

# Evaluation of two methods for estimation of evaporation from Dams water in arid and semi arid areas in Algeria

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## ABSTRACT

*Evaporation is difficult to measure experimentally over water surfaces; several techniques and models have been suggested and used in the past for its determination. There exists a multitude of methods for the measurement and estimation of evaporation. Evaporation pans provide one of the simplest, inexpensive, and most widely used methods of estimating evaporative losses. In the present study, the rate of evaporation starting from a water surface was calculated by modeling with application to dams in wet, arid and semi arid areas in Algeria.*

*We calculate the evaporation rate from the pan using the energy budget equation which offers the advantage of an ease of use but our results do not agree completely with the measurements taken by the National Agency of areas carried out using dams located in areas of different climates. For that we develop a mathematical model to simulate evaporation. This simulation uses an energy budget on the level of a vat of measurement and a Computational Fluid Dynamics (Fluent).Our calculation of evaporation rate is compared then by the two methods and with the measures of areas in situ.*

**Keywords:** Evaporation, Energy budget, Surface water temperature, Dams.

## 1. INTRODUCTION

Many methods for estimation of evaporation losses from free water surfaces were reported and it can be divided into several categories including: empirical methods (e.g. Kohler et al., 1955), water budget methods (e.g. Shuttleworth, 1988), energy budget methods (e.g. Anderson, 1954), mass-transfer methods (e.g. Harbeck, 1962); and combination methods (e.g. Penman, 1948).

Accurate and reliable measurement of evaporation for a long term has been investigated by researchers, while using both the direct and indirect methods of measurements. In the direct method of measurement, the observation from Class A Pan evaporimeter and eddy correlation techniques were used (Linsley et al., 1982), whereas in indirect methods, the evaporation is estimated from other meteorological variables like temperature, wind speed, relative humidity and solar radiation [1].

## 2. MEASUREMENT METHODS

Evaporation pans have been used to measure evaporation for over a century. Two kinds of pans are widely used in the world: The class "A" pan and the sunken pan. The later is the one used in Algeria. It consists of a pan of a square cavity of dimension 0.92m×0.92m×0.50m, almost totally buried in the ground.

It contains water surface up to the original ground surface. The Class-A pan is considered to be the standard international pan [2]-[3].

The rate of evaporation depends on the [4]:

- Vapor pressures at the water surface and their above
- Type of pan environment
- Wind speed
- Atmospheric pressure
- Exchange of heat between pan and ground
- Solar radiation
- Quality of water
- Air and water temperature
- Size of the water body

Almost universally a simple ‘pan factor’  $K_{pan}$  is then introduced and where  $E_{pan}$  is the measured evaporation from the pan [5]-[6], annual dam evaporation estimates are obtained by multiplying the annual pan data by an appropriate coefficient,  $K_p$  as follows:

$$E = E_{pan} \cdot K_{pan} \quad (1)$$

Where  $E$  is evaporation rate from dam or reservoir in unit of depth,  $K_p$  is a pan coefficient, and  $E_p$  is the amount of evaporation from class A pan in unit of depth. A coefficient of 0.7 is applicable when water and air temperatures are approximately equal (Kohler et al. 1955, 1958) [7]-[8].



**Figure 1** Class « A » pan and Colorado pan

(Used at three sites for the comparison with the actual evaporation)

### 3. CALCULATION METHODS

There are many models to estimate evaporation from an open water body, also known as lake evaporation and mentioned in this study as dam evaporation and some of these models are the water budget method, energy budget method, eddy correlation method, mass-transfer method, the Penman method, combination equation and the pan method (Dingman, 1994 and Brutsaert, 1982). 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.

In this study we choose to calculate the evaporation rate from the pan using the energy budget equation and the computational fluid dynamics. They will be detailed as follows:

#### 3.1 The energy budget method

The energy budget method is recognized as the basic method to determine evaporation from an open water surface. The equation of the energy budget is written as:

$$R_n = L_v E + H + G \quad (2)$$

Where  $R_n$  is the net radiation on the surface

A part of it is used to vaporize water and gives rise to a latent heat flux  $L_v E$ , where  $E$  is the evaporation speed per unit area and  $L_v$  the latent heat of water vaporization ( $2.4 \cdot 10^6$  J/Kg). The remainder is dissipated as sensible heat flux  $H$  which heats the air and as a heat flux  $G$  stored in water. Since we can neglect the term of storage compared to the other terms, we let  $G \cong 0$  [9]-[10] and [11].

Then the rate of evaporation becomes:

$$E = \frac{R_n - H}{L_v} \tag{3}$$

With

$$H = h_c(T_s - T_a) \tag{4}$$

And

$$R_n = (1 - \alpha)R_g + \varepsilon\sigma(T_a - 6)^4 - \varepsilon\sigma T_s^4 \tag{5}$$

Where  $h_c$  is the coefficient of convective heat transfer in turbulent boundary layer on flat plate [12]:

$$(h_c = 5.907 V^{0.8} L_c^{-0.2}) \tag{6}$$

$R_g$  is the global radiation which corresponds to the sum of the direct and diffuse solar radiations of short wavelength. It is written as:

$$R_g = 0.271 I_0 \lambda A_1 \sinh + 0.706 I_0 A_1 \sinh \exp\left(\frac{-A_1}{\sinh}\right) \tag{7}$$

The temperature at the surface  $T_s$  is an important input parameter. It's calculated from the resolution of the energy budget equation at the surface (equation (2)). The latent heat flux is calculated from a Stefan equation (equation (5)) based on the Fick law [13]-[14] and [15]. Thus, we have:

$$L_v E = \frac{L_v K_E M_w}{RT_a} [P_{vs}(T_s) - P_v(T_a)] \tag{8}$$

Where

$K_E$  is the convective mass transfer coefficient calculated from the Lewis hypothesis.

$$K_E = \frac{h_c}{\rho c_p} \tag{9}$$

$P_{vs}$  is the saturated vapour pressure calculated from Clapeyron- Clausius formula:

$$P_{vs}(T) = \exp\left(25.5058 - \frac{5204.9}{T}\right) \tag{10}$$

And 
$$p_v(T_a) = H_r P_{vs}(T_a) \tag{11}$$

Replacing equations (4), (5) and (8) in equation (2), the energy budget is finally written as:

$$\begin{aligned} & (1 - \alpha)R_g + \varepsilon\sigma(T_a - 6)^4 - \varepsilon\sigma T_s^4 - h_0(T_s - T_a) \\ & = \frac{L_v K_E M_w}{RT_a} [P_{vs}(T_s) - P_v(T_a)] \end{aligned} \tag{12}$$

The resolution of equation (12) allows us to calculate the surface temperature  $T_s$  at every moment of the day according to the hourly data of the following parameters: the net radiation  $R_n$  per unit area, the air temperature  $T_a$ , the relative humidity  $H_r$  and the wind speed  $V$ . The resolution of this equation is carried out with Dichotomy method. The value of the surface temperature  $T_s$  calculated at every moment gives us access to the water flux evaporated at the surface.

**3.2 Numerical model and calculation method**

The domain of study is a two-dimensional model and has been constructed using the finite control volume approach on a vertical section of a 0,92m x 0,92m x 0,5m ring tank.

A computational grid was established using GAMBIT software and computational fluid dynamics (CFD) was then performed using FLUENT version 6.3 software. The flow is governed by the incompressible unstable equations of Navier-Stokes and energy to determine the heat flux within the pan.

We adopt the Boussinesq approximation.

Computational Fluid Dynamics (CFD), based on the solution of continuity, energy, Navier-Stokes equations, k- ε standard model of turbulence and under the Boussinesq hypothesis, can provide the air speed, temperatures and heat flux.

The continuity equation is:

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{13}$$

The momentum equation is:

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = f_c \varepsilon_{ij3} \Omega_j u_j - \frac{1}{\rho} \frac{\partial P^*}{\partial x_i} + \nu \frac{\partial^2 u_i}{\partial x_j^2} \tag{14}$$

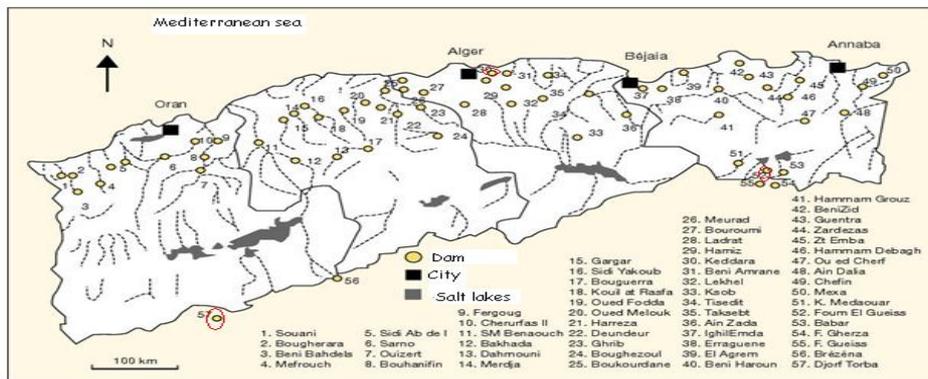
The energy equation is:

$$\frac{dT_v}{dt} = \frac{\lambda}{\rho c_p} \Delta T_v \tag{15}$$

Simplified Assumptions:

- Near the surface, the air flow is quasi- steady.
- We can neglect the effects of pressure and Coriolis forces.
- The flow is modelled by a turbulent flow, homogeneous horizontally, with constant flux, we neglect the interaction of radiative flux and the effect of moisture on the various turbulent mechanisms.
- The corrections made by the introduction of the virtual temperature of the air (to take into account the presence of water vapour) and of the potential temperature (to take into account the variation of the temperature with altitude) can be neglected (for the first meters from the surface).

Three regions representing a large geographical and climatic diversity were chosen in this study to evaluate the selected evaporation models. The first study region is located in Algiers city, the second is located in Khenchla city and the third region is located in Bechar city (Figure 2). [16].

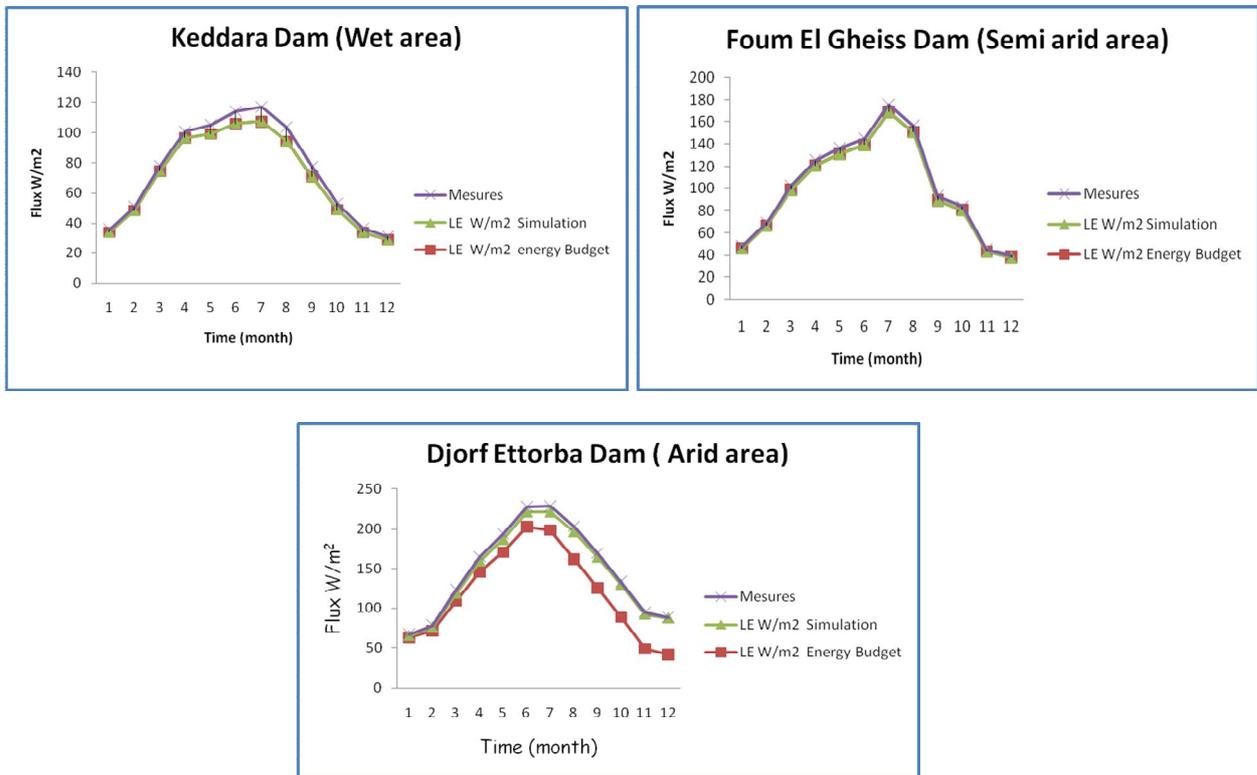


**Figure 2** Geographical and hydrographic situation of the three dams of study

**4. CALCULATION METHODS**

We calculated the evaporation rate for year 2004 for three regions of Algeria:

- Humid region (Kaddara Dam)
- Semi arid region (Foum el Gheiss Dam)
- Arid region (Djorf Ettorba Dam)



**Figure 3** Comparison between measured and simulated and energy budget method evaporation from the pan for the three areas of Algeria

The form of the curves, obtained by the various formulas used for the evaporation calculation, is similar for the three studied areas.

We observe a significant difference between the simulated and the measured evaporation in the hot period for the wet area.

We observe concerning the arid area, a shift between measurement and simulation from June on. Theoretically, the maximum solar radiation is reached in June (21st June), but really the temperature of the air reaches its maximum in July and up to fifteen of August.

## 5. CONCLUSION

Pans are a very practical tool to measure evaporation, especially in the areas where the input climatic variables are not available. But, the comprehension of the phenomenon related to it remains a difficult task. We note that the evaporation calculation, made by the two methods used (Energy budget and using CFD), gives identical results. In addition, this investigation shows:

1-A notable difference between simulated evaporation and that measured in summer period for the wet area. We can not give a coherent explanation to this phenomenon, especially when this variation does not hold for the two other regions. We intend to continue our research in order to give a physical acceptable explanation for this variation.

2- The influence of the lateral conduction between the adjacent soil; in the case of the sunken pans; and the walls of the pan (or between the lateral walls of a class «A» pan and the near air) is minor on the evaporation simulation.

3- The flow mode which prevails above the pan is undoubtedly a laminar mode, which is different from the fully turbulent mode at the surface of a dam. To circumvent this problem, it is necessary to use a larger size pan so that the analogy with a barrage would be closer to reality.

4- Many problems associated with small pans can be eliminated if the size of the pan is increased. Trials with very large pans or tanks are taking place now. With these pans, the height of the lip is small compared to the overall width of the pan, so lip errors are significantly reduced.

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