IMPLEMENTATION OF SOME CALCULATION METHODS OF THE EVAPORATION IN THE CATCHMENTS OF PRUT AND BÂRLAD RIVERS

STAN FLORENTINA[1], NECULAU GIANINA[2]

ABSTRACT. Implementation of some calculation methods of the evaporation in the catchments of Prut and Bârlad rivers. Evaporation is a key element in achieving the water balance within a catchment, without which there is no possibility of making a judicious exploitation of water resources. It is important to be aware of this parameter, especially in dry periods and in those with intense vegetation, in order to estimate the necessary amount of water in atmospheric and soil drought. For this reason, the catchments of Prut and Bârlad rivers were chosen, as they are located in an area vulnerable to drought and because it is essential to know the evaporation in such a region. Obtaining the values of this parameter directly can be made in few places in the country; therefore it is imperative to use indirect methods, too. As a result, this study aimed at the estimation of the evaporation by using several calculation methods and its analysis in comparison with the values obtained directly.

Keywords: potential evaporation, areas vulnerable to drought, methods of calculation

1. INTRODUCTION

Evaporation is a complex hydrometeorological parameter, independent of vegetation and soil characteristics of an area. Evaporation is the most difficult to estimate of all hydrometeorological parameters, since its measurement involves the understanding of several parameters such as: air temperature, precipitations, relative humidity of the air, solar radiation, wind speed, sunshine duration, etc. In Romania the evaporation is a less known climatic parameter. Acquaintances about this parameter are found in synthesis papers on national level like : *Atlasul Climatic al R.S.R.* (1966), *Atlas. Republica Socialistă România* (*sectiunea IV – Clima*, 1972 – 1979), *Clima Republicii Populare Române* (1962 – 1966) and more recently, *Clima României* (2008). Many researchers established calculation methods for the synthetic calculation of this parameter, which include different ratios of essential atmospheric factors, in determining the evaporation process (solar radiation, air temperature, saturation deficit, the wind). The most used methods, both nationally and internationally were: the thermal or radiative balance method (Penman method), methods based on air temperature, (Thornthwaite, Blaney-Criddle, Priestley-Taylor

[1] National Institute of Hydrology and Water Management, Bucharest, Romania, e-mail: florentina.stan@hidro.ro

[2] National Institute of Hydrology and Water Management, Bucharest, Romania, email: gianina.neculau@hidro.ro

methods), methods based on saturation deficit (Papadakis method) and methods based on several climatic factors (Turc method). Most of these methods involve a number of parameters that are not generally measured at the evaporimetric or meteorological stations within the national network, therefore they cannot be used in practice.

Within this paper, for determining the evaporation were chosen the following methods: Thornthwaite, Penman, Priestley – Taylor, Penman - Monteith and FAO. The estimation of the evaporation using various mathematical methods was required, because of the quite pronounced variation of this parameter. The values resulting from the applying of these methods, so called (by Penman,Thornthwaite) potential evaporation were analyzed and compared with the evaporation rate from the water body, those obtained by direct measurements at the evaporimetric stations within the analyzed catchments. The selection of the best model for determining the potential evaporation was based on minimizing the error between the potential evaporation (determined by the methods which are mentioned above) and the actual evaporation (determined by direct measurements made at evaporimetric stations).

2. GENERAL GEOGRAPHICAL FEATURES OF THE EXAMINED CATCHMENTS

The catchments of Prut and Bârlad Rivers overlap the Moldovian Plain and the Eastern extremity of the Bârlad Plateau (Fig. 1).

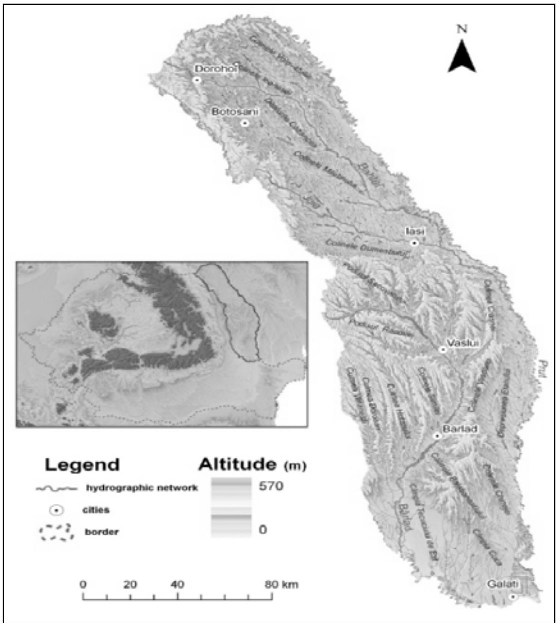

Fig. 1. Morphometric map of the catchments of Prut and Bârlad Rivers and their location within the country

The geographical position of the examined catchments, describe generally a relief with medium altitudes below 200 m, having a wide opening to East and Northeast. The presence of the dominant orographic frame with heights of 300 m to West and South has a part in the emergence of climate features, which are slightly different from the other subunits of the Extra-Carpathian Moldova.

Analysis of hydrometeorological elements (Fig. 2) determined during the evaporation process defined the temperate climate with shades of aridity within the research area. Due to the interaction among the adequate processes and those of local circulation, generated by heat balance of the active area, the air temperature can go over 35°C during summer and in exceptional cases it can reach 40°C (Huşi 40,2°C - July 1938), whereas during winter it falls down in all the subunits of the Plateau, below –25°C, even below –30°C, in the North –32°C, value recorded in February 1911 (Vartolomei, 2008). Multiannual average temperature is of 9°C in the Central and Southern part of the catchment and of 9,5°C in the South-Eastern extremity at altitudes below 50 m, and in the Northern part it can reach 8°C.

Because of its position within the extra-Carpathian region, away from the influence of the Atlantic air masses, wide opened to the air masses action of East, Northeast and North continental origin, the catchments of Prut and Bârlad rivers receive annual quantities of moderate precipitations. In the Northeast part of the area, that is frequently exposed to föhn processes, the quantities of precipitations are low, ranging generally from around 500 mm (564 mm in the North, to Iaşi 529,4 mm) and in the South (Southeast area), they are close to 600 mm. Drought is a common phenomenon within the studied area, taking place especially in late summer and during autumn.

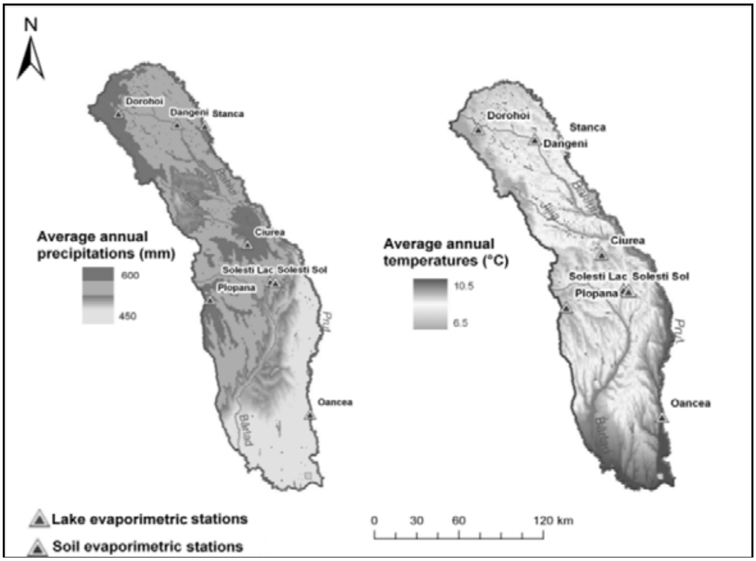

Fig. 2. The map of precipitations and temperatures of the catchments of the Prut and Bârlad Rivers

3. DATA AND METHODS

The performed analyzes are based on the harnessing of the hydrometeorological data series obtained by direct measurements at six evapometric stations of Prut and Bârlad Rivers catchments. From an evapometric point of view, the basin area is poorly equipped and for this reason the Dorohoi and Plopana evapometric stations were taken into account too, even if they had been working until 2006. The valorized hydrometeorological data were obtained from the National Institute of Hydrology and Water Management and they are represented by the following parameters: evaporation, air temperature (average values, maximum and minimum, monthly or annual values), precipitations, wind speed, sunshine duration, relative humidity, all of which are average, annual and monthly values recorded during 1961-2012 at six evapometric stations, and during 1961-2006 at Dorohoi and Plopana evaporimetric stations (Table 1).

Table 1. Analyzed evapometric stations

No.	Analyzed stations	Period of analysis	Altitude (m)
1.	Solesti	1961-2012	113
2.	Oancea	1961-2012	14
3.	Dangeni	1961-2012	150
4.	Stanca	1961-2012	90
5.	Ciurea	1961-2012	120
6.	Plopana	1961-2006	250
7.	Dorohoi	1961-2006	240

Since the evaporation from the water surface (measured parameter at the level of the evaporimeters GGI-3000) is made only during the months having a clear surface, without ice, such as in the period from March to November, then the calculated evaporation (potential) was determined by different methods in the same interval, obtaining thus average, monthly, multiannual values.

Methodologically speaking, this work is based on statistical analysis of the values of the actual evaporation and on the implementation of some calculation methods of the potential evaporation: Penman, Penman – Monteith, FAO, Thornthwaite, Priestley–Taylor.

The term of "potential evaporation" was introduced by **Penman**(1) in 1948, his method of calculation being the most used at global scale, and its success is due to its physical composition (Xu, 2002). Penman method is based on the study of the energetic balance and is showed as follows:

$$E_o = ET = \frac{\Delta}{\Delta+\gamma} H + \frac{\Delta}{\Delta+\gamma} E_a \qquad (1)$$

Where:ET (mm day^{-1}) is evapotranspiration, Δ (mb°C^{-1}) represents the slope of the saturation vapor pressure temperature relationship, γ (mb °C^{-1}) is the psychrometric constant, $E_a = 0.35(0.5 + u_2/100)(e_a - e_d)$, u_2(miles day^{-1}) is the wind speed (1mile = 1609 m), e_a(kPa) is the saturation vapor pressure and e_d(kPa) is the actual vapor pressure, H is the available heat energy and it is calculated from incoming (R_I) and outgoing (R_O) radiation determined from sunshine records, temperature and humidity, using: $H = R_i(1 - r) - R_o$, where r is the albedo and equals 0.05 for water.

The **Penman-Monteith**(2) method has the following equation (Allen et al. 1998):

$$ET_o = \frac{(R_n - G)\Delta + \frac{\rho_a c_p (e_s - e_a)}{r^a}}{\lambda[\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)]} \qquad (2)$$

Where: ET_o (mm day^{-1}) is reference evapotranspiration, R_n(MJ m^{-2} day^{-1}) is the net radiation, G (MJ m^{-2} day^{-1}) is the soil heat flux, (e_s - e_a) (kPa) represents the vapour pressure deficit of the air, ρ_a(kg m^{-3}) is the mean air density at constant pressure, c_p(kJ kg^{-1} °C^{-1}) is the specific heat of the air, Δ (kPa °C^{-1}) represents the slope of the saturation vapour pressure temperature relationship, γ (kPa °C^{-1}) is the psychrometric constant, and r_s(s m^{-1}) and r_a(s m^{-1}) are the (bulk) surface and aerodynamic resistances.

Since, data on r_a and r_s can hardly be determined, Food and Agriculture Organization of the United Nations – **FAO**(3) recommended a new method to calculate the potential evaporation (ETo), showed as indicated (Allen et al., 1998):

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \qquad (3)$$

Where: ET_o(mm day^{-1}) is reference evapotranspiration, R_n(MJ m^{-2}day^{-1}) is net radiation at the crop surface, G (MJ m^{-2}day^{-1}) soil heat flux density, T (°C) is mean daily represents air temperature at 2 m height, U_2(m s^{-1}) represents wind speed at 2 m height, e_s(kPa) saturation vapour pressure, e_a(kPa) actual vapor pressure, (es–ea) (kPa) saturation vapour pressure deficit, Δ (kPa °C^{-1}) represents the slope vapor pressure curve, and γ (kPa °C^{-1}) psychrometric constant.

A simplified version of the Penman equation has been suggested since 1972 by **Priestley and Taylor**(4) and this can be used when it comes to surfaces generally wet, based on solar radiation. The aerodynamic composition was removed and the energetic composition was multiplied by a coefficient α = 1.26 (Xu, 2002):

$$ET = \alpha \frac{\Delta}{\Delta + \gamma} \frac{R_n}{\lambda} \qquad (4)$$

Where: ET (mm day^{-1})represents potential evaporation, R_n (cal cm^{-2} d^{-1}) is the net radiation, λ (cal g^{-1}) is latent heat, Δ (mb°C^{-1}) is the slope of saturation vapour pressure curve ($\Delta = 33.8639[0.05904(0.00738T_a + 0.8072)^7 - 0.0000342]$), and γ (mb°C^{-1}) is the psychromatic constant ($\gamma = \frac{C_p P}{0.622\,\lambda}$), coefficient α = 1.26.

Thornthwaite(5) method consists on determining the evaporation using the meteorological parameters: average temperature of the air and the theoretical duration of insolation (NMA, 2008). The calculation of the potential evaporation using this method is presented as follows:

$$\mathrm{ETP} = 16 * (\frac{10\mathrm{t}}{\mathrm{I}})^{\mathrm{a}}\ \mathrm{F}\,(\lambda) \qquad (5)$$

Where: t is mean monthly air temperature (°C); I represent annual heat index,$\mathrm{I} = \sum_{n=1}^{12} i_n$and $i_n = (\frac{t}{5})^{1.514}$; a=6.75*10^{-7}*I^3-7.71*10^{-5}*I^2+1.79*10^{-2}*I+0.49; F(λ) is correction term which depend on latitude and month of the year (from tables).

Thornthwaite and Penman methods were applied by Donciu (1965) in our country during a more distant and non-homogenous period, because of the lack of direct observations, more precisely from 1896 to 1955. Within this study the same methods are used by collecting data belonging to a larger and homogenous period, such as from 1961 to 2012.

4. RESULTS

Statistical analysis of the values regarding the actual evaporation led to the followings aspects: within the two analyzed catchments the average, multiannual evaporation has values between 900 mm at the evaporimetric station Soleşti and 650 mm at the evaporimetric station Ciurea (Fig. 3); among the basic laws of spatial distribution of evaporation, the effect of vertical zonality is highlighted as well as the slopes exhibition against the prevailing atmospheric circulation and the humidity decrease from West to East, at the same time with the increasing continentality.

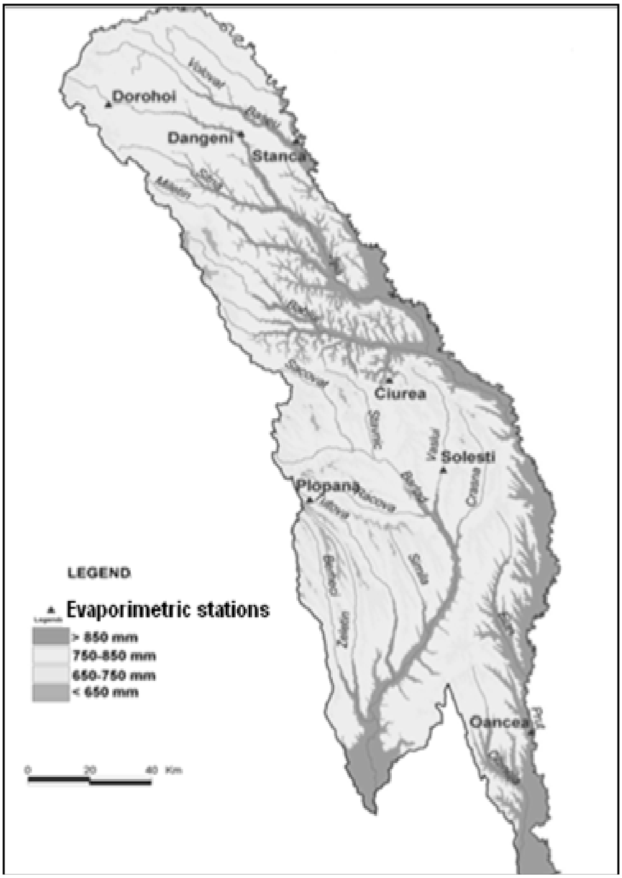

Fig. 3. Evaporation distribution from water surface of Prut and Bârlad catchments

After applying the above mentioned methods it results that the obtained values differ one from another considerably. The best results (the methods that are the closest to the actual evaporation) are given by the FAO method, as concerns the other differentiated methods; these are more significant (Table 2).

Table 2. The values of potential evaporation (average, multiannual values) determined by different calculation methods

Applied methods	Evaporimetric Stations Analized						
	Dorohoi	**Dângeni**	**Stânca**	**Ciurea**	**Plopana**	**Soleşti**	**Oancea**
Actual evaporation	709.2	745.8	864.3	669.8	786.2	926.4	858.6
Penman-Monteith	538.9	530.9	506.7	549.7	537.9	565.6	590.6
FAO	**706.1**	**731.9**	**823.0**	764.4	**778.3**	780.1	**822.9**
Penman	630.1	630.6	645.1	**659.9**	678.0	668.1	705.5
Thornthwaite	647.7	650.9	531.4	672.5	558.9	**847.4**	413.5
Priestley -Taylor	806.0	917.4	734.3	854.4	437.5	706.5	707.6

The formulas that use only the average temperature (Thornthwaite) in calculations are inadequate because these overestimate the potential evaporation during the periods with precipitation deficit, and they underestimate it during wet climates. Similarly the formulas based on net radiation and wind speed (Penman) overestimate the evaporation occurring during wet seasons or climates, and underestimate that of dry seasons and climates. From the analyses performed in the Prut – Bârlad catchments, they concluded that the FAO method enables the application everywhere there is data on temperature, air humidity, wind and sunshine duration; there was no need of direct records of radiation, that are available in a lesser extent.

To highlight the differences among the evaporation values determined by direct measurements and those determined by calculation, the errors for each evaporimetric station were established (Table 3 and Fig. 4).

Table 3. Errors among the measured values and those calculated by different methods

Methods	Dorohoi	Dângeni	Stânca	Ciurea	Plopana	Soleşti	Oancea
Penman-Monteith	24.0	28.8	41.4	17.9	31.6	38.9	31.2
FAO	0.4	1.9	14.8	14.1	1.0	15.8	4.2
Penman	11.2	15.4	25.4	1.4	13.8	27.9	17.8
Thornthwaite	8.7	12.7	38.5	1.9	28.9	8.5	51.8
Priestley -Taylor	13.6	23.0	15.0	27.6	44.4	23.7	17.6

The errors belonging to FAO method are between 0.4 and 15.8%, while the error of Priestly_Taylor methods can reach up to 44%.The errors were processed according to the method(6) used by Xu and Chen (2005):

$$Error(\%) = \frac{ET_{cal}-ET_{obs}}{ET_{obs}} \text{x}100 \qquad (6)$$

Where: ETcal (mm) is calculated evapotranspiration and ETobs (mm) is observed evapotranspiration.

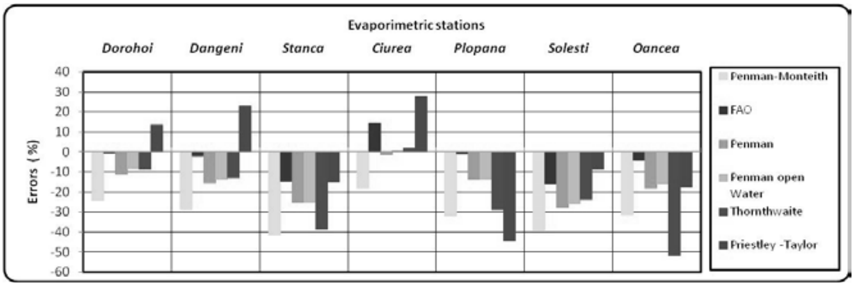

Fig. 4. Distribution of errors emerged among the measured and calculated values

5. CONCLUSIONS AND PERSPECTIVES

The results of the study enable the usage of the direct data from the seven analyzed stations. They have immediate and practical application in providing evaporation data for the hydraulic and hydro-ameliorative works. For the analyzed catchments, the FAO method arises some deviations; consequently its application is suggested to calculate the evaporation in this area. In the future we want to apply the methods described within this study, as well as within other case studies in order to establish a method suitable to the specific physical-geographical conditions at a regional level.

REFERENCES

1. Allen, R., Pereira, L., Raes, D., Smith, M. (1998), *Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56*, Rome;
2. Donciu, C. (1965), *Contribuţii la studiul evapotranspiraţiei potenţiale în R.S. România*, Meteorologie, Hidrologie şi Gospodărirea Apelor, vol. X, nr. 9, Bucureşti;
3. Vartolomei, F. (2008), *Bazinul Prutului - Studiu de Hidrologie*, Teza de doctorat, Universitatea din Bucureşti, Facultatea de Geografie;Xu, C-Y (2002), *Hydrologic Models*, Uppsala University Department of Earth Sciences Hydrology;
4. Xu, C-Y., Chen, D. (2005), *Comparison of seven models for estimation of evapotranspiration and groundwater recharge using lysimeter measurement data in Germany*,Hydrological Processes 19, 3717–3734;
5. * * * Administraţia Naţională de Meteorologie (ANM), 2008 : Clima României, Editura Academiei Române, Bucureşti, 365 p.
6. * * * National Meteorological Administration (2008), *Clima României*, Editura Academiei Române, Bucureşti.
7. * * * Academia Română, 1972 – 1979: Atlas. Republica Socialistă România (sectiunea IV – Clima), Editura Academiei, Bucureşti, 188 p.
8. * * * Institutul Meteorologic (IM), 1962 - 1966: *Clima Republicii Populare Române*, Bucureşti, 166 p.
9. * * * Institutul Meteorologic (IM), 1966: *Atlasul Climatic al R.S.R.*, Bucureşti, 189 p.