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ORIGINAL RESEARCH ARTICLE

Rainwater and fog harvesting from solar panels

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ABSTRACT

BACKGROUND AND OBJECTIVES: Jordan is among the most water-scarce countries in the world. The scarcity of water resources in Jordan is driving the development and advances of non-conventional water techniques that enable integrated management of water resources in addressing water scarcity challenges and promoting sustainable water use. Water harvesting of rainwater and fog techniques is one of the viable solutions to mitigate the water scarcity effects in Jordan. This study aimed to evaluate the quantity of rainwater and fog collected through the utilization of solar panels, while also conducting a feasibility analysis on the economic and environmental aspects of employing solar panels for rainwater and fog harvesting in a solar farm situated in Jordan.

METHODS: In the present study, an in-situ experiment is conducted to investigate rainwater and fog harvesting from solar panels' surfaces that are widely spread in Jordan. The solar farm situated in Hai Al Sahabah, south of Amman, Jordan, incorporates an experimental arrangement that involves the installation of gutters, pipes, and water tanks beneath two solar panel samples. These panels have a total area of 4 square meters and will be monitored for a duration of 60 days.

FINDINGS: The results of the experiment show that the total quantity of the harvested rainwater using two solar panels was 444 liters ranging from 0.8 liters per day to 117.66 liters per day, and the total harvested fog quantity was 28 liters ranging from 0.25 liters per day to 9.75 liters per day. The multilinear regression technique was employed to establish a correlation between the amount of harvested water and the crucial factors of wind direction, wind speed, relative humidity, and temperature at the solar farm. The analysis of the findings revealed a significant relationship between these variables. These relationships can be generalized to provide an estimation for the quantity of rainwater and fog harvesting in other locations. The quantity of harvested rainwater was primarily influenced by wind speed and direction, the quantity of harvested fog was mainly affected by relative humidity and temperature. The current study aims to analyze and deliberate on the collected amounts of water obtained through rainwater and fog harvesting from solar panels. The viability of implementing the method of rainwater and fog harvesting from solar panels will be examined in terms of economic and environmental factors.

CONCLUSION: The quantity of rainwater gathered in this research with just two solar panels shows great potential for widespread use as a supplementary water supply. This method of rainwater and fog harvesting can be effectively applied to solar power plants which are widely spread in Jordan for use in solar panel cleaning, agriculture, groundwater recharge, and reducing stormwater discharge to assess and manage the risk of environmental damage. Rainwater and fog harvesting systems offer a higher level of efficiency and cost-effectiveness compared to other methods, especially when seamlessly integrated into the infrastructure of solar power plants. The benefits of solar panels by producing clean energy are not negotiable but combining energy production with water harvesting in solar power plants would offer even more advantages in enhancing the global environmental situation..

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55	8	1

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INTRODUCTION

Water scarcity has emerged as a global concern that challenges continued human development (Dolan *et al.,* 2021). The intense pressure on available water resources caused by climate change and environmental contamination (Arista *et al.,* 2024) has reached critical levels in many regions since the 80s-70s (Yannopoulos *et al.,* 2019) and continues over this century (Arenas-Sánchez *et al.,* 2016). Millions of families worldwide are suffering from water scarcity (Tzanakakis *et al.,* 2020), and this scarcity is driving the development of non-conventional water techniques that enable integrated water resources management (Lequette *et al.,* 2020). Rainwater harvesting (RWH) is a technique that has garnered considerable interest for its ability to alleviate water supply challenges in urban settings and enhance stormwater control (Campisano *et al.,* 2017). Researchers globally explored RWH from different perspectives, including public utilities (Tran *et al.,* 2020), residential buildings (Gómez and Teixeira, 2017), and nonresidential buildings in Jordan (Saidan *et al.,* 2015). RWH offers benefits that go beyond just aiding in water supply. It also has the capability to transform risks into valuable resources (Saurí and Garcia, 2020). In parallel, fog is a potential source of water that could be harvested through the innovative technology of fog collection (Fessehaye *et al.,* 2014) as it has emerged as a sustainable, simple, and cost-effective technique (Korkmaz and Kariper, 2020) simulating the natural process where surfaces like trees, animals, and rocks collect water from fog (Qadir *et al.,* 2021). The integration of rainwater and fog harvesting (RFH) with solar panels offers a hopeful solution, particularly in rural regions. In addition to supplying extra water for irrigation and drinking purposes, RFH helps in decreasing stormwater and floods in urban areas, as well as improving groundwater replenishment (Rajasekhar *et al.,* 2020) which in turn can prevent seawater intrusion in a coastal aquifer, etc. (Freni *et al.,* 2019). RFH is part of the spectrum of non-conventional water sources, alongside treated wastewater and reclaimed water (Asaad *et al.,* 2023). Many researchers worldwide have explored RFH from solar panels (Zarezadeh, 2023) concluded that the RFH systems can be created with small investments in solar power plants. The adoption of non-conventional water resources like RFH is becoming more common worldwide. However, the successful application of this method is hindered by spatial constraints in traditional water harvesting systems, especially as the demand for green infrastructures like roof gardens continues to rise (Yoo *et al.,* 2022). Solar power plants offer a solution by providing the required space and favorable conditions for successful RFH applications. This integration aligns with the increase in renewable energy source applications to reduce environmental pollution (Jafar-Nowdeh *et al.,* 2020). The combination of water harvesting and power generation in solar power plants represents energy-efficient solutions, accomplishing two goals through a single action. Unlike traditional RWH and fog harvesting systems, where each setup requires an independent collection and storage system, integrating RFH with solar panels allows for a unified collection and storage system. This integration streamlines and improves the effectiveness of the procedure by minimizing the necessary capital and advocating for ecological sustainability (Mao *et al.,* 2021). While significant progress has been made, further research within this branch of non-conventional water resources is essential to rectify these integrated systems.

What brings Jordan to consider rainwater and fog harvesting from solar panels?

in a country with limited resources where access to clean water is among the essential requirements for a comfortable living (Sulistyowati *et al.,* 2023) Jordan is ranked as the second poorest country in water resources that suffers from a major crisis, with only 90 cubic metres (m^3) of water are available per person for annual consumption, and the available water resources can meet 50 percent (%) of the total water demand. Projections indicate that these values are anticipated to decrease further, reaching 60 cubic meters (m^3) annually by 2040 (NWS, 2016-2025). The country's economy and environment can be impacted by this scarcity which is in turn impacted by factors such as the fluctuation in annual precipitation and the swift demographic shift resulting from the arrival of refugees from nearby nations (MWI, 2021). The water sector in Jordan faces significant challenges stemming from water insufficiency and mismanagement, as highlighted by Hussein (2018). This insufficiency can be attributed to regional conflicts and instability in both the region and neighboring nations over the course of several decades (Schyns *et al.,* 2015). This has exacerbated the water crisis in Jordan due to

the influx of refugees from several countries. From 2011 until now, Jordan has experienced a significant increase in the number of Syrian refugees, with over 1.20 million individuals seeking refuge in the country. With Jordan's population exceeding 10 million according to the new figures of Jordanian Statistics 2020, the water demand will increase alongside population growth and economic development (MWI, 2021). To address water scarcity, innovative solutions such as RFH are gaining attention in Jordan. Several water harvesting projects have been implemented in Jordan to collect rainwater from the houses' rooftops (Abdulla, 2020), (Al-Houri *et al.,* 2014) in two case studies investigated from rooftops in Amman, (Jaradat *et al.,* 2023) investigated the fog harvesting from fog collectors in a greenhouse. RFH offers numerous benefits, including its affordability, ease of use, and the provision of potable water, making it suitable for direct consumption (Qasemi *et al.,* 2020). Solar panels play a crucial role in RFH by harvesting the rainwater before reaching the ground to be groundwater or surface water will minimize the needed water treatment, the cost of water extraction, and the number of water losses (Tran *et al.,* 2020). The catchment area material, represented by the solar panels in this study, is essential in determining the harvested water quantity (Wallace *et al.,* 2015). Smooth roofs with a runoff coefficient between 0.9 and 1 have been identified as highly effective in reducing spillage, evaporation, and improving surface wetting (Lin *et al.,* 2021). The objectives of the present study are 1) to evaluate the quantity of rainwater harvested using solar panels 2) to evaluate the quantity of the fog droplets harvested using solar panels 3) to provide a relationship between harvested water quantities and the key parameters of wind direction, wind speed, relative humidity, and temperature of the solar farm that affects the quantity of RFH 4) to provide a feasibility study using solar panels for RFH from economical and environmental aspects. utilizing a pair of solar panels was conducted over a two-month period starting from January 24, 2021, until March 24, 2021, in Hai Al Sahabah, south of Amman, Jordan, during the winter season in Jordan with the highest precipitation rate of the year as reported by the Jordan Meteorological Department (JMD).

MATERIALS AND METHODS

Study area

The study area is located at Hai Al Sahabah, Al Muqabalayn, Amman, Jordan. Its altitude is about

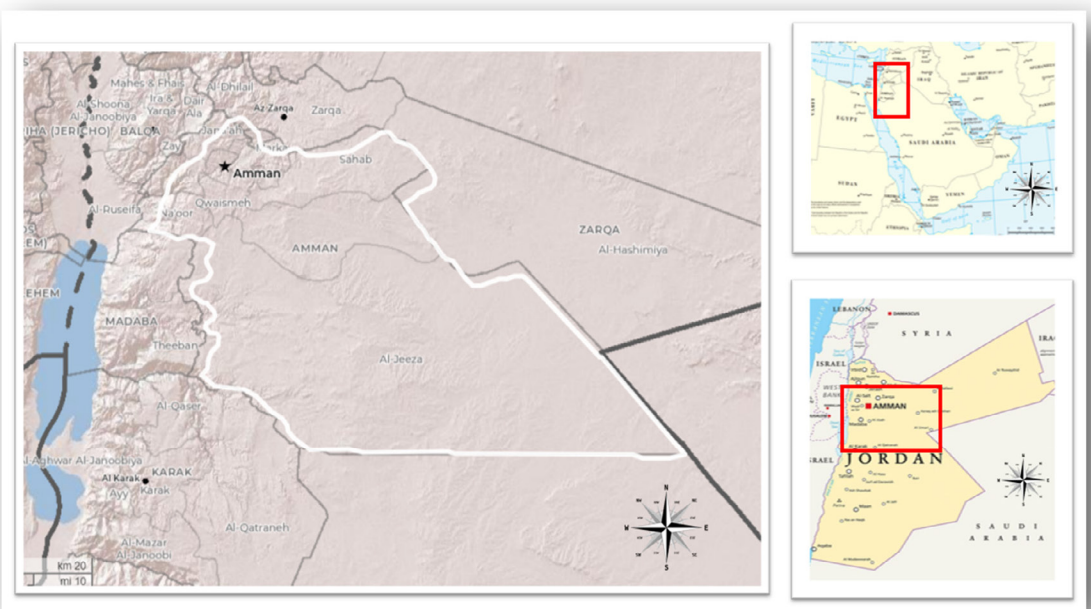

Fig. 1: Geographic location of the study area in Hai Al Sahabah, south of Amman, Jordan

930 metres (m) above sea level with the coordinates of 31°54'25.4"N 35°52'41.0"E. Al Muqabalayn is a town in the southwest of Amman Governorate of northwestern Jordan, as shown in Fig. 1. It is also a district of Amman Governorate. The location has a solar farm with a 7.1-MegaWatt power capacity, 20880 solar panels, and each panel has a 2 square metres (m^2) surface area with a total solar panels' surface area of 41760 m^2. According to JMD, (2021), the nearest station to the solar farm location, which is situated 12 kilometers (km) southwest of Amman airport station, has recorded an average rainfall of 245.6 millimeters (mm) over the past 30 years. The solar farm also has a weather station installed in 2019, which is used in this study to compare the harvested data from the RFH system with the farm weather station data.

Rainwater and fog harvesting collection system

The RFH system should consist of three essential components: a collection area in the present study (solar panel), a conveyance system (gutter), and a storage tank (Jue and Htwe, 2014). In the current study, the collection area refers to the surface of the solar panels, with each cell having a surface area of 2 m^2. The conveyance system comprises gutters and pipes that are utilized to transport the rainwater accumulated on the solar panel surface to cisterns or tanks . Gutters or pipes must be adequately sized, sloped, and installed to ensure a proper collection of the harvested water quantity. The system used in the current study will be divided into two tanks; one tank is to store the collection of rainwater the additional tank will be used for the water fog collection. In order to regulate the separation process, a control panel will be equipped with a rainwater sensor to oversee the operation of the two motor valves. These valves are strategically placed, with one positioned before the rainwater tank and the other installed before the fog water tank, as depicted in Figs. 2 and 3.

Experimental setup

The setup for the RFH experiment is done by installing a galvanized gutter (Local made with dimensions as 2.1 m) Length, 7 centimeters (cm) Depth, and 7 cm Width) placed beneath two solar panels (Poly-crystalline solar panels, 73P, Group 13, Jinko, PRC) and connected through PVC pipes, valves, motor valves (Winner type, WRA-6320 Model, PRC) with two 125 liters (L) water tanks used to collect and store the rainwater and fog during the experiment. The 125 L rainwater tank is connected to a 1 m^3 tank using a submersible water pump (Model KF-106, 45 W, PRC) with a flow meter (K24-BM-1, ESTINK, PRC). The system was controlled

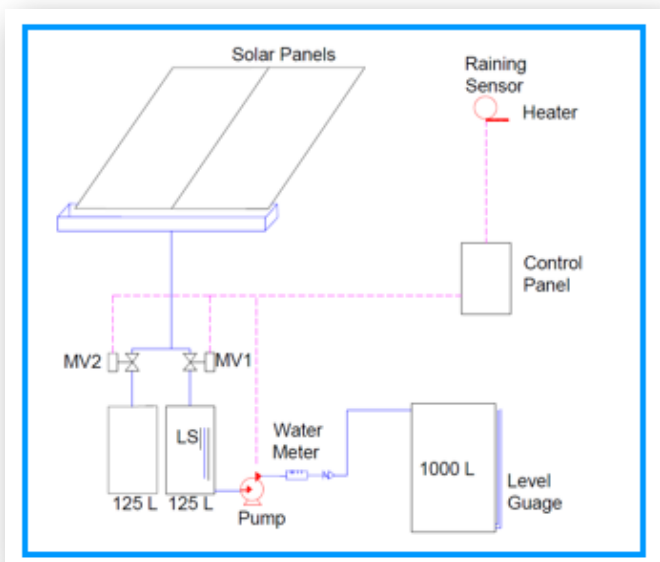

Fig. 2: Rainwater and fog harvesting via solar panels schematic

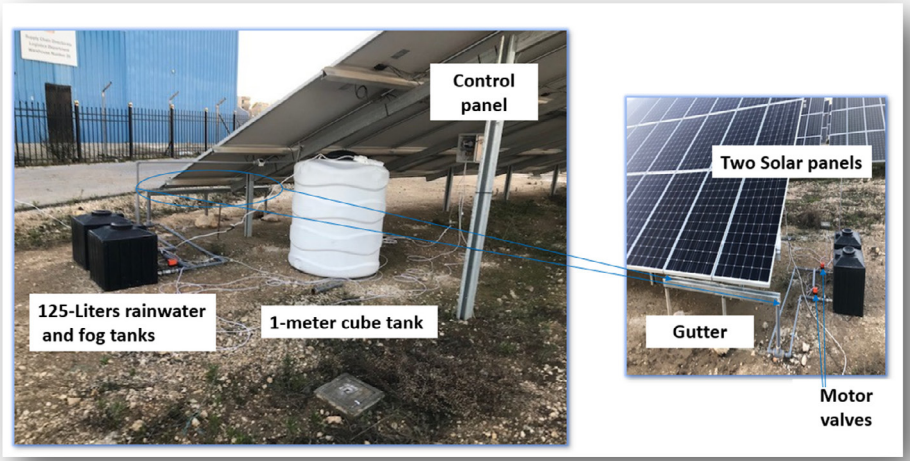

Fig. 3: Rainwater and fog harvesting via solar panels photographic view of the experimental setup

by a control panel for various reasons.

The data on water collected from two solar panels with a combined surface area of 4 m2 is presented. Rainfall data from JMD, (2021) shows an average of 245.6 mm over the past 30 years at the solar farm site. The experiment calculates the volume of rainwater storage based on annual rainfall, total panel area, and a runoff coefficient of 1, using Eq. 1 (Lizárraga-Mendiola *et al.*, 2015).

$$VR = (R \times A \times C/1000) \quad (1)$$

Where *VR* is the annual volume of rainwater that could be harvested (m^3), *R* is the average annual rainfall (mm/y), *A* is the total of two solar panels area (m^2), and *C* is the runoff coefficient (nondimensional). VR in the present study is calculated to be 0.9824 m^3**,** So, a 1 m^3 water tank is suitable for the rainwater storage system.

System method of statement

The installation of a control panel in this experiment serves the purpose of effectively managing the motor valves, rainwater sensor, and level controller that is present within the 125 L rainwater tank. The functionality of the motor valves involves keeping the fog motor valve fully open on non-rainy days (indicated by a red light). Upon rain detection, the rainwater sensor through the control panel triggers the fog motor valve to close while also activating the rainwater motor valve (signaled by a yellow light). The rainwater sensor-controlled system shuts the rainwater valve ten minutes after the last raindrop, signaling the control panel to revert to default settings with the fog motor valve fully open (red light on). The rainwater sensor comes with a built-in heater that warms the sensor surface, causing any water to evaporate and resetting to default settings once the rain ceases. Inside the 125 L rainwater tank, a level controller with three cables; black cable, always submerged as neutral; the blue cable, indicating low-level water in conjunction with the water pump (red light on); and the white cable, denoting high-level water in coordination with the water pump (green light on). The water pump transfers water from the 125L tank to the 1 m^3 water tank and stops the operation when the water level falls below the blue cable level (red light on). A flow meter installed between the two water tanks (125 L and 1 m^3) monitors the quantity of rainwater transferred from the 125 L tank to the 1 m^3 tank. A fog water tank level gauge is in place to calculate the volume of harvested fog inside the tank, with dimensions of 50 cm x 50 cm x the depth of the level gauge.

Data collection

The experiment's monitoring and data collection involves a daily recording of the flowmeter reading, fog water tank level gauge reading, rainwater tank level gauge level reading, and the status of various

system components. A weekly report containing ambient temperature as degrees Celsius (°C), module temperature (°C), wind speed metre per second (m/s), wind direction (degrees), relative humidity as (%), and rainwater (mm) is obtained from the weather station located in the solar farm to compare and evaluate the experiment daily readings. The present study employed multilinear regression (MLR) methods to examine the RFH and establish the correlation between multiple independent variables and the quantities of rainwater or fog harvesting. In MLR, the model is represented by Eq. 2 (Choubin *et al.,* 2016):

$$Y = a_1 X_1 + a_2 X_2 + \ldots + a_n X_n + e \quad (2)$$

Where, Y is the dependent variable (rainwater or fog quantities), X_1, X_2, and X_n are the independent variables, a_1, a_2, and a_n are the coefficients for each independent variable, e is the error term, representing unobserved factors that affect the dependent variable but are not included in the model. The performances of the developed equations in this study were evaluated using statistical tests, namely the coefficient of determination (R^2). R^2 is the square of the correlation coefficient (R) and ranges from 0 to 1. R^2 closer to 1 indicates goodness of fit between observed and predicted dataset. R^2 is expressed by Eq. 3 (Choubin *et al.,* 2016):

$$R = \frac{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)^2 \sum_{i=1}^{n}\left(Y_i - \bar{Y}\right)^2}} \quad (3)$$

Where X_i is the observed values of independent variables, Y_i is the predicted value of the dependent variable for observation i, $\bar{X}$ is the mean of the observed values of the independent variable, $\bar{Y}$ is the mean of the predicted values of the dependent variable.

RESULTS AND DISCUSSION

Collected data

The current study on RFH from solar panels spanned a duration of 60 days. During the 60 days, the system experienced varying weather conditions, including rainy, snowy, and sunny days, the total rainwater harvested from the solar panels' system was 443.66 L, while the total fog water harvested from the solar panels' system was 28.17 L over the experimental solar panels' area of 4 m^2. During the study period, the rainwater and fog data collected from the solar panels' system (Figs. 4 and 5) were obtained through daily readings from the system. In the current study, for two solar panels the harvested rainwater ranged from 0.8 liters per day (L/d) to 117.66 L/d as shown in Fig. 4, and the harvested fog ranged from 0.25 L/d to 9.75 L/d as shown in Fig. 5.

Data analysis

According to Haque *et al*. (2016), comprehending the impact of climate change on the efficiency of water harvesting plays a crucial role in the strategic planning, effective management, and sustainable development of such systems.. A comparison between the harvested rainwater in the present study and the actual rainfall

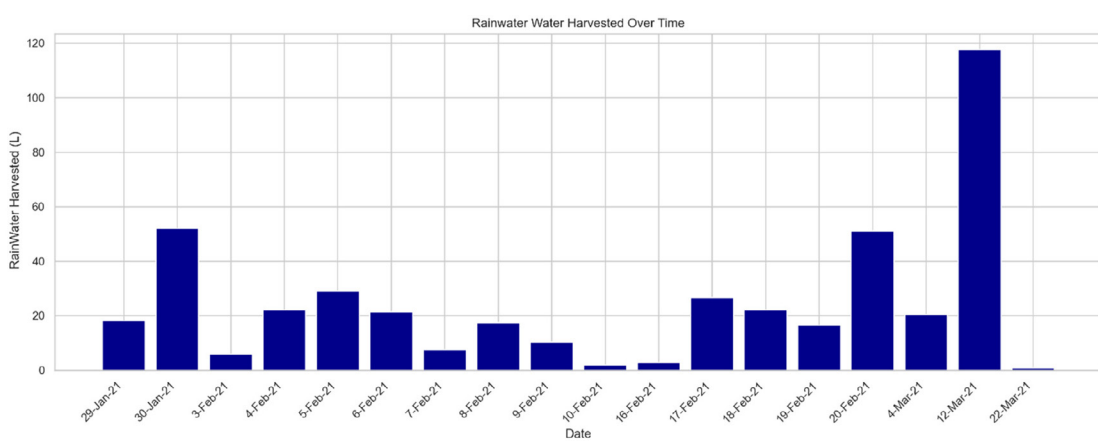

Fig. 4: Harvested Rainwater quantity from solar panels data throughout the duration of the study

data obtained from the solar farm weather station during the study period is shown in Fig. 6. R^2 for this relation is 90%, The percentage of the harvested rainwater to the actual rain is within the range of 50-100%, rainwater collection from solar panels rates ranged from 0.2 liters per square metre per day (L/m^2/d) to 44.42 L/m^2/d. It is important to highlight that the runoff coefficient for the solar panels as shown before in Eq. 1 is equal to 1, while the traditional rainwater systems have an average runoff coefficient of 0.85 for Asbestos Roof, 0.95 for Concrete Roof (Hari *et al.,* 2018). The efficiency of the conventional water harvesting system is greatly impacted by this variation, which ultimately favors the solar panels due to their higher runoff coefficient. The fluctuation in percentage can be ascribed to variables like wind direction, wind velocity, and ambient temperature. The highest percentage of harvested rainwater from the system (101.97%) representing the harvested rainwater of 2.59 mm which is more than the actual rain reading of 2.54 mm can be explained due to the wind direction on that day (280.790 degrees); which caused the rain to be captured more effectively as the solar panels faced west, aligning with other solar panels. Conversely, the lowest percentage of the harvested rainwater from the system was (28.62%) representing the harvested rainwater of 1.89 mm which is less than the actual rain reading of 6.60 mm due to the wind orientation on that

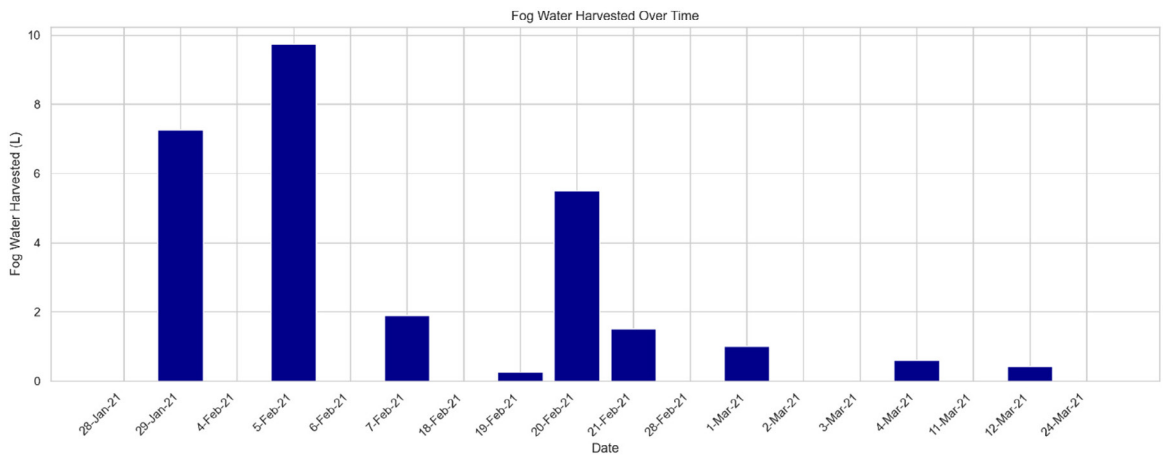

Fig. 5: Harvested fog quantity from solar panels data throughout the study

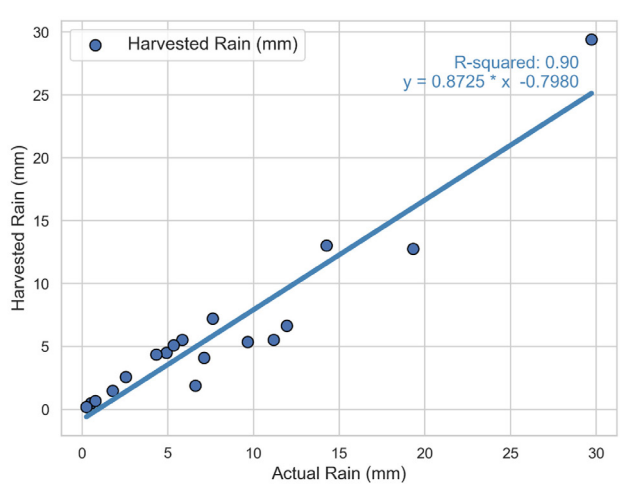

Fig. 6: Actual rain vs. harvested rain

day (152.627 degrees); which played a role, as it went against the direction of the solar panels orientation, leading to reduce the efficiency in rainwater collection. As shown in Fig. 6 the relationship between the actual and harvested rain without considering the other factors as the wind speed and orientation using Eq. 4, which was obtained using MLR.

$$\text{Harvested rain}(\text{mm}) = 0.8725\text{Actual rain}(\text{mm}) - 0.798 \quad (4)$$

Mosa *et al.* (2024) address the impact of variable wind directions and different speeds on the collection efficiency of water harvesting. To determine the expected RWH quantity, the sum of the wind direction in radians, the wind speed in (m/s), and the actual rain in (mm) were calculated based on the data obtained from the study as shown in Fig. 7. The general calculation for the RWH quantity (mm) is given in Eq. 4 which was obtained during data analysis using MLR.

One can notice that the most influential factor on the quantity of the harvested rain is the actual rain quantity with a 0.832 coefficient, the coefficient of determination R^2 for this relation is 94.3%, the wind speed effect is insignificant in the RWH quantity, using Eq. 5 which was obtained using MLR.

$$\text{H.R.} = -0.1075\text{W.D} + 0.0.0002\text{W.S} + 0.8320\text{A.R} \quad (5)$$

Where H.R. represents the harvested rain in mm, W.D. represents the wind direction in radians, W.S represents wind speed in meters per second, and A.R is the actual rain in mm. Eq. 5 allows for the prediction or calculation of harvested rain based on the given factors of actual rain, wind direction, and wind speed. The scientists investigating traditional water harvesting systems are analyzing data on wind direction, wind speed, and rainfall rate in order to enhance the alignment of the house, the design and incline of the roof, and the structural constraints (Yoo *et al.,* 2022), the solar farms provide simple structures with a suitable slope and orientation in open space away from obstacles and structural limitations. As the traditional fog collectors water quantity ranged from 1 L/m²/d to 30 L/m²/d for different types of fog collecters and at different locations (Batisha, 2015), the fog water collection from solar panels rates ranged from 0.1 L/m²/d to 2.44 L/m²/d which seems visible comparing to other special structures constructed specially for fog collection. In the very basic sense, fog is formed when the air temperatures drop to the dew point and when more water vapor is added to the air (Lakra and Avishek, 2022). In the current study, the fog harvesting quantity can be determined based on the sum of the temperature in (°C) and the relative humidity calculated based on the data obtained from the study as shown in Fig. 8. The general form of Eq. 6 using MLR for the fog harvesting quantity (L), noticing that the

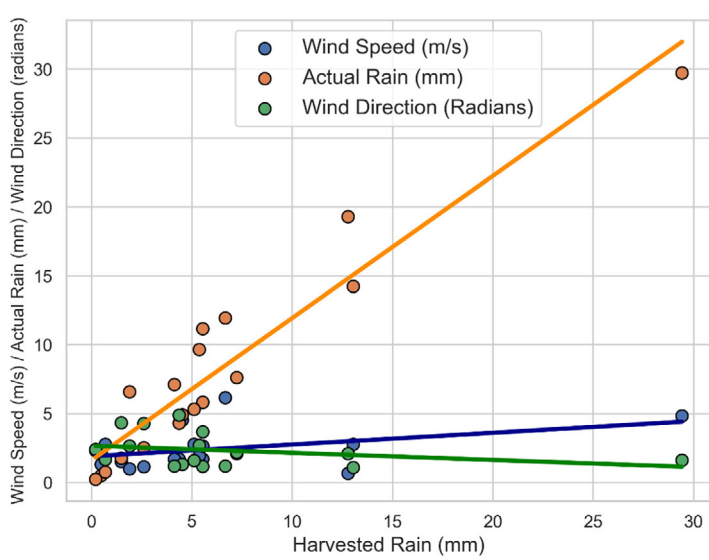

Fig. 7: Effects of wind speed, wind direction, and actual rain on the harvested water quantity

most impact factor on the quantity of the harvested fog is the relative humidity with a 2.2252 coefficient, the coefficient of determination R^2 for this relation is 50%, using Eq. 6, which was obtained using MLR.

$$\mathrm{H.F} = -0.17274\mathrm{T}(\mathrm{C}^\circ) + 2.2252\mathrm{R.H} \quad (6)$$

Where $\mathrm{H.F}$ represents the harvested fog in L, T represents ambient temperature $(^\circ\mathrm{C})$, and $\mathrm{R.H}$ is relative humidity (%). Eq. 6 allows for the calculation or prediction of fog harvesting quantity based on the given factors of temperature and relative humidity.

Various weather conditions and types of roofing materials have the potential to impact the quality of rainwater collected, as highlighted by Alamdari *et al*. (2018). In this study, samples of rainwater and fog were tested, with the results presented in Table 1. The results indicate that the minimum requirements for water treatment, in accordance with Jordan Standards and Metrology Organization (JSMO) for drinking water (JS 286/2015), are needed (Lee *et al.,* 2012) compared the harvested rainwater quality among four roof types (wooden shingles, concrete tiles, clay tiles, and galvanized steel) and results suggested that galvanized steel was suitable for roof rainwater harvesting due to ultraviolet light and high temperature, which acted as a disinfectant against bacterial pathogens, as the case in this study the solar panels can offer high temperature during the power generation and a smooth surface for pollutants slippage comparing to other traditional rough surfaces used in water harvesting. Further investigation is required to explore the correlation between the surface of solar panels and conventional surfaces used for water harvesting.

The feasibility of applying rainwater and fog harvesting from solar panels

Economic aspects of rainwater and fog harvesting from solar panels

Economic analysis considers water saving for agriculture as the main benefit of RWH systems (Pari *et al.,* 2021). RWH in urban areas offers various advantages beyond the environmental aspect, including social and financial benefits. A comprehensive financial analysis of the RWH system is essential to fully understand its impact (Amos *et al.,* 2016). To determine the viability of implementing rain and fog water collection from solar panels in solar farms, a comprehensive evaluation must be conducted. This evaluation should encompass the examination of all solar panels installed on the farm, as well as the central storage tank, piping, earthwork, mechanical work, and electrical work involved. Additionally, a thorough economic analysis should be undertaken to assess the project's feasibility. Considering all of these various actions would result in an increase in financial benefits, as well as a reduction in the payback period (Morales-Pinzón *et al.,* 2015). There are multiple uses for the rainwater and fog water harvested by the solar panels such as (a) to be pumped directly to the main domestic distribution system (Bocanegra-Martínez *et al.,* 2014) (b) for

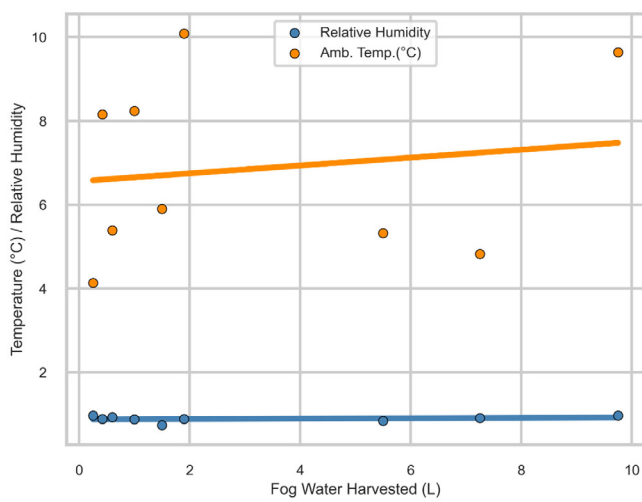

Fig. 8: Effects of ambient temperature and relative humidity on the harvested fog quantity

Table 1: Rainwater and fog harvesting by solar panels- water quality

Test type	Rainwater	Fog water	Jordanian Metrological Standard (JS 286/2015)
Total hardness as Calcium carbonate: $CaCO_3$ (Parts per million: ppm)	95	70	500
Total dissolved solids T.D.S. (ppm)	172	132	1000
Potential of hydrogen (pH)	7.8	7.6	From 6.5 to 8.5
Chloride: Cl (ppm)	0.0	0.0	500
Turbidity (Nephelometric turbidity unit: (NTU)	1.6	8.7	5
Electrical conductivity (EC) (microSiemens per centimeter: µs/cm)	263	202	from 200 to 800
Temperature (°C)	18.7	18.7	18

cleaning purposes of the solar panels (Bednárová *et al.,* 2023) (c) for Groundwater recharge (Noori and Singh, 2023). Since water savings are the primary benefit of the RWH System the water price is a key factor in its economic analysis (Morales-Pinzón *et al.,* 2014). The cost of water in Amman, generally, is often higher than in developed countries. The current water price for the domestic distribution system in Amman stands at 1.43 USD/m^3, while the price for solar panel cleaning is 5.64 USD/m^3. These figures take into account a 4% inflation rate in Jordan, as reported by the Department of Statistics (DOS). In terms of water harvested, the average quantity for all solar panels in the current solar farm, which consists of 20,880 solar panels, is 4,927.68 m^3. This amount is sufficient to meet the annual consumption needs of 55 people. Additionally, the total savings for domestic use are estimated to be around 7,050 USD, while the savings for solar panel cleaning amount to approximately 28,000 USD. The economic advantages of RFH depend on the quantity of water conserved and the cost that would have been incurred otherwise (Amos *et al.,* 2016).

Environmental aspects of rainwater and fog harvesting from solar panels

Rainwater and fog are naturally occurring, relatively clean, and are considerable sources of water in many locations in the world (Muktiningsih and putri, 2021). The RFH system involves collecting rainwater before it reaches the surface, reducing pollution and its effects. Unlike surface and groundwater, rainwater is naturally abundant and does not require pumping. The evaluation conducted by Ghimire *et al.* (2017) suggests that the standard commercial rainwater harvesting system outperforms the municipal water supply system in every aspect, with the exception of Ozone Depletion. RWH systems offer a benefit in times of conventional water supply system failures, like in natural disasters, conflicts, or system breakdowns (Amos *et al.,* 2018). By minimizing environmental and health impacts, as well as reducing stormwater runoff and sewer overflows, these systems have gained popularity among policymakers and environmental organizations due to their self-reliance. Similar to the benefits of rainwater harvesting, fog harvesting initiatives offer numerous advantages. Unlike rainwater harvesting, fog harvesting projects do not require any energy inputs and could potentially be linked to carbon sequestration efforts in conjunction with reforestation projects (Batisha, 2015). Fog harvesting proves to be highly advantageous in regions where traditional water sources are inaccessible due to challenges related to accessibility or population density (Ghosh and Ganguly, 2018). Traditional rainwater harvesting (RWH) and fog harvesting systems typically involve separate collection and storage setups. However, by combining rainwater harvesting with solar panels, a unified system can be created, leading to more efficient environmental damage mitigation. Utilizing the existing spaces provided by solar power plants is another factor that helps reduce environmental impact. Jordanian companies and government sectors are encouraged to demonstrate their commitment to environmental responsibility by supporting the RFH initiative. Despite potential financial constraints, setting up such a project is not the primary obstacle in these cases.

CONCLUSIONS

The utilization of solar panels in RFH presents numerous benefits such as affordability, environmental friendliness, and simplicity in collection. Compared to other established methods, fog harvesting on solar panels demonstrates superior effectiveness due to

the temperature contrast between the surrounding environment and the solar panels' surfaces. This contrast arises from the panels' absorption of sunlight throughout the day, enabling the condensation of fog droplets on the panels' surface, which can then be collected. The glass surface of the solar panels increases the runoff coefficient, resulting in enhanced runoff across the panel surface. This, in turn, improves the efficiency of water harvesting systems for both rainwater and fog. In this study, over a total solar panel area of 4 m^2 the solar panel system has collected a total of 444 L of rainwater ranging from 0.2 $L/m^2/d$ to 44.42 $L/m^2/d$ and 28 L of fog water ranging from 0.1 $L/m^2/d$ to 2.44 $L/m^2/d$ which seems visible comparing to other special structures constructed specially for fog collection. An empirical relationship for the RWH quantity and the sum of the wind direction in radians, the wind speed (m/s), and the actual rain (mm) is developed based on the results of this study. An empirical relationship between the fog harvesting quantity and the sum of the temperature (℃) and relative humidity (%) is developed based on the results of this study. The impact of the elevation, wind patterns, wind velocity, humidity, and temperature on rainwater and fog levels at the solar farm has been found to enhance the likelihood of rainwater and fog formation. It is suggested to utilize this approach in regions with elevated terrain to boost feasibility. According to the Jordanian standards for drinking water, the quality analysis of harvested water suggests that there are minimal treatment requirements. Additional investigation can delve into the water quality obtained from solar panel surfaces as opposed to conventional methods of water harvesting. Based on the findings, it is possible to develop RFH systems by making slight adjustments to the solar panel design and incorporating them into existing solar power plant infrastructure. This approach not only helps achieve the RFH objective but also alleviates the strain on water resources, in addition to fulfilling the primary goal of power generation. RFH has proven to be an economical and straightforward solution, presenting itself as a feasible substitute for conventional methods. The findings of the present investigation show great potential for the practicality and dependability of utilizing solar panels to collect rainwater and fog, which can significantly alleviate the issue of water scarcity in Jordan and across the globe. The escalating water scarcity problem in Jordan necessitates the government to intensify its efforts in implementing educational initiatives aimed at enhancing public understanding of water conservation and sustainable water management. Additionally, it is crucial for the government to allocate resources towards research and development of innovative technologies that promote water efficiency and the preservation of water resources. In the case of RFH the Jordanian government is urged to establish protocols to mandate the incorporation of rainwater and fog harvesting systems by setting standards in the designs and plans of new solar farm projects. While the study shows promising benefits of water harvesting from solar power plants, further research on a larger scale and for a longer duration is necessary for a comprehensive understanding of RFH systems. Additional study should concentrate on investigating the scalability and evaluating the quality of collected water in comparison to conventional methods across various sites and circumstances in Jordan to address the obstacles arising from shifts in rainfall and fog patterns.

AUTHOR CONTRIBUTIONS

I. Alazzam performed the literature review, research experimentation, and interpretation of the results and wrote the manuscript. K. Shatanawi supervised the work, concept formulation, data evaluation, and manuscript edition. R. Al-Weshah helped in the literature review, data evaluation, and manuscript preparation and editing.

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CONFLICT OF INTEREST

The authors declare that there are no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, were observed by the authors.

ABBREVIATIONS

%	Percent
µs/cm	MicroSiemens per centimetre
°C	Degree Celsius
C	Runoff Coefficient
$CaCO_3$	Calcium carbonate
Cl	Chloride
cm	Centimeter
DOS	Department of Statistics
EC	Electrical conductivity
Eq.	Equation
Fig.	Figure
JMD	Jordan Meteorological Department
JS	Jordanian Metrological Standard
JSMO	Jordan Standards and Metrology Organization
km	Kilometre
L	Liter
L/d	Liters per day
$L/m^2/d$	Liter per square meter per day
m	Metre
mm	Millimetre
mm/y	Millimetre per year
m/s	Metre per second (velocity unit)
m^2	Square metre
m^3	cubic metre
MLR	Multilinear regression
MWI	Ministry Of Water and Irrigation
NTU	Nephelometric turbidity unit
pH	Potential of hydrogen
ppm	Parts per million
PVC	Polyvinyl chloride
R	Correlation Coefficient
RFH	Rainwater and fog harvesting
R^2	Coefficient of determination
RWH	Rainwater harvesting
USD	United States Dollars
VR	Annual volume of rainwater

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