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Estimating Evaporation from Dam-Reservoirs in Arid and Semi Arid Regions Case of Algeria

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Key words: Water resources, evaporation, dam-reservoir, arid region, semi-arid region, Algeria

Abstract: Evaporation is the main process of the water cycle and it's considered as major problem reducing the water reserves over the world, especially in arid countries. The most important climatic factors affecting the evaporation process are temperature, wind speed, humidity, solar radiation and atmospheric pressure. Several researchers have studied the evaporation and have given models or approaches to estimate the evaporation rate based on available meteorological data. These models are divided to five categories: water budget, energy budget, mass transfer, combination methods and evaporation pans. We mention that, the measurement of evaporation by using pans over the water bodies still a classical method generating measurement errors. The objective of our research is to elaborate empirical model to estimate evaporation from dam-reservoirs located in semi-arid and arid regions, for that five dam-reservoirs have been chosen: Foum El-Gherza dam, Gazelles Fountain dam, Foum El-Guiess dam, Djorf-Torba dam and Brezina dam. We mention that the empirical developed model is the result of a combination of two models proposed by Blaney-Criddle and Priestley-Taylor (modified). The obtained results by the proposed model show very good performances for the five dam-reservoirs: correlation coefficient is >0.84, the ratio of the rank sum (RSR) is ≤0.54 and the Nash-Sutcliffe criterion (NSE) is ≥0.83. Moreover, the proposed model is compared by measurement evaporation and the following models: Priestley and Taylor, Boutoutaou, Ivanov, DeBruin, Hamon, Blaney-Criddle, Ryan-Harleman and Xiao.

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INTRODUCTION

In many semiarid countries in the world, supplying drinking water and food production is dependent on water storage in reservoirs[1]. The major problem that infects water resources is the evaporation of water bodies due to climate change. The highest temperatures recorded, especially in the summer period led to the desertification of large areas that have been in the past rich in water.

The majority of researchers have defined evaporation as a hydrological phenomenon proceeds more quickly at higher temperatures. It's a primary process of water and heat loss for most of lakes and therefore, a main component in both its energy and water budgets. The accurate estimates of lake evaporation are necessary for water and energy budget studies, lake level forecasts, water quality surveys, water management and planning of hydraulic constructions[2].

Other researchers proposed that evaporation should be considered in the design of various water resources and irrigation systems[3] and can represent a significant part of the water budget for a lake or reservoir and may contribute significantly to the lowering of water surface elevation[4].

An accurate quantification of evaporation is important for water resources management, lake water balance studies and prediction of the hydrological cycles in response to climate change [5-7]. Also, it's necessary for hydrological research on groundwater modeling and large-scale hydrological cycle simulation and helps us gain a better understanding of hydrological responses to climate change in extreme weather conditions[9, 18].

The evaporation plays a key role in water resources management in arid and semi arid climatic regions[10]. In these regions, it implies a complete loss of water resources at the of basin scale. For both scientific and social reasons, a reliable estimate of loss due to evaporation is thus needed for improved management of water resources[11, 12].

The evaporation conditions have been studied for one and a half centuries there are still no sufficiently reliable methods for the measurement evaporation in any geographical environment[13]. The most common and important factors affecting evaporation are solar radiation, daylight, air and water temperature, relative humidity, atmospheric pressure, wind speed, quality of water and surface of the water body. In summary, it has been agreed that solar radiation, wind speed, relative humidity and air temperature have attained special consideration as the most influencing factors by most researchers[13]. Therefore, estimating evaporation from lakes and reservoirs is not a simple task as there are a number of factors affecting the evaporation rate, notably the climate and physiography of the water body and its surroundings[14]. True estimate of evaporation is difficult in various regions[15]. Evaporation from water is most commonly computed indirectly by one or more techniques. These include pan coefficients measured pan evaporation, water balance, energy balance, mass transfer and combination techniques[16].

Although, there are numerous empirical formulas and approaches, availability of climatic data limits their application across all locations[17]. We mention that in situ measurement and model estimation are two main approaches for quantifying open water evaporation[18].

MATERIALS AND METHODS

In terms of quantity of hydro-technical infrastructure Algeria has counted 57 large dams in 2009 with a total capacity of 6.8 Gm^3. However, the quantity of potential freshwater is reduced by siltation of dams, surface evaporation and water leakage from foundations. In 2016, there were 74 dams with a total capacity of 8 billion m^3 and an annual capacity of more than 50 million m^3 is evaporated. It was the raison we decided to study the evaporation in dams located in arid and semi arid area.

The five dam-reservoirs chosen for our research are: Foum El-Gherza, Fountain of Gazelles, Foum- El-Guiess, Djorf-Torba and Brezina which are located in semi-arid and arid regions (Fig. 1).

The Djorf-Torba reservoir-dam is located between North longitude 31°30' 38" and West latitude 2°46'16" from Bechar city. It's used for the purposes of irrigation and water supply. The capacity of water is estimated 350 million m^3. The Brezina dam-reservoir is located 80 km South from El-Bayadh city between North longitude 33°9'48" and Est latitude 1°16'12,5". It's intended for irrigation of the palm trees; its reservoir capacity is estimated 122 million m^3. The third dam-reservoir called Foum El-Gherza is located between North longitude 34°51'50" and Est latitude 5°55'30" from Biskra city, it's used for irrigation with a capacity of 47 million m^3. The forth dam-reservoir is called Fontaine des Gazelles, it's located between North longitude 35°7'20" and Est latitude 5°35'0" from Biskra city. The purpose of this dam-reservoir is irrigation; its capacity is estimated 55 million m^3. The fifth dam-reservoir is Foum El-Guiess, it's located between North longitude 35°9'48" and Est latitude 7°1 12" from Khanchela city, it's used for irrigation too

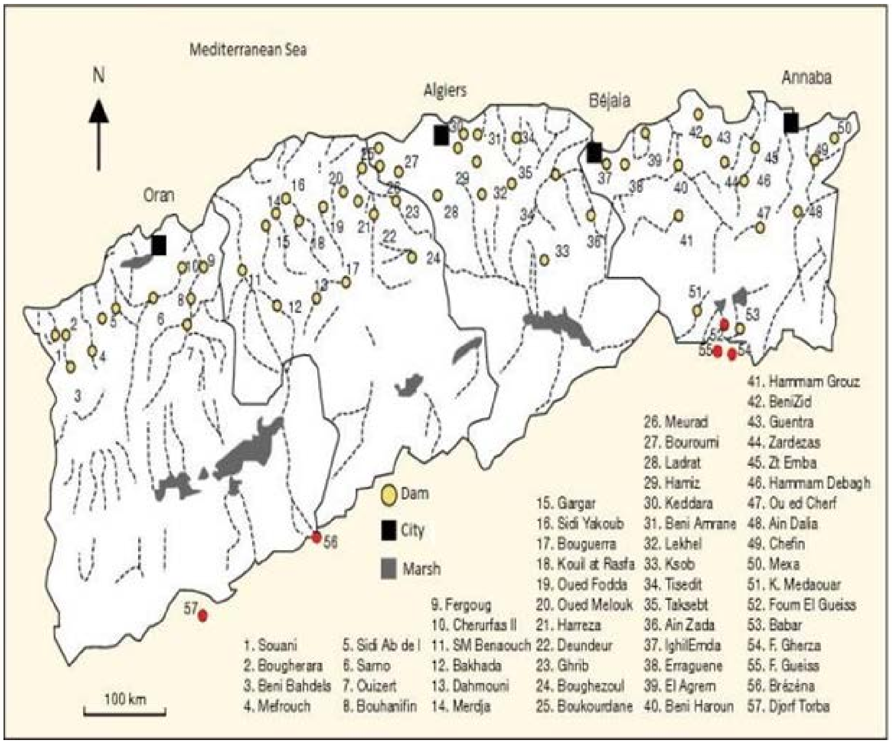

Fig. 1: Distribution of exploited dam-reservoirs in Northern Algeria

Fig. 2(a-d): Existing evaporation pans in the studied dams, (a) Weather station of Foum El-Gherza dam, (b) Weather station of Fontaine des Gazelles dam, (c) Colorado pan-Foum El-Guiess dam and (d) Class-A-pan-Fontaine des Gazelles dam and its capacity is estimated 03 million m^3. The evaporation measurements are carried out by two types of evaporation pans: Colorado pan or class "A" pan (Fig. 2c) and (d). The Colorado pan is much more used in dams. It's a pan of a square cavity of dimension 0.92×0.92×0.50 m, almost totally buried in the ground [19].

The evaporation pans are also based on the law of the water balance with the total absence of underground flows and losses due to infiltration which are very difficult to estimate. The monthly evaporation data series were recorded by the national agency of dams and transfers for each studied dam.

The needed climatic data to estimate the monthly evaporation for each dam are: E: Evaporation (mm); T_{air}: air temperature (°C); V: Wind speed at 2 m (m/sec); D: Daylight (hour); H_r: relative humidity (%); P: at mospheric pressure (kPa); I: Insolation ($kWhm^{-2}$/day).

We notice that, the insolation and the daylight data are not available on weather reports, so, these two unavailable parameters were obtained from NASA Website while respecting the geographic coordinates of each dam. We opted for a series of available climatological data from 2000-2016.

The methods for estimating evaporation rates require various climatological and physical parameters. Some of the data are measured directly by weather instruments. Other parameters are related to commonly measuring data and can be derived with the help of empirical relationship[20]. There are a large number of methods available for estimating evaporation from free water surfaces. Therefore, there is no unique method for measuring and modeling water evaporation[21].

Several methods are currently used to estimate evaporation as[22-28] and others. The empirical models proposed and applied in the Algerian water bodies were proposed by Fekih *et al*.[19] which led to good results.

The main disadvantage for most of these methods is that they require several meteorological data such as air temperature, wind speed, humidity and solar radiation to be measured or estimated at the dam[19].

Priestley and Taylor[23] proposed a simplified version of Penman's combination equation for use when surface areas are generally, wet which is a condition for evaporation. When the aerodynamic component is deleted and the energy component is multiplied by a coefficient (β = 1.26) with either wet or under humid conditions in the surrounding area and for large bodies of water. Therefore, it is possible to write the Priestley-Taylor equation as follow (Benzaghta, 2014):

$$E = \beta\left[\frac{\Delta}{\Delta+\gamma}+\frac{Rn}{\lambda}\right] \quad (1)$$

Where:
E = The open water-evaporation (mm/day)
β = The Priestley-Taylor coefficient
Δ = The slope of the saturated vapor pressure-temperature curve (kPa/°C)
γ = The psychometric coefficient (kPa/°C)
λ = The latent heat of vaporization (MJ/kg)
R_n = Net radiation (MJm^{-2}/day)

Boutoutaou proposed a simple model for estimating evaporation from dam-reservoirs situated in arid and semi-arid regions (Algeria). The model requires three available climatic data which are: air temperature, relative humidity and wind speed. For humid and sub-humid regions:

$$E = 0.342\ n\ D^{0.80}\ (1+0.39\ V_2) \quad (2)$$

For arid and semi-arid regions:

$$E = 0.403\ n\ D^{0.73}\ (1+0.39\ V_2) \quad (3)$$

Where:
E = The open water-evaporation (mm)
n = No. of days of the month (n = 30 or 31 depending on the month and for the daily calculation n = 1)
V = Wind speed at 2 m (m/sec)

$V_2 = 0.78\ V_{10}$. V_{10}-speed measured at 10 m from the ground. In Algeria, at all weather stations, the wind speed is measured at a level of 10 m from the ground. D is air saturation deficit (mb), it's given by the following formula:

$$D = 0.0632\ (100-R_h)\ e^{0.0632\ (Ta)} \quad (4)$$

Where:
R_h = The relative humidity (%)
T_a = Air temperature (°C)

The equation derived by Ivanov[27] estimates the evaporation (mm/month) based on the mean monthly temperature T_a(°C) and relative humidity R_h(%):

$$E = 0.0018\ (25+T_a)^2 (100-R_h) \quad (5)$$

The relative humidity is the ratio of the absolute humidity to the saturation humidity for the air temperature. The saturation humidity is directly proportional to the air temperature and the evaporation ceases when the air relative humidity approaches to 100%. The equation derived by De Bruin[30] is written as follows[31]:

$$E = 1.192\left(\frac{\propto}{\propto -1}\right)\left(\frac{\gamma}{\Delta+\gamma}\right)\frac{(2.9+2.1V)(e_s - e_a)}{\lambda\rho}\times 86.4 \quad (6)$$

Where:

E = Lake evaporation multiplier to 86.4 to convert to mm/day
$\propto = 1.26$ = Priestley-Taylor empirically derived constant, dimensionless
Δ = The slope of the saturated vapor pressure-temperature curve (Pa/°C)
γ = The psychometric coefficient (depends on temps and atmospheric pressure) (Pa/°C)
λ = The latent heat of vaporization ((MJ/kg)
ρ = Density of water (998 kgm^{-3} at 20°C)
V = Wind speed at 2 m above the surface (m/sec)
e_s = Satured vapor at water surface temperature (mb)
e_a = Ambient vapor pressure of the air at dew point temperature (mb)

The new model proposed by Liu *et al*.[18] applied in a hyper-arid environment can estimate daily evaporation with moderate accuracy, expressed as:

$$E = (0.0345+0.002V^{0.5})(42.6824-0.0122R_h^{1.5})(2.66+0.08T_a) \quad (7)$$

Where:

E = The open water-evaporation (mm/day)
V = Wind speed at 2 m (m/sec)
R_h = The relative humidity (%)
T_a = Air temperature (°C)

Blaney[22] described his method as a rapid mean of transferring the results of evapo-transpiration measurements to other areas with similar climate. Briefly, he correlated monthly measured evaporation data with monthly mean temperature times the percentage of day time hours during the year in order to develop a monthly empirical evaporation coefficient. The Blaney-Criddle formula is written as[31, 14]:

$$E = (0.0173\,T_a - 0.314)\,T_a\left(\frac{D}{DTA}\right)\times 25.4 \quad (8)$$

Where:

E = The open water-evaporation (mm/day)
D = Hours of daylight
DTA = Total annual hours of daylight for a specific latitude
T_a = Air temperature (°C)

Hamon[32] formulated a simplified expression based on the relation between potential evapo-transpiration, maximum possible incoming radiant energy and the moisture-holding capacity of the air at the prevailing air temperature. It is often used to estimate lake evaporation or watershed potential evaporation because of its simplicity[33]. The expression is represented by the equation [14]:

$$E = 0.63D\times 10^{\frac{7.5+T_a}{T_a+273}} \quad (9)$$

Where:

E = The open water-evaporation (mm/day)
D = Hours of daylight
T_a = Air temperature (°C)

Ryan and Harleman[34] developed an equation based on Dalton theory to estimate evaporation from heated water bodies[35]. In that case, both forced (wind driven) convection and free (buoyancy driven) convection effectively control evaporation rates while the forced convection is the dominant factor for natural water bodies[14]:

$$E = \lambda^{-1}[2, 7(T_w - T_a)^{1/3} + 3.1\,V)]\,(e_s - e_a) \quad (10)$$

Where:

E = The open water-evaporation (mm/day)
λ = The latent heat of vaporization (MJ/kg)
V = Wind speed (m/sec)
T_w = Water temperature (°C)
T_a = Air temperature (°C)
e_a = The actual vapor pressure (kPa)
e_s = Saturation vapor pressure (kPa)

Let's mention that the analysis of the climatic data of the five dams permitted us to detect the parameters having a significant influence on the evaporation namely: the air temperature, the atmospheric pressure, relative humidity, daylight, wind speed and insolation. The correlation between the measured evaporation and the meteorological data is illustrates in Fig. 3.

The correlation analysis is the most widely method in visualizing relationship between variables of our research data. Figure 3 illustrates positive correlation of $R^2>0.7$ for the variables D, I DTA and evaporation. While the correlation between Δ, T_a, λ and evaporation is strong ($R^2>0.8$).

So, the new model will be based on the four variables D, Δ, T_a, λ and I. The coefficient of determination $R^2>0.78$. This value is generally, considered as a strong linear relationship and statistically significant. It indicates that an increase in D, Δ, T_a, λ and I (insolation) would correspond to an increase in evaporation.

Proposed model: The purpose of the proposed model is to estimate evaporation in arid and semi-arid region

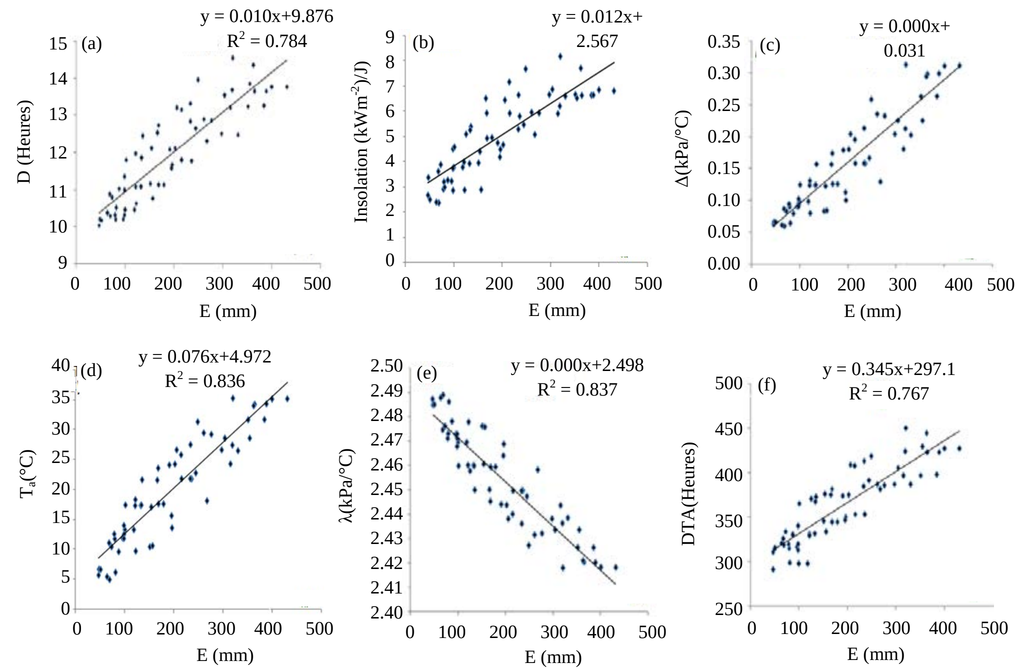

Fig. 3(a-f): Correlation between evaporation and the variables (D, I, Δ, T_a, λ and DTA), (a) Correlation between evaporation and daylight, (b) Correlation between evaporation and insolation (c) Correlation between evaporation and slope of the saturated vapor pressure, (d) Correlation between evaporation and air temperature, (e) Correlation between evaporation and latent heat of vaporization and (f) Correlation between evaporation and the total annual daylight

located in Algeria. It's a result of the combination of two methods: Blaney-Criddle and Priestley-Taylor. After modification, the final formula is expressed as:

$$E = 27.91+T_a\ [0.47\ T_a\ 8.18\left(\frac{DTA}{\sum DTA}\right)+ \left[0.072\left(\frac{\Delta}{\Delta+\gamma}\right)\left(\frac{I}{\lambda}\right)\right] \quad (11)$$

Where:

- E = Open water-evaporation (mm/month),
- I = The monthly averaged insolation (kWm^{-2}/J) (Eq. 12), (MJm^{-2}/J) (Eq. 11))
- T_a = Air temperature (°F) (Eq. 11)
- D = The daylight (hours)
- Δ = The slope of the saturated vapor pressure-temperature curve (kPa/°C)
- DTA = The total hours of monthly daylight
- $\Sigma_1^{12}DTA$ = The total hours of annual daylight (hours)
- λ = The latent heat of vaporization ((MJ/kg)
- γ = The psychometric coefficient (kPa/°C)

$$I = 0.7V+1.06D-10.25 \quad (12)$$

$$DTA = D\times N \quad (13)$$

$$D = 0.15T_a\text{-}0.154P_{atm}+23.1 \quad (14)$$

$$\Delta = \frac{4098es}{(237.3+T_a)^2} \quad (15)$$

$$\lambda = 2.501\text{-}T_a{*}2.361{*}10^{-3} \quad (16)$$

$$\gamma = 0.0016286\frac{P}{\lambda} \quad (17)$$

$$es = 0.6108Exp\frac{(17.27{*}T_a)}{(T_a{*}237.3)} \quad (18)$$

Where:

- I = The monthly averaged insolation ($kWhm^{-2}/day$)
- D = Monthly daylight (hours)
- N = Number of the day for each month
- V = Wind speed at a height of 2 m (m/sec)
- T_a = The air temperature (°C) (Eq. 15, 16 and 18)
- P_{atm} = Atmospheric pressure (kPa)
- es = Saturation vapor pressure (kPa)

To evaluate the proposed model introduced above for estimating evaporation from the five dam-reservoirs. We adopted Nash-Sutcliffe criterion (NSE), the Root Mean

Square Error (RMSE), the Mean Bias Error (MBE), the coefficient of determination (R^2) and the Rank Sum Ratio (RSR), calculated as follows:

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n} \left(E_i^{Measured} - E_i^{Model} \right)^2}{\sum_{i=1}^{n} \left(E_i^{Measured} - E_{Mean}^{Measured} \right)^2} \right] \quad (19)$$

NSE values between 0.0 and 1.0 are generally, viewed as acceptable levels of performance whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value which indicates unacceptable performance[36].

The Root Mean Square Error (RMSE) is one of the commonly used error index statistics[37, 39, 38]. Although, it's commonly accepted that the lower the RMSE the better the model performance[36].

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} \left(E_i^{Measured} - E_i^{Model} \right)^2}{N}} \quad (20)$$

Another statistical index called the Mean Bias Errors (MBE) is calculated as flows:

$$MBE = \frac{1}{N} \sum_{i=1}^{n} \left(E_i^{Measured} - E_i^{Model} \right) \quad (21)$$

Whereas, the coefficient of determination (R^2) values was calculated as:

$$R^2 = \frac{\sum_{i=1}^{n} \left(E_i^{Measured} - E_{Mean}^{Measured} \right) \left(E_i^{Model} - E_{Mean}^{Model} \right)}{\sum_{i=1}^{n} \left(E_i^{Measured} - E_{Mean}^{Measured} \right)^2 \sum_{i=1}^{n} \left(E_i^{Model} - E_{Mean}^{Model} \right)^2} \quad (22)$$

The Rank Sum Ratio (RSR) was calculated as:

$$PSR = \sqrt{\frac{\sum_{i=1}^{n} \left(E_i^{Measured} - E_i^{Model} \right)^2}{\sum_{i=1}^{n} \left(E_i^{Measured} - E_{Mean}^{Measured} \right)^2}} \quad (23)$$

RSR varies from the optimal value of 0 which indicates zero RMSE or residual variation and therefore, perfect model simulation, to a large positive value. The lower Rank Sum Ratio (RSR), the lower the RMSE and the better the model simulation performance. The model performance can be evaluated as "very good" if NSE>0.75 and RSR<0.50[36].

RESULTS AND DISCUSSION

The water evaporation values calculated by the model (Eq. 11) were compared with observed evaporation and calculated evaporation by eight models proposed by other researchers cited in this study (Table 1). From Table 2, the numerical results obtained by the proposed model and the eight selected models showed the following results: The best estimates of evaporation from Foum El-Gherza dam-reservoir are given by the proposed model, Ryan-Harleman, Boutoutaou and Ivanov Models. The Nash-Sutcliffe (NSE) criterion varies from 0.79-0.92 and the Rank Sum Ratio (RSR) varies from 0.27-0.46 (RSR<0.5). These numerical results indicate that the performances of these models are very good. But we mention that the best estimates were obtained by the proposed model with NSE = 0.92≤1, RSR = 0.27<0.5 with minimal RMSE and an excellent correlation (R^2 = 0.95).

The evaporation estimates result of dam-reservoir of Fontaine des Gazelles have very strong correlation obtained by the proposed model, Boutoutaou, Ivanov and Ryan-Harleman Models R^2 = 0.91. The Nash-Sutcliffe criterion (NSE) ranges from 0.81-0.95 and the Rank Sum Ratio (RSR) varies from 0.22-0.44 (RSR<0.5). These results confirm good performances for these models.

The evaporation estimates results of the Brezina dam-reservoir have very good correlation (R^2 = 0.90) obtained by the proposed model, the models of Ivanov, Boutoutaou, DeBruin, Xiao *et al*.[30] Priestley-Taylor, Blaney-Criddle and Ryan-Harleman. The Nash-Sutcliffe (NSE) criterion varies from 0.97-1 and the Rank Sum Ratio (RSR) ranges from 0.06-0.17 (RSR<0.5) which means that the performances of these models are perfect.

In case of the Foum El-Guiess dam-reservoir, the evaporation estimates have very good correlation obtained by Blaney-Cridlle, Ryan-Harleman Models and the proposed model (R^2 = 0.97).

The Nash-Sutcliffe criterion (NSE) ranges from 0.71- 0.96 and the Rank Sum Ratio (RSR) varies from 0.18-0.54. The performances of these models can be considered as good.

The evaporation estimates result of Djorf-Torba dam-reservoir show good correlation by the proposed model and the Xiao's Model (R^2 = 0.8). The Nash-Sutcliffe criterion (NSE) varies from 0.81- 0.86≤1 and the Rank Sum Ratio (RSR) ranges from 0.38-0.43 (RSR<0.5). Both models give very good performances. Figure 4 illustrates the comparison of the evaporation observed and estimated by the different models: Priestley-Taylor, Boutoutaou, Ivanov, DeBruin, Xiao Liu Blaney-Criddle, Hamon, Ryan-Harleman and the proposed model. We notice clearly that Hamon Model gives insatisfactory results from others models and measured evaporation.

Table 2 presents the comparison between the values of the annual evaporation estimates calculated by the proposed model (Eq. 11), the other models and the measured evaporation for the five dam-reservoirs. It shows that:

Table 1: Estimation of annual evaporation estimated by the models

Models	Priestley-Taylor		Boutoutaou	Proposed model	Ivanov
Dams	$E_{measured}$ (mm)	$E_{estimated}$ (mm)	$E_{estimated}$ (mm)	$E_{estimated}$ (mm)	$E_{estimated}$ (mm)
Foum El-Gherza	2631.05	3167.79	3171.42	3171.42	3171.42
		E(%) = 30	E(%) = -20	E(%) = 6	E(%) = -21
Fontaine des Gazelles	2875.62	3137.39	3161.19	3161.19	3161.19
		E(%) = 36	E(%) = -9	E(%) = 14	E(%) = -10
Brezina	2295.10	1826.77	2212.49	2212.49	2212.49
		E(%) = 29	E(%) = 20	E(%) = 25	E(%) = 4
Foum El-Guiess	1351.75	1782.27	1785.44	1785.44	1785.44
		E(%) = -25	E(%) = -31	E(%) = -27	E(%) = -32
Djorf-Torba	2569.13	3382.62	3449.97	3449.97	3449.97
		E(%) = 33	E(%) = -32	E(%) = 7	E(%) = -34

Models	Liu *et al*.[16]	Debruin	Blaney-Criddle	Hamon	Ryan-Harleman
Dams	$E_{measured}$ (mm)	$E_{estimated}$ (mm)	$E_{estimated}$ (mm)	$E_{estimated}$ (mm)	$E_{estimated}$ (mm)
Foum El-Gherza	2701.02	3026.49	1968.75	5124.75	2479.55
	E(%) = - 3	E(%) = -15	E(%) = 25	E(%) = -95	E(%) = 6
Fontaine des Gazelles	2699.31	3007.40	1968.04	5122.56	2436.25
	E(%) = 6	E(%) = -5	E(%) = 32	E(%) = -78	E(%) = 15
Brezina	2315.05	1994.60	1279.88	3462.83	1086.34
	E(%) = -1	E(%) = 13	E(%) = 44	E(%) = -51	E(%) = 53
Foum El-Guiess	2348.23	1925.83	1278.26	3456.34	1271.82
	E(%) = -73	E(%) = -42	E(%) = 6	E(%) = -155	E(%) = 6
Djorf-Torba	2653.30	3327.38	1883.08	4892.84	2859.89
	E(%) = -3	E(%) = -30	E(%) = 27	E(%) = -90	E(%) = -11

Table 2: Statistical results of selected models, proposed model and measured evaporation

Models	Priestley-Taylor						Boutoutaou						Proposed model					
Dams	NSE	RMSE	MBE	R^2	RSR	Rank	NSE	RMSE	MBE	R^2	RSR	Rank	NSE	RMSE	MBE	R^2	RSR	Rank
Foum El-Gherza	0.44	82.58	23.840	0.98	0.75		0.81	48.59	14.03	0.99	0.44	3	0.92	30.30	8.75	0.95	0.27	1
Fontaine des Gazelles	0.22	102.39	29.56	0.98	0.88		0.95	25.34	7.32	0.99	0.22	1	0.83	47.82	13.80	0.94	0.41	3
Brezina	0.99	76.83	22.18	0.95	0.12	6	0.99	48.28	13.94	0.93	0.07	2	0.99	60.59	17.49	0.90	0.09	4
Foum El-Guiess	0.64	35.93	10.37	0.87	0.60		0.49	43.14	12.45	0.99	0.72		0.71	32.63	09.42	0.98	0.54	3
Djorf-Torba	0.40	89.19	25.75	0.57	0.77		-0.13	122.80	35.45	0.68	1.06		0.86	43.53	12.57	0.84	0.38	1

Models	Ivanov						Debruin						Liu *et al*. (2016)					
Dams	NSE	RMSE	MBE	R^2	RSR	Rank	NSE	RMSE	MBE	R^2	RSR	Rank	NSE	RMSE	MBE	R^2	RSR	Rank
Foum El-Gherza	0.79	50.18	14.49	0.99	0.46	4	0.65	65.28	18.84	0.76	0.59	6	0.50	77.61	22.41	0.96	0.70	
Fontaine des Gazelles	0.93	31.06	8.97	0.98	0.27	2	0.73	60.73	17.53	0.77	0.52	5	0.46	84.91	24.51	0.94	0.73	
Brezina	1.00	39.43	11.38	0.90	0.06	1	0.99	50.14	14.47	0.90	0.08	3	0.99	69.52	20.07	0.92	0.10	5
Foum El-Guiess	0.41	46.26	13.36	0.99	0.77		0.33	49.35	14.25	0.95	0.82		-1.14	88.05	25.42	0.95	1.46	
Djorf-Torba	0.04	113.27	32.70	0.74	0.98		0.28	97.86	28.25	0.45	0.85		0.81	50.10	14.46	0.80	0.43	2

Models	Blaney-Criddle						Hamon						Ryan-Harleman					
Dams	NSE	RMSE	MBE	R^2	RSR	Rank	NSE	RMSE	MBE	R^2	RSR	Rank	NSE	RMSE	MBE	R^2	RSR	Rank
Foum El-Gherza	0.70	60.00	17.32	0.99	0.54	5	-4.59	260.44	75.18	0.98	2.36		0.88	38.92	11.24	0.90	0.35	2
Fontaine des Gazelles	0.51	81.30	23.47	0.98	0.70		-3.30	240.73	69.49	0.98	2.07		0.81	50.23	14.50	0.91	0.43	4
Brezina	0.98	92.40	26.67	0.95	0.14	7	0.96	132.21	38.17	0.96	0.20	9	0.97	113.78	32.85	0.94	0.17	8
Foum El-Guiess	0.97	10.89	3.14	0.99	0.18	1	-11.50	212.84	61.44	0.97	3.54		0.93	15.52	4.48	0.97	0.26	2
Djorf-Torba	0.62	71.43	20.62	0.77	0.62		-4.59	272.72	78.73	0.70	2.36		0.07	111.14	32.08	0.59	0.96	

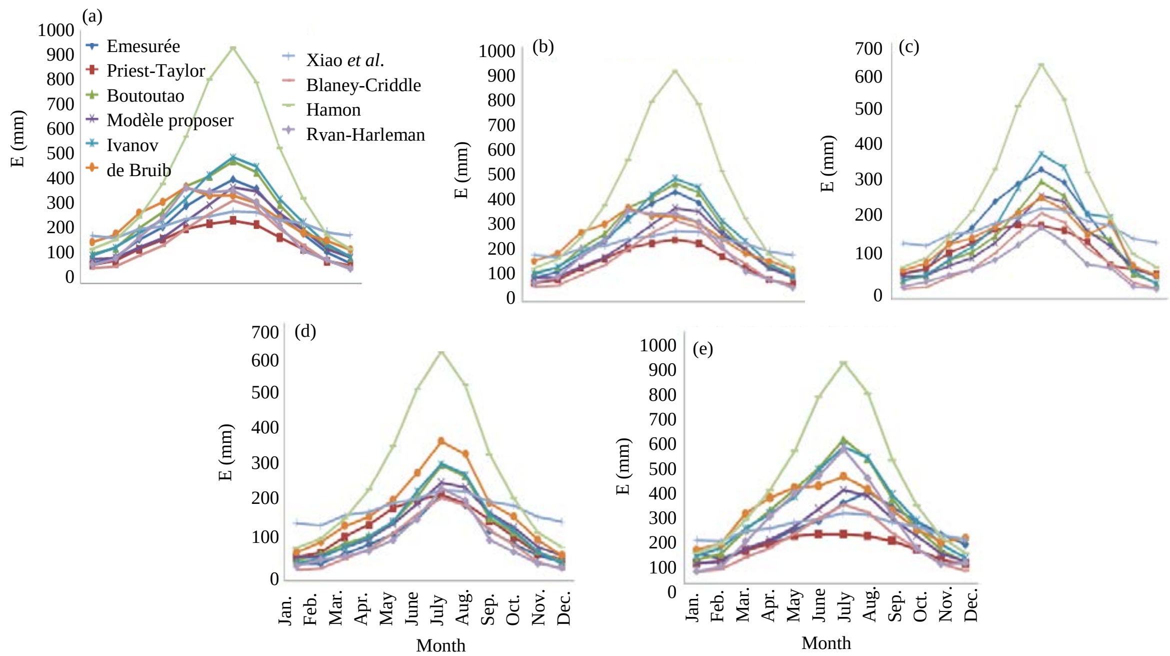

Fig. 4(a-e): Comparison of eight models, proposed model and measured evaporation, (a) Barrage Foum-El-Gherza (2000-2016), (b) Fontaine des Gazelles dam (2001-2016), (c) Brezina dam (2001-2014), (d) Foum El-Guiess dam (2000-2016) and (e) Djorf-Torba dam (2000-2014)

The case of the Foum El-Gherza dam-reservoir, the proposed model and Ryan-Harleman present minimal errors equal 6%. While, Fontaines des Gazelles dam-reservoir, the models of Boutoutaou, Ivanov, Ryan-Harleman and the proposed model present minimal errors ≤14%.

For Brezina dam-reservoir, we note that Ivanov, Boutoutaou and DeBruin models provide minimal errors less than or equal 13%. Whilst, Foum-El-Guiess dam-reservoir, the models of Blaney-Cridlle and Ryan-Harleman present errors equal 6%. Whereas the proposed model and Xiao *et al*. 's Model give errors less or equal 7% for the case of Djorf-Torba dam-reservoir. We notice that the proposed model presents minimal error of 6% and maximal error of 27% followed by Boutoutaou model with minimal error of 9% and maximal error of 32% for the five dam-reservoirs.

From the statistical indexes and the errors obtained from the proposed model and Blaney-Criddle and Boutoutaou models, we can suggest applying the proposed model to estimate evaporation from reservoir-dams in arid and semi-arid regions located in Algeria.

CONCLUSION

Evaporation is an important factor in term of water balance studies. Its estimation becomes impossible in absence of measurement climatological data. The estimation of evaporation from water plan by other estimating methods was developed in geographical and climatic contexts that mean depends on the type of climate where the water plan or dam-reservoir is situated (humid region, arid region, semi-arid region, hyper-arid, etc.).

This study presents a new model to estimate evaporation from five dam-reservoirs located in semi-arid and arid regions (Algeria). The model involves only three available climatic parameters, namely: air temperature, atmospheric pressure and wind speed at a height of 2 m. Statistical indexes show good correlation of estimated and measured evaporation are ranging from 0.84-0.98. The Rank Sum Ratio (RSR) is <0.54 for the five dams. The Nash criterion (NSE) varies from 0.70-0.99 with minimal mean squared errors "RMSE" ≤60.59 and the Mean Bias Errors (MBE) is ≤17.49 which allow us to conclude that the performance of the model is very good.

So, the proposed model can be applied to estimate evaporation from the studied dam-reservoirs in case of absence or lack of information.

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