we need to consider the total yield of each solar still over the testing period.

Total Yield Calculation

- . SS1 Total Yield:

- Sum of all yields (including night): 1920 ml

- SS2 Total Yield:

- Sum of all yields (including night): 3482 ml

Efficiency Calculation (only Day-1 considered for comparision)

The efficiency comparison can be expressed as the ratio of the total yields of SS2 to SS1:

Efficiency Ratio: $\frac{Total\ Yield\ of\ SS2}{Total\ Yield\ of\ SS1} = \frac{3482}{1920}$ = 1.814…………. (Day-1)

This means that SS2 is approximately 1.814 times more efficient than SS1.

Percentage Increase in Efficiency to express this as a percentage increase in efficiency:

Percentage increase: $(\frac{3482-1920}{1920})$*100% =( $\frac{1562}{1920}$) = 81.35%

Thus, SS2 shows an approximately 81.35% increase in efficiency over SS1

On the other hand,

## 4.4. Validation Experiment Test

The validation experiment conducted at Mekelle University on December 12 and 13 was designed in complementing and verifying the findings of the initial experiment performed in Afdera. This phase mainly aimed to evaluate the performance of the solar still under controlled and moderately stable environmental conditions, providing a contrast to the extreme arid conditions of Afdera. Unlike the manual measurement methods employed during the Afdera tests, the validation taken place using instruments such as thermocouples, PicoLogger software, and a pyranometer for precise and automated data acquisition. These tools allowed for more accurate monitoring of temperature, solar radiation, and yield measurements.

By replicating the study in a controlled setup, the validation process sought to enhance the reliability and reproducibility of the solar still's performance metrics. This step is critical in strengthening the robustness of the findings, ensuring that they are not only representative of the extreme conditions of Afdera but also applicable across varying environmental conditions. Ultimately, this validation establishes confidence in the solar still's potential as an efficient and sustainable water distillation solution, particularly for regions facing acute water scarcity challenges.

### 4.4.1. Experimental Setup and Materials

The validation experiment was conducted at Mekelle University's arid campus, under conditions that were moderately controlled compared to the harsh and variable environment of Afdera. The experimental setup was designed to integrate automated and precise measurement tools, ensuring the accurate collection and analysis of data. Thermocouple sensors were employed to monitor temperature variations at key points in the solar still, while the Pico TC-08 data logger recorded these readings with high accuracy and efficiency. A pyranometer was used to measure solar radiation, a critical variable for assessing the still's performance. The daily yield was collected and measured using calibrated measuring jars to ensure consistent and reliable results.

**Materials Used**:

1. **Thermocouple sensors** for precise temperature measurement.
2. **Pico TC-08 data logger** to automate and record temperature readings over time.
3. **Saline water**, representing the typical feedstock for water distillation in arid regions.
4. **Measuring jars** for accurate daily yield quantification.
5. **Pyranometer** to monitor and quantify solar radiation levels throughout the experiment.

This setup allowed for a comprehensive evaluation of the solar still's performance, providing a reliable basis for comparing its efficiency under different environmental conditions.

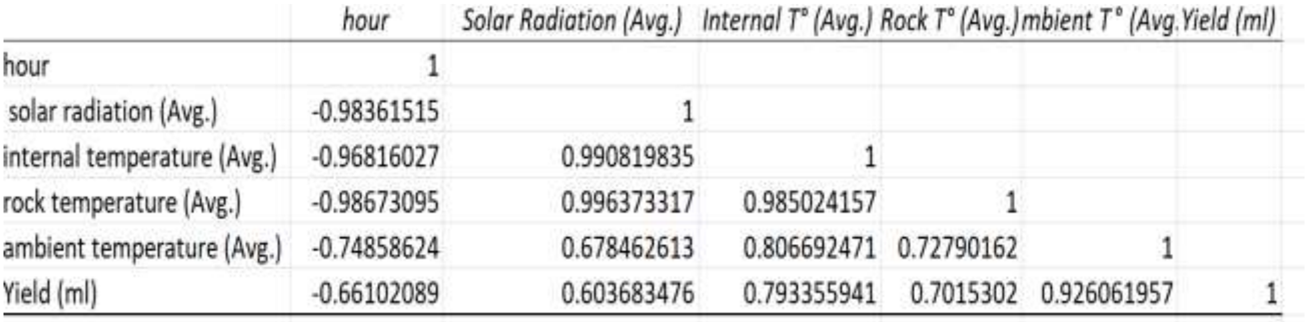
### 4.4.2. Interpretation of Two Days' Data

Data collected over two days were analyzed to track temperature variations, distillation rates, and overall thermal performance of the solar still.

| Hour | solar radiation (Avg.) | internal temperature (Avg.) | rock temperature (Avg.) | ambient temperature (Avg.) | Yield (ml) | remark |
|---|---|---|---|---|---|---|
| 6 | 883.5 | 55 | 58.7 | 25 | 220 | |
| 7 | 832 | 55.1 | 57.5 | 26 | 410 | |
| 8 | 692 | 51 | 49 | 27 | 440 | |
| 9 | 490.8 | 43 | 41.2 | 26 | 360 | |
| 10 | 263.3 | 29 | 32.6 | 25 | 265 | |
| 11 | 55.8 | 20.9 | 25.6 | 23 | 110 | |
| 12 | | 18.4 | 24 | 20 | 60 | |

Table 6: average data of environmental and operational variables

Then, this data analyzed for correlation in Microsoft excel.



| | hour | Solar Radiation (Avg.) | Internal T° (Avg.) | Rock T° (Avg.) | mbient T° (Avg. | Yield (ml) |
|---|---|---|---|---|---|---|
| hour | 1 | | | | | |
| solar radiation (Avg.) | -0.98361515 | 1 | | | | |
| internal temperature (Avg.) | -0.96816027 | 0.990819835 | 1 | | | |
| rock temperature (Avg.) | -0.98673095 | 0.996373317 | 0.985024157 | 1 | | |
| ambient temperature (Avg.) | -0.74858624 | 0.678462613 | 0.806692471 | 0.72790162 | 1 | |
| Yield (ml) | -0.66102089 | 0.603683476 | 0.793355941 | 0.7015302 | 0.926061957 | 1 |

Table 7 : correlation matrix

This correlation matrix provides insights into how various environmental and operational variables are interrelated, shedding light on their collective and individual impacts on yield.

The hour of the day exhibits strong negative correlations with solar radiation (-0.98), internal temperature (-0.97), rock temperature (-0.99), ambient temperature (-0.75), and yield (-0.66). These negative correlations highlight that as the day progresses, the availability of solar radiation decreases, leading to reductions in associated temperatures and yield. This trend aligns with the diurnal cycle, where solar energy peaks around midday and diminishes towards the evening. Thus, the hour serves as a proxy for the natural decline in thermal and solar resources.

Solar radiation shows a robust positive correlation with internal temperature (0.99) and rock temperature (0.99) and a moderate correlation with ambient temperature (0.68) and yield (0.60). This indicates that solar radiation is the primary driver of internal and rock temperatures, with its influence extending to moderate increases in yield. Solar energy acts as the primary source of heat, essential for thermal processes in the system. Internal temperature is strongly positively correlated with rock temperature (0.99), moderately correlated with ambient temperature (0.81), and significantly correlated with yield (0.79). This suggests that internal temperature, primarily influenced by solar radiation, directly impacts the efficiency of heat transfer mechanisms and the evaporation-condensation cycle that drives yield.

Rock temperature exhibits a strong positive correlation with internal temperature (0.99) and moderate correlations with ambient temperature (0.73) and yield (0.70). These correlations underscore the role of rock as a thermal energy storage medium, which stabilizes and sustains heat within the system, thereby influencing yield. Ambient temperature correlates strongly with yield (0.93), highlighting its critical role in determining overall efficiency. Higher ambient temperatures support the evaporation-condensation process by maintaining favorable thermal conditions, even when solar radiation diminishes.

Yield correlates most strongly with ambient temperature (0.93), followed by internal temperature (0.79) and rock temperature (0.70). Solar radiation has a smaller, yet significant, positive effect (0.60). This suggests that while solar radiation is vital for initiating thermal processes, the system's efficiency depends more on ambient conditions and internal thermal dynamics.

Overall, the matrix reveals that yield is predominantly influenced by ambient temperature, internal temperature, and rock temperature, with solar radiation acting as an indirect driver through its impact on these variables. The negative correlation with time emphasizes the temporal limitations of solar energy, which decline as the day progresses. These findings underscore the importance of optimizing thermal storage and leveraging ambient conditions to maximize efficiency, especially during periods of reduced solar radiation.

The data highlighted the consistency of the thermocouple-based measurement system, which provided more granular insights compared to manual methods.

Day-2

| Hour | solar radiation (Wm-2) | rock temperature (Avg) | internal temperature (Avg) | ambient temperature (Avg) | Yield (ml) |
|---|---|---|---|---|---|
| 4 | 731.3 | 31.7 | 24.96 | 18 | 140 |
| 5 | 821 | 41.8 | 28.4 | 20 | 260 |
| 6 | 922 | 59.8 | 36.08 | 22 | 360 |
| 7 | 944.4 | 65.9 | 35.15 | 24 | 420 |
| 8 | 879.9 | 63.96 | 35.86 | 26 | 480 |
| 9 | 731 | 59.04 | 35.14 | 26 | 400 |
| 10 | 540 | 49.11 | 35.33 | 25 | 280 |

Table 8: day-2

The data after correlation and its interpretation

Day-2

| Hour | solar radiation (Wm-2) | rock temperature (Avg) | internal temperature (Avg) | ambient temperature (Avg) | Yield (ml) |
|---|---|---|---|---|---|
| 4 | 731.3 | 31.7 | 24.96 | 18 | 140 |
| 5 | 821 | 41.8 | 28.4 | 20 | 260 |
| 6 | 922 | 59.8 | 36.08 | 22 | 360 |
| 7 | 944.4 | 65.9 | 35.15 | 24 | 420 |
| 8 | 879.9 | 63.96 | 35.86 | 26 | 480 |
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Table 8: day-2

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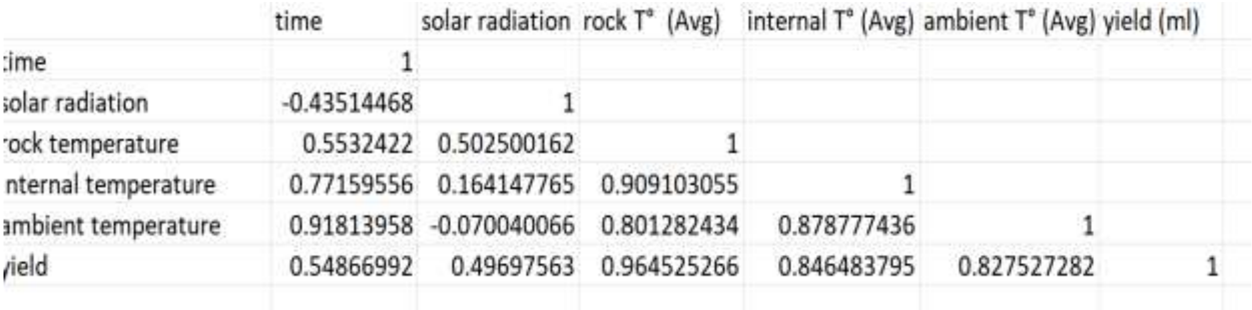


|  | time | solar radiation | rock T° (Avg) | internal T° (Avg) | ambient T° (Avg) | yield (ml) |
|---|---|---|---|---|---|---|
| ime | 1 |  |  |  |  |  |
| olar radiation | -0.43514468 | 1 |  |  |  |  |
| ock temperature | 0.5532422 | 0.502500162 | 1 |  |  |  |
| nternal temperature | 0.77159556 | 0.164147765 | 0.909103055 | 1 |  |  |
| mbient temperature | 0.91813958 | -0.070040066 | 0.801282434 | 0.878777436 | 1 |  |
| ield | 0.54866992 | 0.49697563 | 0.964525266 | 0.846483795 | 0.827527282 | 1 |

Table 9: correlation matrix for day-2

The correlation matrix provides insights into the strength and direction of linear relationships between various variables in the study. One key observation is the moderate positive correlation (0.4969) between solar radiation and yield. This indicates that an increase in solar radiation is associated with higher yields, though the relationship is not particularly strong. It suggests that while solar radiation contributes to yield, other factors may also play significant roles.

Rock temperature shows a very strong positive correlation (0.9645) with yield. This implies that rock temperature is a critical factor in determining yield, likely because the rock retains and radiates heat, enhancing the evaporation and condensation processes. Similarly, the internal temperature of the system strongly correlates with yield (0.8465), supporting the idea that higher internal temperatures drive evaporation, thus boosting water yield.

Ambient temperature also exhibits a strong positive correlation (0.8275) with yield. Warmer ambient conditions appear to improve the system's efficiency, reinforcing the importance of thermal conditions in the system's performance. Solar radiation moderately influences rock temperature (0.5025), indicating that while solar radiation heats the rock, other variables may also affect rock temperature.

Internal and ambient temperatures are strongly correlated (0.8788), which aligns with expectations since internal system temperature is influenced by the surrounding environment. Additionally, time shows moderate to strong correlations with variables such as ambient temperature (0.9181) and internal temperature (0.7716), reflecting the daily heating cycles.

Overall, the data suggests that thermal factors, particularly rock, internal, and ambient temperatures, play dominant roles in the system's yield. The moderate correlation with solar radiation highlights its importance but also indicates that its effects are amplified by heat-retaining mechanisms like rock materials.

#### 4.4.2.1. Calculation of solar still Efficiency

The efficiency (η) of a solar still is calculated as (Tiwari et el, 2007)

$$\boldsymbol{\eta} = \frac{\boldsymbol{m * L}}{\boldsymbol{A * G * t}}$$

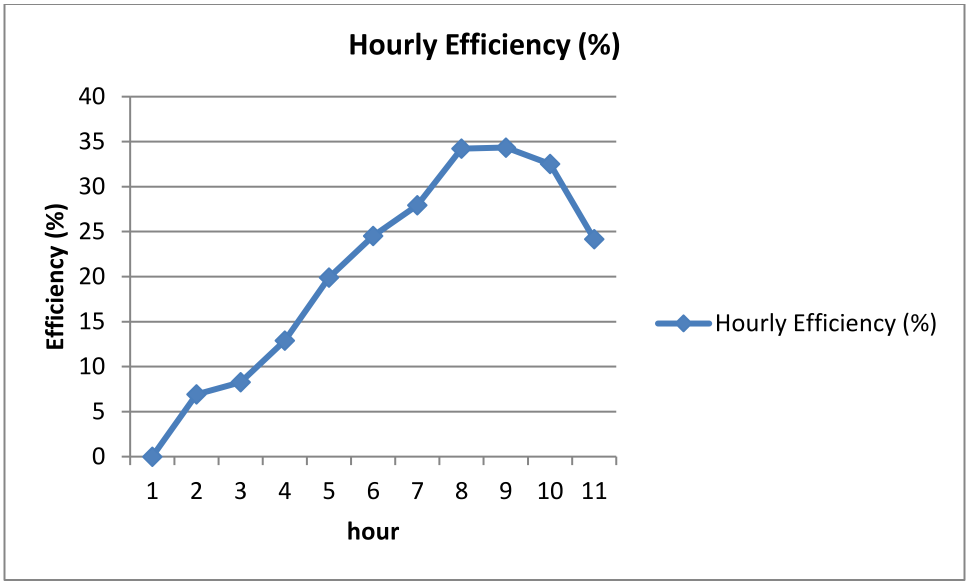
Where:

- $m$: Amount of water distilled (kg or liters, where 1 liter = 1 kg for water).
- $L$: Latent heat of vaporization of water (approx. $2.26 \times 10^6$ J/kg).
- $A$: Surface area of the solar still ($m^2$).

- ***G*****:** Average solar radiation incident on the surface (W/m²).
- ***t***: Time duration of the experiment (seconds).

By substituting the results in the formula, the hourly efficiency of the modified solar still is:

| Hour | Yield (ml) | Avg Solar Radiation hourly (W/m²) | Hourly Efficiency (%) |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 2 | 20 | 181.6 | 6.91 |
| 3 | 60 | 456 | 8.26 |
| 4 | 140 | 681.1 | 12.9 |
| 5 | 260 | 821 | 19.88 |
| 6 | 360 | 922 | 24.51 |
| 7 | 420 | 944.4 | 27.92 |
| 8 | 480 | 880 | 34.24 |
| 9 | 400 | 731 | 34.35 |
| 10 | 280 | 540.5 | 32.52 |
| 11 | 120 | 311.8 | 24.16 |



The efficiency of the solar still varied throughout the day, starting at zero in the early morning when there was no solar radiation, resulting in no water yield. Efficiency peaked during mid-morning to early afternoon (Hours 6 to 8) when solar radiation and water yield were highest, demonstrating a strong correlation between efficiency and solar energy input. Notably, in the late afternoon, despite low solar radiation, the system continued to produce water, indicating the thermal storage capacity of the black rocks used inside the still. This sustained yield underscores the effectiveness of the rocks in retaining heat and maintaining evaporation processes. The declining efficiency in the late afternoon highlights potential thermal saturation or heat transfer inefficiencies, suggesting the need for further design enhancements to optimize performance. These findings demonstrate the importance of advanced thermal storage materials and operational strategies to maximize solar still efficiency across varying radiation levels.

### 4.4.3. Efficiency and Results Comparison with Afdera Test

To evaluate the efficiency of the Mekelle University (MU) validation test compared to the Afdera experimental test, it's essential to analyze the total water yield produced at each location over the testing period. The total yield includes both daytime and nighttime collection, providing a comprehensive comparison. In the Afdera test, the total water yield was recorded as 3,800 ml, while the Mekelle validation test achieved a total yield of 2,860 ml.

**Efficiency Comparison on the next day**

Focusing on the third day of testing ensures consistency in environmental conditions and experimental parameters. The efficiency ratio, calculated as the total yield of Afdera (AFD) divided by the total yield of Mekelle (MKL), is given by;

Efficiency Ratio: $\frac{Total\ Yield\ of\ AFD}{Total\ Yield\ of\ MKL} = \frac{3800}{2860} = 1.33$

This indicates that the Afdera setup was approximately 1.33 times more efficient than the Mekelle test.

To further quantify the efficiency improvement, the percentage increase in yield is calculated using the formula:

Percentage Increase: ((Total Yield of AFD - Total Yield of MKL) / Total Yield of MKL) × 100%

Substituting the values:

Percentage: $(\frac{3800-2860}{2860})*100\% = 32.87\%$

This result demonstrates that the Afdera experimental setup exhibited a 32.87% higher efficiency than the Mekelle validation test.

#### 4.4.3.1. Factors Influencing Efficiency Differences

The observed efficiency disparity between the two setups can be attributed to several factors. Solar radiation plays a significant role, as higher solar irradiance increases the thermal energy available for water evaporation in solar stills, and Afdera, located in the Afar region, is known for its high solar radiation levels, which could enhance the performance of solar distillation systems. Elevated ambient temperatures can also improve the evaporation rate in solar stills, and Afdera's hotter climate compared to Mekelle may have contributed to the increased water yield. Additionally, environmental factors like wind speed and humidity levels affect solar still performance, with higher wind speeds enhancing evaporation rates and lower humidity levels increasing the condensation rate, both contributing to higher water yields. The Afdera experimental setup demonstrated a 32.87% higher efficiency compared to the Mekelle validation test, likely due to favorable environmental conditions such as higher solar radiation and ambient temperatures. Understanding these factors is crucial for optimizing solar distillation systems in different regions.

| | | |
|---|---|---|
| | Afdera | mekele |
| | (Yield in ml) | (yield in ml) |
| 1 | 20 | 0 |
| 2 | 40 | 20 |
| 3 | 80 | 60 |
| 4 | 220 | 140 |
| 5 | 280 | 260 |
| 6 | 480 | 360 |
| 7 | 380 | 420 |
| 8 | 370 | 480 |
| 9 | 320 | 400 |
| 10 | 260 | 280 |
| 11 | 230 | 120 |
| 12 | 200 | 80 |
| Night | 920 | 240 |
| | | |
| **Total** | **3800** | **2860** |

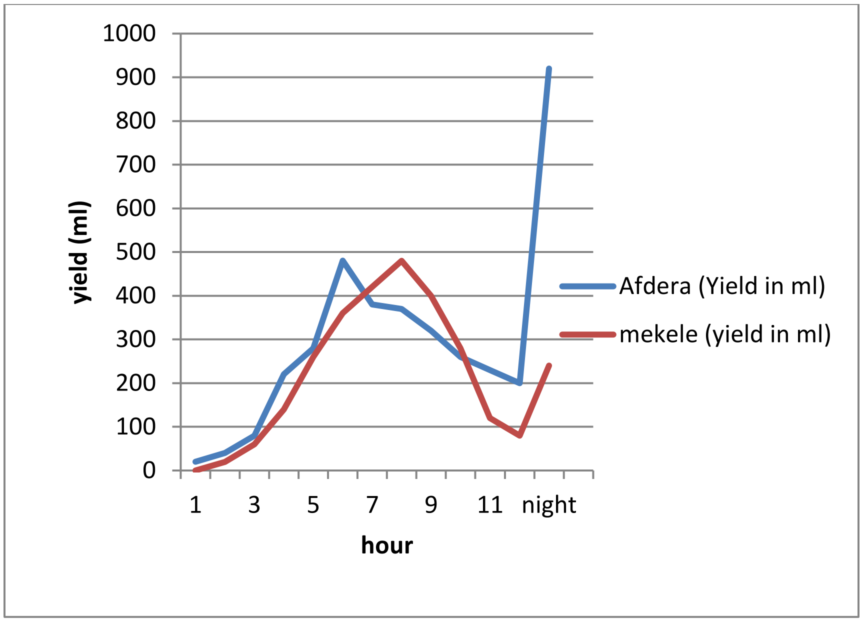


Chart 7: comparison between yields in both areas

Table 10: Yield comparisons between Afdera and Mekelle

This indicates that the Afdera setup was approximately 1.33 times more efficient than the Mekelle test. To further quantify the efficiency improvement, the result demonstrates that the Afdera experimental setup showed a 32.86% higher efficiency than the Mekelle validation test, potentially due to variations in environmental conditions, such as solar intensity and ambient temperature.

# CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

## 5. Yield comparisons for both solar stills

In a comparative study of two solar stills, SS2 consistently outperformed SS1 in water production across various time points. On Day 1, SS2 yielded 3,482 ml, while SS1 produced 1,920 ml; on Day 2, SS2 generated 3,800 ml compared to SS1's 1,780 ml. Both stills reached peak performance at the 6th hour, with SS2 producing 450 ml and SS1 220 ml, highlighting SS2's superior efficiency in utilizing solar energy for evaporation. Environmental factors such as wind speed, humidity, and temperature were recorded, showing varying impacts on both stills' performance. Higher wind speeds generally enhanced condensation by cooling the glass cover, potentially benefiting SS2 more due to its improved design or material efficiency. Additionally, SS2 consistently yielded more water at night (920 ml) compared to SS1 (340 ml), indicating better heat retention and sustained evaporation, due to the use of black rocks.

So, conventional solar still exhibits low efficiency, with a daily yield of only 1920 ml, translating to an overall efficiency of 18.57%, in 12 hour-base calculation, which is below the acceptable range for solar still performance. Its limited output makes it economically unviable for practical desalination purposes in water-scarce regions like Afdera. The design inefficiencies, including inadequate heat retention and poor utilization of solar energy, further exacerbate its shortcomings. Given the low yield and inefficiency, SS1 is not recommended for water desalination in Afdera, where effective and reliable solutions are critical to addressing water scarcity.

On the other hand, modified solar still demonstrates significantly better performance compared to SS1, with daily yields 3800 ml in Afdera, and 2860 ml in Mekelle. The calculated efficiencies in 12 hour-base, are 33.6% in Afdera and 25.2% in Mekelle highlight SS2's superior ability to utilize solar energy effectively. Its enhanced design, featuring black rocks for improved heat absorption and retention, contributes to its higher yield and sustained performance even in less favorable conditions like Mekelle. These results confirm SS2 as a viable and efficient solution for water desalination in regions like Afdera, where reliable and economical systems are essential to addressing water scarcity challenges.

## 5.1. Factors Influencing Solar Still Performance

The efficiency of solar stills is influenced by several factors:

- Climatic Conditions: Solar radiation, ambient temperature, and wind speed significantly affect evaporation rates. Higher solar radiation increases evaporation, while wind speed can enhance condensation by cooling the glass cover.

- Design and Materials: The choice of materials and design features, such as the use of black-painted basins or black-dyed fabrics, can improve heat absorption and retention, thereby enhancing water production. Implications for Solar Still Design

The superior performance of SS2 suggests that incorporating design elements such as black rock enhance heat absorption and retention, leading to higher water production. Additionally, optimizing operating parameters like water depth and feed water temperature can further improve efficiency.

So, the comparative analysis indicates that SS2's design and heat absorption materials contribute to its higher water production compared to SS1. Incorporating materials and designs that enhance heat absorption and retention, along with optimizing operating conditions, can significantly improve the efficiency of solar stills.

## 5.2. Effectiveness of Black Rocks:

SS2's use of black rocks as absorbing materials led to faster initial heat absorption, enhanced midday performance, and sustained higher temperatures into the later hours and night. The thermal mass provided by black rocks contributed significantly to maintaining higher water temperatures, thus improving overall daily yield.

Temperature Trends: SS2 consistently maintained higher internal temperatures, especially during peak sun hours, resulting in higher evaporation rates and increased distillate production. This indicates that SS2 was more efficient in utilizing solar energy throughout the day, contributing to its superior performance over SS1.

Environmental Impact: Environmental variables, particularly wind speed and temperature, played a crucial role in influencing the operational efficiency of both stills. SS2’s superior performance suggests that its design or materials were better suited to capitalize on these environmental factors for increased water yield.

The experiment clearly demonstrates that the modification of using black rocks in SS2 significantly enhanced the efficiency and yield of the solar still compared to the conventional SS1 design. This improvement is attributed to better heat retention, higher evaporation rates, and sustained performance even under varying environmental conditions. These findings underscore the practical advantages of integrating innovative materials in solar still designs to maximize water production in arid regions like Afdera, Ethiopia.

## 5.3. Validation test of mekelle

This study investigates the performance of a solar distillation system through a detailed analysis of the Mekelle validation test, focusing on the interrelationships between various environmental and operational variables and their impact on yield. A correlation matrix reveals significant relationships between the variables, including a strong negative correlation between the hour of the day and key factors such as solar radiation (-0.98), internal temperature (-0.97), rock temperature (-0.99), ambient temperature (-0.75), and yield (-0.66), highlighting the diurnal decline in solar energy and its effects on system performance. Solar radiation correlates positively with internal and rock temperatures (0.99), with moderate correlations to yield (0.60), and shows a significant influence on internal system heat dynamics. Rock temperature (0.96) and internal temperature (0.85) are identified as primary drivers of yield, with ambient temperature (0.83) also playing a crucial role. The correlation between yield and ambient temperature (0.93) is particularly strong, emphasizing the importance of ambient conditions in maximizing system efficiency. In comparison with experiments in Afdera, where the efficiency was 32.87% higher due to more favorable environmental conditions, this study underscores the importance of optimizing thermal storage and understanding regional variations in solar distillation performance. The results suggest that while solar radiation is vital for initiating thermal processes, the system's yield is more strongly influenced by heat-retaining materials like rock and ambient thermal conditions. This research contributes to enhancing the efficiency of solar distillation systems, particularly in regions with varying environmental conditions.

In conclusion, a comparative study conducted in Afdera and validated in Mekelle, the modified solar still (SS2) consistently outperformed the conventional still (SS1) in water production, achieving higher yields both during the day and at night due to its enhanced design and use of black rocks for improved heat retention. SS2 produced 3,482 ml and 3,800 ml on two consecutive days in Afdera, significantly surpassing SS1's 1,920 ml and 1,780 ml. Environmental factors such as wind speed, humidity, and temperature influenced performance, with higher wind speeds aiding condensation and SS2 benefiting more from its efficient thermal storage. The Mekelle validation test further analyzed performance by correlating environmental and operational variables, revealing that solar radiation, internal and rock temperatures, and ambient conditions play critical roles in yield. While Afdera demonstrated 32.87% higher efficiency due to more favorable conditions, which clearly shows the higher difference is mainly during night time. the result emphasizes the importance of optimizing thermal storage and adapting designs to regional variations, highlighting SS2's superior efficiency in harnessing solar energy for water distillation.

## 5.4. Recommendations for Further Research

Based on the scope and limitations of the study on solar stills, here are recommendations for future research:

- Incorporate Design Variations: Investigate the impact of different solar still designs, including double-slope configurations, alongside conventional and modified designs.
- Optimize Absorbing Materials: Further explore various absorbing materials beyond volcanic rocks to enhance heat absorption and retention in solar stills.
- Long-Term Performance Studies: Conduct long-term studies to assess the durability and sustained efficiency of modified solar stills under real-world conditions.
- Advanced Environmental Modeling: Utilize advanced environmental modeling techniques to accurately predict the influence of wind, humidity, and temperature variations on solar still performance

These recommendations aim to expand current knowledge on solar still technology, addressing gaps in design variability, material optimization, environmental influences, and practical applications across diverse environments.

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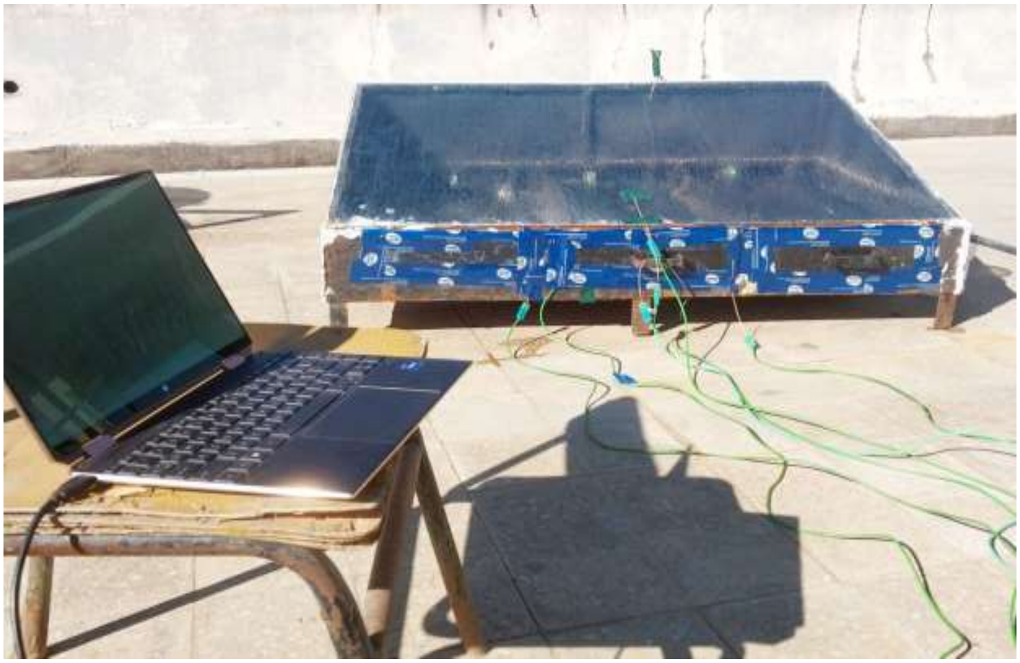
# 7. Appendices

a. Construction

b. Experiment (Afdera)


SMART SENSOR AR212
68.0°C
Digital Thermometer
-50°C~300°C



Experiment (Mekelle)

c. Result