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Research Article

The Impact of Air Pollution on The Performance of Solar Photovoltaic Cells: A Case Study in Baghdad City, Iraq

Israa M. Al-Tameemi^{1,*}¹ Department of Environmental Engineering, Mustansiriyah University, Baghdad, Iraq* Israa.Murtadha@uomustansiriya.edu.iq

ABSTRACT

This study was conducted to evaluate the effect of air pollution due to dust storms on a sustainable source to generate photovoltaic electricity (PV) modules and estimate if the efficiency of the modules could be affected by air pollution. The study is located in Baghdad Province, Waziriya district/ Iraq where training and Energy Research building depends on PV modules for electricity generation. There was a substantial demand to study the effect of accumulated dust on (PV) modules because of the frequency of dust storms in the region due to air pollution and climate change. It was observed that the performance of (PV) modules is considerably affected by dust on the surfaces of such devices by air pollution. The study indicates that there is decreasing in power by as much as 8 % in solar (PV) modules that are left unclean for two weeks in comparison with modules which be cleaned daily.

Keywords: Air Quality, Dust Storm, PV Modules, Photovoltaic, Solar Cells

INTRODUCTION

Multi-temporal It Baghdad, the capital of Iraq with an area of 204 km² is located at 33° 18' 46.0980" N, 44° 21' 41.3568" E in the middle of Iraq. Iraq is faced with a major climate change that impacts on air quality and weathering especially increasing in temperature [1]. Increasing population and development in industry as well as technology in order to meet needs of people lead to increase the pollution [2]. Electricity is the major need in different aspects of life and it is generated from different sources such as fossil fuels. Emissions from electricity power stations including

greenhouse gases (GHG) effects adversely on environment and global warming[3];[4]. As a solution, applying renewable energy being an essential need in order to decrease the traditional sources in power generation. The sun in Iraq regards as one of the renewable energy sources which could be applied to generate electricity through solar photovoltaics' modules (PV) [5]. The mechanisms of solar cells technology is depending on using a semi-conductor (Silicon usually) which absorbs photons from sun light which later converted to voltage [6]. The biggest challenge with solar photovoltaic (PV) systems is that these technologies are affected by weather conditions that affect their performance. In practice, achieving a balance between supply and demand, especially during peak periods, is one of the most important generation bases for planning energy production in power stations[7][8]. The presence of dust has a notable effect on photovoltaic (PV) modules, diminishing the amount of solar radiation that reaches the module and subsequently reducing its efficiency. Dust accumulation additionally hinders the transmission of radiation onto the surfaces of PV modules. To mitigate the impact of dust, experts concur that regular cleaning of PV modules is necessary. The frequency of cleaning may vary, typically ranging from monthly to weekly, contingent upon prevailing weather conditions and the concentration of airborne dust [9], [10]. In Iraq dust storms are a common occurrence [11]. Ministry of Environment Iraq reported 122 dust storms and 283 dust days in 2012, and predicted more than 300 dust storms in the next decade [12]. In 2022, the United Nations and the Iraqi Ministry of Environment jointly declared that Iraq experienced a significant influx of dust storms. Air pollution, especially from vehicles and power plants, can greatly diminish the output and effectiveness of these cells. Certain forms of airborne particles like soil and rock dust have a notable influence on cell performance. Pollutants in the air, such as materials from construction sites, can obstruct solar light from reaching the cells, resulting in decreased power output and efficiency. Conversely, better air quality has the potential to improve solar power performance while reducing the need for installed photovoltaic capacity.

The efficiency of commercial PV panels varies between 15% and 20%. However, when dust accumulates on these panels, their efficiency is significantly reduced; cleaning them requires both time and effort, resulting in higher maintenance costs and decreased efficiency [14]. In regions, like Iraq, where oil and gas resources abundant the solar energy industry faces a challenge

***Corresponding author**

Israa M. Al-Tameemi,

Department of Environmental Engineering, Mustansiriyah University, Baghdad, Iraq

e-mail: Israa.Murtadha@uomustansiriya.edu.iq

due to the impact of dust accumulation on solar panels. The efficiency of cells can drop by much as 50% because of the dust buildup, especially in hot and dry areas. Factors such as dust density, sunlight intensity and surface materials play a role in determining the extent of this efficiency loss. Regular cleaning is essential to minimize this issue. Dust storms worsen the situation in environments with high concentrations of airborne particles. When dust mixes with moisture on panels it forms a layer that is hard to clean off. Research by Darwish et al. Highlights the need for studies on how dust deposition affects the performance of solar energy systems. Understanding this phenomenon requires taking into account environmental and weather conditions specific to each site [15]. The Iraqi Minister of Electricity predicts that by 2030 around 33% of electricity production will be from power plants emphasizing the importance of studying how desert sandstorms impact the efficiency of panels [16]. Despite research, on factors influencing panel performance it is crucial to explore these effects further. Fouad et al., 2017 found that presence of dust and dirt could lead to huge loss in the power generation capacity of a solar cell by blocking the sunlight falling on the PV module [17]. Another study in Baghdad Iraq, quantified the loss in the PV performance due to the dust accumulation, the study revealed that, performance of the PV decreased by 6.24%, 11.8%, 18.74%, daily, weekly, and monthly respectively [18]. In Los Angeles USA, a study compared three identical PV systems connected in a commercial office park. The study reported that the pollution and dust deposition could lead to 5% loss in the system performance annually [19]. This study addresses the effects of dust and dust storms on PV power plants and modules. The results of this study could be used by the Iraqi government as a basis for making decisions about the efficiency, economic feasibility and cleaning process of these plants and their long-term success in providing stable electricity.

MATERIALS AND METHODS

STUDY AREA

The study was conducted in Al-Wazireya district located in Baghdad city, Iraq. Baghdad is the capital of Iraq as shown in Fig.1 The region has a high population density and is facing a significant issue of air pollution resulting from traditional energy generation [20]. Solar energy application is very promising and possible because of the high solar radiation intensity and long brightness period for the year. Baghdad's weather is hot in summer and moderate in winter [21]. During the summer, the average lowest temperature varies from approximately 27°C to 31°C and reaches a peak between 41°C and 45°C. The longest brightness time is reached at 11.4 hours /day in June and the shortest is 6.3 hours /day [22].

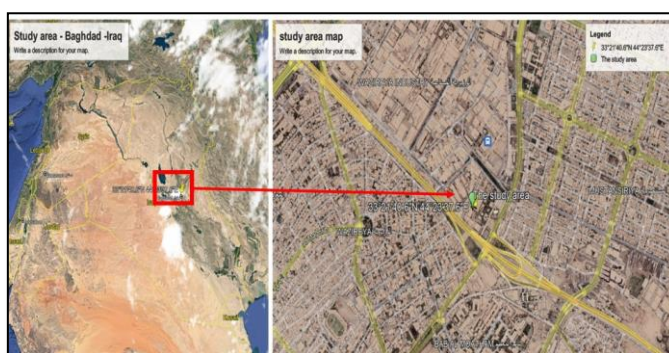


Figure 1. The location of study area.

PHOTOVOLTAIC (PV) STRUCTURE PLATFORM AND MEASUREMENT SYSTEM

The test system was set up on the roof of the building in an open area which is regarded as a solar park in Wazireya District, Baghdad, covering a total area of 489 m². Fig. 2 shows a picture of the test field.



Figure 2. PV modules.

Polycrystalline silicon solar cells invented by Almansour Solar were selected for gathering the PV modules. The rated maximum power output of each module was 340 W under standardized conditions for test. Table 1 shows the module specifications. The

*Corresponding author

Israa M. Al-Tameemi,

Department of Environmental Engineering, Mustansiriya University, Baghdad, Iraq

e-mail: Israa.Murtadha@uomustansiriya.edu.iq

photovoltaic (PV) array consisted of six strings of twelve PV modules. In our study, two arrays have been used. Each array was connected to an inverter in order to transform direct current into alternating current. For the trial, array number 3 was connected with inverter 3 as shown in Fig. 3(a). While array 4 was connected to inverter 4 as appeared in Fig. 3(b).



A) Inverter 3



b) Inverter 4

Figure 3. Inverters overview.

Table 1: Specifications of The PV modules

Parameters	Values
Model	ZS 340P-72
Rated Maximum Power	340 p
Voltage at P _{max} (V _{mp})	37.65 V
Current at P _{max}	9.03 A
Open-Circuit Voltage	44.43 V
Short-Circuit Current	9.57 A
Normal Operating Cell Temperature	46±2°C
Maximum System Voltage	1000 VDC
Maximum Series Fuse Rating	15A
Operating Temperature	-40 to +85°C
Cell Technology	Polycrystalline silicon
Weight	21.8 kg
Dimensions	1956x992x40 mm

This arrangement for structures were used to assess photovoltaic (PV) modules' efficiency when it is clean and unclean in the test system to evaluate the effect of dust which accumulated from dust storm. The power outputs of PV modules were measured with solar inverter SUNNY TRIPOWER model STP 25000TL-30 on daily bases. The Sunny Tripower STP 25000TL-30 is engineered to deliver dependable and effective operation for larger solar setups. Its sophisticated characteristics, excellent efficiency, and durable construction have established it as a favored option for commercial use, enabling businesses and solar project planners to enhance their renewable energy production and maximize their investment returns.

***Corresponding author**

Israa M. Al-Tameemi,
Department of Environmental Engineering, Mustansiriyah University, Baghdad, Iraq
e-mail: Israa.Murtadha@uomustansiriya.edu.iq

It is equipped with an integrated web connect functionality for convenient monitoring and system administration. It offers entry to the Sunny Portal, a cloud-based monitoring platform that enables users to monitor real-time performance data, retrieve historical information, and adjust inverter settings from a remote location.

Daily measurements consist of the calculation of current and voltage readings for PV modules utilizing the SUNNY TRIPOWER model STP 25000TL-30 as shown in Fig. 4.



Figure 4: Screen Of Solar Inverter.

WEATHER STATION

HP2K WIFI weather station was installed to measure ambient temperature, rainfall rate, wind speed, and wind direction as shown in Fig.5



Figure 5: HP2K WIFI Weather Station.

The weather station has a solar-powered sensor wireless data which uploads data storage solar radiation automatically and has a screen as shown in Fig. 6. Table 2 includes detailed information for measuring station meteorological conditions.

*Corresponding author

Israa M. Al-Tameemi,
Department of Environmental Engineering, Mustansiriyah University, Baghdad, Iraq
e-mail: Israa.Murtadha@uomustansiriya.edu.iq



Figure 6: Screen Of HP2K WIFI Weather Station.

Table 2: Detailed Information Of HP2K WIFI Weather Station.

Model	HP2K WIFI
Measuring Humidity	Relative 1% to 99%
Temperature Range	30 °C - 65 °C
Rain Volume Display	0 – 9999mm
Wind Speed	0-50m/s (0~100mph)

Table 3: Weather conditions through study period from HP2K WIFI Weather Station.

Parameters	Values
Stability	Stable
Wind speed	3.88 (m/s)
Solar radiation rate	732.4 (j/cm ² /day)
Length of the day	11.4 hours /day
Temperature average	37.8 °C
Precipitation rate	Less than 1 mm

RESULTS AND DISCUSSION

*Corresponding author

Israa M. Al-Tameemi,
 Department of Environmental Engineering, Mustansiriyah University, Baghdad, Iraq
 e-mail: Israa.Murtadha@uomustansiriyah.edu.iq

The study assessed the impact of dust buildup on photovoltaic systems, irrespective of the specific nature of the accumulated dust. In Figure 7, it was noted that the build-up of dust from a dust storm on the surfaces of PV module 4 over a period of two weeks without cleaning had a negative impact on its performance compared to PV module 3, which was cleaned daily during the test. On the first day of the research on June 5th, 2023, both arrays had similar conditions, resulting in an output power from inverters 3 and 4 of approximately 149537.045 KWh and 143537.045 KWh respectively - a nearly identical performance. Over time, the output from PV module 4 decreased to 132279.982 KWh on the fourteenth day of testing, while the productivity of well-maintained PV modules increased to reach 151592.181 KWh by the end of the study period.

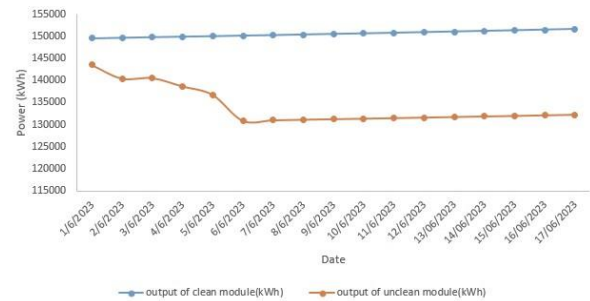
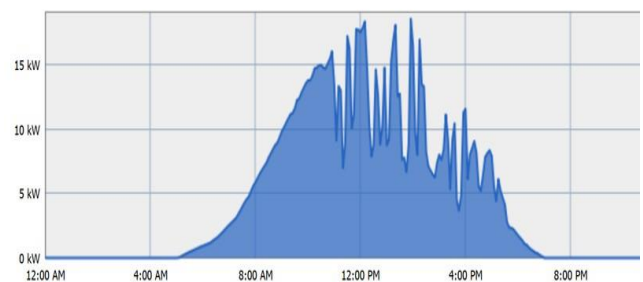
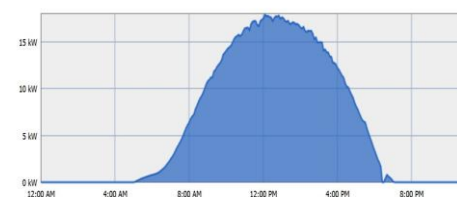


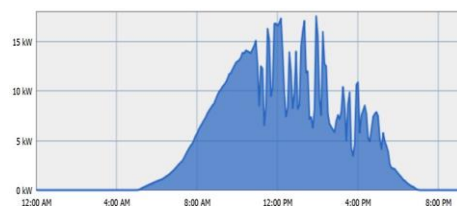
Figure 7: Performance Of Modules. The decrease in power output from the PV modules is attributed to the reduced amount of direct solar radiation reaching the light-transmitting element due to dust deposition caused by frequent dust storms in Baghdad. Fig. 8 (c and d) demonstrates the fluctuating performance of unclean PV after two weeks of accumulating dust, while Fig. 8 (a and b) depicts an increase in power productivity.



(a) Power output for clean PV at the first day of test



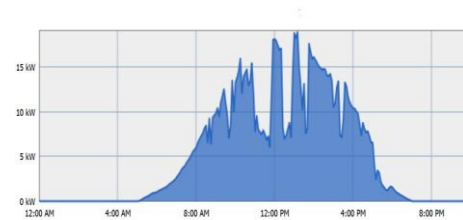
(b) Power output for clean PV at the last day of test



(c) Power output for unclean PV at the first day of test

***Corresponding author**

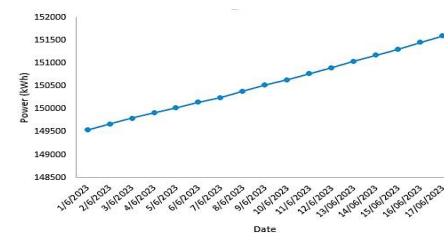
Israa M. Al-Tameemi,
Department of Environmental Engineering, Mustansiriya University, Baghdad, Iraq
e-mail: Israa.Murtadha@uomustansiriyah.edu.iq



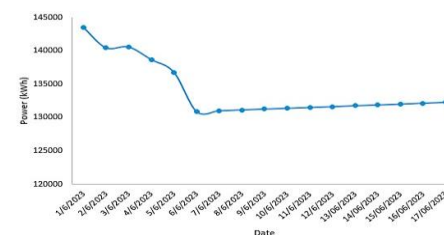
(d) Power output for unclean PV at the last day of test

Figure 8: Performance Of Modules.

Throughout the test period, there was a clear progression in the output energy of clean modules as indicated by Fig.9 (a). The maximum value reached 151592.181 Kwh on the final day of testing whereas a decline in energy generation was noted in units that had accumulated dirt, as displayed in Fig.9 (b).



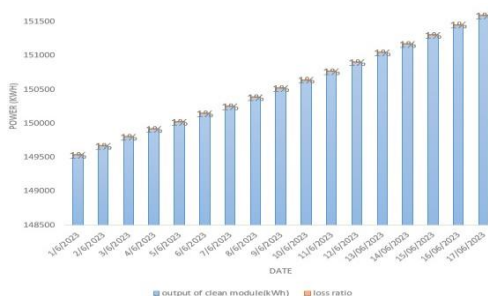
(a) Clean Modules



(b) Unclean Modules

Figure 9: Energy Output (Kwh).

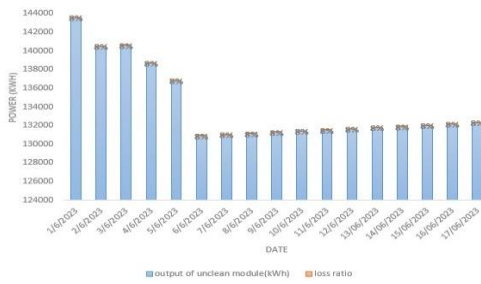
The efficiency of the array connected to inverter 3 experiences a slight decrease of approximately 1%, as illustrated in Figure 10 (a). The fluctuating energy output of the clean modules during the first week can be attributed to changing weather conditions, alternating between dusty and rainy. Conversely, during the second week, consistently sunny weather resulted in more stable energy production. In Figure 9 (b), a significant reduction in energy output is observed for the array connected to inverter 4, which was only washed infrequently (apart from by rain), resulting in an estimated loss ratio of around 8% shown in Figure 10(b). This drop in productivity occurred due to dust accumulation on the surfaces of solar cells leading to decreased photon absorption from sunlight - a crucial factor for motivating semiconductor materials to generate current.



*Corresponding author

Israa M. Al-Tameemi,
Department of Environmental Engineering, Mustansiriyah University, Baghdad, Iraq
e-mail: Israa.Murtadha@uomustansiriya.edu.iq

(a) Clean Modules



(b) Unclean Modules

Figure 10: The Loss Ratio.

The power generation variations between cleaned and uncleaned modules over a period of two weeks are depicted in Figure 11. The observed data indicates that the loss ratio varied within the range of 4% to 13%.

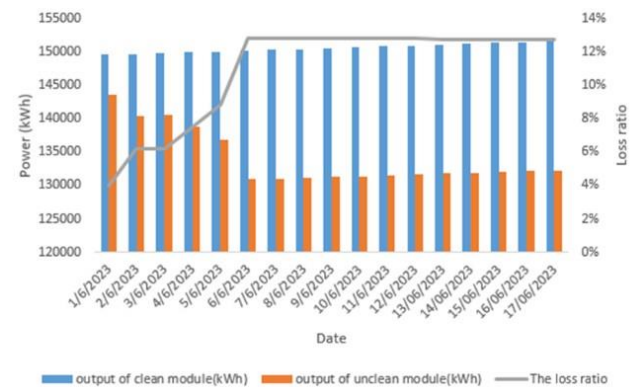


Figure 11: The Loss Ratio between Clean and Unclean Module.

Several studies have emphasized the noteworthy influence of dust on the functioning of photovoltaic cells in Baghdad.[23] and [24] both discovered that the buildup of dust on the solar cells resulted in decreased current, voltage, and power output.[25] and [26] underscored the significance of dust attributes and dust storms in this phenomenon. The selection of PV modules also influences the outcome, as [27]discovered that specific types are better suited for the area. [24] and [28] proposed practical remedies like regular maintenance, while [29] emphasized the significance of the PV module's surface material in both dust accumulation and efficiency decline.

CONCLUSIONS

The main conclusion of this study is that dust storms have been a regular phenomenon in Baghdad and are regarded as air pollution that happens as a result of climate change and temperature increases. The dust accumulated on PV surfaces has an impact on the performance of PV cells because it covers the surfaces of solar cells which means reducing the sun radiation which has photons that are responsible for incentivizing the semi-conductor's cells to generate current. This coverage of solar radiation by accumulation dust has an effect on power output where it has observed a reduction in uncleaned PV modules for two weeks with a loss ratio of around 8%, whereas the cleaned PV modules conserve on its high productivity. Based on the above, it suggested that regular cleaning of PV panels is required particularly during the period of dust storms, and installing an automatic sprayer cleaning system.

*Corresponding author

Israa M. Al-Tameemi,
Department of Environmental Engineering, Mustansiriyah University, Baghdad, Iraq
e-mail: Israa.Murtadha@uomustansiriyah.edu.iq

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ABBREVIATIONS ACRONYMS

a _m	ante meridiem meaning "before midday"
E	East
GHG	Greenhouse gaseous
K	Kilometer
K _{wh}	Kilowatt hour
N	North
PV	Photovoltaic
V _{MP}	Voltage at Pressure max
W	Watt

REFERENCES

- [1] S. H. Halos, A. Al-Dousari, G. R. Anwer, and A. R. Anwer, "Impact of PM2.5 concentration, weather and population on COVID-19 morbidity and mortality in Baghdad and Kuwait cities," *Modeling Earth Systems and Environment*, pp. 1–10, 2021.
- [2] T. Katopodis and A. Sfetsos, "A review of climate change impacts to oil sector critical services and suggested recommendations for industry uptake,"
- [3] *Infrastructures*, vol. 4, no. 4, p. 74, 2019.
- [4] M. Mostefaoui, H. Mazari, S. Khelifi, A. Bouraiou, and R. Dabou, "Simulation of high efficiency CIGS solar cells with SCAPS-1D software," *Energy Procedia*, vol. 74, pp. 736–744, 2015.
- [5] I. Murtadah, Z. T. Al-Sharify, and M. B. Hasan, "Atmospheric concentration saturated and aromatic hydrocarbons around dura refinery," in *IOP Conference Series: Materials Science and Engineering*, 2020. doi: 10.1088/1757-899X/870/1/012033.
- [6] Y. K. Dwivedi et al., "Impact of COVID-19 pandemic on information management research and practice: Transforming education, work and life," *International journal of information management*, vol. 55, p. 102211, 2020.
- [7] P. C. of S. P. R. by J. G. P. and R. S. P. Maximization, "Position control of solar panel receiver by joint generated power and received signal power maximization," *Tikrit Journal of Engineering Sciences*, vol. 25, no. 3, pp. 24–29, 2018.
- [8] H. Böök and A. V Lindfors, "Site-specific adjustment of a NWP-based photovoltaic production forecast," *Solar Energy*, vol. 211, pp. 779–788, 2020.
- [9] W. Köhler and K. I. Morozov, "The solet effect in liquid mixtures—a review," *Journal of Non-Equilibrium Thermodynamics*, vol. 41, no. 3, pp. 151–197, 2016.
- [10] B. Hammad, M. Al-Abed, A. Al-Ghandoor, A. AlSardeah, and A. Al-Bashir, "Modeling and analysis of dust and temperature effects on photovoltaic systems' performance and optimal cleaning frequency: Jordan case study," *Renewable and Sustainable Energy Reviews*, vol. 82, pp. 2218–2234, Feb. 2018, doi: 10.1016/J.RSER.2017.08.070.
- [11] M. A. M. Ramli, E. Prasetyono, R. W. Wicaksana, N. A. Windarko, K. Sedraoui, and Y. A. AlTurki, "On the investigation of photovoltaic output power reduction due to dust accumulation and weather conditions," *Renew Energy*, vol. 99, pp. 836–844, Dec. 2016, doi: 10.1016/J.RENENE.2016.07.063.
- [12] I. A. Dahham, "Effect of the Combined Pollution of Brick Industry and Sandstorms on the Performance of High Voltage Insulators and Flashover Phenomenon," *Tikrit Journal of Engineering Sciences*, vol. 25, no. 1, pp. 69–73, 2018.
- [13] M. T. Chaichan et al., "Sand and Dust Storms' Impact on the Efficiency of the Photovoltaic Modules Installed in Baghdad: A Review Study with an Empirical Investigation," *Energies*, vol. 16, no. 9, p. 3938, 2023.
- [14] S. A. Abdulrahman, "Iraq's environment: from dustfall to soilfall," *International Journal of Environmental Studies*, pp. 1–3, 2022.

*Corresponding author

Israa M. Al-Tameemi,

Department of Environmental Engineering, Mustansiriya University, Baghdad, Iraq

e-mail: Israa.Murtadha@uomustansiriyah.edu.iq

- [15] N. J. Kadia, E. T. Hashim, and O. I. Abdullah, "PERFORMANCE OF DIFFERENT PHOTOVOLTAIC TECHNOLOGIES FOR AMORPHOUS SILICON (A-SI) AND COPPER INDIUM GALLIUM DI-SELENIDE (CIGS) PHOTOVOLTAIC MODULES," *Journal of Engineering and Sustainable Development*, vol. 26, no. 1, pp. 95–105, 2022.
- [16] Z. A. Darwish, H. A. Kazem, K. Sopian, M. A. Al-Goul, and H. Alawadhi, "Effect of dust pollutant type on photovoltaic performance," *Renewable and Sustainable Energy Reviews*, vol. 41, pp. 735–744, 2015.
- [17] J. Terrapon-Pfaff and S. R. Ersoy, "Sustainable transformation of energy systems in MENA countries: comparative report," 2022.
- [18] M. M. Fouad, L. A. Shihata, and E. S. I. Morgan, "An integrated review of factors influencing the performance of photovoltaic panels," *Renewable and Sustainable Energy Reviews*, vol. 80, pp. 1499–1511, 2017, doi: 10.1016/j.rser.2017.05.141.
- [19] M. Saidan, A. G. Albaali, E. Alasis, and J. K. Kaldellis, "Experimental study on the effect of dust deposition on solar photovoltaic panels in desert environment," *Renew Energy*, vol. 92, pp. 499–505, Jul. 2016, doi: 10.1016/J.RENENE.2016.02.031.
- [20] J. Denver, J. A. Miller, J. Jackson, V. Gupta, and J. Hoffner, "Impact of Soiling and Pollution on PV Generation Performance," 2009.
- [21] E. Abdul-Rahman and M. F. A.-D. Ahmad, "Comparison of water quality index at intakes of water treatment plants in Baghdad city," *Tikrit Journal of Engineering Sciences*, vol. 20, no. 4, pp. 23–34, 2013.
- [22] A. R. Abdulmunem, A. A. Jadallah, H. A. Hoshi, and M. H. Jabal, "Effect of colored filters on PV panels temperature and performance under Baghdad meteorological condition," *Tikrit Journal of Engineering Sciences*, vol. 25, no. 4, pp. 46–50, 2018.
- [23] M. J. B. Buni, "A review of solar energy applications in Baghdad-Iraq," *International Journal of Trend in Research and Development*, vol. 7, no. 1, pp. 13–20, 2020.
- [24] Ma. Saidan, A. G. Albaali, E. Alasis, and J. K. Kaldellis, "Experimental study on the effect of dust deposition on solar photovoltaic panels in desert environment," *Renew. Energy*, vol. 92, pp. 499–505, 2016.
- [25] M. T. Chaichan et al., "Sand and Dust Storms' Impact on the Efficiency of the Photovoltaic Modules Installed in Baghdad: A Review Study with an Empirical Investigation," *Energies*, vol. 16, no. 9, p. 3938, 2023.
- [26] A. Ghazi and F. Mustafa, "Dust effects on the performance of PV street light in Baghdad city," in *2013 International Renewable and Sustainable Energy Conference (IRSEC)*, 2013, pp. 18–22.
- [27] A. A. Kazem, M. T. Chaichan, and H. A. Kazem, "Dust effect on photovoltaic utilization in Iraq," *Renew. Sustain. energy Rev.*, vol. 37, pp. 734–749, 2014.
- [28] A. H. Shnishil, S. S. Chid, M. J. Yaseen, and T. J. Alwana, "Influence of air mass on the performance of many types of PV modulus in Baghdad," *Energy Procedia*, vol. 6, pp. 153–159, 2011.
- [29] A. Lay-Ekuakille, A. Ciaccioli, G. Griffio, P. Visconti, and G. Andria, "Effects of dust on photovoltaic measurements: A comparative study," *Measurement*, vol. 113, pp. 181–188, 2018.
- [30] H. Jiang, L. Lu, and K. Sun, "Experimental investigation of the impact of airborne dust deposition on the performance of solar photovoltaic (PV) modules," *Atmos. Environ.*, vol. 45, no. 25, pp. 4299–4304, 2011.

***Corresponding author**

Israa M. Al-Tameemi,

Department of Environmental Engineering, Mustansiriyah University, Baghdad, Iraq

e-mail: Israa.Murtadha@uomustansiriyah.edu.iq