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Effective Hybrid Solar Groundwater Desalination in Rural Areas

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Abstract

This research presents an exclusive study of a hybrid solar groundwater desalination system. Solar desalination technology is the most promising technology in the world that will be useful for drinking applications. The objective of this study is to collect various solar desalination systems attained by main researchers and scientists through numerical and experimental investigations to perform desalination systems to obtain the amount of fresh water. The available desalination technologies are not that effective in rural areas due to a lack of electricity. This research studies various parameters using a single effect boiling method to obtain fresh water that will be useful for drinking application in rural areas. In especially rural areas soft /freshwater for drinking application is a major issue, a hybrid solar groundwater technology is the effective way of desalination. From the pilot experiment, it is seen that parameters such as pH, TDS, Hardness, Calcium values are obtained as per the limits of ISO 10500:2012 and an average of 1.6-1.9 liters of soft water is produced per day using a novel single ETC + CPC desalination system.

Disciplinary: Water Treatment and Desalination Engineering, Renewable Energy, Sustainability, Rural Management.

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1 Introduction

Pure drinkable water is a big problem in rural regions of the world where soft water is becoming very costly. Clean drinking water is one of the most important international health issues today. As per the World Health Organization (WHO), drinkable water for humans, as well as animals is the biggest issue in the world. The areas with the severest water shortages are the warm

different countries in and around the world. Solar desalination is the most promising renewable energy technology in the world. In solar desalination systems, many techniques are available for the generation of freshwaters such as multistage flash desalination (MSF), vapor compression (VC), reverse osmosis (RO), membrane distillation (MD), and electrodialysis. Some methods are in the pilot stage and a few of them are popularly developed such as reverse osmosis.

Various scientists and researchers developed solar desalination systems with analytical and experimental aspects. However, most of the studies mainly concentrate on multi-stage flash (MSF), multi-effect distillation (MED), reverse osmosis (RO), humidification-dehumidification, electrodialysis, hybrid energy systems such as solar and wind energy, solar PV, and solar thermal. Most systems perform for the betterment of the human being, but especially in rural areas, these systems are not affordable due to the inherent limitations of the above systems. This paper mainly reports a hybrid groundwater desalination system using the SEB method which will be useful for drinking application in rural areas. The main purpose of a hybrid energy system is that to avoid loss of solar energy radiations and within less time maximum quantity of soft water to be formed for drinking application. In this paper ETC combines with CPC as a hybrid system in solar groundwater desalination.

1.1 Important Terms of Hybrid Solar Groundwater Desalination System

In a hybrid solar groundwater desalination system, the important terms are commonly used include

- *Intensity of solar radiation:* The intensity of reflected solar radiation depends on the surroundings that it is reflected from the earth's surface. The direction of direct radiation impacted every spot of the earth. (I_g)
- *Wind velocity:* Wind speed/velocity is the fundamental atmospheric quantity caused by air moving from high to low pressure due to changes in temperature.
- *Ambient temperature:* Ambient temperature is the air temperature of any environment where the equipment is stored.
- *Collector outlet temperature:* It is the temperature for the solar collector for the outlet side.
- *Soft water collected:* Soft water collected is a collection of soft water through the condensation process from the condenser.
- *Water flow rate:* It is the volume of the water that passes through a given surface per unit of time.
- *pH:* It is a measure of hydrogen ion concentration and a measure of acidity and alkalinity of a solution.
- *TDS:* It refers to any minerals, salts dissolved in water, and a small amount of organic matter that dissolves in water.
- *Hardness:* Hardness mainly includes concentrations of calcium and magnesium ions expressed in terms of calcium carbonates.
- *ETC:* ETC mainly a transparent glass tube which is connected to the header pipe. Tube in tube arrangement because of vacuum is created inside the tube. Due to the cylindrical shape in evacuated glass tubes, solar radiations impacted perpendicular to ETC tubes. In addition to that selective black coating to the inside of the tube for maximum solar radiation absorption. These tubes are made with

borosilicate glass tube which is strong, resistant to high temperatures, and high transmittance for solar irradiation.

- *CPC:* CPC is one of the collectors which useful for high-temperature applications. It is fabricated in the shape of two meeting parabolas. It belongs to a non-imaging family but it is one of the collectors whose highest possible concentration ratio. Compound parabolic concentrators are non-imaging concentrators. They are having the capability of reflecting to the absorber of all incident radiation. The main purpose of CPC is to absorber the solar radiation and reflected it back with a higher concentration ratio. The necessity of moving the concentrator to accommodate the charging solar orientation can be reduced by using a through with two sections of a parabola. CPC can accept incoming solar radiation over a relatively wide range of angles by storing heat and reflecting back to the entire surface.
- *Combination of ETC and CPC:* The combination of ETC and CPC will be a fruitful solution for groundwater solar desalination. There is a great need for hybridization for various collectors the main reason is that during the operation solar energy is impacted to ETC tube and remaining loss towards the earth. To avoid energy loss, the author thinking of a combination of ETC with CPC. Due to this necessity, a hybrid combination is built to achieve a high amount of soft water to be obtained. Through the pilot testing, various parameters are studied with the help of the experimental setup in a hybrid solar system to achieve better performance.

2 Mechanism of Hybrid Solar Groundwater Desalination Systems

Experimentation for an entire system based on a natural thermosyphon solar water heating system. Thermo-syphon is a method of passive heat exchange based on natural convection which circulates the fluid without the necessity of a mechanical pump. The circulation of the water can be either open-loop as to when the substance in a holding tank is passed in one direction through an evacuated tube collector. With the help of solar energy – solar radiations continuously strike on glass cover, it penetrates into an inner glass tube, a copper tube, and water. Water is heated and converted into steam that is condensed into a surface condenser for the condensation process. Water droplets are formed leaving the bottom side of the ETC tube salt contaminants and without chemical contaminants water drip to the specific channel and collected into the bottle. Ahmed et al. [4] developed a hybrid desalination unit (solar still coupled with ETC tubes). They performed experimentation to improve productivity and efficiency of solar still with ETC tubes, whereas Reddy et al. [3] mainly worked on an evacuated multi-stage distillation system and their results show that 3-4 times more comfortable than conventional solar stills. Arunkumar et al. [6] worked on a solar desalting system and developed an innovative design of tubular solar still for better performance of solar desalination system. Kabeel et al. [17] reviewed various desalination systems and developed solar desalination with the help of HDH technology. Bhambare et al. [29] presented an overview of desalination, solar energy availability, and various solar thermal technologies in Oman. This section focuses on the various past and current development in the various water desalination systems.

Table 1: Summary of different solar desalination systems

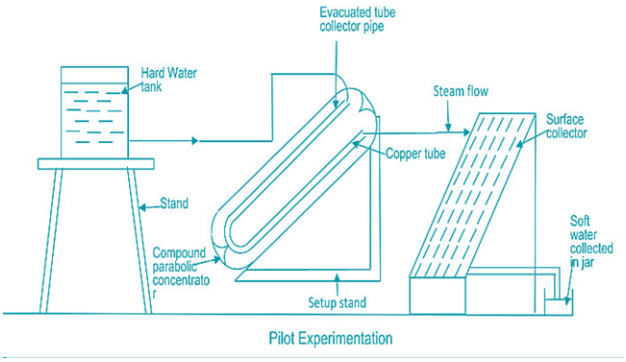
Authors	Solar desalination system	Type of collector	Investigation	Observation
Hunashikatti et al. [1]	Multi-effect boiling	Evacuated tube collector with Solar still	Experimental	Development of a hybrid desalination system. and conducted the detail experimentation on ETC tube with solar still and whole study for various and climatic conditions of Bangalore Karnataka.
Shafii et al. [2]	Multi-stage flash	Evacuated tube collector	Theoretical	Mainly developed the desalination system using ETC and theoretical results shows that quasi-static conditions will improve system efficiency.
Reddy et al. [3]	Multi-stage distillation	Evacuated tube collector	Experimental	Performed an evacuated multi-stage desalination system for an option to meet the demand for urban communities.
Ahmed et al. [4]	Multi-stage distillation	Evacuated tube collector	Experimental	Performed experimental investigation to enhance productivity and better efficiency of solar still with multistage ETC system.
Al-Nimr et al [5]	Multi-stage distillation	Solar and wind energy	Experimental	performed an experimental investigation on a hybrid solar and wind energy for the distillation system.
Arunkumar et al. [6]	Multi-effect distillation	Solar still	Theoretical	Mainly studied theoretically solar water desalting system and better design of tubular solar still.
Kedar et al. [7,8]	Single effect boiling	Evacuated tube collector	Theoretical Experimental	Mainly studied theoretical and experimental analysis of ETC.
Al-Tabbakh AA et al. [9]	Multi-effect distillation	Evacuated tube collector	Experimental	Conducted experimental analysis of ETC collector with serpentine flow through a pipe for finding out high temperature and production of steam.
Borah et al. [10]	Reverse osmosis	Compound parabolic concentrator	Experimental	Developed CPC to increase higher solar radiation with rising temperature. The results showed achieving maximum temperature on fixed CPC.
Saettone erich [11]	Multi-stage flash	Parabolic trough collector	Experimental	Mainly studied a system using a parabolic trough collector with a solar tracking system.
Kedar et al. [12]	Single effect boiling	Compound parabolic concentrator	Analytical	Mainly conducted a theoretical study of CPC in a solar desalination system.
Poblete et al. [13]	Multi-stage flash	Solar pond combined with solar collector	Experimental	Studied various factors for the efficiency of a solar pond and solar collector. Their results show that to improve the thermal performance of solar still.
Kedar et al. [14]	Single effect boiling	Solar desalination using ETC	Experimental	Mainly shown results that 27-28 litres of soft water obtained from the ETC system.
Sotehi et al. [15]	Multi-effect boiling	A hybrid PV and thermal system	Analytical	Theoretically studied photovoltaic and thermal solar water collectors for drinking water production.
Kabeel et al. [16]	Humidification & dehumidification techniques	A hybrid desalination system	Analytical and Experimental	Mainly concentrated to improve the performance of the system and productivity analysis of the solar power.
Kabeel et al. [17]	Humidification and dehumidification techniques	A hybrid desalination system	Analytical and Experimental	Developed desalination unit using HDH technology.
Kabeel et al. [18]	Humidification and dehumidification techniques	A hybrid desalination system	Experimental	Carried out detailed experimental analysis with HDH for different configuration and water flashing evaporation.
Kalogirou [19]	Review of solar desalination	Desalination system	Review of all renewable energy sources	Studied all reviews of renewable energy sources for desalination systems.
Sapre and Auti [20]	Multi-effect boiling	Compound Parabolic Trough	Analytical and Experimental	They had mainly worked on absorber in desalination system with multi-effect boiling method.
Kazemian et al. [21]	Reverse osmosis	Membrane technology	Experimental	They have presented experimental results with RO technology.
Zheng et al. [22]	Multi effect distillation	Compound parabolic Trough	Experimental	developed multi-effect solar desalination system through compound parabolic through the collector.
Murali et al [23]	Solar latent heat storage medium	Solar air heater	Experimental	Developed experimentally studies on solar aluminum can air heater with and without latent heat storage
Auti et al. [24,25,26]	Multi effect boiling	Parabolic concentrator	Experimental	Conducted an exhaustive experimental study on a parabolic concentrator and their results showed maximum drinking water within less time.
Liu et al. [27]	Multi-effect distillation	---	Analytical	Studied theoretical and financial aspects for low-temperature MED system.
Palanisami et al. [28]	Reverse osmosis	Membrane Technology	Experimental	Conducted a study using various experimentation trials using RO membrane technology for seawater.
Bhambare et al. [29]	Multi-effect distillation	---	Analytical	Studied an overview of desalination status and studied requirements of solar thermal technologies in Oman city.
Kabeel et al. [30,31]	Humidification and dehumidification techniques	A hybrid desalination system	Experimental	Developed a hybrid desalination system using HDH technology.
Kedar et al [32,33]	Single effect boiling	A hybrid desalination system	Analytical and Experimental	Developed a mathematical model of a hybrid desalination system using the single effect boiling method. He has registered a patent on solar desalination system using ETC and CPC
Murali et.al [34]	PCM based Solar still	Solar still	Experimental	Developed solar still productivity enhancement by using PCM and Nano-PCM composites.
Murali et.al [35]	Solar latent heat storage medium	Solar air heater	Experimental	Developed experimental thermal performance of solar aluminum cane air heater with and without fins
Sakthivel et al. [36]	----	Heat pipe with evacuated tubes	Analytical	Analytical investigations of solar water heating using heat pipe with evacuated tubes
Swapna et al. [37]	Parabolic concentrator type solar system	Parabolic concentrator	Experimental	A study on one slope solar unit conjoin with parabolic concentrator

From the literature review, the highest number of the available literature is based on various solar desalination methods. In most cases, an initial objective was to achieve overall productivity using different techniques available in solar desalination using ETC, CPC, solar still, and wind turbine. Most of the researchers mainly studied numerical analysis for a hybrid system such as solar and wind energy. However, in some cases, certain limitations are observed in the performance of these methods i.e. R.O., MSF, MEB. In this research using the single effect boiling method certain amount of drinkable soft water is a plan to generate through (ETC + CPC) a hybrid system at affordable costs. Through this study, it plans to perform the tests for various atmospheric and climatic conditions of the Pune region city, focusing on multi-parameters using a single effect boiling method to obtain fresh water that will be useful for drinking application in rural areas.

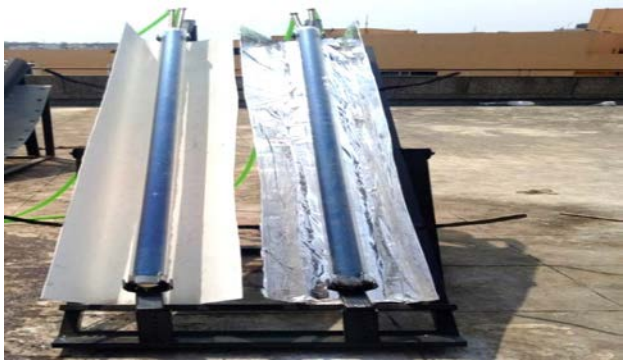
3 Pilot Experimentation

During this study, the experimentation is carried out in the premises of MKSSS's Cummins College of Engineering for Women, Karvenagar Pune. All the performance tests were conducted from morning 7:00 AM to evening 5:00 PM. Ground hard water continuingly flows through an evacuated tube collector. In ETC, copper tubes are added to enhance the rate of heat transfer. The main reason for copper tubes is for higher thermal conductivity. Solar rays impacted the evacuated tube collector and result in heat transfer to water through copper tubes. Water is heated with the help of solar energy and converted into steam. The steam is condensed into the surface condenser (condensation) to form smaller water droplets collected in the bottle/jar.

The instruments are used for experimentation (Figure 1(a, b))- 1) Temperature: For temperature measurement Infrared thermometer IRL-380 is used in the range of (− 50 to 380 °C). 2) Wind velocity: For wind velocity measurement Anemometer KM-910 is used in the range of (0-45) m/s. 3) Solar radiation measurement:- Pyrometer (Solar power meter) KM-SPM-530 is used in the range of (0–2000) W/m^2. 4) Water flowrate: For measuring the flow of water flow meter is used in the range of STD 0.01–100 lpm.



(a)



(b)

Figure 1: (a, b) Schematic representation of experimental setup.

The chemical analysis of both the samples was performed and compared with Indian Standard (ISO-10500-2012). Once all setup is done, water is allowed to pass through the test section from the

hard water tank, and before taking the readings wait for the steady-state condition. Once, the system reaches to steady-state condition, then start to take the readings. The schematic arrangement of the experimental setup is shown in Figure1. Table 2 present the specification of ETC, CPC, and surface condenser.

Table 2: ETC, CPC and Surface Condenser Systems Specification

S. No.	Parameter	Symbol	Dimension
01	Absorber area	A_b	1.6 m^2
02	Diameter of ETC Tube	D	65 mm
03	Length of Compound Parabolic Concentrator	Lc	1500 mm
04	Width of surface condenser	Ws	2 foot
05	Area of surface condenser	Ac	1.127 m^2
06	Length of surface condenser	L_s	6 foot

4 Results and Discussion

The experimental analysis is carried out for various parameters such as pH, TDS, Hardness, Calcium, the intensity of solar radiation, ambient temperature. For the pilot experimentation, we plan to do the initial test of two samples from the Dapodi (Bopkhel) region, COEW, Karvenagar region - to study various parameters pH, TDS, Hardness, Calcium, the intensity of solar radiation, ambient temperature. From the pilot experimentation, it is observed that a hybrid solar ground desalination system produces more than 1.6 l of soft water of Dapodi (Bopkhel) and COEW Karvenagar samples. The entire pilot experimentation was conducted for the time 7:00-18:00 under the atmospheric and environmental conditions. Figure 2 shows the variation of pH for hard water and soft water samples for Dapodi and COEW Karvenagar. The pH of the hard water sample at the Dapodi region is very higher than COEW Karvenagar. From the pilot test, it is seen that for both samples the pH values were 7.69 and 7.25 for Dapodi and COEW Karvenagar regions. These results were obtained through a hybrid system (ETC+CPC) single effect boiling pH reduction 7.89 to 7.69 and 7.37 to 7.25. The obtained pH values of both samples using pilot testing are then compared with ISO 10500:2012 range (as Indian drinking water specification standards) and found within the acceptable limits.

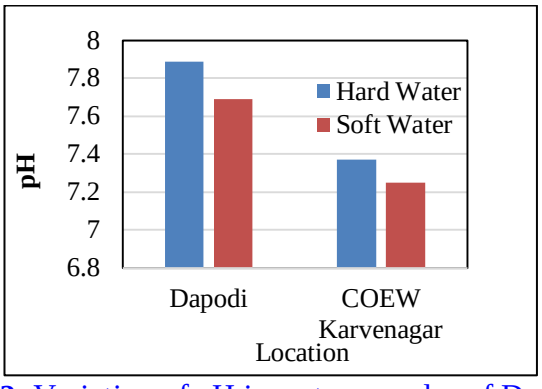


Figure 2: Variation of pH in water samples of Dapodi and COEW Karvenagar Pune.

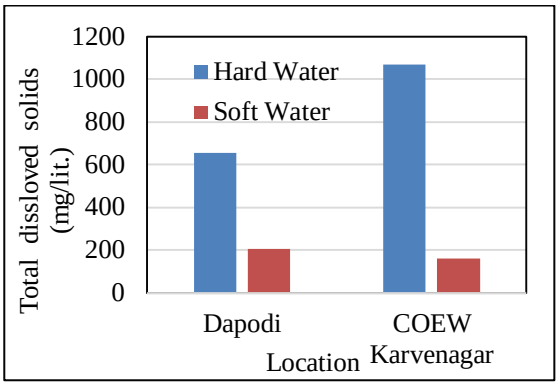


Figure 3: Variation of TDS in water samples of Dapodi and COEW Karvenagar Pune.

Figure 3 shows the variation of TDS for hard water and soft water samples for Dapodi and COEW Karvenagar. The obtained TDS of hard water sample of COEW Karvenagar region is very

higher than Dapodi and observed as 205 and 160 mg/Litre for Dapodi and COEW Karvenagar regions. Through a hybrid system (ETC+CPC) it is observed that single effect boiling TDS reduction obtained as 655 to 205 mg/Litre and 1070 to 160 mg/Litre at both regions. Again it is observed that during pilot testing readings of soft water for both samples when compared with ISO 10500:2012 range (as Indian drinking water specification standards) shows good agreement.

Figure 4 shows the variation of Hardness for hard water and soft water samples for Dapodi and COEW Karvenagar. The hardness of the hard water sample of the COEW Karvenagar region is very higher than Dapodi through both samples pilot testing observation 90 and 120 mg/Litre for Dapodi and COEW Karvenagar regions. Through a hybrid system (ETC+CPC) single effect boiling hardness reduction obtained from 280 to 90 mg/Litre and from 495 to 120 mg/Litre. We observed that pilot testing readings of soft water to both samples compared with ISO 10500:2012 range (as Indian drinking water specification standards) are within the limits.

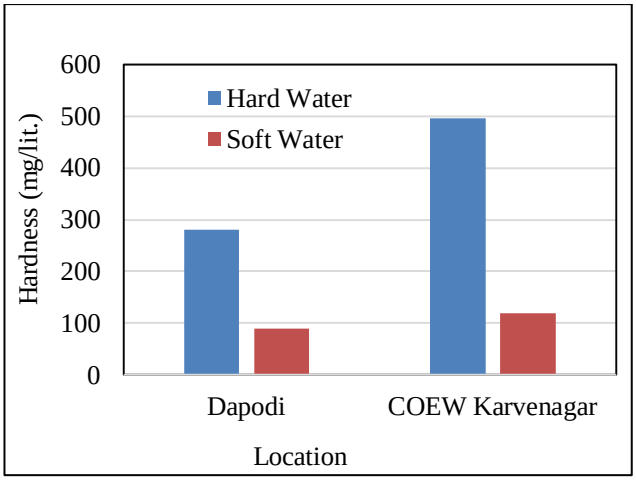


Figure 4: Hardness on hard water and soft water samples

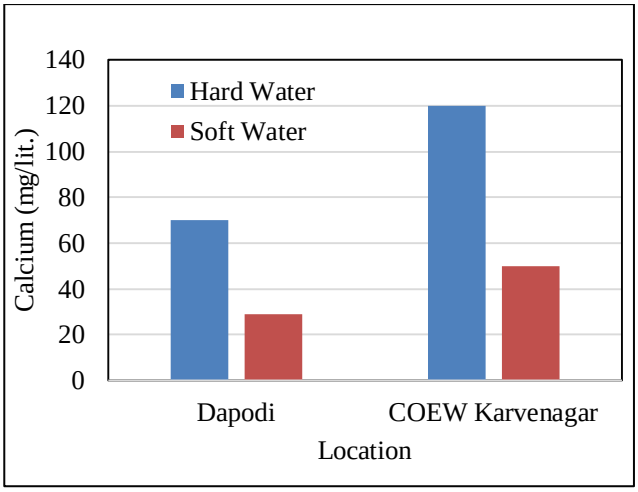


Figure 5: Variation of Calcium in water samples of Dapodi and COEW Karvenagar, Pune.

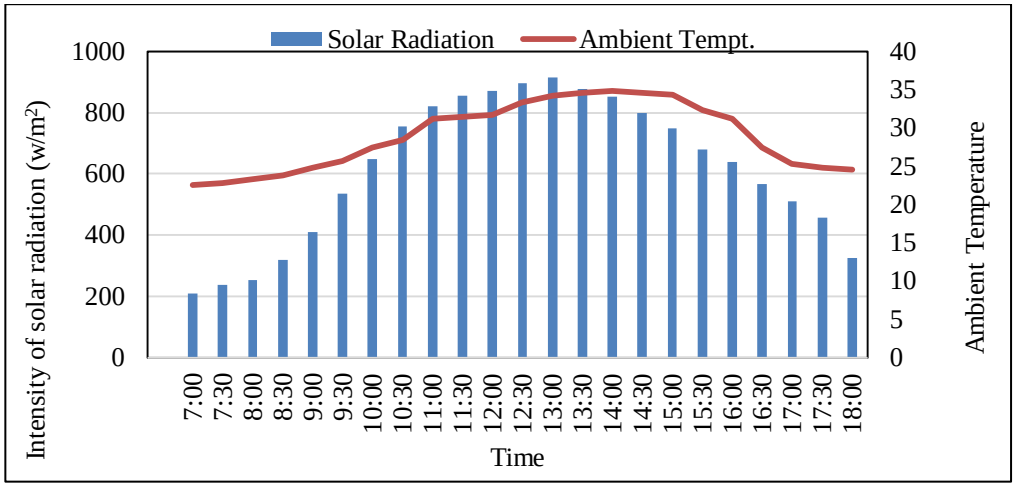


Figure 6: Study of Intensity of solar radiation and ambient temperature with time

Figure 5 shows the variation of Calcium for hard water and soft water samples for Dapodi and COEW Karvenagar. The calcium content of the hard water sample of the COEW Karvenagar region is very higher than Dapodi. Both obtained samples of pilot testing observation are 29 and 50 mg/Litre for Dapodi and COEW Karvenagar regions. Through a hybrid system (ETC+CPC) single

effect boiling calcium achieved reduction as 70 to 29 mg/Litre and 120 to 50 mg/Litre. It is observed that pilot testing readings of soft water for both samples compared with ISO 10500:2012 range (as Indian drinking water specification standards) are within the limits.

Figure 6 shows the solar radiation and ambient temperature study obtained throughout the day at Pune city. Through pilot experimentation, it was observed that solar radiation increased from 10:30 AM to 2:30 PM leads to produce the maximum amount of drinkable water that increases productivity. For Pune city, the ambient temperature varies from 23.5 to 34.8°C. More variation was observed during the morning to evening time. In the afternoon time, maximum ambient temperature was observed for the atmospheric condition of Pune city. Al-Nimr et al. [5] generated 0.5296 *l* of soft water per day for climatic conditions of Irbid, Jordan by using the developed the hybrid-solar-wind-water desalination system. However, we proposed a hybrid system both region samples generated 1.6 *l* and 1.9 *l* soft water per day. Our developed hybrid will improve results as compared to the solar-wind hybrid desalination system also. Again as per parametric observation for pH, TDS, Hardness, and Calcium, the pilot testing shows within limits specified by ISO standard.

5 Conclusion

This paper presents a comprehensive review of different methods of solar desalination systems with analytical and experimental investigations. The available desalination technologies are not that effective in rural areas due to a lack of electricity. This research studies various parameters using a single-effect boiling method to obtain fresh water which will be useful for drinking application in rural areas. In especially rural areas soft /freshwater for drinking application is a major issue, a hybrid solar groundwater technology is the effective way of desalination. Pilot experimentation is also carried out on the solar groundwater desalination system using ETC and CPC. It is seen that parameters such as pH, TDS, Hardness, Calcium values are obtained as per the limits of ISO 10500:2012 and average 1.6 to 2 l freshwater generated per day. From this study, solar a hybrid desalination system (ETC+CPC) is a good option against the different types of existing desalination solutions in mostly rural areas due to very good performance and low maintenance and initial cost. No electricity will be required for the desalination of ground hard water. This hybrid solar groundwater desalination system is an effective way of desalination in rural areas, as a promising solution for the desalination of groundwater in rural areas.

6 Availability of Data and Material

Data can be made available by contacting the corresponding author.

7 Acknowledgment

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8 Conflict of Interest

The authors declare no conflict of interest regarding the publication of this paper.

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