Larhyss Journal, ISSN 1112-3680, n°43, Sept 2020, pp. 91-101

EVAPORATION FROM THE WATER SURFACE OF LAKES AND RESERVOIRS OF THE ARID ZONE OF THE MEDITERRANEAN: CASE OF ALGERIA

EVAPORATION DES PLANS D'EAU EN ZONE ARIDE MEDITERRANENNE : CAS D'ALGERIE

BOUTOUTAOU D.[1], ZEGGANE H.[2], SAGGAI S.[3].

[1] Laboratory for Exploitation and Development of Natural Resources in Arid Zones. Ouargla University, Algeria
[2] Lecturer, University of M'Sila . Algeria
[3] Laboratory of Water and environment Engineering in Saharan Environment (GEEMS). Ouargla University, Algeria.

boutoutaoudjamel@yahoo.fr

Research Article – Available at http://larhyss.net/ojs/index.php/larhyss/index
Received April 10, 2020, Received in revised form August 12, 2020, Accepted August 17, 2020

ABSTRACT

The value of water evaporation is a key data in establishing the water balance of lakes and reservoir dams. In general, the evaporation of water bodies is assessed either from observation data from evaporation pan (Colorado pan and class A pan), or by analogy with other reservoir dams for which these data are available. In frequent cases, the evaluation of the evaporation of water bodies becomes impossible by applying the two methods mentioned because of the reduced number of weather stations or the absence of evaporation pans among their equipment. Applying the analogy with other reservoir dams, it can lead to considerable errors. In order to eliminate the difficulty of determining the evaporation of water, often encountered by engineers and operators of reservoir dams, the development of a calculation method simulating the phenomenon of evaporation is essential.

Keywords: Evaporation, water body, meteorological elements, Algeria.

RESUME

La valeur de l'évaporation de l'eau est une donnée clé pour établir le bilan hydrique des lacs et barrages-réservoirs. En général, l'évaporation des plans d'eau est évaluée soit à partir des données d'observation du bac d'évaporation (bac Colorado et bac de classe A) des stations météorologiques, soit par analogie avec d'autres barrages réservoirs pour lesquels ces données sont disponibles. Dans des cas fréquents, l'évaluation de l'évaporation des masses d'eau devient impossible en appliquant les deux méthodes mentionnées à cause du nombre réduit de stations météorologiques ou de l’absence de bacs d’évaporation parmi leur équipement. L’application de l’analogie avec d'autres barrages réservoirs peut conduire à des erreurs considérables. Afin d'éliminer la difficulté de déterminer l'évaporation de l'eau, souvent rencontrée par les ingénieurs et exploitants de barrages-réservoirs, le développement d'une méthode de calcul simulant le phénomène d'évaporation est essentiel.

Mots-clés: Evaporation, plan d'eau, éléments météorologiques, Algérie.

INTRODUCTION

The value of the evaporation of water does not often appear in newsletters and climatological atlas, published annually by the National Meteorological Office. In hydrology, evaporation is of obvious practical interest (Piri et al., 2009), Because it is responsible for the loss of water volumes (dams, lakes etc.), sometimes very significant in arid and semi-arid zones. Establishing the water balance of a reservoir dam or a lake requires knowledge of the value of evaporation (Remini, 2010, Finch, 2001, Gianniou and Antonopoulos, 2007, Xu et la., 2001).

The value of evaporation is also very necessary for the design of irrigation works (Saggai, 2016, Kumar et al., 2013) and lagoons in the treatment of wastewater. In Algeria, the measurement of evaporation is entrusted to the services of the National Meteorological Office (ONM) and to the services of the national agency of hydraulic resources (ANRH). In the absence of data, the value of evaporation from water bodies is evaluated either from observation data from the evaporation tank (Colorado pan and class A pan) from weather stations, or by analogy with d 'other reservoir dams for which these data are available (Remini, 2005, Boutoutaou, 1995). The error linked to the evaluation by analogy, can reach considerable values (wrong choice of the analogous body of water).

As for the weather stations (evaporation pans), which offer good results, they are unfortunately limited in number and only cover a few regions of the country. Several authors propose models or formulas to calculate the evaporation of the water surface according to different meteorological parameters (Hamon, 1963, Papadakis, 1961, Sredazgiprovodkhlopok, 1970, Priestley and Taylor, 1972). However, it should be noted that generally the extrapolation of these formulas to other regions whose climatic conditions are totally different from those where they were developed can lead to outliers.

In this study, we propose the application of simples formulas linking evaporation to easily accessible meteorological elements.

MATERIALS AND METHODS

Data on water evaporation and meteorological elements are those from the database of the national agency for hydraulic resources (ANRH) and the national agency for dams and transfers (ANBT).

The Systematic observation data (10-15 years of observation, Between 1980 and 1995), were collected from meteorological stations located near the sites of Algerian reservoir dams (Meffrouche, Gargar, Hamiz, Guenitra, Bakhada, Keddara, Beni Bahdel dam, Sidi Mohamed Ben Aouda Experimental Station and El Abiod Sidi Cheikh), their locations are presented on figure 1.

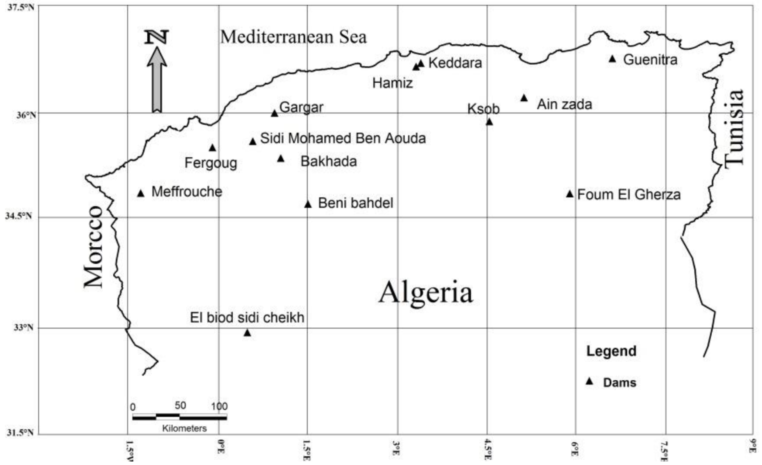

Figure 1: Location of the studied dams.

There are several methods for determining the evaporation of water from dams and lakes. The most famous are:

Water balance method

Water balance method is based on the revenues and expenses of the volume of water in the reservoir dam (figure 2), while taking into account the variation in storage (USSR State Committee for Hydrometeorological and Environmental, 1981).

Figure 2: Reservoir dam.

The evaporation of water (by volume) from a reservoir dam is determined by the following relationship:

$$V_E = V_P + V_S - V_{QS} - V_{QST} \pm \Delta V \tag{1}$$

V_E : Volume of water evaporated from the reservoir ; V_p : Volume of rain, received by the reservoir ; V_S : Volume of surface water entering the reservoir ; V_{ST} : Volume of underground water entering the reservoir ; V_{QS} : Volume of water discharged ; V_{QST} : Volume of underground water leaving the reservoir ; ΔV: Storage or destocking suffered by the reservoir.

The estimation of evaporation by this method is very little used due to the imprecision and the difficulty of measuring most of the components of equation (1), in particular underground inputs and outputs (USSR State Committee for Hydrometeorological and Environmental, 1981).

Evaporation pans methods

The evaporation process of the tanks (figure 3) is also based on the law of the water balance, with the total absence of underground flows and losses by infiltration, parameters very difficult to estimate (Vuglinsky, 1991).

Figure 3: Class A and Colorado evaporation pan

The simplified expression of the water balance of an evaporation pan can be written as follows:

$$E_p = \Delta H \pm P \quad (2)$$

E_p : Evaporation of the evaporation pan ; ΔH : Difference in height of the water body in the pan between two measurements ; P : Rain falling on the evaporation pan.

The transition from the evaporation measured in the pan to the evaporation of the water from the reservoir dam is done by multiplying the measurement results by the coefficient of the pan.

$$E = kE_P \quad (3)$$

E: Evaporation of water from the reservoir ; k: Coefficient of the pan ; E_p : Evaporation from the pan.

There are other methods for calculating the evaporation of water bodies, such as the energy balance method and the turbulent diffusion method. Although precise, these two methods have only been used in exceptional studies.

Hydrometeorological method

The hydrometeorological method is the most used method to determine the evaporation of water bodies (Davydov, 1944., Gwaharia, 1976., Penman, 1948). It is based on Dalton's physical law. The numerical values of this method are standard data which are always available and easy to acquire. According to Dalton the process of evaporation is described by the relation:

$$E = C\,(e_0 - e_z) \quad (4)$$

E : Evaporation, e_0 : Saturing water vapor pressure corresponding to the temperature of the evaporating surface ; e_z : water vapor pressure at a height z; C : Proportionality coefficient.

Dalton's formula (4) in natural conditions (in the mobile atmosphere and with a non-zero wind speed) is written by the following relation:

$$E = (e_0 - e_z)\,(a + bv) \quad (5)$$

a and b are adjustment coefficients of the formula.

Generally, the choice of evaporation calculation formulas is dictated by the availability of meteorological data constituting these formulas. In some cases, the number of meteorological parameters is very limited, which does not allow the calculation of evaporation. To avoid this problem, several authors (Davydov, 1944., Zaykov, 1949) propose other formulations including parameters which are always available and easy to acquire. Taking this situation into account, we replaced the difference in water vapour ($e_0 - e_2$) by the air saturation deficit D, that is to say:

$$e_0 - e_2 = fonct(D) \tag{6}$$

The relation between e_0 , e_2 and D is of the following form:

$$e_0 - e_2 = AD^m \tag{7}$$

A: Empirical coefficient; m : Reduction coefficient.

The value of m according to several authors (Konstantinov and Pasechnyuk, 1979) varies from 0.5 to 0.8, while the value of A, from 1.4 to 2.6.

For the climatic conditions of the southern shore of the Mediterranean, in particular those of Algeria, it is possible to assign two homogeneous zones of evaporation: humid and sub-humid zone and arid and semi-arid zone.

For the humid and subhumid zone the relation $e_0 - e_2 = fonct(D)$ is given by the following form:

$$e_0 - e_2 = 1.47\ D^{0.8} \tag{8}$$

For the semi-arid and arid zones, it is of the following form:

$$e_0 - e_2 = 1.73\ D^{0.73} \tag{9}$$

The correlation coefficient of the relation (8), is 0.88 ± 0.02 (humid and sub-humid region), for the relation (9), it is 0.97 ± 0.01 (arid and semi-arid region). The mean square error of the regression curve is respectively ± 0.11 *mb* and ± 0.015 *mb*.

RESULTS AND DISCUSSIONS

The values of evaporation and meteorological elements measured in weather stations located in several reservoir dams, allowed us to propose the following Dalton type evaporation formula:

$$E = 0.233\ n\ (e_0 - e_2)\ (1 + 0.39\ V_2) \tag{10}$$

E: Evaporation, e_0 : Saturing water vapor pressure corresponding to the temperature of the evaporating surface (millibar) ; e_2 : Water vapor pressure in the atmosphere (millibar), at a height of 2m ; n : Number of days in the month. (for January n = 31, February n = 28.5 etc.). For daily calculations n =1) ; V_2 : wind speed at a height of 2m.

$$V_2 = 0.78\ V \tag{11}$$

V: Wind speed (m/s).

Several authors express the temperature of water as a function of air temperature (Vuglinsky, 1991). For the climatic conditions of Algeria, it can be determined by the abacus or by the following relation (Boutoutaou, 1995):

$$t_w = 1.39\ t - 0.015\ t^2 - 1.62 \tag{12}$$

t_w : Water temperature $°C$; t : Air temperature $°C$.

The values of the evaporation of the water body calculated by the formula (10) for the various Algerian reservoir dams were compared with those measured. The comparison of the results obtained shows that the mean deviation is +1%, the arithmetic mean deviation is ± 18% and the quadratic mean deviation is ± 25%. In 70% of cases, the difference between the evaporation values calculated by formula (10) and measured does not exceed ± 25%.

Some comparisons between the calculated and measured values of evaporation chosen arbitrarily are presented in figure 4.

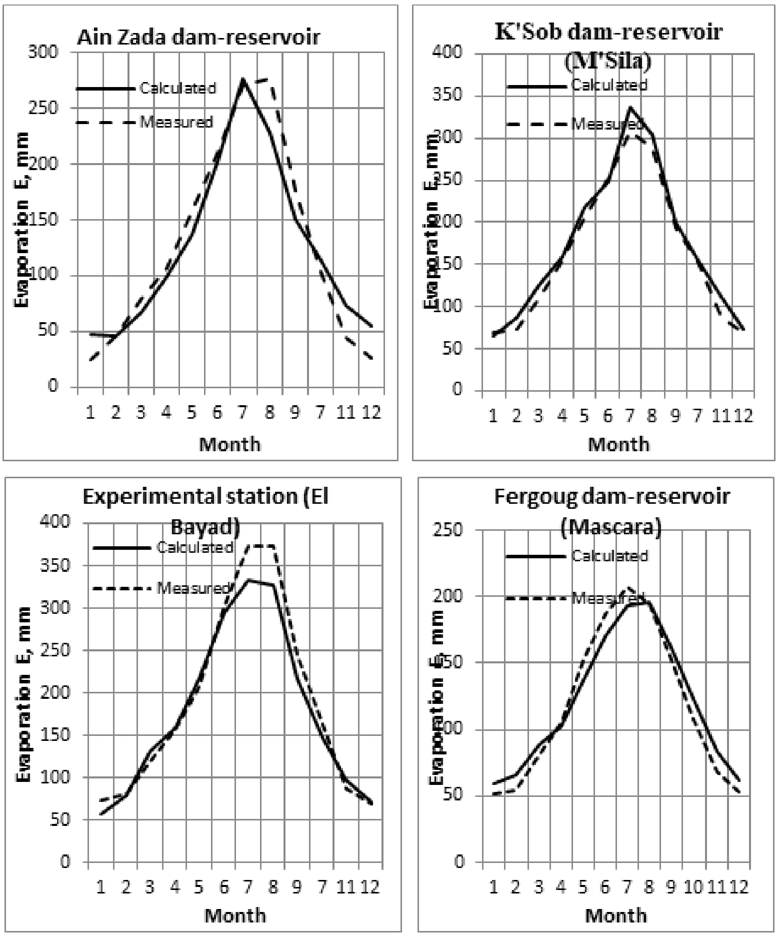

Figure 4: Comparison between the calculated and measured evaporation values.

In the absence of saturing water vapor pressure and water vapor pressure data in air, the evaporation of the water surface can be calculated using the value of the air saturation deficit D. By replacing the relations (8) and (9) in the standard formula for calculating dalton type evaporation (10), we obtain:

For the humid and sub-humid region:

$$E = 0.342\, nD^{0.8}\,(1 + 0.39\, V_2) \tag{13}$$

For the arid and semi-arid region:

$$E = 0.403\, nD^{0.73}\,(1 + 0.39\, V_2) \tag{14}$$

E: Evaporation ; n : Number of days in the month. (for January n = 31, February n = 28.5 etc.). For daily calculations n = 1; V_2 : Wind speed (*m/s*) at a height of 2m ; D : Air saturation deficit (*mb*).

The's air saturation deficit D can be determined by the following relationship :

$$D = 0.0632\,(100 - H)\,\exp\,(0.0632\, t) \tag{15}$$

D: Air saturation deficit (*mb*) ; H : Air humidity (%) ; t : Air temperature (°*C*).

The average error in calculating evaporation using formulas (13) and (14) is approximately ±8%. The mean square error is ±20%. In 80% of cases, the difference between the calculated and measured evaporation values does not exceed ±22%.

APPLICATION

Calculation of the monthly water evaporation from the Foum el Ghorza reservoir dam in Biskra (arid zone) using formula (14). The meteorological data necessary for the calculation are the air temperature t in °*C*, the air humidity H in % and the wind speed V in *m/s*. They are presented in the table 1.

The evaporation calculation is carried out in the same table.1.

As the table1 shows, the values of evaporation from this arid zone are very high, especially in summer when the values can reach 400 mm per month.

The annual value of the evaporation of the Foum El Gherza reservoir dam represents the sum of the monthly values, it is 2744mm (against 2632mm- measured evaporation). The difference is 4.26%.

Table 1: Calculation of monthly evaporation E, mm from the Foum El Gherza reservoir dam (2002-2016).

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Number of days *n*	31	28.5	31	30	31	30	31	31	30	31	30	31
Temperature (t°C)	11.8	13.3	17.6	21.8	26.6	31.6	35.0	34.2	29.4	24.1	17.3	12.6
Humidity *H%*	55.9	47.8	41.4	37.7	32.5	27.5	25.3	28.9	39.0	45.5	53.2	59.3
Wind *V* (m/s)	3.80	4.22	4.86	5.26	5.24	4.12	3.59	3.47	3.63	3.14	3.60	3.21
$V_2=0{,}78V$	2.96	3.29	3.79	4.10	4.09	3.21	2.80	2.71	2.83	2.45	2.81	2.50
Deficit *D* (mb)	5.88	7.65	11.26	15.62	22.92	33.76	43.12	39.02	24.72	15.80	8.83	5.70
Evap. *E calcul* (mm)	98	116	181	234	319	356	408	373	264	183	124	88
Evap.*E Mesured* (mm)	80	100	169	216	298	352	400	365	261	191	121	79
Difference Δ%	23	16	7	8	7	1	2	2	1	-4	2	11

CONCLUSIONS

The construction or operation of reservoir dams requires knowledge of the evaporation of the water level of these structures. The value of evaporation is applied in the establishment in water balances (during the operation of reservoir dams) and the regulation of inputs for the design of future dams. The data of the measured evaporation values are very limited and do not cover the entire Algerian territory. For its determination, we always used the analogy with other reservoir dams for which the evaporation values are available or the evaporation values measured in meteorological stations. The error of determining evaporation by analogy can reach considerable values (poor choice of the analogous reservoir dam). As for the weather stations, which offer good results, they are unfortunately limited in number and they only cover a few regions from the country. The study of several relationships that exist between the evaporation of the water body and meteorological elements has enabled the development of two types of calculation formulas. The first is based on Dalton's law, i.e. based on the difference between the saturated water vapor pressure corresponding to the water temperature and the water vapor pressure in the air , the second, on the air saturation deficit. The choice of calculation by this or that formula is dictated by the availability and nature of the meteorological data.

The values of evaporation calculated by the formulas developed above do not replace the values of evaporation measured but can be representative for the regions with arid and semi-arid climates of the Mediterranean.

REFERENCES

BOUTOUTAOU D. (1995). Evaporation from the surfaces of water bodies of reservoirs and dams in Algeria, Doctoral thesis Ph.D in Technical Sciences, Moscow Institute of Hydraulics, 148p.

DAVYDOV V.K. (1944). Evaporation from a water surface in the European part of the USSR, Proceedings of national institute of hydrology, Series IV, Issue 12.

FINCH J.W. (2001). A comparison between measured and modelled open water evaporation from a reservoir in South-East England, Hydrological Process Journal, Issue15, pp.2771-2778.

GIANNIOU S.K., ANTONOPOULOS V.Z. (2007). Evaporation and energy budget in Lake Vegoritis, Greece, Journal of Hydrology, Vol.345, pp. 212-223.

GWAHARIA V.K. (1976). Evaporation from the water surface of the Caucasus, Proceedings of the All-Union, Hydrological Congress, Tome 6, pp. 237-243, Leningrade, Russia..

HAMON W.R. (1963). Computation of direct runoff amounts from storm rainfall, International Association of Hydrological Sciences, Publ., Issue 63, pp.52-62.

KONSTANTINOV A.R., PASECHNYUK L.E. (1979). On the legality of using air humidity in calculating water consumption, evapotranspiration and evaporation from water bodies, agricultural fields and river spillways, Proceedings of the national institute of hydrology, Vol. 260, p.135.

KUMAR P, RASUL G, AND KUMAR D. (2013). Evaporation estimation from climatic factors, Pakistan Journal of Meteorology, Issue 9, pp. 51-57.

USSR STATE COMMITTEE FOR HYDROMETEOROLOGICAL AND ENVIRONMENTAL CONTROL (1981). Methods of studying and calculating the water balance, Leningrad hydrometeoizdat, p.397.

MEZIANI M., REMINI B., BOUTOUTAOU D. (2020). Estimating Evaporation from Dam-Reservoirs in Arid and Semi Arid Regions : Case of Algeria, Journal of Engineering and Applied Sciences, Volume 15, Issue 9, pp. 2097-2107.

PAPADAKIS J. (1961). Climatic Tables for the World, Juan Papadakis Publisher, Winterbourne, Berkshire, Shire, p.175.

PENMAN H.L. (1948). Natural evaporation from open water, bare soil and grass. Proceeding of the Royal Society of London, Series A, Issue193, pp. 120-145.

PIRI J., AMIN S., MOGHADDAMNIA A., KESHAVARZ A., HAN D. AND REMESAN R. (2009). Daily pan evaporation modeling in a hot and dry climate, Journal of Hydrological Engineering, Issue 14, pp. 803-811.

PRIESTLEY C.H.B.,TAYLOR R.J. (1972). On the assessment of surface heat flux and evaporation using large-scale parameters, Monthly Weather Review, Issue100, pp. 81-92.

REMINI B. (2005). L'évaporation des lacs de barrages dans les régions arides et semi-arides, exemples Algériens. Larhyss Journal, ISSN 1112-3680, N° 04, Juin 2005, pp.81-89.

REMINI B. (2010). La problématique de l'eau en Algérie. Larhyss Journal, ISSN 1112-3680, N° 08, Juin 2010, pp. 27-46.

SAGGAI S., BOUTOUTAOU D., SAKER M.L. (2016). Réduction de l'évaporation des eaux dans les barrages : une stratégie pour augmenter le stockage de l'eau dans les régions arides algériennes. Hydrological Sciences Journal, Vol. 61, N° 8, pp.1548-1554.

SREDAZGIPROVODKHLOPOK (1970). Calculated Mean of Irrigation Norms of Agricultural Crops in the water Syr-Darya and Amu-Darya River Basins, Scientific Information Center of Interstate Coordination Commission (SIC, ICWC), Tashkent, Uzbekistan, p.292.

VUGLINSKY V.S. (1991).Water resources and water balance of large reservoirs of the USSR, Leningrad, hydrometeoizdat, 223p.

XU C.Y., SINGH V.P. (2001). Evaluation and generalization of temperature based methods for calculating evaporation, Hydrological Processes, Issue15, pp.305-319.

ZAYKOV B.D. (1949). Evaporation from the water surface of ponds and small reservoirs on the territory of the USSR, Proceedings of the GGI, National Institute of Hydrology, USSR, Vol.21, Issue 75, pp.54-63.