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Atmospheric pollution

ASSESSMENT OF RELATIONSHIP BETWEEN METEOROLOGICAL ELEMENTS AND AIR POLLUTANTS LOAD IN AN URBAN ENVIRONMENT

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Abstract. The aim of the study is to analyse the relationship between meteorological elements and the main air pollutants based on the data of Szeged city, southern Hungary. Factor analysis was performed for both summer and winter months. Only the two extreme seasons were investigated because the variables in question are then under different processes. The database includes daily means of 11 meteorological elements and 8 air pollutants for the summer (June, July, August) and winter months (December, January, February) of the five-year period 1997–2001, respectively. Four factors were retained both in the summer and winter months that contribute significantly to the formation of weather and air pollution episodes in Szeged. Wind speed is an important parameter in both extreme seasons for diluting air pollution. Strong winds reduce the concentrations of air pollutants, and vice versa. O_3 concentrations are inversely proportional to the concentrations of the primary air pollutants. In Factor 4 only the factor weights of the ozone parameters are almost exclusive for both extreme seasons.

Keywords: meteorological elements, air pollutants, factor analysis, factor loadings, weather types.

AIMS AND BACKGROUND

Since the last century, air pollution has become a major environmental problem, mostly over large cities and industrial areas[1]. For instance, the global mean per capita mortality caused by air pollution is about 0.1% per year. The highest premature mortality rates are found in the Southeast Asia and Western Pacific regions where more than a dozen of the most highly polluted megacities are located[2].

In Hungary, air pollution is one of the highest in Europe. Around 16 000 annual premature deaths attributable to exposure to ambient PM_{10} concentrations are

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estimated in the country[2]. Furthermore, the Pannonian Plain involving Hungary (Fig. 1) is heavily polluted with airborne pollen and most polluted with airborne ragweed (*Ambrosia*) pollen in Europe[3].

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EXPERIMENTAL

Location. Szeged (46.25°N; 20.10°E) is the largest settlement in South-eastern Hungary and is located at the confluence of the Tisza and Maros Rivers (Fig. 1). The area is characterised by an extensive flat landscape of the Great Hungarian Plain with an elevation of 79 m above mean sea level.

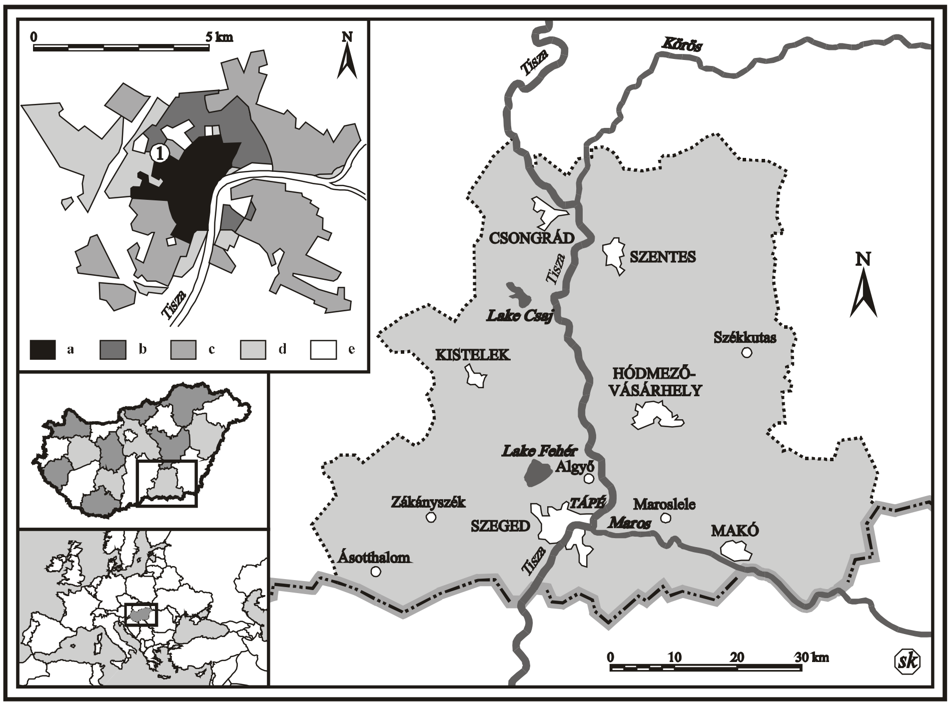

Fig. 1.Types of built-in areas in Szeged: a – downtown (2–4-storey buildings); b – housing estates from prefabricated concrete slabs (5–10-storey buildings); c – separate buildings (1–2-storey buildings); d – industrial sites; e – green areas; (1): automatic air quality monitoring station

Data. The database includes daily means of 11 meteorological elements and 8 air pollutants for the summer (June, July, August) and winter months (December, January, February) of the five-year period 1997–2001, respectively. The daily parameters of the meteorological elements considered are as follows: mean temperature (T_{mean}, °C), maximum temperature (T_{max}, °C), minimum temperature (T_{min},

°C), daily temperature range (DT = $T_{max} - T_{min}$; °C), relative humidity (RH, %), global radiation (I, MJ/m^2), wind speed (WS, m/s) (E, mm), water vapour (VP, mb), saturation vapour pressure (E, mm), potential evapotranspiration (PE, mm) and dew point temperature (T_d, °C). The air pollutant parameters used include daily mean concentrations of carbon monoxide (CO, mg m^{-3}), nitric oxide (NO, mg m^{-3}), nitrogen dioxide (NO_2, mg m^{-3}), particulates (PM, mg m^{-3}), sulphur dioxide (SO_2, mg m^{-3}), ozone (O_3, mg m^{-3}), as well as daily maximum ozone concentration (O_{3max}, mg m^{-3}), and NO_2/NO ratio.

The data come from the monitoring station, which is located in the downtown – at a busy intersection (Fig. 1).

Method. Factor analysis identifies linear relationships among examined variables and thus helps to reduce the dimensionality of the initial database without substantial loss of information. Factor analysis was applied to our initial datasets consisting of 19 correlated variables (including 11 meteorological variables and 8 air pollution parameters characterising the weather and air quality of the actual days) in order to transform the original variables into fewer uncorrelated variables. These new variables, called factors, can be viewed as latent variables explaining the joint behaviour of the meteorological variables and the air pollution parameters.

The number of retained factors can be determined by different criteria. For this aim Guttmann criterion is used, according to which only those factors are retained eigenvalues of which exceed 1. The most common and widely accepted one is to specify a least percentage (80%) of the total variance of the original variables that has to be explained[4] by the factors. In order to select the most appropriate factors (axes), the factors should be rotated. This procedure maximises or minimises factor loadings (namely, most factor loadings are transformed towards 0, while the remaining ones to 1), in order to better interpreting the rotated factors. When using factor analysis, orthogonal varimax rotation is applied during which the factors remain uncorrelated[4,5].

When factor analysis is performed on the standardised data sets, factor loadings derived are correlation coefficients between the original variables and the coordinate values (i.e. factor values) belonging to the rotated axes. Statistical significance of a given factor loading as correlation coefficient can be calculated with the following formula:

$$t = \left(\frac{r^2(n-2)}{1-r^2}\right)^{1/2}, \tag{1}$$

where r is the given factor loading and n – the number of element pairs.

Statistical calculations are performed by using SPSS (9.0) software package.

RESULTS AND DISCUSSION

In winter, there are usually two main large-scale weather types over the Pannon Basin. In one case, cyclones pass through the Pannon Basin. In this case strong westerlies occur, the sky is cloudy and it falls. In the other case, the Siberian high pressure formation settles on the basin and, as a result, sky is clear and possibly weak breezes are experienced. If this weather is likely to remain for a week or so, the absolute humidity and temperature may drop to very low values. Towards the end of this macrocirculation formation, the daily minimum temperature can often drop below –10°C. During such weather, strong night-time temperature inversions areformed, which often remain until noon.

During the summer, like the winter case, two major air pressure systems dominate the Pannon Basin. Cyclonic formations coming from the west carry high moisture air masses. In this case strong winds blow and the weather is rainy. In the other case, subtropical air masses from the Atlantic reach the Pannon Basin, which can stay for several days. In this case, the air pressure gradient may be poor, local circulation systems can develop, relative humidity is low, and in the last days of the formation, the daily maximum temperature can often rise above 35°C.

WINTER MONTHS

The factor weights of the rotated component matrix for the winter months are shown in Table 1. After performing the factor analysis, 4 factors were retained according to the Guttmann criterion. The eigenvalues of the retained and rotated components as well as the variances and cumulative variances explained by each component are also found in Table 1. The 4 retained factors explain 72.9 % of the total variance of the original 19 variables.

The statistical explanatory capacity of the non-rotated factors decreases steeply. Rotation allocates the fraction of the original variance (72.9% in the above case) more evenlyamong the retained factors, compared to the 4 retained factors prior to rotation.

In the following, the relationship of the examined 19 variables is analysed according to the weight of the retained and rotated factors (Table 1).

Factor 1. Rotated Factor 1 explains 30.5% of the total variance, including daily mean temperature, dew point temperature, vapour pressure, saturation vapour pressure, daily minimum and maximum temperatures, wind speed, potential evaporation and daily temperature range. It can be seen that the temperature parameters (T_{mean}, T_{min}, $T_{max,}$ ΔT) are not closely related to global radiation in winter as they belong to different factors. In this part of the year, irradiance depends on the third factor. This finding also confirms that air temperature in winter is primarily dependent on the temperature characteristics of air masses over the Pannon Basin and not on irradiance (Table 1).

If the air temperature rises, the air can absorb more water vapour. If the vapour pressure rises, the air must be cooled to a lesser extent under unchanged air pressure to become saturated. When the air is cooled in this way, its temperature in the state of saturation is the dew point temperature. When the vapour pressure rises, the dew point also rises, and vice versa. The relationship between temperature and saturation vapour pressure is exponential. If the air temperature rises, the minimum and maximum temperatures, though not necessarily but generally, increase. Between the wind speed and the humidity parameters (dew point temperature (T_d), vapour pressure (VP) and potential evaporation (PE)) generally linear proportions can be experienced (except for cold and dry arctic air intakes coming with strong winds). The higher wind speed increases the potential evaporation (PE) and, thus, the vapour pressure (VP), and consequently the dew point temperature (T_d) is higher.

Factor 2. Factor 2 explains 17.4% of the total variance, including wind speed, primary air pollutants (NO_2, CO, PM_{10}, NO, NO_2/NO, SO_2 and O_3), as well as global radiation and daily temperature range. The opposite relationship between wind speed and primary air pollutants is obvious. That is, high concentrations of air pollutants can be observed during calm and slightbreezes, and vice versa[6] (Table 1).

The NO_2/NO ratio is another component of Factor 2. The NO_x concentration is generally increased as the concentration of NO increases more than that of NO_2. Consequently, high concentrations of NO are associated with low values of NO_2/NO, and in turn. The low absolute weight of O_3 in Factor 2 is due to the fact that part of the variance of ozone as a secondary air pollutant is controlled by the concentrations of the primary pollutants, while the other part by the irradiance. The role of solar radiation is well known in the photochemical ozone production and can be expressed by the chemical equations (2)–(3):

$$NO_2 + h\nu \rightarrow NO + O \quad (2)$$

$$O + O_2 + M \rightarrow O_3 + M \quad (3)$$

where M is generally an O_2 or a N_2 molecule. The intensity of solar radiation can vary considerably from day to day, and this change is also reflected in the variability of ozone concentration.

Signal conditioning procedures and correlation must be implemented before determining the statistical functions and parameters[7,8]. Rusanescu et al.[9] indicate, by using also correlations, that there are areas more exposed to increased risk of pollution, in particular those with a high density of buildings and traffic. Correlation is a statistical tool for many applications, also in medical approaches it has a large development[10,11]. Further the concentration of diverse pollutants is statistically analysed in correlation with other factions, for exemple heavy metals with soil components is in close depencency, as prooved by Popovici[12]. Also in diverse cases, corrrelation is used to produce results concerning analysis of behavioural-norm cognition and tourist satisfaction[13].

Table 1. Factor loadings of the rotated component matrix, winter months

Parameters	Factor 1	Factor 2	Factor 3	Factor 4
Mean temperature (T_{mean})	**0.965**	0.001	**0.178**	–0.013
Dew point temperature (T_d)	**0.961**	0.016	**–0.188**	–0.042
Vapour pressure (VP)	**0.959**	0.021	**–0.189**	–0.014
Saturation vapour pressure (E)	**0.953**	0.009	**0.214**	0.036
Minimum temperature (T_{min})	**0.840**	–0.056	0.028	**–0.255**
Maximum temperature (T_{max})	**0.831**	**0.190**	**0.371**	–0.063
Wind speed (WS)	**0.499**	**–0.411**	*0.086*	**0.237**
NO_2	0.001	**0.840**	**0.201**	–0.045
CO	–0.056	**0.817**	**–0.169**	**–0.202**
PM_{10}	–0.022	**0.791**	0.045	*0.095*
NO	**0.148**	**0.764**	0.070	*–0.079*
NO_2/NO	**–0.133**	**–0.423**	**–0.180**	**0.254**
SO_2	**–0.115**	**0.312**	0.031	**0.179**
Relative humidity (RH)	0.037	0.030	**–0.912**	*–0.087*
Global radiation (I)	–0.070	**0.128**	**0.744**	**0.181**
Potential evaporation (PE)	**0.566**	–0.010	**0.739**	*0.106*
Daily temperature range (DT)	**0.283**	**0.374**	**0.560**	**0.219**
O_3	*–0.093*	**–0.192**	**0.197**	**0.900**
O_{3max}	0.001	0.056	**0.234**	**0.900**
Eigenvalue*	5.80	3.30	2.74	2.00
Explained variance (%)	30.52	17.36	14.43	10.54
Cumulative variance (%)	30.52	47.88	62.31	72.85
Method: principal component analysis				
Rotation: varimax method, Kaiser normalisation				

*Rotated sum of the squared weights; (thresholds of significance: italic: $x_{0.05}$ = 0.078; bold: $x_{0.01}$ = 0.111; bold underlined: $x_{0.001}$ = 0.123)

Daily temperature range (ΔT) also has a significant weight in Factor 2. The probable cause is the presence of wind speed in this factor. During strong winds, the lower layers of the atmosphere are well mixed and hence the daily temperature change (also range) will be small. Consequently, the difference between daily minimum and maximum temperatures decreases to a minimum. This is the reason why wind speed and daily temperature range are in opposite relationship (Table 1).

Factor 3. This factor explains 14.4% of the total variance, including mean and maximum temperature, dew point temperature, vapour pressure, saturation vapour pressure, relative humidity, irradiance, potential evaporation and daily temperature range. Due to the intense solar radiation the temperature increases, which encourages evaporation. (Increasing evaporation does not necessarily mean low actual moisture content). At low moisture content, relative humidity decreases with increasing temperature. Ultimately, this is why the intensity of evaporation increases. If solar radiation is strong, the maximum temperature rises, just like the daily temperature range, and in turn (Table 1).

Factor 4. This factor accounts for 10.5% of the total variance. Though the most important factor loadings with far the highest weights belong to the average daily and maximum daily ozone concentrations (both with weights 0.900), loadings of minimum temperature, wind speed, CO, NO_2/NO, SO_2, irradiance and daily temperature range are also significant. Factor 4 has the third highest weight in the NO_2/NO ratio. This weight indicates that, regarding the chemical components, only part of the O_3 variance is controlled by solar radiation. As a consequence of the straight proportionality between the NO_2/NO ratio and the ozone parameters, the high NO_2 concentration means high ozone concentration and, vice versa (see equation (3) and Table 1).

SUMMER MONTHS

Results regarding summer months can be found in Table 2. Four factors were retained and rotated, which account for 70.1% of the total variance of the 19 variables.

Factor 1. This factor, explaining 28.6% of the total variance, includes concentrations of PM_{10}, NO_2, CO, O_3 and O_{3max}, in addition the parameters of moisture (VP, T_d, E, RH, PE) and temperature (T_{mean}, T_{min}, T_{max}, ΔT). The parameters that form Factor 1 of the summer and winter months have a great similarity (Table 2).

Factor 2. This factor explains 16.4% of total variance and contains temperature (T_{mean}, T_{max}, ΔT) and moisture (VP, T_d, E, RH, PE) variables, as well as irradiance and wind speed. In summer the temperature is controlled by irradiance, unlike the winter conditions. This is due to the fact that temperature parameters are generally proportional to irradiation. (A counter example: for instance, the passing of a cold front where the intensity of irradiance increases due to the cloud breaks, while the air temperature is still decreasing due to cold advection.) At the same time, when the temperature rises, saturation vapour pressure and potential evaporation increase, while relative humidity – with given moisture content – decreases (Table 2).

Factor 3. This factor accounts for 14.8% of total variance, includes temperature variables (T_{mean}, T_{max}, ΔT), humidity parameters (E, RH, PE) and primary air pollutants (PM_{10}, NO, NO_2, CO, NO_2/NO, SO_2, O_3, O_{3max}), as well as irradiance wind speed. Concentration of the primary air pollutants, in accordance with the results obtained for the winter months, is directly dependent on wind speed. Strong winds provide good ventilation, resulting in lower concentrations of primary air pollutants. In contrast, mild air movements (or total calm) are not conducive to turbulent diffusion processes and contribute to night time temperature inversions. In the latter case, air pollution is strongly increased[12] (Table 2).

Factor 4. This factor explains 10.3% of the total variance, and factor loadings of O_3, O_{3max} stand out with their extreme high weights, exceeding 0.900. Nevertheless, both meteorological parameters with temperature (T_{mean}, T_{min}, T_{max}, ΔT) and humidity (E, RH, PE) variables, as well as chemical (NO_2, NO_2/NO) components show significant factor loadings. In the summer, in the long-lasting existence of anticyclonic large-scale weather situations, changes in ozone concentration are basically controlled by primary air pollutants and not by the total amount of irradiance, which in this case changes hardly from one day to another. In addition, the daily mean value of this secondary air pollutant is inversely proportional to the daily mean values of the primary air pollutants. This behaviour of ozone can be explained by the fact that O_3 depends on the NO_2/NO ratio. Namely, high values of this ratio involve high ozone concentrations (see chemical equations in Factor 2 for winter months (Table 2).

Table 2. Factor loadings of the rotated component matrix, summer months

Parameters	Factor 1	Factor 2	Factor 3	Factor 4
Vapour pressure (VP)	**0.943**	**–0.165**	–0.004	–0.022
Dew point temperature (T_d)	**0.942**	**–0.180**	0.001	–0.002
Mean temperature(T_{mean})	**0.870**	**0.422**	*0.088*	**0.126**
Saturation vapour pressure (E)	**0.864**	**0.438**	*0.091*	**0.118**
Minimum temperature (T_{min})	**0.813**	0.045	0.075	**0.152**
Maximum temperature (T_{max})	**0.737**	**0.481**	**0.210**	**0.125**
PM_{10}	**0.571**	**0.181**	**0.450**	**0.159**
Relative humidity (RH)	0.005	**–0.901**	**–0.116**	**–0.176**
Potential evaporation (PE)	**0.515**	**0.763**	**0.128**	**0.178**
Global radiation (I)	–0.048	**0.715**	**–0.109**	–0.001
Daily temperature range (ΔT)	**0.203**	**0.640**	**0.221**	0.020
NO	0.003	0.036	**0.861**	–0.034
NO_2	**0.154**	0.016	**0.852**	**0.228**
CO	**0.483**	0.002	**0.656**	0.042
Wind speed (WS)	–0.019	**–0.114**	**–0.536**	0.024
NO_2/NO	–0.018	–0.016	**–0.380**	**0.264**
SO_2	–0.023	0.261	**0.284**	*–0.105*
O_3	*0.106*	**0.121**	**–0.172**	**0.915**
O_{3max}	**0.187**	*0.086*	**0.148**	**0.911**
Eigenvalue*	5.42	3.12	2.82	1.96
Explained variance (%)	28.55	16.40	14.85	10.32
Cumulative variance (%)	28.55	44.95	59.79	70.11
Method: principal component analysis				
Rotation: varimax method, Kaiser normalisation				

*rotated sum of the squared weights; thresholds of significance: italic: $x_{0.05} = 0.077$; bold: $x_{0.01} = 0.110$; bold underlined: $x_{0.001} = 0.121$)

CONCLUSIONS

Based on the results, 4 factors can be considered both in the summer and winter months, which contribute significantly to the formation of weather and air pollution episodes in Szeged. Wind speed is an important parameter in both extreme seasons for diluting air pollution. Strong winds provide good ventilation. Consequently, they reduce the concentrations of air pollutants, and vice versa. O_3 concentrations are inversely proportional to the concentrations of the primary air pollutants. In fact, only the factor weights of the ozone parameters are almost exclusive in Factor 4, for both extreme seasons.

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