Applied Science and Innovative Research
ISSN 2474-4972 (Print) ISSN 2474-4980 (Online)
Vol. 2, No. 1, 2018
www.scholink.org/ojs/index.php/asir

Original Paper

Direct Measurements and New Mathematical Methods to Estimate the Pond Evaporation of the French Midwest

Mohammad Aldomany[1*], Laurent Touchart[1], Pascal Bartout[1] & Quentin Choffel[1]

[1] EA 1210 CEDETE (laboratory 2: lakes, ponds, wetlands and rivers). Department of Geography, University of Orleans, Orleans, France

[*] Mohammad Aldomany, Department of Geography, University of Orleans, 87100, Orleans, France

Received: November 15, 2017 Accepted: November 23, 2017 Online Published: December 9, 2017

doi:10.22158/asir.v2n1p1 URL: http://dx.doi.org/10.22158/asir.v2n1p1

Abstract

Despite many scientific papers published around the world on the evaporation of water bodies, few detailed evaporation studies exist for ponds, especially the ponds of humid areas like the French Midwest. Two full years of daily evaporation measurements on two different types of ponds were carried out using a transparent floating evaporation pan. A comparison between a class A evaporation pan and the transparent floating evaporation pan shows that the latter has almost no influence on the water temperature. As a consequence, the measurements taken by this evaporation pan were used to evaluate the reliability of 18 different mathematical methods. These mathematical methods use climate data provided by a weather station installed at the edge of the studied ponds to calculate evaporation. The comparison between measured and calculated evaporation shows that the new empirical formula of Aldomany is the best formula that we can use to estimate the ponds evaporation.

Keywords

pond, floating evaporation pan, Penman equation, French Midwest

1. Introduction

The vast majority of research aimed at studying evaporation from open water bodies is devoted to the water bodies found in hot climates (Bouchardeau & Lefèvre, 1957; Riou, 1975, on Lake Chad. Neumann, 1953, on Lake Houle and Lake Tiberiade) or the great lakes (Afanas'ev, 1976, on Lake Baikal; Nicod & Rossi, 1979, on Lake Victoria) and the emblematic reservoirs such as Mead in USA (Anderson & Pritchard, 1951). However, a few studies have been devoted to the study of the evaporation from small lakes and ponds (Rosenberry et al., 2007; Aldomany et al., 2013). Evaporation from small open water bodies such as ponds represents a very important component in their local hydrologic budget, yet its quantification continues to be a theoretical and a practical challenge in surface hydrology and micrometeorology (Assouline et al., 2008)

Long-term observations and field data are important for understanding pond evaporation, creating estimation methods, and evaluating effects of evaporation changes (caused by climate change or land use evolution) on water resources. However, it is challenging and difficult to make direct measurements of pond evaporation over a long period, because it involves significant financial investment in instruments, field maintenance and field work on a pond. Like lake evaporation, pond evaporation is affected not only by climatic variables, soil properties and topography (Friedl, 1996; Gash, 1987), but also by pond characteristics such as depth, surface area, water clarity and temperature. Pond water itself influences the energy budget and pond evaporation through the changes in water temperature and water mixing (turn over).

In France, despite the numerical (more than 250 000 ponds according to Bartout & Touchart, 2013), the socio-economic (Lemoine & Le Bihan, 2010) and the ecological importance of ponds [“*ponds are important hotspots for biodiversity. Collectively, they support more species, and more scarce species, than any other freshwater habitat*” (Céréghino et al., 2008)], few studies have been devoted to the study of the evaporation from small water bodies such as ponds. In other words, in France [the first European country in number of artificial ponds (Bartout et al., 2015)], we find almost no detailed study on ponds evaporation. All we can find about the estimation of the pond evaporation in France, are only numbers extracted from studies carried out for regions where the climatic conditions are very different from those of the French Midwest, or they are numbers coming from studies based on methodologies that do not provide reliable results.

This lack of studies on the evaporation of ponds can have several origins: 1) the absence of accurate measurement tools and the lack of qualified personnel to read the measuring instruments each day on the field; 2) the high cost of some measuring instruments; 3) the small size of ponds restricts the possibility to use remote sensing and other automatic determinations; 4) When evaporation is estimated, frequently it is based on sparse or remotely collected data (official meteorological stations located at some distance from the water body).

For all these reasons, one of the main objectives of evaporation studies that are based on direct measurements is to find a mathematical formula for estimating evaporation from easily measured data such as meteorological data. Because of many previous works, with various, and even contradictory, results, we will try to find the best mathematical method to calculate the evaporation of different types of ponds in the French Midwest in comparison with mathematical formulas and direct measurements. We will consider the formula that gives the closest results of the direct measurements as the most reliable formula to estimate the evaporation of the ponds. Such a mathematical formula will help us to improve the reliability of one of the indicators of the pond’s water budget. This improvement of the determination of the pond evaporation will help the managers to take the best decisions in order to achieve the goal set by the Water Framework Directive (WFD-2000), the Water and Aquatic

Environments Law of December 30, 2006 and the Grenelle Environment Forum.

1.1 Study Areas Physical and Climatic Characteristics

The first step in our research was to find a pond that has all or almost all the features that distinguish one type of ponds from the others. The studied ponds where we carried out the daily measurements of the evaporation are characteristics of the two large types of ponds existing in the French Midwest which contains more than 50% of French ponds (Bartout & Touchart, 2015).

The studied ponds are Cistude pond, as a representative of the pellicular ponds and the pond of Château (Castle), as a representative of deep ponds (Figure 1).

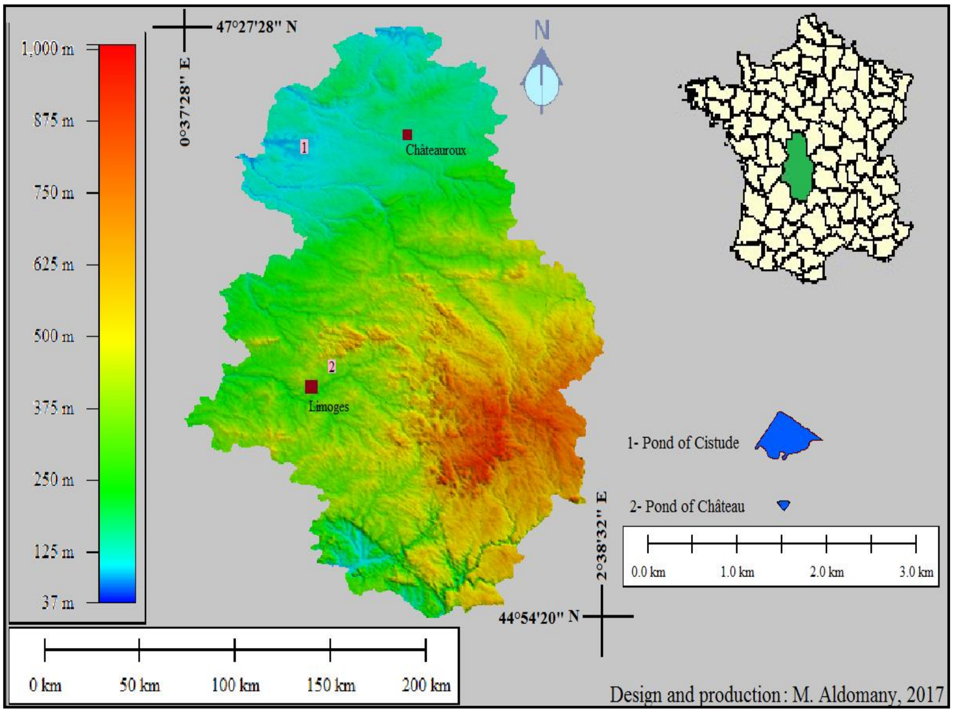

Figure 1. Location of Cistude Pond and the Pond of Château

According to the classification of regional climates in France conducted by Beltrando (2004), all of our study sites are located in the temperate oceanic climate. But, following the peculiarities of the topography, which determines specific flows of the air and the nature of the surfaces at the substrate-atmosphere interface, which determines the exchanges energy and water transfers, we need to talk about the local climate rather than the regional climate. According to the classification of types of climate in France carried out by Joly et al. (2010), Cistude Pond is found in the "degraded oceanic climate of the central and northern plains". The main characteristics of this type of climate are: an annual thermal amplitude greater than 15 ℃, an average annual temperature close to 11 ℃ and an annual cumulative precipitation of around 700 mm. The pond of Château located within the limits of the "altered ocean climate". This type of climate is wetter than the previous one (average annual rainfall exceeds 1000 mm) but its average annual temperature exceeds the threshold of 11 ℃.

The Cistude pond is located in the natural reserve of Cherine. It is 3 km east-southeast of Saint-Michel-en-Brenne and 35 km west of the town of Châteauroux at the confluence of latitude 46°47’34.88”N and longitude 1°11’58.33”E. This pond covers 8.7 hectares and the overflow is located at an altitude of 280 meters. Its average depth is 0.8 meter and its maximum depth slightly exceeds 2 meters. It is set on modal brown soils, mesotrophic. Regarding the watershed of Cistude pond, it is one of several ponds that are interconnected by a small stream and they form a chain of ponds. Cistude pond is the fifth pond in this chain (Figure 2).

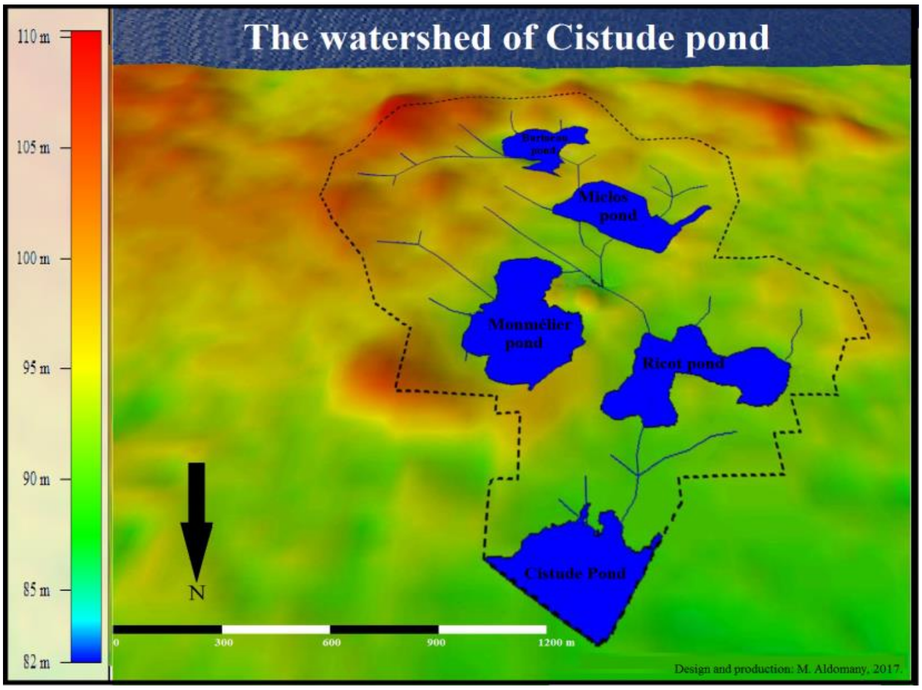

Figure 2. The Watershed of Cistude Pond

The pond of Château is located 11 km north-northeast of the city of Limoges (Limousin region, municipality of Rilhac-Rancon), at the intersection of longitude 1°19m27s East and latitude 45°55m16s North. Its area is equal to 0.43 hectare and the overflow is located at an altitude of 322 meters. Its average depth is 2.28 meters and its maximum depth slightly exceeds 4.25 meters. Although the catchment area of the pond of Château is very small (17 hectares), it perfectly represents the watershed characteristics of the Limousin region. Unlike Cistude pond is located in a flat area, the pond of Château is in a valley with steep slopes (Figure 3). Like many ponds in this area, it is located on a granite substrate.

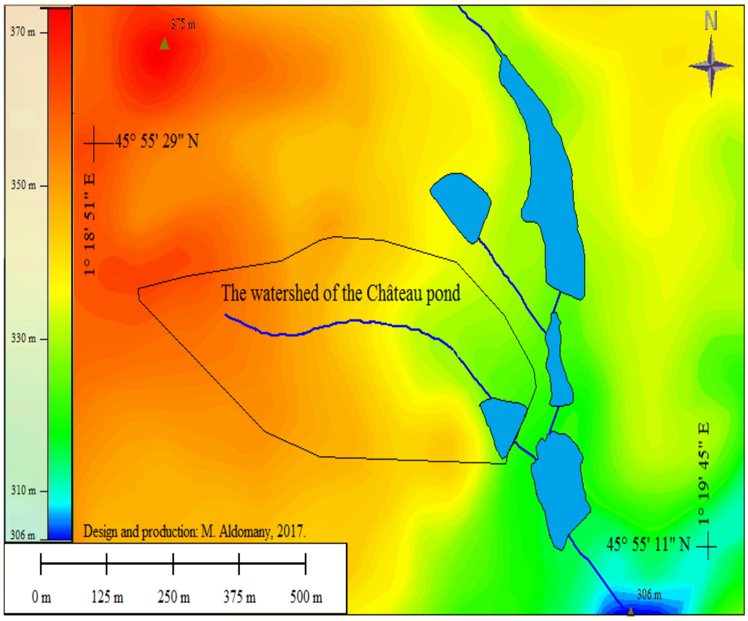

Figure 3. The Watershed of the Château Pond

2. A Methodology Adapted to the Study of the Ponds Evaporation

2.1 The Different Methodologies Used to Study the Evaporation from Water Bodies

To carry out this study we had to find the best methodology that allows us to obtain reliable results. For this reason, we started this research with a bibliographic study which allowed us to know all the methodologies already used to carry out the studies on the subject of the evaporation of the open water bodies. According to our research, we found five different methodologies; each of them has positive and negative points.

Beginning with The eddy-covariance method. It is considered as the most accurate and reliable method to estimate evaporation from large water bodies (Stannard & Rosenberry, 1991; Assouline & Mahrer, 1993; Assouline et al., 2008; Tanny et al., 2008). This method uses sophisticated instruments to measure humidity and wind speed at high frequencies (typically 10 times per second), and this information is then used to calculate the flux of water vapor to or from the water body surface or cultivated land (i.e., condensation and evaporation, respectively) (Ikebuchi et al., 1988). It is considered among the best method for special and short-term observations, but it requires more expensive instruments. Furthermore, making measurements like this over small water bodies such as the ponds comes with its own set of challenges. For example, moving platforms (such as buoys) are problematic for the eddy covariance technique and also don’t stand up to heavy freezing spray (Lenters et al., 2013). Tanny et al. (2008) showed that if the water level of the studied lake is variable, the sensor footprint area will change. So, erroneous measurements will be recorded. Also, if the water body is small (as the case of the vast majority of French ponds), the sensor’s footprint may occasionally extend beyond the physical limits of the reservoir (depending on wind direction and air flow properties). In that case, the measured flux would be a mixture of that from the water surface and the surrounding region outside of the pond. For all the above reasons, the Eddy-covariance method is not the best method for reliable evaporation measurements on ponds.

The Stable Isotope Method (Oxygen eighteen ^{18}O and Deuterium ^{2}H), it was created by Craig and Gordon (1965) to estimate the water balance, in general, and the evaporation, in particular, of the water bodies. It has been then modified and applied to various lacustrine systems by subsequent authors (Dinçer, 1968; Zuber, 1983; Gonfantini, 1986; Krabbenhoft et al., 1990; Gat & Bowser, 1991). Equilibrium equations for isotopic tracers of ^{18}O and ^{2}H provide independent hydrological information that may be useful for estimating evaporation and other water balance parameters, as it was demonstrated in previous studies of water bodies (Gat, 1970; Gibson et al., 1993; Mayr et al., 2007; Mügler et al., 2008). In a nutshell, the theory of the isotopic method is based on a mass of evaporated water enriches in its composition in stable isotopes, and the remaining water becomes relatively richer in oxygen 18 and in deuterium. This enrichment can be measured easily and accurately to determine evaporation by comparing the percentage of stable isotopes for different dates using a precise equation. Although this model may be effective in describing the annual water balance of large-volume lakes in temperate climates, which are generally only moderate seasonal variations in volume and isotopic composition, they may be less appropriate to describe the shallow lakes existing in cold continental climates. In the latter case, this is due to transient isotopic and hydrous conditions that result from the seasonality of atmospheric and hydrological processes (Gibson, 2002). One of the weak points of this method is the expense because it requires continuous samples of the water from pond at several depths, from the incoming and outgoing streams, precipitation and air humidity. In addition, large inter-site and inter-annual isotope variations are observed for shallow lakes, while, deep lakes have similar isotope values and small inter-annual variations (Mayr et al., 2007). For these reasons, this method remains an alternative to estimate the evaporation of the ponds but it is not the preferred method to carry out this kind of studies especially for ponds.

Since 1977, remote sensing data have been used to quantify evaporation and evapotranspiration at regional and global scales (Jackson et al., 1977; Price, 1982; Seguin & Itier, 1983; Hope et al., 1986; Choudhury et al., 1986, 1987; Seguin et al., 1989; Diak, 1990; Brunet et al., 1991; Diak & Whipple, 1993; Carlson et al., 1994). It can be an effective tool for capturing spatial and temporal variations in water surface temperature in large lakes (Ebaid & Ismail, 2010; Sima et al., 2013) and despite all types of models based on satellite data for estimating evaporation and/or TE (Boulard, 2016), recent studies have shown great uncertainty regarding the results obtained by these models (Dirmeyer et al., 2006; Haddeland et al., 2011; Vinukollu et al., 2011; Chen et al., 2014). In addition, the difference between remote sensing model estimates and *in situ* meteorological data methods can be as high as 50% of total annual averages (Jiménez et al., 2011; Mueller et al., 2011). Remote sensing, at least in these days, is not suitable for estimating the evaporation of small bodies of water such as ponds.

The Bowen Ratio Energy Budget (BREB) method was used to provide more accurate estimates as part of a detailed water budget study of the lake (Winter et al., 2003). Generally considered to be among the most robust and most accurate methods for determining evaporation (Harbeck et al., 1958; Gunaji, 1968; Sturrock et al., 1992; Lenters et al., 2005), BREB evaporation estimates are assumed to be within 10% of true values when averaged over a season, within 15% when averaged over a month (Winter, 1981) and at more than 30% of true values when averaged over a weekly to biweekly (Winter et al., 2003). Despite this margin of error in this method, the majority of studies without direct field measurements use the calculations of this method as reference values to evaluate the reliability of the other mathematical formulas in order to estimate the evaporation from meteorological data.

The fifth methodology to estimate the evaporation of water bodies is the direct measurement. The class A evaporation pan is the most used instrument to measure (or more precisely) to estimate the evaporation of shallow water bodies (Likens, 1985; Brutsaert & Yeh, 1976; Morton, 1983; Rimmer et al., 2009; Ponce, 1989). Evaporation pan measurements must be used with a limitation: the pan coefficient (multiplying the coefficient with the pan evaporation data to get lake evaporation) depends on season, location and the specific pan in use (Abtew, 2001).

At the end of this bibliographic research which allowed us to know the different methods used to study the evaporation of the water bodies, to show the strength, the weakness and the possibility of using each method, we found that, in order to obtain reference values for evaluating the various mathematical formulas that calculate evaporation from meteorological data, it not be better than direct daily measurements. But as we have seen before, the class A evaporation pan is always used with a correlation coefficient, because it has a considerable influence on water temperature. For this reason, our own evaporation pan has been built (transparent floating evaporation pan).

Our direct measurements have been carried out for two hydrological years. During the first year (August 2013-August 2014), the Cistude pond (shallow pond) was our field of study. Daily measurements were taken at 12:00. A meteorological station (Weather Monitor II) was installed 50 meters from the pond. During the second year (September 2014-August 2015), we measured evaporation at the Château pond (deep pond). Daily measurements were taken around 12:00 and a weather station was installed exactly at the edge of the pond. To measure the temperature of the water we used the water temperature recorder, it is Tinytag Data Loggers whose measuring range is -40 to 85 ℃. This tool provides us with hourly data on water temperature.

2.2 A Comparison between a Pan A and a New Floating Evaporation Pan

Two types of evaporation pans were used in our research. The first is a class A evaporation pan (metal pan) measuring 121.9 cm in diameter, its depth is 25.4 cm. The water depth is maintained between 7 and 5 cm from the edge (Figure 4). The second is a transparent floating evaporation pan. It is a transparent rectangular plastic pan measuring 52.5 cm x 36.5 cm from its upper side and 48.5 cm x 32.5 cm from its bottom side, its depth is 20 cm and its surface is about 0.2 m^2. It is placed directly in the water (Figure 5). The evaporation from the two pans is measured using a gauge hook, calibrated in millimeters on the central rod, the system allows an accuracy of 0.05 mm in our case. This gauge is placed in a stilling well of 10 cm in diameter.

Figure 4. The Class A Evaporation Pan

Figure 5. Transparent Floating Evaporation Pan

The main disadvantage of the transparent floating evaporation pan was its stability on the surface of the water during the days of high wind speed. To solve this problem, we installed two wooden barriers around the pan. The height of these barriers is 12 cm, half of which is immersed in water. These frames work to prevent waves from reaching the pan (Figure 5). The operation kept the surface of the water completely quiet in the direct surroundings of the floating pan. From that moment, we can obtain very reliable measurements with a margin of error not exceeding 0.05 mm even for days of very high wind speed.

Once the problem of the stability of the floating pan on the surface of water is solved, the only element to know the best evaporation pan is the influence of these instruments on the temperature of the water. Hence, we installed three thermometers (one in each pan and the third on the surface of the pond). After comparing the data of the thermometers we found the following results:

At the average daily water temperature scale, the floating pan has almost no influence on the water temperature compared to the water temperature of the pond and the correlation coefficient between the two temperatures is almost equal to 1 (R^2 = 0.997). On the other hand, the class A evaporation pan warms its water. The coefficient of correlation between the temperature of the water existing in this pan and that of the surface of the pond is less than the previous one (R^2 = 0.894) and it disturbs the evaporation measures taken by this type of evaporation pans. In fact, if we stop here, the floating pan is better than the metal pan to measure evaporation from small water bodies like ponds. But to be on the safe side, we consider that it will be more important and more precise to show the hourly variations of the water temperature in the floating pan, the metal pan and at the pond surface. Figure 6 shows the hourly variations of these data for the period from (05 August 1:00) to (15 August 2015 23:00).

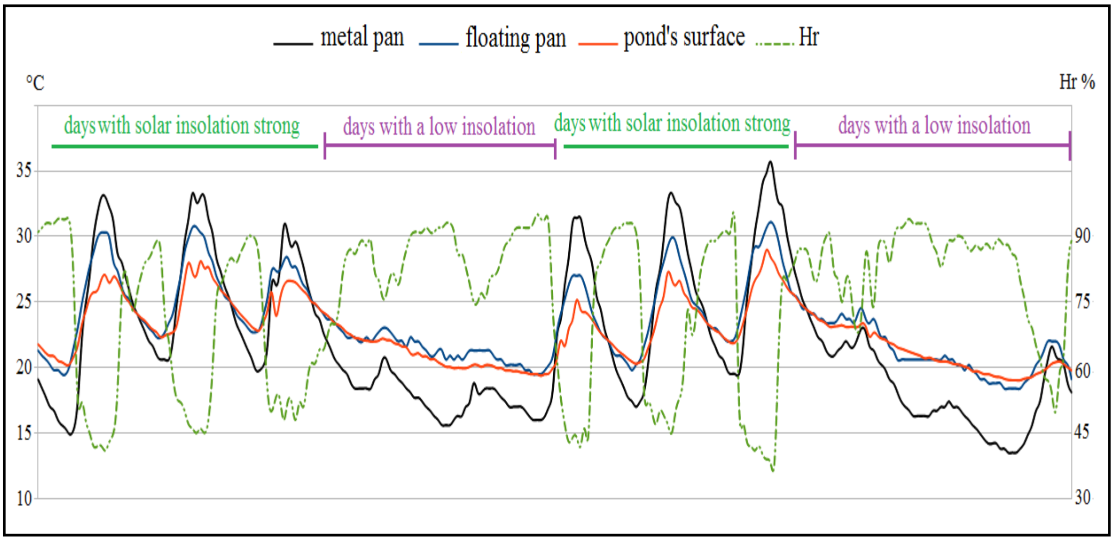

Figure 6. The Hourly Variations in the Relative Humidity and Water Temperatures of the Metal Pan, the Floating Pan and That of the Pond Surface for the Period (05 to 15 August 2015)

To deal with Figure 6 we will distinguish two cases: the first represents the sunny days, the second case represents the days of a dense cloud cover.

Starting with the first case (sunny days) we will also distinguish two cases, namely, the daytime period and the nighttime period. During the daytime the water temperature of the metal evaporation pan increases rapidly since the sun rise, it exceeds the temperature of the pond surface after only one hour from the reception of direct solar radiation. It is due to the low specific heat of the metal compared to that of water and the small amount of water existing in the evaporation pan compared to that of the pond. The temperature of the water in the metal pan continues to increase rapidly to record its highest values around 15:00 and 16:00 hours. Between 11:00 and 17:00 hours the water temperature of the class A evaporation pan greatly exceeds the pond surface temperature. Knowing that during this period the relative humidity registers its lowest values, we can say that it will considerably increase the rate of evaporation from the metal pan compared to that of the pond, in other words, the evaporation measured during the daytime period using the metal pan is overestimated compared to the real evaporation from the surface of the pond. Similarly, the temperature of the water in the floating evaporation pan increases since sunrise and exceeds that of the surface of the pond. The difference this time is lower compared to the class A evaporation pan. On the other hand, during the night time the water temperature of the metal pan decreases rapidly. Generally, two hours after sunset, the water temperature of the metal pan becomes lower than of the pond surface. Two hours before sunset the water temperature in the floating evaporation pan becomes almost equal to that of the pond surface temperature, until the end of the night. This equilibrium results from direct contact between the floating pan and the superficial layer of pond. Up to here, we can say that the floating evaporation pan is better than the Class A evaporation pan. We can also generalize this result to warm countries or, at least, to countries that have a dry and sunny season like the Middle East countries.

In the second case (days of heavy cloud cover) we notice that the differences between daytime and night time are very small. In this case, the difference between the water temperature in the floating pan and that of the pond surface is limited. So, we can say that the floating tank can give very reliable measurements of the evaporation from ponds during these days. The water temperature of the class A evaporation pan is always lower than that of the pond surface. So, he gives underestimated measures for these days. The reason for this difference between the temperature of the Class A pan and the pond superficial layer is presumably the thermal condition differences of the pan water as compared to pond water. The pan cannot store energy over this time period while the pond has significant energy storage capacity and can gain or lose energy through in and outflow. The pan, which was deployed on a raised platform, may have had enhanced advective heat flux through its sides and bottom.

From the comparison of the water temperatures, we can conclude that the water of the floating pan is practically in the same conditions as the pond water and that the measurement of the evaporation in this pan is probably very close to that of the pond. The class A evaporation pan, which gives different values, is probably a poorer indicator of the evaporation of the pond. The floating pan is the best instrument used in our research. We consider the evaporation measurements obtained through the transparent floating evaporation as our reference values.

2.3 The Mathematical Formulas Used to Calculate Evaporation

2.3.1 ‘‘Aldomany” a New Empirical Formula for Estimating the Evaporation from the Ponds and Shallow Water Bodies

After an experiment of more than 840 days of daily measurements, we are able to propose a new empirical formula for calculating evaporation from ponds and other shallow water bodies. The main objective of this new approach is to make available to everybody (experts and non-experts) a formula very easy to use to estimate the evaporation of the ponds.

This empirical formula is the result of two Multiple Linear Regressions (MLR) calculated using SPSS statistical software (version 22).

The first multiple linear regression was calculated between the evaporation measured during a complete hydrological year for a shallow pond (Cistude pond) and the five most important meteorological factors in the evaporation process that were collected at the edge of this pond.

$$E = 0,111\ Rs + 0,174\ T°w - 0,061\ T°a - 0,012\ Hr + 0,518\ V - 0,244 \quad (1)$$

where: *E* is evaporation in (mm/day); *Rs* is the solar radiation reaching the surface of the pond in (MJ/m²/day); *T°a* is the average daily temperature of the air in (°C); *T°w* is the average daily temperature of the water in (°C); *Hr* is the average daily relative humidity of the air in (%); *V* is the average wind speed in (m/s).

The second multiple linear regression was calculated between the evaporation measured during a complete hydrological year for a deep pond (Château pond) and the five most important meteorological factors in the evaporation process that were collected at the edge of this pond.

$$E = 0,115\ Rs + 0,185\ T°w - 0,032\ T°a - 0,032\ Hr + 0,021\ V + 1,953 \quad (2)$$

According to P. Bartout (2015), 61% of the ponds existing in the Limousin region (i.e., 13949 out of 22788) have a maximum depth of less than 2 meters (i.e., pellicular ponds) and 39% (i.e., 8839 out of 22788) have a maximum depth greater than 2 meters (i.e., deep ponds). We used these percentages to generalize our formula to the Limousin region.

So the formula "Aldomany" is the sum of 0.61 * (equation 1) + 0.39 * (equation 2) =>

$$E = 0,1 * Rs + 0,178 * T°w - 0,049 * T°a - 0,019 * Hr + 0,324 * V + 0,61 \quad (3)$$

It is very important to mention that for Aldomany formula and all the other mathematical formulas that require data on water temperature that is not always available, we can estimate the water temperature from that of the air using simple equations. According to our data collected *in situ* for two complete hydrological years, these equations vary according to the type of water body.

For shallow ponds (average depth less than one meter), the temperature of the superficial layer of water can be estimated according to the following equation:

$$T°w = 1,167\ T°a - 0,175 \quad (4)$$

For a deep pond (average depth exceeds two meters), the temperature of the surface layer of water can be estimated according to the following equation:

$$T°w = 0,955\ T°a + 2,367 \quad (5)$$

2.3.2 Seventeen Different Mathematical Formulas for Calculating Evaporation from Meteorological Data

In addition to Aldomany formula, we used seventeen different formulas to calculate evaporation, including five mass transfer formulas; six combination formulas; five simplified formulas and the formula of Bowen Ratio Energy Budget (BREB). Much of the mathematical methods used in this research exist in different formats in other scientific papers. This difference comes from the modifications we've made on the formulas that calculate monthly evaporation or those that calculate evaporation in inches per day to obtain evaporation in (mm per day). The following table shows the formulas used in this search. These formulas are explained in detail in the thesis of Aldomany (2017, pages 123 to 143).

Table 1. The Methods Used for Calculation of Evaporation

Method	Reference	Equation
BREB	Yao (2009)	$E = \frac{Rnet - S}{\lambda \times (1 + \beta)}$
Meyer	Aldomany (2017, p. 132)	$E = \alpha\,(1 + 0.01\,U)\,(es - ea)$
Rohwer	Aldomany (2017, p. 133)	$E = 19.558\,(1.465 - 0.0186\,P)\,(0.44 + 0.118\,U)\,(es - ea)$
Penman 1948 (mass transfer)	Aldomany (2017, p. 133)	$E = 8.89\,(1 + 0.24\,U)\,(es - ea)$
Romanenko	Aldomany (2017, p. 133)	$E = \alpha'\,(Ta + 25)^2\,(100 - H)$
Konstantinov	Aldomany (2017, p. 134)	$E = 0.61 * \left(\frac{Tw - Ta}{U}\right) + 4.22\,U * (es - ea)$
Penman 1948 (combination)	Penman (1948)	$E = \frac{\Delta}{\Delta + \gamma}\frac{Rnet - S}{\lambda} + 0.0026\,(1 + 0.54\,U')(1 - h)(esa \times 100)$
Penman-Monteith	Allen et al. (2006)	$E = \frac{0.428\,\Delta(Rnet) + \gamma\frac{900}{Ta + 273}U'(esa - er)}{\Delta + \gamma(1 + 0.34\,U')}$
Penman-Monteith modified	Aldomany (2013)	$E = \frac{0.428\,\Delta(Rnet) + \gamma\frac{900}{Tw + 273}U'(ess - er)}{\Delta + \gamma(1 + 0.34\,U')}$
Priestley-Taylor	Priestley and Taylor (1972)	$E = 1.26\frac{\Delta}{\Delta + \gamma}\frac{Rnet - S}{\lambda}$
Debruin-Keijman	Debruin and Keijman (1979)	$E = \frac{\Delta}{0.95\,\Delta + 0.63\,y}\frac{Rnet - S}{\lambda}$
Brutsaert-Stricker	Brutsaert and Stricker (1979)	$E = 1.52\frac{\Delta'}{\Delta' + \gamma'}\frac{Rn - S'}{\lambda'\rho}86.4 - \frac{\gamma'}{\Delta' + \gamma'}0.26(0.5 + 0.54\,U')(es' - ea')$
Jensen-Haise	Jensen and Haise (1963)	$E = (0.014((1.8\,Ta + 32) - 0.5)) \cdot (\frac{Rs}{\lambda'})$
Stephens-Stewart	McGuinness and Bordne (1972)	$E = [0.0082(Ta' - 1.19) \cdot (\frac{Rs'}{1500})]25.4$
Makkink	Hiemstra and Sluiter (2011)	$E = 0.65(\frac{\Delta}{(\Delta + \gamma)}) \cdot (\frac{Rs}{\lambda})$
Thornthwaite	Bouteldjaoui et al. (2011)	$E = 16(\frac{10Ta}{I})^{\alpha} \cdot f(m, \phi)$
Boyd	Aldomany (2017, p. 143)	$E = \frac{(9.94 + 5.039\,Ta) * 0.8}{n}$

Where:

E is evaporation (mm/day); $\mathbf{R_{net}}$ is the net radiation (MJ/m^2/day); **S** is the variation of the heat stored in the water (MJ/ m^2/day); **λ** is the latent heat of evaporation (MJ/m^2/day); **β** is the Bowen Ratio; **α** is a constant varies according to the number of days in a given month. It takes the following values (9.9786, 9.6345, 9.3133, 9.0129) for the months (February "28 days", February "29 days", the months of 30 days and the months of 31 days) respectively; **U** is the average daily wind speed in (miles per hour); **es** is the vapor pressure of saturated air at the water surface temperature (Inch of mercury); **ea** is the current pressure of the vapor in the air (Inch of mercury); **P** is the atmospheric pressure (Inches of mercury); **α'** is a constant varies according to the number of days in a given month. It takes the following values (6.43 * 10^{-5}, 6.21 * 10^{-5}, 6 * 10^{-5}, 5.81 * 10^{-5}) for the months (February "28 days", February "29 days", the months of 30 days and the months of 31 days) respectively; **Ta** is the average daily temperature of the air (℃); **H** is the relative humidity (%); **Tw** is the average daily temperature of the water surface (℃); **Δ** is the slope of the saturated vapor pressure-temperature curve at mean air temperature (kPa/℃); **γ** is a psychrometric "constant" (depends on temperature and atmospheric pressure) (kPa/°C); **U'** is the windspeed at 2 m above surface (m/s); **h** is the daily average of the relative humidity ($h \leq 1$); **esa** is the vapor pressure of saturated air at the air temperature (kPa); **er** is the current pressure of the vapor in the air (kPa); **ess** is the vapor pressure of saturated air at the water surface temperature (kPa); $\mathbf{R_n}$ is the net radiation (W/m^2); **S** is the variation of the heat stored in the water (W/m^2); **Δ'** is the slope of the saturated vapor pressure-temperature curve at mean air temperature (Pa/℃); **γ'** is a psychrometric "constant" (depends on temperature and atmospheric pressure) (Pa/℃); **λ'** is the latent heat of evaporation (MJ/kg); **ρ** is the density of water = 998 (kg/m^3) at 20 ℃; **es'** and **ea'** are respectively the saturation and current water vapor pressure at the air temperature (millibar); **Rs** is the solar radiation measured by the pyranometer of the weather station (MJ/m^2/day); **Ta'** is the average daily temperature of the air (℉); **Rs'** is the solar radiation measured by the pyranometer of the weather station (calorie/cm^2); **I** is an annual thermal index; **f(m, ϕ)** is a corrective factor depending on the month (m) and the latitude (ϕ); **n** is the number of days of the month concerned.

3. Results and Discussion

Direct measurements of evaporation for two hydrological years and on two different types of ponds in French Midwest shows that the evaporation process does not stop even for the coldest months of the year. Evaporation measured ranged from 0.05 to 8.3 mm/day and is on average of 2.6 mm/day during the 2013-2014 hydrological year from a shallow pond. It is ranged from 0.1 to 8 mm/day and averaged to 2.64 mm/day during the 2014-2015 hydrological year dedicated from a deep pond. Evaporation in our study area records its lowest values during the months of December and January. It reaches its highest values during the months of June and July. Due to the amount of water existing in each type of pond, the evaporation of shallow ponds is higher than deep ponds during the spring. On the other hand, because the solar energy stored in deep ponds is greater than that stored in shallow ponds, evaporation from deep ponds is higher than shallow ponds during the fall (Figure 7).

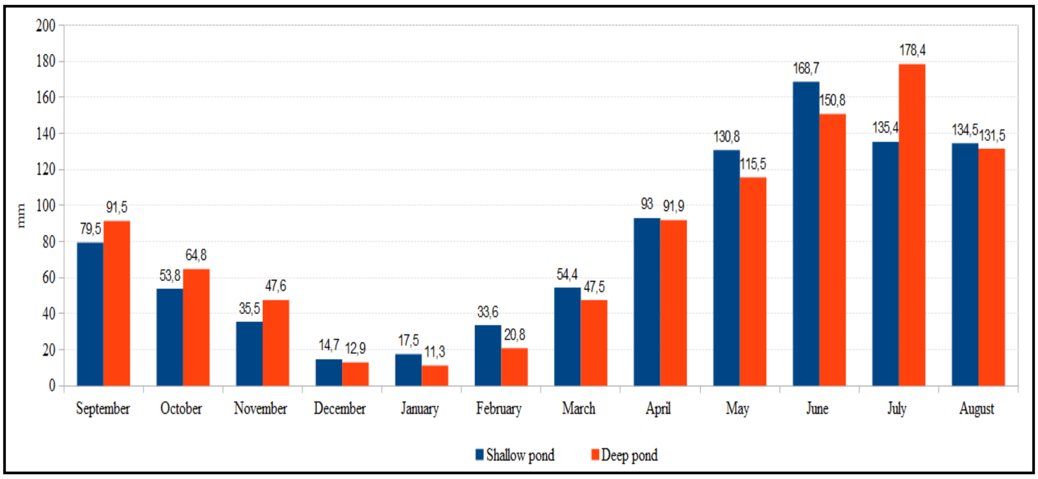

Figure 7. The Monthly Amounts of Evaporation Measured at the Cistude Pond (Shallow Pond) and at the Château Pond (Deep Pond)

On the both ponds studied, the annual sum of measured evaporation exceeds 950 mm. It was equal to 951.4 mm for the Cistude pond during the hydrological year (August 2013-July 2014) and 964.5 mm for the Château pond during the hydrological year (September 2014-August 2015). In fact, these values (951.4 mm and 964.5 mm) are among the highest for our region of study, because the comparison of the meteorological data measured at the edge of the ponds with the meteorological data of the last forty years from the Meteo-France stations close to these ponds, shows that the two years of measurements are among the hottest and sunniest years.

3.1 The Best Mathematical Method for Estimating the Ponds Evaporation

To find out the best mathematical method used in our research to estimate the ponds evaporation from meteorological data, we compared the evaporation measured by the transparent floating evaporation pan with the results of the 18 different methods at three time scales.

On an annual scale and without modifying any of the values calculated according to the 18 mathematical formulas we find that only three formulas give estimates within 10% of the measured evaporation 1- DeBruin-Keijman (+ 9.13 mm); 2- Priestley-Taylor (+ 48.81 mm); and 3- Aldomany (-52.93 mm). For this time scale, the majority of mathematical formulas (10 / 18) give estimates within (25%) of the annual sum of measured evaporation. Five methods give estimates at more than (25%) of the annual sum of evaporation measured, namely 1- Penman (mass transfer) (-226.59 mm); 2- Romanenko (-250.41 mm); 3- Meyer (-272.1 mm); 4- Stephens-Stewart (-290.86 mm); and 5- Rohwer (-295.06 mm).

Although the BREB method is often used as a reference method to evaluate the reliability of other methods, it has a deviation of 151.4 mm from the measured evaporation. This difference represents more than 15% of the annual evaporation, 5% greater than the percentage proposed by (Winter, 1981) at this time scale. “*BREB determined evaporation estimates are assumed to be within 10% of true values when averaged over a season*” (Winter, 1981).

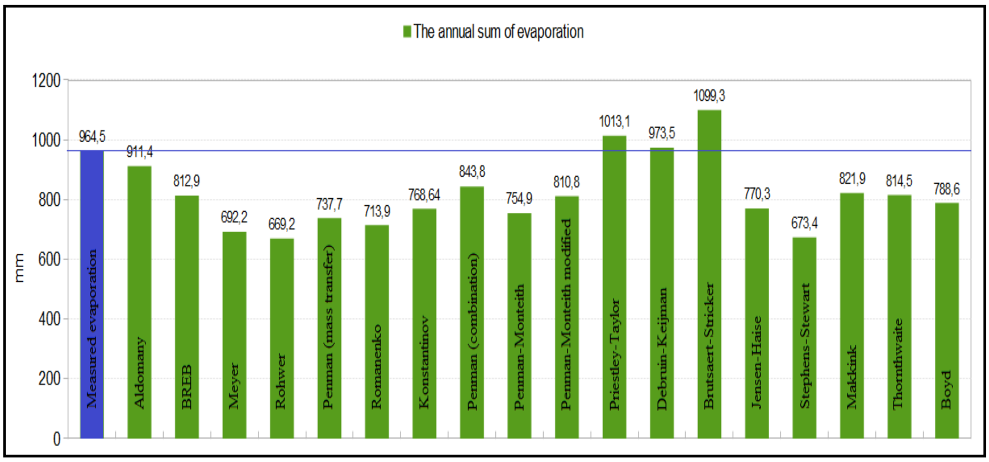

Figure 7. The Annual Sum of Measured and Calculated Evaporation at the Château Pond for the 2014-2015 Hydrological Year

The comparison between measured and calculated evaporation on a monthly scale shows that the reliability of mathematical methods varies from one month to another.

The Table 2 clearly shows that with the exception of Aldomany formula which gives estimates within 10% of the measured evaporation for 8 months/12 and estimates within 25% of the measured evaporation for 11 months out of 12, the majority of mathematical methods give results at more than 25% of the evaporation measured during the cold period of the year, more precisely, between October and January when the evaporation is normally low or very low. Therefore, a difference of five or six millimeters between the measured and calculated evaporation can represent more than 10% of the total evaporation of these months. On the other hand, most of the methods give results within 25% of the monthly sum of measured evaporation for the rest of the year. For this part of the year, especially for the months of June, July, August and September, evaporation is generally high. Therefore a difference of 15 mm between the measured and calculated evaporation can represent only a part less than 10% of the total evaporation of the month concerned of this period.

The comparison between measured and calculated evaporation on a monthly scale shows that simplified methods such as Makkink and Stephens-Stewart can give much better estimates than methods widely used in the scientific literature to estimate evaporation as the BREB method and the formula of Penman-Monteith.

Table 2. The Difference in (mm) between the Measured Monthly Evaporation and That Calculated at Cistude Pond for the 2013-2014 Hydrological Year

	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.
Aldomany	8.7	17.3	9.8	-8.64	-1.2	0.5	0.6	20.7	5.5	-7.8	-15.5	9.2
BREB	-8	-19.5	-38.5	-28.8	7.2	-8.5	-10.1	15.6	-16.7	-17.8	-15.4	-1.4
Meyer	-17	-5.7	-19	-19.4	-4.2	-10.6	-17.3	-9.4	-18.8	-37.7	-31.2	-10.8
Rohwer	-20	-11	-21	-19	-5	-11	-17	-11	-19	-28	-30	-11
Penman (M-T)	-7.9	-3.7	-17.5	-17.6	-3.8	-9.9	-15.5	-6.1	-12.4	-19.5	-16.7	1.5
Romanenko	-48.8	-13	-15.6	-12.2	-7	-5.8	-0.5	-8.3	-35.4	-71.8	-79	-55.8
Konstantinov	-5.4	1	6.3	-7.5	344.9	-20.2	-17.8	9.6	9.1	-4.7	-11.3	-1.5
Penman (C)	-12.7	-17.2	-36.2	-26.9	8.5	-6.3	-6.9	14.8	-18.9	-22.6	-21.5	-6.1
P-M	-28.6	-22.5	-34.7	-23.3	11.6	-3.4	-4.1	11.7	-23	-34.1	-42.5	-25.5
P-M modifided	-14.3	-15.1	-33.4	-23.7	8	-7.5	-7.9	16.4	-11.2	-13.6	-21.8	-7.9
P-T	18.5	-5.3	-34.7	-27	12.5	-5.9	-3.6	31	-1.2	5.1	16.7	27.4
D-K	12.2	-8.1	-35.3	-27	13.2	-5.9	-3.7	30.9	-2.6	2	8.8	19.4
B-S	35.6	-0.6	-37.5	-31.6	12.2	-9.6	-7	39.7	6	18.1	36.8	47.1
J-H	5.9	-8.3	-17.6	-26.7	-10.7	-9.7	-20.8	-16.6	-32.4	-43	-11.5	15.7
S-S	3.7	-1.1	-8	-15.8	5.4	1.2	-3.6	17.1	-7.1	-20.4	-16.4	2.5
Makkink	-3.8	-6.4	-11.1	-16.9	4.7	0.1	-5.4	13.1	-11.8	-26.4	-24.1	-4.5
Boyd	-34.6	6.13	18.1	5.2	14.8	19.2	4.2	-0.2	-20.7	-51.3	-66.6	-30.3
Thornthwaite	-26.3	0.2	6.4	-13.1	-2.1	4.8	-10.9	-18.6	-34.5	-55.2	-51.7	-7.8

Because we are looking for the most accurate method for estimating pond evaporation, we had to compare the daily evaporation measurements with the method results at the same time step.

Although several mathematical methods used in this research give estimates of evaporation below zero even during the hottest months of the year (for example: -2.3, -1.85, -3.4 mm per day), comparisons between measured and calculated evaporation at the annual and monthly scales are performed using the results obtained without making any corrections to calculations that may not be acceptable. If we can consider a value of (-0.9 mm per day) as a representative value for condensation during the months of December, January or February, a value of (-2.3 mm per day) is not, at all, acceptable to represent condensation during the months of August or July. After verifying that negative values of evaporation do not result from an error in the application of the mathematical formulas concerned and to avoid the erroneous influence of these negative values on the daily difference between measured and calculated evaporation, we estimate that the use of the Root Mean Squared Deviation (RMSD) is the best solution to solve this problem.

Table 3 shows the root mean square deviation between the measured evaporation and the calculated evaporation according to the 18 mathematical formulas used in this research. The RMSD cited in this table represents the average value of (365 days).

Table 3. The RMSD in (mm) between Measured and Calculated Evaporation at the Cistude Pond for the Period from August 14, 2013 to August 13, 2014

Method	Aldomany	BREB	Rohwer	Meyer	Penman (M-T)	P-M modified	Konstantinov	Penman (C)	PM
RMSD	0.52	1.37	0.79	0.76	0.69	1.04	2.14	1.3	1.15
Method	Romaninko	P-T	D-K	B-S	J-H	Makkink	Thornthwaite	Boyd	S-S
RMSD	1.07	1.66	1.61	2.06	0.87	0.64	0.86	0.93	0.64

Table 3 shows that half (9/18) of the methods used have a RMSD within 1 mm of measured evaporation. The empirical formula of Aldomany has the lowest RMSD (0.52 mm/day). In second place come the Stephens-Stewart and Makkink methods with a RMSD of (0.64 mm/day). In fourth place comes the oldest formula proposed by Penman (Penman-mass transfer) with a RMSD of (0.69 mm/d). The RMSD of the formulas of Meyer and Rohwer equal to 0.76 and 0.79 mm/day. Although these two methods give very far estimates of real evaporation at monthly and yearly scales. Their RMSD is not very high because they do not give negative results during the evaporation calculation. Despite the Thornthwaite method who only requires data on air temperature, it gives more better results than most of the methods using data on the majority of climatic factors that control the evaporation process. Three methods have a RMSD close to one millimeter per day (Boyd, Penman-Monteith modified using surface water temperature instead of air temperature and the method of Romaninko). A RMSD is slightly larger of one millimeter for the standard Penman-Monteith formula using air temperature and for the Penman combination formula.

In fact, what surprised us when analyzing the data is that the BREB method, which is often used as a reference method to evaluate the reliability of other methods in the absence of direct measurements, has a high RMSD and was not among the best method neither on an annual scale nor on a monthly scale. The DeBruin-Keijman and Priestly-Taylor methods have a large RMSD. The main cause of the large difference between these three methods and the measured evaporation comes from the negative results of evaporation obtained by these methods even during the hottest months of the year.

4. Conclusions and Perspectives

This paper shows three important facts too often underestimated up to now in limnology. The first one is technical: until these days there is no better than direct measurements to obtain reference values of evaporation from small water bodies such as ponds.

This research confirms that the evaporation measurements carried out by the transparent floating evaporation pan are closer to the actual evaporation of the ponds, because this tool, with the exception of the daytime period of the day of very high insolation, has almost no influence on the water temperature. So, these measurements have to be used as reference values to evaluate the reliability of mathematical methods to calculate evaporation from meteorological data.

The second one is practical for local managers: the comparison between measured evaporation and calculated evaporation according to 18 different methods shows that the new empirical formula of Aldomany is the best formula that we can use to estimate the evaporation of common ponds existing in the French Midwest, because it takes into consideration all the meteorological factors that control the evaporation process including the water temperature. At the annual scale, Aldomany formula succeeded in giving an estimate within 5.5% of measured evaporation; on a monthly scale, it gave estimates within 10% of measured evaporation for 8 months/12 and estimates within 25% for 11 months/12; on a daily scale, this formula has the smallest RMSD (0.52 mm/d). Knowing that the average daily evaporation of the study period was equal to (2.64 mm/d), this means that the Aldomany formula gives estimates within 20% of the measured evaporation on this time scale.

The modified Penman-Monteith formula, which uses the water surface temperature instead of the air temperature, gives results closer to the direct measurements at the three time intervals (annual, monthly and daily) than the original formula which uses the air temperature.

This research also shows that several simplified methods can give better estimates than those obtained by methods commonly used in the scientific literature to calculate the evaporation of water bodies such as the methods of BREB, Penman-Monteith and others.

The third one is for managers who are working on water balance management and more generally hydrosystems: this paper shows that the evaporation of a shallow pond is quantitatively and temporally distinct from a deep pond, itself distinct from a lacustrine evaporation. So the models built for lacustrian countries will not work for ponds ones; It is therefore a question of adapting the recommendations to the real objects present in the territory.

All of these results then allow us to look at the potential. For the practical part, it is very important to note that the Aldomany formula must be tested on other ponds (with various sizes, especially on larger ponds) of the same region and in other regions where the climatic conditions are different to confirm or, perhaps, to invalidate its functioning.

For the management part, with these “reliable” estimates of evaporation, we will continue our research by comparing the amount of water lost by ponds through evaporation and that lost by other types of land use (Forests and wet plains) via the evapotranspiration and the interception. We believe that such a comparison will enable us to know if a pond exists in a humid ocean climate, losing less or more water by evaporation than a wetland or a forest by evapotranspiration. The results of this comparison will help to confirm or invalidate that ponds are primarily responsible for water loss especially during the summer period, idea generally used by managers of these water bodies when they implemented the WFD recommendations without correct data.

References

Abtew, W. (2001). Evaporation estimation for Lake Okeechobee in South Florida. *Journal of Irrigation and Drainage Engineering, 127,* 140-147. https://doi.org/10.1061/(ASCE)0733-9437(2001)127:3(140)

Afanas'ev, A. N. (1976). *Vodnye resursy i vodnyj balans bessejna ozera Bajkal* (p. 240). Novosibirsk, Nauka.

Aldomany, M. (2013). *L'évaporation des étangs: Le cas du Centre-Ouest de la France* (p. 129). Mémoire de Master 2, Univ. d'Orléans.

Aldomany, M. (2017). *L'évaporation dans le bilan hydrologique des étangs du Centre-Ouest de la France (Brenne et Limousin)* (p. 332). Université d'Orléans, Thèse de doctorat en géographie.

Aldomany, M., Touchart, L., Bartout, P., & Nedjai, R. (2013). The evaporation of ponds in the French Midwest. *Lakes, Reservoirs and Ponds, Romanian Journal of Limnology, Bucharest*, *7*(2), 75-88. http://www.limnology.ro/Lakes/2013/201307206.pdf

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (2006). *Crop evapotranspiration-Guidelines for computing crop water requirements: Irrigation and Drainage Paper No. 56* (p. 300). United Nations Food and Agriculture Organization, Rome, Italy.

Anderson, E. R., & Pritchard, D. W. (1951). P*hysical limnology of Lake Mead. San Diego, California, US Navy Electronics Laboratory, Report 258, Problem NEL 2J1* (p. 152).

Assouline, S., & Mahrer, Y. (1993). Evaporation from Lake Kinneret 1: Eddy correlation system measurements and energy budget estimates. *Water Resources Research*, *29*(4), 901-910. https://doi.org/10.1029/92WR02432

Assouline, S., Tyler, S. W., Tanny, J., Cohen, S., Bou-Zeid, E., Parlange, M. B., & Katul, G. G. (2008). Evaporation from three water bodies of different sizes and climates: Measurements and scaling analysis. *Advances in Water Resources*, *31*, 160-172. https://doi.org/10.1016/j.advwatres.2007.07.003

Bartout, P. (2015). *Les territoires limniques. Nouveau concept limnologique pour une gestion géographique des milieux lentiques* (p. 444). Université d'Orléans, Thèse d'HDR en géographie.

Bartout, P., & Touchart, L. (2013). L'inventaire des plans d'eau français: Outil d'une meilleure gestion des eaux de surface. *Annales de Géographie*, *691*, 266-289. https://doi.org/10.3917/ag.691.0266

Bartout, P., & Touchart, L. (2015). La stabilité limnique dans le bassin de la Vienne: La place des plans d'eau au sein des milieux et des sociétés depuis le XIXe siècle. *Norois*, *234*, 65-82. https://doi.org/10.4000/norois.5581

Bartout, P., Touchart, L., Terasmaa, J., Choffel, Q., Marzecova, A., Koff, T., ... Aldomany, M. (2015). A new approach to inventorying bodies of water, from local to global scale. *Die Erde, Journal of the Geographical Society of Berlin*, *146*(4), 245-258.

Beltrando, G. (2004). *Les climats. Processus, variabilité et risques* (p. 261). Paris, Armand Colin.

Bouchardeau, A., & Lefèvre, R. (1957). *Monographie du lac Tchad* (p. 112). Paris, Orstom.

Boulard, D. (2016). *Capacité d'une chaîne de modélisation hydroclimatique haute résolution à simuler des indices de déficit hydrique: Application aux douglasaies et hêtraies de Bourgogne* (p. 198). Univ. Bourgogne, Thèse de doctorat en Géographie (Climatologie).

Bouteldjaoui, F., Bessenasse, M., & Guendouz, A. (2011). *Etude comparative des différentes méthodes d'estimation de l'évapotranspiration en zone semi-aride (cas de la région de Djelfa)* (pp. 109-116). Nature et Technologie.

Brunet, Y., Nunez, M., & Lagouarde, J. P. (1991). A simple method for estimating regional evapotranspiration from infrared surface temperature data. *ISPRS Journal of Photogrammetry and Remote Sensing*, *46*, 311-327. https://doi.org/10.1016/0924-2716(91)90062-Z

Brutsaert, W. H., & Yeh, G. T. (1976). Implications of a type of empirical evaporation formula for lakes and pans. *Water Resources Research*, *6*, 1202-1208. https://doi.org/10.1029/WR006i004p01202

Brutsaert, W., & Stricker, H. (1979). An advection-aridity approach to estimate actual regional evapotranspiration. *Water Resources Research*, *15*(2), 443-450. https://doi.org/10.1029/WR015i002p00443

Carlson, T. N., Gillies, R. R., & Perry, E. M. (1994). A method for making use of thermal infrared temperature and NDVI measurements to infer water content and fractional vegetation cover. *Remote Sensing Reviews*, *9*(1), 161-173. https://doi.org/10.1080/02757259409532220

Céréghino, R., Biggs, J., Oertli, B., & Declerck, S. (2008). The Ecology of European ponds: Defining the characteristics of a neglected freshwater habitat. *Hydrobiologia*, *597*, 1-6. https://doi.org/10.1007/s10750-007-9225-8

Chen, Y. et al. (2014). Comparison of satellite-based evapotranspiration models over terrestrial ecosystems in China. *Remote Sensing of Environment*, *140*, 279-293. https://doi.org/10.1016/j.rse.2013.08.045

Choudhury, B. J., Reginato, J. R., & Idso, S. B. (1986). An analysis of infrared temperature observations over wheat and calculation of latent heat flux. *Agricultural and Forest Meteorology*, *37*, 75-88. https://doi.org/10.1016/0168-1923(86)90029-8

Choudhury, B. J., Idso, S. B., & Reginato, J. R. (1987). Analysis of an empirical model for soil heat flux under a growing wheat crop for estimating evaporation by an infrared-temperature based energy balance equation. *Agricultural and Forest Meteorology*, *39*, 283-297. https://doi.org/10.1016/0168-1923(87)90021-9

Craig, H., & Gordon, L. I. (1965). Deuterium and oxygen 18 variations in the ocean and the marine atmosphere. In E. Tongiorgi (Ed.), *Stable isotopes in oceanographic studies and paleotemperatures* (pp. 9-130). Proceedings of the Spoleto Conferences in Nuclear Geology, Lischi e F., Pisa.

DeBruin, H. A., & Keijman, J.-Q. (1979). The Priestley-Taylor evaporation model applied to a large, shallow lake in the Netherlands. *J. Appl. Meteorol.*, *18*, 898-903. https://doi.org/10.1175/1520-0450(1979)018%3C0898:TPTEMA%3E2.0.CO;2

Diak, G. R. (1990). Evaluation of heat flux, moisture flux and aerodynamic roughness at the land surface from knowledge of the PBL height and satellite-derived skin temperature. *Agricultural and Forest Meteorology*, *52*, 181-198. https://doi.org/10.1016/0168-1923(90)90105-F

Diak, G. R., & Whipple, M. A. (1993). Improvements to models and methods for evaluating the land-surface energy balance and "effective" roughness using radiosonde reports and satellite-measured "skin" temperatures. *Agricultural and Forest Meteorology*, *63*, 189-218. https://doi.org/10.1016/0168-1923(93)90060-U

Dinçer, T. (1968). The use of oxygen-18 and deuterium concentrations in the water balance of lakes. *Water Resources Researche*, *4*(6), 1289-1306. https://doi.org/10.1029/WR004i006p01289

Dirmeyer, P. A., Gao, X., Zhao, M., Guo, Z., Oki, T., & Hanasaki, N. (2006). GSWP-2: Multimodel analysis and implications for our perception of the land surface. *Bulletin of the American Meteorological Society*, *87*, 1381-1397. https://doi.org/10.1175/BAMS-87-10-1381

Ebaid, H. M. I., & Ismail, S. S. (2010). Lake Nasser evaporation reduction study. *Journal of Advanced Research, Cairo University*, *1*, 315-322. https://doi.org/10.1016/j.jare.2010.09.002

Friedl, M. A. (1996). Relationships among remotely sensed data, surface energy balance, and area-averaged fluxes over partially vegetated land surfaces. *Journal of Applied Meteorology*, *35*, 2091-2103. https://doi.org/10.1175/1520-0450(1996)035%3C2091:RARSDS%3E2.0.CO;2

Gash, J. H. C. (1987). An analytical framework for extrapolating evaporation measurements by remote sensing surface temperature. *International Journal of Remote Sensing*, *8*, 1245-1249. https://doi.org/10.1080/01431168708954769

Gat, J. R. (1970). Environmental isotope balance of Lake Tiberias. *Isotopes in Hydrology, IAEA, Vienna*, 151-162.

Gat, J. R., & Bowser, C. (1991). The heavy isotope enrichment of water in couplet evaporative systems. In: Stable Isotope Geochemistry: A Tribute to Samuel Epstein. *The Geochemical Society*, *3*, 159-168.

Gibson, J. J. (2002). Short-term evaporation and water budget comparisons in shallow Arctic lakes using non-steady isotope mass balance. *Journal of Hydrology*, *264*, 242-261. https://doi.org/10.1016/S0022-1694(02)00091-4

Gibson, J. J., Edwards, T. W. D., Bursey, G. G., & Prowse, T. D. (1993). Estimating evaporation using stable isotopes: Quantitative results and sensitivity analysis for two catchments in northern Canada. *Nordic Hydrol*, *24*, 79-94.

Gonfiantini, R. (1986). Environmental isotopes in lake studies. In P. Fritz, & J. C. Fontes (Eds.), *Handbook of environmental isotope geochemistry* (pp. 113-168). The Terrestrial Environment. 2, Elsevier, Amsterdam.

Haddeland, I. et al. (2011). Multimodel estimate of the global terrestrial water balance: Setup and first results. *Journal of Hydrometeorology*, *12*, 869-884. https://doi.org/10.1175/2011JHM1324.1

Hiemstra, P., & Sluiter, R. (2011). *Interpolation of Makkink evaporation in the Netherlands*. Royal

Netherlands Meteorological Institute, Ministry of Infrastructure and the Environment, 32 p. + Annexes.

Hope, A. S., Petzold, D. E., Goward, S. N., & Ragan, R. M. (1986). Simulated relationships between spectral reflectance, thermal emissions, and évapotranspiration of a soybean canopy. *Water Resources Bulletin*, *22*(6), 1011-1019. https://doi.org/10.1111/j.1752-1688.1986.tb00772.x

Ikebuchi, S., Seki, M., & Ohtoh, A. (1988). Evaporation from Lake Biwa. *Journal of Hydrology*, *102*, 427-449. https://doi.org/10.1016/0022-1694(88)90110-2

Jackson, R. D., Reginato, R. J., & Idso, S. B. (1977). Wheat canopy temperature: A practical tool for evaluating water requirements. *Water Resources Research*, *13*(3), 651-656. https://doi.org/10.1029/WR013i003p00651

Jensen, M. E., & Haise, H. R. (1963). Estimating evapotranspiration from solar radiation. Proceedings of the American Society of Civil Engineers. *Journal of the Irrigation and Drainage Division*, *89*, 15-41.

Jiménez, C. et al., (2011). Global intercomparison of 12 land surface heat flux estimates. *Journal of Geophysical Research*, *116*, D02102. https://doi.org/10.1029/2010JD014545

Joly, D., Brossard, T., Cardot, H., Cavailhes, J., Hilal, M., & Wavresky, P. (2010). *Les types de climats en France, une construction spatiale* (pp. 1-24). Cybergeo: European Jornal of Géography, Cartogaphie, Imagerie, SIG.

Krabbenhoft, D. P., Bowser, C. J., Anderson, M. P., & Valley, J. W. (1990). Estimating groundwater exchange with lakes 1. The stable isotope mass balance method. *Water Resource Researche*, *26*, 2445-2453. https://doi.org/10.1029/WR026i010p02445

Lemoine, E., & Le Bihan, V. (2010). *Valeurs d'usages et de non usages des étangs piscicoles en France* (p. 125). Itavi-Lemna.

Lenters, J. D., Anderton, J. B., Blanken, P., Spence, C., & Suyker, A. E. (2013). Assessing the Impacts of Climate Variability and Change on Great Lakes Evaporation. In D. Brown, D. Bidwell, & L. Briley (Eds.), *2011 Project Reports*. Available from the Great Lakes Integrated Sciences and Assessments. (GLISA) Center.

Likens, G. E. (1985). *An Ecosystem Approach to Aquatic Ecology: Mirror Lake and its Environment* (p. 16). Springer-Verlag, New York.

Mayr, C. et al. (2007). Precipitation origin and evaporation of lakes in semi-arid Patagonia (Argentina) inferred from stable isotopes (δ18O, δ2H). *Journal of Hydrology*, *334*, 53-63. https://doi.org/10.1016/j.jhydrol.2006.09.025

McGuinness, J. L., & Bordne, E. F. (1972). *A comparson of lysimeter derived potential evapotranspiration with computed values* (p. 71). Technical Bulletin 1452, US Department of Agriculture Agricultural Research Service, Washington, DC.

Morton, F. I. (1983). Operational estimates of lake evaporation. *Journal of Hydrolgy*, *66*, 77-100. https://doi.org/10.1016/0022-1694(83)90178-6

Mueller, B. et al. (2011). Evaluation of global observations-based evapotranspiration datasets and IPCC AR4 simulations. *Geophysical Research Letters*, *38*, L06402. https://doi.org/10.1029/2010GL046230

Mügler, I., Sachse, D., Werner, M., Xu, B., Wu, G., Yao, T., & Gleixner, G. (2008). Effect of lake evaporation on δD values of lacustrine n-alkanes: A comparison of Nam Co (Tibetan Plateau) and Holzmaar (Germany). *Organic Geochemistry*, *39*, 711-729. https://doi.org/10.1016/j.orggeochem.2008.02.008

Neumann, J. (1953). Energy balance and evaporation from sweet water lakes of the Jordan Rift. *Bulletin of the Research Council of Israel*, *2*, 337-357.

Nicod, J., & Rossi, G. (1979). Données nouvelles sur l'hydrologie du lac Victoria. *Annales de Géographie*, *488*, 459-466.

Penman, H. L. (1948). Natural evaporation from open water, bare soil and grass. *Proceedings of the Royal Society, London Ser A*, *193*, 120-145. https://doi.org/10.1098/rspa.1948.0037

Ponce, V. M. (1989). *Engineering Hydrology, Principles and Practices*. Prentice Hall, Englewood Cliffs, NJ.

Price, J. C. (1982). *Estimation of regional scale evaporation through analysis of satellite thermal-infrared data*. IEEE Trans. Geosci. Remote Sens.

Priestley, C. H. B., & Taylor, R. J. (1972). On the assessment of surface heat flux and evaporation using large-scale parameters. *Mon. Weather Rev.*, *100*(2), 81-92. https://doi.org/10.1175/1520-0493(1972)100%3C0081:OTAOSH%3E2.3.CO;2

Rimmer, A., Samuels, R., & Lechinsky, Y. (2009). A comprehensive study across methods and time scales to estimate surface fluxes from Lake Kinneret, Israel. *Journal of Hydrology*, *379*, 181-192. https://doi.org/10.1016/j.jhydrol.2009.10.007

Riou, Ch. (1975). *La détermination pratique de l'évaporation* (p. 228). Application à l'Afrique centrale, Paris, Mémoire Orstom.

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. https://doi.org/10.1016/j.jhydrol.2007.03.018

Seguin, B., & Itier, B. (1983). Using midday surface temperature to estimate daily evaporation from satellite thermal IR data. *Int. J. Remote Sens.*, *4*(2), 371-383. https://doi.org/10.1080/01431168308948554

Seguin, B., Assad, E., Freaud, J. P., Imbernon, J., Kerr, Y. H., & Lagouarde, J. P. (1989). Use of meteorological satellites for rainfall and evaporation monitoring. *Int. J. Remote Sens.*, *10*, 847-854. https://doi.org/10.1080/01431168908903948

Sima, S., Ahmadalipour, A., & Tajrishy, M. (2013). Mapping surface temperature in a hyper-saline lake and investigating the effect of temperature distribution on the lake evaporation. *Remote Sensing of Environment*, *136*, 374-385. https://doi.org/10.1016/j.rse.2013.05.014

Stannard, D. I., & Rosenberry, D. O. (1991). A comparison of short-term measurements of lake evaporation using eddy correlation and energy budget methods. *Journal of Hydrology*, *122*, 15-22. https://doi.org/10.1016/0022-1694(91)90168-H

Tanny, J., Cohen, S., Assouline, S., Lange, F., Grava, A., Berger, D., … Parlange, M. B. (2008). Evaporation from a small water reservoir: Direct measurements and estimates. *Journal of Hydrology*, *351*, 218-229. https://doi.org/10.1016/j.jhydrol.2007.12.012

Vinukollu, R. K., Meynadier, R., Sheffield, J., & Wood, E. F. (2011). Multi-model, multi-sensor estimates of global evapotranspiration: Climatology, uncertainties and trends. *Hydrological Processes*, *25*, 3993-4010. https://doi.org/10.1002/hyp.8393

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. https://doi.org/10.4236/jwarp.2009.12010

Zuber, A. (1983). On the environmental isotope method for determining the water balance of some lakes. *Journal of Hydrology*, *61*, 409-427. https://doi.org/10.1016/0022-1694(83)90004-5