International Journal of Data Science and Advanced Analytics

Journal homepage: www.ijdsaa.com

Impact of Weather on Solar Panel Efficiency

Mustafa Hamid AL-Jumaili[1], Firas Fadhil Salih[2], Omar A. Aldhaibani[3]
[1, 2]University of Anbar, Iraq, [3]Liverpool John Moores University, UK
[1]Mustafa.hamid@uoanbar.edu.iq , [2] Firas.fadhil@uoanbar.edu.iq, [3] O.A.Aldhaibani@ljmu.ac.uk
Corresponding author email: Mustafa.hamid@uoanbar.edu.iq

Abstract— Photovoltaic systems are a popular form of renewable energy technology used to harness power in a sustainable manner. The effects of environmental factors such as rainfall on photovoltaic systems have been found to be quite pronounced through competing effects on irradiance attenuation and natural cleaning. This study aims to evaluate the effects of rainfall intensity on photovoltaic power output through a dynamic model of rainfall-soiling-power and experimental measurements. The study used a photovoltaic power system installed in Ramadi, Iraq. The experiment measured and monitored rainfall intensity, reference panel power, and natural panel power. The study used a mathematical model to simulate the effects of rainfall attenuation, soiling, and natural cleaning. The model simulated a dynamic model of dirt accumulation and predicted photovoltaic power output. The experiment found that light rain has a detrimental effect on photovoltaic power output through irradiance attenuation, but high rain intensity enhances power output through natural cleaning. The study found that high rain intensity, i.e., rain intensity above or equal to 15 mm, enhances power output by 9%. The model simulated power output with high accuracy and provided valuable insights on understanding photovoltaic power output behavior. The study found that rain plays a vital role in natural cleaning, thereby improving photovoltaic power output efficiency.

Keywords— Solar cell; Solar Panel Efficiency; Weather Impact; PV Panel; Sustainable Energy; Rain Effect on PV.

1. Introduction

Energy consumption is growing tremendously year by year due to rapid growth, comfort needs, increased mobility, and a growing global population. In the present scenario, fossil fuels like oil, coal, and gas are the major sources of energy [1]. Due to the vast usage of fossil fuels, environmental contamination is also one of the major issues nowadays. A great promise in meeting global energy demand with limited pollution and saving the environment is promised by renewable energy technologies [2]. Solar energy is considered highly recognized as the most promising and stable source of renewable energy. Because of this fact, most country governments are encouraging incentives in constructing solar energy-based power plants [3]. Various thermodynamic processes can convert solar energy into human-useable types of energy. In general, solar energy conversion can provide electrical energy, heat, kinetic energy, and chemical energy [4].

When assessing the use of PV technology, operating efficiency is a critical factor to consider. PV is typically tested inside under controlled test conditions (STC) of 25 degrees Celsius and 1000 W/m2 of solar irradiation [5]. The sunlight spectrum through the atmosphere, on the other hand, fluctuates based on location and meteorological circumstances, as well as airborne pollutants like water vapor, CO2, and dust particles, which can impact their efficiency, power production, and lifetime [6-8].

https://doi.org/10.69511/ijdsaa.v7i1.302
Received 25 April 2025; Received in revised form 20 July 2025; Accepted 18 September 2025.
Available online 18 September 2025.

The research has studied and analyzed the effects of types of pollutants indoors and outdoors on current, voltage, efficiency, and power of a PV panel [9]. Also, it has been indicated that dust has a deterring factor on the performance of the solar cell. In [10], the author provides a study on the effects of soiling on the energy output in ground-mounted solar systems in countryside southern Italy. It has also been observed that soil type and the process of washing are other factors affecting pollution-related losses, as in the case of a system built on sandy soil, there is about 7% of loss. In [11], the author reflects upon research findings concerning the effect of deposited dust on the power output from solar photovoltaic modules in the Eastern part of Saudi Arabia. The research depicts that the solar PV modules, if left uncleaned, may lose up to 50 percent of their output for over six months. In [12], one year of observations in Spain using a semi-automatic equipment based on short-circuit measurements of two PV panels is presented. Soiling rates between June and October are computed for the driest season of the year. More time is available for the accumulation of particles on the surface, and thus it would have a higher soiling factor with time [13-15]. This study points out that rates are similar in previous research findings.

Meanwhile, there have been some attempts to conduct research into showing how rainfall affects polluted PV solar cells in performance as part of the following studies. The authors in [16] have indicated that glass transmittance is particularly influenced by dust deposition density, tilt angle, and orientation of the surface regarding wind direction. Besides, the rain washed off the dust that had deposited on the clear cover of the PV cell and increased the transmittance, thus the power production increased. In, the study in Belgium [17], rain seems to have a noticeable influence to wash out large particles of dust settling on PV module and less influence on tiny particles. The influence that hard and soft shading have on the performance of the photovoltaic panels, and how directly the shade influences power production, is considered in [18].

Some of the renewable energy studies include, but are not limited to, a wide range of domains such as solar energy [19, 20], autonomous vehicles [21, 22], communications quality of service (QoS) [23], wireless sensors [24], materials of solar panel manufacturing [25], and machine learning and deep learning [26], and several other research areas. In this view, our interest is focused on the performance of the solar panel under special weather conditions.

Due to the long daily duration of light hours and high levels of solar radiation, Iraq possesses a big potential of solar energy harvesting. This privilege makes Iraq very suitable for large PV plants building in the region [27, 28]. The effect of dusty weather conditions in Ramadi-Iraq was studied on the properties of PV modules. Results were obtained with an efficiency of 13.7% more, while the minimum was 9.8% with dust, amounting to 16.2 g/m2, with a drop in charging power of 28.5% regarding without dust, which means to say that the charging parameter decreases at an increased rate of dust.

In [29] environmental factors influencing the performance of PV panels were studied by the detailed investigation of performance of two identical PV installations in respect to their exposure to weather. The effect of dust deposition on panels, exposed to outdoors, was tested through a set of outside glass units, mounted on a roof at different tilt angles and analyzed after one to four weeks of exposure. Experiments showed that as few as small particles could cut down the transmission of light by as much as 11%. The average size of dust particles collected from outdoor glass units is less than 400 microns, but the effect on sunlight transmittance caused by the glasses was about 5% after one month of the experiments. The climatic nature of Iraq contains a desert environment where sand and dust storms are increasing day by day in the country. This paper, based on the above discussion, presents a study of the effect of rainfall for washing off the PV panel with fixed tilt angle and examines the performance of the solar panel for six months. Although there are several articles that have studied the weather effect on solar panels, this paper is the first study, to our knowledge, focuses on the effect of rainfall on PV panels.

The remaining six sections are as follows: Section 2 describes the rainfall percentages and data calculations of air temperature and sunshine hours. Section 3 describes the methodology of the search and measurement setup. Section 4 discusses the mathematical model, model component and the dynamic Rainfall–Soiling–Power Model. Section 5 show the model validation while section 6 discusses the results in view of an analysis of advantages and disadvantages of power production and rainfall. Conclusions and important findings are summarized in Section 7.

2. Rainfall Percentages

The climate in Ramadi, Iraq, is characterized by significant seasonal variations in temperature [30]. During the winter months, the average temperature in January is around 9.5 °C (49 °F), but the summer months bring extreme heat, with average temperatures rising to 45 °C (113 °F) in July and occasionally reaching as high as 47 °C (116 °F). Summer in Ramadi is intensely hot, with peak temperatures nearing 50 °C (122 °F), and the sun shines brightly for most of the day. While the winter days are typically mild and pleasant, nighttime temperatures can drop significantly, often falling below freezing, creating a sharp contrast between day and night. Figure 1 illustrates the average air temperatures over a six-month period, from October to March, which includes the colder winter months. Ramadi experiences a limited amount of annual rainfall, with approximately 150 mm (6 inches) of precipitation, almost all of which occurs between October and March. The dry season stretches from June to September, during which virtually no rain falls. This rainfall pattern means that the city's wet season coincides with the cooler part of the year, while the hot summer months are marked by drought-like conditions. Figure 2 provides a visual representation of the monthly average precipitation levels in Ramadi, showing the concentration of rainfall during the late autumn and winter months.

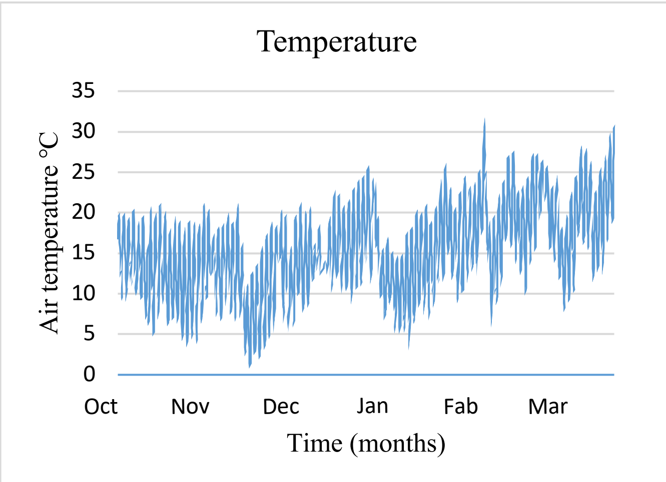

Fig. 1. Air temperatures in Ramadi city for six months.

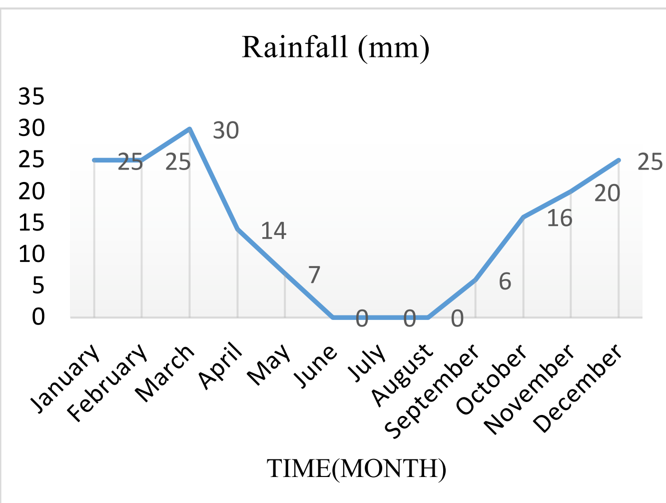

Fig. 2. Monthly average rainfall in Ramadi city

In Ramadi, the sun shines quite often even from October to March as shown in table 1, however, some weather fronts might have an impact on the city. Even though cloud banks might occasionally reach the region in the summer, bright sky dominate. Figure 3 shows the average solar radiation during the day in March 2024, in Ramadi city. It is obvious from these table and figure that the city has a very high solar radiation up to 1000 Watt/m2 and long hours of sunshine up to 11.5 hours per day. Thus, it is a suitable place for installing solar farms with high performance.

Table 1. Sunshine hours in Ramadi city

Time (Month)	Average (Hours)	Total (Hours)
Jan.	6	190
Feb.	7	205
Mar.	8	245
Apr.	8.5	255
May	9.5	300
Jun.	11.5	350
Jul.	11	345
Aug.	11.5	355
Sep.	10.5	315
Oct.	9	275
Nov.	7	215
Dec.	6.5	195
Year	8.9	324

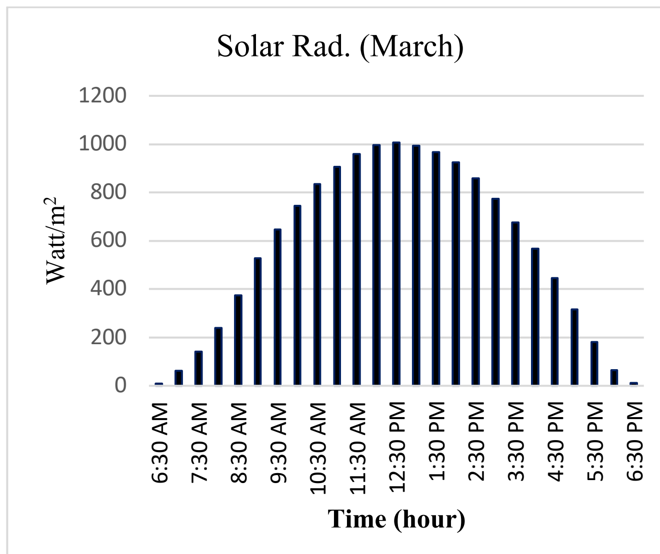

Fig. 3. Average solar radiation during the day in March 2024.

2.1. Weather Station

Figure 4 shows the wireless weather station that was used in this research. It has a transmission range of up to 300 meters and data updates every 60 seconds. It also features a display. The solar-powered sensor suite includes an auto-emptying rain bucket, an exterior temperature, humidity sensor, a wind gauge, and mounting hardware. A wireless transmission kit is provided for remote Anemometer installation. Indoor humidity and temperature, barometric pressure, dew point, tendency and graph, and wind chill.


Fig. 4. The wireless weather station that is used in this research.

3. Methodology

3.1 Measurement setup

The research site is located at the Renewable Energy Research Center, University of Anbar, near the city of Ramadi, which is at latitude 33.4366° N and longitude 43.2683° E. Figure 5 shows the measuring system, which contains two identical solar panels from the same manufacture (Kyocera) to guarantee identical electrical parameters. The first panel is regularly cleaned and used as a reference PV module, while the second one is left without cleaning, letting it naturally be cleaned and showing the effect of rainfall on the characteristics of the photovoltaic panel. The weather station is installed on the same site with different kinds of sensors calculating the temperature, the rain, and other climate changes. First, the calculation of the rainfall effect will be done in accordance with the power production of each PV module and the rainfall ratio of the same day, reference-cleaned and tested-uncleaned. Throughout the experiment, all the power produced by both panels is recorded using a data logger.

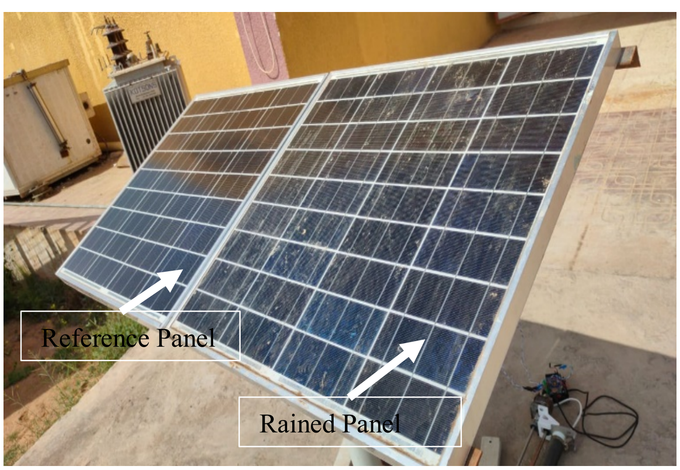

Fig. 5. The reference panel is on the left and the rained panel is on the right.

3.2 Work Steps

The work steps for the experiment begin with providing two identical Kyocera 54-watt solar panels and manufacturing a suitable frame to hold both panels securely. Next, a suitable location is chosen for mounting the panels, ensuring that they are positioned at a 33° tilt angle facing south for optimal sunlight exposure. A data logger is then installed to record the system's performance, and maximum power point tracking (MPPT) is implemented to optimize energy capture. A dummy load is connected to the power produced by the panels. One panel is cleaned weekly while the other is left uncleaned to simulate natural conditions. Data is collected periodically, and the performance of each panel is analyzed by comparing the energy production to solar radiation data from a nearby weather station. Finally, charts are drawn up based on the results to evaluate and compare the efficiency of each panel. Figure 6 shows the flowchart of the work steps that are used in this paper.

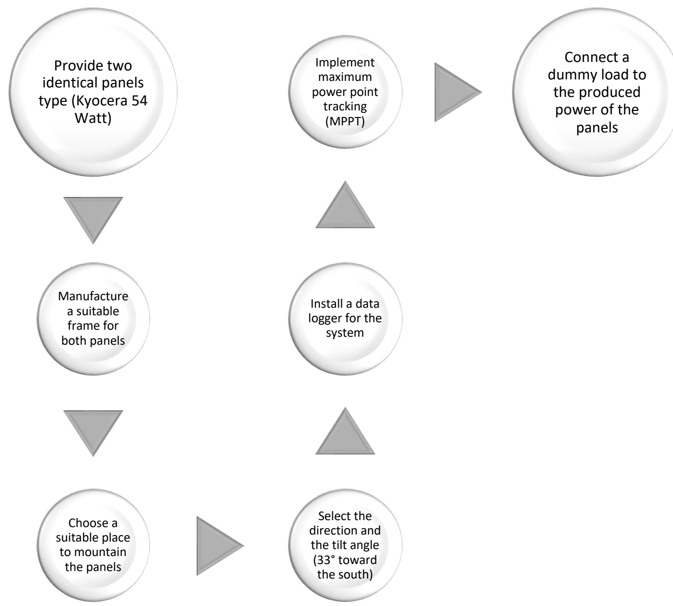

Fig.6. Flowchart of the work steps of the project.

4. Mathematical Model

To characterize the impact of rainfall on the output power of photovoltaic systems, a mathematical model was proposed that accounts for the combined effect of rainfall attenuation, accumulation of dirt, and the cleaning action of rainfall. The mathematical model describes the net power output $P_{net}(t)$ of a photovoltaic panel in terms of the rainfall intensity R(t) and the amount of dirt accumulation D(t).

Variables:

- P_0: Maximum power under Standard Test Conditions (STC)
- P_{net} (R, D): Net power output under rainfall and soiling conditions

- $R(t)$: Rainfall intensity (mm/h)
- $D(t)$: Dirt accumulation level (dimensionless, $0 \le D \le 1$)
- $\eta(R)$: Efficiency factor considering light attenuation from clouds and rain
- $C(R)$: Cleaning effectiveness of rainfall
- t: Time (hours)

Assumptions:
The model is based on the following physical assumptions:

- Rainfall attenuates solar irradiance reaching the panel surface.
- Light rainfall provides limited cleaning effect.
- Heavy rainfall provides significant cleaning of accumulated dirt.
- Dirt accumulates gradually over time due to environmental exposure.
- Rainfall cleaning effectiveness increases nonlinearly with rainfall intensity.

4.1 Model Components:

1. Efficiency Loss from Rain Attenuation

Model how rain reduces irradiance:

$$\eta(R)= 1-a_1 R \qquad (1)$$

a_1 is the rainfall attenuation coefficient (mm^{-1})
R is rainfall intensity.

2. Cleaning Effect of Rainfall

Rainfall removes accumulated dirt from the photovoltaic surface. The cleaning effectiveness is modelled using an exponential function:

$$C(R)=1- e^{(-b1\,R)} \qquad (2)$$

b1 is the cleaning coefficient,
C(R) ranges from 0 (no cleaning) to 1 (complete cleaning).
This nonlinear function captures the stronger cleaning effect of heavy rainfall.

3. Dirt Accumulation Dynamics

Dirt accumulation increases over time but decreases due to rainfall cleaning. The dirt accumulation dynamics are modelled using the differential equation:

$$dT/dD =\delta-\gamma C(R) \qquad (3)$$

δ is the dirt accumulation rate,
γ is the cleaning efficiency coefficient.
This equation describes the balance between continuous dirt accumulation and rainfall cleaning.
For numerical implementation, the discrete-time form is used:

$$D(t+1) = D(t)+\delta-\gamma C(R(t)) \qquad (4)$$

with constraint:

$$0 \le D(t) \le 1$$

4. Power Output Model:

The net photovoltaic power output is modelled as:

$$P_{net} =P_0 \cdot \eta(R)\cdot(1-\alpha D(t)) \qquad (5)$$

α is the soiling loss coefficient,
D(t) represents dirt accumulation.
This equation captures the combined effects of rainfall attenuation and dirt accumulation on power output.

4.2 Dynamic Rainfall–Soiling–Power Model

To describe the interrelationship between rainfall, soiling, and power, a dynamic rainfall-soiling-power model has been developed. In this model, the rainfall intensity is considered the system input, soiling accumulation the system state, and net power output the system output. In this model, the soiling accumulation state is updated dynamically using Eq. 4, and the net power output is calculated using Eq. 5. This model helps in the simulation and prediction of PV performance in various environmental conditions.

5. **Model Validation**

To validate the proposed model, observed rainfall intensity and photovoltaic power data were used. In the experiment, the reference panel power $P_0(t)$ and the power generated by the panel under test were measured, and the rainfall intensity was used as the input signal. The proposed model was written using the MATLAB program according to Equations (4) and (5), and the parameters used in the simulation are listed in Table 2.

Table 2. Model parameters used in the rainfall–soiling–power model

Parameter	Description	Value
a_1	Rain attenuation coefficient	0.015
b_1	Cleaning coefficient	0.2
δ	Dirt accumulation rate	0.01
γ	Cleaning efficiency	0.5
α	Soiling power loss coefficient	0.3

Figure 7 illustrates the dynamic behavior of the rainfall-soiling-power model by considering the actual rainfall data as the input signal. The top graph indicates the rainfall intensity over time, including significant rainfall events exceeding 15 mm. The second graph indicates the actual dirt accumulation level over time. The level increases gradually during dry periods due to constant dust accumulation and decreases rapidly following rainfall events due to the cleaning action. The bottom graph indicates the actual net photovoltaic power output. During the arid periods, the gradual increase in the dirt accumulation level results in reduced photovoltaic power

output due to significant soiling loss. On the other hand, significant rainfall events cause rapid changes in the dirt accumulation level, which enables significant recovery in the photovoltaic power output.
The results verify the accuracy of the rainfall-soiling-power model in simulating the dynamic behavior of rainfall intensity, dirt accumulation level, and actual photovoltaic power output. The results match the actual experimental results by indicating rapid performance degradation during the dry periods and rapid performance recovery following significant rainfall events.

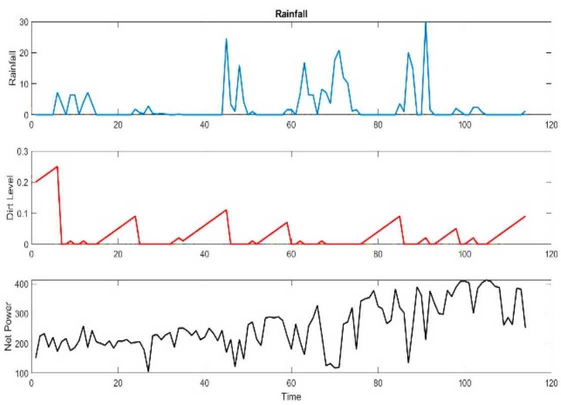

Fig. 7. Dynamic rainfall–soiling–power model response showing rainfall input, dirt accumulation, and net photovoltaic power output.

6. Results and Discussion

Figure 8 shows the daily rainfall data collected during the six-month period from October 1, 2023, to March 31, 2024. The period corresponds to the wet season in Iraq, where rainfall events are expected to clean the panels as part of the natural process. The dry season in Iraq corresponds to the period from April to September, where rainfall is minimal with increased levels of dust accumulation on the panels. As shown in Figure 8, rainfall events were intermittent with several heavy rainfall events with rainfall rates higher than 15 mm, thus providing an opportunity for natural cleaning of the panels.
While figure 9 shows the daily energy output comparison between the reference panel and the tested panel during the same period from October 1, 2023, to March 31, 2024. The reference panel was cleaned every seven days to ensure optimal performance and was used as the basis of comparison with the tested panel. The tested panel was exposed to natural environmental conditions without any artificial cleaning to assess the effect of rainfall events in the cleaning of the panels.
During the initial two weeks in October, the performance of the panels was almost identical, as shown in Figure 9, with minimal levels of dust accumulation on the panels. As the panels accumulated more dust, the performance of the tested panel gradually deteriorated relative to the reference panel. The light rainfall events with rainfall rates less than or equal to 5 mm in late October and early November failed to improve the performance of the panels but instead reduced the performance temporarily due to the formation of mud layers as a result of the interaction between rainfall and dust accumulation on the panels. The formation of mud layers is common in arid desert environments where high levels of dust are present in the air, as in the case of Ramadi.
Light rainfall events with rainfall rates less than or equal to 4 mm in early January and late March failed to clean the panels but instead reduced their performance in some cases. The above observations indicate that rainfall events are dependent on the intensity of rainfall in order to clean the panels effectively.

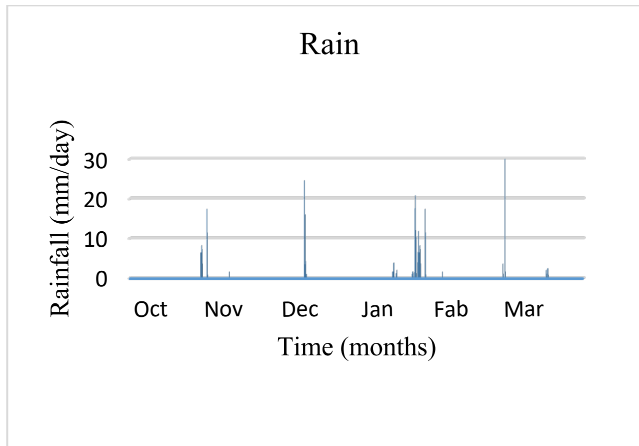

Fig. 8. Daily rainfall for six months in Ramadi city.

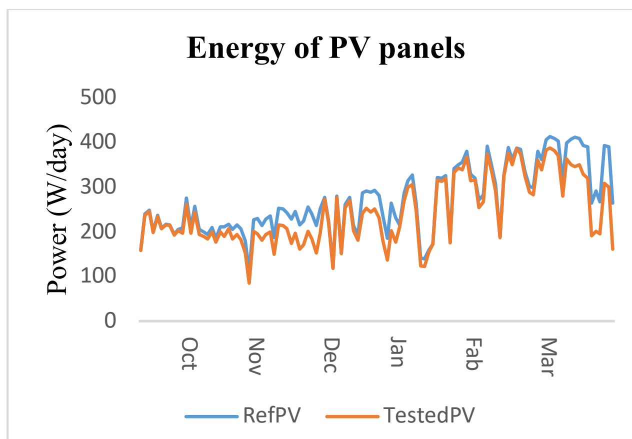

Fig. 9. Energy of both panels reference one and tested one for six months.

The summary of the relationship between rainfall intensity and changes in photovoltaic energy performance is shown in Figure 10. As shown in this figure, light rain with intensity less than 15 mm resulted in a reduction in energy between -2% and -10%. This reduction in energy is attributed to mud formation on the surface. On the other hand, rain intensity higher than 15 mm resulted in a significant improvement in photovoltaic performance, with gains up to 25%. This indicates the existence of a rain cleaning threshold.

As shown in Figure 11 below, there is an evident increase in the performance ratio before and after the occurrence of heavy rainfall events (≥15 mm), with improved performance in the PV system after the rainfall events. The median performance ratios increased from 0.95 to 0.98 after the rainfall events. In addition to that, there is an evident improvement in the minimum performance ratios, implying that there was an effective removal of dirt from the PV surface. The reduced variability in the performance ratios after the rainfall events also proves that there was an improvement in the PV performance after the rainfall events.

Quantitatively, the improvement in efficiency due to heavy rainfall is 9%, implying that there was an improvement in the PV efficiency after the rainfall events. The experimental findings have validated the proposed rainfall-soiling-power model and have shown that it is effective in accurately predicting the dynamic interaction between rainfall events, dirt accumulation, and PV power outputs.

From the experimental findings above, it is evident that there is a double-edged effect of rainfall events on PV performance. In the first place, rainfall with low intensity reduces PV performance due to irradiance attenuation and formation of mud on the PV surface. On the other hand, heavy rainfall events improve PV efficiency by providing an effective cleaning service to the PV surface. The findings have shown particular importance in the context of PV system performance in arid regions where rainfall acts as an effective cleaning service to PV surfaces.

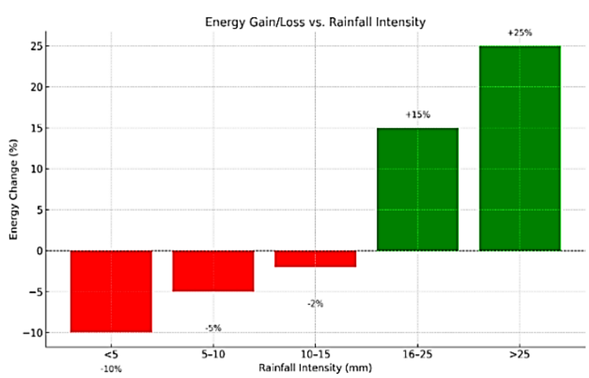

Fig. 10. Graphical representation of PV energy gain/loss vs. rainfall.

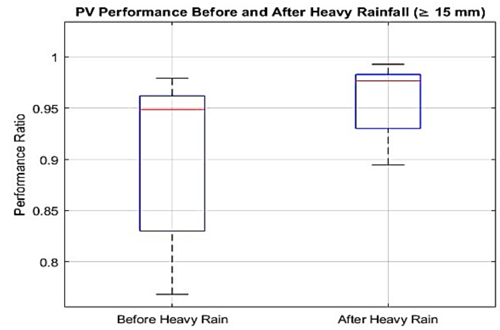

Fig. 11. The performance ratio before and after heavy rainfall events.

6.1 Advantages of Rainfall on Photovoltaic Performance

Rainfall provides a number of advantages to photovoltaic systems in terms of improved performance through natural cleaning. The natural cleaning process occurs when dust and dirt on the surface of photovoltaic systems are washed off. The dust and dirt on the surface of photovoltaic systems decrease solar irradiance on photovoltaic cells, thereby resulting in a loss in power output due to shading effects. The soiling loss in arid environments can be as high as 15 to 25 percent depending on the level of dust on the surface.

The natural cleaning process through heavy rainfall is effective in improving the performance of photovoltaic systems. The natural cleaning process occurs when there is sufficient rain to wash off dirt on the surface of photovoltaic systems. The experimental results from this study have shown that rainfall above a certain level, i.e., 16 mm, provides a high level of improvement in the performance of photovoltaic systems. As shown in Figure 11, the natural cleaning process through heavy rainfall resulted in a mean improvement in efficiency of 9 percent, with a high level of improvement in performance ratio.

The existence of a rain cleaning threshold is a major operational parameter in improving the performance of photovoltaic systems. Rainfall below this level is not sufficient to wash off dirt on the surface, but rainfall above this level is sufficient to wash off dirt on the surface. This natural cleaning process through rainfall can be used to improve the performance of photovoltaic systems by minimizing manual cleaning costs, particularly in desert environments.

6.2 Disadvantages of Light Rainfall on Photovoltaic Performance

On the other hand, unlike intense rain, light rain has a negative effect on photovoltaic performance. Rainfall less than 15 mm, below the cleaning threshold, cannot provide enough cleaning power to remove accumulated dust from the surface. Instead, light rain mixes with dust particles to form mud, which sticks to the surface. This mud increases optical loss because it blocks solar radiation from reaching the photovoltaic cell. Unlike dust, mud sticks to the surface and cannot be blown off by wind; rather, it has to be cleaned manually. As found in this study, light rain causes a decline in photovoltaic performance, resulting in a loss in generated power between 2% and 10%, depending on the intensity of rain and previous dust accumulation on the surface. Besides, light rain causes accelerated soiling on the surface, thereby requiring frequent cleaning, leading to a reduction in photovoltaic efficiency and an increase in operational costs because of manual cleaning activities. Although rain provides many advantages to photovoltaic systems, light rain causes a decline in photovoltaic performance and increases soiling loss.

7. **Conclusion**

This research aimed to investigate the impact of rainfall on the performance of photovoltaics. The researchers used a combination of hands-on measurements and a dynamic model of rainfall, soiling, and power. They monitored the performance of two identical panels, one of which was kept clean while the other was left to experience the effects of the weather. The research showed that rainfall has a two-fold impact on the performance of photovoltaics. It showed that light rainfall does not completely remove the soiling of the panels but sometimes causes the panels to dip slightly in performance because of the muddy film it leaves behind. On the other hand, heavy rainfall was seen to clean the panels very well. The researchers were also able to identify the rainfall cleaning threshold of 15 mm. This means that if the rainfall is heavy enough to reach 15 mm or more, the panels can improve in performance by 25%, with the average increase in efficiency being 9%.

The dynamic model of rainfall, soiling, and power developed in the research was also seen to perform well. This research has several implications. It showed that in an arid environment, heavy rainfall can actually clean the panels. Knowing the rainfall cleaning threshold is important because it can reduce the need for cleaning the panels. This can increase the efficiency of the panels.

References

[1] V. V. Tyagi, N. A. A. Rahim, A. Jeyraj, and L. Selvaraj, "Progress in solar PV technology: Research and achievement," Renewable and Sustainable Energy Reviews, vol. 20, pp. 443-461, 2013.

[2] D. Gayen, R. Chatterjee, and S. Roy, "A review on environmental impacts of renewable energy for sustainable development," Int. J. Environ. Sci. Technol., vol. 21, no. 5, pp. 5285–5310, 2024.

[3] K. Ukoba, K. O. Yoro, O. Eterigho-Ikelegbe, C. Ibegbulam, and T. C. Jen, "Adaptation of solar power in the Global South: Prospects, challenges and opportunities," Heliyon, 2024.

[4] T. M. N. T. Mansur, N. H. Baharudin, and R. Ali, "A comparative study for different sizing of solar PV system under net energy metering scheme at university buildings," Bull. Electr. Eng. Inform., vol. 7, no. 3, pp. 450-457, 2018.

[5] M. I. Islam, M. S. B. Jadin, A. Al Mansur, and T. Alharbi, "Electrical performance and degradation analysis of field-aged PV modules in tropical climates: A comparative experimental study," Energy Convers. Manage. X, vol. 24, p. 100719, 2024.

[6] S. Ghazi and K. Ip, "The effect of weather conditions on the efficiency of PV panels in the southeast of UK," Renewable Energy, vol. 69, pp. 50-59, 2014.

[7] M. Memiche, C. Bouzian, A. Benzahia, and A. Moussi, "Effects of dust, soiling, aging, and weather conditions on photovoltaic system performances in a Saharan environment—Case study in Algeria," Global Energy Interconnection, vol. 3, no. 1, pp. 60-67, 2020.

[8] M. T. Chaichan and H. A. Kazem, "Experimental evaluation of dust composition impact on photovoltaic performance in Iraq," Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, pp. 1-22, 2020.

[9] Fatima, K., Minai, A. F., Malik, H., & Márquez, F. P. G. “Experimental analysis of dust composition impact on Photovoltaic panel Performance: A case study”. *Solar Energy*, *267*, 112206, 2024.

[10] Borah, P., Micheli, L., & Sarmah, N. Analysis of soiling loss in photovoltaic modules: a review of the impact of atmospheric parameters, soil properties, and mitigation approaches. *Sustainability*, *15*(24), 16669, 2023.

[11] M. J. Adinoyi and S. A. M. Said, "Effect of dust accumulation on the power outputs of solar photovoltaic modules," Renewable Energy, vol. 60, pp. 633-636, 2013.

[12] R. Conceição, I. Vázquez, L. Fialho, and D. García, "Soiling and rainfall effect on PV technology in rural Southern Europe," Renewable Energy, vol. 156, pp. 743-747, 2020.

[13] T. Sarver, A. Al-Qaraghuli, and L. L. Kazmerski, "A comprehensive review of the impact of dust on the use of solar energy: History, investigations, results, literature, and mitigation approaches," Renewable and Sustainable Energy Reviews, vol. 22, pp. 698-733, 2013.

[14] S. Ghazi, A. Sayigh, and K. Ip, "Dust effect on flat surfaces–A review paper," Renewable and Sustainable Energy Reviews, vol. 33, pp. 742-751, 2014.

[15] M. R. Maghami, H. Hizam, C. Gomes, M. A. Radzi, M. I. Rezadad, and S. Hajighorbani, "Power loss due to soiling on solar panel: A review," Renewable and Sustainable Energy Reviews, vol. 59, pp. 1307-1316, 2016.

[16] H. K. Elminir, A. E. Ghitas, R. H. Hamid, F. El-Hussainy, M. M. Beheary, and K. M. Abdel-Moneim, "Effect of dust on the transparent cover of solar collectors," Energy Convers. Manage., vol. 47, no. 18-19, pp. 3192-3203, 2006.

[17] R. Appels et al., "Effect of soiling on photovoltaic modules," Solar Energy, vol. 96, pp. 283-291, 2013.

[18] Mustafa H. Al-Jumaili, A. S. Abdalkafor, and M. Q. Taha, "Analysis of the hard and soft shading impact on photovoltaic module performance using solar module tester," Int. J. Pow. Elec. & Dri. Syst., vol. 10, no. 3, pp. 1015-1020, 2019.

[19] Al-Jumaili M. H., H. M. Haglan, M. K. Mohammed, and Q. H. Eesee, "An automatic multi-axis solar tracking system in Ramadi city: Design and implementation," Indonesian J. Electr. Eng. Comput. Sci., vol. 19, no. 3, pp. 1126-1234, 2020.

[20] K. W. Abid, B. H. Sulaiman, O. I. Abd, and H. A. Rahman, "Study the impact of the ideality factor and the dust on the performance of solar panels," J. Green Eng., vol. 10, pp. 2615-2626, 2020.

[21] M. H. Al-Jumaili and Y. E. Özok, "New control model for autonomous vehicles using integration of Model Predictive and Stanley based controllers," Sci. Rep., vol. 14, no. 1, p. 19872, 2024.

[22] Al-Jumaili M. H., Y. E. Özok, A. A. Ibrahim, and O. Bayat, "A robust hybrid control model implementation for autonomous vehicles," in 2024 8th Int. Artif. Intell. Data Process. Symp. (IDAP), pp. 1-5, IEEE, Sep. 2024.

[23] O. A. Aldhaibani et al., "A centralized architecture for autonomic quality of experience oriented handover in dense networks," Comput. Electr. Eng., vol. 94, p. 107352, 2021.

[24] M. H. Al-Jumaili and B. Karimi, "Maximum bottleneck energy routing (MBER)—An energy efficient routing method for wireless sensor networks," in 2016 IEEE Conf. Wireless Sensors (ICWiSE), pp. 38-44, Oct. 2016.

[25] E. H. Sabbar et al., "Effects of Ag content on microstructure evolution, intermetallic compound (IMC) and mechanical behaviour of SAC solder joints," Microelectron. Reliab., vol. 147, p. 115103, 2023.

[26] A. H. Abdulwahhab et al., "A review on medical image applications based on deep learning techniques," J. Image Graph., vol. 12, no. 3, 2024.

[27] A. R. Alzyoud et al., "The impact of integration of solar farms on the power losses, voltage profile and short circuit level in the distribution system," Bull. Electr. Eng. Inform., vol. 10, no. 3, pp. 1129-1141, 2021.

[28] Y. Elamri et al., "Rain concentration and sheltering effect of solar panels on cultivated plots," Hydrol. Earth Syst. Sci., vol. 22, no. 2, pp. 1285-1298, 2018.

[29] S. A. Kalogirou, R. Agathokleous, and G. Panayiotou, "On-site PV characterization and the effect of soiling on their performance," Energy, vol. 51, pp. 439-446, 2013.

[30] "Annual weather of Ramadi city- western of Iraq," Climates to Travel. [Online]. Available: https://www.climatestotravel.com/climate/iraq. [Accessed: Aug. 2025].