The Dry Deposition of the PM\textsubscript{10} and PM\textsubscript{2.5} to the Vegetation and its Health Effect in the Ciuc Basin

ROBERT SZEP\textsuperscript{1*}, REKA KERESZTES\textsuperscript{2}, GYORGY DEAK\textsuperscript{3}, FRANCISC TOBA\textsuperscript{4}, MARIETA GHIMPUSAN\textsuperscript{4}

\textsuperscript{1} Sapientia Hungarian University of Transylvania, Faculty of Technical and Social Sciences, 1 Libertatii Sq., 530104, Miercurea Ciuc, Romania
\textsuperscript{2} INCDPM - National Institute for Research and Development in Environmental Protection, 294 Splaiul Independentei, 060031, Bucharest, Romania
\textsuperscript{3} Spiru Haret University of Bucharest, 13 Ion Ghica Str., 030045, Bucharest, Romania
\textsuperscript{4} University Politehnica of Bucharest, Department of Analytical Chemistry and Environmental Engineering, 1-7 Gheorghe Polizu Str., 011061, Bucharest, Romania

The pollutants emitted into the atmosphere may be transformed after certain time; they can come out from the atmospheres dry or wet deposition. The plant species characteristic to the Ciuc basin is the pine, forming large forests that constitute the primary surface deposition. According to that, dry deposition calculations have been carried out based on the pine forests. Regarding the deposition changes, PM\textsubscript{2.5} and PM\textsubscript{10} do not differ, but their effects on the health are very different. This results especially from their dimension and concentration. Their deleterious effect on the human health in the Ciuc basin was examined through the relative risk factor. The results showed that people are more disposed to cardiovascular diseases, lung cancer, acute and chronic respiratory diseases, asthma and other diseases. In addition, regarding the microclimate formation (atmospheric stability) in the Ciuc basin, the atmospheric pollution does not concern only the city of Miercurea Ciuc. The calculated risk factors are applied to the entire population within the basin.

Keywords: particulate matter, dry deposition, human health, relative risk, atmospheric stability

Particulate matter is the complex component of urban and non-urban environments, with a large variety of chemical and physical properties, in interaction with the dynamism and complexity of the nature [1-7]. It is classified in accordance to the pollutants diameter, which plays an important role in the nature, period and the severity of the diseases. According to the researches, the PM types with different characteristics cause different health effects [8].

In 1989 the EPA declared the standard PM diameter to 10\mu m, and in 1997 to 2.5 \mu m. In 2000 the WHO has established that the PM\textsubscript{2.5} contains the PM\textsubscript{10}, and it results from the transport, industrial sector, heating (butane, wood, waste, coal), open waste yards, agricultural waste etc. [9].

PM\textsubscript{2.5} is a solid pollutant having a diameter of less than 2.5 micrometers, while the PM\textsubscript{10} has a diameter of less than 10 micrometers, particle mostly derived from the incomplete combustion of fossil fuels and biomass burning. According to the WHO regulations, related to the PM\textsubscript{10}, the annual average limit value is 10 \mu g/m\textsuperscript{3} and the 24-hour average limit 25 \mu g/m\textsuperscript{3}. However, in Kathmandu, Nepal, values higher than 500 \mu g/m\textsuperscript{3} have been already measured.

According to the WHO survey, in 2012 were registered 3.7 million premature deaths as result of the air pollution, representing half of the initial estimations (7 million) [9].

Around 3 billion people in the world are using coal or biomass to heat their houses. Besides these, large quantities of wood, waste and charcoal are burned. Mostly in Africa, the use of fossil fuels and traditional biomass shows an upward trend, and in the near future is expected the highest increase of energy consumption. According to UNEP, by 2030 it will contribute 50% to the emission of pollutants. The highly developed countries have reduced the air pollution in the recent years, partly due to the restrictions on emissions, including in case of the vehicles. Still, researches showed that 50% of the diseases caused by the air pollution can be attributed to the traffic. In case of the developing countries, such as China and India, a rapid growth of the transport can be registered, exceeding the emission limit values [9].

It is scientifically proven that there is a strong correlation between the mentioned airborne dust, allergens, asthma, respiratory diseases, tumor formations and cardiovascular diseases [10-13]. The most exposed to risk are the children, due to the fact that their immune system is not developed enough. In the United States, 78% of the air carcinogenic compounds are constituted from these particles. The most dangerous are the small particles, because during inhalation, they are not blocked by the nose hairs. They may contain various heavy metals, asbestos, organic contaminants. Stuck to the pollen they can intensify the allergic effects [14]. According to the CAFE (Clear Air for Europe) survey, nearly 300 thousand people from the EU could die each year as a result of the less than 2.5 micrometers polluting particles. Our research aims to determine the effects of PM pollutants on human health and vegetation within the Ciuc Basin.

Experimental part
The location under survey is the Ciuc basin, a bowl-shaped basin with a length of 60 km and an average height of 600 m, being situated in the Eastern Carpathians. The highest mountains within the basin range between 1000 and 1800 meters [15]. There are two monitoring stations in the basin, with a distance between them of 3.6 km.

\* email: szeprobert@yahoo.com
During the research, were processed the data from the regional monitoring station, which obtains the PM data using LSPM10analyzer. It was also used the daily gravimetric data sampled by FOX pump and monitoring system.

Results and discussions

The dry deposition of PM$_{10}$ and PM$_{2.5}$

The deposition of solid pollutants may occur in dry or wet conditions. In this case, was examined the dry deposition for the PM$_{10}$ and PM$_{2.5}$ pollutants.

The flux of the above mentioned atmospheric pollutants is the product (multiplication) of the wind speed ($v_d$) and the pollutant concentration ($c_r$) [16-18]:

$$ F_t = v_d \cdot c_r $$

(1)

The deposition velocity ($v_d$) is strongly influenced by the gravitational settling velocity ($v_g$) of the particle [19]:

$$ v_d = \frac{1}{R_a + R_b + \frac{v_g}{v_d}} $$

(2)

where: $R_a$ – aerodynamic resistance, $s/m$; $R_b$ – viscous sub-layer resistance, $s/m$; $v_g$ – gravitational settling velocity, $s/m$.

$$ v_g = C_c \left( \rho_p - \rho_a \right) \frac{d_p^2 g}{18 \mu} $$

(3)

where: $\rho_p$ – particle density, $kg/m^3$; $\rho_a$ – air density, $kg/m^3$; $d_p$ – particle diameter, $m$; $g$ – gravitational acceleration, $m/s^2$; $\mu$ – dynamic viscosities, $Pas$; and $C_c$ – Cunningham’s correction factor.

The first factor of the dry deposition is the aerodynamic resistance [20,21]:

$$ R_a = \frac{1}{u_a} \left[ \ln \left( \frac{z}{z_0} \right) + 4.7 \left( \frac{z}{L} \right) \right], \text{h}a L > 0, $$

(4)

and

$$ R_b = \frac{1}{u_a} \left[ \ln \left( \frac{1 + \frac{z}{d}}{1 + \frac{z_0}{d}} \right), \text{h}a L < 0, $$

(5)

where $k$ – von Karman’s constant, 0.4; $z$ – vertical coordinate, $m$; $z_0$ – roughness length, $m$; $d$ – reference height (60-80% of the vegetation, building is height), $m$; $L$ – Monin-Obukhov height, $m$.

The viscous sub-layer resistance is different in stable and neutral air conditions:

$$ R_b = \frac{1}{u_a \left( \frac{2}{5} \frac{L}{z} + 10^{-2} \frac{z}{z_L} \right)}, \text{h}a L > 0 $$

(6)

and in unstable conditions:

$$ R_b = \frac{1}{u_a \left( 1 + 0.24 \frac{z}{z_L} \right) \left( \frac{2}{5} \frac{L}{z} + 10^{-2} \frac{z}{z_L} \right)} $$

(7)

where: $Sc$ – Schmidt-number; $St$ – Stokes-number; $D$ – diffusion coefficient and $k$ – Boltzmann’s constant.

The particle deposition velocities calculated with the above mentioned method in case of small particles are in the range of 0.02 and 0.05 cm/s, and in case of permanent vegetation-covered areas (coniferous forests) these deposition velocities are higher [22].

The biological effect of the deposition manifests itself through stomata closing mechanism, which blocks the photosynthesis and reduces in the long run, the vegetation productivity [8]. However, the pollutants come out from the air mass which becomes cleaner [22]. According to Fowler et al. (2002) [16] in the presence of vegetation, the atmosphere may cleanse from 5 to 50% through deposition.

In the period of March 2012 and March 2013, the deposition of PM$_{10}$ and PM$_{2.5}$ showed similar changes in the Ciuc basin. According to the daily average data, the deposition values are rising in the spring period, while in the summer are recorded the highest values, and later when the temperature drops they become lower and lower (fig. 1).

The daily average flux changes show opposite curves: the high flux can be associated with low deposition values and the low flux with high deposition values. Between the hourly average of PM$_{10}$ concentration and its flux -0.725 Spearman rank correlation can be detected, which sustains the above written views.

The minimum values of the daily hourly deposition is registered in morning between 5:00 and 8:00 A.M., due to the morning rush hour. As shown in the figure 2, a constant rise of the values was reported in the morning hours, while between 13:00 and 16:00 in the afternoon, is reached the maximum deposition limit, and then the values start to fall steeply again. In case of the hourly PM$_{10}$ flux: the high flux is associated with low deposition values and low flux with the high deposition value. Consequently, the lowest flux is reported in the afternoon hours and the highest values are registered in the morning hours (fig. 2).
In case of the seasonal analysis, the situation is as follows: the deposition values are the highest in summer and the lowest in winter. Breaking down these data to hours we get similar results as in case of the annual data (fig. 3). As shown in figure 4, the seasonal values are different, but the daily hourly distribution of data shows the same direction. The intensity of the hourly value changes is the highest in summer and then it steadily decreases in the following order: spring, autumn, winter.

The health impact of PM10 and PM2.5

According to the WHO (2009) data, the average PM10 concentration in Romania is 76 µg/m3 and annually, 9,600 deaths occur as a result of the PM10. This statistic shows that in most cases the deaths are caused by musculoskeletal disorders, cardiovascular diseases and cancer. Analyzing the statistics on health data in Harghita County, we obtained the same results. In 2012, from a total of 1137 persons, 695 have died due to cardiovascular diseases, 207 of deaths were caused by cancer and 67 were caused by respiratory diseases (fig. 5).

The inhabitants from most of the cities live exposed to a high health risk factor due to the air pollution. They are more predisposed to cardiovascular diseases, long-running cancer, acute and chronic respiratory diseases, asthma and other diseases [9].

Researches showed that the PM concentration determine diseases on short (days, weeks) and long term (years), that are closely connected to the resulting deaths [14]. The researchers did not find a limit value below which the PM concentration does not affect the human health [11, 12, 23].

Using the method of [24], the number of deaths caused by the air pollution per 1000 persons, could be estimated. As a first step, the number of deaths was calculated, in case if there is no anthropogenic PM pollution [8, 24-27].

\[
P_0 = \frac{P_e}{1 + \left[ RR \cdot \frac{B - E}{E} \right]^{10}} \quad (8)
\]

where: \( P_0 \) – number of deaths, in case of natural PM pollution (in our case 7.5 µg/m3); \( P_e \) – mortality rate per 1000 persons; \( E \) – mass of PM10 to the population [28]

\[
B = \text{PM10 mortality limit (from natural source)}; \text{the work can be conducted using four different values: 7.5, 5, 10 and 0} \mu g/m^3, \text{depending on the given subject and location.}
\]

\[
RR = \text{relative risk factor in case of 10} \mu g/m^3 \text{PM10 concentration growth. Different empirical formulas can be used to calculate the relative risk [29]. In table nr.1 can be find the formulas used in this case.}
\]

\[
Mortality factor increase in case of 10 \mu g/m^3 PM_{10} concentration:
\]

\[
Pc = \frac{N_{RAD}}{EPM \cdot P_{exp}} \quad (11)
\]

where \( Pc \) – the population of the given region.

During the diseases, as a result of the exposure to PM concentration, the sick person spends the most part of the day or the whole day in bed, he is absent from his work and does not exert any activity. These days are called restricted activity days = RAD [30, 31] and are calculated based on the following formula:

\[
N_{RAD} = E \cdot P_{exp} \cdot \frac{9 \cdot \text{pm} \text{-conc} \cdot \text{conc} \text{-days}}{100} \quad (12)
\]

where \( N_{RAD} \) is the number of the restricted activity days; \( E \) – the annual PM10 or PM2.5 concentration and \( P_{exp} \) the population.

In this chapter we focus first of all on the relative risk factors, which show the exposure of the population within the Ciuc Basin, to the PM10 and PM2.5 concentration, in certain periods.
Evans et al. (2013) [32] have performed a study using satellite observations about the PM<sub>2.5</sub> relative risk indicators for the period 2001-2006 according to the WHO regions. In our case the WHO regions are: Europe-A, Europe-B and Europe-C, where A – very low child mortality rate and low adult mortality rate; B – low child and low adult mortality rate; C – low child and high adult mortality rate.

In these regions, the total PM<sub>2.5</sub> concentration is ranging between 10.3 and 16.4 µg/m<sup>3</sup>, while the relative risk factors of cardiovascular diseases are between 1.06 (1.03-1.08) and 1.14 (1.08-1.19), and in case of lung cancer between 1.06 (1.03-1.10) and 1.15 (1.06-1.25). Although in some cases these values are similar, and in other cases lower than our calculations, they reflect the similarities between the European and the Ciuc basin averages (table 2).

In case of the Ciuc basin the average PM<sub>2.5</sub> concentration is 25.52 µg/m<sup>3</sup>, the relative risk of the cardiovascular diseases is 1.19 (1.12-1.27), and in case of lung cancer is of 1.30 (1.19-1.42). The highest values are primarily attributable to the closed basin and to the resulting inversion [33].

In case of the PM<sub>10</sub> the relative risk factor values are lower: due to its size, the particle settles out quicker and easier.

It has been performed a calculation of the relative risk factors, broken down by season. According to this, the highest relative risk values have been reported in autumn and winter in case of both pollutants (fig. 6 and fig. 7). Based on these calculations we can confirm that there is a correlation between the winter inversion in the Ciuc Basin and the higher air pollutant emissions [33]. The atmospheric stability periods of the basin cause automatically the accumulation of the pollutants. According to the national river regulations, during the 1980s the basin has lost 30-40% of its active water surface thus reducing the evapotranspiration. Possibly, this has greatly contributed to longer increasingly atmospheric stability periods in the Ciuc basin, but this is a subject of a future research.

The calculated basic mortality value is 12.02, which increases by 0.14 if to the concentrations from natural sources are added 10 µg/m<sup>3</sup> anthropogenic pollution. These calculations are made to 103308 inhabitants, 66737 being over 30 years. These values are valid to PM<sub>10</sub> containing PM<sub>2.5</sub> too.

The mass calculated to the population is 0.12 µg/m<sup>3</sup>PM<sub>10</sub>/person and 0.14 µg/m<sup>3</sup>PM<sub>2.5</sub>/person. Also, if we refer the previous values calculated to 1000 persons, to the population over the age of 30, it turns out that the anthropogenic PM pollution has contributed in 1.5% to the deterioration of the health condition of the individuals who died in 2012.

The number of death occurred clearly due to the air pollution is 0. High concentrations have been reported, but these recorded concentrations were not that high so as to cause death [33-35]. The number of restricted activity days is 13-15, which means that during the diseases, as a result of the exposure to air pollution in such concentration, the sick person spends 13 to 15 days at home.
Conclusions

The PM deposition show lower values in winter and spring, while in other periods their level can be considered equal. This is attributable to the activity of the vegetation and to the bad absorbing nature of the icy surface. According to the seasonal analysis, the deposition values are the highest during summer and the lowest during winter. The biological effect of the deposition manifests itself through stomata closing mechanism, which blocks the photosynthesis and reduces in the long run, the productivity of the vegetation. It has a similar effect on the human lung reducing its surface.

The deleterious effect of the air pollution exposure is reflected by the relative risk values and the diseases proportion of the deceased persons in the studied period. According to our observations most oftte, people have suffered on cardiovascular diseases, respiratory diseases and cancer. The relative risk factors have also shown an increased disposition to these diseases in the region.

The higher the pollutant concentration in the atmosphere of the basin is, the higher the risk factor values of diseases are. Moreover, the high concentrations are caused by the stable atmosphere, which is more than likely the result of river regulation. Therefore, the main thing to do for reducing the risk of diseases, is to increase and restore the surface area of the rivers, in order to achieve a higher evapotranspiration refracting to the atmospheric stability and decreasing the pollutant concentrations.

Acknowledgements. Particular thanks for the support of Environmental Protection Agency of Hargita for the meteorological and particular matternates.

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REV.CHIM.(Bucharest) ● 67 ● No. 4 ● 2016 http://www.revistadechimie.ro 643

Manuscript received: 18.06.2015