Italian Journal of
Agrometeorology
Rivista Italiana di Agrometeorologia

Firenze University Press
www.fupress.com/ijam

OPEN ACCESS

Citation: E. Hojjati, G. Mahtabi, F. Taran, O. Kisi (2020) Estimating evaporation from reservoirs using energy budget and empirical methods: Alavian dam reservoir, NW Iran. *Italian Journal of Agrometeorology* (2): 19-34. doi: 10.13128/ijam-1033

Received: July 26, 2020

Accepted: September 19, 2020

Published: January 25, 2021

Copyright: © 2020 E. Hojjati, G. Mahtabi, F. Taran, O. Kisi. This is an open access, peer-reviewed article published by Firenze University Press (http://www.fupress.com/ijam) and distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Competing Interests: The Author(s) declare(s) no conflict of interest.

Estimating evaporation from reservoirs using energy budget and empirical methods: Alavian dam reservoir, NW Iran

Elahe Hojjati[1], Ghorban Mahtabi[1,*], Farshid Taran[2], Ozgur Kisi[3]

[1] *Department of Water Engineering, University of Zanjan, 45371-38791, Zanjan, Iran*
[2] *Department of Water Engineering, University of Tabriz, 51666-16471, Tabriz, Iran*
[3] *Faculty of Natural Sciences and Engineering, Ilia State University, Tbilisi, Georgia*
* Corresponding author. E-mail: ghmahtabi@znu.ac.ir; ORCID: 0000-0002-3532-8933

Abstract. Accurate estimation of evaporation from open water resources like lakes and dam reservoirs is necessary to proper water balance management, especially in arid and semi-arid regions. A detailed daily evaporation study was conducted on Alavian dam reservoir, located in the northwest of Iran. A two-dimensional hydrodynamic model was used to obtain the distribution of daily water temperature of the reservoir. The water temperature model was calibrated and validated using a three-year observed data set (2013-2016). The Bowen ratio energy budget (BREB) is accepted as a standard approach in estimating evaporation from lakes. To select the best evaporation method(s) over the lake, evaporation rates were determined using 30 empirical methods. These methods were evaluated and ranked with respect to the BREB values. The estimated evaporation values by the BREB approach showed that the monthly mean and the annual evaporation from the Alavian reservoir during 2015-2016 were equal to 4.08 mm day^{-1} and 1508 mm year^{-1}, respectively. The Rohwer (Dalton) and the deBruin (combination) methods with the RMSEs of 0.71 and 0.79 mm day^{-1}, respectively, provided the best performances. To summarize, the methods depended only on measurement of vapor pressure deficit and wind speed (e.g., Rohwer, deBruin and McMillan) were relatively found to be more cost-effective and more practical alternatives for determining evaporation at the studied area, owing to their high efficiency and simplicity.

Keywords. Alavian reservoir, evaporation, energy budget, empirical methods, temperature simulation.

1. INTRODUCTION

In many arid and semi-arid areas, surface water is an important resource for drinking, agriculture and industry. Since the water demand has increased due to climate change, socioeconomic and environmental conditions, the use of water resources should properly be managed and optimized. Iran is located in an arid and semi-arid region in which many efforts are made to increase the water use efficiency. Evaporation from freshwater lakes or dam reservoirs, as a main factor in water loss from surface water resources, can play an important role in water resources management in arid and semi-arid regions. In the recent years, climate change has been a big problem for the activities related to agriculture (e.g., change in pattern of rainfall and temperature) which have important effects on the availability of water resources in Iran (Zarghami et al., 2011). In this situation, the evaluation of evaporation from lakes or reservoirs is necessary to manage and control any water loss in the available resources. These issues increase the importance of understanding the evaporation components, as well as the accurate estimation of the evaporation losses. Open-water evaporation is a continuous hydrological process affected by different parameters such as solar radiation, air and water temperature, wind speed, vapor pressure deficit, atmospheric pressure, surface area, water depth and water quality (Brutsaert, 1982). Hence, estimation of evaporation is a very difficult task since it depends on many climatic and geologic parameters.

Different approaches can be utilized to estimate evaporation using meteorological data from free surface resources. They are classified as: (1) water budget, (2) evaporation pans, (3) Bowen ratio energy budget, and (4) empirical methods. The empirical methods can be categorized into five groups: combination, solar radiation-temperature, Dalton (mass-transfer), temperature-day length and temperature (Rosenberry et al., 2007). The Bowen-ratio energy-budget (BREB) approach is one of the most accurate approaches for continuous long-term evaporation monitoring (Harbeck et al., 1958; Omar and El-Bakry, 1981; Lenters et al., 2005). Omar and El-Bakry (1981) evaluated the evaporation rate from Aswan High dam reservoir using the energy-budget and mass transfer methods during 1970-1971 based on measurements over the reservoir. They concluded that the energy budget was the most fundamental method for estimating the evaporation. The effects of errors in the water surface temperature and the vapor pressure on the evaporation calculations were smaller when using the energy budget method. Also, the monthly deviation of evaporation estimated by two methods was 10-14% of actual values. Lenters et al. (2005) presented a comprehensive, 10-years analysis of seasonal, intra-seasonal, and inter-annual variations in lake evaporation for Sparkling Lake, northern Wisconsin (USA). The results of a long-term energy budget method showed that the mean evaporation rate for the lake over the study period was 3.1 mm day^{-1} with a coefficient of variation of 25%.

The BREB, as a standard approach, is commonly used to determine the evaporation losses and the efficacy of different empirical methods with different climatic and physical settings. For instance, Rosenberry et al. (2004) compared evaporation rates calculated by 12 methods with the energy budget method in Cottonwood Lake in east-central North Dakota, USA. Rosenberry et al. (2007) assessed 15 approaches in Mirror Lake in northeastern USA and then adjusted the methods to better fit the BREB values. Gorjizade et al. (2014) tested eight methods in Dez reservoir in Iran, and concluded that the Priestly-Taylor and the DeBruin-Kejiman approaches performed superior to the other alternatives. The evaluation of 19 methods by Majidi et al. (2015) in Doosti Reservoir in Iran suggested that Jensen-Haise, Makkink, Penman and deBruin were the best approaches considering the BREB values. Antonopoulos et al. (2016) evaluated the Artificial Neural Networks (ANN) and 3 classical empirical methods in Lake Vegoritis, Greece. Hussain (2017) used seven methods to estimate the evaporation from Brullus Lake in the north of Nile Delta in Egypt, recognizing Makkink as the best method followed by DeBruin-Kejiman. Bozorgi et al. (2018) evaluated and ranked 12 methods in Karkheh reservoir in Iran, indicating that Stephens-Stewart, Makkink, Jensen-Haise, and Blaney-Criddle were the best methods, respectively.

In the BREB method, devices and sensors like precision spectral pyranometer are used for accurate measuring of the energy budget fluxes. However, if the access to these devices and sensors is not possible, a number of auxiliary equations can be used to determine the fluxes (Torres and Calera, 2010). The most difficult parameter to estimate is the thermal energy stored in the lake. To compute the energy budget flux, the main parameter to measure is the water temperature profiles. The variations in the water temperature present the changes in the thermal energy of the lake. The flux can be calculated from the outcomes of turbulent diffusion or hydrodynamic models (QUALAKE-DOT or CE-QUAL-W2) which can compute the lake temperature profiles, and therefore the changes in the thermal energy (Antonopoulos and Gianniou, 2016). Up to now, limited studies have been performed to determine the storage heat flux of energy budget using simulation of temperature profile of a lake/reservoir (Gianniou and Antonopoulos, 2007; Antonopoulos et al., 2016). Gianniou and Antonopoulos (2007) determined daily evaporation and energy budget in Lake Vegoritis in Greece for the year 1993. They used the one-dimensional eddy diffusion model (QUALAKE-DOT) to compute the daily water temperature profile of the lake and the thermal energy stored in the lake. Throughout the evaporation calculation, two statistics suggested by Tanner et al. (1987) and Payero et al. (2003) were applied.

The aim of the present study is to (1) estimate the daily evaporation from the Alavian reservoir in Maragheh, Iran, based on the energy budget, and (2) evaluate the suitability of 30 empirical equations. A two-dimensional hydrodynamic model (CE-QUAL-W2) was implemented to obtain the distribution of water temperature in the reservoir. A comprehensive comparison was made to select the most accurate approaches in estimating the lake evaporation based on the energy budget method.

2. MATERIALS AND METHODS

2.1. Alavian reservoir

Sufi-Chay River is located in Urmia Lake basin in the northwest of Iran. Alavian dam reservoir is constructed on the Sufi-Chay River in East Azerbaijan Province at a distance of 3.5 km from the northwest of Maragheh City with longitude 46°15'E and latitude 37°25'N. The main purpose of the construction of the Alavian dam are to collect and control the Sufi-Chay surface streams and provide drinking water for Maragheh City, compensate for part of agricultural needs of Maragheh-Bonab plain, the industrial areas and the hydroelectric power generation. Fig. 1 illustrates the location of the Alavian dam. The surface area, surface elevation, and the volume of the lake from October 2015 to September 2016 (the year for this study) are 1.57 km^2, 1554.51 m and 27.26 mcm, respectively. The maximum depth of the reservoir is 60 m. The climate in the region is semi-arid with 299.4 mm annual mean precipitation. The annual temperature is 13.5 °C in July-September (summer) and January-March (winter). In the results and discussion section, the Alavian dam has been compared with Vegoritis Lake (Gianniou and Antonopoulos 2007) since there are effective similarities between the two lakes. The surface elevation, the surface area, and the volume of the Vegoritis Lake in 1993 (the year of the study) were 513 m, 33.5 km^2, and 810.4 mcm, respectively. These parameters, as the differences between the two lakes, mainly affect the amount of evaporation, but not the evaporation process. In other words, the more the lake surface area is, the more the evaporation will be. Other parameters like climatic parameters and depth of the lake affect the evaporation process. The maximum depth of the Vegoritis Lake

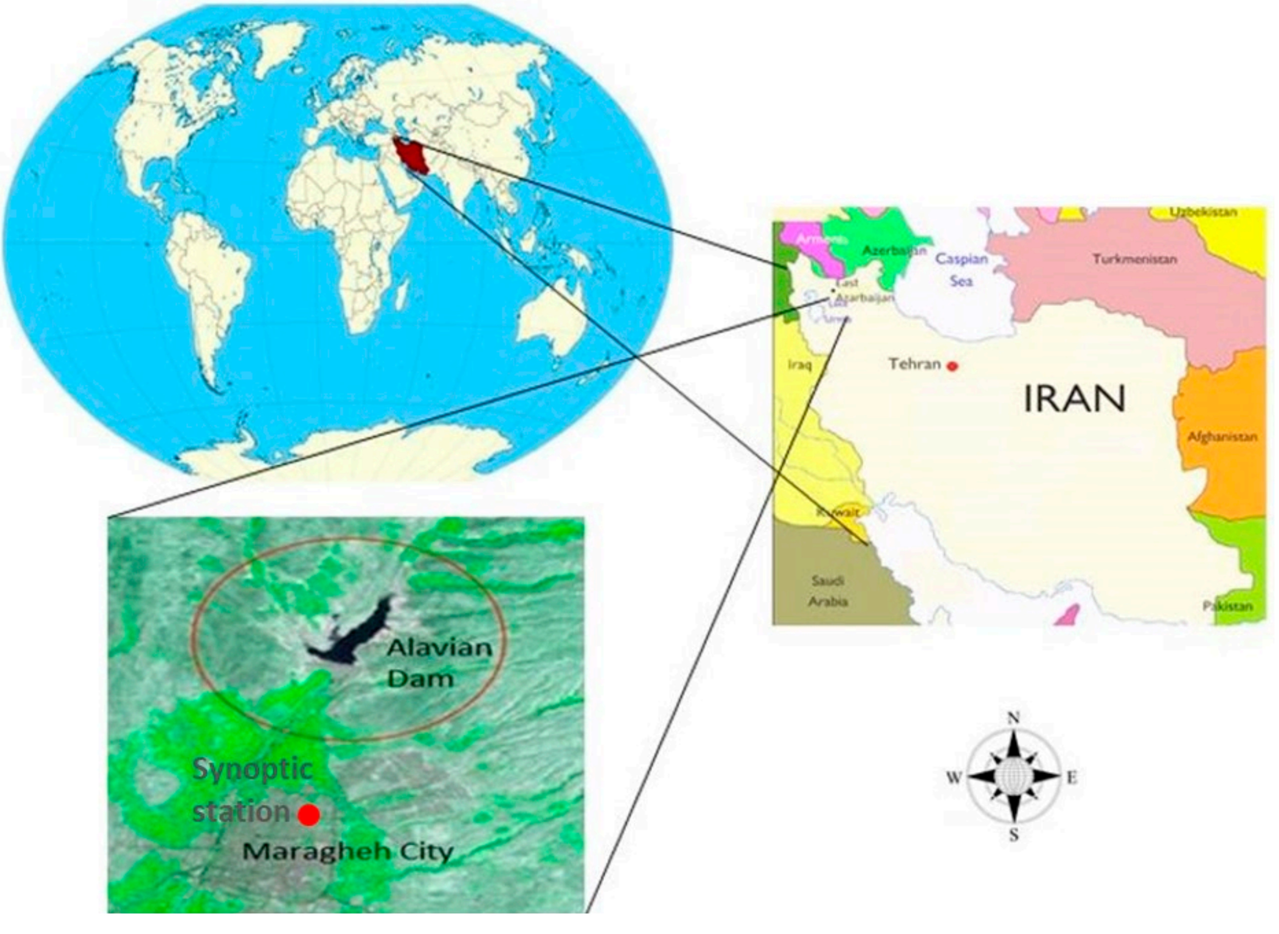

Fig. 1. Location of the Alavian Dam reservoir in East Azerbaijan Province, Iran.

was 48 m (as the similarity between the two lakes). The climate in the Vegoritis area is semi-arid with two-distinguishing warm–dry and cold–wet periods during the year (as similarity). The annual mean temperature was 12.1 °C, with July and January being the warmer and the colder months of the year, respectively (as similarity). These similarities in the evaporation process show that the two lakes could effectively be compared.

2.2. Energy budget method

In order to determine the amount of energy necessary to evaporate water from free surfaces, a Bowen-ratio energy-budget (BREB) approach or, in general, a surface energy budget can be used. That is, in the water system, the energy conservation equation can be applied to determine the evaporation rate (Winter et al., 2003; Lenters et al., 2005; Rosenberry et al., 2007). The BREB is considered as the standard and reference approach in long-term and continuous monitoring and estimating the evaporation from lake surface and requires a large amount of meteorological and hydrological data. The energy budget of a lake can be stated as:

$$Q_s - Q_{sr} + Q_a - Q_{ar} - Q_{bs} - Q_e - Q_h - Q_w + Q_v + Q_b = Q_x \tag{1}$$

where Q_s is the incoming shortwave radiation, Q_{sr} is the reflected shortwave radiation, Q_a is the incoming longwave radiation from the atmosphere, Q_{ar} is the reflected longwave radiation from the atmosphere, Q_{bs} is the emitted longwave atmospheric radiation from the water body, Q_e is the energy used for evaporation, Q_h is the energy conducted from the water body as sensible heat, Q_w is the energy advected from the water body to the atmosphere by the evaporated water, Q_v is the net energy advected into the water body by precipitation, surface water, and ground water, Q_b is the net energy conducted between the lake water and the bottom sediments, and Q_x is the alteration in the energy content of the water body. The unit utilized for the fluxes of Eq. (1) is W m^{-2}.

The fluxes Q_e, Q_h, and Q_w, not measured directly, were estimated as functions of the evaporation rate by employing the following equations:

$$Q_e = \rho E L_v \tag{2}$$

$$Q_h = \beta Q_e \tag{3}$$

$$Q_w = \rho c E (T_w - T_b) \tag{4}$$

where ρ is the water density (998 kg m^{-3} at 20 °C), E is the water evaporation (m s^{-1}), L_v is the latent heat of vaporization (J kg^{-1}), β is the Bowen ratio (dimensionless), c is the specific heat capacity of water (4186 J kg^{-1} °C^{-1}), T_w is the water surface temperature (°C) and T_b is an arbitrary base temperature of 0 °C. When Bowen ratio values (β) are close to -1, extremely inaccurate values for the latent heat flux (Q_e) are estimated. A simple way of facing this problem, as proposed by Tanner et al. (1987), is to reject the data for which $-1.25 < \beta < -0.75$. Furthermore, faulty meteorological data or the fact that they come from different stations could sometimes result in fluxes with the wrong sign (Payero et al., 2003). Valid data should be met the following criteria:

a) Excluding data when $-1.25 < \beta < -0.75$
b) $L_v(\Delta e + \gamma \Delta T)(Q_{rn} - Q_x) > 0$ (5)

where $\Delta e = e_{sw} - e_a$, $\Delta T = T_w - T_a$, e_{sw} is the saturation vapor pressure at the water surface temperature (mbar), e_a is the air vapor pressure above water surface (mbar), and T_a is air temperature (°C).

In many cases, especially in large and deep lakes, the fluxes Q_v and Q_b are too small and many researchers agree to omit the fluxes with small values and insignificant effects (Stauffer, 1991; Sacks et al., 1994; dos Reis and Dias, 1998; Winter et al., 2003; Gianniou and Antonopoulos, 2007; Rosenberry et al., 2007). Winter et al. (2003) reported that energy advected to and from the lake by precipitation, surface water, and ground water (Q_v) was found to have little effect on evaporation rates. Net energy gain related to surface water was small since the water temperatures were low when the largest inflows and outflows occurred during spring and the late fall. Net energy gain related to groundwater was small since groundwater inflow was a small part of the water budget and the temperature of groundwater was relatively low (Winter et al., 2003).

Finally, by combining Eqs. 1, 2, 3 and 4, the following equation is obtained:

$$E = \frac{Q_s - Q_{sr} + Q_a - Q_{ar} - Q_{bs} - Q_x}{\rho(L_V(1+\beta) + cT_w)} = \frac{Q_{rn} - Q_x}{\rho(L_V(1+\beta) + cT_w)} \tag{6}$$

where E is the water evaporation (m s^{-1}), Q_{rn} is the net radiation (W m^{-2}), and $Q_{rn} = Q_s - Q_{sr} + Q_a - Q_{ar} - Q_{bs}$. In Eq. (6), the fluxes Q_s and Q_a are calculated from meteorological data (Allen et al., 1998; Antonopoulos *et al.*, 2016), and Q_{sr} and Q_{ar} are fixed portions of Q_s and Q_a, respectively (Anderson, 1954; Koberg, 1964). Q_{bs} is computed from the lake surface water temperature by utilizing the law of Stefan-Boltzmann (Rosenberry et al., 2007). The alteration in the energy content of the water body (Q_x) can be calculated by the variation of the lake temperature for each energy-budget period (here the period is a day) (Gianniou and Antonopoulos, 2007; Duan and Bastiaanssen, 2015), according to the following equation:

$$Q_x = \frac{\rho.c}{A_s} \sum_{0}^{z} \frac{\Delta T_{(z,t)}}{\Delta t} A_z.\Delta z \tag{7}$$

where ρ is the water density (kg m^{-3}), c is the specific heat capacity of water (J kg^{-1} °C^{-1}), A_s is the lake surface area (m^2), A_z is the horizontal area as a function of depth (m^2) and $T_{z,t}$ is the water temperature (°C) as a function of depth (z) and time (t). In this study, to determine the water temperature distribution and, as a result, the thermal energy stored in the lake, the mathematical model CE-QUAL-W2 (version 3.7, developed by Edinger and Buchak, 1975) was employed

2.3. Lake water temperature modelling

Many models have been developed in hydrodynamic and water quality simulation of lakes/reservoirs. These models are widely used especially when there are limited water temperature measurements. The CE-QUAL-W2 is a two-dimensional, longitudinal-vertical, laterally averaged model which has been developed since 1975 (Buchak and Edinger, 1984). This model is successfully applied to simulate hydrodynamic, temperature and water quality in lakes/reservoirs in different regions (Kim and Kim, 2006; Gianniou and Antonopoulos, 2007; Norton and Bradford, 2009; Buccola and Stonewall, 2016). The CE-QUAL-W2 model depends on the solution of two-dimensional unsteady hydrodynamic and advection-dispersion equations. The input data required for modeling by CE-QUAL-W2 are: geometric data, meteorological and hydrologic data, shading or vegetation coefficient, wind sheltering coefficient, inflow, outflow, and water temperature distribution. The following data are required to set up the input geometry: topographic map and volume-area-elevation table of the reservoir. The topographic map is utilized to produce bathymetric cross-sections which are inputs of the model. The volume-area-elevation table of project is utilized to compare with the one that is produced by the model (in calibration stage). The meteorological data includes air temperature (TAIR) (C˚), dew point temperature (TDEW) (C˚), wind direction (PHI) (Radian), wind speed (WIND) (m s^{-1}) and cloud cover (CLOUD) (%). In the present research, these daily data were obtained from the nearest station (with a full data set) to the Alavian dam and introduced to the model (Maragheh synoptic station). The vegetation coefficient and the wind sheltering coefficient were evaluated in the calibration stage (Kim and Kim, 2006). The upstream boundary conditions were introduced to the model using the reservoir inflows (Tazeh-Kand hydrometric station located at the upstream of the Alavian dam) and the inflow temperature (the measured water temperature data). The downstream boundary conditions were determined by the outflows and the water surface level in the reservoir (the operating data of the reservoir).

The parameter set of the CE-QUAL-W2 model was calibrated and validated by utilizing the volume-area-elevation table and the water temperature measurements in the Alavian reservoir during October 2013-September 2016. The constants and coefficients of the model were determined from the literature and modified by using trial and error method during the calibration stage.

After simulating the vertical lake water temperature profiles, the values of thermal energy content of the water body were calculated using Eq. (7) during October 2015-September 2016. Finally, the daily evaporation values for the Alavian reservoir were computed using Eq. (6) for 2015-2016. Throughout the evaporation calculation, the two techniques suggested by Tanner et al. (1987) and Payero et al. (2003) were employed to eliminate the faulty meteorological data or wrong sign of fluxes.

2.4. Evaluation of the empirical methods

To determine the best method(s) for estimating evaporation from the Alavian reservoir, the performance of 30 methods were evaluated by comparing with the BREB approach. In Table 1, the empirical equations used in this research are grouped according to method type. The combination groups are the most data-intensive as they need many energy fluxes and climatic data. The Dalton group requires the measurement of wind velocity and saturated and actual vapor pressures. The solar radiation-temperature group requires the measurement of T_a and Q_s. The last two groups need mean air temperature. The temperature-day length group also requires day length of the studied area.

To discuss the performances of the examined methods, the three MBE (Eq. 8), RMSE (Eq. 9) and NS (Eq. 10) standard statistical indices were used. The MBE (mean bias error), indicates the average of deviations of computational values from observed values, which represents underestimation or overestimation of the model or the equation. The RMSE (root mean square error) shows the average value of errors in the set of predictions, regardless of their direction. The RMSE values closer to zero indicate the better performance of a model or an equation. The NS (Nash–Sutcliffe) is one of the best indicators of performance and accuracy evaluation of a model or an equation. Its larger amount indicates that the model/equation is more accurate (Nash and Sutcliffe, 1970). The NS and the RMSE indices are used to rank the empirical equations.

Tab. 1. The empirical methods or equations used in calculating evaporation from the Alavian reservoir.

Method	Reference	Equation	Developed for
Combination group			
De Bruin–Keijman	deBruin & Keijman (1979)	$\mathrm{E}=\alpha\frac{s}{0.85s+0.63\gamma}\frac{Q_{rn}-Q_x}{L\rho}\times 86.4$	Daily
Brutsaert–Stricker	Brutsaert & Stricker (1979)	$\mathrm{E}=(2\alpha-1)(\frac{s}{s+\gamma})\frac{(Q_{rn}-Q_x)}{L\rho}\times 86.4-\frac{\gamma}{s+\gamma}0.26(0.5+0.54U_2)(e_s-e_a)$	Daily
Priestley–Taylor	Stewart & Rouse (1976)	$\mathrm{E}=\alpha\frac{s}{s+\gamma}\frac{Q_{rn}-Q_x}{L\rho}\times 86.4$	Periods of 10 d or greater
Penman	Brutsaert (1982)	$\mathrm{E}=(\frac{Q_{rn}s}{s+\gamma}+\frac{\gamma e_a}{s+\gamma})/(\rho L)$	Periods greater than 10 d
De Bruin	deBruin (1978)	$\mathrm{E}=1.192(\frac{\alpha}{\alpha-1})(\frac{\gamma}{s+\gamma})\frac{(2.9+2.1U_2)(e_s-e_a)}{L\rho}\times 86.4$	Periods of 10 d or greater
Dalton group			
Meyer	Patel & Majmundar (2016)	$\mathrm{E}=(1+\frac{U_9}{16}).K_M.(e_s-e_a)$	Daily
Marciano	Marciano & Harbeck (1954).	$E=0.03U_2(e_s-e_a)$	Daily
Shahtin	Hajian & Lotfollahi-Yaghin (2015)	$E=(0.116+0.017U_2)(e_s-e_a)$	Daily
Hefner	Marciano & Harbeck (1954).	$E=0.028U_2(e_s-e_a)$	Daily
Box	Shah (2012)	$E=0.0000778(e_s-e_a)$	Daily
Leven	Shah (2012)	$E=0.0000094(e_s-e_a)^{1.3}$	Daily
Himus-Hinchley	Shah (2012)	$E=0.0000258(e_s-e_a)^{1.3}$	Daily
Boelter	Shah (2012)	$E=0.0000162(e_s-e_a)^{1.22}$	Daily
Biasin-Krumme	Shah (2012)	$E=-0.059+0.000079(e_s-e_a)$	Daily
Ryan–Harleman	Rasmussen et al. (1995)	$\mathrm{E}=\frac{(2.7(T_w-T_a)^{0.333}+3.1U_2)(e_{sw}-e_a)}{L\rho}\times 86.4$	Daily
Tichomirof	Hajian & Lotfollahi-Yaghin (2015)	$E=(e_s-e_a)(15+3U_{10})$	Monthly
Harbeck	Shuttleworth, (1993)	$E=2.209A_s^{-0.05}U_2(e_{sw}-e_a)$	Monthly
Shuttleworth	Shuttleworth, (1993)	$E=2.209A_s^{-0.05}U_2(e_{sw}-e_a)$	Monthly
McMillan	Sweers (1976)	$E=(5\times 10^6\times A_s^{-1})^{0.05}(3.6\times 2.5U_3)(e_{sw}-e_a)$	Monthly
Rohwer	Patel & Majmundar (2016)	$E=0.77(1.465-0.00073P_a)(0.44+0.073U_{0.6})(e_s-e_a)$	Monthly
Patel-Majmundar	Patel & Majmundar (2016)	$E=-3.5-0.14T_w+0.25T_a+0.27U_2+0.9(e_s-e_a)+0.15S$	Monthly
Solar radiation, temp. group			
Jensen–Haise	McGuinness & Bordne (1972)	$E=(0.014T_a-0.37)(Q_s\times 3.523\times 10^{-2})$	Periods greater than 5 d
Makkink	McGuinness & Bordne (1972)	$\mathrm{E}=((52.6\frac{s}{s+\gamma}\frac{Q_s}{L\rho})-0.12)$	Monthly
Stephens–Stewart	McGuinness & Bordne (1972)	$E=(0.0082T_a-0.19)(Q_s\times 3.495\times 10^{-1})$	Monthly
Temp., day length group			
Hamon	Hamon (1961)	$\mathrm{E}=0.55(\frac{D}{12})^2\frac{SVD}{1000}(25.4)$	Daily
Blaney–Criddle	McGuinness & Bordne (1972)	$E=(0.0173T_a-0.314)\times T_a\times(D\div D_{ta})\times 25.4$	Monthly
Temperature group			
Papadakis	McGuinness & Bordne (1972)	$\mathrm{E}=0.5625(e_{s\max}\times 10^{-2}-(e_{s\min}\times 10^{-2}-2))(\frac{10}{d})$	Monthly
Thornthwaite	Mather (1978)	$\mathrm{E}=(1.6(\frac{10T_a}{I})^{6.75\times 10^{-7}I^3-7.71\times 10^{-5}I^2+1.79\times 10^{-2}I+0.49})(\frac{10}{d})$	Monthly
Ivanov	Filimonova & Trubetskova (2005)	$E=0.0018(T_a+25)^2(100-RH)$	Monthly
U.S.B.R	Hajian & Lotfollahi-Yaghin (2015)	$E=0.883(4.57T_a+43.3)$	Monthly

α = 1.26 = constant of Priestley–Taylor approach, dimensionless,
s = slope of the saturated vapor pressure–temperature curve at average air temperature (Pa ^{o}C^{-1}),
γ = psychrometric "constant" (dependent on atmospheric pressure and temperature) (Pa ^{o}C^{-1}),
Q_{rn} = net radiation (=Q_s - Q_r + Q_a - Q_{ar} - Q_{bs}) (W m^{-2}),

Q_s = incoming shortwave radiation (W m^{-2}),
Q_x = change in heat stored in the water body (W m^{-2}),
L = latent heat of vaporization (MJ kg^{-1}),
ρ = density of water (998 kg m^{-3} at 20 °C),
$U_{0.6}$ = wind speed at 0.6 m above surface) km h^{-1}),
U_2 = wind speed at 2 m above surface (km h^{-1} for Patel and Majmundar, Shahtin, Hefner and Marciano and m s^{-1} for the other equations),
U_3 = wind speed at 3 m above surface (m s^{-1}),
U_9 = wind speed at 9 m above surface) km h^{-1}),
U_{10} = wind speed at 10 m above surface) m s^{-1}),
P_a = atmospheric pressure (mm Hg),
S = duration of sunshine (hr),
A_s = area of the water surface (m^2),
K_M = coefficient: 0.36 for large, deep waters and 0.50 for small, shallow waters,
e_{sw} = saturated vapor pressure at temperature of the water surface (mb),
e_s = saturated vapor pressure at temperature of the air (mb for Brutsaert–Stricker, Ryan–Harleman and deBruin and mm Hg for the other equations),
e_a = vapor pressure at temperature and relative humidity of the air (mb for Brutsaert–Stricker, Ryan–Harleman and deBruin and mm Hg for the other equations),
SVD = saturated vapor density at mean air temperature (g m^{-3}),
T_a = air temperature (°F for the Blaney–Criddle, Jensen–Haise and Stephens–Stewart equations and °C for the other equations),
T_w = water surface temperature (°C),
D = daylight hours,
D_{TA} = total annual hours of daylight for specific latitude; for Alavian Lake, D_{TA} = 4470,
$e_{s\ min}$ and $e_{s\ max}$ = saturated vapor pressures at daily minimum and maximum air temperatures (Pa),
I = annual heat index ($I=\sum i$, $i=(T_a/5)^{1.514}$),
d = number of days in month,
RH = relative air humidity (%).

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(E_{i,pre} - E_{i,ref}) \tag{8}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(E_{i,pre} - E_{i,ref})^2} \tag{9}$$

$$NS = 1 - \frac{\sum_{i=1}^{N}(E_{i,pre} - E_{i,ref})^2}{\sum_{i=1}^{N}(E_{i,ref} - \overline{E}_{i,ref})^2} \tag{10}$$

where $E_{i,ref}$ are the values of reference method (the energy budget evaporation), $E_{i,pre}$ are the calculated values by the other methods, $\overline{E}_{i,ref}$ is the mean values of reference method, and N is the total data pairs.

3. RESULTS AND DISCUSSION

3.1. Water temperature distribution in Alavian dam reservoir

Fig. 2 shows some characteristics of the simulated vertical water temperature profiles versus the measured ones in the Alavian reservoir for different days of the year 2015-2016. The outcomes show that there is a good fit between the measured and simulated water temperature profiles. Based on the simulation results, the values of mean absolute error (MAE) range from 0.68 to 2.2° C for the different water temperature profiles, which seems appropriate regarding the magnitude and the depth of the Alavian reservoir (Kim and kim, 2006; Gianniou and Antonopoulos, 2007). The results indicate that the reservoir has a positive thermal stratification in spring and summer to mid-fall, and a negative thermal stratification in winter.

3.2. Estimation of evaporation

Fig. 3 illustrates the daily and the monthly mean evaporation values derived from the energy budget method in the Alavian reservoir for the one-year period (October 2015 to September 2016). According to this Fig., the daily and the monthly evaporation rates decrease during fall and winter and reach the minimum values in November, January and February. Subsequently, as the temperature increases in the late winter (March) and during the spring, the evaporation rate increases. However, in some days of spring (Fig. 3a), due to the cloudy conditions and precipitation, the evaporation rate reduces sharply. In summer, the evaporation reaches to peak value and the maximum daily evaporation rate becomes about 15.57 mm day^{-1} in April (mean monthly of 10.39 mm). In September, due to the decrease in the air and the water temperature, the evaporation experiences a downward trend again. In general, the mean monthly and the annual evaporation from

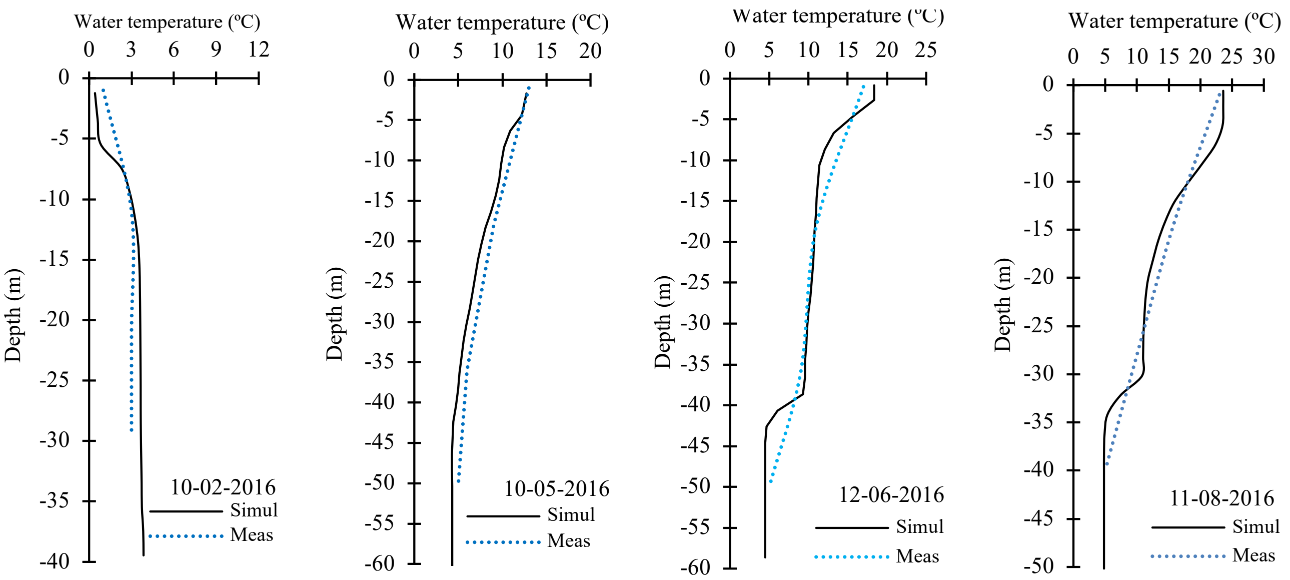

Fig. 2. The simulated (–– Simul) and measured (**…** Meas) temperature profiles in Alavian Reservoir.

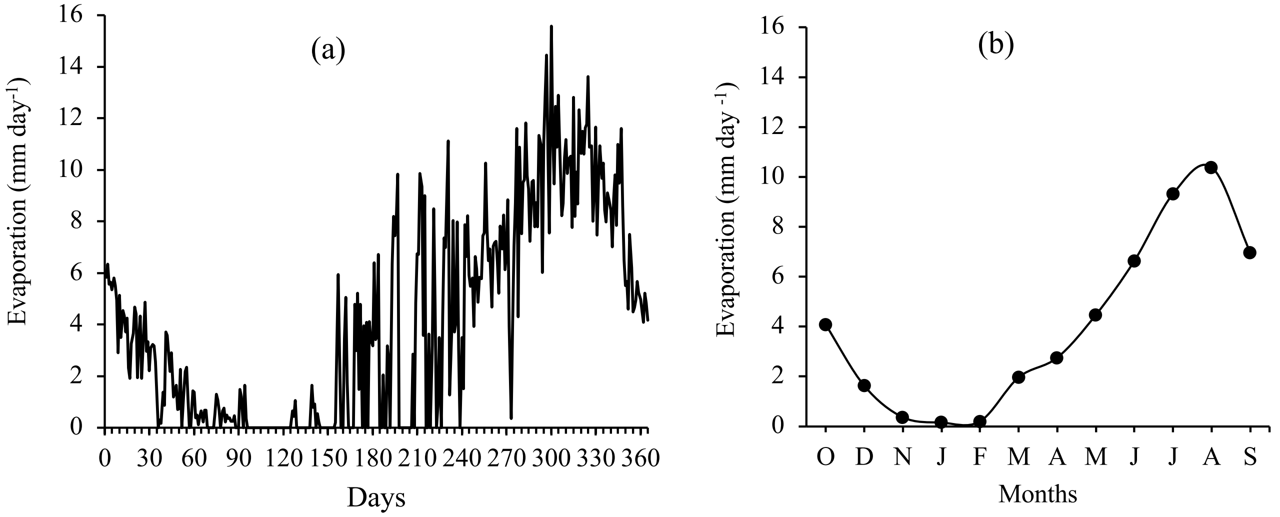

Fig. 3. Daily (a) and monthly (b) estimated evaporation values for Alavian Reservoir during 2015-2016.

the Alavian reservoir during 2015-2016 are equal to 4.08 mm day^{-1} and 1508 mm year^{-1}, respectively. Based on the evaporation values and the surface area of the reservoir, the annual volume of evaporation from the reservoir was obtained equal to 2.8 mcm. Since Maragheh city has a population of nearly 176000 and the daily water usage for human consumption in this city is about 240 liter per day per person, the amount of evaporation over the lake is more than 19% of the annual volume of water consumed in the city (15 mcm). On the other hand, the annual evaporation over the lake is about 6.7% of the annual water volume allocated from the Alavian reservoir to the agricultural sector (42 mcm). It could be concluded that the importance of evaporation losses over the Alavian reservoir is more in human usage management than the agricultural sector.

Obviously, the results of the daily evaporation are prone to possible errors due to the use of the reconstructed water temperature profiles data. According to the sensitivity analysis performed by Gianniou and Antonopoulos (2007) on the energy budget parameters, a 10% change in the surface water temperature leads to a 16.8% change in the evaporation values of a reservoir. Regarding the good accuracy of the water temperature simulation, the accuracy of the evaporation values derived from the energy budget method can be confirmed in comparison with the possible errors (Gianniou and Antonopoulos, 2007; Antonopoulos et al., 2016).

3.3. Water temperature and energy budget components of the reservoir

Fig. 4 shows the monthly variation of air (T_a) and lake surface (T_w) temperature for 2015-2016. Based on the results, the mean annual air and water surface temperature are equal to 14.22 and 11.93 °C (with a difference of 2.30 °C), respectively. According to Fig. 4, the monthly air temperature during the year except for November and December is higher than the monthly reservoir surface temperature. In these two months, the air temperature faster decreases than the reservoir surface temperature does (Fig. 4) due to the large water heat capacity (Gianniou and Antonopoulos, 2007). The difference between the air and the surface water temperatures shows an increasing trend during spring and summer and a decreasing trend in fall. The study conducted by Omar and El-Bakry (1981) on evaporation rate from Aswan Reservoir in Egypt also showed that the monthly air temperature throughout the year, except for fall, was higher than the monthly surface water temperature, which is in good agreement with the results of the present study. According to Hasani et al. (2008) on Al-Ghadir reservoir and Majidi et al. (2015) on Doosti reservoir, monthly air temperature is higher than water surface temperature in summer and vice versa during winter. The study carried out by Gianniou and Antonopoulos (2007) on Vegoritis Lake in Greece showed that the air temperature was higher than the surface water temperature during the spring and was lower in other seasons.

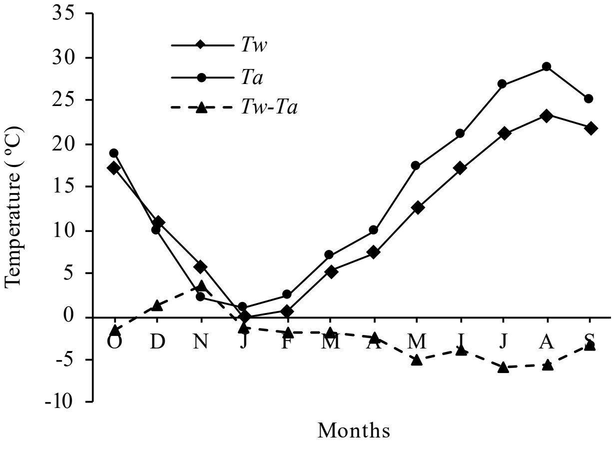

Fig. 4. The Mean monthly variation of air temperature (T_a) and lake surface temperature (T_w) for the Alavian Reservoir.

In Fig. 5a, the mean monthly values of the energy budget components during 2015-2016 are shown. Among the energy budget components, the incoming (Q_a-Q_{ar}) and the outgoing (Q_{bs}) long-wave radiations have the largest mean annual rates (Q_a-Q_{ar}=304.16-9.12=295.03 W m^{-2} and Q_{bs}=364.18 W m^{-2}). Accordingly, the mean energy loss is equal to 69.15 W m^{-2}. The energy source, i.e. the net short-wave solar radiation (Q_{ns}=Q_s-Q_{sr}), has a mean annual rate of . The short-wave radiation (Q_s) has a characteristic seasonal variation, so that the highest rates happen in the late spring to the mid-summer, and the lowest rates belong to the mid-fall to the early winter. The seasonal variations of the short-wave radiation (Q_{sr}=0.07× Q_s), the long-wave atmospheric radiation (Q_a), the reflected atmospheric radiation (Q_{ar}=0.03× Q_a) and the reversed radiation (Q_{bs}) are also similar to that of Q_s.

The changes of net radiation (Q_{rn}) are similar to the seasonal variation of its components (Fig. 5b). It has positive mean annual value since the net radiation is the energy source for all biological and physical activities of a lake ecosystem (Gianniou and Antonopoulos, 2007). As shown in Fig. 5b, the variation of Q_{rn}-Q_x(Q_x is the component of the alteration in the thermal content of the reservoir water) has a characteristic seasonal variation, so that its increasing trend begins in the late winter and reaches to the maximum value in the mid-summer, which is also the time of peak evaporation. During this time, the reservoir continuously receives and stores thermal energy through net radiation. Subsequently, the stored energy is released in the form of sensible heat and mostly latent heat in fall and winter, causing a gradual cooling of water at the depth of the reservoir. This energy budget in the reservoir leads to a positive thermal stratification in spring and summer to mid-fall and a negative thermal stratification in winter. The mean annual of Q_x in the Alavian reservoir for the studied year is equal to -12.39 W m^{-2}. Typically, the mean annual of the Q_x flux in a reservoir becomes equal to zero for a few years, and the energy stored in spring and early summer are released in the form of sensible heat and latent heat in the surrounding environment (Gianniou and Antonopoulos, 2007). Therefore, it is described as the phase lag between the occurrence time of the maximum net radiation and evaporation. The comparison between Fig.s 3b and 5b shows that the phase lag in the Alavian reservoir is one month. The results obtained by Gianniou and Antonopoulos (2007) on energy budget of Vegoritis Lake in Greece also presented a phase lag of one month.

3.4. Performance and ranking of the methods

Table 2 gives the statistical results of the examined methods in estimating the evaporation rate from the Ala-

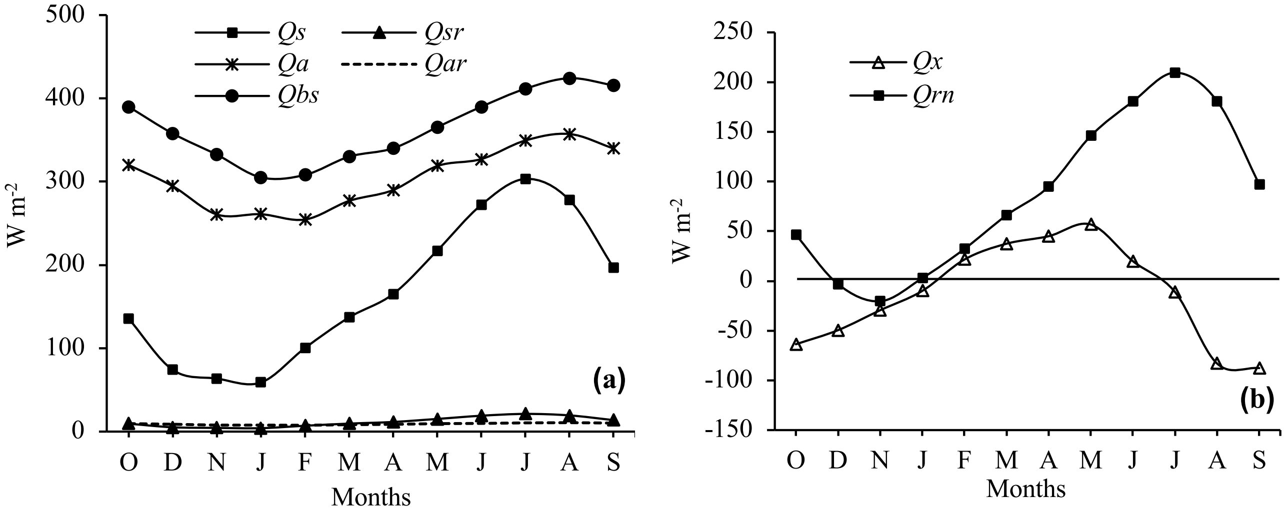

Fig. 5. The Mean monthly variation of the energy budget components for the Alavian Reservoir during the year 2015-2016.

vian reservoir during 2015-2016. In this table, the methods within each group and also between all groups were ranked on the basis of both the RMSE and the NS criteria. Also, the MBA criterion indicates the overestimate or underestimate of the methods.

In the combination group, there was no significant difference in the performances of the methods. However, the deBruin method yielded the best estimates with NS=0.95, RMSE=0.79 mm day^{-1} and a negligible positive bias (MBE=0.11 mm day^{-1}). The deBruin is a relatively cost-effective method in comparison with the other methods of this group, due to the necessity for measurement of T_a, e_a, and U, which makes it a good choice to use at the Alavian reservoir. Based on the MBE values, four of the five combination methods had a small overestimate (positive MBE). Rosenbery et al. (2004) and (2007) reported similar results regarding the overestimate of the methods of this group. The overestimations of evaporation were observed during fall and winter and smaller underestimations were observed during spring and summer (Fig. 6). In this group, the highest overestimate and underestimate belonged to the Penman approach with MBE=0.5 mm day^{-1} and the Brutsaert-Stricker approach with MBE=-0.2 mm day^{-1}, respectively.

In the Dalton group, the Rohwer method had the best performance with NS=0.96, RMSE=0.75 mm day^{-1} and a negligible bias (MBE=-0.30 mm day^{-1}). This method requires only the measurement of wind velocity, vapor pressure deficit and air pressure. Simplicity and superior performance of the Rohwer method can be the most important advantages of applying this method in the studied area. Also, the McMillan method with the second ranking had a reasonable performance (NS=0.93, RMSE=0.92 mm day^{-1}) as well as the Rohwer method. In this group, these two methods produced the most accurate evaporation values and could be considered as appropriate methods even by the limited observations of the input data. In contrast, the two methods of Biasin-Krumme with NS=-0.48, RMSE=4.14 mm day^{-1} and Bax with NS=-0.47, RMSE=4.12 mm day^{-1} had the worst performances in the estimation of evaporation. The Boelter, Leven and Hefner methods were preceded by the Biasin-Krumme and Bax methods. All the methods require only the measurement of vapor pressure deficit. It was noticed that in these methods, the mass transfer coefficient became more prominent than vapor pressure deficit and calibration of the coefficients gave better results. The Biasin-Krumme with MBE =-3.22 mm day^{-1} and the Tichomirof with MBE=0.77 mm day^{-1} had the highest underestimate and overestimate, respectively. In this group, all the methods except Rohwer, McMillan, Meyer, and Tichomirof had a negative bias (underestimates) that often occurred during all months (Fig. 6). As shown in this group, the monthly-scale methods are more accurate than the daily-scale ones. The better performance of monthly-scale approaches could be attributed to longer time periods due to the reduction of the uncertainty in the evaporation parameters (Majidi et al., 2015). However, different behaviors of Dalton approaches are related to having various coefficients and, due to a disparity in the estimates of the daily-scale Dalton methods, it can be said that the calibration of the mass transfer coefficients for the Alavian reservoir is necessary.

In the radiation-temperature group, the Jensen–Haise method had the best performance with NS=0.88 RMSE=1.17 mm day^{-1} and a negative bias (MBE=-0.86 mm day^{-1}). The Jensen–Haise method uses incoming

Tab. 2. The statistical results and ranking of the methods in calculating evaporation from the Alavian reservoir during 2015-2016.

Method	NS	RMSE (mm day^{-1})	MBE (mm day^{-1})	Rank in group	Overall rank
Combination group					
deBruin–Keijman	0.93	0.90	0.05	2	3
Brutsaert–Stricker	0.91	1.01	-0.20	5	7
Priestley–Taylor	0.93	0.92	0.22	4	6
Penman	0.93	0.91	0.50	3	4
deBruin	0.95	0.79	0.11	1	2
Dalton group					
Meyer	0.78	1.61	0.55	7	14
Marciano	0.20	3.03	-2.48	11	25
Shahtin	0.37	2.70	-2.19	10	23
Hefner	0.13	3.18	-2.60	12	26
Box	-0.47	4.12	-3.20	15	29
Leven	-0.26	3.81	3.03	13	27
Himus-Hinchley	0.81	1.48	-1.18	6	13
Boelter	-0.33	3.93	-3.10	14	28
Biasin-Krumme	-0.48	4.14	-3.22	16	30
Ryan–Harleman	0.71	1.84	-1.40	8	15
Tichomirof	0.87	1.23	0.77	3	10
Harbeck	0.83	1.38	-1.08	4	11
Shuttleworth	0.83	1.42	-1.12	5	12
McMillan	0.93	0.92	0.14	2	5
Rohwer	0.96	0.75	-0.30	1	1
Patel-Majmundar	0.56	2.26	-1.93	9	18
Solar radiation, temp. group					
Jensen–Haise	0.88	1.17	-0.86	1	8
Makkink	0.43	2.57	-1.70	2	20
Stephens–Stewart	0.36	2.71	-2.07	3	24
Temp., day length group					
Hamon	0.43	2.57	-2.02	2	21
Blaney–Criddle	0.87	1.20	-0.74	1	9
Temperature group					
Papadakis	0.69	1.90	-0.93	1	16
Thornthwaite	0.37	2.70	-2.09	4	22
Ivanov	0.65	2.01	1.72	2	17
U.S.B.R	0.49	2.42	-0.95	3	19

short-wave radiation (Q_s) as a substitution for the net radiation (Q_{rn}) and heat storage (Q_x) fluxes. It probably decreases the uncertainty of the fluxes, and therefore the Jensen–Haise method (with periodical time scale) could produce reliable results in comparison with the monthly methods of this group (Majidi et al., 2015). In this group, the evaporation values were underestimated during all months (except for January and February), indicating less amount of evaporation relative to the BREB values (Fig. 6). This underestimation has also been reported in the results of Majidi et al. (2015). The Stephens–Stewart method yielded evaporation rates with a considerable negative bias (MBE=-2.07 mm day^{-1}) which has a good agreement with the results of Rosenberry et al. (2007). The low accuracy of the Stephens-Stewart and the Makkink approaches in comparison with the Jensen–Haise approach is attributed to the coefficients used in the methods.

In the temperature-day length group, the Blaney–Criddle method had a better performance with NS=0.87, RMSE=1.20 mm day^{-1} and a negative bias (MBE=-0.74 mm day^{-1}). Both the Blaney–Criddle and the Hamon methods provided underestimated results (Fig. 6) which are in agreement with the results of Majidi et al. (2015) and Rosenberry et al. (2007). The Blaney–Criddle (temperature-day length) and the Jensen–Haise (radiation-temperature) methods showed almost similar performances. It can be said that day length is a good indicator of solar radiation, and due to the easy measurement of temperature and day length, the Blaney–Criddle is known as a practical and applicable method with acceptable performance.

In the temperature group, the Papadakis method with NS=0.69, RMSE=1.90 mm day^{-1} and MBE=-0.93 mm day^{-1} provided more reliable evaporation estimates than the others. The Papadakis method, followed by the Ivanof method, provided relatively well evaporation estimates. In this group, all methods except the Ivanof produced underestimated results. The underestimations were observed during spring and summer months (Fig. 6). Rosenberry et al. (2004) and Patel and Majmundar (2016) stated that some methods of temperature group (Papadakis and Thornthwaite methods) tend to underestimate evaporation rates.

In general, comparison of the best methods in the five groups showed that the Rohwer equation (Dalton group) with the minimum RMSE (0.71 mm day^{-1}) and the maximum NS (0.96) had the best performance in the estimation of evaporation from the Alavian reservoir. This method requires vapor pressure deficit, wind speed and air pressure. Considering its simplicity and good performance, the Rohwer method surprisingly performed well in comparison with the other methods, specially the combination groups. Patel and Majmundar (2016) analyzed the evaporation estimation methods in the Dharoi Reservoir during a 10-year study period (2001–2010). They concluded that the Rohwer method provided the best estimates compared to other empirical methods. A survey on the overall rank of the methods in the five groups showed that the combination equations had a better performance than the other groups and the Rohwer method followed by the deBruin, deBruin–Keijman and the Penman approaches (combination group), respectively. Numerous researchers such as Abtew (2001), Mosner and Aulenbach (2003), Winter et al.

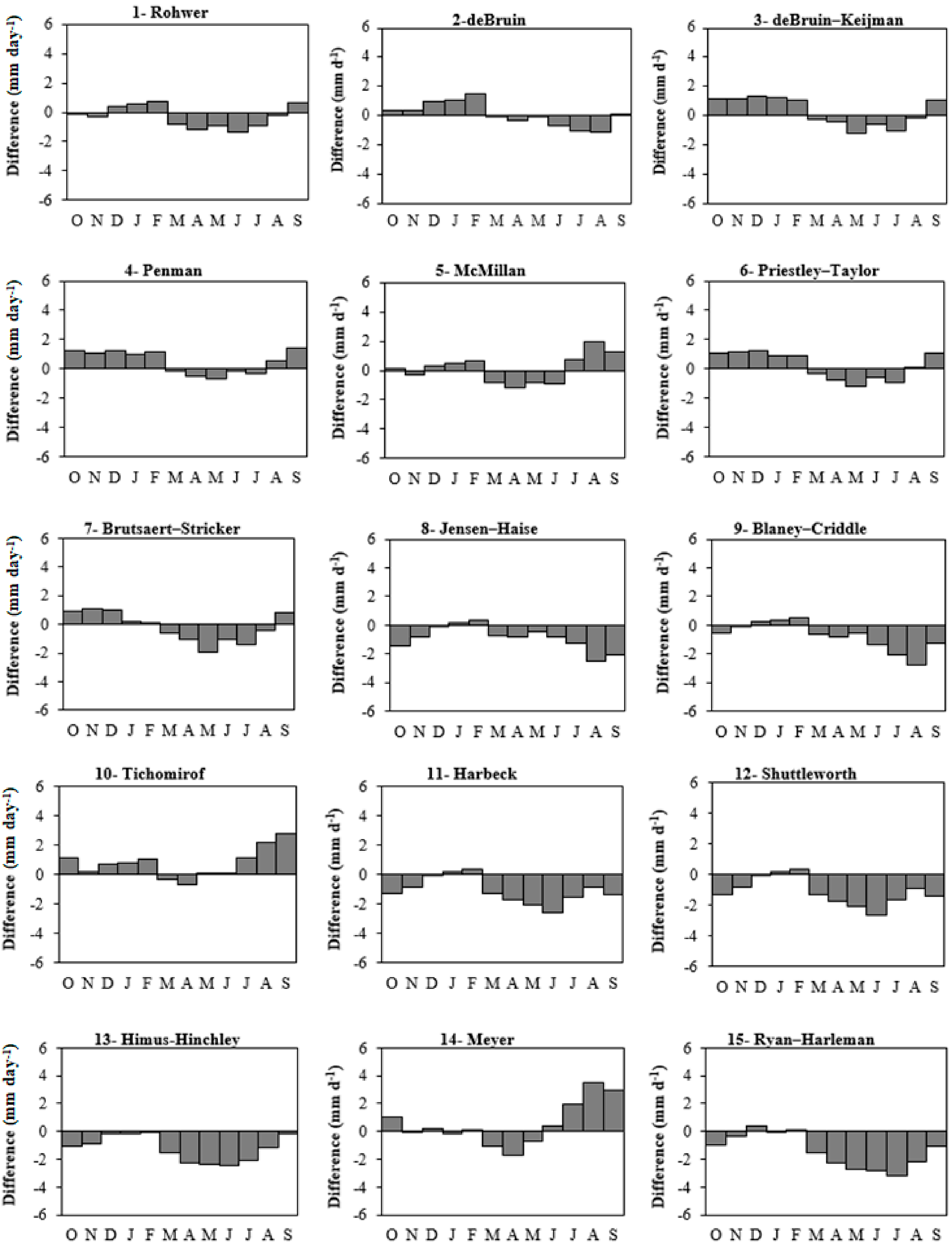

Fig. 6. Differences in calculated evaporations between 30 empirical approaches reported in Table 2 and BREB values, in mm day^{-1}.

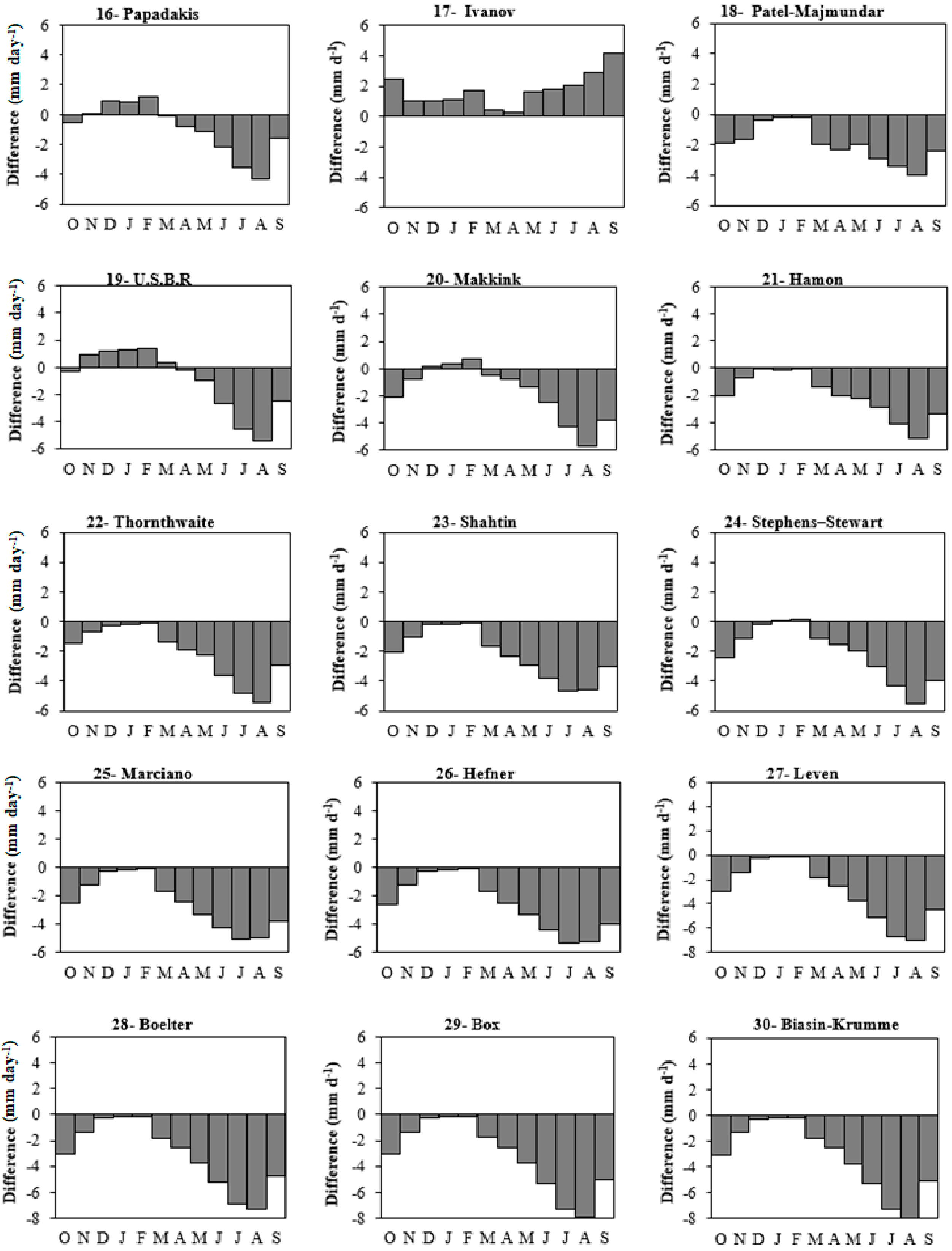

Fig. 6. (continued).

(2003), Rosenberry et al. (2007) Hasani et al. (2008), Yao (2009) and Majidi et al. (2015) have stated the superiority of the deBruin, the Penman and the deBruin–Keijman methods compared to other methods in the calculation of evaporation from a reservoir. The McMillan method, ranked 5th, requires the measurement of wind velocity, vapor pressure deficit and area of the water surface. The Jensen–Haise (radiation-temperature) and Blaney–Criddle (temperature-day length group) methods, ranked as 8th and 9th, had the highest ranks among the evaporation methods, next to the best methods of Dalton and combination groups. Considering the needed column of inputs or data and the efficacy of the examined approaches, it can be said that the Rohwer, the deBruin and the McMillan are the most appropriate methods in estimating the reservoir evaporation in the studied area. Also, among the examined methods, the Biasin-Krumme had the highest error (RMSE=4.41 mm day^{-1}) and the worst performance (NS=-0.48) in estimation of the evaporation. The Box, Boelter and Leven were preceded by the Biasin-Krumme method, respectively.

4. CONCLUSION

In this study, daily evaporation rates from Alavian dam reservoir in northwestern Iran were estimated from October 2015 to September 2016. The two-dimensional temperature stratification prediction model CE-QUAL-W2 was used to simulate the daily lake temperature profile. The simulation model was calibrated and validated using vertical profiles of water temperature data for the year 2013-2016. The thermal energy stored in the reservoir was then calculated by utilizing the distribution of water temperature. Finally, daily evaporation values were calculated by utilizing the BREB method, considering the two criteria suggested by Tanner et al. (1987) and Payero et al. (2003). The estimations by the BREB, as a reference method, were compared to those by 30 empirical methods. The examined methods were evaluated and ranked with respect to the RMSE and NS indices to obtain the best method(s) in the study area.

The results of the lake water temperature model indicated that the reservoir had a positive thermal stratification in spring and summer to mid-fall, and a negative thermal stratification in winter. Monthly air temperature during the year except for the two months of November and December was higher than the monthly reservoir surface temperature. The average value of the evaporation calculated by the energy budget approach for the studied year was equal to 4.08 mm d^{-1}. Performance evaluation of all the methods examined in this study highlighted the superiority and efficacy of the Rohwer and the deBruin–Keijman and the deBruin methods in the estimation of evaporation in a semi-arid area. Lack of meteorological data is a main consideration in calculating evaporation rate and selecting an evaporation estimation method. The Rohwer and the deBruin demand less data and require only vapor pressure deficit and wind speed. It is worth noting that these variables in the two methods have an important role in the process of evaporation. Under the limited data condition, the Rohwer and the deBruin methods can be used with acceptable performances. Also, the deBruin–Keijman and Penman methods (combination group) and McMillan (Dalton group) provided the next-best values. In contrast, the estimates obtained by the Biasin-Krumme, Box, Boelter and the Leven methods had the highest difference with the BREB values. In the Dalton group, the results revealed the necessity of calibration and adjustment of some evaporation estimation methods, especially the daily-scale methods. The MBE values showed that the Ivanof and Biasin-Krumme methods had the highest overestimation and underestimation, respectively.

ACKNOWLEDGMENTS

The authors are grateful for the supports and the partial fund provided by the University of Zanjan and for the data and collaborations provided by East Azerbaijan Regional Water Company.

REFERENCES

Abtew W., 2001. Evaporation estimation for Lake Okeechobee in South Florida. Journal of Irrigation and Drainage Engineering, 127: 140-147.

Allen R., Pereira L., Raes, D., Smith M., 1998. Crop evapotranspiration: guidelines for computing crop water requirements. FAO Irrigation and Drainage, Paper 56, FAO, Rome, Italy.

Anderson E.R., 1954. Energy-budget studies, water-loss investigations: Lake Hefner studies. Paper 269, US Geological Survey Professional.

Antonopoulos V.Z., Gianniou S.K., Antonopoulos A.V., 2016. Artificial neural networks and empirical equations to estimate daily evaporation: application to lake Vegoritis, Greece. Hydrological Sciences Journal, 61 (14): 1-27.

Bozorgi A., Bozorg-Haddad O., Sima S., Loáiciga H.A., 2018. Comparison of methods to calculate evaporation from reservoirs. International Journal of River Basin Management, 17: 1-42.

Brutsaert W., Stricker H., 1979. An advection–aridity approach to estimate actual regional evapotranspiration. Water Resource Research, 15 (2): 44-450.

Brutsaert W., 1982. Evaporation into the atmosphere: Theory, history, and applications. Boston: Kluwer.

Buchak E.M., Edinger J.E., 1984. Longitudinal–vertical Hydrodynamics and Transport: Development, Programming and Applications, Document 84-18-R, Prepared for the U.S. army corps of engineers waterways experiment station, Vicksburg.

Buccola N.L., Stonewall A.J., 2016. Development of a CE-QUAL-W2 temperature model for Crystal Springs Lake, Portland, Oregon. Open-File Report 2016–1076, U.S. Geological Survey.

De Bruin H.A.R., 1978. A simple model for shallow lake evaporation. Journal of Applied Meteorology, 17: 1132-134.

De Bruin H.A.R., Keijman J.Q., 1979. The Priestley–Taylor evaporation model applied to a large shallow lake in the Netherlands. Journal of Applied Meteorology, 18: 898-903.

dos Reis R., Dias N., 1998. Multi-season lake evaporation: energy budget estimates and CRLE model assessment with limited meteorological observations. Journal of Hydrology, 208; 135-147.

Duan Z., Bastiaanssen W.G.M., 2015. A new empirical procedure for estimating intra-annual heat storage changes in lakes and reservoirs: Review and analysis of 22 lakes. Remote Sensing of Environment, 156; 143-156.

Filimonova M., Trubetskova M., 2005. Calculation of evaporation from the Caspian Sea surface. In: Proceedings of the International Symposium on Stochastic Hydraulics, Nijmegen, The Netherlands.

Gianniou S.K., Antonopoulos V.Z., 2007. Evaporation and energy budget in Lake Vegoritis, Greece. Journal of Hydrology, 351 (3): 212-223.

Gorjizade A., Akhond-Ali A.M., Zarei H., Seyyed Kaboli H., 2014. Evaluation of Eight Evaporation Estimation Methods in a Semi-Arid Region (Dez reservoir, Iran). International journal of Advanced Biological and Biomedical Research, 2 (5): 1823-1836.

Harbeck G.E.J., Kohler M.A., Koberg G.E., 1958. Water-loss investigations: Lake Mead studies. Professional Paper 298, US Geological Survey.

Hajian R., Lotfollahi-Yaghin M.A., 2015. Modeling the amount of free water surface evaporation from Mahabad Dam's lake using artificial neural networks and comparing the model with experimental equations. Journal of Renewable Natural Resources Bhutan, 3 (5): 196-210.

Hamon W.R., 1961. Estimating potential evapotranspiration. J. Hyd. Div., 87: 107-120.

Hassani A., Tajrishi M., Abrishamchi A., 2008. Comparison of Several Evaporation Models Applied to Reservoir of the Saveh Dam, Iran. In: The 3rd International Conference on Water Resources and Arid Environments and the 1st Arab Water Forum, Riyadh, Saudi Arabia.

Hussain M.M.A., 2017. Evaporation and Evaluation of Seven Estimation Methods: Results from Brullus Lake, North of Nile Delta, Egypt. Atmospheric and Oceanic Sciences, 2 (3): 66-74.

Kim Y., Kim B., 2006. Application of a 2-Dimensional Water Quality Model (CE-QUAL-W2) to the Turbidity Interflow in a Deep Reservoir (Lake Soyang, Korea). Lake and Reservoir Management, 22 (3): 213-222.

Koberg G.E., 1964. Methods to compute long-wave radiation from the atmosphere and reflected solar radiation from a water surface. Professional Paper 272-F, US Geological Survey.

Lenters J., Kratz T., Bowser C., 2005. Effects of climate variability on lake evaporation: results from a long-term energy budget study of Sparkling Lake, northern Wisconsin (USA). Journal of Hydrology, 308: 168-195.

Majidi M., Alizadeh A., Farid A., Vazifedoust M., 2015. Estimating Evaporation from Lakes and Reservoirs under Limited Data Condition in a Semi-Arid Region. Water Resource Management, 29: 3711-3733.

Marciano J.J., Harbeck G.E., 1954. Mass-transfer studies. In: USGS (Editor), Water-Loss errors in daily and monthly input data. Hydrological Processes, 11 (11); 1465-1473.

Mather J.R., 1978. The Climatic Water Budget in Environmental Analysis. Lexington: Lexington Books.

McGuinness J.L., Bordne E.F., 1972. A comparison of lysimeter-derived potential evapotranspiration with computed values. Technical Bulletin 1452, US Department of Agriculture Agricultural Research Service, Washington, DC, USA.

Mosner M.S., Aulenbach B.T., 2003. Comparison of methods used to estimate lake evaporation for a waterbudget of Lake Semnole, southwestern Georgia and northwestern Florida. In: Proceedings of the 2003 Georgia Water Resources Conference, Athens, Georgia, USA.

Nash J.E., Sutcliffe J.V., 1970. River flow forecasting through conceptual models, part I–a discussion of principles. Journal of Hydrology, 10: 282-290.

Norton E.G., Bradford A., 2009. Comparison of two stream temperature models and evaluation of potential management alternatives for the Speed River, Southern Ontario. Journal of Environmental Management, 90; 866-878.

Omar M.H., El-Bakry M.M., 1981. Estimation of Evaporation from The Lake of the Aswan High Dam (Lake Nasser) Based On Measurements Over the Lake. Agricultural Meteorology, 23: 293-308.

Patel J.A., Majmundar B.P., 2016. Development of evaporation estimation methods for a reservoir in Gujarat, India American Water Works Association, 108 (9); 489-500.

Payero J., Neale C., Wright J., Allen R., 2003. Guidelines for validating Bowen ratio data. Transactions of the ASAE, 46 (4): 1051-1060.

Rasmussen A.H., Hondzo M., Stefan H.G., 1995. A test of several evaporation equations for water temperature simulations in lakes. Water Resources Bulletin, 31 (6): 1023-1028.

Rosenberry D.O., Stannard D.I., Winter T.C., Martinez M.L., 2004. Comparison of 13 equations for determining evapotranspiration from a prairie wetland, Cottonwood Lake area, North Dakota, USA. Wetlands, 24 (3): 483-497.

Rosenberry D.O., Winter T.C., Buso D.C., Likens G.E., 2007. Comparison of 15 evaporation methods applied to a small mountain lake in the northeastern USA Journal of Hydrology, 340, 149-166.

Sacks L., Lee T., Radell M., 1994. Comparison of energy budget evaporation losses from two morphometrically different Florida seepage lakes. Journal of Hydrology, 156: 311-334.

Shah M.M., 2012. Calculation of evaporation from indoor swimming pools: further development of formulas. ASHRAE Transactions, 118 (2): 460-66.

Shuttleworth W.J., 1993. Evaporation. In: Maidment DR (ed) Handbook of hydrology. New York: McGraw-Hill.

Stauffer R., 1991. Testing lake energy budget models under varying atmospheric stability conditions. Journal of Hydrology, 128: 115-135.

Stewart R.B., Rouse W.R., 1976. A simple method for determining the evaporation from shallow lakes and ponds. Water Resources Research, 12 (4): 623-628.

Sweers H.E., 1976. Anomogram to estimate the heat–exchange coefficient at the air–water interface as a function of wind speed and temperature; a critical survey of some literature. Journal of Hydrology, 30: 375-401.

Tanner B., Greene J., Bingham G., 1987. A Bowen ratio design for long term measurements. In: Proceedings of the International Winter Meeting of the ASAE, Hyatt Regency, Chicago, USA.

Torres E.A., Calera A., 2010. Bare soil evaporation under high evaporation demand: a proposed modification to the FAO–56 model. Hydrological Sciences Journal, 55 (3): 303-315.

Winter T.C., Buso D.C., Rosenberry D.O., Likens G.E., Sturrock A.M.J., Mau D.P., 2003. Evaporation determined by the energy budget method for Mirror Lake, New Hampshire. Limnology and Oceanography, 48 (3): 995-1009.

Yao H., 2009. Long-Term Study of Lake Evaporation and Evaluation of Seven Estimation Methods: Results from Dickie Lake, South-Central Ontario, Canada. Journal of Water Resource and Protection, 2: 59-77.

Zarghami M., Abdi A., Babaeian I., Hassanzadeh Y., Kanani R. 2011. Impacts of climate change on runoffs in East Azerbaijan, Iran. Global and Planetary Change, 78: 137-146.