JHE Journal of Hydrosciences and Environment

Comparison and Measurement of Evaporation From Water Surface of the Reservoirs in Arid Areas and Evaluation of A Glass Cover to Reduce Evaporation

S. A. Hashemi Monfared[1*], K. Zoraghi[2], M. Azhdary Moghaddam[3], M. Dehghani Darmian[4], A. Abdollahi[4]

1. Associate Professor, Department of Civil Engineering, Faculty of Shahid Nikbakht Engineering, University of Sistan and Baluchestan, Zahedan, Iran, Tel: (+98) 5431136430, Fax: (+98)5433447092, (corresponding author).*
2. MSc. Graduate, Department of Civil Engineering, Faculty of Shahid Nikbakht Engineering, University of Sistan and Baluchestan, Zahedan, Iran.
3. Associate Professor, Department of Civil Engineering, Faculty of Shahid Nikbakht Engineering, University of Sistan and Baluchestan, Zahedan, Iran,
4. Ph. D. Candidate, Department of Civil Engineering, Faculty of Shahid Nikbakht Engineering, University of Sistan and Baluchestan, Zahedan, Iran.

ARTICLEINFO

Article history:

Received: *4 July 2018*
Accepted: *21 November 2018*

Keywords:
Evaporation,
Physical coverage,
Arid zone,
LST,
MODIS,
Class-A evaporation pan.

ABSTRACT

Every year, significant amounts of freshwater are disappeared from watersheds by evaporation. Many regions of the world have been struggling with arid and semi-arid climates in recent decades. The problem of water shortage that is induced by water evaporation from lakes and water reservoirs or water use for irrigation and domestic consumption has turned into a grave challenge, especially in summer. The present experimental study focuses on the accurate measurement of evaporation and presents a novel approach to decreasing this phenomenon in the south-east of Iran (Zahedan). For this purpose, four ponds with dimensions of 120x95x70 (length, width, and depth) were constructed in Zahedan's Meteorological Organization field in order to be compared with the results of induced class-A evaporation pan. Two daily time periods (30 days) were selected to measure hydrologic parameters with respect to the spring and summer conditions as well. After the experimental results were evaluated, six relations were extracted for the accurate estimation of evaporation in arid zones. Finally, a composition type of glass physical covers was fabricated and used to decrease evaporation. The cover was made of waste glass, rubber and some glue for the buoyancy. Solar radiation and air free oxygen were allowed to be in contact with the water surface. The results showed that the rate of evaporation decreased by up to 40 percent using these covers just for the 50 percent of the surface covering.

1. Introduction

Evaporation is an important factor in a hydrologic cycle and water reserve. Many studies are conducted to measure evaporation by analytical and differential equations. Several factors affect water evaporation from free surfaces, e.g. air temperature, solar radiation, wind speed, air humidity, atmospheric pressure, air, surface evaporation (Penman, 1948; Dalton, 1802; Mayer, 1928; Rohwar, 1933). In general, the main factors that are involved in the water evaporation rate from oceans, lakes, rivers, ponds, and other bodies of water are air temperature, relative humidity, water temperature, and wind speed (Kumara and Arakeri, 2015). Some investigations have attempted to specify the influence of wind as a dependent function on the evaporation from water surfaces. For instance, McJannet et al. (2012) determined the relationship between evaporation and various wind speeds at a height of about 2 meters from the ground. It was found that wind had a great influence on evaporation from the studied pond in Australia. In addition to these factors, as well as the fact that the height of marine inversion is effective on evaporation from lakes, the forecast of evaporation from a lake should be considered by synoptic features (Shilo et al., 2015). There are many methods to predict water evaporation from a surface. A common technique is to use water electrical conductivity (Nordbo et al., 2011; Tanny et al., 2008, 2011). Another technique is fuzzy logic and neural network when a logical statistic of evaporation is available. The rate of evaporation estimation by the relationship among input data that are included in the solar radiation is relative to humidity, temperature, air pressure, etc. (Kişi, 2006; Beruton, 2000). Neural networks are a powerful tool to predict the rate of evaporation with various complexities. Lu et al. (2014) used neural networks to predict the rate of evaporation in an indoor swimming hall that involved five pools. In most experiments, the evaporation was a function of air temperature, air humidity in the indoor environment, and

* Corresponding author's email: Hashemi@eng.usb.ac.ir

temperature of the water. Research results have proven that there is a relationship between evaporation and meteorological parameters in a certain area with a certain climate. Empirical relationships, which estimate evaporation, are very diverse and they need to be calibrated for any given region (Vanzyl et al., 1989). Aschonitis et al. (2012) is an example of works done on different climates. They evaluated pan coefficient equations in a Mediterranean semi-arid environment by using ASCE standard Penman-Monteith. Among six different equations to estimate K_P, Cuenca (1989)'s equation closed the Penman-Monteith method (reference method). As another example, Sheikh and Mohammadi (2013) addressed evapotranspiration in semi-arid regions of Iran. They estimated the amount of evaporation and compared it with five experimental results. Also, the Hargreaves-Samani method had the closest results to the standard method of FAO Penman. McMahon et al. (2013) estimated potential evaporation in Australia with standard meteorological data. Measuring methods included Penman, Penman-Monteith, Priestley Taylor and class-A evaporation pan. Considering the importance of the issue of water scarcity and droughts, scholars and researchers have provided solutions to reduce evaporation. These solutions can be divided into physical, mechanical, biological, and chemical methods as explained below in more details.

1.1. Physical and mechanical solutions

The physical and mechanical solutions use parts and coverings that are floated on water. There are different types of floating covers, such as E-vap cap, CURE, c.w. NEAL, E Vap-Mat, febtech, etc. (Schmidt pers. comm., 2005). Shadow materials that reduce solar radiation and wind speed are effective in reducing evaporation from surface water so that they decrease evaporation nearly to 80% (Alvarez, 2006; Bastiaanessen and Bandara, 2001). Black plastic balls, 4-inch balls, were released into water level in 2015 in the Los Angeles Department of Water and Power. This solution is another way to reduce evaporation and prevent the growth of algae, but it is not applicable in areas with high wind velocity.

1.2. Chemical solutions

Conservation of water quality is an important factor to be considered (Hashemi Monfared and Dehghani Darmian, 2016; Hashemi Monfared et al., 2017; Dehghani Darmian et al., 2018). The application of monolayer and polyacrylamide products are chemical methods to reduce evaporation. In general, chemical methods are not as effective as physical methods in evaporation control. This approach makes limitations for animals (Anonymous, 2005). This type of cover will impair the quality of water and is not applicable for domestic goals.

1.3. Biological solutions

Some herbal coverings like lily leaves and moss reduce evaporation from water surfaces. This method is, however, recommended to a lesser extent because it is not more efficient than other available methods in reducing evaporation (Watts, 2005). The knowledge of evaporation rate can play a significant role in water saving in civil engineering works and the development of water resources management, making it necessary to investigate into an accurate method-based reality. Presently, the rate of evaporation is determined by using a class-A evaporation pan. Because the physical characteristics and the position of class-A evaporation pan are similar in different environments, this causes the measurement of evaporation not to yield an exact amount in some cases since wind velocity may be high, air humidity may be low, air temperature may change suddenly and no vegetation may be available. Therefore, in the region of Sistan and Baluchestan, a case study in Zahedan City, in the bed-ground are built the small ponds like ponds that are located near the natural conditions of reservoirs and water surface. This paper introduces a new environmentally-friendly method to reduce evaporation, in which glass debris cover is used as a physical solution

2. Materials and Methods

The present study addressed the accurate measurement of evaporation and a plan to reduce it in Sistan and Baluchestan (Zahedan). For this purpose, ponds were built, and data on standard evaporation pan collected in Zahedan Meteorological Organization (synoptic stations located at Zahedan's Airport) were used for comparison. In order to increase the accuracy of the results, some synoptic station equipment was used in Zahedan (the station does the project by elaborated operators).

As mentioned, the study was carried out at Zahedan Airport (Lat. 29° 28' N., Long. 60°53' E.). The weather station was located 1370 meters above sea level. To measure the actual evaporation in this arid region, four ponds with the dimensions of 120 × 95 × 70 cm (length × width × depth) were built in the bed ground. Comparing the evaporation from the surface of the ponds with class-A evaporation pan, the area of surface reservoirs was equal to that of class-A evaporation pan (amount of surface area =1.14 m^2). The slope of walls in these ponds was 0.5 (see Figure 1) considering soil stability and the existence of some reservoirs in the adjacent catchments. Additionally, the conditions of penetration in ponds were similar to those of class-A evaporation pan (no-penetration boundaries). Thus, the body of ponds was sealed by a plastic cover. Hence, first the bed ground was excavated, and a layer of concrete was poured. Then, two layers of thick plastic were used to insulate the pond beds from humidity. Next, the framework of the entire slope and the other components were done and the body of them was prepared. One concrete layer with 7 cm thickness was used to protect the insulation layer. Finally, for security, an insulating layer that contained cement and stone powder was applied. This layer was over the concrete layer to almost zero influence.

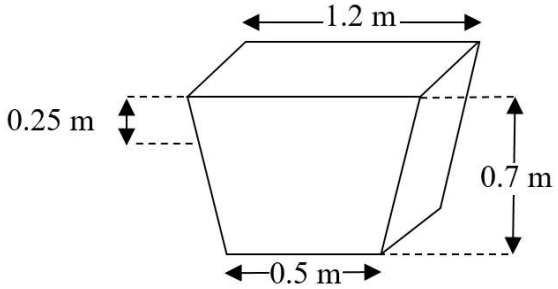


Fig. 1. dimensions of the pond in the study area

After the construction of ponds was completed, a wire mesh was used on the surface of the pond like the wire on the pan to prevent the water loss by local fauna. Because the site was far from the city to prevent the entrance of animals and rubbish by the wind or storm, it was fenced.

2.1. Experimental method

Four separate ponds were constructed in the study site. One of them was used as a storage, one as control, and two as a site to measure evaporation. In summer, one of the ponds was half-covered by a glass to reduce the evaporation.

In order to regulate the temperature of the added water to the pond with the water content of the pond, one of the ponds was chosen as water storage. This reduced the error of the daily measurements. After the daily data were measured, the water tank was refilled with water again. The experiments were done one month in spring and one month in summer (from May 22 to June 21, 2015, and from August 23 to September 22, 2015). The evaporation of water from the pan and pond was measured at 10:30 (0600 GMT) every day. Then, the amount of the added water to the ponds and pan was recorded. The amount of water was added by 1- and 4-liter standard cups. To convert the added water into evaporation (millimeter), the coefficients 0.88 and 0.76 were used for the pan and ponds, respectively. The height of the evaporation pan was 255 mm (about 25 cm). Meanwhile, the height from the surface of the pond was separated to measure evaporation. The average surface area of the pond to calculate the amount of evaporation was 0.99 (1.2×.825=0.99) when the area of the pond was 1.14 equivalent to the pan. Therefore, because of the inclined walls of the pond, the pan coefficient was considered 0.76 ($\frac{0.88\times 0.99}{1.14}=0.76$). In order to prevent the sedimentation on the body, the errors in the results and the turbidity of water were reduced, which are influential on the rate of evaporation from ponds, so they were washed weekly.

2.2. Testing tools list

Instruments used in this research included actinograph, soil thermometers, grass minimum thermometers, rain gauge, wind velocity meter, pan evaporation, sunshine recording, hydrograph, maximum and minimum thermometer, wet bulb, and dry bulb thermometer. Here is expressed the time when the data were recorded from any device. The data from actinograph were recorded every day at 1800 (6:00 p.m.). This device was set at zero again the next day, and this procedure was done for two months. Soil thermometers were put at various depths in the soil, such as 5, 10, 20, 30, 50, and 100 cm below the ground, and they showed the temperature at the mentioned depths. The data were recorded at three times, i.e. 0300, 0900, and 1500 GMT. The temperatures were recorded by grass minimum thermometers at 0600 GMT. At 15:00 o'clock, when the soil thermometers recorded numbers, we took the cap of the thermometers. Consequently, the thermometer cooled down during the night when it was cold. So, it recorded the minimum temperature. At 0300, when the soil thermometers recorded numbers, we put the cap on them to protect them from direct sunlight. An anemometer was placed on class-A evaporation pan in order to measure the amount of airflow over the pan during the day and night. The measurement was performed from 06:00 to 06:00 on the next day. This reading from this device was used as the difference between two consecutive days. Sunshine was recorded at a height of about 1.5 meters above the ground. A paper was put in the device from 1500 to 1800 GMT and it was removed at the same time on the next day. The thermometer recorded the maximum and minimum temperatures at 0300 and 1500 GMT; then, they were set at zero after every recording. Because this zone is a tropical one, according to the standards, instead of recording at 1500, it was performed at 1200.

2,3. Using of the glass plates as a way to reduce evaporation

So far, many methods have been provided to reduce water evaporation from dam ponds and they can be divided into three categories: chemical, physical, and biological methods. The disadvantages of these methods are that they are very expensive to get built and their condition-based maintenance is very difficult. After several tests, we achieved a modern environmentally-friendly method to reduce evaporation. It was made from scrap glass. The advantages of this method are its low cost, use of recyclable materials, use of available and low-cost materials, very simple production and no loss of water quality in a long run (due to sunlight exposure) as well as the ability of plan development. After it was tested on the ponds, satisfactory results were obtained.

To test the glass, some sheets were prepared at dimensions of 89 × 65 cm, and the glass pieces were glued together with the silicone adhesive. This adhesive had little effect on water quality and the living organisms in the water. To float the cover glass on the surface of pond water, fiber was used and they were connected with the same adhesive.

3. Results and Discussion

3.1. Measurements in the spring season - May and June

The environmental factors, such as air temperature, rate of clouds in the sky, air humidity, wind speed and direction, evaporation from class-A pan and built ponds, solar radiation, sunny hours, minimum and maximum water temperature, and rainfall quantity at 0600 GMT (at 10:30 AM local time), were measured in the spring. In this section, statistical analysis of effective factors on evaporation is discussed by SPSS software (version 20). Figure 2 shows the rate of evaporation from the ponds and pan in the spring. In most days, the amount of evaporation from the ponds outweighed that from the pan. The rate of evaporation from the ponds was less than that from the pan on days 10, 14, 18, 23, 25, 26, 27, 28, 29, 30, and 31. This was due to the changes in the environment temperature. Thus, on days when the minimum temperature of the earth decreased or the maximum temperature of the water increased, the amount of evaporation from the ponds was less than the pan

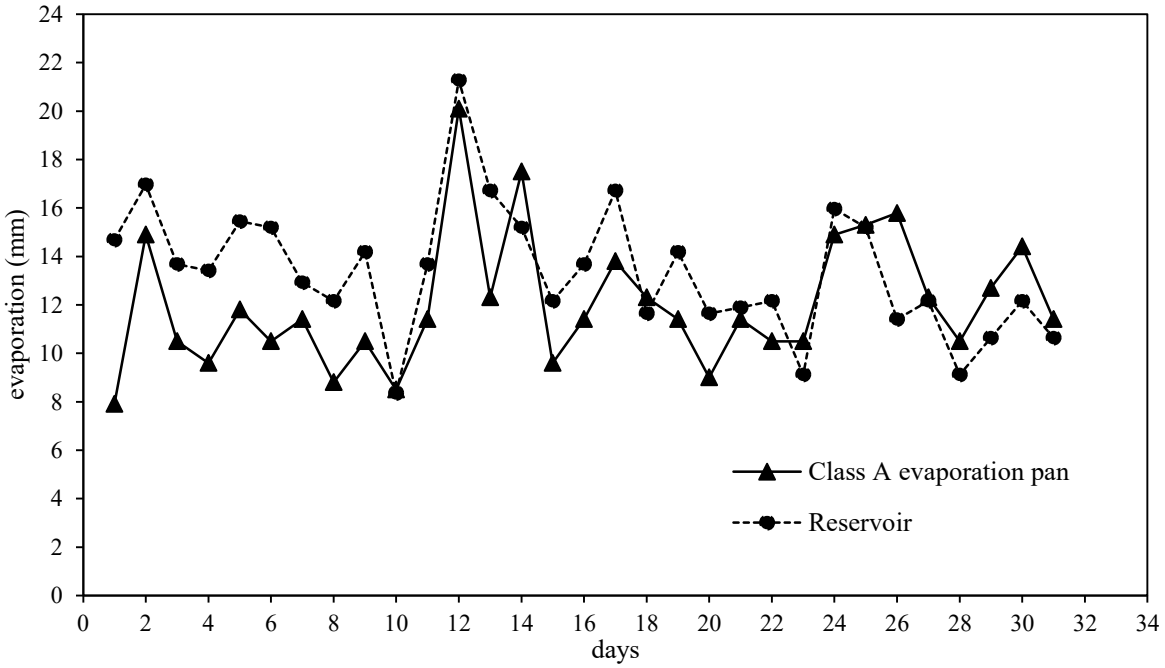


Fig. 2. The comparison of evaporations from the ponds and the pan in the spring

Tables 1 and 2 focus on evaluating the measured evaporation from the pan and ponds as well as the environmental factors in the spring by using Pearson's correlation. Among the parameters, the significance of relation according to the second column number (sig) is specified. There is a significant relationship between evaporation from the built ponds and air temperature, wind, minimum ground temperature, and maximum water temperature (Table 1). Factors, such as humidity, clouds in the sky, radiation, minimum water temperature, and rainfall, had no significant impact on evaporation. Table 2 shows that evaporation from the pans was significantly related to wind, minimum ground temperature, and maximum water temperature. However, there was no significant relationship among other factors, such as air temperature, humidity, the rate of clouds in the sky, minimum water temperature, and rainfall.

Table 1. The results of Pearson's coefficient of correlation between environmental factors and evaporation from the ponds in the spring

Variable	Sig. (2-tailed)	Pearson's coefficient of correlation
Air temperature	0	-0.589
Cloud	0.959	0.01
Humidity	0.265	0.206
Wind speed	0.013	0.44
Radiation	0.281	0.2
Sun clock	0.609	-0.096
Ground temperature	0.037	0.376
Minimum water temperature	0.233	-0.221
Maximum water temperature	0	-0.706
Rainfall	0.499	0.126
Pan	0.001	0.578

Table 2. The results of Pearson's coefficient of correlation between environmental factors and evaporation from the pans in the spring

Variable	Sig. (2-tailed)	Pearson's coefficient of correlation
Air temperature	0.149	-0.265
Cloud	0.53	-0.117
Moisture	0.325	0.183
Wind speed	0.011	0.45
Radiation	0.487	0.13
Sun clock	0.606	0.096
Ground temperature	0.024	0.404
Minimum water temperature	0.681	0.077
Maximum water temperature	0.01	-0.455
Rainfall	0.578	-0.104

3.2. Verification of the relationships

Tables 3 and 4 and Figures 3 to 5 show the validity of the theory relationships. Two relationships achieve correspondence to the last column of Table 3 (sig). This column is zero, which indicates the best kind of convergence. Therefore, the results are acceptable.

Table 3. The results of analysis of variance (ANOVA) in the spring

ANOVA[a]					
Model	Sum of squares	df	Mean square	F	Sig.

1	Regression	151.303	4	37.826	14.743	.000[b]
	Residual	66.709	26	2.566		
	Total	218.012	30			
2	Regression	147.444	3	49.148	18.805	.000[c]
	Residual	70.568	27	2.614		
	Total	218.012	30			

b. Predictors: (Constant), watermax, earths, temperature, wind
c. Predictors: (Constant), watermax, earths, temperature

In Table 4, the coefficients are presented in column B, which shows the relationship between environmental factors and evaporation. Accordingly, coefficients can be provided to calculate the theoretical evaporation from the built ponds in the spring.

Table 4. The results of the coefficients in the spring

Coefficients[a]

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	45.445	5.833		7.791	.000
	Temperature	-.278	.151	-.244	-1.843	.077
	wind	.169	.138	.167	1.226	.231
	Earths	.212	.110	.259	1.934	.064
	Watermax	-.789	.195	-.537	-4.039	.000
2	(Constant)	46.233	5.851		7.901	.000
	Temperature	-.289	.152	-.254	-1.903	.068
	Earths	.291	.090	.356	3.246	.003
	Watermax	-.817	.196	-.556	-4.175	.000

Figure 3 illustrates the frequency in continuous variables. The horizontal and vertical axes indicate interest variable and frequency samples in each category of continuous variable, respectively. Since the curve is bell-shaped, implying normal distribution of the variable, the obtained relationships are normal and acceptable.

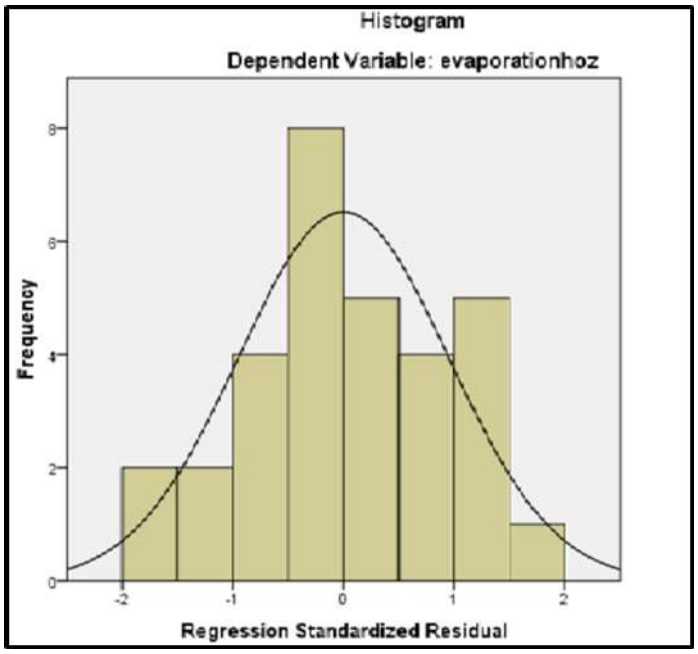


Fig. 3. Diagram of distribution frequency of variables in the spring obtained from SPSS software

Figure 4 displays a scatterplot in which the clustered points are clearly shown around a straight line or a curve. Also, it provides an objective understanding of the scattering data on a line or curve. There is no priority known as the theoretical relationship that can be used in most situations. Although the scatterplot shows the existence of a relationship, it is far from linearity. Drawing a scatterplot in regression analysis has great importance and use between two data sets to guess the type of relationship in them. In fact, a relationship that is a form line between two variables is speculated; then, little data were collected from the two variables. Next, the data were drawn to make points appear in a two-dimensional graph, which is called a scatterplot. This graph illustrates the relationships between variables and plays an important role in regression analysis. Allowing the data is almost along the straight line, which indicates the relations have been obtained properly.

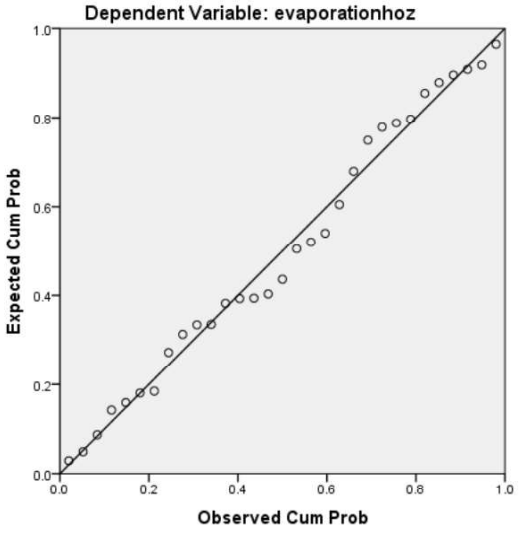


Fig. 4. The scatterplot in the spring by SPSS software

Figure 5 is related to residual statistics. Predicted value and residual variable are included, which are not the

standard variables. This graph does not show a specified pattern, so the assumption establishes linearity of the model and proves the error variance.

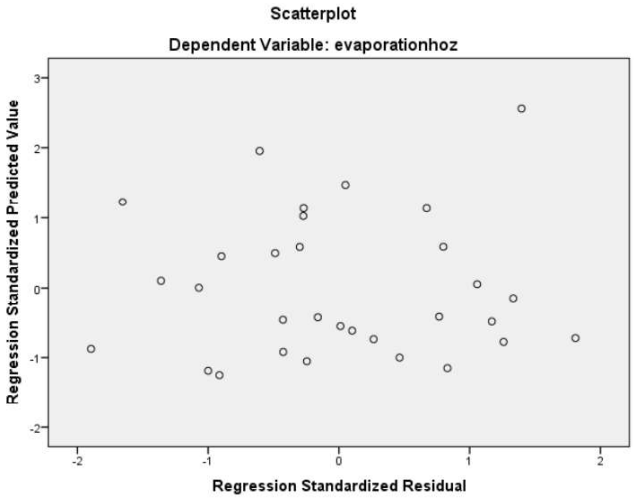


Fig. 5. The scatterplot of residuals versus predicted value in the spring

3.3. Empirical formula derived in the spring

Based on the results presented in Tables 3 and 4 in the spring, it is clear that the parameters such as air temperature, wind speed, minimum ground temperature, and maximum water temperature have a significant relationship with evaporation. Thereupon, the correlation coefficients in Table 4 can be calculated by two empirical relations to measure the rate of evaporation in the spring as:

$$E = 45.445 - 0.278T_{air} + 0.169V_{wind} + 0.212T_{earth} - 0.789T_{\max,water} \quad (1)$$

$$E = 46.233 - 0289T_{air} + 0.291T_{earth} - 0.817T_{\max,water} \quad (2)$$

where E, T_{air}, V_{wind}, T_{earth} and $T_{max,water}$ denote evaporation, air temperature, wind speed, minimum ground temperature, and maximum water temperature. In Figures 6 and 7, the amount of evaporation is shown by two empirical relationships. Knowing the above parameters, these equations can be used. The maximum error of Equations (1) and (2) compared to the evaporation of the ponds was 0.367 % and 0.314%, respectively.

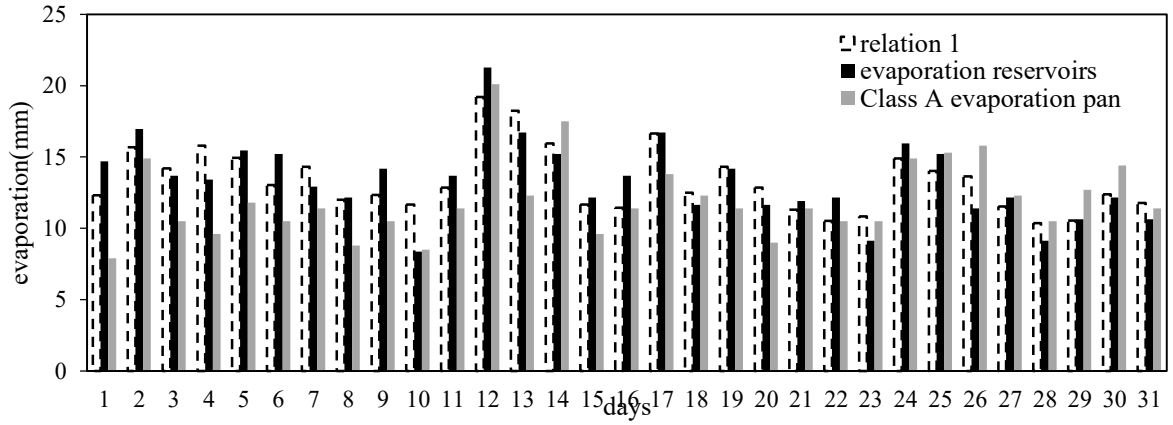


Fig. 6. The comparison of the results of the empirical relation (1), the pan and the ponds in the spring

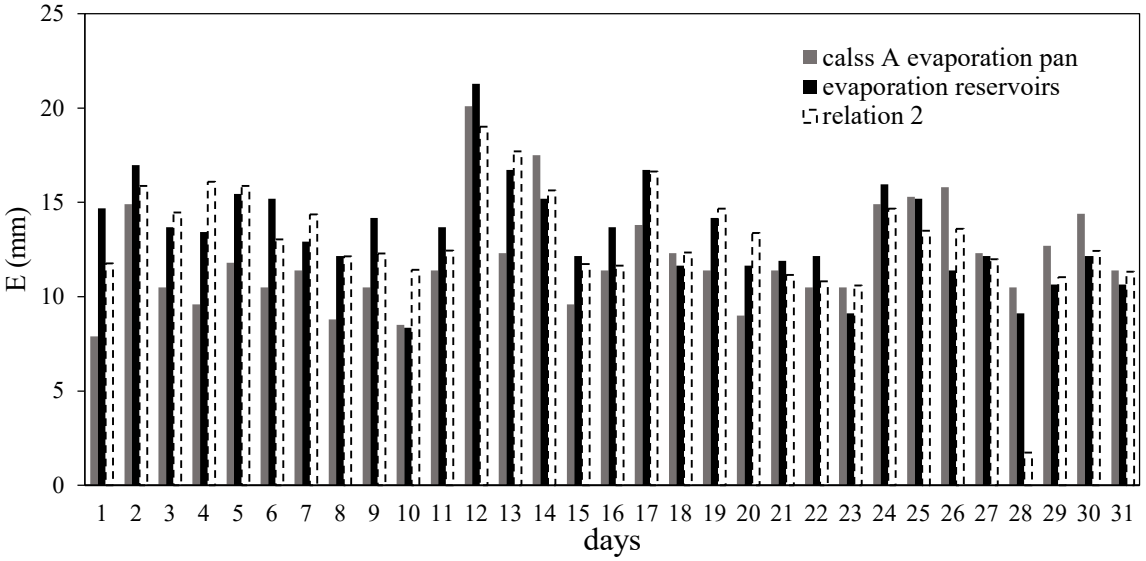


Fig. 7. The comparison of the results of the empirical relation (2), the pan and the ponds in the spring

3.4. Measurements in the summer - August and September

All environmental factors examined in the spring were also investigated in the summer. Figure 8 shows the rate of evaporation from the ponds and pan in the summer. On some days, the amount of evaporation from the ponds was less and more than that from the pan. This is a change in the environment temperature. On days when the air was cold, evaporation from the ponds was less than that from the pan.

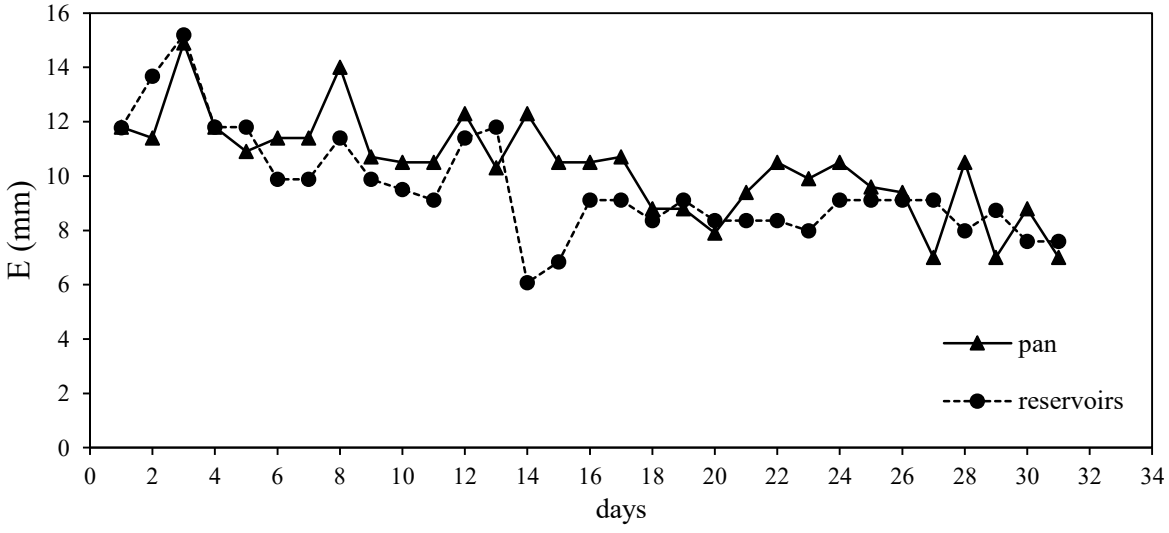


Fig 8. The comparison of evaporation rate from the ponds and the pan in the summer

Table 5 reveals a significant relationship among evaporation from the built ponds and air temperature, wind, sunny hours, minimum ground temperature, and minimum and maximum water temperature. But, factors such as humidity, clouds in the sky, radiation, and rainfall did not have a significant impact on evaporation in the summer.

Table 5. The results of Pearson's coefficient of correlation between environmental factors and evaporation from the ponds in the summer

Variable	Sig. (2-tailed)	Pearson Correlation
Air temperature	0	0.625
Cloud	0.171	252
Moisture	0.522	0.119
Wind speed	0.002	0.544
Radiation	0.957	-0.01
Sunny hours	0.001	-0.562
Ground temperature	0	0.791
Minimum water temperature	0.002	0.536
Maximum water temperature	0.037	0.377
Rainfall	0.26	0.209

Column 2 in Table 6 shows the value (sig). So, there is a significant relationship between the evaporation from the pan and environmental factors like air temperature, wind, and minimum and maximum water temperature. The other factors cast no influence on evaporation.

Table 6. The results of Pearson's coefficient of correlation between environmental factors and the pan in the summer

Variable	Sig. (2-tailed)	Pearson Correlation
Air temperature	0.002	0.532
Cloud	0.956	-0.01
Moisture	0.575	0.105
Wind speed	0.015	0.432
Radiation	0.171	0.252
Sunny hours	0.087	-0.312
Ground temperature	0	0.676
Minimum water temperature	0.001	0.571
Maximum water temperature	0.033	0.385
Rainfall	0.429	0.147

From Table 7, four relations that are according to the last Column can be calculated, and the results are acceptable and suitable.

Table 7. The results of ANOVA for data collected in the summer

ANOVA[a]

Model		Sum of squares	df	Mean square	F	Sig.
1	Regression	82.474	6	13.746	9.843	.000[b]
	Residual	33.515	24	1.396		
	Total	115.989	30			
2	Regression	82.160	5	16.432	12.144	.000[c]
	Residual	33.829	25	1.353		
	Total	115.989	30			
3	Regression	82.027	4	20.507	15.699	.000[d]
	Residual	33.962	26	1.306		
	Total	115.989	30			
4	Regression	81.813	3	27.271	21.544	.000[e]
	Residual	34.177	27	1.266		
	Total	115.989	30			

b. Predictors: (Constant), watermax, wind, sunny hours, watermin, temperature, earths
c. Predictors: (Constant), watermax, wind, watermin, temperature, earths
d. Predictors: (Constant), wind, watermin, temperature, earths
e. Predictors: (Constant), watermin, temperature, earths

The coefficient in column B shows the relationship between environmental factors and rate of evaporation. By using this, the relationship can be provided to calculate evaporation from the built ponds.

Table 8. The results for coefficients in the summer

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5.614	4.098		1.370	.183
	temperature	.156	.141	.266	1.106	.280
	wind	.078	.152	.083	.511	.614
	sunny hours	-.165	.348	-.093	-.474	.640
	earths	.381	.152	.816	2.504	.019
	Water min	-.287	.190	-.438	-1.513	.143
	Water max	.058	.107	.098	.543	.592
2	(Constant)	4.143	2.635		1.573	.128
	temperature	.195	.113	.333	1.723	.097
	wind	.060	.145	.064	.415	.682
	earths	.423	.123	.904	3.434	.002
	Water min	-.325	.170	-.495	-1.908	.068
	Water max	.025	.080	.042	.314	.756
3	(Constant)	4.568	2.221		2.057	.050
	temperature	.206	.105	.353	1.969	.060
	wind	.058	.143	.061	.405	.689
	earths	.423	.121	.904	3.497	.002
	Water min	-.321	.167	-.489	-1.923	.065
4	(Constant)	4.909	2.023		2.427	.022
	temperature	.210	.103	.358	2.040	.051
	earths	.457	.086	.977	5.337	.000
	Water min	-.357	.139	-.544	-2.575	.016

Figures 9, 10 and 11 depict the relationships in the summer. In the spring, the same figures were observed. These prove that the relationships are acceptable and correct.

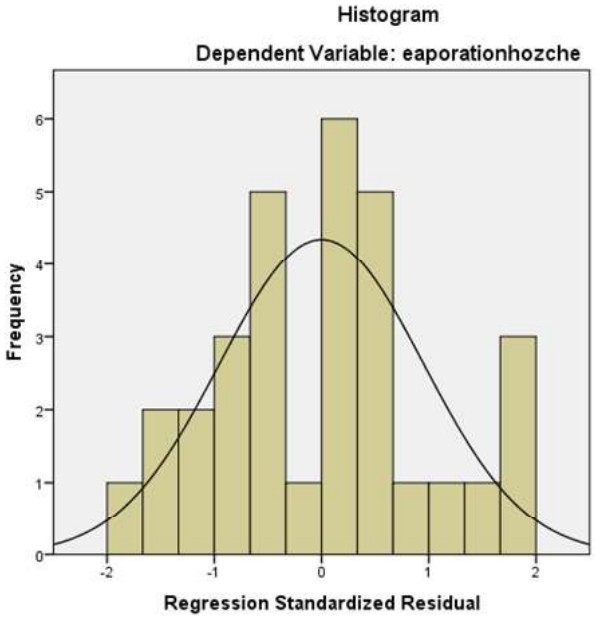


Fig. 9. The diagram of frequency distribution of the variables in the summer derived from SPSS software

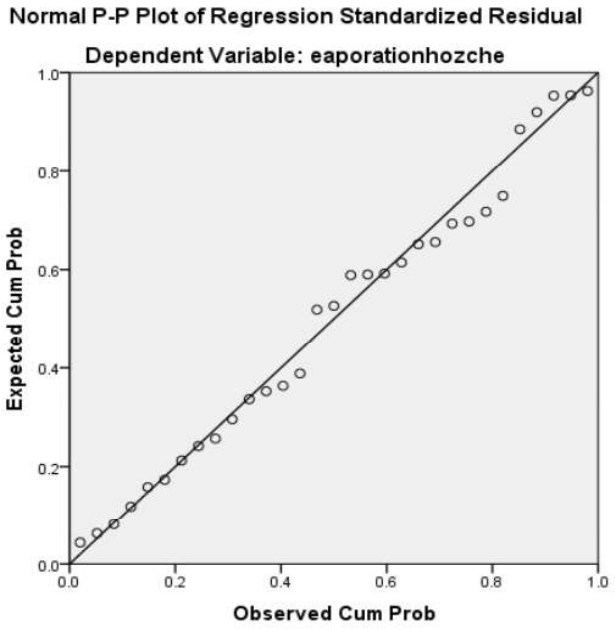


Fig 10. The scatterplot in the summer derived from SPSS software

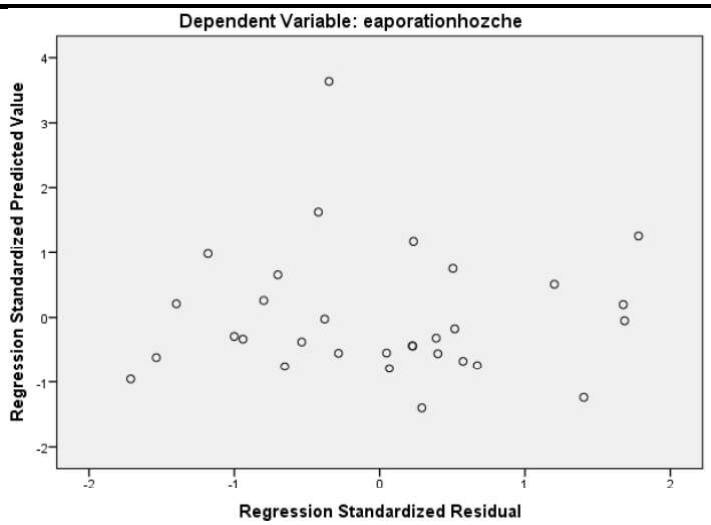


Fig 11. The scatterplot of residuals versus predicted value in the summer

3.5. Empirical formula obtained in the summer

Results are presented in Table 7 and 8 in the summer to be specified; besides, the effective parameters in the spring, the sunny hours and minimum water temperature, have a relationship with evaporation. By using the coefficient in Table, four empirical formulae can be calculated to measure the amount of evaporation in the summer as:

$$E = 5.614 + 0.156T_{air} + 0.078V_{wind} - 0.165S + 0.381T_{earth} - 0.287T_{\min,water} + 0.058T_{\max,water} \quad (3)$$

$$E = 4.143 + 0.195T_{air} + 0.06V_{wind} + 0.423T_{earth} - 0.325T_{\min,water} + 0.025T_{\max,water} \quad (4)$$

$$E = 4.568 + 0.206T_{air} + 0.058V_{wind} + 0.423T_{earth} - 0.321T_{\min,water} \quad (5)$$

$$E = 4.909 + 0210T_{air} + 0.457T_{earth} - 0.357V_{\min,water} \quad (6)$$

where S and $T_{min, water}$ denote sunny hours and minimum water temperature.

Figures 12, 13, 14 and 15 compare the value from four relationships, measured ponds and pan. Maximum error in Equations (3), (4), (5) and (6) are 0.143%, 0.132%, 0.128% and 0.133%, respectively.

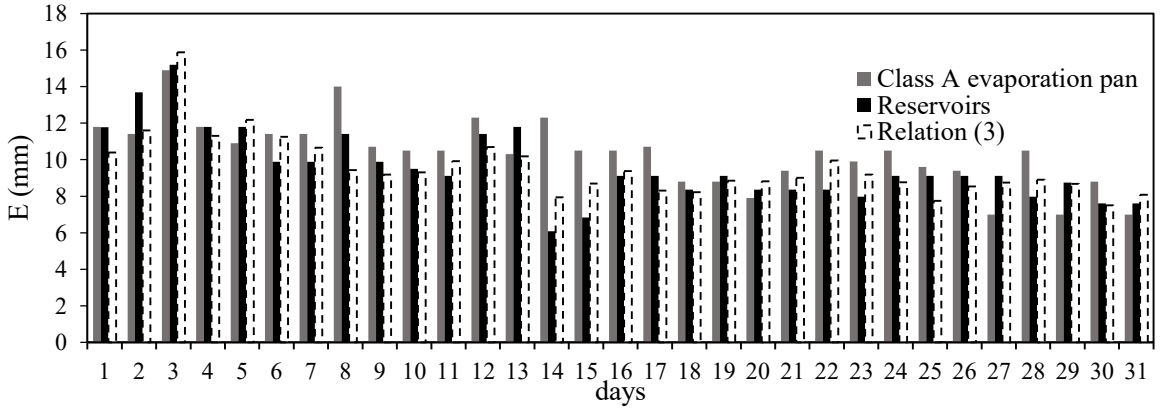


Fig 12. The comparison of the results of the empirical relation (3), pan and ponds in summer

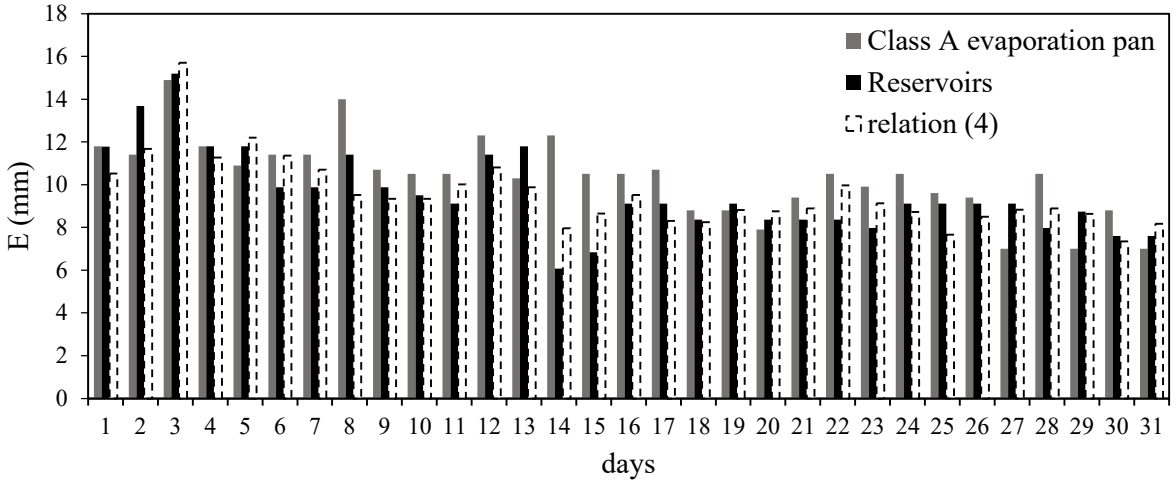


Fig 13. The comparison of the results of the empirical relation (4), pan and ponds in the summer

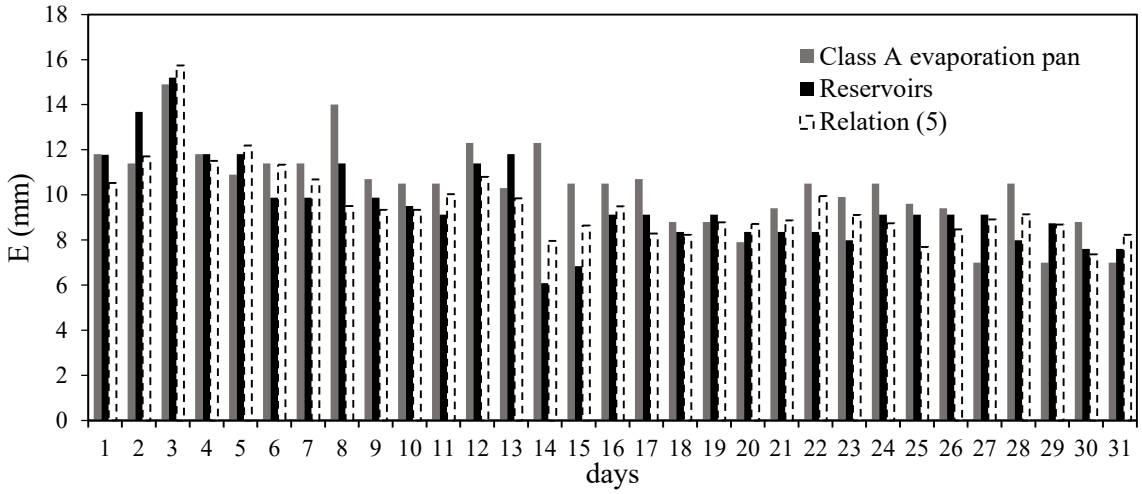


Fig. 14. The comparison of the results of the empirical relation (5), pan and ponds in the summer

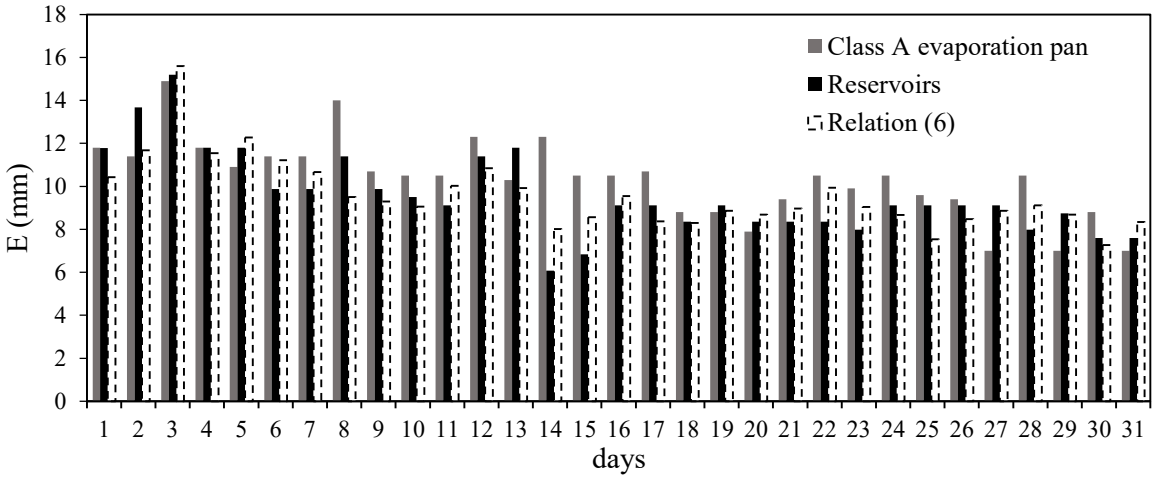


Fig. 15. The comparison of the results of the empirical relation (6), pan and ponds in the summer

3.6. Measured evaporation from the surface with physical cover

One way to reduce evaporation from the ponds is the use of physical cover. The fundamental problem of physical covers that they hinder the ingress of air and light into the fluid. This reduces the quality of the fluid in a short time. In this paper, recycled materials made of glasses and polystyrene were applied to cover the surface of the ponds. The cover allows the penetration of light and air into the fluid and prevented its quality loss. The application of recycled materials to control evaporation helps to preserve the environment.

Figure 16 compares the rate of the evaporation from the pan and ponds with and without cover in the summer. Obviously, the ponds covered with glass exhibited a lower rate of evaporation from the surface. The results showed that the cover reduced evaporation by 30-40%.

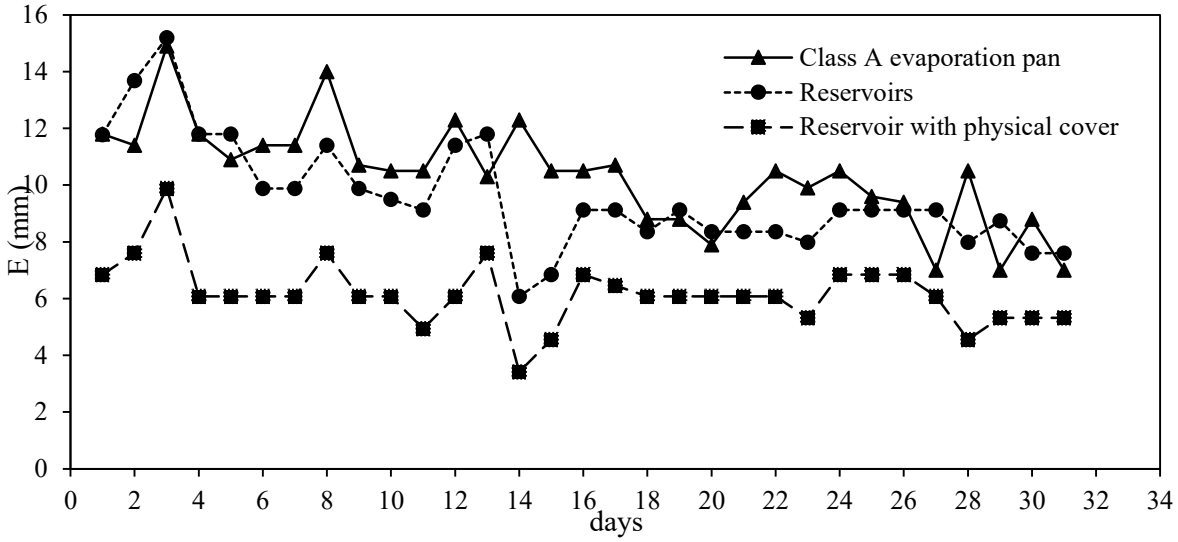


Fig. 16. The comparison of evaporation from the pan and from the ponds with and without cover in the summer

4. Conclusion

This study aimed to measure and compare evaporation from ponds and class-A evaporation pan in hot-dry regions. For this propose, four ponds were built. We investigated the rate of evaporation under sudden thermal stresses and other environmental factors in two seasons: spring and summer. In each season, the effective parameters were recorded, such as air temperature, wind speed, minimum ground temperature, maximum water temperature, and sunny hours. According to these parameters, relationships were presented for two seasons. The analytical statistics were done by SPSS software. The error for the relationships was less than 1%. To reduce evaporation from the ponds, a physical cover was used. It was a new method to reduce evaporation. This cover was built from scrap glasses to cover 50% of the pond surface. This cover had no impact on water quality and reduced evaporation by up to 40 percent. Future works are suggested to address other materials to check if they can reduce evaporation to a greater extent without hurting the environment.

5. References

1. Penman, H.L., 1948. Natural evaporation from open water, bare soil and grass. Proc. R. Soc. Lond. A, 193(1032), pp.120-145.
2. Dalton, J., 1802. Experiments and observations to determine whether the quantity of rain and dew is equal to the quantity of water carried off by the rivers and raised by evaporation: With an enquiry into the origin of springs. R. & W. Dean.
3. Rohwer,carl,1943; Evaporation from different types of pans. Proe. Amer. Soc. Civil Engrs.,59,223-253;1943.Trans.Amer. Soc.civil Engrs.,99,673-703.
4. Meyer, A.F. 1928. The Elements of Hydrology, 2nd edition. New York: John Wiley & Sons
5. Alvarez, V.M., Baille, A., Martínez, J.M. and González-Real, M.M., 2006. Efficiency of shading materials in reducing evaporation from free water surfaces. Agricultural Water Management, 84(3), pp.229-239.
6. Bastiaanssen, W.G.M. and Bandara, K.M.P.S. 2001 Evaporative depletion of irrigated watersheds in Sri Lanka. Irrig. Sci. 2001 21 1-15.

7. Tanny, J., Cohen, S., Assouline, S., Lange, F., Grava, A., Berger, D., Teltch, B. and Parlange, M.B., 2008. Evaporation from a small water reservoir: Direct measurements and estimates. Journal of Hydrology, 351(1-2), pp.218-229.
8. Aschonitis, V.G., Antonopoulos, V.Z. and Papamichail, D.M., 2012. Evaluation of pan coefficient equations in a semi-arid Mediterranean environment using the ASCE-standardized Penman-Monteith method. Agricultural Sciences, 3(01), p.58.
9. McJannet, D.L., Webster, I.T. and Cook, F.J., 2012. An area-dependent wind function for estimating open water evaporation using land-based meteorological data. Environmental modelling & software, 31, pp.76-83.
10. McMahon, T.A., Peel, M.C., Lowe, L., Srikanthan, R. and McVicar, T.R., 2013. Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis. Hydrology and Earth System Sciences, 17(4), pp.1331-1363.
11. Sheikh, V. and Mohammadi, M., 2013. Evaluation of reference evapotranspiration equations in semi-arid regions of northeast of Iran. International Journal of Agriculture and Crop Sciences, 5(5), p.450.
12. Lu, T., Lü, X. and Viljanen, M., 2014. Prediction of water evaporation rate for indoor swimming hall using neural networks. Energy and Buildings, 81, pp.268-280.
13. Kumar, N. and Arakeri, J.H., 2015. Natural Convection Driven Evaporation from a water surface. Procedia IUTAM, 15, pp.108-115.
14. Shilo, E., Ziv, B., Shamir, E. and Rimmer, A., 2015. Evaporation from Lake Kinneret, Israel, during hot summer days. Journal of Hydrology, 528, pp.264-275.
15. Bruton, J.M., McClendon, R.W. and Hoogenboom, G., 2000. Estimating daily pan evaporation with artificial neural networks. Transactions of the ASAE, 43(2), p.491.
16. Kişi, Ö., 2006. Daily pan evaporation modelling using a neuro-fuzzy computing technique. Journal of hydrology, 329(3-4), pp.636-646.
17. Vanzyl, W.H., De Jager, J.M. and Maree, C.J., 1989. The relationship between daylight evaporation from short vegetation and the USWB Class A pan. Agricultural and forest meteorology, 46(1-2), pp.107-118.
18. 21. Hashemi Monfared, S.A., Dehghani Darmian, M., 2016. Evaluation of Appropriate Advective Transport Function for One-Dimensional Pollutant Simulation in Rivers. Int. J. Environ. Res. 10 (1),77-84.
19. 22. Hashemi Monfared, S.A., Dehghani Darmian, M., Snyder, S.A., Azizyan, G., Pirzadeh, B., Azhdary Moghaddam, M., 2017. Water Quality Planning in Rivers: Assimilative Capacity and Dilution Flow. Bull Environ Contam Toxicol, 99 (5), 531-541.
20. 23. Dehghani Darmian, M., Hashemi Monfared, S.A., Azizyan, G., Snyder, S.A. Giesy, J.P., 2018. Assessment of tools for protection of quality of water: Uncontrollable discharges of pollutants. Ecotox Environ Safe. 161, 190-197.
21. 24. Anonymous, 2005. Flexible solutions. Website accessed on 1 March 2005. http://www.flexiblesolutions.com/media/news_releases/OwensLakeWaterSavrTrials.htm.
22. 25. Watts, P.J., 2005. Scoping Study: Reduction of Evaporation from Farm Dams. Final Report to the National Program for Sustainable Irrigation. Feedlot Services Australia Pty Ltd, Toowoomba, Australia.
23. 27. Nordbo, A., Launiainen, S., Mammarella, I., Leppäranta, M., Huotari, J., Ojala, A. and Vesala, T., 2011. Long-term energy flux measurements and energy balance over a small boreal lake using eddy covariance technique. Journal of Geophysical Research: Atmospheres, 116(D2).
24. 28. Tanny, J., Cohen, S., Berger, D., Teltch, B., Mekhmandarov, Y., Bahar, M., Katul, G.G. and Assouline, S., 2011. Evaporation from a reservoir with fluctuating water level: Correcting for limited fetch. Journal of hydrology, 404(3-4), pp.146-156.