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REDUCING THE EVAPORATION LOSSES FROM HADITHA AND DUKAN DAM RESERVOIRS USING FLOATING PHOTOVOLTAIC PANELS

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Graphical abstract

Abstract

The worldwide water and energy problem has become a pressing issue that requires collaborative action. Floating solar power plants have recently gained significant attention as a dependable alternative. These plants utilize photovoltaic modules placed on the water constructions surface, such as dams reservoir. The present study investigates the impact of covering the water reservoirs of Haditha and Dukan Dam in Iraq on evaporation losses. The effect of meteorological conditions is examined in the period from July to the end of December. Also, the impact of the coverage percentage has been investigated for values 20%, 40%, 60% and 80%. The results showed that as the maximum temperature decreases from 46 °C to 25.6 °C decreases the evaporation rate from Haditha reservoir by 84%, while decreasing the maximum temperature from 46 °C to 22 °C reduces the evaporation rate by 88% from Dukan reservoir. Also, The results reveal that the maximum water saved from Haditha and Dukan reservoirs could reach 12,587,487 m^3/day and 8,444,493 m^3/day respectively

Keywords: Floating PV system, Evaporation, Water conservation, Water scarcity, Evaporation reduction

1.0 INTRODUCTION

Water management in arid and semi-arid areas has become a crucial problem owing to several causes, including population increase, climate change, and regional transitions. Hence, effectively administrating these resources conserves a significant quantity of water and contributes to economic development while reducing water scarcity disparities. Evaporation from lakes and huge water bodies is a significant cause of water losses in these regions. Dry conditions and high temperatures cause billions of cubic metres of freshwater to be lost. The rate of evaporation loss differs between reservoirs and is influenced by fluctuations in hydro-meteorological data. Examining the evaporation process will enhance our comprehension of the mechanisms and patterns that govern the natural movement of water and its related processes [1–4].
Studies on estimating water evaporation in lakes and reservoirs have been conducted since the early 1900s. The quantification of weather conditions involves the analysis of meteorological data, including solar radiation levels, wind speed, relative humidity, air
temperature, and atmospheric pressure. Furthermore, acquiring it directly is a challenging task, so alternative approaches for estimating it indirectly were devised [5-6].

The floating photovoltaic (FPV) system is a potential approach for mitigating evaporation from open water surfaces. Compared to solar panels put on land, floating solar panels have several advantages. These include fewer obstructions obstructing sunlight, increased convenience, improved energy efficiency, and higher power generation efficiency due to the lower temperature beneath the panels. The solar installation has many advantages, including the reduction of water evaporation rates, the management of algae development, and the potential improvement of water quality via the shading offered by the plant. [7] as listed in table 1

Table 1 Advantages and disadvantages of FPV [8-9].

Advantages	Disadvantages
• Higher conversion efficiencies due to the cooling nature of water and in many cases the absence of dust. • FPV installations can reduce surface water evaporation. Particular importance in arid regions. • FPV requires no land, so does not compete with other land-users such as agriculture, mining or tourism. • FPV limits algae growth thus improving water quality. • Risk of theft and vandalism is reduced.	• Higher initial investment, operation & maintenance costs. • Electrical safety challenges when building and operating PV in water. • Metallic structures are more prone to corrosion, hence FPV has a shorter lifetime than ground-mounted PV. • Lack of separate regulations for permitting and licensing FPV projects.

Depending on climatic conditions and the type of solar cells, a typical overland photovoltaic (PV) module converts 4–18% of the incident solar energy into electricity. Solar radiation is converted to heat for the remainder of the incident, resulting in a substantial increase in the temperature of the PV [10-13]. By its installation on water, an FPV experiences a considerably reduced ambient temperature as a result of the cooling influence of water. Consequently, floating-type solar panels have an 11% greater efficiency than ground-mounted solar panels [14-18].

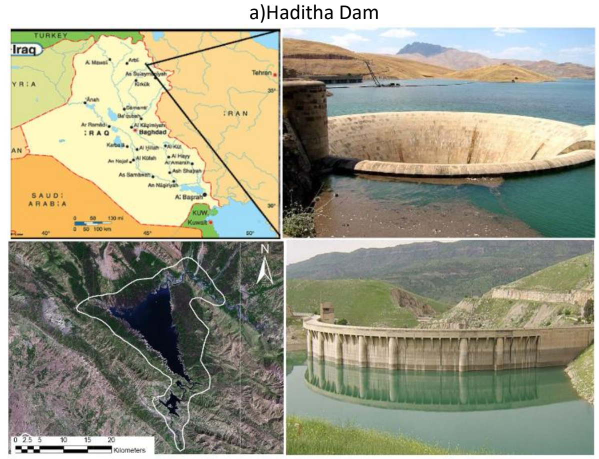
There have been many investigations on FPV, evaluating them from various perspectives. Abid et al. [19] conducted a review to evaluate the potential and to emphasize the significance of floating solar panel technology. They explored various possibilities of FPV in different global regions and emphasized the importance of these technologies in areas with limited water resources. El-Hamid et al. [20] investigated experimentally the effect of using FPV as a cover on Nasser Lake in Egypt on evaporation losses. The findings indicated that when 25%, 50%, 75%, and 100% of the lake surface is covered, it results in a conservation of approximately 2.1, 4.2, 3.7, and 84 billion cubic metres per year, respectively. Also, the results indicated that covering low-depth areas of the lake could save more water than covering high-depth regions. Scavo et al. [21] modelled and analysed the influence of PVs on the evaporation rate from the water surface of basins. The experimental measurements of the evaporation were compared with results from numerical models from literature. The results showed that installing suspended and floating PVs on 30% of the lake could reduce the evaporation rate by 18% and 42%, respectively. Santos et al. [22] evaluated the influence of using FPV on the evaporation rate of the Passaúnaa reservoir in Brazil. The evaporation rate was calculated using the Penman-Monteith method. The results demonstrated that covering the whole surface of the reservoir could save 2.69 million m^3. Farra et al [23] reported that using FPV system could save 12700 m^3 of water in Jordan. Yigit and Akçadag [24] investigated the effect of FPV system on the evporation from turgutla pond in Turkey. They roported a reduction in water evporation by 94.4 m^3.

In recent years, evaporation losses from rivers, lakes, and reservoirs in Iraq have become a severe problem due to the small amount of water released from dams in Turkey due to political issues and the shortage of rains. According to the Iraqi Ministry of Water Resources, the evaporation losses in 2023 were about 3.6 billion m^3[25]. Therefore, assessing and reducing evaporation losses has become a persistent need. The present work assesses the evaporation losses from several main dams in Iraq and proposes an effective method of using floating photovoltaic panels as a cover to reduce the evaporation losses. Also, the effect of the coverage percentage of the FPV on the water surface is investigated. To the authors' knowledge, no work dealt with this issue in Iraq.

2.0 STUDY AREA

The present work assesses the evaporation from the reservoirs of the Haditha and Dukan dams, as in Figure 1. Haditha Dam is an earth-fill dam situated on the Euphrates River, north of Haditha City. It makes Lake Qadisiya. The dam has a length exceeding 9 kilometres and a height of 57 metres. It is designed to produce hydroelectricity, regulate the flow of the Euphrates, and supply water for irrigation. With a capacity of 600 MW, it is the second-largest hydroelectric contributor to the Iraqi power system. Dukan Dam is a multi-purpose concrete arch dam on the Little Zab River in Al Sulaymaniyah Governorate, Kurdistan Region of Iraq, which creates Lake Dukan. The dam is 360 metres in length and 116.5 metres in height, and its hydroelectric power station has a maximum capacity of 400 MW. Table 2 presents the geographical details of the two dams and lakes.

a)Haditha Dam



b) Dukan Dam

Figure 1 Photo of the studied dams.

Table 2 Details of the studied reservoirs

Reservoir	Governorate	Latitude(N)	Longitude (E)	Surface area (km^2)	Elevation (m)
Haditha	Al-Anbar	34°12′ 25″	42°21'18″	500	154
Dukan	Al-Sulaymaniyah	35°57′ 15″	44°57′10″	270	515

3.0 METEOROLOGICAL DATA

The meteorological data in this study are acquired from weather stations in the vicinity to the reservoir sites. The evaporation rate was calculated using the Penman technique, using air temperature, relative humidity, and wind speed as input variables, over the period of 1 July 2023 to 31 December 2023.

4.0 EVAPORATION MODEL

The FPV system prevents evaporation not just in the region it covers but also across the entire surface of the lake. Water evaporation is reduced for two primary reasons. The first reason is the decreased interaction between air and water caused by the covered zone, which immediately impacts the decrease in evaporation. The second reason is the modification in the lake's thermal equilibrium as a result of the power plant's construction, which lowers the lake's temperature and consequently decreases total surface evaporation. It is crucial to determine evaporation accurately. Nevertheless, the estimation of water evaporation is impacted by many factors, including but not limited to the chemical properties of water, wind speed, air saturation deficit above the water's surface, and light solar radiation reaching the water's surface. Several models have been used to investigate the evaporation rate on water surfaces in the literature. Evaporation is typically calculated using many methods, including water budget analysis, mass transfer techniques, pan evaporation measurements, the Penman-Monteith model, and the energy balance approach. Moreover, numerous empirical relationships and equations have been formulated that include variables such as temperature, daily daylight hours, and solar radiation. Penman's approach is a commonly employed technique among various mathematical procedures that have been altered in various manners [26]. Valiantzas [27] provided a simplified formula, as in eq (1), using regular meteorological data:

$$\mathrm{E_o} \approx 0.051\,(1-\alpha)\,R_s\sqrt{T+9.5} - 2.4\left(\frac{R_s}{R_A}\right)^2 + 0.052(T+20)\left(1-\frac{RH}{100}\right)(a_u - 0.38 + 0.54\,u) \quad (1)$$

Where E_0 represents the mean daily evaporation of water from the surface (mm/day) at sea level (z = 0), and R_S is the average number of hours of sunshine per day, computed using eq (2):

$$\mathrm{R_s} = \mathrm{R_A}(0.5 + \tfrac{n}{N}) \quad (2)$$

Where N and n are the maximum possible number of sunny hours for the selected month and the observed average number of sunny hours, respectively. N can be calculated using eq (3) for a selected month (i) when the geographic width. φ is available, as follows:

$$N = 4\,\varphi\,\sin(0.53i - 1.65) + 12 \quad (3)$$

The solar irradiance on the Earth's atmospheric surface ($\mathrm{R_A}$) is estimated using the following approximation:

$$\mathrm{R_A} = 3\,N\,\sin(0.131\,N - 0.95\,\varphi) \qquad |\varphi| > \frac{23.5\pi}{180} \quad (4)$$

$$\mathrm{R_A} = 118\,N^{0.2}\,\sin(0.131\,N - 0.2\,\varphi) \qquad |\varphi| < \frac{23.5\pi}{180}$$

(5)

In Eq. (1), The symbol α represents the reflection coefficient, also known as albedo. The water surface, which is measured on a scale from 0 to 1, is set at 0.08 in this study [23]. T is the average of extreme temperatures (T_{min}; T_{max}) for the analyzed month (◦C).
The daily average relative air humidity is denoted by RH, whereas u represents the mean wind speed (m/s) at a height of 2 metres above the water surface. Eq. (1) is modified empirically for higher altitudes z (m) as in eq (6) [28]:

$$E = E_o + 0.00012\,z \quad (6)$$

The daily volume of evaporated water (V) may be calculated using eq (7) by multiplying the evaporation rate (E) by the surface area (A) of the lake in contact with atmospheric air:

$$V\left(\frac{m^3}{day}\right) = E\left(\frac{m}{day}\right)\;A(m^2) \quad (7)$$

To determine the evaporation rate from the lake when FPV are installed, the area substituted in eq (7) is the area of the lake minus the area of the FPV. Figure 2 shows the flow chart of volume of evaporated water.

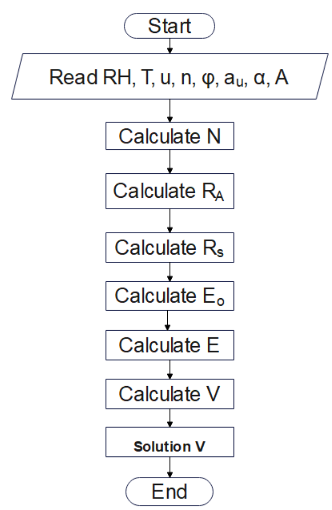


Figure 2 Flow chart of evaporated water volume.

5.0 RESULTS

5.1 Meteorological Data

Figure 3 displays the fluctuation of meteorological data obtained from the weather station near the locations of the studied dams. These data are utilized to calculate the evaporation rates using various approaches. The meteorological dataset spans a duration from 1 July to 31 December 2023. The maximum and minimum temperature range was (12.5-48.6)°C and (3.3-34.2)°C, respectively, for Haditha Dam, while the range was (10.4-46.4) °C and (31-(-1)) °C respectively for Dukan Dam. The wind speed ranges from 4 m/s to 31 m/s for Haditha Dam and 8.1 m/s to 46.4 m/s for Dukan Dam. The maximum and minimum recorded relative humidity was 84.2% and 12.6%, respectively, for Haditha Dam, while 98% and 9.3% for Dukan Dam.

Figure 4 presents monthly average weather conditions to illustrate better the differences between the conditions of the studied dams. Haditha's maximum and minimum temperatures are higher than those of Dukan Dam. This is because Dukan Dam is located in the north of Iraq in the mountainous areas, which are colder than the area where the Haditha Dam is located in eastern Iraq, where the weather is hotter. The relative humidity for Haditha Dam is higher than that for Dukan Dam until the middle of September, when it becomes the opposite until the end of December. The wind velocity in the area of Dukan Dam is higher than that of Haditha Dam throughout the studied period.

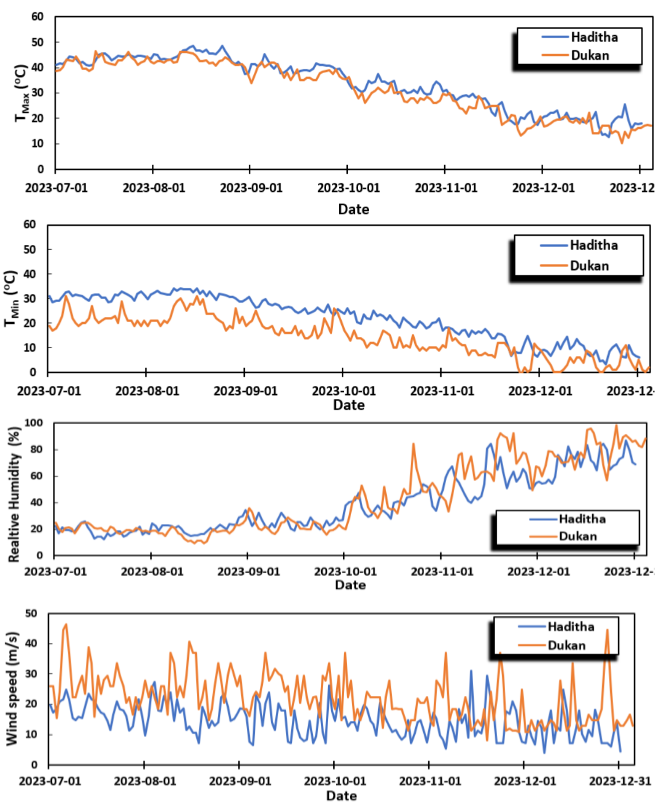


Figure 3 Weather data for the locations of the studied dams

5.2 Evaporation Rate

Figure 5 illustrates the daily average evaporation for Haditha and Dukan Dams from July to the end of December. It can be seen that evaporation from both reservoirs declines to reach its minimum value in December. This reduction in evaporation is attributed to the decrease in temperature and increase in relative humidity as the year approaches its end. It can be concluded that as the maximum temperature decreases from 46 °C to 25.6 decreases the evaporation rate from Haditha reservoir by 84%, while decreasing the maximum temperature from 46 to 22 °C reduces the evaporation rate by 88% for Dukan reservoir during the period from July to December. Also, as the wind velocity decreases from July to December, it results in lower evaporation from Haditha and Dukan reservoirs due the lower mass transfer between the air the water surface. Finally, increasing of relative humidity results in higher water vapor concentration in air which leads to a lower evaporation rate from water surface.

Also, the figure indicates that the daily evaporation rate from Dukan Dam reservoir is higher than that from Haditha Dam reservoir. This is because the wind speed in the area of Dukan Dam is significantly higher than in the area of Haditha Dam.

Figures 6 and 7 show the volume of evaporation water savings (m^3/day) from installing FPV panels in the Haditha and Dukan Dams reservoirs during the investigated months. The savings rates in evaporated water depend on the percentage of the water surface area covered by the FPV panels. The savings range in water from Haditha reservoir for covering the water surface by 20%, 40%, 60%, and 80% is (516,744-3,146,872), (865,011-6,293,744), (1,297,517-9,440,615), and (1,730,023-12,587,487) m3/day for the months July, August, October, November, and December respectively. The savings range in water from Dukan reservoir for covering the water surface by 20%, 40%, 60%, and 80% is (234,893-2,111,123),(469,786-6,4,222,246),(704,680-9,6,333,369), and (939,573-8,444,493) m^3/day for the months July, August, October, November, and December respectively. The daily volume of water saved from Haditha reservoir is higher than that saved from Dukan reservoir due to the larger size of Haditha reservoir.

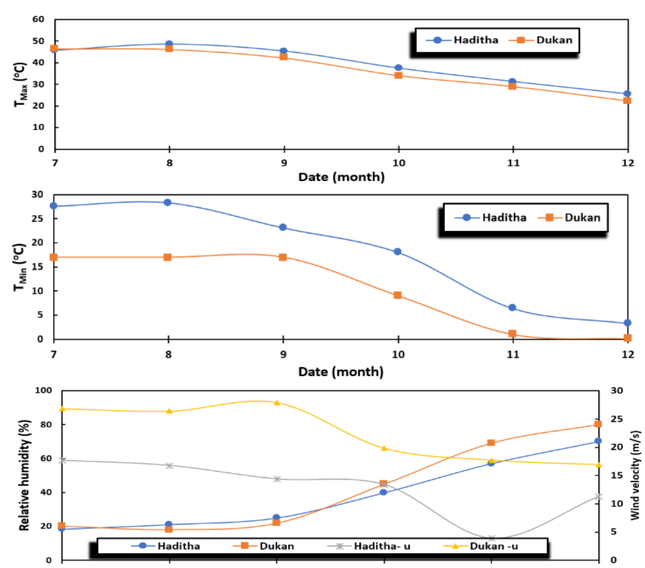


Figure 4 monthly average weather data

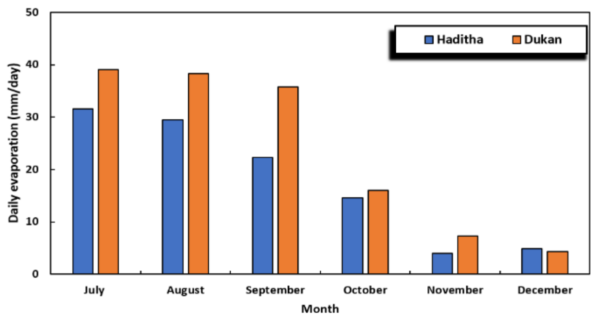


Figure 5 Average daily evaporation savings for each month

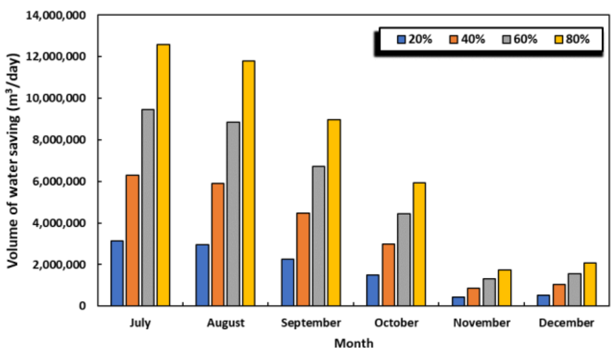


Figure 6 Effect of coverage percentage on the volume of daily water evaporation savings for each month from Haditha Dam reservoir

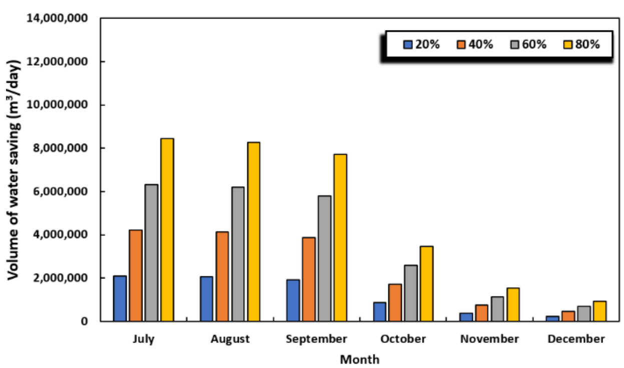


Figure 7 Effect of coverage percentage on the volume of daily water evaporation savings for each month from Dukan Dam reservoir

6.0 CONCLUSION

In the last decade, significant attention has been paid to a technology known as floating PV due to its ecological and environmental benefits, especially for installing large-scale systems on dams, lakes, and reservoirs. The present research represents unprecedented work to reduce evaporation losses in Iraq by covering the water reservoirs with photovoltaic systems. The effect of metrological conditions and coverage percentage on evaporation has been investigated for Haditha and Dukan dam reservoirs. The main finding can be summarized as: Installing FPV panels on the reservoirs of Haditha and Dukan dams offers a highly efficient solution for Iraq. Covering 80% of the area of Haditha and Dukan reservoirs with floating photovoltaic panels saves about 12,587,487 and 8,444,493 m^3/day.

- The weather conditions strongly affect the evaporation rate from the water surface
- Increasing the coverage percentage from 20% to 80 % increases the water saving from 3,146,872 to 12,587,487 m3/day in July for Haditha reservoir while increasing the save from 2,111,123 to 8,444,493 m^3/day for Dukan reservoir.
- As the year approaches its end, the evaporation rate from the water surface decreases due to the decreased temperature and increased relative humidity.

As a potential for future work, the PV panel can be submerged partially in the water to enhance the cooling process in order to enhance its efficiency. Also, the FPV can be additionally cooled with spraying water on the upper face.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

References

[1] Stan, F.; Neculau, G.; Zaharia, L.; Ioana-Toroimac, G.; Mihalache, S. 2016. Study on the Evaporation and Evapotranspiration Measured on the Căldăru¸sani lake (Romania). *Procedia Environmental Sciences.* 32: 281-289. DOI: https://doi.org/10.1016/j.proenv.2016.03.033

[2] Pochwat, K.; Slys, D.; Kordana, S. 2017. The temporal variability of a rainfall synthetic hyetograph for the dimensioning of stormwater retention tanks in small urban catchments. *Journal of Hydrology* 549: 501-511. DOI: https://doi.org/10.1016/j.jhydrol.2017.04.026

[3] Stec, A.; Zele ˇnáková, M. 2019. An Analysis of the Effectiveness of Two Rainwater Harvesting Systems Located in Central Eastern Europe. *Water* 11: 458. DOI: https://doi.org/10.3390/w11030458

[4] Kaya, Y.Z.; Zelenakova, M.; Üne¸s, F.; Demirici, M.; Hlavata, H.; Mesaros, P. 2021, Estimation of daily evapotranspiration in Košice City (Slovakia) using several soft computing techniques. *Theoretical and Applied Climatology*. 1-12. DOI: https://doi.org/10.1007/s00704-021-03525-z

[5] Harwell, G.R. 2012. Estimation of Evaporation from Open Water: A Review of Selected Studies, Summary of U.S. Army Corps of Engineers Data Collection and Methods, and Evaluation of Two Methods for Estimation of Evaporation from Five Reservoirs in Texas. USA; Geological Survey Scientific Investigations Report; USGS: Reston, VA, USA, DOI: https://doi.org/10.3133/sir20125202

[6] Curtarelli, M.P.; Alcântara, E.H.; de Araújo, C.A.S.; Stech, J.L.; Lorenzzetti, J.A. 2013, Assessment of Temporal Dynamics of Evaporation in the Itumbiara Reservoir, GO, Using Remote Sensing Data. *An Interdisciplinary Journal of Applied Science (AMBIAGUA)* 8: 272-289. DOI: https://doi.org/10.4136/ambi-agua.1083

[7] Sahu, A.; Yadav, N.; Sudhakar, K. 2016, Floating photovoltaic power plant: A review. *Renewable and Sustainable Energy Reviews*. 66: 815-824. DOI: https://doi.org/10.1016/j.rser.2016.08.051

[8] Friel D, Whittaker M, Doran T, Howlin WJ. 2019. A review of floating photovoltaic design concepts and installed variations. *4th International Conference on Offshore Renewable Energy,* ASRANet Ltd.

[9] A. Sahu, N. Yadav, and K. Sudhakar, 2016. "Floating photovoltaic power plant: A review," Renewable and Sustainable *Energy Reviews,* 66: 815-824, Elsevier Ltd, DOI: 10.1016/j.rser.2016.08.051.

[10] Dubey, S.; Sarvaiya, J.N.; Seshadri, B. 2013. Temperature dependent photovoltaic (PV) efficiency and its effect on PV production in the world a review. *Energy Procedia* 33: 311-332. DOI: https://doi.org/10.1016/j.egypro.2013.05.072

[11] Syahriman, M.; Azmia, M.; Othmana, M.; Yusof, H.; Ruslanb, M.; Hafidz, H.; Sopianb, K.; Azran, A.M.Z. 2013. Study on electrical power output of floating photovoltaic and conventional photovoltaic. In *AIP Conference Proceedings;* 1571: 95. American Institute of Physics: Hong Kong, China.

[12] Kušnír, M.; Vranay, F.; Vranayova, Z.; Kapalo, P.; Koši˘canová, D. 2015. Synergy between progressive indoor environment cooling and photovoltaic system. In *Proceedings of the International Conference SGEM 2015, Sofia: STEF92 Technology*, Albena, Bulgaria, 18-24 June 541-546.

[13] Kušnír, M.; Vranay, F.; Koši˘canová, D.; Vranayova, Z.; Kapalo, P.; Gavlík, M. 2014. Utilizing solar energy in order to reduce energy loads of building. In Proceedings of the *17th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction (PRES 2014), Prague, Czech Republic,* 23-27 August 2014. 1483-1488.

[14] Gotmare, J.A.; Prayagi, S.V. 2014. Enhancing the performance of photovoltaic panels by stationary cooling. *International Journal of Science, Engineering and Technology* 2: 1465-1468.

[15] Dash, P.K.; Gupta, N.C. 2015, Effect of temperature on power output from different commercially available photovoltaic modules. *International Journal of Engineering Research and Applications*. 5: 148-151.

[16] Fesharaki, V.; Jafari, D.M.; Jafari, F.J. 2011. The effect of temperature on photovoltaic cell efficiency. In *Proceedings of the 1st International Conference on Emerging Trends in Energy Conservation, ETEC Tehran,* Tehran, Iran, 20-21 November 2011. 20-21.

[17] Baskar, D. 2014 Efficiency improvement on photovoltaic water pumping system by automatic water spraying over photovoltaic cells. *Middle-East Journal of Scientific Research.* 19: 1127-1131.

[18] Choi, Y.K. 2014. A study on power generation analysis of floating PV system considering environmental impact. *International Journal of Software Engineering and Applications* 8: 75-84.

[19] Abid, M.; Abid, Z.; Sagin, J.; Murtaza, R.; Sarbassov, D.; Shabbir, M. 2018. Prospects of floating photovoltaic technology and its implementation in Central and South Asian Countries. *International Journal of Environmental Science and Technology*, 16: 1755-1762. DOI: https://doi.org/10.1007/s13762-018-2080-5.

[20] Abd-Elhamid, H. F., Ahmed, A., Zeleňáková, M., Vranayová, Z., & Fathy, I. (2021, March 11). Reservoir Management by Reducing Evaporation Using Floating Photovoltaic System: A Case Study of Lake Nasser, Egypt. *Water,* 13(6): 769.DOI: https://doi.org/10.3390/w13060769

[21] Bontempo Scavo, F., Tina, G. M., Gagliano, A., & Nižetić, S. (2020, February 5). An assessment study of evaporation rate models on a water basin with floating photovoltaic plants. *International Journal of Energy Research,* 45(1): 167-188. DOI: https://doi.org/10.1002/er.5170

[22] Santos, F. R. D., Wiecheteck, G. K., Virgens Filho, J. S. D., Carranza, G. A., Chambers, T. L., & Fekih, A. 2022. Effects of a Floating Photovoltaic System on the Water Evaporation Rate in the Passaúna Reservoir, Brazil. *Energies,* 15(17): 6274. DOI: https://doi.org/10.3390/en15176274

[23] Farrar, L. W., Bahaj, A. S., James, P., Anwar, A., & Amdar, N. 2022. Floating solar PV to reduce water evaporation in water stressed regions and powering water pumping: Case study Jordan. *Energy Conversion and Management,* 260: 115598. DOI: https://doi.org/10.1016/j.enconman.2022.115598.

[24] Yiğit, M. G., & Akçadağ, B. (2024). Empowering Sustainability: Floating Solar Photovoltaic Systems in Agriculture for Reduced Costs Carbon Emissions and Evaporation. *Global Challenges,* 8(7). DOI: https://doi.org/10.1002/gch2.202300321

[25] M. Jensen, 2010. Historical Evolution of ET Estimating Methods: A Century of Progress, *CSU/ARS Evapotranspiration Work*. 12: 1e17. https:// coagmet.colostate.edu/ET_Workshop/pdf/1_Jensen.pdf

[26] J.D. Valiantzas, 2006. Simplified versions for the Penman evaporation equation using routine weather data*, Journal of Hydrology.* 331: 690e702, DOI: https://doi.org/10.1016/ j.jhydrol.2006.06.012.

[27] M. Fereshtehpour, R. Javidi Sabbaghian, A. Farrokhi, E. B. Jovein, and E. Ebrahimi Sarindizaj, 2021. "Evaluation of factors governing the use of Floating solar system: A study on iran's important water infrastructures," *Renewable Energy*, 171: 1171-1187. DOI: 10.1016/j.renene.2020.12.00