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CONNECTION BETWEEN METEOROLOGICAL ELEMENTS AND POLLUTANTS CONCENTRATIONS AT SZEGED, HUNGARY

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Summary: The aim of the study is to define those factors, which are relevant in forming weather and air quality conditions in Szeged, Hungary. The database consists of daily averages of 11 meteorological and 8 air pollution parameters for the summer and winter months for the five-year period 1997-2001. In order to explain the connections between the 19 variables, the multivariate statistical method of factor analysis is used. Our results show that four factors for both the winter and summer months can be considered main contributors to the formation of weather and air pollution conditions at Szeged.

Key words: factor analysis, factor loadings, air pollutants, meteorological elements

1. INTRODUCTION

Meteorological conditions influence the levels of air pollutants. Serious pollution episodes do not come from local sources but they are related to given weather conditions, during which pollutants can be accumulated. It has been found that nocturnal temperature inversions with light winds or calm weather, namely an anticyclonic circulation pattern, are a favourable condition for pollutants accumulation at Szeged region.

The aim of the study is to analyse the connection between meteorological elements and the concentrations of the main air pollutants at Szeged. Hence, it is aimed to define those factors, which are relevant in forming the weather and air quality conditions at Szeged. The above-mentioned objective is reached by using the multivariate method of factor analysis. The analysis was performed both for the summer and winter data, since during these two opposite seasons of the year the examined variables are controlled by different processes.

Our further aim is to analyse the connection of circulation patterns with the concentration levels of air pollutants. Namely, to determine circulation types to various pollution levels. However, this aim will be the subject of another paper.

2. CLIMATIC CHARACTERISTICS AT SZEGED

Szeged lies at approximately 20°06'E and 46°15'N near the confluence of the rivers Tisza and Maros. It is the largest city in the south-eastern part of Hungary. The city is flat and low (79 m above sea level), therefore its climate is free from orographical effects (Fig. 1). Consequently, its geographical conditions favour the development of an undisturbed urban climate. The number of inhabitants is up to 155,000 and the surface of its built-up area is about 46 km^2. The total urban spread extends well beyond the city limits and north of the city includes the largest oil field in Hungary with several oil torches. This oil field is a significant source of NO_x and sulphur dioxide. The small power station, working with natural gas (located in the western part of the city) and motor vehicle emissions have largely contributed to the nitrogen oxide levels at Szeged. Though Szeged and its surroundings are an open region, the city has the lowest elevation in Hungary, in addition the country lies in the Carpathian Basin. Hence, Szeged is a so-called double-basin situated city, which strengthens the effects of anticyclonic circulation patterns in accumulating pollutant concentrations.

In the winter, two types of circulation patterns can generally be observed over the Carpathian Basin. In the first case, trajectories of cyclones pass through the Carpathian Basin, with strong westerlies, clouds and rain. In the other case, a Siberian high pressure system develops over the basin, causing clear weather and weak flow. If this weather remains for a week or longer, very low absolute humidity and temperature can be measured. Towards the end of the episode the diurnal minimum temperature can frequently decrease below -10°C. During these days strong nocturnal temperature inversions form that frequently remain even till noon.

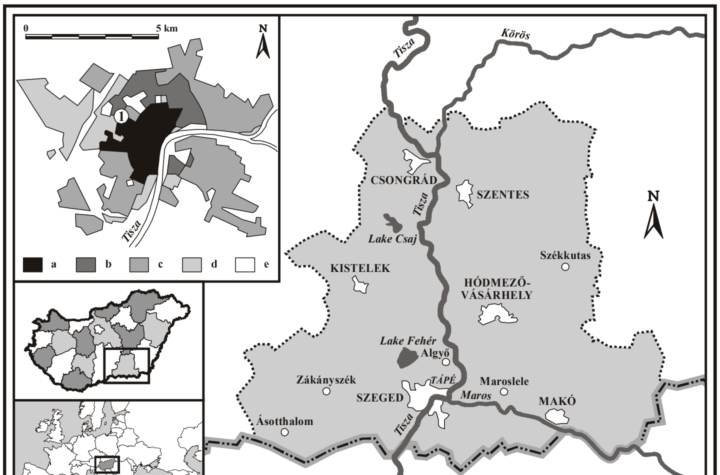

Fig.1 Geographical position of Szeged, Hungary and built-in types of the city
[a: centre (2-4-storey buildings); b: housing estates with prefabricated concrete slabs (5-10-storey buildings); c: detached houses (1-2-storey buildings); d: industrial areas; e: green areas; (1): monitoring station]

During the summer, similarly to the case in winter, two major pressure systems prevail over the Carpathian Basin. The western cyclonic air currents bring air masses with high humidity. In this case the winds are strong, with rainy weather. In the other case the Atlantic subtropical anticyclone reaches the basin and can remain several days long. During this occasion the pressure gradient is weak, local circulation systems can develop, relative humidity is low, while towards the end of the episode the diurnal maximum temperature frequently rises over 35°C.

3. DATA

The database consists of daily averages of 11 meteorological and 8 air pollution parameters for the summer (June, July, August) and winter (December, January, February) months for the five-year period 1997-2001. The meteorological parameters are: mean air temperature [T_{mean} (°C)], maximum temperature [T_{max} (°C)], minimum temperature [T_{min} (°C)], diurnal temperature range [ΔT (°C)], relative humidity [RH (%)], irradiance [I (Wm^{-2})], wind speed [WS (ms^{-1})], vapour pressure [VP (mb)], saturation vapour pressure [E (mb)], potential evaporation [PE (mm)] and dew point temperature [T_d (°C)]. The air pollution parameters, with their concentrations, are the following: carbon monoxide [CO ($mg\ m^{-3}$)], nitric oxide [NO ($\mu g\ m^{-3}$)], nitrogen dioxide [NO_2 ($\mu g\ m^{-3}$)], total suspended particulate [TSP ($\mu g\ m^{-3}$)], sulphur dioxide [SO_2 ($\mu g\ m^{-3}$)], ozone [O_3 ($\mu g\ m^{-3}$)], maximum ozone concentration during the day [O_{3max} ($\mu g\ m^{-3}$)] and the NO_2/NO ratio. The monitoring station is located in the downtown and it is operated by the ATIKÖFE (Environmental Protection Inspectorate of Lower-Tisza Region, branch of the Ministry of Environment).

4. METHOD

In order to reduce the dimensionality of the above data set and thus to explain the relations between the 19 variables, the multivariate statistical method of factor analysis is used. The main object of factor analysis is to describe the initial variables $X_1, X_2, \dots, X_p$ in terms of *m* linearly independent indices ($m < p$), the so-called factors, measuring different „dimensions" of the initial data set. Each variable *X* can be expressed as a linear function of the *m* factors as:

$$X_i = \sum_{j=1}^{m} \alpha_{ij} F_j \tag{1}$$

where α_{ij} are constants called factor loadings. The square of α_{ij} represents the part of the variance of X_i that is accounted for by the factor F_j. It is a common practice both the initial set of parameters X_i and the resultant factors F_j to be standardised having zero mean and unit variance. The first argument for using standardised variables is of giving all variables equal weight, whereas the original variables may have extremely different variances. Another objective for using standardised variables is to overcome the problem of the different units of the various variables used. From the above, it is apparent that $\alpha_{ij} \leq 1$. If a factor loading $|\alpha_{ij}| \to 1$, it will mean that the variable X_i is highly correlated to the factor F_j.

Furthermore, a high correlation of some of the initial variables with the same factor is a strong evidence of their covariability. The knowledge of covariability among the variables is a very important tool, since significant conclusions can be drawn for the causes of variation and/or the linkages between the initial variables (Bartzokas and Metaxas 1993, 1995, Sindosi et al. 2001).

One important stage of this method is the decision for the number (m) of the retained factors. On this matter, many criteria have been proposed. In this study, the *Guttman criterion* or *Rule 1* is used, which determines to keep the factors with eigenvalues > 1 and neglect those ones that do not account for at least the variance of one standardised variable X_i. The extraction was performed by *Principal Component Analysis*. (the *k*th eigenvalue is the variance of the *k*th principal component.) There is an infinite number of equations alternative to equation (1). In order to select the best or the desirable ones, the so-called „factor rotation" is applied, a process, which either maximises or minimises factor loadings for a better interpretation of the results. In this study, the „varimax" or orthogonal factor rotation is applied, which keeps the factors uncorrelated (Jolliffe 1990, 1993).

The analysis was applied on the table of the initial data consisting of 19 columns (parameters) and 451 rows (days) for the winter months (December, January, February) and 460 rows (days) for the summer months (June, July, August).

All statistical computations were performed with SPSS (version 9.0) software.

5. RESULTS

5.1 Winter months

The rotated component matrix with factor loadings for the winter months is found in Table 1. After performing the factor analysis, 4 factors were retained according to the *Guttman criterion*. Eigenvalues of the retained and rotated components, as well as variances and cumulative variances explained by the components are also reported in Table 1. The 4 retained factors explain 72.9% of the total variance of the original 19 variables.

When performing factor analysis on the standardised data, the factor loading is the correlation coefficient between the given factor scores data set and the original one. The statistical significance of a given factor loading, as correlation coefficient, can be checked by calculating the

$$t = \sqrt{\frac{r^2(n-2)}{1-r^2}} \qquad (2)$$

formula, where r is the given factor loading, n is the number of element pairs [n = 451 for the winter months (December, January, February) and n = 460 for the summer months (June, July, August), respectively], $n - 2$ is the degree of freedom, and t is the value to be determined being of Student's distribution. If the absolute value of t calculated (when the degree of freedom is $n - 2$ and the significance level is 5%) is higher than the threshold value in the table of the Student's t-distribution (namely: $9{\cdot}10^{-5}$), then we can conclude that the 0-hypothesis, according to which the given factor scores time series and the original one are independent, is not fulfilled. Consequently, if factor loadings are higher than $9{\cdot}10^{-5}$, the *a priori* hypothesis of the two time series being independent is rejected at the 5% significance level. In Table 1, factor loadings exceeding $|0.3|$ are only presented for clarity reasons.

Henceforth, the connection of the examined 19 parameters according to the loadings of the retained and rotated factors are analysed (Table 1).

Factor 1 explains 30.5% of the total variance and involves the diurnal mean temperature, the dew point temperature, the vapour pressure, the saturation vapour pressure, the diurnal minimum and maximum temperatures, the wind speed and the potential evaporation. It is shown that temperature parameters (T_{mean}, T_{min}, T_{max}) are not strongly related with irradiance in winter. In this period of the year irradiance depends on the third factor. This can be explained by the fact that winter air temperature depends mainly not on irradiance but on the thermal characteristics of air masses over the Carpathian Basin.

Table 1 Factor loadings of the rotated component matrix, winter months.
It is noted that factor loadings of less than 0.3 are not considered.

Parameters	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
T_{mean}	0.97			
T_d	0.96			
VP	0.96			
E	0.95			
T_{min}	0.84			
T_{max}	0.83		0.37	
WS	0.50	-0.41		
NO_2		0.84		
CO		0.82		
TSP		0.79		
NO		0.76		
NO_2/NO		-0.42		(0.25)
SO_2		0.36		
RH			-0.91	
I			0.74	
PE	0.57		0.74	
ΔT		0.37	0.56	
O_3				0.90
O_{3max}				0.90
Eigenvalue*	5.80	3.30	2.74	2.00
Variation explained, %	30.52	17.36	14.43	10.54
Cumulative variances, %	30.52	47.88	62.31	72.85

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalisation
*Rotation sum of squared loadings

If air temperature rises, the water vapour capacity of the air increases. If the water vapour pressure increases, the temperature at which air gets saturated, namely the dew point temperature, also rises and vice versa. The temperature is in exponential connection with the saturation vapour pressure. If air temperature rises, this involves an increase of the minimum and maximum temperatures, too. Wind speed is in direct proportion to humidity parameters (T_d, VP, PE). Higher wind speeds increase potential evaporation (PE) and, in this way, vapour pressure (VP), consequently the dew point temperature also becomes higher.

Factor 2 explains 17.4% of the total variance and includes the wind speed, the primary pollutants (NO_2, CO, TSP, NO, NO_2/NO and SO_2) and the diurnal temperature range. The inverse relation between wind speed and the primary pollutants is obvious. Namely, high concentrations of pollutants occur during light wind conditions and vice versa (Horváth et al. 2001).

The NO_2/NO ratio is another component of Factor 2. An increase of NO_x is generally accompanied by a higher increase of NO than that of NO_2. Consequently, high values of NO involve low values of NO_2/NO ratio and vice versa. Low loading of O_3 (below $|0.3|$) in Factor 2 is due to the fact that part of the variation of O_3 as secondary pollutant is controlled by the concentrations of the primary ones and another part of its variation is controlled by the irradiance. The role of solar radiation in producing photochemical O_3 is well known and it can be expressed by the following chemical equations:

$$\begin{aligned} NO_2 + h \cdot \nu &\rightarrow NO + O \\ O + O_2 + M &\rightarrow O_3 + M \end{aligned} \tag{3}$$

(M is usually a molecule of O_2 or N_2). During the winter months the intensity of solar radiation may vary significantly from day to day and this variation is also reflected in the variability of O_3 concentration (Sindosi et al. 2001).

The diurnal temperature range also has an important loading in Factor 2. Its reason might be the presence of wind speed in this factor. Under strong wind conditions the lower atmosphere layers are well mixed and, hence, diurnal temperature variations are small. Consequently, the differences between maximum and minimum temperatures are minimal. For this reason, signs of wind speed and diurnal temperature range are opposite.

Factor 3 explains 14.4% of the total variance and includes the maximum temperature, the relative humidity with negative sign, the irradiance, the potential evaporation and the diurnal temperature range. The intense solar radiation causes high evaporation rates indicating low relative humidity. If solar radiation is high, this involves higher maximum temperature as well as higher diurnal temperature range and vice versa.

Factor 4 explains 10.5% of the total variance and contains the ozone concentration and maximum ozone concentration only, both with high loadings (0.90). The next highest loading in Factor 4 belongs to NO_2/NO (in parenthesis). This loading indicates that only a part of the variation of O_3 is controlled by the irradiance. As a consequence of the direct proportion between the NO_2/NO ratio and the ozone parameters, a higher NO_2 concentration implies higher ozone concentration and vice versa (see eq. 3) (Table 1).

5.2. Summer months

The results of the analysis for the summer months are found in Table 2. Four factors were retained and rotated, which explain 70.1% of the total variance of the 19 variables.

Factor 1 (with explaining 28.5% of the total variance) includes besides humidity (VP, T_d, E, PE) and temperature (T_{mean}, T_{min}, T_{max}) parameters the concentrations of TSP and CO, as well. This classification seems to be similar to that of Factor 1 in the case of the winter months.

Factor 2 explains 17.4% of the total variance and comprises temperature (T_{mean}, T_{max}, ΔT) and humidity (E, RH, PE) variables and the irradiance. In summer, temperature is controlled by irradiance contrary to the case in winter. This is why temperature parameters are directly proportional to irradiance. At the same time, if the temperature rises, the saturation vapour pressure and the potential evaporation increase, while the relative humidity decreases.

Factor 3, which explains 14.8% of the total variance, includes the primary pollutants (TSP, NO, NO_2, CO, NO_2/NO) and the wind speed. The concentration of the primary pollutants depends directly on wind speed along with the results of the analysis for the winter months. Strong winds make good ventilation conditions, which results in low concentrations of primary pollutants. On the contrary, light winds do not favour diffusion processes, furthermore they contribute to the formation of nocturnal temperature inversions, which are associated with increased pollution (Sindosi et al. 2001).

Table 2 Factor loadings of the rotated component matrix, summer months
It is noted that factor loadings less than 0.3 are not considered.

Parameters	Factor 1	Factor 2	Factor 3	Factor 4
VP	0.94			
T_d	0.94			
T_{mean}	0.87	0.42		
E	0.86	0.44		
T_{min}	0.81			
T_{max}	0.74	0.48		
TSP	0.57		0.45	
RH		-0.90		
PE	0.52	0.76		
I		0.72		
ΔT		0.64		
NO			0.86	(0.23)
NO_2			0.85	
CO	0.48		0.66	
WS			-0.54	
NO_2/NO			-0.38	(0.26)
SO_2				
O_3				0.92
O_{3max}				0.91
Eigenvalue*	5.42	3.12	2.82	1.96
Variation explained, %	28.55	16.40	14.85	10.32
Cumulative variances, %	28.55	44.95	59.79	70.11

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalisation.
*Rotation sum of squared loadings

Factor 4 explains 10.3% of the total variance and contains the ozone parameters (O_3, O_{3max}) only. In Factor 4 the NO_2/NO ratio and the NO_2 have the next highest loadings (in parenthesis) (Table 2). Although these loadings are rather low, they indicate the connection of these parameters with O_3 and O_{3max}. In summer, changes of O_3 concentrations are mostly controlled by primary pollutants and not by the total amount of irradiance, which varies very little from day to day. In addition, the mean daily value of this secondary pollutant is inversely proportional to the mean daily values of the primary ones. This behaviour of O_3 can be explained by the fact that O_3 depends on the ratio of NO_2/NO. Namely, high value of this ratio implies high O_3 concentrations, since the equation (2) fulfils.

6. CONCLUSIONS

In this paper, the relation between meteorological variables and the concentration of the main air pollutants was studied at Szeged, by using the statistical method of factor analysis. According to the results, four factors both for the winter and summer months can be considered as main contributors to the formation of weather and air pollution conditions at Szeged. Wind speed is an important parameter in diluting concentrations of air pollutants both in winter and summer. High wind speed is accompanied with good ventilation conditions and, consequently, with low concentration levels of primary pollutants and vice versa. O_3 concentrations seem to be inversely proportional to the concentrations of primary pollutants. The ozone parameters have the basic loadings in Factor 4 both for the winter and summer months. It is revealed that temperature is controlled by irradiance in summer, while this is not the case in winter, when temperature depends mainly on thermal characteristics of air masses affecting the Carpathian Basin.

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