Determining the Empirical Relation for Estimating the Evaporation from Open Water Surfaces

Maziar Asmani[1]; Kazem Bashirnejad[1*]; Payman Bashi Shahabi[3]

[1]*PhD student, Islamic Azad University, Khorasan Branch, Mashhad, Iran*

[2]*Mechanics department, Islamic Azad University, Mashhad Branch, Mashhad, Iran*

[3]*Mechanics department, Islamic Azad University, Mashhad Branch, Mashhad, Iran*

Abstract

Evaporation is an important factor in managing the water resources and it is through the exact calculation of evaporation that effective solutions can be implemented for reducing the effects of droughts as well as protecting the water resources. Correct estimation of evaporation parallel to proper water resources' management and determination of an empirical relation with an optimal precision can result in the correction of the amounts of evaporation from the pans and obtainment of more precise results within shorter periods of time. Due to the shortage of the evaporimeter stations and absence of sufficient statistics on evaporation, various empirical methods have been suggested by various researchers for estimating the evaporation from the open liquid surfaces. However, the offered empirical relations have a lot of weak points in such a way that the comparison of the results of these relations and the statistics obtained from empirical relations for Dusti Dam is reflective of evident errors. In the present research paper, a laboratory devise will be designed for simulating the different climatic conditions and it was subsequently calibrated and validated using the data recorded in a meteorological station near Dusti Dam. Various experiments were carried out in different climatic conditions and a new empirical relation was offered for estimating the evaporation amounts following the analysis of the laboratory data; the amounts of RMSE, MAD, MSE, MAPE and correlation coefficient (R) obtained based on the proposed relation are respectively equal to 0.684, 0.559, 0.468, 8.165 and 0.96 which are lower in contrast to the other three empirical relations.

Keywords: *evaporation, empirical method, simulator*

1. Introduction

The importance of evaporation and transpiration in the hydrological cycle is clarified when knowing that about 57% of the water pouring on the lands in the form of atmospheric precipitations are directly vaporized. Every year, thousands of billion cubic meters fresh water that has been collected with a lot of costs is vaporized from the dam's reservoir and the salt and minerals remained following vaporization reduce the water quality [1]. Iran is situated in the arid and semi-arid region of the world in such a way that its average annual rainfall is about one third of the annual rainfall of the planet earth and its evaporation average is about three times the annual evaporation average of the planet earth [2]. One of the important ways of adaptation to dryness in Iran is the optimal and sustainable use of the water resources; therefore, in order to prevent water crisis, there is a need for proper water resources management. One of the important issues in the discussion about evaporation from open water surface is recording the amount of evaporation. Evaporation pan is utilized worldwide as an index for determining the evaporation from the lakes and the reservoirs for the ease of interpreting the data obtained thereof [3]. Due to the impossibility of installing pans in all the regions and, more importantly, the underestimations made using the pans [4], mathematical methods and empirical relations of evaporation estimation are being more prevalently applied. Most of the researchers have endeavored through correcting the existent empirical relations and discovering the new relations to find simple and, in the meanwhile, precise relations for substituting the field methods. In this regard, determination of evaporation using

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empirical relations seems to be necessary due to the complexity of these two relations [5]. Most of the empirical methods offered for estimating evaporation are based on Dalton relation and irradiation-temperature. The most important meteorological parameters influencing the evaporation from the open water surfaces are temperature, wind speed, sun's irradiation, relative humidity and saturated vapor pressure [6]. The offered empirical relations take each of the foresaid parameters into account to try reducing the evaporation estimation error. The precision of the empirical relations differs in various regions and their results need to be further investigated and calibrated [7]. Since the climatic conditions differ in every region, the most suitable empirical method of evaporation estimation with the lowest difference from the pan results should be inevitably determined [8]. Correct evaporation estimation is necessary in the water resources planning and the determination of an empirical method with a favorable precision can somewhat resolve the problems and issues related to evaporation pan and the desired results can be consequently attained by spending lower time and cost. Thus, considering the fact that the introduced methods are often empirical, they should be calibrated for every region. So, a method should be introduced that is capable of calculating evaporation from the open surfaces under various climatic conditions and with sufficient precision [5]. Since Dusti Dam is shared by Iran and Turkmenistan and its water reservoir influences the agriculture and social life of the two country, the present study concentrates on the meteorological data of the foresaid dam with the objective of correcting the evaporation pattern as the parameter influencing the water resources management therein. It is worth mentioning that Dusti Dam has been constructed on a Harirud Border River in the area of Sarakhs County in the northeast of Khorasan-e-Razavi. It is an earthen dam with clay core and reaching 78m in height and 650m in its crest length. This dam's reservoir can accommodate 250.1 billion cubic meters of water.

Figure 1. Location of Dusti Dam

Evaporation from open water surfaces serves numerous functions. Evaporation from the lakes, reservoirs and basins influences the optimal exploitation of the water resources. Evaporation from the evaporation ponds and solar pools is of a great importance for the designing of such systems [8]. In general, four methods can be applied for estimating the evaporation [9]:

A) Empirical methods wherein use is made of meteorological parameters and are generally based on Dalton law and irradiation-temperature;

B) Water balance method that depends on the estimation of the inflow and outflow;

C) Energy balance method that needs the determination of all the components existent in relation to energy balance;

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D) Combined methods of evaporation estimation.

There are countless factors involved in the use of empirical methods and they have to be taken into consideration in estimating the evaporation from open water surfaces. In between, the most important factors are surface area, water depth and the peripheral environment's conditions. Usually, the vaster the surface, the lower the evaporation for the water added to the air changes the air nature in the course of the evaporation process. Depth influences the water temperature and, especially, the higher depths cause annual water temperature cycles lagging behind the annual air temperature cycles [10]. The evaporation from the water surfaces is usually higher in the arid regions, particularly the places wherein considerable horizontal heat transfer streams exist, than the humid regions [11].

In hydrology, the estimation of the evaporation from open water surfaces is carried out for computing the water wastages in the reservoirs. The amount of evaporation is measured based on the height with its unit being usually millimeter, centimeter and/or inch [12]. The simplest instrument of evaporation measurement is pans placed on the land near a reservoir and/or floating on the water. It is now for many years that the researchers and engineers are using evaporation pans for calculating evaporation from the lakes and reservoirs' surfaces as well as measuring the evaporation and transpiration in plants. To do so, the amount of evaporation from the pan is measured and use is subsequently made of specific coefficients to obtain the evaporation from the water surface and or the evaporation/transpiration potential. According to the statistics obtained from the evaporation pan, the amount of evaporation from water surfaces can be estimated from the following equation [1]:

$$E_w = K\, E_{pan} \quad (1)$$

Where, E_w is the evaporation from the surface of water in reservoir; E_{pan} is the evaporation from the pan and K is a constant the amount of which ranges from 0.6 to 0.8 but it is averagely set at 0.7.

In general, many efforts have been made for predicting and assessing evaporation under various geographical conditions and, in line with this, empirical relations have been suggested for assessing evaporation. A number of the most important empirical relations pertinent to open water surfaces have been summarized below:

- **Jensen-Haze Relation:**

Jensen-Haze relation was first published in 1963 [13]. This method is the result of 3000 observations pertaining to evaporation-transpiration and it has been obtained through soil sampling experiments during 30 years. This method is mostly used in west America.

$$E = 0.03523\, R_S\, (0.014T_a - 0.37) \quad (2)$$

In the above relation, besides temperature, the number of sunny hours and the irradiation intensity should be measured. The foresaid equation has been applied in numerous researches in Iran as well as in the other regions around the globe [14]. The results of the studies by Najafi [15] in Isfahan, Mirza'ei et al [16] in Qarreh Sue Water Basin in the northwest of Iran, Sharifian and Alizadeh [17] in Gorgan, Musavi Bayegi et al [18] in Mashhad and Sepahkhah and Fouladmand [19] in Bajgah region of Fars Province are indicative of the inappropriateness of Jensen-Haze equation for estimating evaporation in other regions and places. The results obtained by Alizadeh et al [20] for the estimation of evaporation/transpiration in Kerman, as well, showed that Jensen-Haze equation features a low precision. However, in the study by Alizadeh et al [21] in the same region, it was made clear that the aforementioned equation is suitable but only after correcting the temperature data for calculating the daily evaporation/transpiration. The studies by Sabziparvar et al [22] in Hamadan Province, as well, indicated that Jensen-Haze equation is suitable for estimating the transpiration in comparison to Penman-Monteith equation. Vazifehdust et al [9] performed studies on Dusti Dam and the results indicated the high precision of Jensen-Haze for the aforesaid region.

Studies by Al-Qabari [23] on four regions in the south of Saudi Arabia, Rosenbery et al [24] in north of Dakota in America, Jabolani [25] in Zimbabwe and Trajkovic and Colakovic [26] in Nowy Sad in Serbia, as well, indicated the inappropriateness of Jensen-Haze equation for estimating evaporation/transpiration as compared to the other equations.

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- **Stiffens/Stewart Relation:**

Various relations have been offered using meteorological data under different climatic conditions for calculating evaporation [27]. Al-Shalan and Saleh [28] evaluated 23 credible climatic method for estimating evaporation in very arid regions and concluded that Stiffens-Stewart model is the best for arid regions. This model was later on revised by Clayton [29] and used as one of the common empirical methods. This method is also termed porosity equation which is similar to Jensen-Haze relation [30].

$$E=0.03495(0.0082\ T_a-0.19)\ R_S \tag{3}$$

- **Hamon Relation:**

Hamon [31] presented a simple expression based on evaporation/transpiration and this relation is applied for estimating evaporation from the lakes or basins [32]:

$$E = 0.63D^2 \times 10^{\frac{7.5\times Ta}{Ta+273}} \tag{4}$$

Where, D is based on the sunny hours and T_a is also the average daily temperature.

2. Study Method

2.1. Investigation of the Climatic Data

In the present study, use was made of the meteorological information that had been recorded in one year from 2017 to 2018 in an hourly manner for Dusti Dam station; therefore, the mean daily data of the meteorological station have been applied as the observatory data in this study with the information including minimum temperature, maximum temperature, sunny hours, wind speed, relative humidity percentage and intensity of irradiation. Based on the analysis of the data that had been recorded in one year, the average annual temperature of the study region is 30.25°C. The intensity, duration and quality of the sun’s incoming energy directly influences the amount of evaporation from the surface waters. The largest number of the monthly sunny hours in the study region is equal to 12 in July. The study of the average monthly wind speed trend in the foresaid station resulted in the idea that the region’s winds enjoy an intermediate speed. Moreover, the highest wind speed was found occurring during the dry seasons and the lowest wind speed happens in winter. The highest wind speed is equal to 2.125m/s in July.

2.2. Laboratory Device for Simulating the Climatic Conditions:

The important parameters for simulating the climatic conditions are temperature, humidity, sun’s irradiation and wind speed. The laboratory device can be set with values for the above parameters in such a way that the intensity of the sun’s irradiation can be set from zero to a thousand watts per square meter; the temperature can be set from 10 to 50 degrees centigrade; the wind speed can be set from zero to 10 meter per second and the amount of relative humidity can be set from ten to 90 percent. Efforts were made in the present study to build a climate simulator capable of taking the parameters influencing the evaporation into account and recreating them and calculating the evaporation accordingly. As shown in figure (2), the simulator has been designed and constructed using the aforementioned items; also, considering the existent meteorological data in the aforesaid evaporation simulator, the foresaid items were set and efforts were subsequently made to assess evaporation using a graded pan and scales with 1g precision. The environment and the water temperature ranged between 15 and 40 degrees centigrade and the wind speed was varying between zero and three meters per second and the irradiation intensity was set in a range between 200 and 800 watts per square meter. The evaporation amount is measured from the Pan 1 in an hourly and daily manner. According to the existent studies [6], besides the temperature and irradiation intensity, wind speed was also taken into consideration and the temperature was regulated using a cooling/heating system. Then, wind speed was regulated using three fans and the sun’s irradiation intensity was set at the desired level using a combination of infrared, halogen and sodium vapor lamps. The system was operated for one hour under the abovementioned conditions and the existent data were collected and recorded from temperature, humidity, wind speed and

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scale sensors and they were once again measured after another hour of the system's continuous working following which the evaporation rate was computed accordingly. At first, the data were recorded once every one hour for 24 hours; after confirming the experimental results' replicability, they were collected in two hours for every meteorological data.

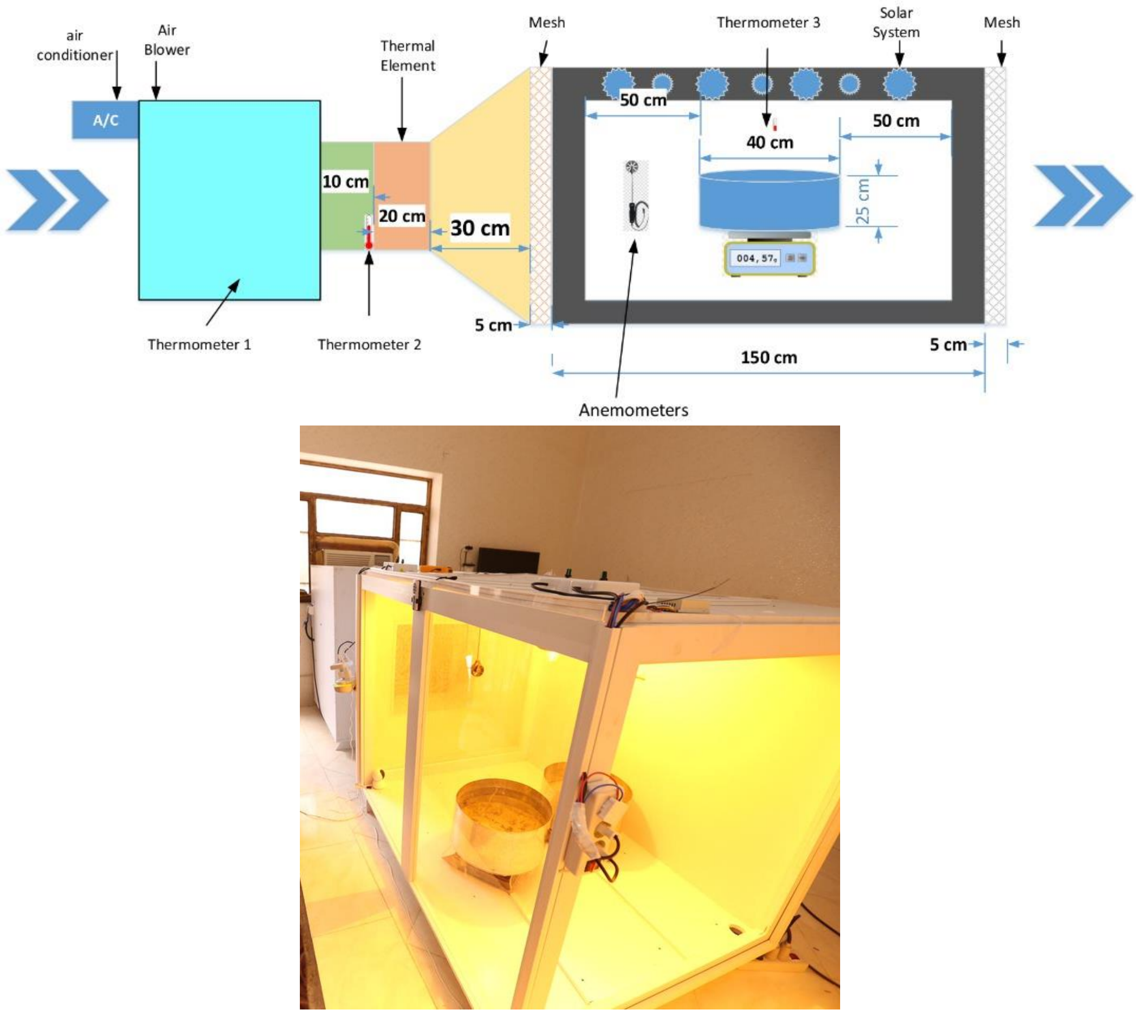

Figure 2. The General Schematic View and Image of the Simulator

The evaporation simulator is comprised of the following parts.

Table 1. Specifications of the Simulator

System name	Name of the device used	Precision	Minimum and maximum measurement	Number
Cooling system	Gas cooler 18000	-	18°C to 25°C	1
Blowing system	Blowing fan VIK-45T4S	-	-	3
	Air Flow=5300 m^3/h			
	Speed(rpm)= 1340			
	Power(W)= 310			
	Current(A)= 1.5			
	Voltage(V)= 220			

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	Fan Dia.(mm)= 450			
Heating system	A thermal 2000W element FH2000P	-	5°C	1
Vaporized water measurement system	Camry digital scale	1g	1g to 30kg	2
Lighting system	GE halogen lamp TU250R/IR/RU/E27	5W/m^2	2 to 1000 watts/m^2	4 along with dimer
	Asram Sodium Vapor Lamp 28000			1
	8W solar halogen lamp			20
Measurement instrument	Anemometer Model GM8902Plus	0.1m/s	0 to 45m/s	1
	Solar meter model DT-1307	1W/m^2	0 to 1999W/m^2	1
	Shiaomi Temperature and humidity sensor	Temperature: 0.3C Humidity: 3%	20 to +60	

Based on the existent meteorological data, temperature, irradiation intensity and wind speed were determined and the aforesaid data have been illustrated in the following diagram for three experiments as compared to the recorded meteorological data:

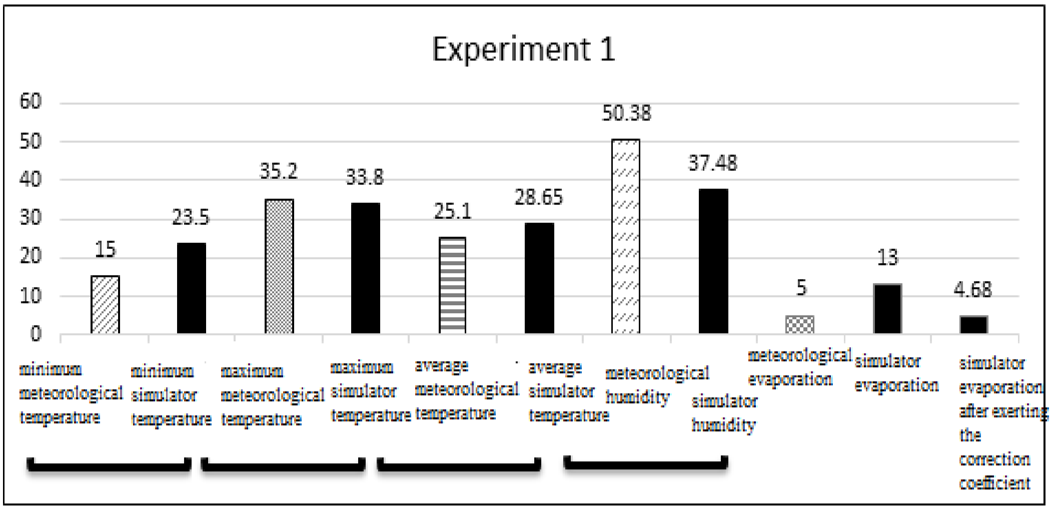

Figure 3. Comparison of the Meteorological and simulator Data for Experiment 1 (Temperature: Degree Centigrade; Humidity: Percentage and Evaporation: Millimeter)

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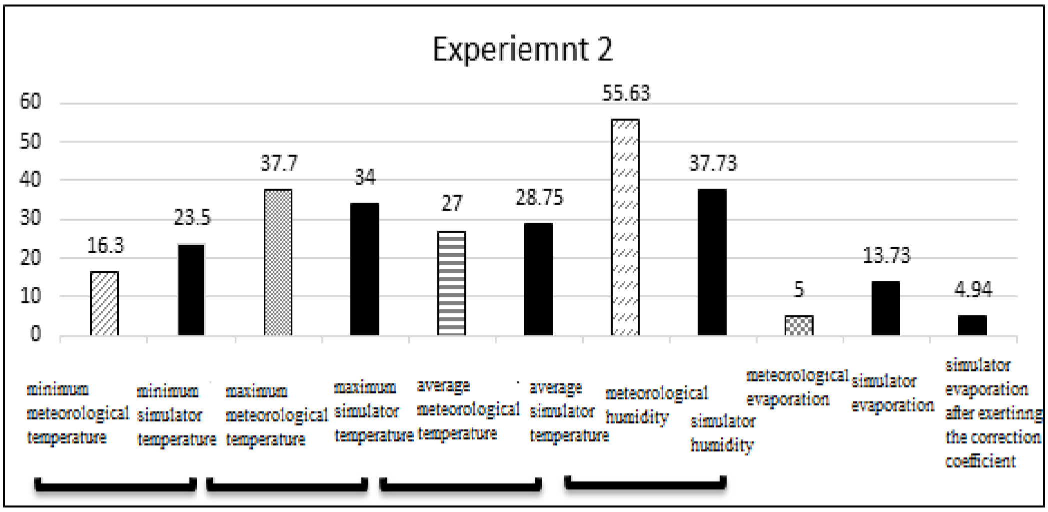

Figure 4. Comparison of the Meteorological and Simulator Data for Experiment 2 (Temperature: Degree Centigrade; Humidity: Percentage and Evaporation: Millimeter)

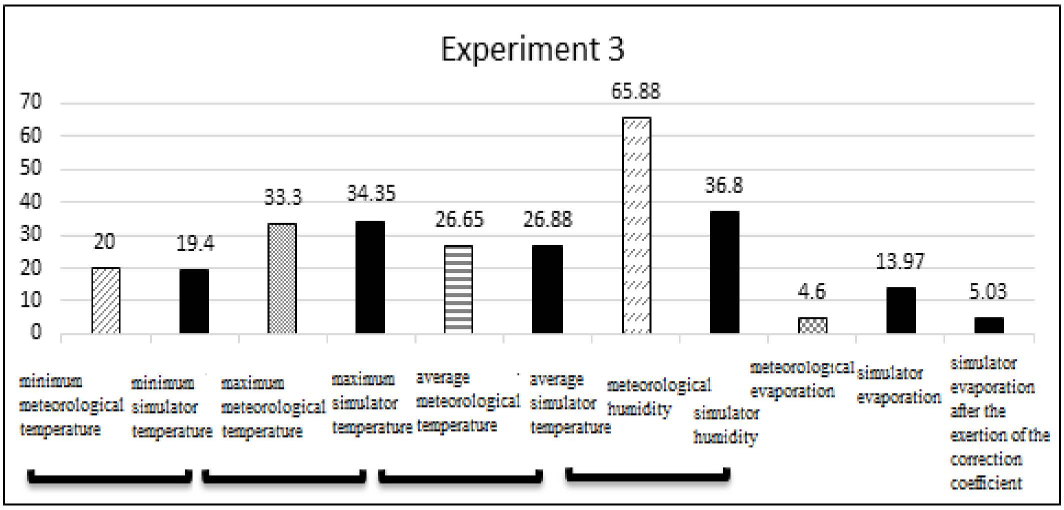

Figure 5. Comparison of the Meteorological and Simulator Data for Experiment 3 (Temperature: Degree Centigrade; Humidity: Percentage and Evaporation: Millimeter)

Table 2. Values Extracted from Simulator for the Empirical Relation

	Average temperature	Wind speed	Irradiation intensity	Amount of pan's evaporation	Simulator evaporation rate	Simulator's evaporation error	Simulator's evaporation rate (after correction)	Pan and simulator error
Experiment 1	28.65	1	256	5	13	62%	4.68	6%
Experiment 2	28.75	0.6	200	5	13.73	64%	4.94	1%
Experiment 3	26.88	1	220	4.6	13.97	67%	5.03	-9%

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According to the above data, the mean error of the simulator is 64% and it only suffices to multiply the abovementioned values by 0.36 (1-0.64) for correcting the simulator's evaporation rates. It is subsequently observed that the simulator's error ranges between -9 and +6. Based on the above data, the following three relations can be considered based on such parameters as average temperature, wind speed and sun's irradiation:

$$28.65\ T + 1\ W + 256\ R = 4.68 \quad (5)$$

$$28.75\ T + 0.6\ W + 200\ R = 4.94 \quad (6)$$

$$26.88\ T + 1\ W + 220\ R = 5.03 \quad (7)$$

Mathematically solving the above equations, values are obtained as follows: T=0.279, W=2.697 and R=-0.023. So, the evaporation relation can be considered as shown beneath based on the aforementioned three parameters:

$$E = 0.278\ T_a + 2.697\ W - 0.023\ R_S \quad (8)$$

2.3. Empirical Relations for Estimating the Evaporation from Open Water Surface

So far, many relations have been offered for estimating evaporation in various spots worldwide. Three empirical relations were selected, used and compared in this study. Table (3) gives the equations for these empirical relations:

Table 3. Empirical Relations for estimating evaporation from Open Water Surfaces

Relation's name	Relation's equation
Jensen-Haze	$E = 0.03523 R_s\ (0.014 T_a - 0.37)$
Stiffens-Stewart	$E = 0.03495(0.0082 T_a - 0.19) R_s$
Hamon	$E = 0.63 D^2 x 10^{\frac{7.5xT}{T_a+273}}$
Current research	$E = 0.278\ T_a + 2.697\ W - 0.023\ R_S$

In the equations inserted in the above table, E is the evaporation from open water surfaces in millimeter per day; W is the wind speed in an elevation from ground level in meter per second; T is the average air temperature in degree centigrade; Rs is the intensity of sun's irradiation in watts per square meter and D is the coefficient of Hamon relation and it is calculated based on the number of sunny hours.

4. Validation and Precision of the Relation

The following relations have been used for assessing the amount of error:

Root mean square error: $RMSE = \sqrt{\frac{\sum_{t=1}^{n}(A_t - F_t)^2}{n}}$ (9)

Median absolute deviation: $MAD = \frac{\sum_{t=1}^{n}|A_t - F_t|}{n}$ (10)

Mean squared error: $MSE = \frac{\sum_{t=1}^{n}(A_t - F_t)^2}{n}$ (11)

Mean absolute percentage error: $MAPE = \frac{\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t}\right|}{n} \times 100$ (12)

Correlation coefficient: $$R^2 = \frac{\left(\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})\right)^2}{\left(\sum_{i=1}^{n}(X_i - \bar{X})^2(Y_i - \bar{Y})\right)^2}$$ (13)

The amounts of evaporation from open water surfaces obtained using the empirical relations have been compared with the amounts of evaporation from the pan. The performance of the

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empirical relations has been evaluated based on five statistics, namely RMSE, MAD, MSE, MAPE and R and the results have been presented in table (4).

Table 4. Results Obtained from the Empirical Relations

Row	Names of the empirical relations	RMSE	Mad	MSE	MAPE	R
1	Current research	0.684	0.559	0.468	8.165	0.96
2	Jensen-Haze	0.775	0.597	0.601	8.837	0.94
3	Stiffens-Stewart	1.962	1.509	3.851	27.113	0.95
4	Hamon	1.624	1.357	2.638	21.518	0.90

Based on table (4), the relation proposed in the current research has been found with lower values for the abovementioned for error scales and higher correlation coefficient hence it is more exact. After the aforesaid relation, Jensen-Haze was found with a relatively acceptable precision. Comparing the data obtained from the relations in table (2) to the results obtained from evaporation

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pan, the following diagrams (figure 6) were delineated using the linear regression equation (Y) and correlation coefficient (r2) and they confirm the calculation results.

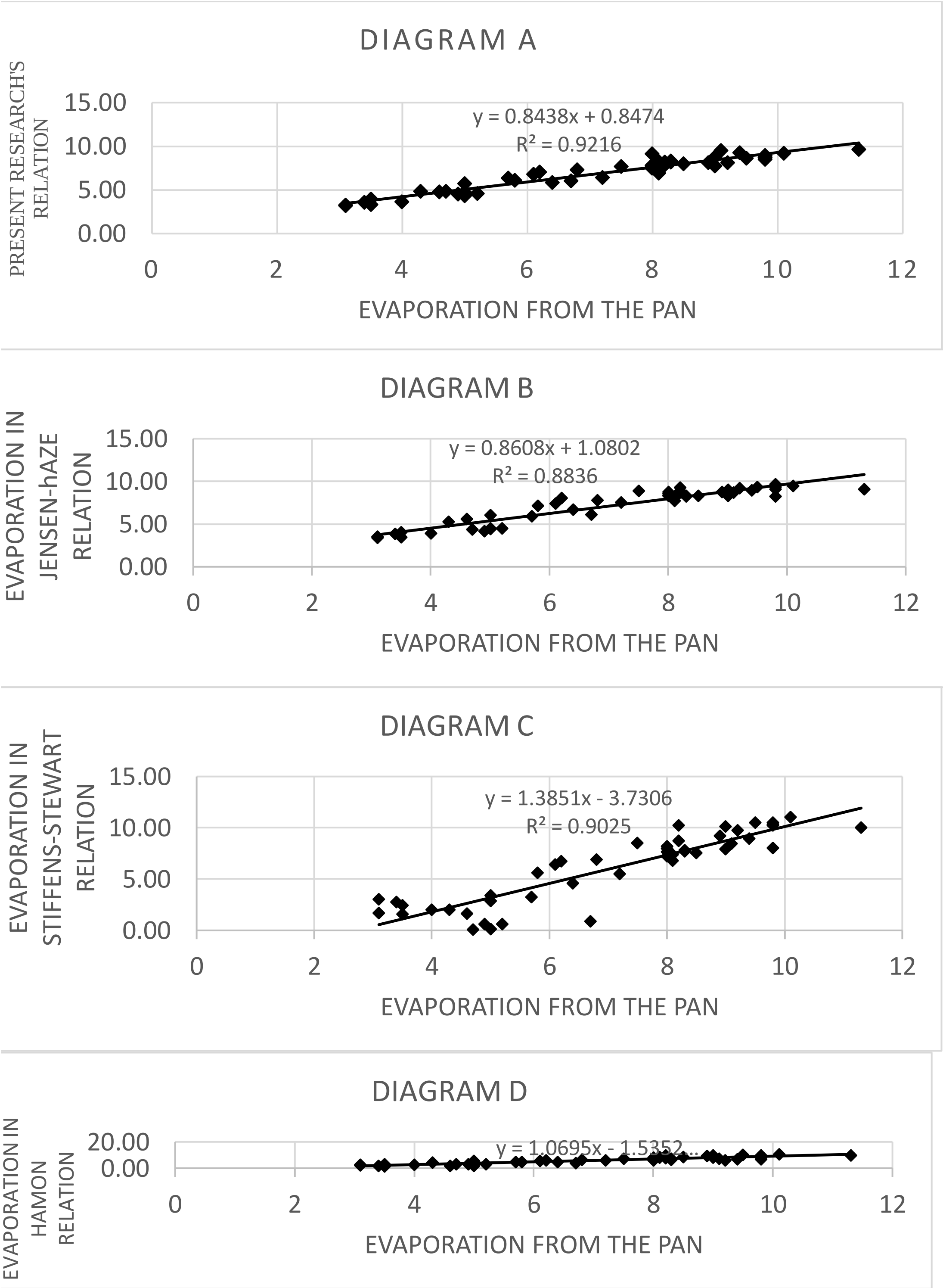

FIGURE 6. A: Comparison of the evaporation Pan and the Relation Proposed in the Present Research
B: Comparison of the Evaporation Pan and Jensen-Haze Relation
C: Comparison of the Evaporation Pan and Stiffens-Stewart Relation
D: Comparison of the Evaporation Pan and Hamon Relation

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In figure (6), the scatter diagram of the evaporation from pan and the current research's proposed empirical relation, Jensen-Haze relation, Stiffens-Stewart relation and Hamon relation has been displayed. The correlation coefficients related to the amounts of evaporation estimated by the current research's experimental model, Jensen-Haze empirical model, Stiffens-Stewart empirical model and Hamon empirical model are equal to 0.9238, 0.878, 0.807 and 0.8262, respectively.

5. Conclusion

Evaporation from the open water surfaces is of a great importance in water resources management and conservation of these resources, particularly in the reservoirs behind the dams and lakes. Another point is that Iran is situated in an arid and semi-arid region of the world hence the evaporation rates are essentially high and, considering the studied region's annual 306mm rate of rainfall, the annual evaporation would be equal on average to 4589; in other words, the evaporation rate is 15 times the rainfall amount and it is more than the world's reported averages.

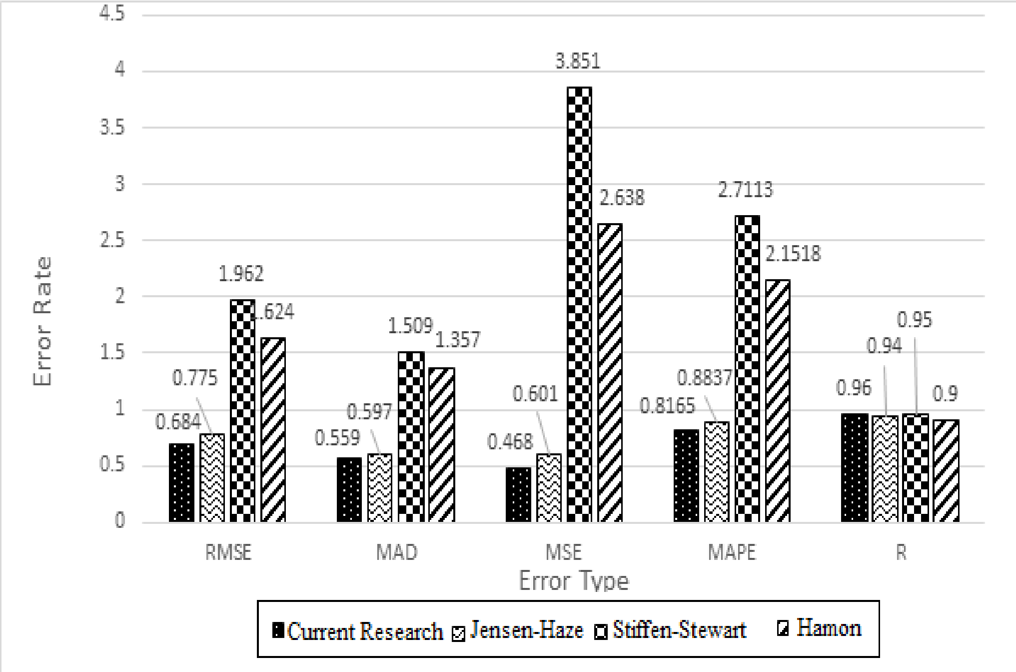

Figure 7. Comparison of the Amounts of the Calculated Errors for Empirical Relations

The use of the empirical methods makes the evaporation estimation methods less costly and fast and, in case of using the proper method, a suitable estimation can be achieved in a high precision without using the evaporation pan. In this study, use was made of a constructed simulator to obtain a new empirical relation (relation 8). The performance of the empirical relations was evaluated in this study based on five statistics, namely RMSE, MAD, MSE, MAPE and R, and it was shown that the present study's proposed relation (0.684, 0.559, 0.468, 8.165 and 0.96) features a precision higher than the other methods of estimating the evaporation from the open water surfaces. Jensen-Haze relation was ranked second (0.775, 0.597, 0.601, 8.837 and 0.94). The veracity of the data and the proper match of these two optimal empirical methods (current research's proposed model and Jensen-Haze model) were assessed based on the performance evaluation scales and it was found out that the present study's proposed method is more reliable considering its lower error rate. Stiffens-Stewart and Hamon empirical relations were found with intermediate precisions in estimating the evaporation from the open water surfaces.

Acknowledgments

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