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THE INFLUENCE OF EVAPOTRANSPIRATION AND WET DEPOSITION ON THE VARIATIONS OF PM_{10} CONCENTRATION IN THE CIUC BASIN

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Abstract. Trend analysis for potential evapotranspiration (PET) and climatic water balance (CWB) is critical in identifying the particulate matter concentration (PM_{10}) variations. The PET is computed based on the monthly average temperature for the Ciuc basin using Thornthwaite parameterization. The highest levels of evapotranspiration appear during the months of May and June. The lowest levels of particulate concentration characterize the period during April-June. Precipitation is highest during May and June. Particulate matter in the highest cloud water is 0.014 $\mu g/m^3/mm$ during April and 0.010 $\mu g/m^3/mm$ during May. One can observe a significant level of negative correlation between particulate matter concentration, the potential evapotranspiration and precipitation.

Introduction

The aerial aerosols are systems of fine solid and fluid particles dissipates in the atmosphere. Based on their formation, they can be categorized as primary particles, which come to the atmosphere directly, and secondary particles which

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originate from chemical transformations. One may distinguish between natural sources of pollution, such as maritime-, soil- and biological aerosols, forest fires, volcanic ashes and anthropogenic sources of pollution, like aerosols deriving from traffic and transportation, energy production, as well as industrial and agricultural activities. The solid particles contain sulfates, nitrates, polycyclic hydrocarbons, nitrogen oxides and toxic metals. Most of these particles derives from traffic pollution (Thomas and Charvet, 2017).

The variations of particulate matter concentration are mainly influenced by meteorological conditions. The studied region, the Ciuc basin is known for its special microclimatic conditions, with long episodes of static stability, involving thermal inversions, which favors the accumulation of pollutants (Korodi et al., 2017; Szép et al., 2016, 2017a, 2019). In this study, we focus mainly on the effects of moisture (water vapor and precipitation) and its movements. The evapotranspiration plays and important role in the hydrological and energetic cycles (Hoedjes et al., 2008). There are significant correlations between the particulate matter and the relative humidity of the atmosphere (Szép et al., 2016a). As a matter of fact, particulate matter particles contribute to cloud formation (Burkart et al., 2011; Brebbia et al., 2011). Moreover, particulate matter composition influences precipitation composition as well (Brebbia et al., 2011; Szép et al., 2017a; 2018; 2019; Keresztesi et al., 2018). The meteorological and climatic importance of particulate matter includes the absorption and scattering of radiation in the atmosphere and the modifications of the optical properties of clouds and snow/ice surfaces (Osada et al., 2014). According to Yao (2017) $PM_{2.5}$ concentration has a significant causative influence on evapotranspiration. Wet below-cloud scavenging involves all the phenomena by means of which particles are removed from the air through a number of various types of precipitation: rain, snow, fog, and ice (Olszowski, 2015). Relative humidity plays a role during dry deposition as well (Szép et al.,2016b). According to numerical studies, weak precipitation with an intensity of less than 0.1 mm/h is able to remove 50–80% of the below-cloud aerosol, both in terms of number and mass, during a 4-h period (Zhang et al., 2004; Langner et al., 2011).

This study emphasizes on the trend analysis of particulate matter concentration with respect to the wet episodes and evapotranspiration. Hence, the objectives of this study are: to identify the PET based on temperature variable; to verify the CWB with respect to the PET and precipitation; to determine the PM_{10} concentrations in different time scales; and to identify the average PM_{10} concentration which was deposited by the precipitation.

2. Materials and methods

2.1. Sampling

The Ciuc basin is situated in the Carpathian Mountains, at 650-700 meters above sea level (Fig. 1). Its length is 60 kilometers, its average width is 10-12 kilometers, stretching over an area of 680 km^2, between 46°30'- 46°10' North latitude and 25°40'-26°00' East longitude (Kristó, 1994). The basin is characterized by a local mezzo- and microclimate, owing to specific terrain articulations. Furthermore, the basin is sheltered from the wind and is characterized by temperature inversions during three of the four seasons (autumn, winter and spring), resulting in foggy periods lasting several days and hard frosts during an anticyclone (Szép and Mátyás, 2014; Szép et al., 2016c; Szép et al., 2017b; Boga et al., 2017; Petres et al., 2017).

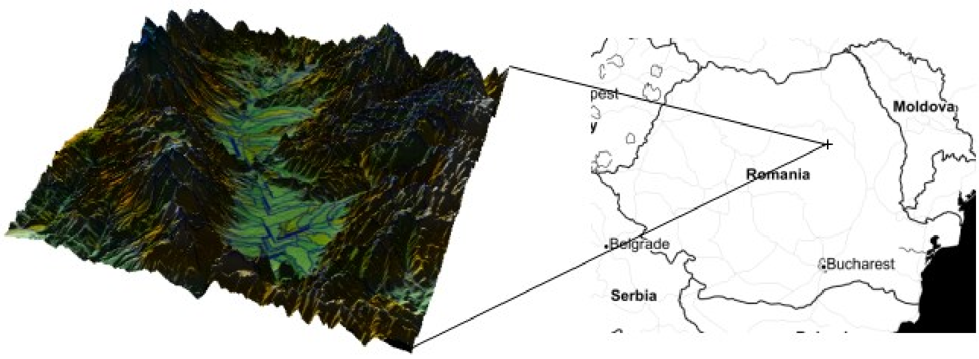

Fig. 1. The location of the Ciuc basin and its hydrology

The basin is sectioned by Olt river, which plays an important role in the hydrology and climate changes. The average precipitation level in the Ciuc basin is 500-600 mm/year, half of which arrives as snow. The Ciuc basin is characterized in a higher proportion by alkaline rainfalls (Keresztesi et al., 2017). The studied area is rich in mineral springs and mofette emanations, which are a sign of post-magmatic activity, and are influencing the composition of the atmosphere and precipitation (Szép et al., 2019, 2018, 2017b).

2.2. Statistical analysis

Data for this research for the period 1 January 2012 – 31 December 2012 was provided by the regional meteorological station from the studied area. PM_{10} concentration was recorded by an automatic LSPM10 analyzer through nephelometry. This method consists of the measurement of the intensity of the light scattered by the particle. Air temperature was measured with a TS thermometer sensor (with a measuring range between -30°C and +50°C), placed at 2 m above the ground. Relative air pressure and relative humidity was measured with a BP-S and a RH-S Orion instruments. Wind speed was detected by spoon wind speedometer at 10 m height (WS-S Orion).

2.3. Potential evapotranspiration and climatic water balance

Evapotranspiration is a combination of evaporation (soil surface) and transpiration (plants) that manifests a water movement from the earth to the atmosphere. PET is defined as the amount of water that would be transpired and evaporated when soil moisture availability is not limited, which depends on the climate (Hui-Mean et al., 2017).

Thornthwaite parameterization is a simple approach for calculating potential evapotranspiration that requires only station is latitude as input data and monthly average temperature (Thornthwaite, 1948):

$$\mathrm{PET} = 16\mathrm{K}\left(\frac{10\mathrm{T}}{\mathrm{H}}\right)^{\mathrm{m}} \quad (1)$$

where K is the correction coefficient; T is the monthly average temperature, °C; H is the heat index; m is the coefficient.

The monthly CWB is defined as the difference between the monthly precipitation (P) and monthly PET.

a. Wet deposition

During wet deposition pollutants are removed from the atmosphere. In the process of rain formation, a water film layer emerges on the surface of aerosol particles. Depending on the size of the particle, the degree and velocity of dissolution in the precipitation are different. Particle movement in the atmosphere is characterized by the Brownian motion. During their motion particles coagulate, and their concentration in the atmosphere decreases as a result. Aerosols can also collide with water drops during diffusion phoresies (Mészáros, 1977). This is most common in mixed clouds containing ice crystals and water drops. Diffusion phoresies occurs when the diffusing water of gas exerts a force acting on the particles in the direction of diffusion.

Junge (1963) described the trace constituents' concentrations (C_a) in the cloud water with a simple formula:

$$C_a = \frac{\varepsilon_a M_a}{w} \quad (2),$$

where: ε_a – represents the aerosol fraction in the cloud which according to the experiments of Junge (1963) equals 0.5 with higher concentrations of aerosols, while in tropospheric background aerosols may reach a value between 0.9-1.0; M_a – is the mass concentration of aerosol particles; w – is the water content of the cloud.

The essential parameter of wet deposition is the washout coefficient, which can be described by the following formula:

$$\Lambda = \mathrm{Ar}^{\mathrm{B}} \quad (3),$$

where r – is the amount of precipitation (mm) and A, B are constants, empirical values.

The velocity of wet deposition of PM_{10} can be determined by the following formula (Maryon and Brtain, 1996):

$$\mathrm{v_w} = \Lambda \cdot \mathrm{H} \quad (4),$$

where H is the height of the cloud base.

b. Statistical analysis of meteorological conditions

The average temperature for the year of 2012 was 7.74ºC. Summer average temperature was 22.2ºC, average winter temperature is -6.2ºC. Maximum wind speed was 5.94 m/s, i.e. a moderate wind speed class. Average yearly wind speed was 0.44 m/s, i.e. weak breeze category. Average temperature was 6.40°C, which according to Petres et al. (2017) is an average for the period of 2006-2015. The highest temperature was 35.29°C, the lowest was -24.51°C. Annual amount of precipitation was 672.00 mm, with the following seasonal distribution: spring 308.00 mm, summer 147.00 mm, winter 125.00 mm, autumn 93.00 mm. According to a multi-year precipitation analysis, the precipitation in the Ciuc basin is alkaline (6.57 pH) (Szép et al., 2017a).

3. Results and discussion

a. PET and CWB in the Ciuc basin

PET is strongly dependent by temperature, estimating the amount of water loss through evaporation and transpiration. The higher values of PET indicate an increasing crop water demand and vice versa (Hui-Mean et al., 2017). As Fig. 2 shows, the evapotranspiration values reach the highest levels during May (73.00 mm) and June (84.00 mm). These values are lowest during the winter as frozen soil and the blanket of snow impedes evapotranspiration. Since evapotranspiration involves soil, water and vegetation, we researched the dispersion of water quantity evaporated by the soil during the year 2012, the results of which can also be observed in Fig. 2. The highest levels of soil evaporation are reached during the months April (62.34 mm), May (73.00 mm), and June (49.12 mm). Beyond meteorological conditions, the water uptake capacity of the soil is influenced by various factors characteristic to the soil.

Soil types of the Ciuc basin include umbrisol, cambisol, podzol, and chernozem types (Stănilă et al., 2011). These can be characterized by a good water retention ability. These types of soils do not get dried as a result of evaporation and they do not loose large quantities of water.

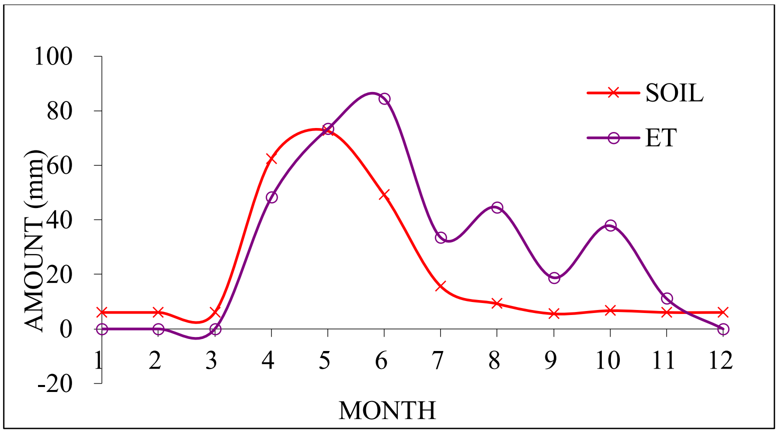

Fig. 2. Variation of monthly PET and soil evaporation during the study period.

b. Variations of PM_{10} according to meteorological data

The yearly PM_{10} average of the Ciuc basin is 46.60% lower than the permitted limit (50.00 µg/m^3). During the winter months, this value decreases to 2.30%. In the seasonal pattern, particulate matter concentration is highest during the winter period (Table 1), being caused by the burning of biomass which is far more significant than in other periods of the year.

Table 1. PM_{10} concentration statistics according to the seasonal pattern

µg/m^3	**yearly**	**spring**	**summer**	**autumn**	**winter**
Max	186.47	50.69	60.39	151.03	186.57
Mean value	21.35±14.7	8.30±3.88	16.61±4.03	22.10±12.09	39.08±29.39

During our research on the relationship between precipitation and PM_{10} concentration, we divided the year 2012 into three periods: without precipitation, precipitation less than 1 mm, and precipitation above 1 mm. Results show the relative negative significant correlation between precipitation and PM_{10}. During the period without precipitation, PM_{10} concentration reached an average of 32.65 µg/m^3. In the period with under 1 mm precipitation (103.30 mm) we reached the value of 20.93 µg/m^3. In the period with a precipitation above 1 mm (575.59 mm), the average PM_{10} concentration decreased to 16.82 μg/m^3. Taking Spearman's rank correlation into account ($p<0.001$), significant correlation values could only be observed between the hourly mean annual values: particulate matter and temperature (-0.749), particulate matter and wind speed (-0.642), particulate matter and relative humidity (0.748). According to the seasonal pattern, one can observe a significant correlation between particulate matter and temperature (-0.520), as well as particulate matter and relative humidity (0.344) only during the autumn period.

c. The influence of evapotranspiration on PM_{10} concentration

The value of Spearman's rank correlation between the potential evapotranspiration and PM_{10} concentration is -0.829 ($p<0.0001$) (Fig. 3).

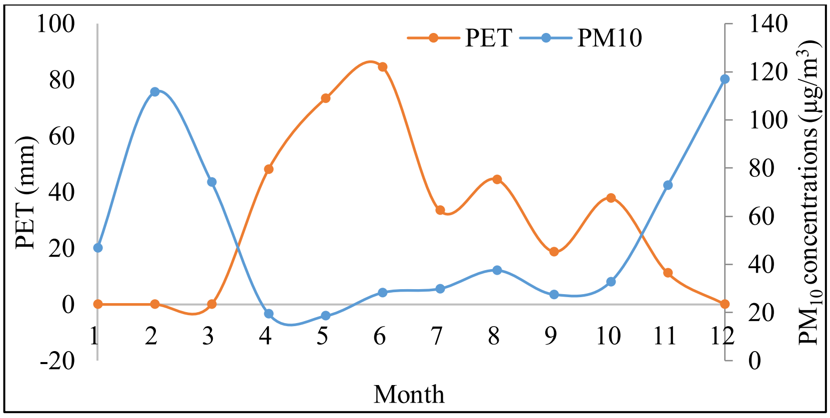

Fig. 3. Variation of monthly PET and PM_{10} during the study period

During evapotranspiration, the height of the lifting condensation level (LCL) decreases with the evaporation reaching the atmosphere. At this phase, the PM_{10} concentration is still high, deposition has not begun yet. When temperature reaches the dew point values, the atmosphere becomes instable and as a result of rainfall PM_{10} concentration decreases (Szép et al., 2016a). The potential evapotranspiration of the Ciuc basin is influenced by the pine forests, the agricultural lands (potatoes and grain lands), and to a less significant degree by the Olt river. Fog created as a result of intensive evaporation is characteristic to the flood plain of the river. In these periods, the condensation nuclei of the fog particles are formed of particulate matter as well. With the fogs rising from the atmosphere, additional dust particles are deposited into the cloud mass, which then are removed from the atmosphere with precipitation.

d. PM_{10} wet deposition

In our analysis of PM_{10} wet deposition velocity in 2012, we characterized the cloud condensation nuclei concentrations. Results lead us to conclude that the highest concentration appears during spring (in April 0.014 µg/m^{3}mm; in May 0.010 µg/m^{3}mm). PM_{10} particles are of solid state, so that in their encounter with water vapor transforms them into condensation cores. Through their accumulation clouds are formed.

In the Ciuc basin most typical rainfall is convectional. The air is warmed up from below, expands and rises. The air rises while its vapor is cooled, deposited and huge thunder clouds are formed, being followed by rainstorms, showers and thunder storms. During the spring period, the rainout coefficient is high, inversely proportional to the cloud condensation nuclei concentration (Fig. 4).

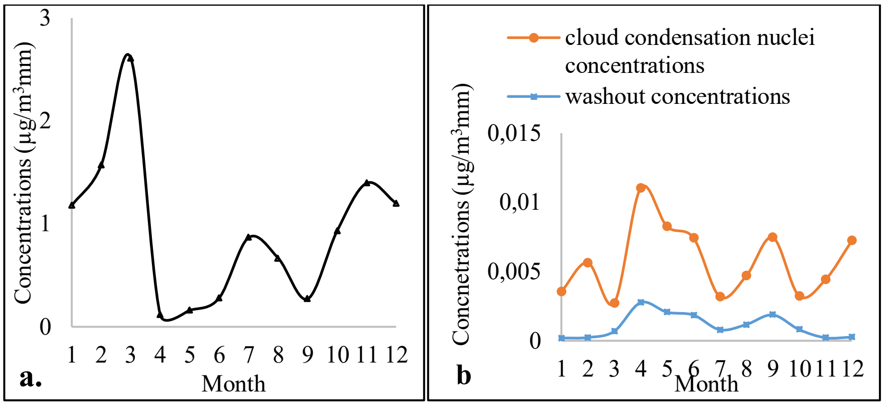

Fig. 4. a. Particulate matter concentrations (C_a) in the cloud water. b. Cloud condensation nuclei concentrations with rain out and washout concentrations

In calculating wet deposition, both the rainout and the washout coefficients are taken into account. As one can observe in Fig. 5, PM_{10} wet deposition is particularly high in the April-September period. During these months the PM_{10} concentration is very low (Kajino and Aikawa, 2015). At an average, wet deposition velocity is the highest during April (0.125 m/h), and lowest in January (0.013 m/h). In our analysis of particulate matter deposition, we took the gravitational collision theory into account. In contrast to smaller particles, aerosol particles with a radius larger than 1 µm cannot follow airflow around the water drops. When deviating from their track, they collide with the water drops.

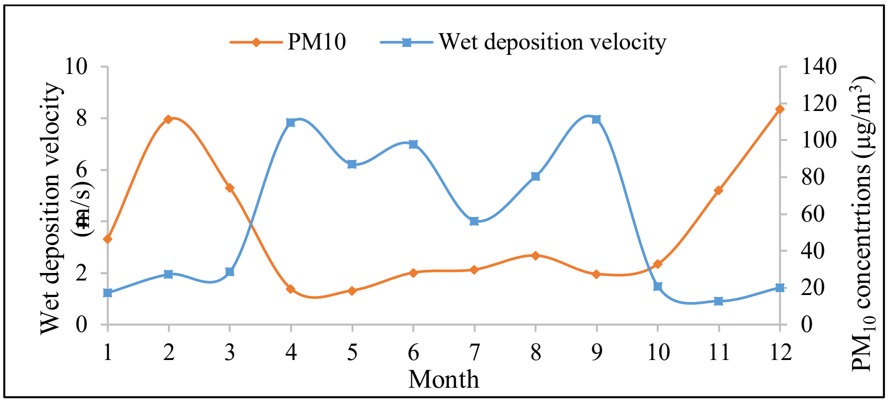

Fig. 5. Wet deposition velocity and PM_{10} concentration

Based on the diagrams in Fig. 4 and Fig. 5, we believe to have demonstrated our thesis, namely that the decrease of PM_{10} concentration shows a significant negative correlation with precipitation. The Spearman rank correlation value is -0.762 ($p<0.001$).

Conclusions

According to the hypotheses of this study, potential evapotranspiration of the basin, as well as precipitation as a result of atmospheric saturation influence the changes in PM_{10} concentration. In both cases one can observe a significant negative correlation. In conclusion, we may say that PM_{10} concentration decreases both with the potential evapotranspiration and the precipitation. PM_{10} concentration is influenced by evapotranspiration indirectly and by precipitation directly. For the Ciuc basin lower particulate matter concentration is characteristic to the period during April-September. In the same period, precipitation and evapotranspiration values are high as well.

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