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THE INFLUENCE OF THE METEOROLOGICAL CONDITIONS ON THE EXTREME HIGH PM_{10} CONCENTRATIONS IN HUNGARIAN URBAN AREAS

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Abstract: In this paper, the effects of meteorological parameters on mass concentrations of particles with an aerodynamic diameter of 10 µm or less (PM_{10}) and their seasonal behaviour were investigated. Hourly data of PM_{10} between 2006–2015 obtained from the Air Quality Monitoring Network of Budapest were used. In the analysis one-hour meteorological data containing information about the temperature, wind velocity and direction and inversion height were also applied. The four seasons were separately examined for the period of 2006–2015, because the weather conditions can have impact on the emission from residential combustion.
In Hungary the yearly average PM_{10} concentrations have rarely exceeded 40 µgm^{-3} but at the same time the daily average value of 50 µgm^{-3} has been exceeded several times in a year despite the effort of the local government. An important aspect to be considered when studying trends of air pollution is that the trends do not only depend on the emissions of certain pollutants but also on the meteorological conditions in the area of interest. Regression analysis was used for finding a relationship between PM_{10} concentration and several meteorological parameters. In order to investigate the relationship between PM_{10} concentrations and meteorological variables properly, one has to consider that these relationships are presumably non-linear.

Key words: urban air quality, statistical models, PM_{10} predictors, emission

INTRODUCTION

Nowadays particulate matter (PM) is one of the most frequently mentioned pollutants since it has many negative impacts on the ecosystem, built environment and especially on human health. Particulate matter can have both natural and anthropogenic origin that influences its composition and size. These properties can change from time to time and from space to space depending on emission sources and atmospheric and weather conditions. International organizations and governments have tried worldwide to reduce emissions of PM and risks to health from the exposure to PM.

PM is a complex mixture of suspended particles and aerosols composed of small droplets of liquid, dry solid fragments, and solid cores with liquid coatings. These particles vary greatly in their physical and chemical properties, which are shape, size, solubility, residence time, reactivation, toxicity and chemical composition and structure. Moreover to the definition of these properties, determination of pollution reduction strategies also depends on the definition of their pollution sources. Local and regional meteorology, including wind speed, wind direction, atmospheric stability, long-range transport and pollution dispersion are all factors that play an important role in PM concentration reduction strategies. Analysis of local and regional meteorology is important to fully understand the processes responsible for the spatial and temporal distribution of PM in all geographic regions.

The effect of meteorology on PM_{10} trends has been analysed in several scientific studies (Velders and Matthijsen, 2009, Barmpadimos et al., 2010). Most of these articles finally concluded that beside the changes in anthropogenic emissions, the changes in meteorology can also be responsible for long term changes in PM_{10} concentrations.

In our previous work (Ferenczi and Bozó, 2016) it was determined that the effect of transboundary sources on the air quality of Greater Budapest Area is essential and its fraction is higher than 50% in case of PM_{10}. Primarily during winter and fall seasons, episodes of poor air quality related to high concentrations of particulate matter are frequent in Budapest and these situations are often connected to special meteorological conditions – such as cold air cushion – which do not help the mixing and dilution of air pollutants. Usually this type of meteorological condition is coupled with very low ambient air temperature which can urge the usage of more solid fuel (wood and coal), therefore result in an increase of PM_{10}

emission from domestic heating. In this type of smog situation the effect of the long range-transport is not the determinant and the role of the local meteorological situation is the dominant. As long as the meteorological situation does not change, the air quality in the city will not improve. In all cases, a significant change in meteorological conditions (intensive horizontal and vertical mixing of the air) will result in the disappearance of smog situations.

DATABASE

The evaluation of the air quality of Budapest is based on data of the Air Quality Monitoring Network of Budapest and the meteorological observations of the Hungarian Meteorological Service. In the city of Budapest, the monitoring of PM_{10} with fine temporal resolution has started in 2005, and the availability of the hourly PM_{10} data has been suitable for a detailed analysis since 2006. Figure 1. shows a map with the PM_{10} monitoring stations in Budapest. In the southeastern part of Budapest, the *Gilice tér* suburban background station was selected for a detailed analysis, because this is a common meteorological and air quality station in the area of the Marczell György Main Observatory of the Hungarian Meteorological Service. At this location, PM_{10} concentrations and detailed meteorological observations are also available for a long time period.

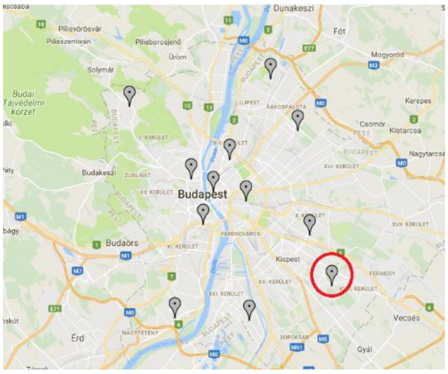

Figure 1. Map showing the locations of the stations of the Air Quality Monitoring Network of Budapest. *Gilice tér* station was marked with red circle.

TEMPORAL VARIATION OF THE CONCENTRATION OF PM_{10}

First the number of exceedances of the EU air quality standard (50 μgm^{-3} daily average value must not be exceeded more than 35 times during the year) was determined. Unfortunately, PM_{10} concentrations have exceeded the EU air quality standard several times a year, despite the effort of the local government. It was observed that mostly during the heating season concentration values above the threshold value can be detected. Figure 2. shows the number of times in a year when PM_{10} concentrations exceeded the threshold value between 2006 and 2015. Figure 2. also indicates that mainly in the fall (green colour) and winter (purple colour) periods the occurrence of situations with high PM_{10} concentration values is frequent.

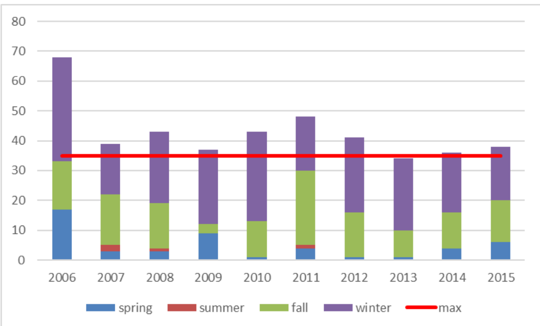

Figure 2. Number of exceedances of the threshold value (50 μgm^{-3}) as a function of seasons (2006–2015)

In Figure 3. the diurnal variations of PM_{10} concentrations in Budapest Gilice tér station during the weekdays and weekends of the year are presented. There is not a huge difference between the curves, however, at the weekends PM_{10} concentrations are lower during the day. At night, the concentration values are very similar.

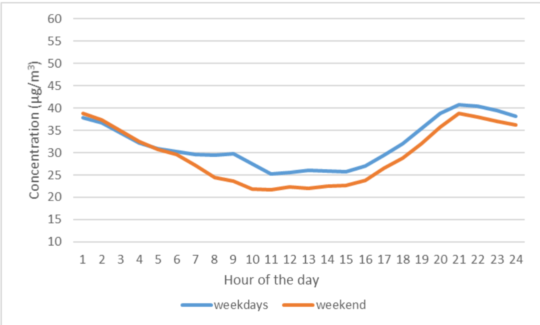

Figure 3. Diurnal variation of PM_{10} concentrations at Gilice tér station, Budapest (averaged over the 10-year period of 2006–2015)

When we take a look at Figure 4., where the four season are displayed separately, the seasonal differences appear clearly. In central Europe the definition of the seasons are the following. Spring: from March 1 to May 31; summer: from June 1 to August 31; fall: from September 1 to November 30; and winter: from December 1 to February 28. In general, it can be identified that PM_{10} concentrations have a typical diurnal variation, which is the same in every season. The maximum concentration can be expected at night, while the minimum concentration can be observed between 11am and 3 pm. The biggest difference between the daily maxima and minima can be observed in the fall.

In Hungary there are three important factors that have essential effects on PM_{10} concentrations: local anthropogenic emissions, external sources outside of the country and the meteorological conditions which affect pollutant diffusion and deposition. In Hungary the effect of natural sources are negligible. The most important local emissions, which have significant effects on the PM_{10} concentrations at Gilice tér, are traffic and residential heating. The impact of traffic on PM_{10} is continuous throughout the year, however, the effect of residential heating is considerable only in winter. Watching the diagrams, it can be observed that the averaged PM_{10} concentration values in spring, summer and fall are quite similar to each other between 11 am and 4 pm. It is possible that during this time period, there is no need to take into account the effect of residential heating. During spring and fall, although depending on the local weather conditions, the population use the combustion equipment mostly at night. In winter, the effect of residential heating has to be taken into account throughout the whole day.

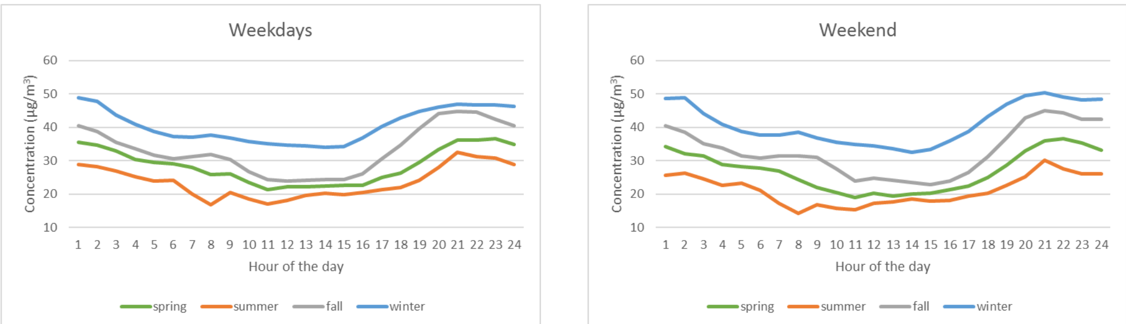

Figure 4. Diurnal variation of PM_{10} concentrations in different seasons at Gilice tér station, Budapest (2006–2015)

REGRESSION ANALYSIS

In order to investigate the relationship between PM_{10} concentrations and meteorological variables properly first the correlation coefficients between meteorological variables like temperature, visibility, wind direction and speed, relative humidity, atmospheric pressure, global radiation and PM_{10} were determined (Table 1.). Positive (relative humidity, atmospheric pressure) and negative correlations (temperature, visibility, wind direction and speed, global radiation) were found between several meteorological parameters and PM_{10} values. The seasonality of the correlation between PM_{10} and meteorological parameters was analysed separately and big differences were found between the seasons. The highest negative value of the correlation coefficient can be observed in the cases of temperature, visibility and wind speed in the winter period. This fact demonstrates that the meteorological conditions have significant role in the development of smog situations in Budapest. The correlation coefficient has no remarkable seasonality only in case of visibility, which is consistent with the results of other studies (Lee et al., 2014).

Table 1. Correlation coefficients between PM_{10} and several meteorological parameters

	spring	summer	fall	winter
temperature (°C)	-0,17	0,15	-0,22	***-0,42***
visibility (m)	-0,40	-0,29	-0,45	***-0,46***
wind direction	-0,16	-0,21	-0,25	-0,23
wind speed (m/s)	-0,29	-0,21	-0,36	***-0,42***
relative humidity (%)	0,11	0,06	0,26	0,20
pressure (hPa)	0,13	0	0,24	0,21
global radiation(J/cm²)	-0,25	-0,24	-0,23	-0,12

Regression analysis was chosen to find a relationship between PM_{10} concentrations and several meteorological parameters. Regression analysis was applied in winter, because a correlation coefficient above 0.4 between meteorological variables (temperature, visibility, wind speed) and PM_{10} can be observed only in this season. First we had to decide whether the connection between meteorological parameters and PM_{10} is linear or exponential. Table 2. shows the R^2 values that we got when we chose linear and exponential trend lines for three meteorological parameters. In the case of temperature, the linear trend line is a best-fit straight line and in the cases of visibility and, wind speed the exponential trend line is a best-fit curved line.

Table 2. R^2 values for several meteorological parameters

winter	linear	exponential
temperature (°C)	**0,17**	0,16
visibility (m)	0,21	**0,35**
wind speed (m/s)	0,17	**0,28**

The primary aim of our regression analysis was to determine the meteorological situation in wich the PM_{10} concentration is expected to exceed the 50 μgm^{-3}concentration. The studies presented so far helped us to determine the most important meteorological factors, which have essential effect on the PM_{10} concentration in the winter period. From these results, it can be concluded that temperature and wind speed are the most relevant parameter and of course, between visibility and PM_{10} concentrations there is a strong connection. Probably the effect of temperature on the PM_{10} concentration is very complex, because low temperature and poor vertical mixing can be observed together in winter and at the same time low temperature induces the usage of more solid fuel, which means that the emission of PM_{10} from domestic heating will be high.

As a result of our regression analysis it is possible to predict whether the PM_{10} concentration in an exact situation will exceed the 50 μgm^{-3} value or not. In the multiple regression analysis the dependent variable which we want to predict is the PM_{10} concentration and the independent variables were: temperature, wind speed and visibility. Table 3. shows the summarized results of the analysis which was significant.

Table 3. Results of multiple regression analysis for predicting PM_{10} concentration

winter	coefficients	standard error	p-values
intercept	59,09	0,29	0
temperature (°C)	-1,67	0,04	0
visibility (m)	-0,0006	1,47E-05	1,67E-302
wind speed (m/s)	-3,91	0,13	5,30E-203

The equation, which predicts the PM_{10} concentration using the values of temperature, visibility and wind speed is:

$$PM_{10}=59.09 - 1.67*[T] + 0.0006*[V] - 3.91*[WS], \quad R^2=0.32,$$

where T is temperature (°C), V is visibility (m) and WS is wind speed (m/s).
This equation is not able to forecast the exact PM_{10} concentration, it just indicates, whether the concentration will be over 50 μgm^{-3}or not. The method was tested on our test database, and in 75% of the cases did we get reliable results. It means if we have a good forecast for temperature, wind speed and visibility, we will be able to forecast whether the PM_{10} values will be over 50 μgm^{-3}or not with the probability of 75%.

CONCLUSIONS

In this paper, the effects of meteorological parameters on PM_{10} concentration and their seasonal behaviour were examined. As a result of the investigation, it can be said that the meteorological conditions have significant roles in the development of smog situations in Budapest in winter.
The results of our regression analysis showed that the concentration of PM_{10} is associated with specified meteorological parameters. However, the results from this study show that the relationship between PM_{10} and each meteorological parameter is not too strong. The statistical model developed for PM_{10} and the meteorological parameters (temperature, visibility and wind speed) show that the value of R^2 is 0.32. Despite this weak R^2 value our model can be used to decide whether PM_{10} values will be over 50 μgm^{-3}or not.

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