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THE ANALYSIS OF EVAPOTRANSPIRATION IN CONSTANTA IN THE INTERVAL OF TIME 1970-1995

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Abstract

The evapotranspiration is one of the components of hydrological cycle. This element is essential in calculus of hydrological water balance, design water works, determination of climate change, water resources planning and management. The aim of this study is to analyze the measured and estimated evapotranspiration at a station in Constanta. In order to estimate the evapotranspiration four methods were used: Thornthwaite, Hargreaves, Turc and Priestley and Taylor. The results of these equations were compared with observed evaporation. We used the data recorded in the interval of time 1970-1995. For these years, we were given: the annual medium temperatures and the monthly measured evapotranspiration.

Key Words: *evapotranspiration, solar radiation, temperatures.*

INTRODUCTION

The concept of evapotranspiration provides a convenient index to represent or estimate the maximum water loss to the atmosphere.

The evapotranspiration represents the process of losing water through direct evaporation (E) and through the perspiration of the plants (T) (Nagy, 1982; Luca and others., 2008).

The total consumption of water is synonymous with the term evapotranspiration This term is used in climatology and it is noted with $\sum(e + t)$ or ET (Botzan, 1972, Luca and others, 2008).

Regarding this phenomenon, the following difference must be highlighted between the terms below:

a. Real evapotranspiration (E.T.R.)

-This represents the realized water consumption of agricultural crops in normal conditions of water supply met in nature.

b.Maximum real evapotranspiration (E.T.R.M.)

- This represents the total water consumption of agricultural crops in optimum water supply conditions. This consumption ensures optimum moisture for the obtaining of a maximum agricultural production in economic conditions.

c. Potential evapotranspiration (E.T.P.)

- This represents the total water consumption of agricultural crops which forms the vegetal cover with high density, low waist, uniform, in full development and with water from abundance. (Luca, 2010).

The evapotranspiration or the total water consumption of a culture is influenced by a series of factors which are classified as following (Popescu, 1978):

-Climatic factors: wind, radiations, precipitations etc.;

-Pedagogical factors which are needed for the water supply of the plants;

-Biological factors specific for the vegetation which are used to compare the plants morphologically as well as physiologically, determining them to consume more or less water.

The evapotranspiration (ET) is an important factor which determines not only the growth of the plants and the carbon assimilation, as well as the most important element of the water circuit in nature.

ET has a large practical applicability because allows the evaluation of the additional water content in the atmospheric and pedospheric drought through a system of irrigation which ensures the conditions for a normal vegetation. By knowing the quantities of precipitations of a region and the potential ET, the water overflow or deficit from the soil can be determined so that the hydric balance could be established.

Estimates of PET are necessary in many of the rainfall-runoff and ecosystem models that are used in global change studies.

The increase of evapotranspiration together with the reduction of the percolation and the infiltration spillages leads to soil drought and as a direct result of the growth of ET are the physiological drought, the reduction of plant's growing development, fires etc. According these results, a social-economical drought can be identified and it's composed of three impacts: economic, social and environmental. The socio-economic drought is associated with lack of belongings and services which has its origins in the meteorological and hydrological drought. It occurs at different scales and has the effects at a regional or national scale after a long period of severe meteorological droughts (Barbu, Popa, 2001).

Description of the analyzed area

Streamflows, water quality, and ecosystem processes can respond substantially to small changes in precipitation or evapotranspiration.

This is especially true for the coastal regions where evapotranspiration is the dominant factor on surface and ground water flow patterns. Thus, it is important to identify the differences among the evapotranspiration methods when evapotranspiration is used to predict the actual evapotranspiration, because different evapotranspiration methods give widely different annual values at particular locations as demonstrated in previous studies (Federer *and others*, 1996).

For this evapotranspiration study, we used recorded data from a meteorological station from Dobrogea specifically the one from Constanta (Photo no.2).

Dobrogea (Photo no.2) is limited to the north of the Danube Delta and Macin Mountains, east of the Black Sea and west of the lower Danube. This includes in the northeast of Bulgaria, Dobrich and Silistra regions.

Photo no.2 The location of the meteorological and rain meter stations from Dobrogea(by Lungu M.,2008 and modified by Popescu A.)

Photo no.1. Dobrogea's region and the coastal area of the Black Sea (www.maps.google.ro, modified by Popescu A)

This morphological unit from the valley of the Danube, the Black Sea and Bulgaria border area consists of the following relief:

-Dobrogea mountains are found between the Danube valley and Babadag;

-North Dobrogea Plateau between the Danube Dobrudja Mountains, Black Sea and South Dobrogea Plateau;

-South Dobrogea Plateau between North Dobrogea Plateau, the Danube, the Black Sea and the border with Bulgaria.

Most of Dobrogea region has an arid climate with high average temperatures (10^o-11^{o}C), high summer temperatures (22^o-23^{o}C), low rainfall (around 400mm/an), tropical days and frequent droughts. The chill wind is frequent and in the winter is frosty and dry at summer. The coastal climate is influenced by Pontic moderate heat with stronger sunstroke and daytime breezes.

Dobrogea is divided into two sectors regarding the type of climate. The western part of Dobrogea has a temperate continental climate, while the east side has a seaside or coastal climate.

Temperate continental climate supports three external influences as a consequence of "the buffer "between the adjacent continental land surrounding it to the north, west and south and the Black Sea to the east: continental influences, Pontic and respectively the advection of air (www.mdrt.ro/PATZzona costiera faza III.pdf).

The unique feature of Dobrogea maritime climate is given by the presence of the paramarine sea and lakes, it's lack of thermal extremes throughout the year, a much higher air humidity in the warm interval compared with the continental areas and the existence of local movements of air masses, type breezes. Due to the predominantly western air circulation, the moderating influence of the Black Sea is felt only on a wide strip of 20-25 kilometers along the shoreline (www.scribd.com/Strategia-de-Conservare-a-Biodiversitatii-Costiere).

Coastline or coastal climate has meteorological parameters differences based on the geographical location, never the less with common features like: thermal amplitudes lower than on the mainland, higher humidity, and sea and land breezes (Teodoreanu, 2002).

Due to the influence of marine waters, the evolution of annual air temperature in the coastal area exists a delay phase of heating and cooling. Autumn is warmer and cooler in the spring than in Central Dobrogea, in October the average temperature is 3 to 4.5 ^{0}C higher than in April. (www.scribd.com/ Strategia-de-Conservare-a-Biodiversitatii-Costiere).

Consistent with outside influences, the air temperature is moderate, being yet in the coastal zone, the largest in the country.

Average annual temperatures are higher than the national values average of 11.2 ° C (in the north) and 11.5 (South); average temperature for the period from June to August is around 21°C and the period December-February about 1°C(www.mdrt.ro/ PATZzonacostierafazaIII.pdf).

Summers are very hot and dry (average temperature in July is + 22 ° C), while winters have moderate temperatures (average temperature in January is - 2°C). Due to the high values of solar radiation and how air masses of continental and maritime origin shift, coastal climate is warm and drier (www.scribd.com/Strategia-de-Conservare-a-Biodiversitatii-Costiere).

Rainfall is more abundant in the south than the north coast, the aspect is determined of the existence of a large areas covered with water at Cape Midia, which contributes in the summer months the air to descent and reduces the formation process of cumuliform cloud from which could possibly fall precipitation (www.scribd.com/Strategia-de-Conservare-a-Biodiversitatii-Costiere).

Average annual quantities in the coastal zone are between 400-450 mm (411 mm Constance in 2008). During the year, annual maximum rainfall according the monthly average is recorded in June (45-55 mm) and a minimum in February (18-35 mm) with the same west-east decreasing trend.

On the coast, there is secondary maximum in November-December but with smaller values (30-40mm) determined by the Mediterranean and pontic cyclones from this period (www.mdrt.ro/PATZzonacostierafaza III.pdf).

The largest rain quantities fall in April and May and in autumn in September and November. A low level of rainfall are recorded in Julie and August and there are moths with many days of clear sky (29-31) but with a high probability of torrential rains (www.scribd.com/Strategia-de-Conservare-a-Biodiversitatii-Costiere).

MATERIAL AND METHODS

There are approximately 50 methods or models available to estimate PET, but these methods or models give inconsistent values due to their different assumptions and input data requirements, or because they were often developed for specific climatic regions (Grismer *et al.*, 2002). Past studies at multiple scales have suggested that different PET methods may give significantly different results (Crago and Brutsaert, 1992; Amatya *et al.*, 1995; Federer *et al.*, 1996; Vörösmarty *et al.*, 1998).

The four evapotranspiration methods selected in this comparison study are commonly used and require relatively fewer input requirements.
In determining the evapotranspiration from Dobrogea, we considered a time interval between the years 1970-1995, using monthly average temperatures for each year and monthly measured evapotranspiration.
The values of ET were compared with the calculated values through four methods:

a) Thornthwaite method

Thornthwaite method is more adapted in the temperate moist areas, in dry climate and it has the tendency to underestimate the values of the evapotranspiration (Musy and others, 1992).
The method is based on the correlation between the water consumption of a crop and the air temperature. According to recent studies made in our country (Botzan and Merculiev, 1966; Pleşa and Florescu 1974; Grumeza,Merculiev and others, Kleps, 1989) it had come to the conclusion that the obtained results with this method, based on the air temperature, it is more accurate and approximates with the results obtained in the field (Luca, 2010).
The expression of evapotranspiration with Thornthwaite method is:

$$\boldsymbol{ETP} = 1,6 \cdot \left(\frac{10}{I}\right)^{a} \cdot t^{a} \cdot \mathrm{f}$$

were:
ETP – monthly evapotranspiration (mm);
I – the annual heat index is defined as the sum of monthly heat indices *I*,

$$\boldsymbol{I} = \sum_{ian}^{dec} i\,, \qquad i = \left(\frac{\mathrm{t}}{5}\right)^{1,514}$$

t – average monthly temperature (°C);
a – coefficient based on *I*, determined by the following formula:
a = $(0,0675 \cdot I^2 - 7,71 \cdot I^2 + 1792 \cdot I + 49239) \cdot 10^{-5}$
f – factor based on the real duration of the month f = N · ρ;
N – real duration of the month (days);
ρ – parameter which depends on the number of days in one month ρ= n/ (30 · 12);
n – the astronomical duration of one day (hours).

b) Metoda Heargreaves (1975)

A number of investigations compared the estimates for ET with different models. Heargreaves equation produces correct estimations of the potential of the evapotranspiration and in some cases, much more correct estimations result from using another methods (http://www.civil.uwaterloo.ca/watflood/Manual/02_03_1.htm).
This empirical model is based on the temperature and the solar radiation as it follows:

$$\boldsymbol{ET} = K \cdot R_a \cdot (T + 17,8) \cdot \sqrt{T_{max} - T_{min}}$$

$$\boldsymbol{R_a} = 0,408 \cdot R_a(MJ \cdot m^2 \cdot zi^{-1})$$

where:
ET- evapotranspiration (mm/zi);
k- coefficient with the value 0,023;
Ra- extra-terrestrial radiation;
$\mathbf{T_{max}}$- maximum temperature;
$\mathbf{T_{min}}$- minimum temperature.

c) Modelul Turc (1961)

Turc's formula is applicable in all climate zones. It has an error of 10% in arid and humid areas where evapotranspiration values exceed 20% (Musy and others, 1992).
In Turc's formula are introduced two variables such as: solar radiation and relative humidity. In its simplified form, the formula is written for the monthly and decay calculation as it follows (Maftei, 2004):

$$\mathbf{ETP} = 0,4 \cdot (R_s + 50) \cdot \frac{t}{t + 15}$$

$$\mathbf{ETP} = 0,13 \cdot (R_s + 50) \cdot \frac{t}{t + 15}$$

where:
Rs – global solar radiation or short wavelength radiation monthly or decadal (calc/cm²*day).

$$\mathbf{R_s} = R_a \cdot \left(a + b \cdot \frac{n}{N}\right)$$

t – average temperature of the period considered (ºC);
$\mathbf{R_S}$ – extra-terrestrial radiation (calc/cm²j);
N – astronomical time of day (hours/month or decade);
n – actual duration of bright of the sun (hours/month or decade)
a, b – coefficients depending on climate zone (a= 0,24 and b= 0,5).

d) Priestley and Taylor method (1972)

Priestley and Taylor model is a modification of Penman's equation, which is more theoretical.

An empirical approximation of Penman's equation was made by Priestley and Taylor and it eliminates the need to input data but instead to rely on solar radiation.
It is assumed that under ideal conditions, ET will have eventually a steady rate for air mass moving over a vegetation layer with high water intake. The air mass becomes saturated and the ET's actual rate will be equal to the potential rate of Penman's ET. Priestley and Taylor found that the ET derived from areas with abundant vegetation and increased moisture is generally higher than the equilibrium potential rate
(http://www.civil.uwaterloo.ca/watflood/Manual/02_03_1.htm).
Priestley and Taylor found that the ET derived from well-stocked with water vegetation was higher than the equilibrium potential rate and it could be estimated using the α (albedo) factor.
This model of equation is used for areas with low humidity and it's described as following:

$$\boldsymbol{\lambda ET} = k \cdot \frac{\Delta \cdot R_n}{\Delta \cdot \gamma}$$

$$\boldsymbol{\lambda} = 2{,}501 - 2{,}361 \cdot 10^3 \cdot t$$

$$\Delta = \frac{4098 \cdot [0{,}6108 \cdot \exp\left(\frac{17{,}27 \cdot t}{T + 237{,}3}\right)]}{(T + 237{,}3)^2}$$

$$\boldsymbol{R_{ns}} = (1 - \alpha) \cdot R_s$$

where:
Δ – slope of saturation water vapor.
$\boldsymbol{\gamma}$ **-** psychometric constant (0,66 h Pak).
$\mathbf{R_n}$ – net radiation ($MJn^{-2}zi^{-1}$);
λ – latent heat of vaporization (MJ/kg);
k – coefficient = 1,26;
α – albedo= 0,25.
The reason why these models are successful is due to the theories they reflect. Compared with Penman's equation, models take into account the solar radiation and average amount of energy lost as heat in the amount available for evapotranspiration.

RESULTS AND DISCUSSIONS

The ET was calculated with four methods (Thornthwaite, Haregreaves, Turc and Priestey and Taylor), on an annual and multiannual basis for the period 1970-1995. We took into account the measured ET values between the years mentioned for each month separately. Therefore, a real and accurate comparison could be made between the calculated values and the measured ones.
The minimum values of ET are recorded in winter months (January, February and December) and the maximum values are recorded in summer months (June, July, August).
Because we had 25 years to analyze, the graphics for all the years were too large to include them in the article, so we enclosed them in the annex 1 and 2. For the determination of which method is more efficient in the determining of evapotranspiration, we chose only 5 years (1991-1995). We made four graphs which include all five years (1991 -1995) for each method as follows:

a. Thorntwaite Method

Thornthwaite method is a method for arid areas. As it shows the graph in Photo no.3 we used monthly average measured evapotranspiration for years between 1991-1995 and monthly values of evapotranspiration calculated by this method for each year separately. The Photo no. 3 shows that the calculated ET presents similar values in all five years analyzed (1991-1995).

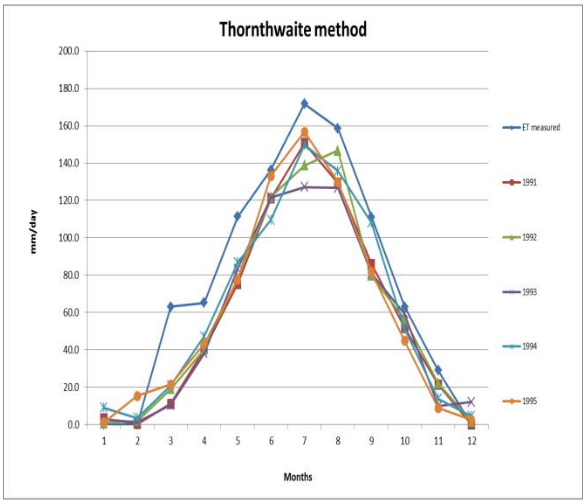

Photo no. 3 The analysis of ET with Thorntwaite method (1991-1995**)**

After analyzing the maximum values of the calculated ET, we can notice that there is considerable difference between the maximums recorded. The maximum measured ET has a value of 171.7 mm/day in July and the maximum calculated ET was of 156.8 mm/day

in 1995. The difference between these two values is of 14.97 mm/day and the percentage is of 8.72%.
The average values of the calculated ET for all five years (493.91 mm/day) differs with 22.43% meaning 142.85 mm/day from the average of the measured ET for this time interval (636.76 mm/day)

b. Haregreaves Method

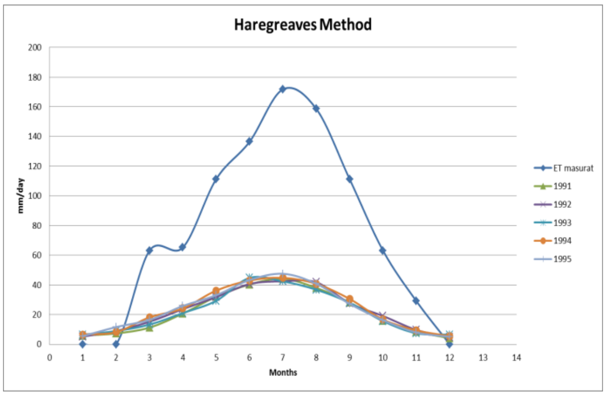

Photo no. 4 The analysis of ET with Haregreaves method (1991-1995**)**

Regarding the Haregreaves method, the maximum values of calculated ET were recorded in June-July in 1995, and the most significant was of 47.47 mm/day, being with o percentage of 72.35% lower than the measured ET which recorded a value of 171.73 mm/day.
The difference between the annual average of the measured evapotranspiration of 636.76 mm/day and the calculated ET with a value of 269.98 mm/day was 366.78 mm/day which means that the measured ET is with 57.60% bigger that the calculated one. From this percentage we can determine that the method does not have a very large accuracy coefficient.

c. Turc Method

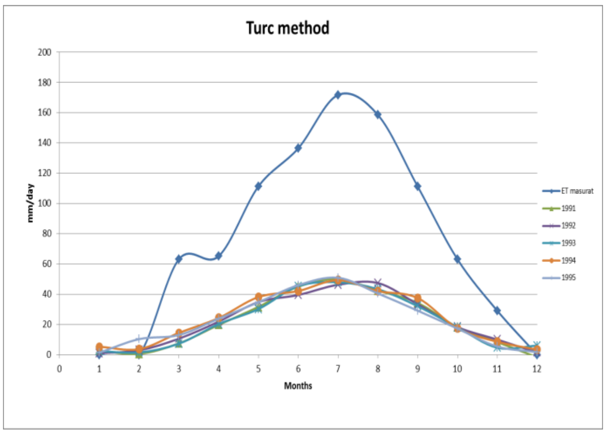

Photo no. 5 The analysis of ET with Turc method (1991-1995**)**

According the Photo no. 5, the calculated ET differs very much from the measured one. In 1995, in July, the calculated ET reached the value of 50.85 mm/day which means that is with 70.38% lower than the measured ET which recorded a value of 171.73 mm/day.
At the Turc method, there is a significant difference between the annual average of the measured and calculated ET with a value of 367.82 mm/day. According to the percentage, the measured ET is with 57.76% bigger that the calculated one.

d. Priestley – Taylor Method

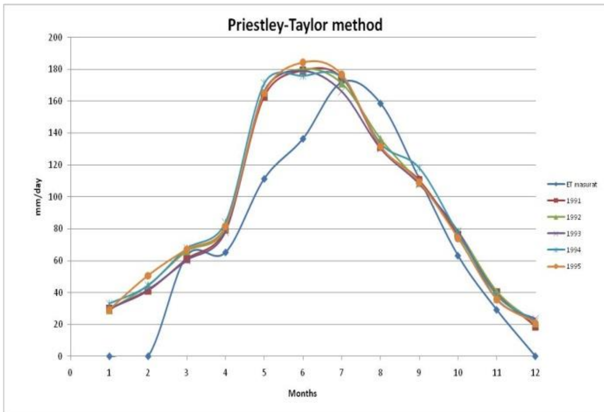

Photo no. 6 The analysis of ET with Priestley-Taylor method (1991-1995**)**

Regarding this method, the maximum values of the calculated ET were recorded in June-July and the largest value was in 1995 of 184.4 mm/day which means that the calculated ET is with 26.01% bigger that the measured ET.
The minimum value was recorded in December 1991 and it was 18.78 mm/day.
At this method too, there is significant difference between the annual average of the measured and calculated ET with a value of 481.92 mm/day, the last mentioned being with 43.05% bigger.

CONCLUSIONS

The current study suggests that evapotranspiration is difficult to estimate accurately and should be used with caution for estimating actual water loss from natural systems.
This commonly used evapotranspiration methods for this comparison study gave a wide range of values.
From the results obtained from this study it is revealed that evapotranspiration measured

values are higher than those calculated, and the differences were significant for all studied years between the period of time 1970-1995.

Because we had 25 years to analyze, the graphics for all the years were too large to include them in the article, so we enclosed them in the annex 1 and 2. For the determination of which method is more efficient in the determining of evapotranspiration, we chose only 5 years (1991-1995). We made four graphs which include all five years (1991 -1995) for each method

For Thornthwaite method the measured average of annual evaporation is 142.85 mm/day higher than the calculated average evapotranspiration for the years 1991-1995.

The difference between the average of annual measured and calculated evapotranspiration for Hargreaves method was 366.78 mm/day, so evapotranspiration measured is 57.60% higher than the calculated one. For Turc method, this difference was 367.82 mm/day (representing a percentage of 57.76%).

In case of Priestley-Taylor method the calculated annual averages of evapotranspiration has exceeded the measured ones, the difference being 481.92 mm/day, which represents a percentage of 43.05%.

We conclude that the methods Hargreaves, Priestley-Taylor and Turc do not have a very high coefficient of accuracy for this region, the differences between calculated and measured values being very high. Hargreaves and Turc gave much lower values than the reference ones, while Priestley-Taylor method exceeded by far the reference ones.

On the other hand, Thornthwaite method was able to lead to the best results with greater accuracy, demonstrating that this is a more efficient method for calculating evapotranspiration for arid areas.

We note that in the winter evapotranspiration is low do the the fact that when the temperature is 0 or below 0, according to the formulas at all the methods used, the ETP will be also 0.

With the weather warming, the growing season starts, so the evapotranspiration records a continuous growth and a peaking point in June and July. Physiological processes decrease with cool weather, vegetation a transpiration decrease, which leads to a decrease of the evapotranspiration.

The knowledge and study of evapotranspiration values leads over time to the implementation of a drought monitoring system, which will identify areas prone to drought episodes negative with effect on the vitality, health, production and productivity of plants. Based on complex analysis it will be able to quantify the effect of droughts of different intensities on silvicultural and economic goals in high risk areas to drought. Elements of statistical and mathematical modeling measurement and drought intensity may underline vulnerability to the impact of drought environment.

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