energies

Article

Potential of Floating Photovoltaic Technology and Their Effects on Energy Output, Water Quality and Supply in Jordan

Mohamad Al-Widyan [1], Mohammad Khasawneh [1] and Muna Abu-Dalo [2,*]

1 Mechanical Engineering Department, Faculty of Engineering, Jordan University of Science and Technology, Irbid 22110, Jordan; widyan@just.edu.jo (M.A.-W.); moe.khasawneh@outlook.com (M.K.)
2 Department of Chemistry, Faculty of Science and Arts, Jordan University of Science and Technology, Irbid 22110, Jordan
* Correspondence: maabudalo@just.edu.jo

Abstract: In this work, floating photovoltaic systems were experimentally studied under Jordan's weather conditions to determine their effects on energy output, water quality and supply. A limited number of studies have addressed the effect of floating photovoltaic systems on water quality and evaporation reduction especially in a semi-arid region like Jordan. Energy measurements were taken from August 2020 to January 2021 using an Arduino board with data logging sensors. Water quality parameters were tested for collected samples on a monthly basis from August 2020 to February 2021 using a spectrophotometer. Results revealed that the floating panel temperature was lower than the ground-mounted counterpart. An average increase of 1.68% in voltage and 4.40% in current were observed for the floating panel compared to the ground-mounted panel which translates to an average increase of 5.33% in power generation over the ground-mounted panel. Furthermore, efficiency and fill factor increased by 4.89% and 5.51%, respectively. Evaporation results showed that covering water bodies with panels can save a considerable amount of water. Over a period of 30 days, the 30% coverage pan saved 31.2% (36 mm) of water while the 50% coverage pan saved 54.5% (63 mm) of water in the same period compared to the uncovered pan. Moreover, this study involved examining the effect of shading caused by the floating structure on water quality. Results showed a reduction in pH, improvement in transparency, and an increase in total organic carbon indicating water quality enhancement and algal biomass reduction. However, due to the respiration of algae, the dissolved oxygen declined significantly, accompanied by the release of phosphate due to algae decomposition. Overall, findings of this research provided better understanding of floating photovoltaic systems and their applicability in Jordan to provide a safe and reliable supply of water and energy. Additionally, such systems can help to diversify the energy mix and help Jordan to alleviate some of the problems associated with limited energy and water resources.

Keywords: floating photovoltaic system; renewable energy; water quality; water evaporation

Citation: Al-Widyan, M.; Khasawneh, M.; Abu-Dalo, M. Potential of Floating Photovoltaic Technology and Their Effects on Energy Output, Water Quality and Supply in Jordan. *Energies* **2021**, *14*, 8417. https://doi.org/10.3390/en14248417

Academic Editor: Emeka H. Amalu

Received: 9 November 2021
Accepted: 3 December 2021
Published: 14 December 2021

1. Introduction

In several different business areas all over the world, the substitution of traditional energy systems that are based on fossil fuels with other alternative and renewable energy techniques has been emphasized. As the world has been relying heavily on fossil fuels with their detrimental consequences, the increased use of renewable energy sources not only decreases greenhouse gas emissions but also reduces the reliance on imported energy sources [1]. Additionally, limited fossil fuel resources and increasing energy demand have led to the continuing exploitation of renewable energy especially solar energy, which is a free and unlimited source of energy, eco-friendly and sustainable. However, solar energy has issues with land availability and land acquisition, particularly in large-scale solar energy project development. Most of the sites that are considered for solar projects with good solar energy resources are located in countries where the weather is generally hot and dry. Although at such locations the radiation is higher, the energy output is less due to the heating of solar panels and the high operating temperature. To overcome this problem, the concept of installing photovoltaic (PV) panels on water bodies has been explored. Floating photovoltaic (FPV) installations are opening new possibilities for solar generation capacity expansion, especially in countries with high population density and competing uses of available land.

FPV systems have several advantages compared to ground-mounted systems. When mounting PV panels on a body of water, the cooling effect of the water body, mainly due to the lower ambient temperature present above the surface of the water and the evaporative cooling effect of the water, can decrease the operating temperature of PV panels thus improving the efficiency of the system and increasing energy yield [2,3]. In addition to the cooling effect, FPV systems have increased energy yield due to the reduced presence of dust [4]. Furthermore, FPV systems shade water bodies and help in reducing water evaporation which is a major cause of global water supply depletion. Reported values of global water loss due to evaporation can be as high as 40% [5,6]. Moreover, the shade offered by these floating PV panels will help to minimize the bloom of algae by reducing the process of photosynthesis [7,8].

Jordan, a developing country that imports 95% of its energy needs [9], plans to diversify the energy mix and generate 14% of the country's electricity using renewable energy by 2030, utilizing mainly wind and solar energy [10]. In the past two decades, Jordan has faced two major energy crises: the Iraqi oil crisis in 2003 and the Egyptian natural gas crisis in 2011. In 2011, the disruption of Egyptian natural gas imports increased Jordan's energy bill to USD 4.8 billion, which is 20% of the country's GDP [11]. Following these crises, protecting the country's energy supply became a national priority [1].

Throughout the world, the safe and reliable supply of water and energy is a basic need and essential for sustainable and continued socio-economic development. As for water, Jordan is considered one of the lowest countries of water availability per capita [12], which is estimated to be less than 100 m^3/year. Due to the lack of natural resources, the country depends heavily on artificial dams and exposed water bodies. However, high temperatures and low humidity in Jordan result in an extremely high evaporation rate. In 2019, the total evaporation rate of water bodies in Jordan was estimated to be 92.7% of the total amount of rainfall over the country [13].

Throughout the globe, the current floating PV projects include conventional PV arrays and concentrated PV arrays that take advantage of surrounding water bodies to prevent overheating of the panel. For the most part, these projects are supported and constructed in a reservoir or a pond on a pontoon-based floating structure. Reducing water evaporation [8] and reducing algae growth [14], are typical benefits of such systems. In addition, in most of the reported cases, the energy output is enhanced because of the water body's cooling effect, as illustrated by Majid et al. (2014) [2]. Reported increment values vary depending on the size of the system. On a small scale, the floating system was 0.79% more efficient than the traditional ground-mounted system and the average temperature of the floating panel was decreased [15]. On the other hand, Choi et al. (2016) [16] analyzed data from two floating PV systems, 100 and 500 kW systems installed on the Hapcheon dam reservoir, Korea. The findings show that the floating PV system is 11% more efficient when compared to the overland system. FPV systems are gaining attention all over the world, countries such as Australia, Japan, and Bangladesh expressed their interest in such technology [17–19].

Floating photovoltaic technology is developing at a rapid rate. Multiple large-scale projects are currently producing electricity at MW level [20,21]. Many countries have invested in FPV systems, China has invested the most in recent years, which makes them the market leader in FPV technology. Plants reaching the hundreds of megawatts were installed in Southeast Asia and specifically in China, making FPV become a major in the renewable energy market [22]. Floating photovoltaic technology reached a milestone of 1.1 GW-peak in 2018, which ground-mounted PV reached in 2000. FPV is projected to increase at a much faster rate than typical ground-mounted PV [20]. Some studies already addressed the possibility of using FPV systems in conjunction with other renewable power generation technologies such as hydropower [23].

Additionally, floating PV systems can improve water quality of the reservoir or water body by reducing algae growth. By covering water bodies with PV panels, the amount of sunlight entering water would decrease which, in turn, will reduce the algae photosynthesis process. Studies show that covering a water body can have some positive advantages for water such as decreased algal biomass [24,25], decreased turbidity [24,26], and improved water quality [27].

The main objective of this research is to study the characterizing parameters of floating PV technology under Jordan's weather conditions. In this project, an experimental setup of the floating photovoltaic system was created to study the effect of floating technology on energy production, evaporation rate, mitigating algae bloom, improving water quality, and increasing water supply. A limited number of studies addressed the effect on water quality as a result of being covered by floating PV panels [28]. Similarly, the effect of water evaporation has been addressed by some studies [29,30]. This research fills the gap by experimentally investigating the quality of water covered by floating PV panels and the effect of shading on water evaporation in a semi-arid region. Additionally, in this study, the effect of FPV compared to a land-mounted counterpart on energy output was investigated experimentally under typical Jordanian weather conditions. To the best of our knowledge, this paper is the first to study the characterizing parameters of the floating PV technology and its potential applicability in Jordan to provide a safe and reliable supply of water and energy.

2. Materials and Methods

This work was conducted on the campus of Jordan University of Science and Technology (JUST) (32.49°N 35.98°E). The experiment was set up at the banks of the artificial lake located at JUST. The purpose of the lake is to harvest rainwater and collect treated wastewater from the two wastewater treatment plants located near the university. The lake suffers from an algae bloom problem, especially in the summer, which has a negative effect on the ecology of the lake. Algae growth is due to high concentrations of nitrogen and total phosphorus. Figure 1 presents a flowchart of the methodology of this research and shows the steps taken to during this experiment.

The Köppen Climate Classification subtype for Jordan is "Bwh". (Hot arid desert Climate). The average temperature for the year in Amman is 17.2 °C. The warmest month, on average, is July. The coolest month on average is January. The highest recorded temperature in Amman is 41.7 °C, which was recorded in August. The average amount of precipitation for the year in Amman is 274.3 mm. There is an average of 57 days of precipitation, with the most precipitation occurring in January with 13 days.

2.1. The Photovoltaic System

Two identical PV panels were installed, using metal structures. The first panel was ground-mounted PV, the second was floating PV as shown in Figure 2. The azimuth angle was set at 0° (North facing) and the tilt angle was set to 30°. The floating PV structure was submerged in a metal tank with the dimensions of 1.6 × 1.6 × 0.65 m.

In this study, Philadelphia Solar PS-P60 Poly-Crystalline 275 W solar panels were used. Technical specifications of the PV panel are shown in Table 1.

The output of the PV panel was connected to a load resistor, the value of which was calculated based on the maximum power point values given in Table 1, the value of the load resistor turned out to be 3.55 Ω. Measurements taken for the PV panel included voltage, current, PV temperature, ambient temperature, and solar radiation.

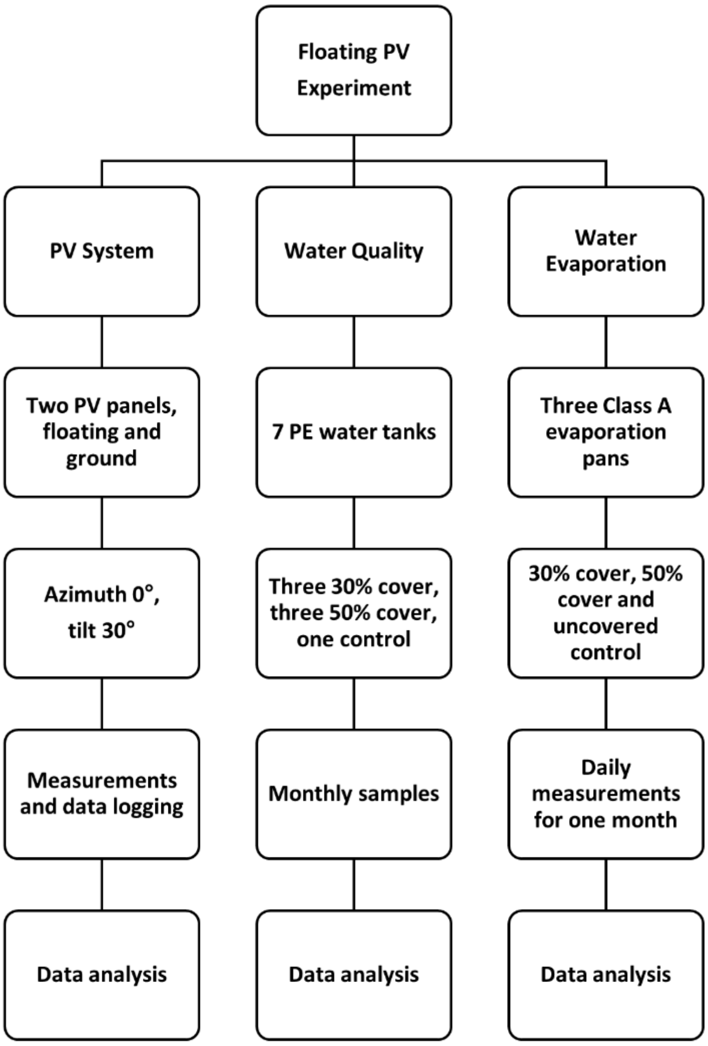

Figure 1. Flowchart of experiment methodology.

Figure 2. Floating PV panel used in this study.

Table 1. Technical specification of the PV panel [31].

Electrical Characteristics	
Open circuit voltage V_{OC} (V)	38.13
Short circuit current I_{SC} (A)	9.20
Maximum power voltage V_{mpp} (V)	31.25
Maximum power current I_{mpp} (A)	8.81
Module efficiency η (%)	16.9

2.2. Water Quality

To evaluate water quality, seven polyethylene water tanks were set up at the selected location. The exterior surface of all tanks was painted black to limit the entrance of sun rays. Two coverage percentages were chosen for this experiment, 30% and 50%. Three tanks were set up for 30% coverage and were numbered 1 to 3 and three tanks were set up for 50% coverage and were numbered 4 to 6. One tank was left uncovered as a control. The tanks have a maximum capacity of 1 m^3. Wood planks were used as the cover and set up to a 30° tilt angle and an azimuth angle of 0° was chosen (north-facing). The width of the wood planks was calculated to give the required covering percentage at high noon. Figure 3 shows the setup used in this study.

Figure 3. Water tanks setup.

The tanks were filled with water from JUST artificial lake which is suffering from green algal bloom as a result of high concentration of nitrogen and phosphorus. Physical, chemical water quality parameters were examined monthly throughout the experimental period. The experiment lasted for 7 months (August 2020 to February 2021). Physical parameters including temperature, conductivity, salinity, and TDS were measured on-site using UltraPen PT1 (Myron L) (Carlsbad, CA, USA). Orion Star A111pH meter (Thermo Scientific, Chelmsford, MA, USA) and Dissolved Oxygen (DO) was measured using HACH HQd portable DO meter (Hack, Loveland, CO, USA). Water transparency as a turbidity indicator was measured using Secchi disc #1062 (LaMotte, Chestertown, MD, USA). Chemical parameters were measured once a month, except for total organic carbon which was tested every three months, using a spectrophotometer (Lovibond SpectroDirect, Dortmund, Germany) at 330–900 nm. These methods comply with standard methods for the examination of water and wastewater (APHA, 2012) [32]. The analysis was based on the average triplicate analysis of each covering percentage.

2.3. Water Evaporation

Water evaporation measurement was carried out using Class A evaporation pan, which consists of a cylinder with a diameter of 120.7 cm that has a depth of 25 cm. The pan sits on a level wooden base. Evaporation was measured daily as the depth of water (in millimeters). The measurement day started by filling the pan to exactly 5 cm from the top of the pan. After 24 h, water level remaining in the pan was measured and recorded. Three class A evaporation pans were used in this experiment, the first had 30% of its surface area covered by a wood plank, the second had 50% coverage, and the third was uncovered to be used as a control. Daily measurements were recorded over the 30 days of June 2021.

3. Results

3.1. PV System

The following results were obtained from a single day of testing (24 August 2020). As depicted in Figure 4a for that day, ambient temperature fluctuated from 16 to 36 °C and the highest and lowest solar radiation ranged between 0 and 976 W/m^2.

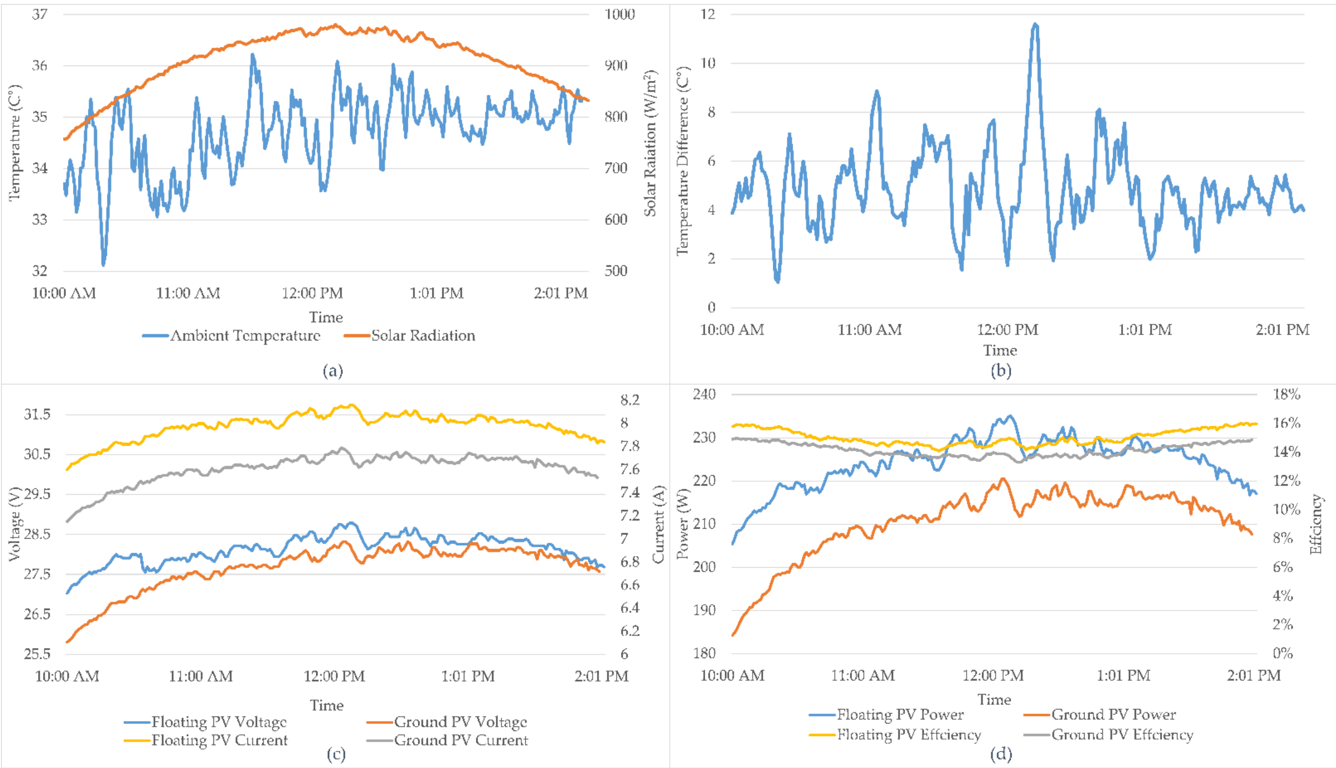

Figure 4. (**a**) Ambient temperature and solar radiation on testing day. (**b**) Difference of operating temperature between ground and floating PV panels. (**c**) Voltage and current variation for ground and floating PV panels. (**d**) Power and efficiency variation of ground and floating PV panels.

The cooling effect of water caused the operating temperature of the floating PV panel to drop. The maximum temperature of the FPV during the experimental day was 48.7 °C at around noon compared to 54.5 °C for the ground PV. The difference between ground and floating PV operating temperatures was calculated and presented in Figure 4b, which shows that the maximum temperature difference was 11.5 °C. Note that the maximum difference between floating and ground PV panels was recorded at 12:17 p.m., where the ambient temperature was at its highest.

The cooling effect of water seems to have only a slight effect on the voltage of the PV panel, Figure 4c shows that the voltage is slightly higher for floating PV panel in the middle of the day; the maximum voltage during this experimental day for the ground system was 28.32 V compared to 28.79 V for floating system, which accumulates to a 1.66% increase. It is important here to note that the difference between floating and ground PV panels in terms of voltage is largest at the beginning of the day and tapers off at the end of the day, as can be seen in Figure 4c. In contrast, the presence of water under the PV panel caused the current to be significantly higher; the maximum current measured during the experimental day was 8.16 A for FPV and 7.79 A for the ground counterpart, an increase of 4.75%. The gap between both panels is consistent throughout the day.

Higher voltage and current for the FPV led to higher power output as demonstrated in Figure 4d, which also shows the maximum power generation for the floating PV was 235.03 and 220.52 W, an increase of 6.6%. Similar to the voltage, the gap between both panels is consistent during the whole day. The higher values of voltage and current and the consequent gain in power produced caused the efficiency of the PV panel to increase. Figure 4d shows the fluctuation of efficiency of the panels during the experimental day. It is readily noted from Figure 4d that the maximum efficiency for the FPV was 16.46% in comparison to 15.26% for the ground PV, an increase of 7.86%.

Energy produced during a period of time can be used to measure the effectiveness of the floating PV system. Figure 5 shows the energy output of ground and floating PV between 10 a.m. and 2 p.m. for different testing days. As shown in Figure 5, the energy of the FPV system was higher than ground-mounted PV system in all of the testing days, an increase ranging from 2.46% to 8.81%. Examining the average increment for the different parameters will give us a clearer picture of the results. Table 2 shows the percentage of increment for the floating PV panel of different parameters compared to the ground-mounted PV panel.

3.2. Water Evaporation

Findings indicated that all configurations showed a linear pattern for the cumulative daily measurements of evaporation. Furthermore, cumulative daily evaporation measurements were 115.5, 79.5, and 52.5 mm for uncovered, 30% coverage, and 50% coverage, respectively. In contrast, daily averages during the measurement period were found to be 3.85, 2.65, and 1.75 mm for uncovered, 30% covered, and 50% covered, respectively. Figure 6 shows the cumulative daily evaporation and daily averages for the three configurations.

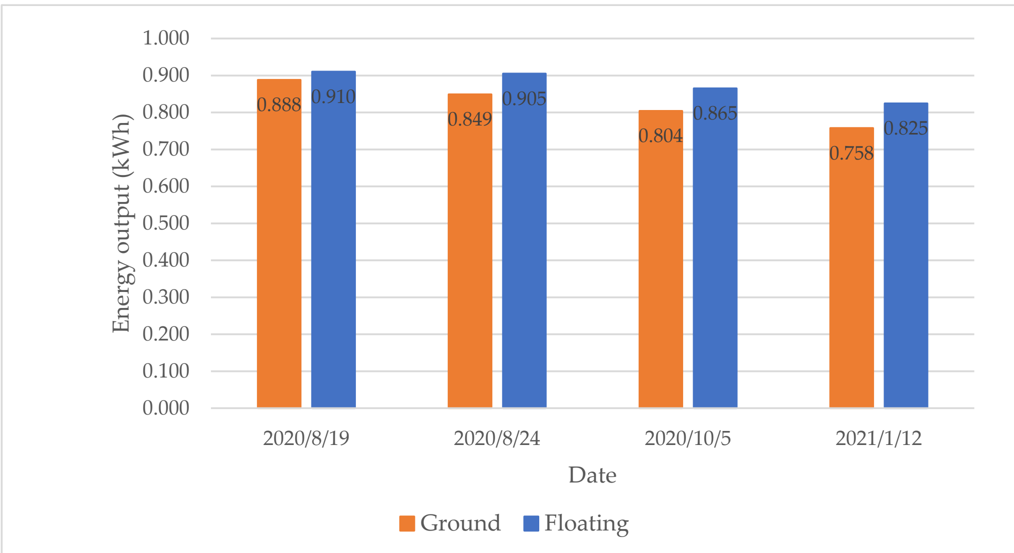

Figure 5. Energy output of different testing days for the period between 10 a.m. and 2 p.m.

Table 2. Percentage increment for floating PV of different parameters with respect to ground-mounted PV.

Date	Voltage	Current	Power	Efficiency	Fill Factor
19/08/2020	0.64%	1.35%	1.58%	2.62%	2.22%
28/08/2020	1.66%	4.75%	6.60%	6.58%	7.86%
01/09/2020	1.36%	4.57%	5.97%	5.56%	5.97%
05/10/2020	2.00%	6.06%	8.37%	4.25%	8.37%
27/10/2020	3.00%	3.36%	3.98%	3.58%	3.17%
12/01/2021	1.41%	6.32%	5.48%	6.77%	5.46%
Average	1.68%	4.40%	5.33%	4.89%	5.51%

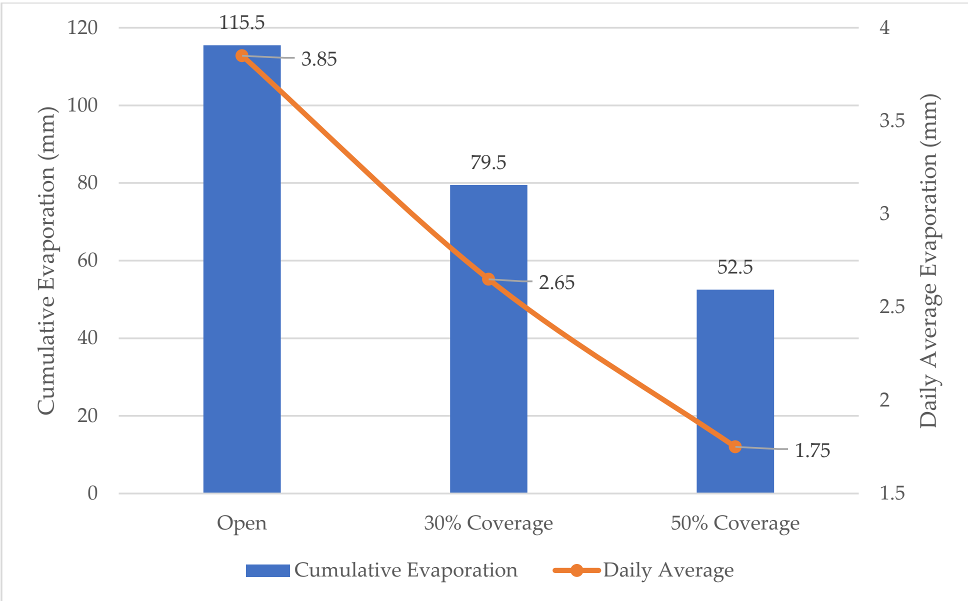

Figure 6. Cumulative and daily average evaporation measurements.

3.3. Water Quality

pH values in water did not significantly vary in both the control tank and 30% coverage tank during the 7 months (August–February) testing. A decrease in pH from 0.8 to 1 was observed in the 50% coverage tank in the months from December and February. However, a reduction of 11% in pH was observed in 50% coverage tanks during the whole study period. Figure 7a shows pH values during experimental period.

Salinity results indicated that the difference in water salinity was minimal in all water tanks between the three configurations during the experimental period. However, the salinity of water in all tanks was on an upward trend. Salinity increased threefold from the start to the end of the experiment. Figure 7b shows the values of salinity in ppt during the study period.

Water transparency level started at about 30 cm for the three setups (covered and uncovered water tanks). The Control tank remained at 30 cm for the entire duration of the experiment. Comparatively, the transparency level increased by 55% in the 30% coverage tank (from 30 to 46 cm) and by 76% in 50% coverage tanks (from 30 to 54.6 cm). Figure 7c shows water transparency levels during the experimental period.

Figure 7d shows that the levels of dissolved oxygen were 14 mg/L at the beginning of the experiment in all water tanks. In the first month, a substantial decline was observed i.e., control tank dropped to 5.57 mg/L, 30% covered tanks dropped to 6.25 mg/L, and 50% covered tanks dropped to 4.87 mg/L. There was a decline of about 60% for all configurations. The level of DO remained almost constant for the consequent months for all configurations.

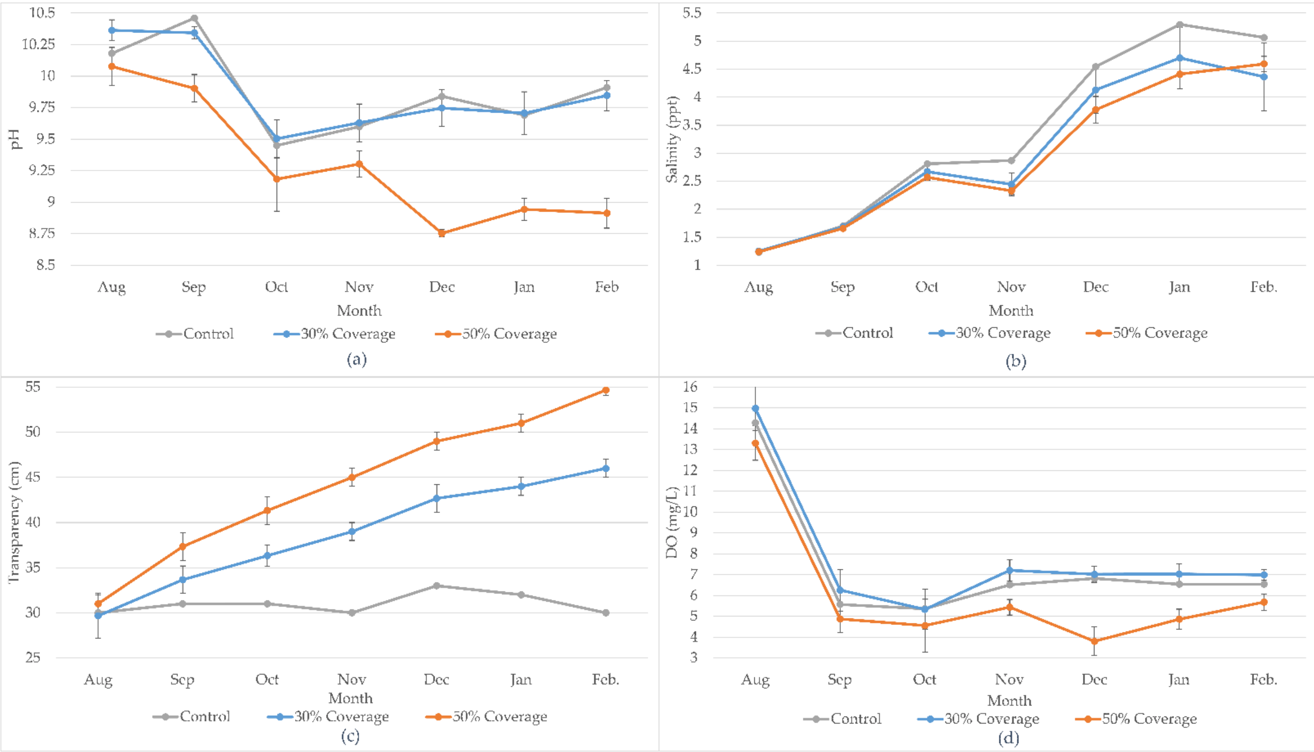

Figure 7. (**a**) pH levels during experimental period. (**b**) Salinity levels during experimental period. (**c**) Variation of water transparency levels during the experimental period. (**d**) Levels of dissolved oxygen during the experimental period.

Figure 8a presents the levels of orthophosphate, the values started at about 20 mg/L PO_4-P then declined significantly in the first two months to 5 mg/L PO_4-P for the control tank and 6.67 mg/L PO_4-P for the tanks with 30% coverage. However, these levels remained constant until the end of the experiment. For tanks with 50% coverage, Figure 8a shows a slight drop in orthophosphate levels in the first two months to 17.67 mg/L PO_4-P then increased after that to reach a maximum of 22.33 mg/L PO_4-P in January. Control and 30% coverage tanks achieved a 75.8% reduction in orthophosphate values, while the values for orthophosphate did not change in 50% coverage tanks during the experimental period.

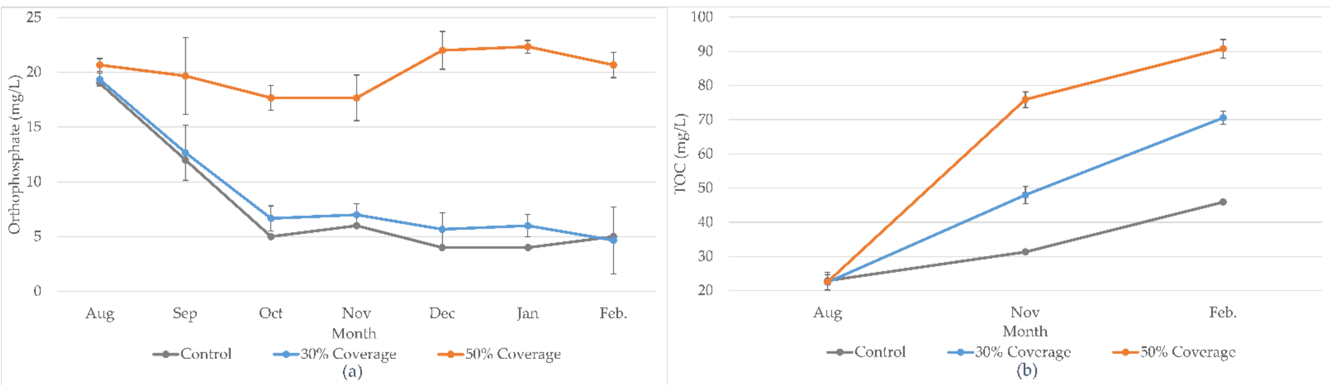

Figure 8. (**a**) Variation of orthophosphate during the experimental period. (**b**) Levels of TOC during the experimental period.

Figure 8b shows that total organic carbon (TOC) was initially about 22 mg/L C. During the first three months of the experiment, TOC increased to 31.3, 47.9, and 75.9 mg/L C for, respectively, the control tank, 30% coverage tanks, and 50% coverage tanks. During the last three months of the experiment, where TOC reached 45.9, 70.6, and 90.8 mg/L C for control, 30% coverage, and 50% coverage tanks, respectively. From Figure 8b, it may be noted that TOC maintained an increasing trend with time for all three configurations, namely, control, 30% coverage, and 50% coverage. In addition, at any given time, TOC levels were consistently the highest for 50% coverage followed by the 30% coverage and finally the control which indicates the effect of coverage on TOC levels and thus algal biomass.

4. Discussion

PV panels are susceptible to thermal deterioration when the temperature exceeds a certain level. For crystalline cells, electrical parameters such as output voltage, current, power, and efficiency are dependent on operating cell temperature. The presence of water under the PV panel acted as a cooling mechanism and thus decreased the operating temperature, increased the voltage and current of the PV panel. Voltage measurements recorded the lowest increment in electrical parameter of the PV panel with an average increment of 1.46% over the ground PV panel over the 6 testing days in comparison to 4.4% for the current. This can be attributed to the lower operating temperature and negative temperature coefficient. Obviously, the combination of higher voltage and current leads to higher power generation, an average of 5.33% compared to the ground-mounted PV panel. Furthermore, the efficiency of the floating PV panel increased when compared to the ground-mounted PV panel by an average of 4.89%. Energy produced by the floating PV panel was always higher than the ground-mounted PV panel. The increment of energy ranged between 2.46% and 8.81% throughout the different testing days.

As for water evaporation, it was noticed that the reduction in evaporation is consistent with the coverage percentage. Findings showed that water savings were 31.2% and 54.5% for, respectively, the 30% and 50% coverage pans over the uncovered (control) pan.

pH values in water did not significantly vary in both the control tank and 30% coverage tank. However, a reduction of 11% in pH was observed in 50% coverage tanks during the whole study period. The drop in pH values could be attributed to algae photosynthesis inhibition. It is well known that algae consume CO_2 from water during photosynthesis, which can raise the pH in the water [25], but in photosynthesis inhibition, higher CO_2 concentration in water, is expected to lower the pH value.

Salinity of water in all tanks is on an upward trend, which may be due to the fact that water is evaporating from tanks and concentrations of salts are increasing. Additionally, the decomposition of algae in water leads to an increase in water salinity. This is due to solids that dissolve in the water breaking into positive and negative ions [33]. Increasing salinity affects DO values due to oxygen being less soluble in salty water than freshwater.

Water transparency increased for the 30% and 50% covered tanks and remained almost constant for the control tank; this can be attributed to the fact that algal biomass is diminishing due to the reduced photosynthesis process. The 50% coverage tanks achieved a 57.3% decrease in DO value during the 7 months of the experiment, under full or partial light shading conditions, the photosynthesis rate of algae was reduced and the respiration is dominant, causing the algae to decompose and consume its components and oxygen in the water [34]. Control and 30% coverage tanks achieved a 75.8% reduction in orthophosphate values, while the values for orthophosphate did not change in 50% coverage tanks during the experimental period. The constant trend in PO_4-P values in 50% coverage tanks and the decrease in control and 30% coverage tanks and the lower pH level in 50% coverage tanks and the lower DO values reached by the 50% tanks indicate that 50% coverage is much more beneficial in algal biomass control in water. The increase of orthophosphate for 50% coverage tanks is due to the low level of DO under light shading conditions, which led to the release of orthophosphate in water from algae decomposition [35]. The release of orthophosphate in water under light shading conditions can be mitigated by the introduction of aeration in water as demonstrated by Chen et al. (2009) [25]. The 30% coverage tanks experienced an increase of about 214% in TOC, whereas 50% coverage tanks experienced an increase of about 300%. The significant increase in TOC concentrations can be explained by the decomposing algae in the water that is dissolving and led to the release of organic carbon into water [36,37]. TOC levels indicate that the coverage percentage has a direct effect on algal biomass present in water, where the higher the coverage percentage the more effective it becomes in controlling algae bloom.

5. Conclusions

The results of this work demonstrated that floating PV systems produced higher voltage, current, and efficiency. Findings of this study showed current increased by an average of 4.4% over the ground-mounted PV panel, while efficiency and power increased by 5.33% and 4.89%, respectively.

Water evaporation measurements demonstrated the benefits of using floating PV systems on water saving and evaporation reduction from open water surfaces. Results showed the amount of water saved is consistent with the coverage percentage, where 50% covered pan saved 54.5% while the 30% covered pan saved 31.2% when compared to the uncovered pan.

Water quality under the floating PV system conditions showed improvement especially for algal biomass control, where shading from sunlight inhibited algae growth. This is more clearly visible in the 50% coverage tanks more than 30% coverage. Signs of algal biomass inhibitions were lower pH, where the pH for the 50% coverage tanks decreased by 11% by the end of the experiment. Furthermore, lower DO levels in water tanks, where values dropped by 65% in the 50% coverage tanks, monthly increasing water transparency levels, where 50% coverage tanks transparency increased by 76% by the end of the experiment while 30% coverage tanks increased by 55%, constant orthophosphate in 50% coverage tanks while in the 30% coverage and control values declined monthly by 75.8% and increasing TOC values, where 50% and 30% coverage tanks increased threefold and two-fold, respectively.

These results can act as an indication of the benefits of floating photovoltaic systems on energy yield, water quality, and evaporation reduction. Still, more extensive studies need to be conducted in order to quantify the benefits of such systems if used on open water bodies. Results of this study will lay the first stone for a full-size system in Jordan on an open water body, in which the advantages of such a system can be more extensively quantified.

It may be concluded based on the findings of this research that FPVs have the potential to improve power generated from PV panels and further can have a sensible positive effect on both water quality and supply. The use of FPV systems in Jordan can reduce the dependency on oil and gas for power generation and give a significant contribution to diversifying the energy mix. Furthermore, improved water quality and reduced evaporation will help Jordan to overcome the problems with our limited water resources. In a country like Jordan where energy and water resources are quite scarce, FPVs represent a promising tool for alleviating the vital consequences of shortages in both energy and water and securing the national supply of energy and water.

Author Contributions: Conceptualization, M.A.-W. and M.A.-D.; methodology, M.A.-W., M.A.-D. and M.K.; investigation, M.K.; writing—original draft preparation, M.K.; writing—review and editing, M.A.-W. and M.A.-D. and M.K.; visualization, M.K. and M.A.-D.; supervision, M.A.-W. and M.A.-D.; project administration, M.A.-W. and M.A.-D.; funding acquisition M.A.-W. and M.A.-D. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Deanship of Scientific Research at Jordan University of Science and Technology (JUST) (financial support project No. (488/2020) and the Middle East Desalination Research Centre (MEDRC).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data from this study can be made available upon request.

Acknowledgments: The authors would like to acknowledge the deanship of research at Jordan University of Science and Technology-Jordan for funding support and the Middle East Desalination Research Centre (MEDRC) for their financial support.

Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

Abbreviation	Description
FPV	Floating Photovoltaic
PV	Photovoltaic
GDP	Gross Domestic Product
JUST	Jordan University of Science and technology
TDS	Total Dissolved Solids
DO	Dissolved Oxygen
TOC	Total Organic Carbon

References

1. Kiwan, S.; Al-Gharibeh, E. Jordan toward a 100% Renewable Electricity System. *Renew. Energy* **2020**, *147*, 423–436. [CrossRef]
2. Majid, Z.A.A.; Ruslan, M.H.; Sopian, K.; Othman, M.Y.; Azmi, M.S.M. Study on Performance of 80 Watt Floating Photovoltaic Panel. *J. Mech. Eng. Sci.* **2014**, *7*, 1150–1156. [CrossRef]
3. Yadav, N.; Gupta, M.; Sudhakar, K. Energy Assessment of Floating Photovoltaic System. In Proceedings of the 2016 International Conference on Electrical Power and Energy Systems (ICEPES), Bhopal, India, 14–16 December 2016; pp. 264–269. [CrossRef]
4. Patil Desai Sujay, S.; Wagh, M.M.; Shinde, N.N. A Review on Floating Solar Photovoltaic Power Plants. *Int. J. Sci. Eng. Res* **2017**, *8*, 789–794.
5. Helfer, F.; Lemckert, C.; Zhang, H. Impacts of Climate Change on Temperature and Evaporation from a Large Reservoir in Australia. *J. Hydrol.* **2012**, *475*, 365–378. [CrossRef]
6. Santafé, M.R.; Ferrer Gisbert, P.S.; Sánchez Romero, F.J.; Torregrosa Soler, J.B.; Ferrán Gozálvez, J.J.; Ferrer Gisbert, C.M. Implementation of a Photovoltaic Floating Cover for Irrigation Reservoirs. *J. Clean. Prod.* **2014**, *66*, 568–570. [CrossRef]
7. Abdelal, Q.; Floating, P.V. An Assessment of Water Quality and Evaporation Reduction in Semi-Arid Regions. *Int. J. Low-Carbon Technol.* **2021**, *16*, 732–739. [CrossRef]
8. Sharma, A.K.; Kothari, D.P. Floating Solar PV Potential in Large Reservoirs in India. *Int. J. Innov. Res. Sci. Technol.* **2016**, *2*, 97–101.
9. Sandri, S.; Hussein, H.; Alshyab, N. Sustainability of the Energy Sector in Jordan: Challenges and Opportunities. *Sustainability* **2020**, *12*, 10465. [CrossRef]
10. Ministry of Energy and Mineral Resources. *Summary of the Overall Strategy For the Energy Sector 2020–2030*; Ministry of Energy and Mineral Resources: Amman, Jordan, 2020; Volume 2020.
11. Nayef Saeedan, M. *Sustainable Energy Mix and Policy Framework for Jordan*; Friedrich-Ebert-Stiftung: Amman, Jordan, 2011.
12. USAID Water Resources & Environment | Jordan | U.S. Agency for International Development. Available online: https://www.usaid.gov/jordan/water-and-wastewater-infrastructure (accessed on 14 November 2019).
13. Ministry of Water and Irrigation. *Jordan Water Budget 2019*; Ministry of Water and Irrigation: Amman, Jordan, 2019.
14. Alam, M.Z.B.; Ohgaki, S. Evaluation of UV-radiation and its residual effect for algal growth control. In *Advances in Water and Wastewater Treatment Technology*; Elsevier: Amsterdam, The Netherlands, 2001; pp. 109–117.
15. Sahu, A.; Yadav, N.; Sudhakar, K. Floating Photovoltaic Power Plant: A Review. *Renew. Sustain. Energy Rev.* **2016**, *66*, 815–824. [CrossRef]
16. Choi, Y.K.; Choi, W.S.; Lee, J.H. Empirical Research on the Efficiency of Floating PV Systems. *Sci. Adv. Mater.* **2016**, *8*, 681–685. [CrossRef]
17. Rahman, M.W.; Mahmud, M.S.; Ahmed, R.; Rahman, M.S.; Arif, M.Z. Solar Lanes and Floating Solar PV: New Possibilities for Source of Energy Generation in Bangladesh. In Proceedings of the 2017 Innovations in Power and Advanced Computing Technologies (i-PACT), Vellore, India, 21–22 April 2017; pp. 1–6. [CrossRef]
18. Rosa-Clot, M.; Tina, G.M.; Nizetic, S. Floating Photovoltaic Plants and Wastewater Basins: An Australian Project. In *Energy Procedia*; Elsevier Ltd.: Amsterdam, The Netherlands, 2017; Volume 134, pp. 664–674.
19. Ueda, Y.; Sakurai, T.; Tatebe, S.; Itoh, A.; Kurokawa, K. Performance Analysis of PV Systems on the Water. In Proceedings of the 23rd European Photovoltaic Solar Energy Conference, Valencia, Spain, 1 September 2008; pp. 2670–2673. [CrossRef]
20. World Bank Group. *World Bank Where Sun Meets Water: Floating Solar Market*; World Bank Group, ESMAP SERIS: Washington, DC, USA, 2019; Volume 1, pp. 1–131.
21. Yousuf, H.; Khokhar, M.Q.; Zahid, M.A.; Kim, J.; Kim, Y.; Cho, E.C.; Cho, Y.H.; Yi, J. A Review on Floating Photovoltaic Technology (FPVT). *Curr. Photovolt. Res.* **2020**, *8*, 67–78. [CrossRef]
22. Inernational Renwable Energy Agency. *Thailand Renewable Energy Outlook Based on Renewables Readiness Assessment and Remap Analysis*; Inernational Renwable Energy Agency: Abu Dhabi, United Arab Emirates, 2017.
23. Lee, N.; Grunwald, U.; Rosenlieb, E.; Mirletz, H.; Aznar, A.; Spencer, R.; Cox, S. Hybrid Floating Solar Photovoltaics-Hydropower Systems: Benefits and Global Assessment of Technical Potential. *Renew. Energy* **2020**, *162*, 1415–1427. [CrossRef]
24. Yeh, T.Y.; Ke, T.Y.; Lin, Y.L. Algal Growth Control within Natural Water Purification Systems: Macrophyte Light Shading Effects. *Water. Air. Soil Pollut.* **2011**, *214*, 575–586. [CrossRef]

25. Chen, X.C.; Kong, H.N.; He, S.B.; Wu, D.Y.; Li, C.J.; Huang, X.C. Reducing Harmful Algae in Raw Water by Light-Shading. *Process Biochem.* **2009**, *44*, 357–360. [CrossRef]
26. Chen, X.; He, S.; Huang, Y.; Kong, H.; Lin, Y.; Li, C.; Zeng, G. Laboratory Investigation of Reducing Two Algae from Eutrophic Water Treated with Light-Shading plus Aeration. *Chemosphere* **2009**, *76*, 1303–1307. [CrossRef]
27. Gallego-Elvira, B.; Baille, A.; Martin-Gorriz, B.; Maestre-Valero, J.F.; Martínez-Alvarez, V. Energy Balance and Evaporation Loss of an Irrigation Reservoir Equipped with a Suspended Cover in a Semiarid Climate (South-Eastern Spain). *Hydrol. Process.* **2011**, *25*, 1694–1703. [CrossRef]
28. de Lima, R.L.P.; Paxinou, K.; Boogaard, F.C.; Akkerman, O.; Lin, F.Y. In-situ Water Quality Observations under a Large-scale Floating Solar Farm Using Sensors and Underwater Drones. *Sustainability* **2021**, *13*, 6421. [CrossRef]
29. Bontempo Scavo, F.; Tina, G.M.; Gagliano, A.; Nižetić, S. An Assessment Study of Evaporation Rate Models on a Water Basin with Floating Photovoltaic Plants. *Int. J. Energy Res.* **2021**, *45*, 167–188. [CrossRef]
30. Naganathini, R.; Nagavinothini, R. Investigation on Floating Photovoltaic Covering System in Rural Indian Reservoir to Minimize Evaporation Loss. *Int. J. Sustain. Energy* **2021**, *40*, 781–805. [CrossRef]
31. Philadelphia Solar PS-P60-275W Data Sheet. Available online: https://www.philadelphia-solar.com/uploads/P60_outline.pdf (accessed on 5 July 2021).
32. APHA. *Standard Methods for the Examination of Water and Wastewater*, 22th ed.; Rice, E.W., Baird, R.B., Eaton, A.D., Clesceri, L.S., Eds.; American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF): Washington, DC, USA, 2012.
33. Zhang, C.; Zhang, W.; Huang, Y.; Gao, X. Analysing the Correlations of Long-Term Seasonal Water Quality Parameters, Suspended Solids and Total Dissolved Solids in a Shallow Reservoir with Meteorological Factors. *Environ. Sci. Pollut. Res.* **2017**, *24*, 6746–6756. [CrossRef] [PubMed]
34. Kirk, J.T.O. *Light and Photosynthesis in Aquatic Ecosystems*; Cambridge University Press: Cambridge, UK, 1994; ISBN 0521459664.
35. Jiang, X.; Jin, X.; Yao, Y.; Li, L.; Wu, F. Effects of Biological Activity, Light, Temperature and Oxygen on Phosphorus Release Processes at the Sediment and Water Interface of Taihu Lake, China. *Water Res.* **2008**, *42*, 2251–2259. [CrossRef] [PubMed]
36. Sun, X.; Qin, B.Q.; Zhu, G.W. Release of Colloidal Phosphorus, Nitrogen and Organic Carbon in the Course of Dying and Decomposing of Cyanobacteria. *China Environ. Sci.* **2007**, *27*, 341–345.
37. Nguyen, M.-L.; Westerhoff, P.; Baker, L.; Hu, Q.; Esparza-Soto, M.; Sommerfeld, M. Characteristics and Reactivity of Algae-Produced Dissolved Organic Carbon. *J. Environ. Eng.* **2005**, *131*, 1574–1582. [CrossRef]