Dew Point - indirect Particulate Matter Pollution Indicator in the Ciuc Basin – Harghita, Romania

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Breathing in air polluted with drifting dust harms human health, therefore predicting the concentration of air pollutants and the timely warning of the most sensitive target groups are very important. The present paper aimed to create an easily accessible and usable model on the level of the Ciuc basin in Transylvania, Romania, in order to forecast the periods when the concentration of drifting dust exceeds the limits that are still not harmful for human health. The model was presently only tested for the conditions of the Ciuc basin, yet the examination of the results of the model based on PM_{10} temperature – dew point dependency, is also planned in the case of other basins. The results show that in the colder periods PM_{10} concentrations in the air are more abundant, and the daily variations of the concentration of this particulate matter in the air is primarily defined by specific basin conditions. The frequent atmosphere stability resulting from the relief features of the basin causes frequent temperature inversion – high barometric air pressure, increasing the relative humidity of the air. Examining the average values of several years, eight inversion episodes have been identified, generally occurring almost at the same period of the year. These are characterized by quite high PM_{10} concentration, low dew point depression, as well as almost saturated air mass. When the daily temperature fell below the multi-annual monthly average dew point, high PM_{10} concentrations could be observed. Otherwise, the concentration of PM_{10} particles was lower.

Keywords: dew point temperature, particle matter, dew point depression, lifting condensation level, air quality index

The pollution of the atmosphere of the earth is increasing all the time. The European Union has set a goal to reduce this, thus imposing limit values to air pollutants that need to be observed by all EU member states (Directive 2008/50/CE). In the case of the drifting particulate matter (PM_{10} and $PM_{2.5}$) examined in this study, the 24-hour limit value for PM_{10} is 50μg/m^3, whereas its annual limit is 40 μg/m^3. In the case of $PM_{2.5}$ the annual limit value is 25 μg/m^3. In Romania, based on the last data of the World Health Organization (WHO) the population-weighted annual mean PM_{10} is greater than 35 μg/m^3, which exceeds the 25 μg/m^3 limit value. The highest $PM_{2.5}$ concentration measured by the WHO Aphekom project was the one in Bucharest, of the 25 European cities partaking in the project(reaching 38.2 μg/m^3) [1,2]. This problem is not only characteristic for metropolis-sized cities, but also to smaller settlements, where the density of the pollution is also caused by climatologic features, according to which the concentration of particulate matter is the highest in the winter [3].

These drifting particles are especially risky for human health [4-6], therefore their concentration is frequently applied to determine air quality [7-11]. According to the warning of the Environmental Protection Agency (EPA) drifting particulate matter is responsible for premature death in people with heart or lung disease, nonfatal heart attacks, irregular heartbeat, aggravated asthma, decreased lung function, and increased respiratory symptoms, such as irritation of the airways, coughing or difficulty breathing. People with heart or lung diseases, children and older adults are the most likely to be affected by particle pollution exposure [12].

The present study examines the changes in PM_{10} and $PM_{2.5}$ concentrations between 2012 and 2015, their connections with meteorological parameters, primarily dew point and temperature. Furthermore, the quality of the air in the given period was also investigated with the help of air quality index (AQI). Our aim with the present paper was to describe a forecast model, with the help of which drifting particle-related health problems can be prevented by predicting high concentration periods. The model describes the dependency on temperature of the dew point, in function of which the periods when the concentration of drifting particles exceeds limit values can be found.

Experimental part

The Ciuc basin is located in the Eastern Carpathian Mountains. Its average altitude is 600 m, bordered on the south by 1000-1800 m high mountains [13]. The average temperature in the basin is very low, only 0.2°C less than that of the bordering mountains [13]. Fog and temperature inversion are characteristic for the Ciuc basin in the cold periods [13].

The data about air pollutants and meteorological data are collected by a regional-type measuring station. In our case, PM_{10} was sampled with an Automatic analyzer $LSPM_{10}$ equipped with PM_{10} and $PM_{2.5}$ impactors, and Low

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volume gravimetric sampler for PM_{10}/$PM_{2.5}$ - lead analysis (FOX Pump and Sentinel). The air temperature was sampled by a TS Thermometer sensor (measuring range: -30°C and +50°C) in two-meter height, the pressure (Mod BP-S) and relative humidity (Mod RH-S) with an Orion. Wind speed is detected by a WS-S Orion type hemispherical cup anemometer at a height of 10 m.

In the data processing specific mathematical methods were used, with the help of which we attempted to create a reliable, easy-to-use model characteristic for the Ciuc basin. In order to describe the relations, daily and multi-annual monthly average dew point values were calculated. In parallel with that, values of lifting condensation level and of temperature-dew point spread were also determined. Bernoulli binomial probability and the integral Moivre-Laplace formula was calculated, and various statistical methods used to determine the correlations of the model.

Results and discussions

Daily and seasonal PM variability

In the studied period (2012-2015) the multi-annual average PM_{10} and $PM_{2.5}$ concentrations varied from 15.61±8.16 μg/m^3 and 34.08±27.88 μg/m^3, respectively. In table 1 PM_{10} concentrations (12.08μg/m^3 - 19.02μg/m^3) are not considerably higher than the European Union air quality annual (40μg/m^3) [14], but the $PM_{2.5}$ data (18.29μg/m^3 - 34.08μg/m^3) are considerably higher than the EPA annual $PM_{2.5}$ standards (12μg/m^3) and with the exception of year 2014 they are also higher than the one year EU limit (25 μg/m^3) [3, 16].

Table 1

MEAN ±SD PM_{10} AND $PM_{2.5}$ CONCENTRATIONS IN THE CIUC BASIN

	PM_{10} (μg/m^3)	$PM_{2.5}$ (μg/m^3)
2012	19.02 ± 7.85	34.08 ± 27.88
2013	15.34 ± 10.74	26.82 ± 23.13
2014	12.08 ± 7.65	18.29 ± 13.54
2015	15.07 ± 11.66	31.15 ± 27.26

The PM data were analyzed on a seasonal basis. The highest mean value for PM_{10} was in the winter (24.25±18.02μg/m^3) followed by autumn (18.78±9.69μg/m^3), summer (11.58±5.12 μg/m^3) and spring (7.34±3.17 μg/m^3). For the $PM_{2.5}$ the highest mean value was in the winter (52.88±37.10 μg/m^3) followed by autumn (28.27±18.35μg/m^3), spring (9.84±4.59μg/m^3) and summer (9.58± 3.56μg/m^3) [17-19]. The high PM concentration of the cold period can probably be attributed to the burning of biomass and to local traffic [20], as well as to the stability of the basin's atmosphere [21].

Regression analysis between mass concentration of $PM_{2.5}$ and PM_{10} was calculated and significant positive correlation (r=0.71) was observed between $PM_{2.5}$ and PM_{10}.This is a correlation since both $PM_{2.5}$ and PM_{10} are associated with local traffic[22, 23] and biomass burning [20] and other commune sources.

Association of PM and weather parameters

The short time scale changes of the concentrations are primarily due to meteorological parameters, such as temperature, air pressure, humidity, dew point temperature, wind speed [23]. Figure 1 shows the day-to-day variability of fine and inhalable particles $PM_{2.5}$, and PM_{10}), relative humidity and temperature in the period between June 2012 and June 2015. December 2014 data is missing, because the measuring tools did not work. The figure shows that the changes of PM concentrations are apparent in winter periods. At the same time, temperature values are low and RH values are high.

For $PM_{2.5}$ and PM_{10} in studied period significant negative relationship (Spearman rank correlations, $p<0.001$) were observed with temperature (-0.54 and -0.40) and wind speed (-0.43 and -0.37) [25] and positive correlations ($p<0.001$) were observed with relative humidity (RH) (+0.25 and +0.20) respectively [17, 26, 27]. In the cold period (November-February) these correlations were the following: temperature (with PM_{10}: -0.27 and $PM_{2.5}$: -0.51), wind speed (with PM_{10}: -0.33 and $PM_{2.5}$: -0.30) and RH (with PM_{10}: +0.12 and $PM_{2.5}$: +0.18), whereas in the warm period (March-October): temperature (with PM_{10}: +0.09 and $PM_{2.5}$: -0.11), wind speed (with PM_{10}: -0.11 and $PM_{2.5}$: -0.22) and RH (with PM_{10}: -0.23 and $PM_{2.5}$: -0.17). For RH, the positive correlations with PM are associated with windless, cloudy and weak sunshine days, which encourage the accumulation and chemical reaction of pollutants [18, 28], significantly influenced by static atmosphere stability [29]. Furthermore, RH plays an important role in the densification of pollution, especially in case of high RH and under dew point temperature the concentration of pollutants is also higher [30].

A break in the stability of the atmosphere can be observed when the wind appears. In this case, the bigger the wind speed is, the thinner the atmosphere becomes. In our case this is also proven by the observation that in the wind speed range of the basin (0-4 m/s), in the case of winds with a speed between 0-1 m/s (calm) PM concentrations are 62.72% ($PM_{2.5}$) and 46.29% (PM_{10}) higher than in the case of winds in the range of 2-4 m/s, which represents 7.23% of the total period length. This also suggests that pollution is predominantly of local origin [23], as the wind speed category of the studied period is defined mostly by calmness (in 92.77% of the period), thus PM pollution is most probably locally generated, and not transported there from elsewhere, and are accumulated due to atmospheric stability [31-33].

The degree of instability increases together with temperature values, resulting in lower concentrations of drifting particles, as intense radiation heats the underlying

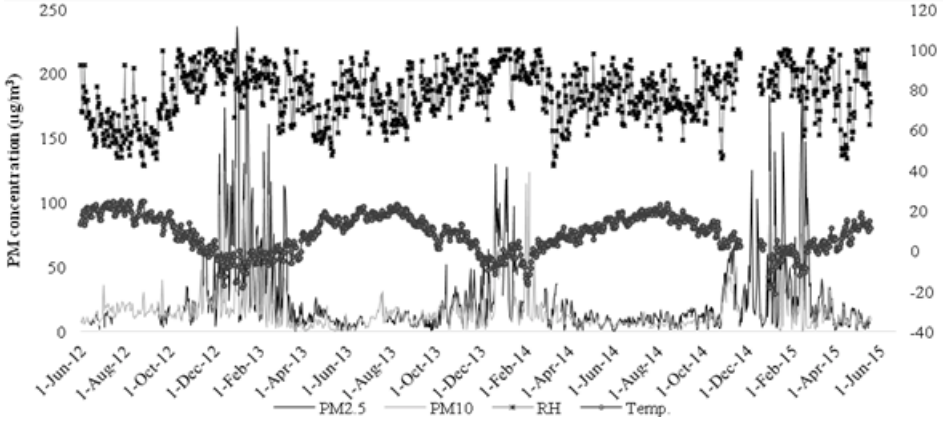

Fig. 1 Day to day variability of fine and inhalable particles ($PM_{2.5}$, PM_{10}), relative humidity and temperature in period 2012-2015

surface [25]. Conversely, if temperature values become lower, the mentioned connection can be observed: lower temperature and higher RH bring about higher PM concentrations. It is true, that if in the winter period the given daily temperature falls below the multi-annual monthly average dew point, PM_{10} densification and transgression can be observed, respectively if the difference between temperature and dew point is small, the phenomenon of fog becomes more frequent, which also results in densification or transgression.

The relationship between PM concentration and the dew point temperature

In cold periods, the high relative humidity is often associated with fog events and in warm periods, the high humidity is often associated with rainy events [26]. Thus, in both cases drifting particles removed from the atmosphere through humid precipitation. Recent studies show a strong connection between RH values and dew point temperature (t_d) (every 1°C dew point temperature rise brings about 5% of RH decrease, if t_d = t, dry-bulb temperature, when RH =100% [30]), according to which the more instable the atmosphere is, the lower the RH value will be, and on warmer days evapotranspiration is higher.

At dew point temperature water vapors condense, by which, according to our hypothesis a part of the drifting particle concentration also condenses. In order to verify that dew point must be calculated. To determine it, we start from RH, which is the ratio of the actual water vapor pressure (e_s) and over a plane of water vapor pressure (e). In function of these pressures and temperature, dew point temperature can be expressed as follows:

$$e_s(t_d) = e(t)$$

$$t_d = \frac{B\left[\ln\left(\frac{RH}{100}\right) + \frac{At}{B+t}\right]}{A - \ln\left(\frac{RH}{100}\right) - \frac{At}{B+t}}$$

where A and B are coefficients, and values for the coefficients: A=17.625, B = 243.04°C and values for e_s with a relative error of < 0.4% over the range -40°C ≤ t ≤ 50°C [30-34].

Thanks to the closed basin of the Ciuc basin, various atmospheric phenomena can be more observed more precisely, which in this case means that PM pollution is built upon the relationship between temperature, dew point and RH. In the periods when RH is increasing, calculated multi-annual average PM values are also observably quite high (fig. 2.).This is primarily characteristic for late autumn and winter months, respectively more in the case of PM_{10}.

In these late autumn and winter months, the changes in multi-annual daily average PM concentrations were examined in function of multi-annual monthly average dew point values, and concluded that in November, at temperatures below dew point average PM concentration was 20.46% higher, while $PM_{2.5}$ was 24.44% higher than the average concentrations measured at temperatures above dew point. Furthermore, this was also characteristic for the months of December (PM_{10}: 74.43%; $PM_{2.5}$: 5.44%), January (PM_{10}: 41.26%; $PM_{2.5}$: 11.92%) and February (PM_{10}: 61.43%; $PM_{2.5}$: 14.48%). In other words, the present paper found that the multi-annual monthly average dew point and temperature can be considered as indirect air pollution indicators in the lower troposphere of the Ciuc basin, predominantly in the case of PM_{10}. As we will see in what comes, the above statement did not prove to be true for $PM_{2.5}$. In fact, in the case when daily average temperature falls below the multi-annual monthly average dew point values, the densification of PM pollution can be observed; while when daily average temperatures are above the value of dew point, the concentration of pollution decreases together with stability, resulting in pollution dilution and its partial humid precipitation. In fact, at temperatures below the multi-annual average dew point value PM densities, whereas at temperatures above dew point it precipitates, yet part of it remains in the atmosphere with the evaporation of fine water particles. Parallel to that the already mentioned RH formation can also be observed: under dew point temperatures it is higher, while at temperatures above dew point it is lower [30]. More precisely, its average value at temperatures below dew point is 87.11% and above dew point the average value is 78.19%.

From the end of October, we can already witness a higher atmospheric stability and periods of inversion, until the end of February [21 29, 33, 36], yet frequent temperatures below dew point were also observed in this period. In the following months of the year, the multi-annual average temperatures were above dew point. In the case of PM_{10} no high concentrations appear in the period between March and October, and it can also be seen on Fig. 3 that in the warmer period, daily temperatures are above the multi-annual monthly average dew point, and that PM_{10} concentrations are also low. In the case of $PM_{2.5}$ this observation is not typical, because these particles behave differently as a result of meteorological parameters, due to their smaller size and different source [37]. In the case of the above described $PM_{2.5}$, when temperature goes beyond dew point, the decrease of their concentration in the atmosphere is quite low (an average 14.07% in the period of autumn and winter), which is most probably true because resulting from their smaller size, they do not create larger condensation nuclei, thus remain in the RH fraction, that does not precipitate with increasing temperatures, but evaporates instead, unlike PM_{10} particles, the concentration of which gets reduced by 49.40% after the temperature goes beyond dew point in the mentioned late autumn and

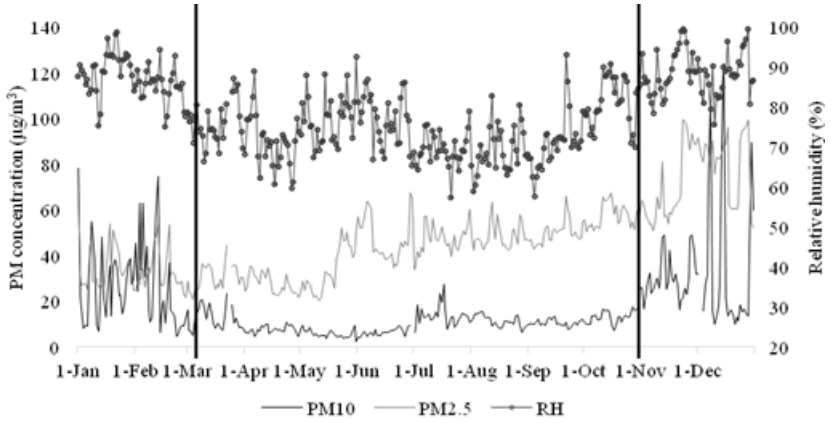

Fig. 2 Changes of multi-annual average PM concentrations and of RH

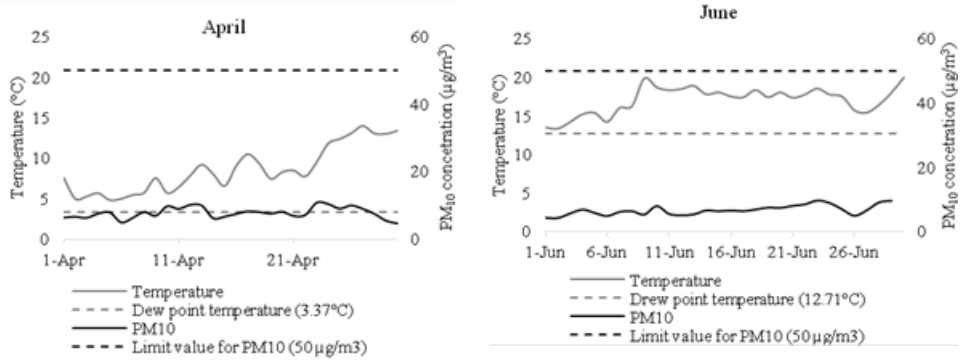

Fig. 3 Changes in multi-annual average PM concentrations and temperatures, in function of dew point, in the warm season

winter period, as these result in larger condensation nuclei, larger water molecules that can precipitate more easily. Furthermore, $PM_{2.5}$ concentrations were high during the entire examined period (June 2012– June 2015); their multi-annual average value (47 µg/m^3) exceeding the annual limit concentration value set by the EU (25µg/m^3). In what follows, the model described will only be discussed for PM_{10} particle concentrations.

In the case of multi-annual average PM concentrations, the periods that overlap each year were selected. A total number of eight periods with transgressions could be observed: 1-3 January (average PM_{10} concentration: 38.07 µg/m^3) and 7-9 January (average PM_{10} concentration: 47.94 µg/m^3), 2-4 February (average PM_{10} concentration: 39.16 µg/m^3) and 11-13 February (average PM_{10} concentration: 58.54µg/m^3), 26-30 November (average PM_{10} concentration: 40.53 µg/m^3), 7-8 December (average PM_{10} concentration: 89.07 µg/m^3), 14-15 December (average PM_{10} concentration: 106.24 µg/m^3) and 30-31 December (average PM_{10} concentration: 74.84 µg/m^3) (fig. 4.).

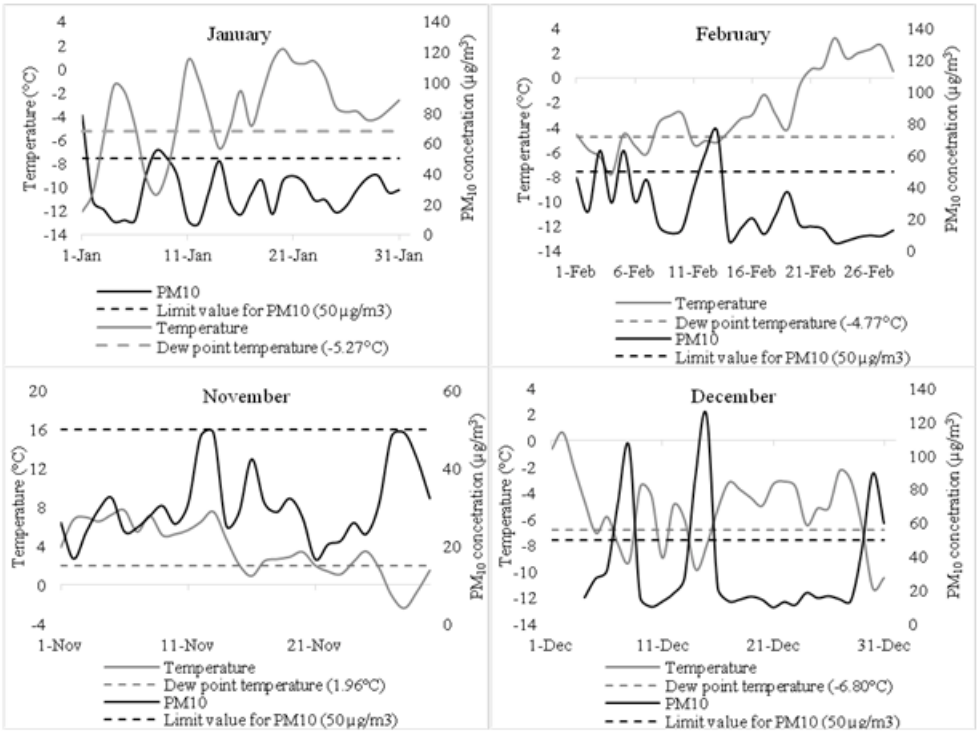

Fig. 4 Changes in multi-annual average PM concentrations and temperatures, in function of dew point, in the cold season

Table 2

THE DIFFERENCE BETWEEN THE MULTI-ANNUAL DAILY AVERAGE TEMPERATURES AND THE MULTI-ANNUAL MONTHLY AVERAGE DEW POINTS, AS WELL AS THE DIFFERENCES BETWEEN MULTI-ANNUAL DAILY AVERAGE PM_{10} CONCENTRATIONS AND THE MULTI-ANNUAL MONTHLY AVERAGE AND MULTI-ANNUAL AVERAGE PM_{10} CONCENTRATIONS

Period	$T_{multiaverage,\ daily}$ - $t_{d,multiaverage\ monthly}$ (% difference)	$PM_{10,daily}$-$PM_{10,monthly}$ (% difference)	$PM_{10,daily}$-$PM_{10,yearly}$ (% difference)
1-3 January	80.16	37.60	135.03
7-9 January	80.64	68.83	188.36
2-4 February	40.27	51.58	135.54
11-13 February	10.28	126.63	252.16
26-30 November	10.84	21.08	143.83
7-8 December	26.46	166.07	435.80
14-15 December	31.14	217.36	539.08
30-31 December	60.24	123.56	350.20

In these periods, the deviation of the multi-annual daily average temperatures from the multi-annual average dew point values was between 10.28-80.64%, while that of the PM_{10} concentration from monthly average PM_{10} concentrations was between 21.08-217.36%, and from the multi-annual average (16.63 μg/m^3) was between 135.03–539.08% (table 2). The value of daily temperature was below dew point value, thus PM_{10} concentration accumulated and can be well observed that in each of the eight periods, their values were higher than the monthly and annual PM_{10} concentrations.

The Bernoulli binominal probability distribution was calculated for these periods.

$$f_c(t) = \sum_{k=0}^{n} e^{itk} C_n^k p^k q^{n-k} = (pe^{it} + q)^n$$

where C represents the number of cases; 0<p< 1 probability; q = 1 - p; $i = \sqrt{-1} \in C$; k = 0, 1, 2 ... , n the frequency of the occurrence of the event; n repetitions [37].

The binominal function is used in cases when each case can have two different outcomes: successful or unsuccessful, each case is independent of any other case, and when the probability of the result is constant during the entire experiment. According to our results, under such atmospheric conditions, the probability that PM_{10} concentrations will exceed the limit value is represented in the distribution graph on figure 5. Based on multi-annual data, on 32 days we recorded temperature values lower than the monthly average dew point, of which on 12 cases the PM_{10} concentration exceeded the limit value (50μg/m^3). The result of the probability calculus based on the Bernoulli binominal distribution in this case is 0.1, as it can be observed on figure 5, which is a very high probability.

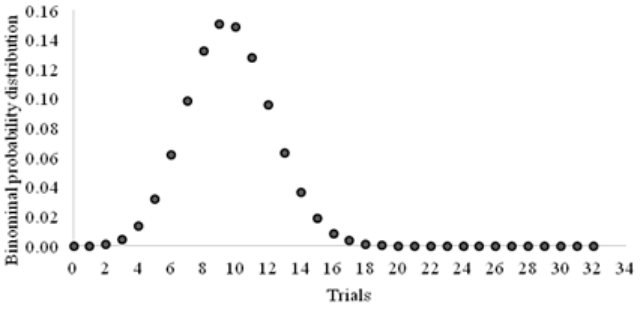

Fig. 5 Binominal probability distribution in case of 32 trials

Following that, with the help of the integral Moivre-Laplace formula the results of the Bernoulli binominal probability distribution were refined:

$$\lim_{n\to\infty} \sum_{a \le \frac{k-np}{\sqrt{npq}} \le b} C_n^k p^k q^{n-k} = \frac{1}{\sqrt{2\pi}} \int_a^b e^{\frac{-x^2}{2}} dx$$

Let $0 < p < 1, q = 1 - p$ and a uniform limit in $-\infty \le a \le b \le \infty$ [38].

$$\sum_{k \ge 12} C_n^k p^k q^{n-k} = \sum_{\frac{12-np}{\sqrt{npq}} \le \frac{k-np}{\sqrt{npq}} \le \frac{n-np}{\sqrt{npq}}} C_n^k p^k q^{n-k}$$

$$\approx \int_{\frac{32-9.6}{\sqrt{9.6 \cdot 0.7}}}^{\frac{12-9.6}{\sqrt{9.6 \cdot 0.7}}} \frac{1}{\sqrt{2\pi}} e^{\frac{-x^2}{2}} dx$$

$$= \Phi(8.641) - \Phi(0.926) \approx 0.5 - 0.38 = 0.12$$

According to our findings, the probability that because of the atmospheric features of the identified eight periods (32 days) a PM_{10} limit transgression will not occur on more days than the currently observed 12 occasions, can only be stated with a probability of 12%. In other words: 1-0.12=0.88 in the cold season, in the case of atmospheric conditions that are similar in nature to those of the identified eight periods there is an 88% probability for PM_{10} limit values transgression to occur.

The role of the temperature-dew point spread and the lifting condensation level in air pollution

Atmospheric processes are often linked to each other. In our case it is an important phenomenon that when dew point values are very close to temperature values (and both are low), fog can appear or clouds can appear very low [35]. In case of high RH, the dry air parcel will start to rise adiabatically and become colder, until the air parcel becomes 100% impregnated with water vapors [35]. Here it reaches the condensation level called lifting condensation level (LCL). This is the cumulus cloud-base height [30] and was calculated using following equation:

$$LCL \approx \left(20 + \frac{t}{5}\right)(100 - RH)$$

where t is the temperature at the ground level and RH is the ground level relative humidity [30].

In the troposphere levels close to the surface, in case of high RH the LCL level can form on a very low level. If in the period between November and March we consider an LCL formation under 20m (located within this air mass even in the case of inversion), then in the case of these days the average RH value is 99.80% (min: 99.02%; max: 100%), the average LCL value is 4.16 m (min: 0m; max: 19.59m), and the average value of pollution will be higher in the case of PM_{10} with 48.29% and in the case of $PM_{2.5}$ with 57.04% as compared with the multi-annual average value of the whole period (PM_{10}: mean: 22.55 μg/m^3, min: 5.39 μg/m^3, max: 67.75 μg/m^3; PM2.5: mean: 40.08 μg/m^3, min: 6.18 μg/m^3, max: 127.3 μg/m^3). At the same time the temperature-dew point spread ($t-t_d$) is also low on the mentioned days (43 days), having an average value of 0.000011°C (min: 0°C; max: 0.000132°C). In other words, the lower the value of temperature-dew point spread, the higher are the values of RH (r = -0.739) and of pollution ($r_{(t-td)-PM10}$=-0.420; $r_{(t-td)-PM2.5}$=-0.202;) (fig. 6).

The mathematical description of the model

Under dew point temperature, the value of RH is higher, or increasing, the lower the difference between the temperature of the air and the dew point is:

if t t_d <<, then RH increase

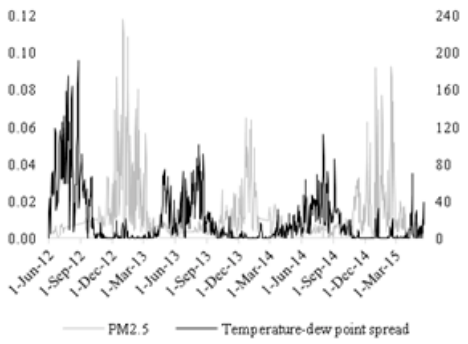

Fig. 6 The changes of $PM_{2.5}$ concentration and temperature-dew point spread in the examined period

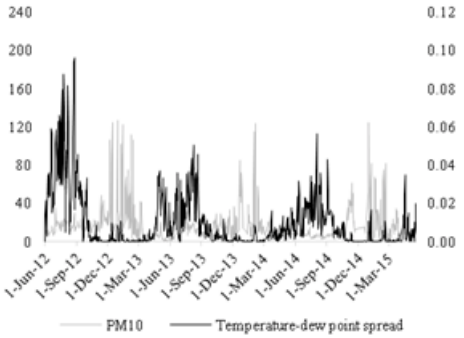

Fig. 6 The changes of PM_{10} concentration and temperature-dew point spread in the examined period

In parallel with that the higher the humidity of the air is, the lifting condensation level will be in the lower altitude.

if RH <<, then LCL decrease

In other words, if the altitude of the LCL is closer to the surface, fog will appear, or lower clouds, which will prevent the humid precipitation of drifting particles, which will accumulate due to a stable air stratum. For the humid precipitation of drifting particles air temperature must reach dew point value. Once it exceeds that, the air stratum will become more unstable as the temperature rises, thus getting more diluted and the concentration of drifting particles decreases due to humid condensation, causing the air to become drier. In the following hours, this evaporation increases with temperature, leading with lower afternoon and evening temperatures, in more stable atmospheric conditions to increased RH, respectively PM accumulation. In case daily temperature changes are divided into three cycles, - temperatures below dew point, increasing temperatures above dew point and temperatures having a decreasing tendency above dew point, - we can observe the phenomena described above, according to which the average values of increasing hourly temperatures above dew point are higher (average: 10.10°C), whereas the average of the hourly temperature values showing a decreasing tendency above dew point is lower (average: 9.50°C). In parallel with that the changes of the PM_{10} concentration and of RH can also be observed: the instability occurring as a result of the increasing temperature results in decreasing PM_{10} concentrations (average: 12.97 μg/m^3) and RH values (average: 73.20%), while as a consequence of the more stable atmosphere resulting from cooling temperatures, again shows tendencies for higher PM_{10} concentrations (average: 14.59 μg/m^3) and RH (average: 74.67%).

When the previous environmental conditions are fulfilled, the following mathematical relations hold:

$$if \sum_{n} t_h < t_{d,\,mma}\ , then\ C_{PM10,h} > C_{PM10,\,mma}$$

where t_h is the hourly air temperature in °C; $t_{d,\,mma}$ is the multi-annual monthly average dew point temperature in °C; $C_{PM,\,h}$ is the hourly PM_{10} concentration; $C_{PM10,\,mma}$ is the multi-annual monthly average PM_{10} concentration and n is the number hours.

This means that if daily hourly temperature does not exceed the multi-annual monthly dew point value, then one can talk about the densification of the PM_{10} concentration and often about transgressions, too, as it was previously shown, the reason of which is the dependency of temperature from the dew point. The application of the model is only suitable to predict the changes of PM_{10} concentrations, as in the case of $PM_{2.5}$ concentrations, it did not bring about the expected results. The meteorological parameters applied in the model are comprised by Barnes in a k proportionality value [38], which we also make use of, in order to fundament our model:

$$k = \frac{T_d - T_{LCL}}{T - T_d}$$

where T_{LCL} is the temperature at the LCL and T is the potential temperature.

When examining the k proportionality factor, it was concluded that it was independent of the pressure value, and that it is non-linearly related to the values of temperature and of temperature-dew point stream. In fact, it is in a linear relationship with the value of dew point [39]. According to our results, the value of k and the concentration of PM_{10} change oppositely (fig. 7). In other words, in the cold season, when PM_{10} concentrations are high, k values are low:

if, C_{PM10} <<, then k decrease

If we correlate this k proportionality factor with the PM10 concentrations, we get a negative correlation (r = -0.299) for the studied period (June 2012 – July 2015), which increases in the cold season to -0.309. In other words, all this proved that the results of our model are correct, sustainable and adequate to forecast larger pollution periods. If we examine the figure below, we discover a period/phase shift between PM and k, which means that pollutants react with a delay to the changes of meteorological parameters. In spite of that, the correlations show a certain connection in the winter periods.

The accumulation of PM_{10} places a significant burden on the human organism; therefore, this model becomes an important and quickly and easily accessible tool that can be used in predicting such periods and warning sensitive target groups.

Air quality according to $PM_{2.5}$ concentration

As in the Ciuc basin the densification of PM in the winter period represents a significant problem, thus the model described above plays an important role in the examination of the air pollution of the basin, respectively it is also important to examine the quality of the air, which has been carried out in the examined period (2012-2015). It has been

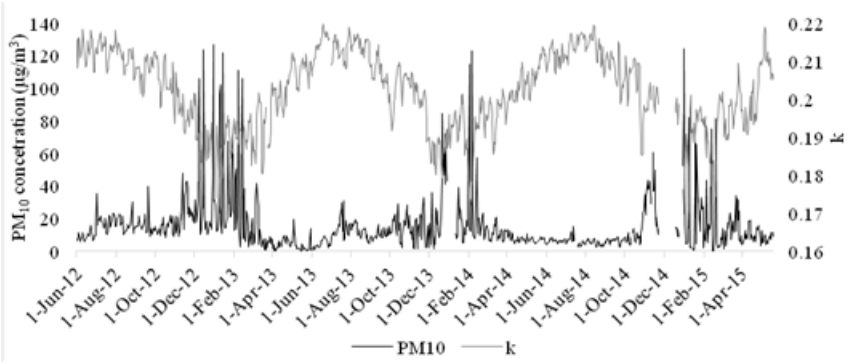

Fig. 7 Changes of PM_{10} concentrations and of the value of the k proportionality factor in the studied period

Air Quality Index (AQI) values	Levels of health concern	Colors
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for sensitive groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 to 500	Hazardous	Maroon

Table 3
THE AIR QUALITY INDEX VALUES AND RELATED SIX LEVELS OF HEALTH CONCERN [7]

calculated separately for each of the four years, taking $PM_{2.5}$ concentrations into account, as these give a more precise air quality definition than PM_{10} concentrations. The U.S. Environmental Protection Agency (EPA) strengthened the nation's air quality standards for fine particle pollution to improve public health protection [40]. EPA created the Air Quality Index (AQI) for fine particle pollution and was calculated by using following equation [40]:

$$AQI = \left(\frac{100}{n}\right)\sum_{k=1}^{n}\left(\frac{APC_k}{SPC_k}\right)$$

where, n – number of criteria pollutant; APC – actual pollutant concentration and SPC – standard pollutant concentration [16].

These index is color-coded and converts concentrations for fine particles to a number on a scale from 0 to 500 and EPA is changing the upper end of the range for the categories (Good, Moderate, Unhealthy for Sensitive Groups, Unhealthy, Hazardous) (table 3) [41].

During the air quality assessment, the mentioned EPA classification was utilized [7]. Accordingly, in the period between 2012 and 2015 the atmosphere was good in 45.86% of the cases, moderate in 34.86% unhealthy for sensitive groups in 6.54%, unhealthy in 11.22% and very unhealthy in 1.53% of the cases (fig. 8). In accordance with our calculations, the periods marked in our model make up 21.36% of the time classified as unhealthy by the AQI, while the very unhealthy periods make up 64.29% of it.

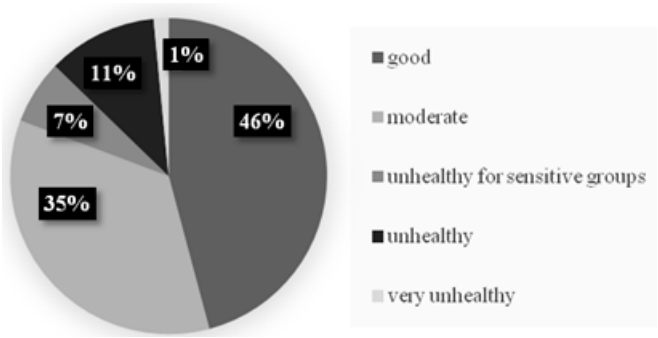

Fig. 8 Multi-annual monthly average AQI classification, based on the color scale of table 3

In an annual distribution the average quality of air in 2014 can be classified as good (AQI = 47.12), whereas it classifies as moderately polluted in 2012 (AQI = 97.37), 2013 (AQI = 70.11) and 2015 (AQI = 78.18). In the multi-annual monthly classification polluted or strongly polluted air quality are primarily characteristic for the cold season (October- March). Better (moderate) air quality is characteristic for the period between April and September [41]. As a result of the decreased drifting particle pollution registered after every incidental solution, the health of society improves and the chance for economic growth increases [42].

In another paper was studied the air pollution with $PM_{2.5}$ and PM_{10} in Tg. Jiu [43].

Conclusions

In the inversion periods identified in the Ciuc basin the meteorological conditions are characteristically the same: low temperature values, low temperature-dew point spread, high relative humidity, calm winds, anticyclone, and stable air circulation. In the period of winter, the inversion type called cold air cushion is frequently characteristic, lasting for several days, with stronger, dynamic atmosphere movements needed to break it.

Depending on these observations, a model was defined to describe PM_{10} concentration growth in the Ciuc basin, in order to permit it easy use with the main purpose of warning the sensitive inhabitants of the region, respective those with health problems caused by drifting particles about growing PM_{10} concentrations.

The model can be summarized to the conclusion that when the measured or forecast daily average temperatures do not exceed the multi-annual monthly average dew point, the phenomenon of PM accumulation occurs and in many cases these concentrations transgress the limit values permitted by law.

It is important to recognize and filter out the periods when there is a high probability for high PM_{10} concentration, because by warning the population in time, the health problems caused by drifting particles can be prevented. In the Ciuc basin, in the case of the atmospheric conditions of the identified eight periods in the winter season there was a transgression of PM_{10} concentration on 12 days, respectively there is a chance of 88% for the number of these days to grow. In the future we wish to test the model for other geographic regions as well. At the same time, the thorough knowledge of the above relationships will make it possible in the future to assess how the hydrological balance can be improved on the level of micro regions, and thus reduce the number of days with large-scale drifting particle pollution. As a result of the decreased drifting particle pollution registered after every incidental solution, the health of society improves and the chance for economic growth increases.

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