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Evaluation of Eight Evaporation Estimation Methods in a Semi-arid Region (Dez reservoir, Iran)

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Abstract

Establishing satisfactory estimation methods of lake evaporation has been crucial vital for research and management of water resources and ecosystems. Determining the accurate method to estimate evaporation from reservoirs in the investigation and management of water resources is very important. Hence, in this study eight empirical methods such as; Makkink, DeBruin-Kejiman, Penman, Priestley-Taylor, Hamon, Jensen-Haise, Mayer and Rohver methods was used to estimate the evaporation from the Dez reservoir. These methods are divided into four categories: 1. Methods based on energy budget 2. Methods based on mass transfer 3. Methods based on radiation and temperature and 4. Combination of energy budget and mass transfer. The energy budget method is used to estimate evaporation rate as the reference method. Results showed that Priestly-Taylor and DeBruin-Kejiman estimation methods are better than other methods for this region.

Keywords: Evaporation, energy budget method, empirical methods, pan evaporation, Dez reservoir

Introduction

In many semi-arid countries in the world, supplying drinking water and food production is dependent on water storage in reservoirs (Helfer et al., 2012). In addition to flood control dams store water for downstream uses, hydroelectric power production, fish farming and tourism tool to create large water storage reservoirs are considered. Since the evaporation rate is very high in semi-arid countries, estimates and forecasts of reservoir evaporation rate can be useful in the management of major water source (Craig, et al., 2005). About 13 percent of the annual volume of Karkheh Dam That equivalent 106.54 million cubic meters of evaporation from the reservoir to the dam of the hydroelectric dam to keep out that according to this value will be more important. Annual evaporation volume of the four major dams Shahid Abbas pour, Dez, Karun 3 and 4 of 4.27 million cubic meters, which is much greater than the volume of water stored in the Masjed Soleiman dam (NoName, 2013). As well as outside of Iran, in Australia, about 40% of the total volume of water stored in reservoirs is lost because of high evaporation rate (Helfer, et al., 2012). The basic data show that maintaining the volume of water lost could have a significant impact on regional economic and social development and prevent the loss of human and economic capital. Therefore, accurate understanding of the evaporation rate is very important. Evaporation from Saveh (Alghadir) dam reservoir were calculated based on the data of evaporation pan of Saveh Dam and energy budget method as the reference methods and using empirical formulas . Results showed that are consistent with the energy budget model introduced in that region (Hassani, 2013). Benzaghta and et al (2012) three evaporation estimator methods such as; namely Penman, Priestley-Taylor and Linacre chose and examined them and the statistical analysis concluded that the rate of evaporation estimated by the model for the region was significant (Ali Benzaghta, et al., 2012). Gallego-Elvira, et al calculated the evaporation from covered reservoirs in dry areas and evaporation estimation methods to estimate the evaporation rate and the amount of ways to get fit (Gallego-Elvira,, et al., 2012). YAO derived values of the seven estimated evaporation method compared with energy budget method as reference method and the conclusion reached that in cold seasons, the best method to estimate of evaporation is water budget method and on shorter tome (Overview or monthly) DeBruin-Kejiman method gives the best results. (YAO, 2009). Armstrong et al in a study of several model for a seasonal time scale of 15 min were examined and Compared with the measured evaporation data results show that all three methods are suitable for use for periods longer than a day to evaporation has been estimated but none of the proposed methods for estimating daily or sub daily, continuously not reliable (Armstrong, et al., 2008). Gianniou and Antonopoulos in a study of water budget and energy budget methods, using a one-dimensional model of the distribution of daily temperature were estimated and finally concluded that the evaporation rate is rising in spring and low in summer, the energy is stored in the the reservoir (Gianniou, et al., 2007). Vardavas and Fountoulakis using monthly data and take advantage of Priestley-Taylor for four regions of the predicted results obtained by this method correspond with the observations (Vardavas, et al., 1996). Winter et al in a study, compared 11 evaporation estimation method using energy budget as the reference method, result was that the methods Jensen-Haise and Makkink gives better results than other methods (Winter, et al., 1995). Omar and El-Bakry using monthly data and using energy budget and aerodynamic bulk evaporation rate, the monthly regional Aswan Dam calculate and found that the maximum amount of evaporation 10.9 mm in the day and the lowest amount 3.8 mm was in the day (OMAR , et al., 1981). Schertzer calculated monthly evaporation values using the energy budget as reference method compared with the calculated values of the mass transfer method and water budget method, results show that the values of the water budget method more consistent with reference method (Schertzer, 1978).

Since in Iran have not a comprehensive study on the evaporation rate from water reservoirs. So in this research effort, the amount of evaporation from the Dez lake Using methods namely Penman, Priestley–Taylor, DeBruin-Kejiman, Jensen-Haise, Makkink, Meyer and Rohver and water budget as the reference method be calculated. And the best method for estimate the evaporation rate based on the energy budget method for Dez reservoir region is introduced.

Materials and Methods

Study Area: Dez dam in Khuzestan province, 25km northeast of Dezful, the main branches of Dez River has been constructed. Its geographical location is 32° 36' E, 48° 27' 50.4"N. The central part of the catchment is located in Khuzestan province and it has a catchment area of 17,430 square kilometers and a length of 515 kilometers (Afshin, 1990). The dam is 203 meters in height and storage volume 3.3 billion cubic meters and a length of 65 kilometers was used in 1963 as well as the disposal of climate data from 30-year daily average meteorological parameters are shown in Table 1. It is also a multi-purpose dam and upstream flood control and irrigation for large sections of north land of Khuzestan and electricity and water supply to justify exploitation. Due to population growth and industries and major projects of water supply for providing drinking water to the city of Susa, Ahwaz, Dasht-e-Azadegan, Abadan, Khorramshahr and Shadegan will be responsible for reviewing water quality and quantity is very important (NoName, 2006).

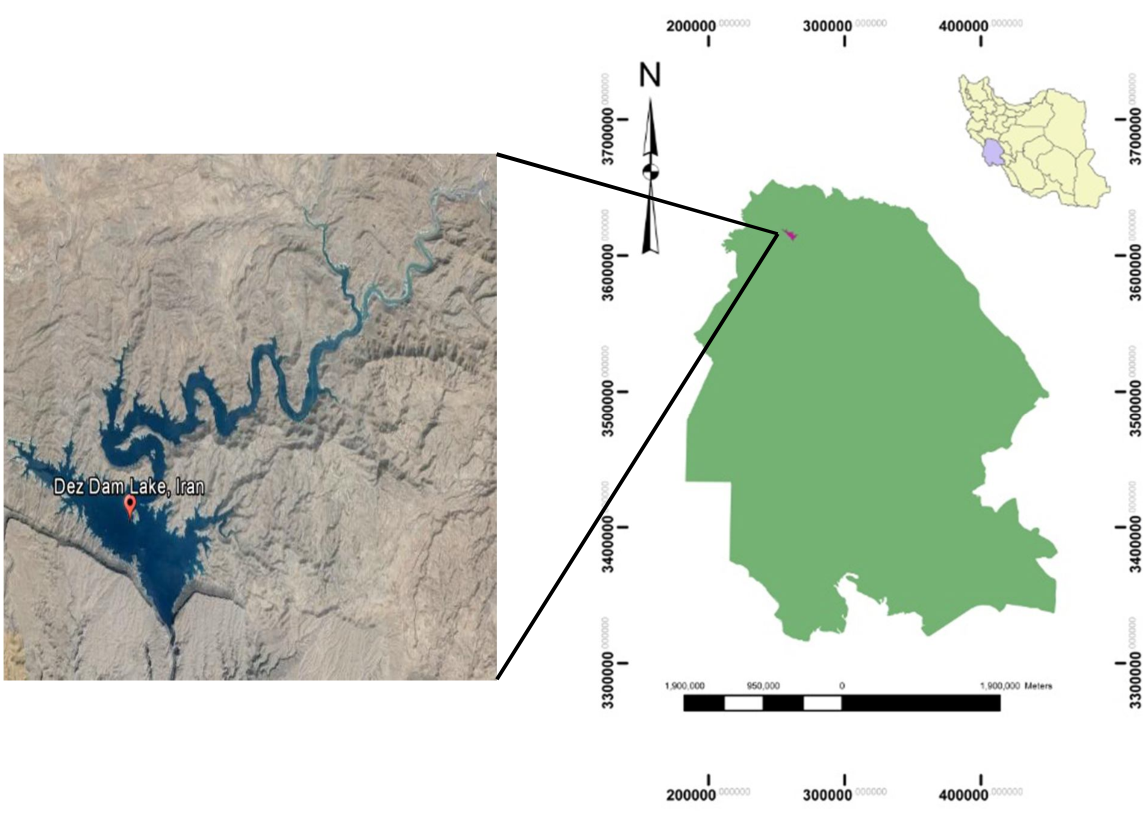

Figure 1- Study Area

Observation Data:

Data required for calculations are daily long and short wave length radiation data, daily minimum and maximum temperature, daily relative humidity and daily wind speed that they are available from weather stations that is measured at the Dez dam site. Series of meteorological data for 30 years, from 1981 until 2011.

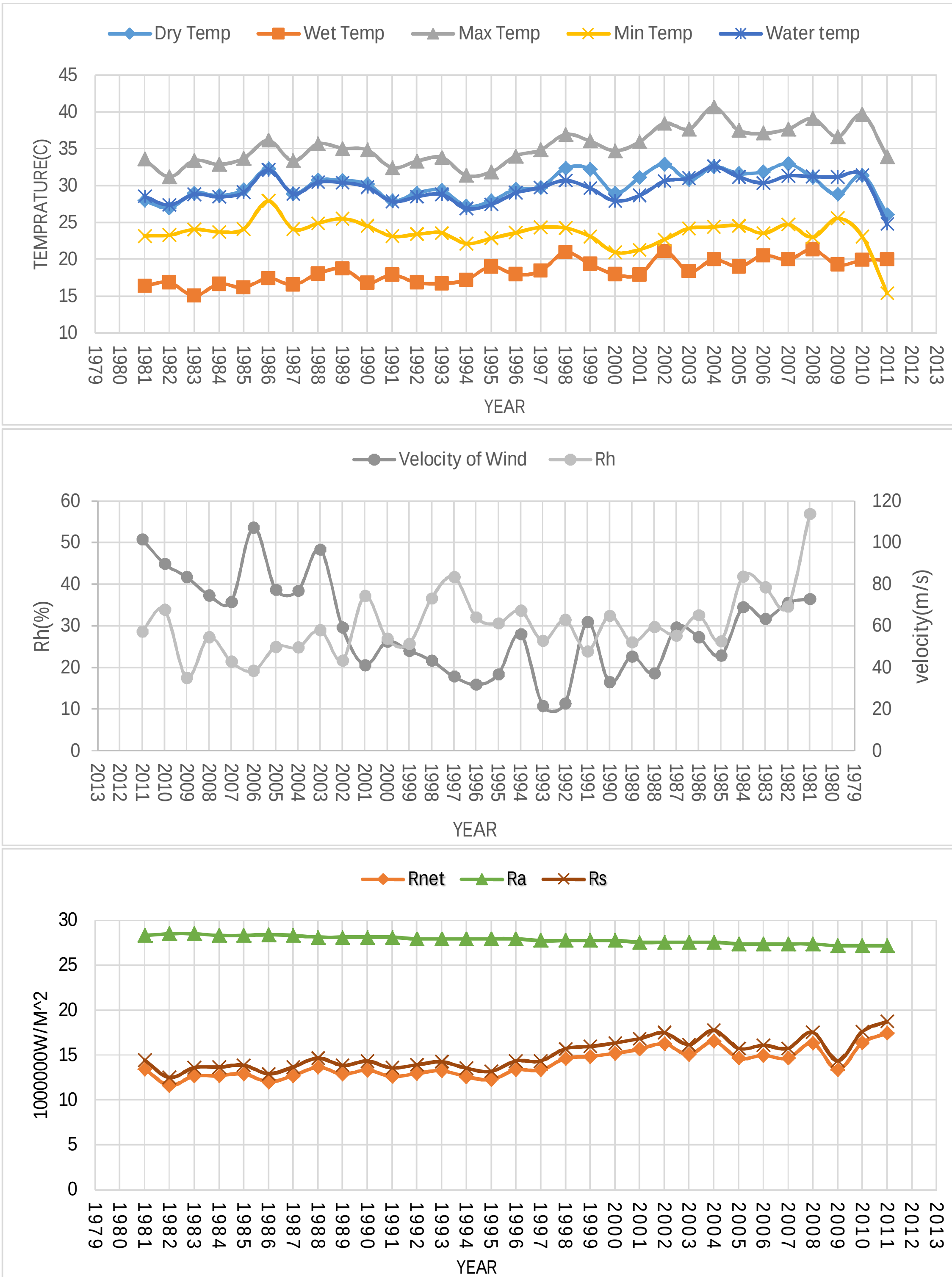

Figure 2- averages of meteorological variables

The temperature profiles for Dez reservoir for 6 depth and is related to years 2007 to 2008. These depths are surface, 2.5, 5, 10, 20 and 50 meters (from surface to depth) and has taken monthly as shown in Figure 3. Temperature profiles of Dez reservoir has not picked up on a regular basis and most complete information related to 12 months that is harvested from November 2007 to October 2008, so these data were used to estimate evaporation. Figure 2 shows the thermal profiles reservoir what Show that the temperature changes at different depths throughout the year and show the effects of increasing and decreasing temperature below the water surface on evaporation.

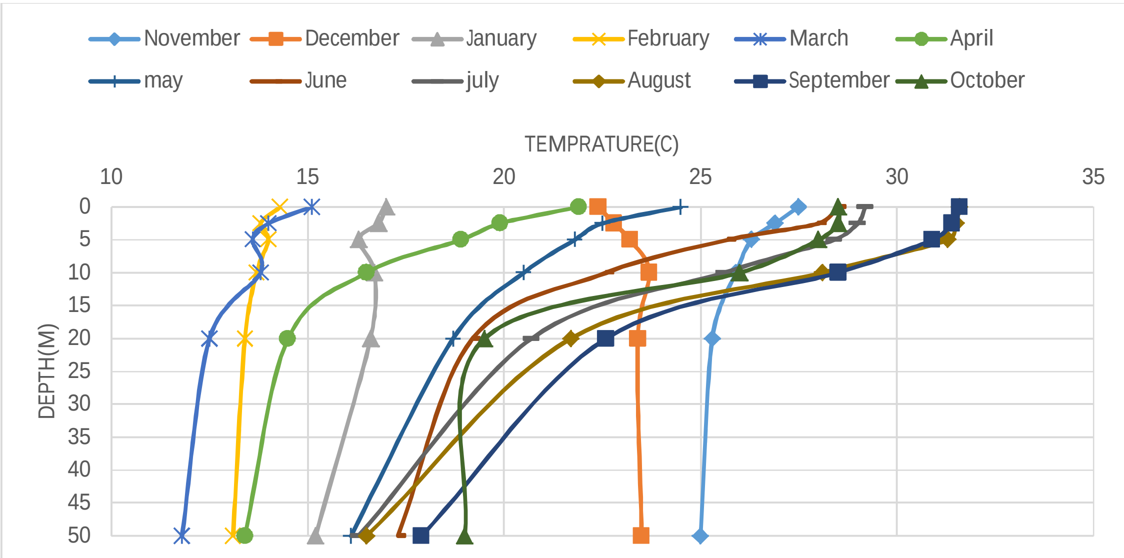

Figure 3- Dez reservoir temperature profiles in different months

The concept of period in computing evaporation from the lake surface evaporation is very important because it is related to the heat stored in the reservoir that difference of it for first day and last day of the period is to be calculated (YAO, 2009). Because of the limited data used in this study, a one-month period is considered.

Method of calculating evaporation

Reference Evaporation Derived by Energy Budget

Energy budget method (Bowie, et al., 1985), (Sturrock, et al., 1992)is used to estimate the evaporation rate that More in calculating the evaporation of water surface, such as lakes is used, based on the principle of energy conservation (Safavi, 2009). The energy budget method after direct measurement of evaporation is most accurately measured (Ali Benzaghta, et al., 2012). The biggest problem of this method, it requires to large amounts of data and this data is difficult to measure, for a lake and a period of time energy budget method is expressed as follows:

$$\lambda E = R_{net} + H_{sed} + A_{net} - H - S \qquad (1)$$

In the above equation, all parameters of energy are joules, λE is latent energy used by evaporation of lake water during the period, λ is the latent heat of vaporization (2.46×10^6 J kg-1), E is the evaporation (mm) within the period, R_{net} is net radiation, H_{sed} is heat released by lake sediments and is negligible for most cases, A_{net} is net heat advected into the lake from precipitation, inflows and outflows, and is also negligible, H is sensible heat transfer from lake surface to atmosphere, and S is the change of heat stored in the lake (due to temperature changes) during the period. The negligibility of the net heat advection A_{net} could be supported by the study results of Lenters et al (D. Lenters, et al., 2005). The sensible heat term can be expressed as H=B· λ E, where B is the mean Bowen ratio for the period. Removing the two negligible terms, Equation (1) is rewritten as

$$E = \frac{R_{net} - S}{\lambda(1 + B)} \quad (2)$$

The net radiation is an accumulation of daily net radiation in the period:

$$R_{net} = \sum_{i=1}^{n} [(1 - \alpha_{sw}) r_{swd}(i) + (1 - \alpha_{lw}) r_{lwd}(i) - r_{lwu}(i)] \quad (3)$$

Where i is the order of any day in the period (i=1, 2… n days), $r_{swd(i)}$ is daily downward shortwave radiation which is observed at the meteorological station, α_{sw}=0.07 is the shortwave albedo of water (value taken from Lenters et al. (D. Lenters, et al., 2005)), $r_{lwd(i)}$ is daily downward long wave radiation, α_{lw}=0.03 is the long wave albedo, and $r_{lwu(i)}$ is daily upward longwave radiation. Longwave radiations are calculated by $r_{lwd(i)}=\varepsilon_a \sigma T_a{}^4$, $r_{lwu(\mathrm{i})}=\varepsilon_s \sigma T_s{}^4$, where ε_a=0.91 and ε_s=0.97 are emissivity of the atmosphere and surface water respectively, T_a and T_s are daily air temperature and surface water temperature (in unit of °K). The daily air temperature is provided by routine monitoring, while surface water temperature is observed only on the first and last day of a period. The daily water temperature within a period is obtained by interpolation between the two days' temperature values. The heat storage change S in Equation (2) is calculated by using vertical lake zones and lake temperature profiles. Temperature profiles are observed at the central lake where it has the deepest water. The water body is divided into vertical zones from Lake Surface to Lake Bottom, and the number of zones may differ a little among periods. The heat stored in the lake on the last and first day of the period is calculated, and their difference is the change in heat storage,

$$S = S_2 - S_1 = \frac{\rho_w c_w}{a_{s2}} \sum_{j=1}^{m_2} T_2(j) a_2(j) Z_2(j) - \frac{\rho_w c_w}{a_{s1}} \sum_{j=1}^{m_1} T_1(j) a_1(j) Z_1(j) \quad (4)$$

where $S2$ and $S1$ are heat storage on the last and first day respectively, ρ_w=1000 $kg\, m^{-3}$ is water density, c_w=4186 $J\, kg^{-1}\, °C^{-1}$ is specific heat of water, a_{s2} and $a_2(j)$ are the lake surface area and water area (m_2) of any zone j (j=1, 2, …, m_2 starting from the lake surface zone) on the last day, $T_2(j)$ and $Z_2(j)$ are the temperature and thickness of zone j on the last day.

Similarly, a_{s1}, $a_1(j)$, $T_1(j)$, $Z_1(j)$ are the surface area, water area, water temperature and zone thickness respectively on the first day. Water area a (m^2) at a height h (m) from lake bottom is estimated by an empirical relation derived from observed lake morphometry data as follows.

$$a = 4093.7h^2 - 985100h + 6 \times 10^7 \quad (5)$$

As in Equation (6), the period-mean Bowen ratio B is calculated from daily Bowen ratios which is derived from air and lake surface temperatures.

$$B = \frac{\gamma}{n}\sum_{i=1}^{n}\frac{T_s(i) - T_a(i)}{e_{ss}(i) - e_{sa}(i)} \quad (6)$$

where γ is psychometric constant (67 Pa/ °C), n is the number of days in a period, i is any day within a period, $T_s(i)$ and $T_a(i)$ are daily mean temperature (°C) of lake surface and air above the lake respectively, $e_{ss}(i)$ and $e_{sa}(i)$ are saturated vapour pressure (Pa) at the lake surface and air temperatures.($e_{ss} - e_{sa}$) is deficit of saturated vapor pressure as following (Amin, 2011).

$$e_{ss} - e_{sa} = \left[(\exp(\frac{16.78\,T - 116.9}{T + 237.3}))(1 - \frac{R_h}{100})\right] \quad (7)$$

Where T and R_h are daily mean temperature (°C) and relative humidity (%).

In this study due to lack of data on the thermal profile of reservoir evaporation is 2007-2008 for the year and monthly respectively.

Evaporation Methods

Eight methods are selected for calculation of lake evaporation at Dez Lake and are later compared to each other. They are Hamon (HM), Penman (PM), Priestley-Taylor (PT), DeBruin-Kejiman (DK), Jensen-Haise (JH), Makkink (MK), Mayer (MY) and Rohver (RH). Methods for estimating evaporation from water surface are extensive that they can be classified according to the manner and method of estimation of evaporation.

Methods based on radiation and temperature

Hamon Method

It is often used to estimate lake evaporation or watershed potential evaporation because of its simplicity (YAO, 2009). For a given lake, daily evaporation e (mm) is calculated from daily temperature Ta (°C) as follows.

$$e = 0.63.D^2.10^{\frac{7.5T_a}{T_a+273}} \quad (8)$$

Where D is the ratio of maximum sunshine duration (hour) to 12 hours, and is determined by latitude of the lake and the date:

$$D = \frac{1}{90}\arccos\{-tan\varphi.\tan\left[23.45^{\circ}\sin\left(\frac{j-80}{365}.360^{\circ}\right)\right]\} \quad (9)$$

Where φ is the latitude (32.15° for Dez Lake), J is the Julian day of any date of interest. Total evaporation E in a period is the sum of daily evaporations of all included days.

Jensen-Haise Method

Daily evaporation is first calculated by the following Equation.

$$e = [0.014(1.8T_a + 32) - 0.5].\frac{r_{swd}}{\lambda} \quad (10)$$

Where T_a is daily temperature (°C), r_{swd} is daily shortwave radiation as used in Equation (3). The total evaporation in a period is the sum of the daily rates.

Makkink Method

Daily evaporation is calculated as

$$e = 0.61.\frac{\Delta}{\Delta + \gamma}.\frac{r_{swd}}{\lambda} - 0.012 \quad (11)$$

$$\frac{\Delta}{\Delta + \gamma} = 0.439 + 0.01124\, T_a \quad (12)$$

And then the total evaporation is obtained.

Methods based on mass transfer

Mass transfer methods are based on the calculation of mass transfer from the surface water of the mass vapor to the atmosphere, is built. Mass transferred from the water surface is based on Dalton's law proportional to saturated vapor pressure difference

$$E = k(e_{ss} - e_{sa}) \quad (13)$$

Mayer method

Meyer formula based on wind speed of 9 m above ground level presented as follows

$$E = K_m.(e_{ss} - e_{sa})(1 + \frac{U_9}{16}) \quad (14)$$

Where e_{ss} and e_{sa}previously defined in millimeters of mercury and U_9 Average monthly wind speed at a height of 9 meters (km/h) and $K_m$constant factor for deep water is about 0.36 for the shallow water is about 0.5 (Safavi, 2009).

Rohver method

Rohver addition to correction factor for wind speed, the pressure is another factor to be used and his formula presented as follows

$$E = 0.771(1.456 - 0.000732P_a)(0.44 + 0.0733U_{0.6})\,(e_{ss} - e_{sa}) \quad (15)$$

Where e_{ss} and e_{sa}previously defined in millimeters of mercury, P_a Average pressure in millimeters of mercury and $U_{0.6}$ Average monthly wind speed at the height of 0.6 meters of ground surface.

Methods based on energy budget

Priestley-Taylor Method

Evaporation is estimated based on radiation and heat storage only, as done by Winter et al (Winter, et al., 1995)

$$E = 1.26.\frac{\Delta}{\Delta+\gamma}.\frac{R_{net}-S}{\lambda} \quad (16)$$

Where the variable Δ/(Δ+ γ) is estimated in Equation (12).

DeBruin-Kejiman Method

The DeBruin-Kejiman equation is written as (Winter, et al., 1995) (YAO, 2009)

$$E = \frac{\Delta}{0.95\Delta + 0.63\gamma}.\frac{R_{net}-S}{\lambda} \quad (17)$$

Where the slope of saturated vapor pressure curve Δ could be estimated by using Equation (12), and net radiation and lake heat storage change have been estimated in the energy budget calculations.

Penman combination methods of energy budget and mass transfer

Penman with combination methods of energy budget and mass transfer and omit temperature of water surface of these methods, calculate rate of evaporation from water surface. Form of this equation presented as follows

$$E = \left(\frac{\Delta}{\Delta+\gamma}\right)\frac{R_{net}-S}{\lambda} + \left(\frac{\gamma}{\Delta+\gamma}\right)\frac{6.43(1+.54U)(e_{ss}-e_{sa})}{\lambda} \quad (18)$$

In above equation U is average daily wind speed (m/s), Δ the slope vapor pressure curve mean temperature and γ is psychometric constant coefficient that function of air pressure, Where the variable Δ/(Δ+ γ) is estimated in Equation(**Error! Reference source not found.**.

$$\frac{\gamma}{\Delta+\gamma} = 0.5495 - 0.01119\, T_a \quad (19)$$

Comparison and Evaluation of Eight Methods

The difference of method-calculated evaporations from the energy-budget E_{WB} values is used as an accuracy index of an evaporation method. Comparing the differences of eight methods will provide a quantitative evaluation of their performance and accuracy. The root mean square deviation (RMSD) is a frequently-used measure of the differences between values predicted by an estimator and the values observed from the thing being estimated.

$$RMSD = \sqrt{\frac{\sum(\hat{y}-y)^2}{n}} \quad (20)$$

Another indication of how well the estimator follows predicts the variations in the measured values could be given by a coefficient of efficiency (CE) as proposed and applied by Nash and Sutcliffe (Nash, et al., 1970). This CE index is expressed as

$$CE = 1 - \frac{\sum(E_{est}-E_{ref})^2}{\sum(E_{ref}-E_{mean})^2} \quad (21)$$

Where E_{est} and E_{ref} are the estimated and reference (or measured) evaporation for a span (or interval) respectively, and E_{mean} is the mean of reference evaporations. A larger CE number indicates a more accurate estimator and also mean bios error is another parameter that can be used to determine the amount of deviation from the reference method. If the value is positive the model is over estimated and is negative the estimated model is under estimated.

$$MBE = \frac{1}{n}\sum(\hat{y} - y) \quad (22)$$

All three indices were evaluated in this study to evaluate and compare the accuracy and performance of the eight evaporation methods, and a performance rank is then proposed.

Results

Judgment concerning which of the methods used in estimating evaporation from Dez reservoir is the most appropriate Depending on exact determination evaporation using valid methods (such as energy budget method) and compare the results with values that is accurate (Hassani, 2013).

Table 1-Emount of evaporation derived by energy budget method

April 2008	Mar 2008	Feb 2008	Jan 2008	Dec 2007	Nov 2007
201	176	87	53	77	157
Oct 2008	Sep 2008	Aug 2008	July 2008	June 2008	May 2008
247	281	322	335	314	267

According to Table 1 is the highest evaporation calculated by energy budget method as the reference method are related to July (with the evaporation rate of 335 mm) and the least amount of evaporation of January (the evaporation rate of 53 mm). Due to the different values obtained by different methods indicates that each of these methods are appropriate for specific regional climate conditions are applicable. According to the monthly average evaporation amount (210 mm) and annual evaporation (2517 mm) is observed that about 50% of the evaporation rate are 4 months That are June, July, August and September and only about 9 percent to 3 months That are December, January and February this show that The region has warm, dry summers and cool winters and dry. According to data from pan evaporation data and data that result from energy budget method, pan factor is accordance with Table 2

Table 2-evaluation pan evaporation factor for Dez reservoir region

Parameter	amount
Annual Evaporation Rate with energy budget method	2617
Annual Evaporation Rate with data from pan evaporation	3836
Pan factor for Dez dam Region	0.66

Compare the energy budget method with other methods

As mentioned energy budget method, if data are available is the best method for estimating evaporation (Hassani, 2013) also in many references this method as the standard method has been introduced and the result of other method compared with it. In this research as well as the energy budget method is reference method.

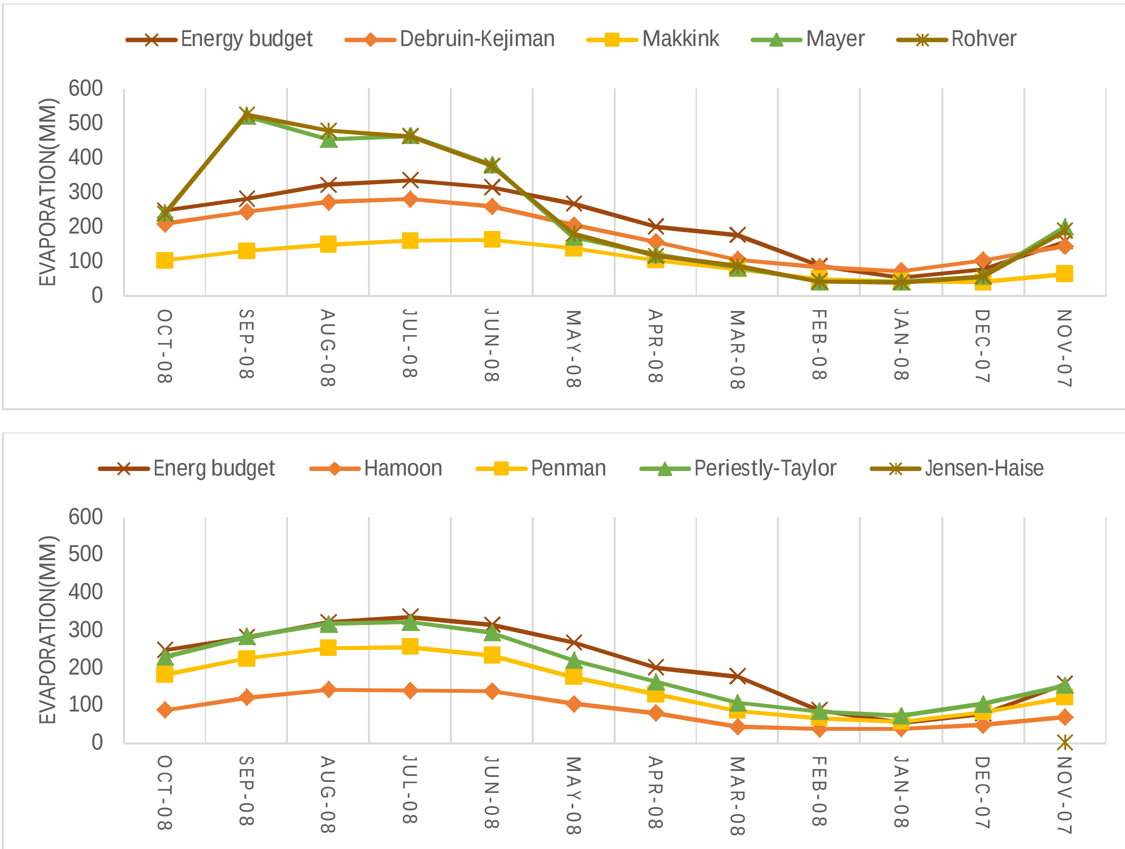

Figure 4- comparison of eight methods with energy budget method

According to the above figures it can be seen that the results obtained from Priestley-Taylor and DeBruin-Kejiman largely obtained from the evaporation rate matching energy budget. Results obtained from three Penman, Hamon, and Makkink Is almost identical with the graph obtained by evaporation of the energy budget method but these three methods have estimated the evaporation rate is less than the energy budget method. Evaporation rate estimated in two ways, Mayer and Rohver matches energy budget method. But these two methods to estimate evaporation in the warm months more of the energy budget method and in the cold months are estimated less than budget method. The saturation vapor pressure deficit in the months of June, July, August and September is higher than of other month so in this reason that Mayer and Rohver method more estimated because just these two models are related to vapor pressure deficit. As can be seen in the cold months all methods have a closer estimate And significant changes are observed in the warm months that its reason is In the colder months have low temperature change so evaporation models have less difference in their estimate but in the warm months, Due to the high temperatures, the estimated difference is greater. Evaporation volume (m^3) for months derived by evaporation method as following.

Table 3- volume of evaporation derived by evaporation method

	Energy budget	Hamon	penman	Priestley-Taylor	makkink
November	5525184	2397844	4238748	5340823	2227671
December	2363616	1467182	2516627	3170949	1233663
January	1372012	950345	1457298	1836195	1085229
February	2352263	980791	1798607	2266244	1332747
March	6686088	1636549	3221850	4059531	2950813
April	10008822	3945082	6457695	8136696	5151187
May	14560231	5675865	9531227	12009346	7484634
June	18818052	8203657	13937487	17561233	9734639
July	19622627	8137438	14956164	18844767	9394971
August	17743827	7812409	13870130	17476364	8199654
September	13615894	5862744	10856764	13679522	6343922
October	10195402	3587180	7511465	9464445	4237808

	DeBruin-Kejiman	Jensen-Haise	Mayer	Rohver
November	5055762	3009066	6993221	6631189
December	3155705	1145403	1728561	1737041
January	1848050	718919	1051406	1001685
February	2277070	969211	1132695	1161415
march	3998534	3105147	3110166	3303980
April	7810241	6721993	6025255	5790927
May	11215882	10616668	9269528	9834011
June	15531256	16000733	22765448	22548291
July	16406647	15941744	27152245	27063009
August	14963511	14345681	24968912	26369511
September	11821654	10921021	25225755	25404652
October	8639287	6459707	9953380	9796070

Table 4- Determining the best method for estimating evaporation

Method	RMSD	CE	MBE	Rank
Priestley-Taylor	29.43	0.905	-14.4	1
DeBruin-Kejiman	44.02	0.787	-31.88	2
Penman	63.92	0.552	-54.7	3
Jensen-Haise	64.32	0.547	-61.48	4
Mayer	101.78	-0.133	20.94	5
Rohver	103.97	-0.183	22.61	6
Makkimk	120.51	-0.589	-108.18	7
Hamon	136.58	-1.041	-122.96	8

According to the classification of the methods for estimating evaporation and above table characterized by Methods related to energy budget (Priestley-Taylor and DeBruin-Kejiman) have best estimate of the evaporation estimates and Combined energy budget and mass transfer method (Penman) Second priority, And Methods based on mass transfer (Mayer and Rohver) Third priority And finally Methods of radiation and temperature (Makkink and Hamon) to estimate evaporation from this area was the last priority and Have the lowest accuracy. So by comparing the statistical parameters calculated in order to compare the results and choose the best method in accordance with the results of the budget method as accurate data as can be seen in Table 3. The method Priestley-Taylor and DeBruin-Kejiman first priorities are used to estimate evaporation from Dez Dam region. These results also are consistent with the results observed in figures. The values obtained from the MBE index is observed among the methods studied, Mayer and rohver methods are over estimate and other them are under estimate

Conclusion

In this study the monthly rate of evaporation from the Dez dam reservoir by a number of authentic and accurate methods and models, for twelve months were evaluate. Results show, the average annual evaporation rate of the water budget method gives approximately 2517 mm. About 50 percent of the average monthly evaporation are for 4 months such as June, July, August and September and only about 9 percent are for 3 months, December, January and February. The mean annual evaporation using energy budget and evaporation pan measurements are 2517 and 3836 mm. Evaporation pan factor was determined and its value is equal to 0.66. The empirical formula for the Dez region, according to the results of this study to estimate the evaporation rate is better that Priestley-Taylor and DeBruin-Kejiman methods be used. Because only 12 months of statistics are availability in this study be used It was examined 12 months, the analysis in this region is better to be studied by more statistics.

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