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Evaporation and evapotranspiration in Romania

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Abstract

Evaporation and evapotranspiration are two of the most important elements for achieving a comprehensive study of water balance components and of conceptual hydrological models, lately becoming parameters of great interest in research on climate change. This study can be used for determining of evaporation and evapotranspiration rates at micro-scale using indirect methods. The importance of this study consists in identifying the regions exposed to significant water release in terms of water evaporation and evapotranspiration, in order to improve the practices and methods of water reserve management nationwide. In Romania, the spatial distribution of the analyzed variables is, for the most part, determined by the relief, which constitutes the main factor that dictates the particularities of both the local and regional climate. Among the morphometric characteristics of the relief, altitude plays the most important role in the spatial conditioning of the analyzed parameters. The spatial distribution of evaporation and evapotranspiration, at annual, seasonal and monthly levels in Romania was made through the spatial interpolation method (Digital Terrain Model with a resolution of 30 m). The results of the analysis revealed the following aspects: on a multi-year period, evaporation in Romania ranges from 300 mm - 800 mm/year, with the highest values recorded in the south east of the country and the Danube Floodplain (over 1,000 mm/year), western part (over 800 mm/year) and the lowest values registered in the mountain areas (less than 400 mm/year). The values of evapotranspiration vary between 300 mm/year and 625 mm/year, with a maximum of over 650 m/year in the plains and a minimum of less than 300 mm/year in the mountains.

Keywords: *evaporation in Romania, interpolation, spatial and temporal distribution*

Rezumat. Evaporaţia şi evapotranspiraţia în România

Evaporaţia şi evapotranspiraţia constituie unele dintre cele mai importante elemente pentru realizarea unui studiu complet al bilanţului hidric, componente ale modelelor hidrologice conceptuale, devenind în ultimul timp şi parametri de interes major în studiile privind schimbările climatice. Prezentul studiu poate fi valorificat în determinarea pe cale indirectă a ratelor privind evaporaţia şi evapotranspiraţia la microscară. Importanţa acestui studiu constă în identificarea regiunilor expuse la cedări semnificative de apă prin prisma evaporaţiei şi a evapotranspiraţiei, în vederea îmbunătăţirii practicilor şi metodelor de gestionare a rezervei de apă, la nivel naţional. În România, distribuţia spaţială a parametrilor analizaţi este, în cea mai mare parte, determinată de relief care constituie principalul factor ce determină particularităţile climatului local şi regional. Dintre caracteristicile morfometrice ale reliefului, altitudinea are rolul cel mai important în condiţionarea spaţială a parametrilor analizaţi. Distribuţia spaţială a evaporaţiei şi a evapotranspiraţiei, la nivel anual, sezonier şi lunar, pe teritoriul Romaniei s-a făcut prin metoda de interpolare (Modelul Digital al Terenului cu rezoluţie de 30 m). Rezultatele analizei au evidenţiat următoarele aspecte: la nivel multianual evaporaţia pe teritoriul României variază între 300 mm/an şi 800 mm/an, cu cele mai mari valori în partea de sud est a ţării şi în lunca Dunării (cu valori > 1000 mm/an), în partea de vest şi în extremitatea sud vestică a ţării valorile ajung şi la peste 800 mm/an, iar cele mai reduse valori se înregistrează în zonele montane, sub 400 mm/an. Valorile evapotranspiraţiei sunt cuprinse între 300 mm/an şi 625 mm/an, cu maxime > 650 în zonele de câmpie şi cu minime (sub 300 mm/an) în zona montană.

Cuvinte-cheie: *evaporaţia în România, interpolare, distribuţia spaţială şi temporală*

Introduction

The evaporation is the process by which water changes from a liquid to a gas or vapor, under the impact of physical atmosphere processes on the surface of open water (Thornthwaite et al., 1939; Touchart, 2006; Godard et al., 2004; Cosandey et al., 2012).

Evapotranspiration defines the amount of water transferred into the atmosphere by evaporation, through the transpiration of plants (biological processes of plants by which water is extracted from the soil by the roots and guided by stems and leaves to the atmosphere) (Allen et al., 1998; Serban et al., 1998; Jensen, 2010). The evapotranspiration rate from a crop reference surface, with specific characteristics, is called the actual evapotranspiration (Allen et al., 1998). Potential evapotranspiration refers to the maximum rate of evapotranspiration from a large area covered completely by vegetation with adequate soil moisture (Morton, 1983; Lhomme, 1997).

The knowledge of evaporation and evapotranspiration processes is essential for the analysis of climatic changes and hydrological budget. These processes vary regionally and seasonally so, for a good water management system, it's very important to have a thorough understanding of these processes and knowledge about their spatial and temporal fluctuation (Papadopoulou et al., 2003). International studies presented different methods to measure the evaporation using pans (Thornthwaite et al., 1939; Penman, 1954; Allen et al., 1998; Xu et al., 2001) or to estimate this process (Walkusz et al., 2009; Jhajharia et al., 2006; Dąbrowski, 2007; Al Domany et al., 2013).

In 1954 in Romania, based on studies and previous research from other countries, the organization of evaporation network was started. First of all, the evaporimeter raft type GGI-3000 were installed at the surface of some romanian lakes (i.e. Căldărușani, Bistreț, Amara lakes). Nowadays, Romania has a dense evaporimeter network based on 54 evaporimeter stations installed at the surface of lakes and soil. Previous studies in Romania developed the aspects regarding the methodology of measuring the evaporation (Stoenescu et al., 1962; Tibacu, 1973; Badescu, 1974) and also described a series of equations including: Vikulina, Horton, Dalton (Serban, 198) Davydov and Zaikov (Stoenescu et al., 1962). Recent papers investigated the links between the evaporation and others climatic parameters: air temperature, relative humidity, sunshine duration and wind (Păltineanu et. al, 2012; Croitoru et al., 2013; Neculau et al., 2014; Stan et al., 2014, 2015).

The objectives of this paper are:

(i) to analyze the spatial regionalization of evaporation in Romania;

(ii) to calculate and regionalize the evapotranspiration by using indirect methods.

The importance of this study consists in identifying the regions exposed to significant water release in terms of evaporation and evapotranspiration, in order to improve the practices and methods of water resource and demand management nationwide.

Materials and methods

The present study was performed based on direct data obtained from observations and measurements carried out on evaporation from the water surface at 54 evapometric stations (Fig.1) distributed uniformly across the country, with a running time of over 35 years.

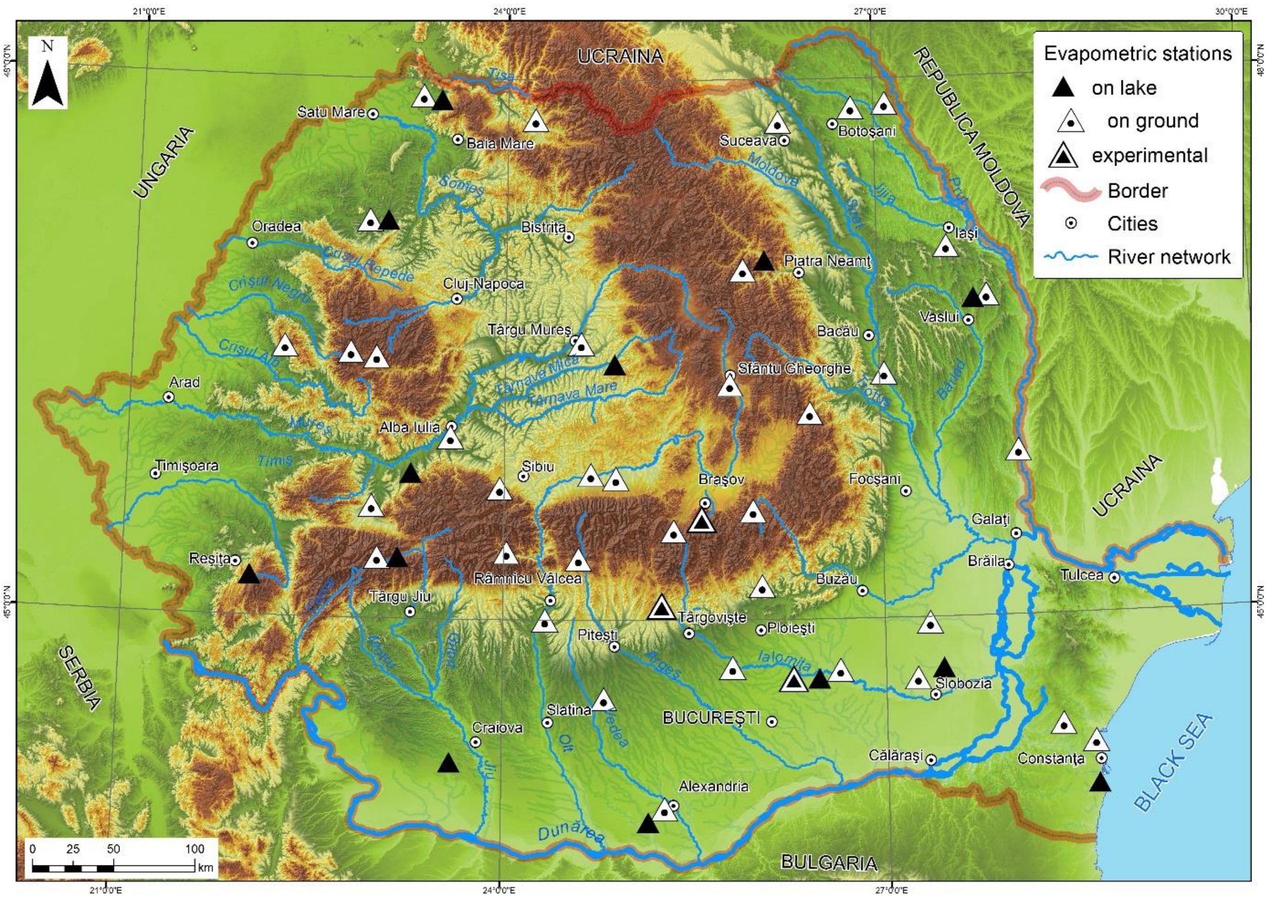

Fig. 1: Spatial distribution of analyzed evapometric stations

In Romania, there are three types of evapometric stations: ones are located in the central part of the lakes (known like evaporimeter raft), others situated on the ground, near the aquatic bodies and the last ones are used to developed experimental studies. All these stations are equipped with evaporimeter type GGI-3000, a cylindrical tank with an area of 3000 cm^2 filled with water.

Data series analysed in our study involve the following variables: water surface evaporation,

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precipitation, air temperature, relative air humidity, sunshine duration and wind speed.

These data were analyzed at monthly intervals.

In order to identify the most important variables which influence the regionalization of evaporation and evapotranspiration, was used the simple linear regression method. Taking into account the strong correlation between evaporation and climatic parameters we chose the indirect method to estimate the evapotranspiration.

Theories of the climate variables influence on evaporation go back at least to the 18th century, when Dalton (1802) noted (equation 1):

$$E = f(\bar{u})(e_o - e_a) \qquad (1)$$

where: E is the rate of evaporation expressed as rate per unit time, $\bar{u}$ is mean wind speed, e_o is the saturation vapor pressure at the temperature of the water surface and e_a is the vapor pressure of the air (Jensen, 2010).

In our study evapotranspiration, parameter that is measure at just three experimental evapometric stations by using lysimeters type G1 (area of 1m^2), was determined on the basis of the evaporation from the water's surface, in combination with a transmission coefficient (Kp) of the evapometric basin (equations 2 and 3).

$$ETP = Kp * E \qquad (2)$$

where: ETP is the rate of evapotranspiration per unit time, Kp is the pan coefficient and the E is the rate of measured evaporation (Snyder et al., 2005).

$$Kp = 0.482 - 0.024\ln(F) - 0.000376U + 0.0045H \qquad (3)$$

where: U is the wind speed at 2 m above the ground; F is the distance field/area cultivated or uncultivated land around the basin to a barrier against the wind (m), it may take from 1 to 1000 m and H is the relative humidity (%) (Snyder et al., 2005).

The validation of evapotranspiration, resulted from the product of measured evaporation and the evapometric basin coefficient (equation 2), was made based on direct data obtained from the experimental evapometric stations like Căldăruşani station (Fig. 2).

The transmission coefficient of the evapometric basin was calculated through the *Snyder method* that takes into consideration the values of relative air humidity and wind speed (equation 3).

For the spatial distribution of evaporation and evapotranspiration in Romania, in addition to the use of exploratory analysis of the data set with known values, an important step was the identification, selection and quantification of the existing statistical relationships between the independent variables, compared to the dependent variable.

Consequently, on the basis of data from 54 evapometric stations, we were able to establish a relationship between evaporation and the main climate and morphometric parameters like air temperature, wind speed, air humidity, and elevation.

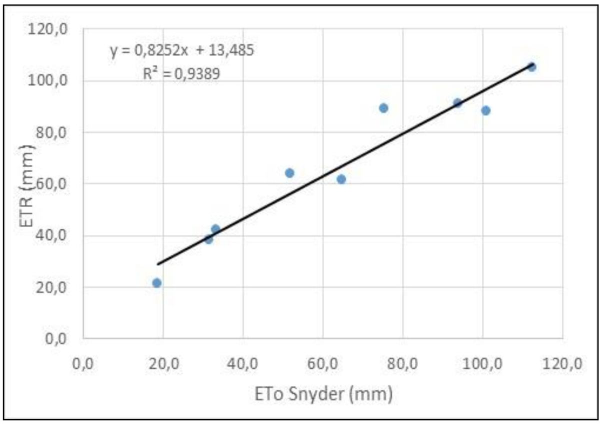

Fig. 2: Relationship between monthly measured evapotranspiration (ETR) and evapotranspiration obtained using the Snyder method at the Căldăruşani evapometric station

The dependence between evaporation and the climate parameters was highlighted by the *simple linear regression method*. As such, we drew correlations between evaporation and a single climate parameter – air temperature, wind speed and relative humidity (Fig. 3).

For these individual relationships, the best method turned out to be linear regression.

Establishing the correlations between evaporation and climate parameters illustrated the following aspects: air temperature, sunshine duration and wind speed have a positive influence on evaporation (direct relationship); between evaporation and relative air humidity exists an inverse relationship, with a weaker degree of correlation R^2 = 0.80).

Among the morphometric characteristics, altitude plays the most significant role in the spatial determination of evaporation. The interdependence between evaporation and altitude (Fig. 4) highlights a reduction of evaporation as altitude increases, which is more intense between 0 and 500 meters. The equation that results from the polynomial regression of evaporation and altitude (Fig. 4) formed the basis of the regionalization of evaporation, by using the Spatial Analyst - Raster Calculator GIS extension. Therefore, The Altimeter Numeric Model represents a predictor for the regionalization of the two parameters.

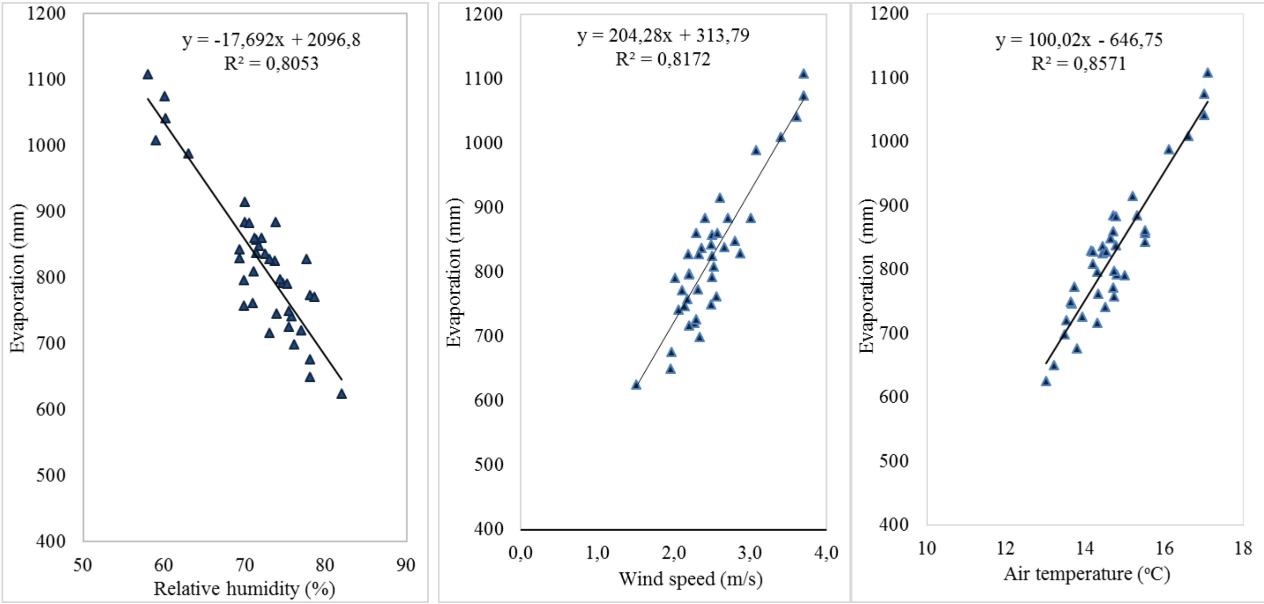

Fig. 3: Correlation between mean annual evaporation and relevant climate parameters at the Alexandria evapometric station

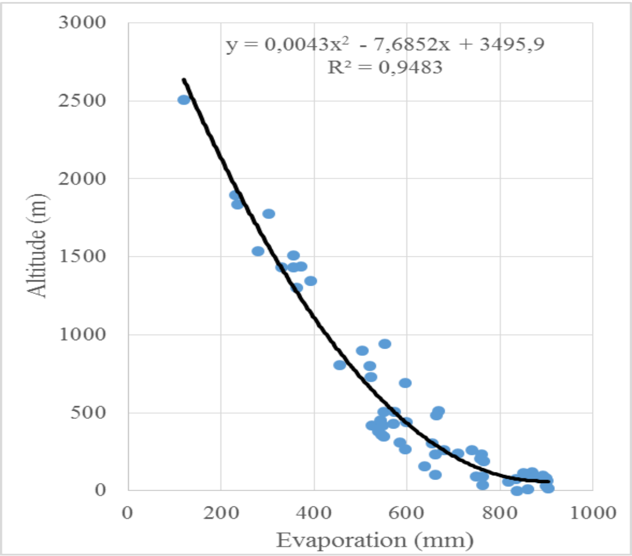

Fig. 4: Correlation between average multi-annual evaporation and the altitude of evapometric stations

Creating the evaporation and evapotranspiration maps at annual, seasonal and monthly levels, in view of performing an analysis of spatial distribution, was achieved by interpolating evaporation and evapotranspiration parameters with the altitude (The Digital Terrain Model, with a 30-meter resolution).

Results and discussions

The results achieved, using the altitude as predictor variable, are the spatial distribution of evaporation and evapotranspiration in Romania for the period 1961 – 2013.

In this case was create the map of the **spatial distribution of annual evaporation in Romania** for the 1961 – 2013 interval. From this map, it was possible to see that evaporation oscillates between 300 and 800 mm/year (Fig. 5).

The highest values, of more than 750 mm/year, are recorded in the Romanian Plain and the Danube Floodplain (ex. ES Jirlău - 1042 mm/year, ES Bistreţ – 1048 mm/year), in the Western Plain (ex. ES Cefa – 891 mm/year), in Dobrogea and, sporadically, in the Moldavian Plain.

Values between 600 şi 750 mm/year (Fig. 5), can be found in hilly and plateau areas, whereas in some mountainous areas evaporation can fall below 400 mm/year (ES Valea de Peşti – 363 mm/an), while in mountainous depressions evaporation values can reach 550 mm/year (ES Poiana Braşov – 552 mm/an).

In the context of global climate changes, the issue of identifying trends in evaporation, particularly in Romania's drought-affected areas (such as the Romanian Plain, the Moldavian Plain and Dobrogea, which are affected by hydrological, climatic and soil drought) has received a lot of attention.

Therefore, it was possible to identify at national level, on the basis of existing studies made for the period 1961-2013 (Stan et al., 2015, Neculau et al., 2015), an intensification of evaporation in south-eastern Romania (especially at the Căldăruşani, Oancea and Jirlău stations) and a reduction of evaporation in the south-west (Fântânele and Furculeşti stations) and in the areas where the plains meet the plateaus, as well as in the Sub-Carpathians (Stolnici, Focşani).

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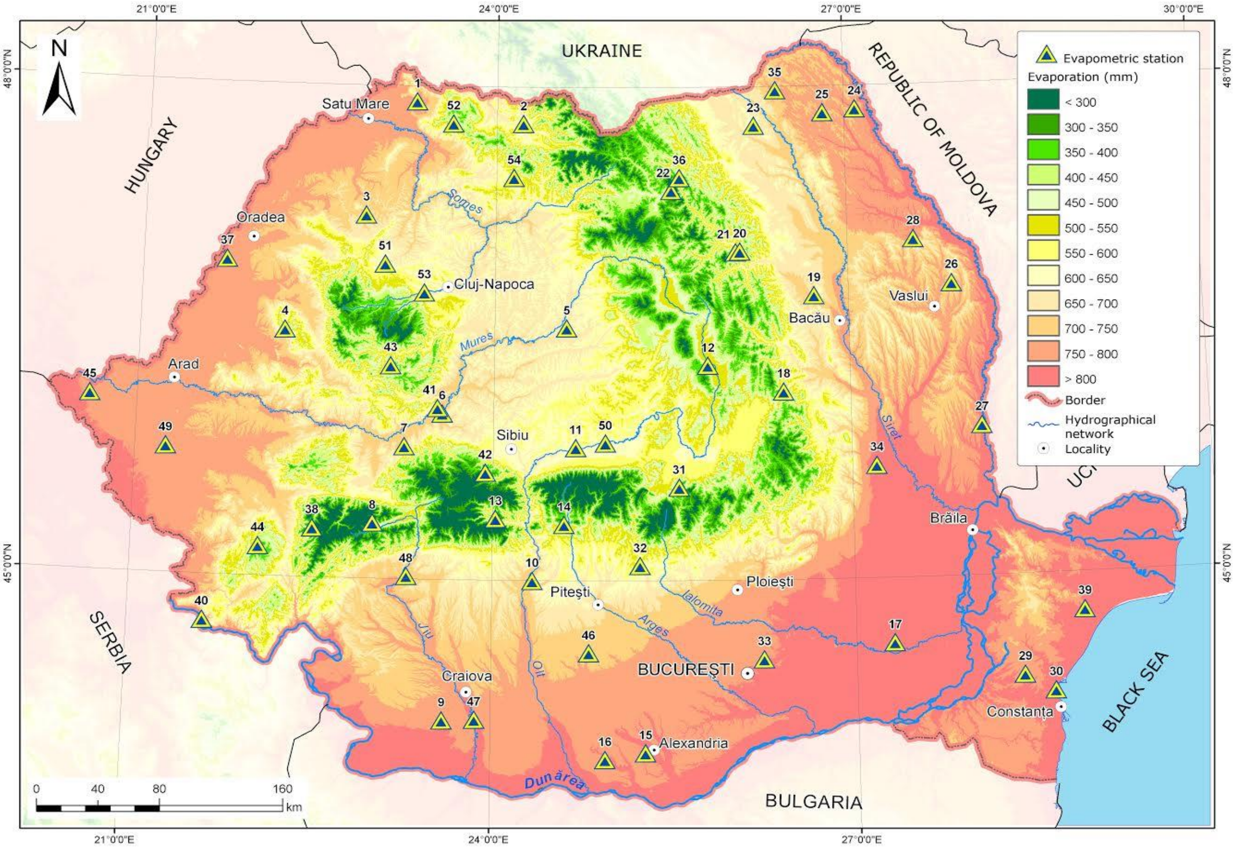

Fig. 5: Spatial distribution of annual evaporation in Romania (1961 – 2013)

The seasonal analysis of evaporation included only three seasons (spring, summer and autumn), because this process can only be studied during the ice-free period, between March and November, as the layer of ice that covers water bodies in winter prevents any air-water exchanges.

After establishing the correlations between seasonal evaporation and altitude, we noticed the existence of a strong connection, with correlation coefficients of more than 0.86 (Fig. 6).

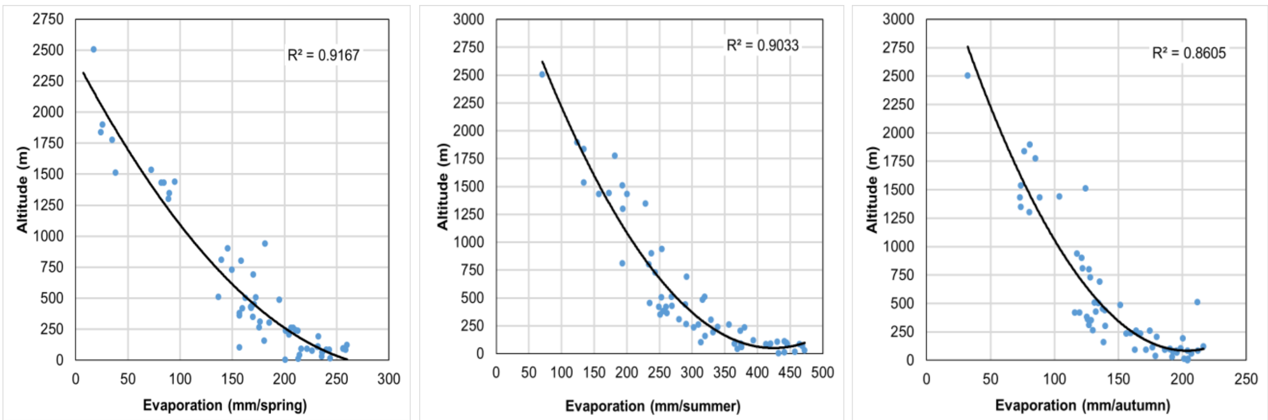

Fig. 6: Correlation between average seasonal evaporation and the altitude

During **spring,** based on a spatial analysis, it was possible to see that evaporation varies between 100-225 mm/season, with the highest values recorded in the eastern part of the Bârlad Plain, Danube's Floodplain and the Danube Delta (Fig. 7).

In general, spring evaporation ranges from 220 to 225 mm in the Moldavian Plateau, Dobogea's Plateau, the Romanian Plain and the Western Plain. In mountainous areas, spring evaporation does not exceed 150 mm, and can even fall below 100 mm at higher altitudes, of more than 1800 meters.

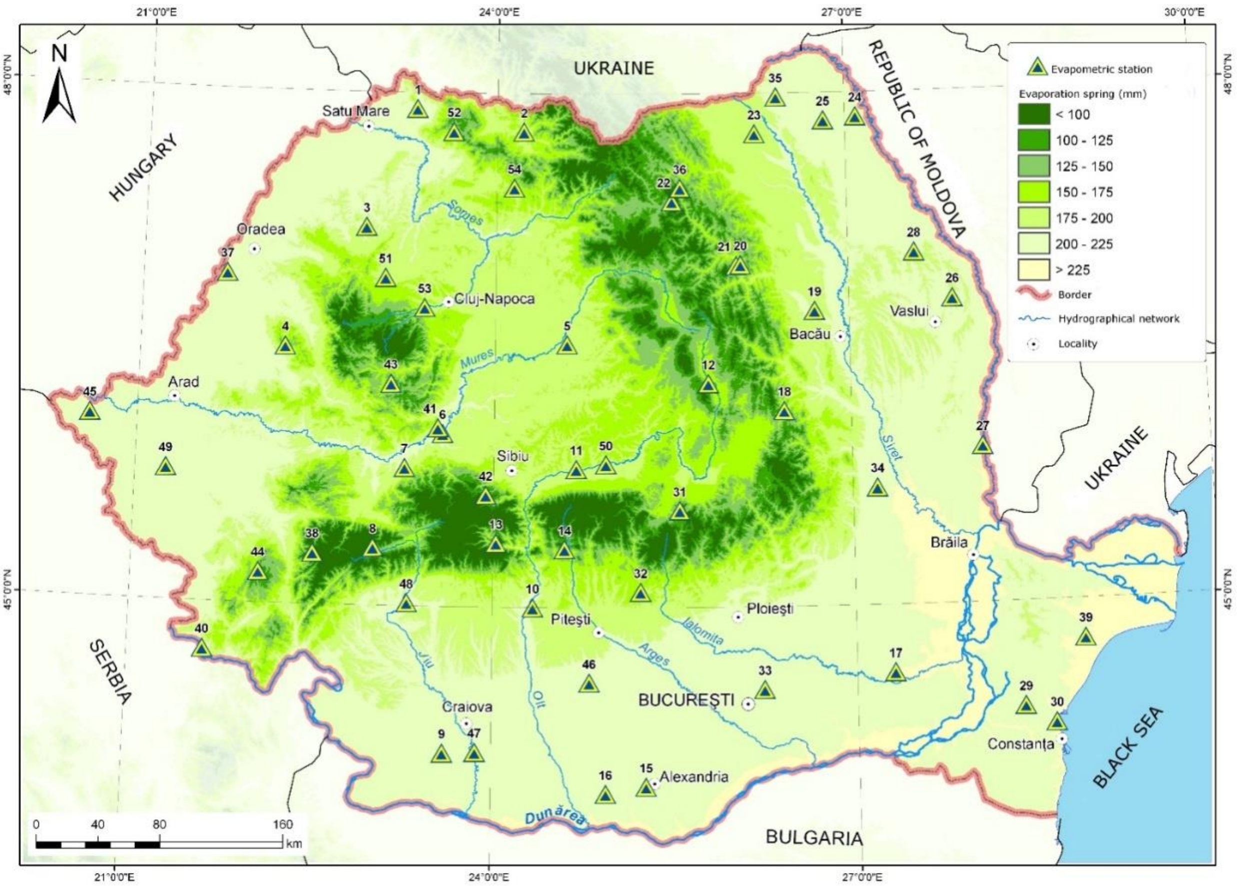

Fig. 7: Spatial distribution of spring evaporation in Romania

The evaporation process intensifies in summer, as air temperature and sunshine duration increase. At national level, summer evaporation fluctuates between 150 and 375 mm (Fig. 8).

The highest values, of more than 375 mm, are to be found in the eastern part of the Romanian Plain and in the Danube's Floodplain, whereas the lowest values (of less than 150 mm) are recorded in the Meridional Carpathians and in the northern part of the Oriental Carpathians, at altitudes of more than 1800 meters. Below 250 meters, summer evaporation can exceed 100 mm/month, and, in July, can even reach 160 mm/month in eastern Romania. The areas where evaporation is highest during summer are Dobrogea (the littoral and Danube's Delta), the south-eastern portion of the Romanian Plain (Bărăganul Mostiştei, Bărăganul Ialomiţei and Brăila's Plain), Danube's Floodplain, the southern part of the Moldavian Plateau (Lower Siret's Plain and Prut's Corridor).

June is the month with the longest daily sunshine duration, but, despite this, evaporation does not reach its maximum value due to increased cloudiness (Păltineanu, et al. 2007). Thus, monthly evaporation reaches 140 mm/month in the Bărăgan Plain, Prut's Corridor and the littoral area.

July is the month when the highest values of evaporation are recorded, which can exceed 160 mm in the Danube's Floodplain, Bărăgan's Plain and Prut's Basin (ex. Teascu, Amara and Oancea stations).

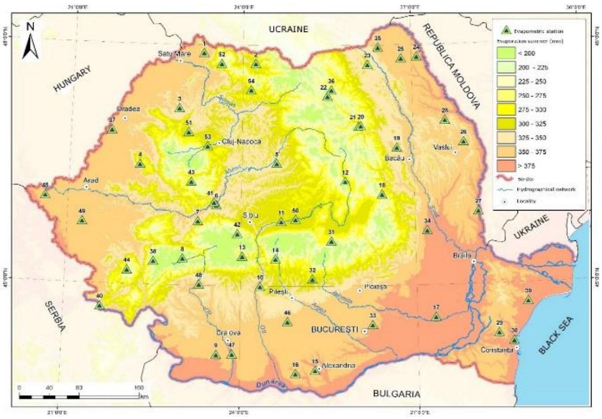

Fig. 8. Spatial distribution of summer evaporation in Romania

August is similar to June with regards to evaporation, and, as such, values of 150 mm/month are measured in south-eastern Romania, while in the mountains, at altitudes above 1500 meters, evaporation can fall to just 50 mm.

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Evaporation is significant, particularly during summer, when vegetation and plants mature and require irrigations for supplementing water provided rainfall. Therefore, by calculating the difference between the amount of water provided by precipitations and water lost through evaporation during summer, we achieved a negative result, with a water deficit of more than 100 mm in July and August (Fig. 9), and more than 350 mm at annually scale (Tab. 1).

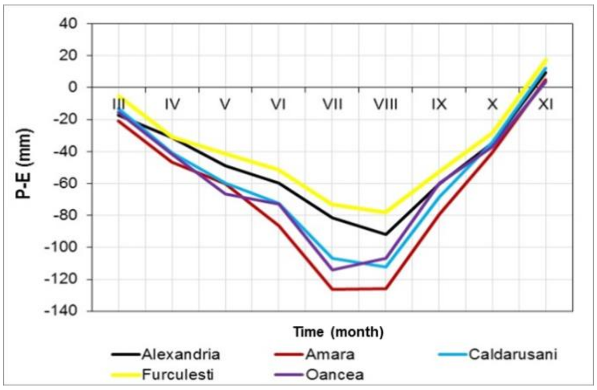

Fig. 9. Monthly difference between precipitations (P) and evaporation (E)

Table 1: Annually values of precipitation, evaporation and water deficit

Evapometric station	Mean annual precipitations (mm)	Mean annual evaporation (mm)	P-E
Alexandria	406	837	-431
Furculeşti	414	765	-351
Amara	348	960	-621
Oancea	385	894	-509
Cădăruşani	469	973	-504

Starting from September, evaporation drops, and during autumn, it ranges between 100 and 175 mm (Fig. 10). Once again, the highest values are found in the lowlands, such as the Romanian Plain and the Western Plain. For hilly regions and the Sub-Carpathians, evaporations measures between 100 – 150 mm/season.

***The second objective* of this paper** was the creation of a map of evapotranspiration at national level in Romania. It was achieved starting from the values of water surface evaporation, measured with GGI-3000 (Epan) instruments, with the addition of a transmission coefficient for the evapometric basin, determined with the Snyder method (equation 3).

After determining evapotranspiration (calculated with the Snyder method), we proceeded to establish its correlation with altitude, and achieved a strong relationship between these two parameters (illustrated by a correlation coefficient of 0.966), which is inversely proportional, as altitude increases while evapotranspiration decreases. Consequently, at altitudes of 0 to 250 meters, evapotranspiration registers values of more than 600 mm/year, between 250 and 500 meters' evapotranspiration varies from 400 to 600 mm, and above 1250 meters' evapotranspiration falls below 400 mm/year. By analysing the map of multi-annual evapotranspiration (1961 – 2013), it was possible to determine that evapotranspiration fluctuates between 300 and 625 mm/year (Fig. 11).

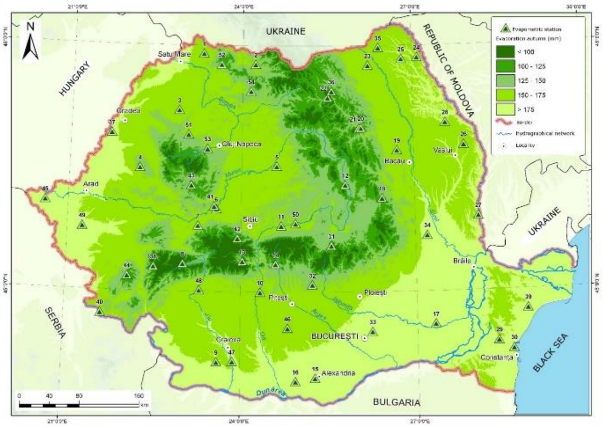

Fig. 10. Spatial distribution of evaporation in autumn, Romania

The highest values of real evapotranspiration, of more than 625 mm/year, are found in the following areas: most of the Romanian Plain, the Floodplain and Delta of the Danube, Banat's Plain, the Black Sea littoral zone and the eastern part of Dobrogea's Plateau. Values from 575 and 625 mm/year are recorded in the northern part of the Romanian Plain, the Getic Plateau, Barlad's Plateau and the Moldavian Plain, the Western Hills and the northern portion of the Western Plain.

The Sub-Carpathians and the Transylvanian Plateau exhibit evapotranspiration values ranging from 500 to 550 mm/year, while in the mountains, real evapotranspiration decreases significantly with altitude, reaching values of less than 300 mm/year in the Carpathian summits.

The last stage of the present study involved the process of verifying the degree of error for the chosen spatialization method. It involved extracting estimated values from the evaporation grid using the Grid Values to Points function (from the Shapes-Grid module) and comparing these values with those measured at the stations that were included in our analysis.

Thus, it was possible to see that the extrapolation method for evaporation at national level has a tendency to underestimate evaporation at altitudes below 250 meters and to overestimate it at higher altitudes. The difference between estimated and measured values was no greater than 100 mm, though for altitudes above 900 meters this threshold can be exceeded (Fig. 12).

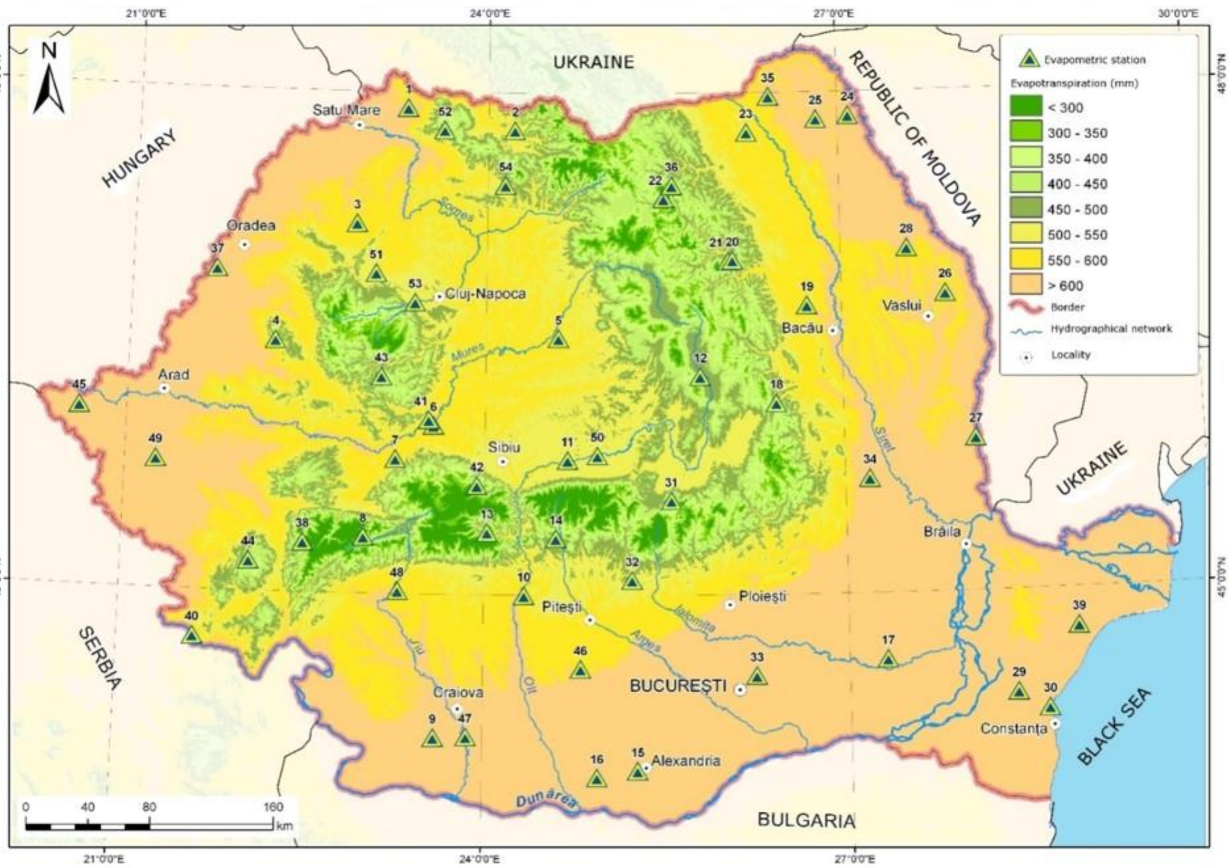

Fig. 11. Spatial distribution of evapotranspiration in Romania, 1961 – 2013

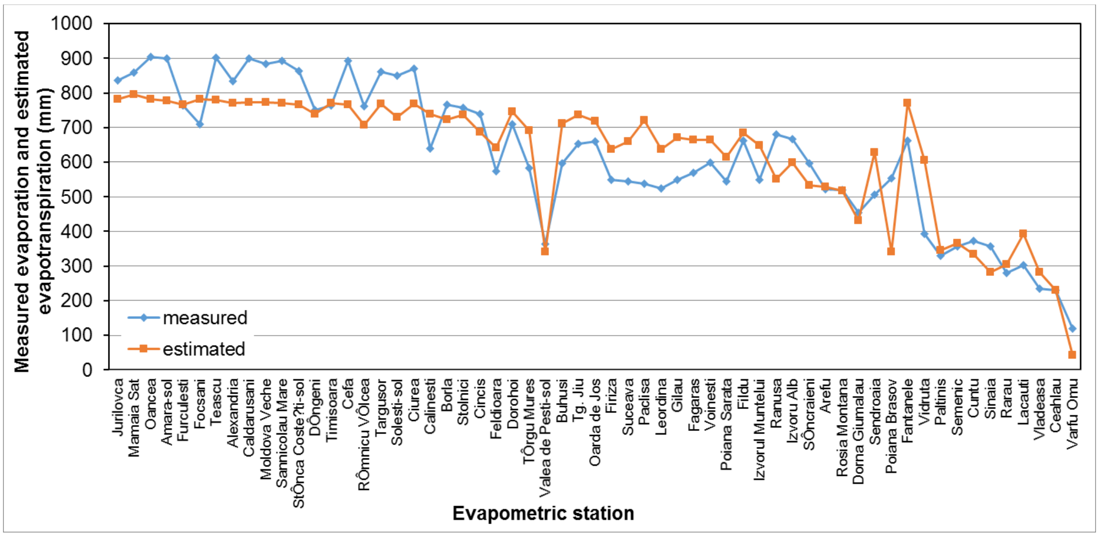

Fig. 12: Evaporation measured at evapometric stations and evaporation obtained by extrapolating values in GIS

Conclusion

This study can be used for determining the indirect method of evaporation and evapotranspiration rates at micro-scale. In Romania, the spatial distribution of the analyzed parameters is, for the most part, determined by the relief, which constitutes the main factor that dictates the particularities of both the local and regional climate.

In Romania evaporation oscillates between 400 and 750 mm/year. The highest values, more than 750 mm/year, are recorded in the Romanian Plain and the Danube Floodplain, in the Western in

Dobrogea and, sporadically, in the Moldavian Plain. During spring evaporation varies between 100 - 225 mm/season, with the highest values recorded in the eastern part and in the Danube Delta. The evapotranspiration values varied between 300 and 625 mm/year. The highest values of real evapotranspiration, of more than 625 mm/year, are found in the most of the Romanian Plain, the Floodplain and Delta of the Danube, Banat's Plain, the Black Sea littoral zone and the eastern part of Dobrogea's Plateau.

The extrapolation method for evaporation at national level has a tendency to underestimate evaporation at altitudes below 250 meters and to overestimate it at higher altitude. The difference between estimated and measured values was not greater than 100 mm, though for altitudes above 900 meters this threshold can be exceeded. These errors are explained by the small number of evapometric stations in Romania, aggravated by the lack of such stations in vast areas that are not monitored.

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