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Concentration of contaminating gases and their connection with large-scale weather situations in Szeged

Abstract The aim of the study is to determine how contaminating gases are concentrated during various weather conditions which are closely related to various large-scale weather situations in the town of Szeged. The data are derived from an automatic meteorological station in the downtown, beside a highway. Measurements taken every 30 minutes between 1996-1998 are used in the paper. Values of CO, NO, NO_2, NO_x, O_3, SO_2 and dust are analysed as functions of various large-scale weather situations, established by Péczely for the Carpathian Basin.

Keywords: contaminating gases, large-scale weather situations, Kolmogorov-Smirnov test, central limit theorem, a special case of the Student t-test

1. Introduction

From the summer of 1996 an automatic environmental monitoring system has been operating in Szeged. This station measures not only climatic elements (air temperature, humidity, radiation, pressure, precipitation and wind speed and direction) but concentration of environmental parameters, namely CO, NO, NO_2, NO_x, O_3, SO_2 and dust, as well (Fig. 1.).

Daily average concentrations ($\mu g\ m^{-3}$) of the above mentioned parameters between 1st January 1997 and 31st December 1998 forms the data basis of the analysis.

The aim of the study is to detect what kind of role the macrosynoptic types play in concentration of environmental parameters.

The methods are applied to characterize air pollution parameters in various large-scale weather situations valid for the Carpathian Basin. Péczely (1957, 1983) introduced a classification of the Central-European macrosynoptic circulation patterns.

2. Method

2.1. Kolmogorov-Smirnov test

In order to decide if the empirical distribution functions considered, coming from two independent probability variables, are from different distributions the *Kolmogorov-Smirnov test* was applyed.

The concentration series grouped within different macrotypes form 13 statistical samples according to the 13 macrosynoptic types from Péczely.

Let ξ_j^i the daily average concentration of a given contaminating gas found in the *i*-th macrotype from Péczely falling into the group *i* (*i = 1,2, ... , 13*) where n_i is the number of days (measurements) (*j = 1,2, ... ,* n_i) . The distribution functions for each macrotype are estimated by emiprical distribution functions (F_i) derived from the samples. If the concentration series, belonging on the one hand to the group *i* on the other hand to the group *k* (*i, k = 1,2, ... , 13*) ($i \neq k$), are from different distributions, it means that each type determines its specific concentration distribution.

The 0-hypothesis, set up to decide if it is true or not, is the following:

$$H_0: \; F_{n_i}(x) = F_{n_k}(x) \; ; \quad (i, k = 1,2, \ldots , 13) \;\; (i \neq k) \; .$$

The test statistics is as follows:

$$D_{1,2} = \sqrt{\frac{n_i \cdot n_k}{n_i + n_k}} \cdot \sup_{-\infty \langle x \langle +\infty} \left| F_{n_i}(x) - F_{n_k}(x) \right| \; ,$$

for which

$$\lim_{\substack{n_1 \to \infty \\ n_2 \to \infty}} P(D_{1,2} \langle x) = \sum_{i=-\infty}^{+\infty} (-1)^i \cdot e^{-2 i^2 x^2} = K(x) \, , \; \text{if } x > 0.$$

The x_α values, which are needed to define the acceptance interval, are found in the table of the K(x) distribution function, where $K(x_\alpha) = 1 - \alpha$. The acceptance interval is the $(0; x_\alpha)$ interval at the α significance level. Namely, the 0-hypothesis is kept if $0 \leq D_n < x_\alpha$ and the it is rejected if $D_n \geq x_\alpha$ (Dévényi and Gulyás, 1988). For our decision $\alpha = 0.1$ was chosen for which $x_\alpha = 1.23$. The interval, in which the 0-hypothesis is accepted on a given (in our case 90 %) significance level, can be determined from the table of K(x) distribution.

2.2. Central limit theorem

The sample sizes are large enough for using the central limit theorem to find the 90 per cent confidence intervals for mathematical expectation (*m*) of concentrations to each large-scale weather situations.

$$\lim_{n \to \infty} P\left(\frac{\bar{\xi} - m}{\sigma / \sqrt{n}} \langle x\right) = \Phi(x) \, ,$$

where $\Phi(x)$ is the distribution function of the standard normal distribution. Distribution of absolute value of probability variables of standard normal distribution is known according to which

$$P\left|\frac{\bar{\xi} - m}{\sigma / \sqrt{n}}\right| \langle x) = 2\Phi(x) - 1 \; , \quad x \geq 0 \; .$$

Let choose an α value. Since $2\Phi(x_\alpha) - 1 = 1 - \alpha$, consequently $\Phi(x_\alpha) = 1 - \alpha/2$. Therefore the $(\bar{\xi} - x_\alpha \cdot \frac{\sigma}{\sqrt{n}}; \bar{\xi} + x_\alpha \cdot \frac{\sigma}{\sqrt{n}})$ statistics give a confidence interval with $1 - \alpha$ probability to the m expected value. (Dévényi and Gulyás, 1988). These intervals are presented in Fig. 2.

2.3. A special case of the Sudent's t-test

A new statistical test is developed for determining statistical significance of differences of expected values of not independent time series.

In order to establish if there happened any significant change within a given time series, a new statistical test was developed by Makra (Makra, et al., 1999). The basic question of this test is whether significant difference can be revealed between the mean of an optional share sample of a given time series and the mean of the whole sample itself, namely that of the given time series.

We developed the expression $\frac{\overline{M} - \overline{m}}{\sqrt{\frac{N-n}{N \cdot n}} \cdot \sigma}$ which is a probability variable with N(0;1) distribution.

Now, from the table of the distribution function of the standard normal distribution, it can be determined that x_p to a given $0<p<1$ number for which:

$$P\left(\left|\frac{\overline{M} - \overline{m}}{\sqrt{\frac{N-n}{N \cdot n}} \cdot \sigma}\right| > x_p\right) = p \ .$$

If the absolute value of the above probability variable with N(0;1) distribution is higher than x_p then it is said that $\overline{\boldsymbol{M}}$ and $\overline{\boldsymbol{m}}$ differ significantly. The 0-hypothesis, according to which there is no difference between them, can be realized not more than the critical p probability.

Being supported by this theoretical basis, significant difference can be revealed between the mean of an optional share sample of a given time series and the mean of the whole sample. Namely the period, that is to say the start and end, of the significant change in the examined parameter can be determined. Significance-tests are carried out at $p=0.01$ probability level.

Results

The methods are applied to characterize air pollution parameters in various large-scale weather situations valid for the Carpathian Basin. Péczely (1957, 1983) introduced a classification of the Atlantic-European macrosynoptic circulation patterns for the Carpathian Basin on the basis of sea level pressure systems.

As for the *Kolmogorov-Smirnov test*, macrotype No. 3 was taken out of consideration since its case number was very little. All the other possible combinations were tested in this way. Namely, the *Kolmogorov-Smirnov test* was performed to distribution functions of concentrations of various contaminating parameters for all pairs of Péczely-macrotypes (Table 1-2.). Altogether $\binom{n}{2}$ cases (macrotype pairs) were analysed for each contaminating parameter. The symbol "+" for a given pair of Péczely-macrotypes in Table 1. shows significant difference between the distribution functions of the parameter examined. Table 2. shows the rate of rejection (%) of similarity between two given, optional macrotypes. The last column shows that, considering all possible macrotype pairs, the 0-hypothesis is rejected in 70-79 % in case of CO, NO, NO_2, while this rate is 46-58 % in case of O_3, SO_2 and dust (Table 2.). This means that the above mentioned rates of macrosynoptic types determine different concentration populations.

This test was applied to determine if concentration of pollutants is changing significantly in various large-scale weather situations.

By applying the *central limit theorem* we received confidence intervals with 90 % probability level for the concentrations of the various parameters at each Péczely-macrotype. The main conclusion of our calculations is that width of the interval is basically dependent on the case number of the given macrotype. If the latter is little, the standard deviation of the concentration is large, consequently the confidence interval is wide.

By applying the *Makra-test* the effect of the Péczely macrotypes in either enrichment or dilution of various pollutants can be calculated. The results are as follows.

In the yearly data mCc, AB, CMw, An and AF macrotypes furthermore groups of those connected with meridional northerly current (mCc+AB) and those connected with zonal easterly current (An+AF) are effective in enrichment of pollutants. Ae, As and A macrotypes as well as group of those connected with zonal westerly current (zC+Aw+As) results in significant dilution.

In the summer half-year the role of AB macrotype together with the group connected with meridional northerly current (mCc+AB) is positive while that of Ae weather situation and the group connected with meridional southerly current (mCw+Ae+CMw) is negative in enrichment of pollutants.

In the winter half-year mCc, CMw and An macrotypes furthermore those of meridional northerly current (mCc+AB) and zonal easterly current (An+AF) are effective in enrichment of pollutants while during As and A weather situations dilution is significant.

During the winter Cmw and An macrotypes as well as groups of those connected with meridional southerly (Ae+CMw) and zonal easterly air currents (An+AF) are effective in enriching pollutants, at the same time during As and A macrotypes pollutants are significantly diluting.

During spring the role of AB and An macrotypes together with the groups of those connected with meridional northerly current (An+AF) is positive while that of Ae and A macrotypes together with the group of those connected with meridional southerly current (mCw+Ae) is negative in enriching pollutants.

During the summer the role of AB macrotype is positive while that of Ae type is negative in enriching pollutants.

During the autumn only Ae and A weather situations are significant, both promote diluting pollutants.

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Conclusions

Summarizing the role of the various macrotypes in enriching or diluting pollutants, it can be stated that mCc, AB, CMw, An and AF weather types have positive role in enriching pollutants while during Ae, As and A types together with mCw and CMw types dilution is significant. With other words meridional northerly and zonal easterly currents are most effective in enriching pollutants at the same time meridional southerly current and A type are the most significant in diluting pollutants.

This result was not expected at all since normally anticyclonic and near anticyclonic types are expected for enriching while cyclonic types are expected for diluting pollutants. Understanding of this result needs further examination. Probably the Péczely-tipization is not the best category-system for grouping environmental parameters.

Appendix

The classification is based on the position of cyclonic and anticyclonic pressure systems relative to the Carpathian Basin considering the sea level pressure maps in the Atlantic-European region. Thirteen types are defined. These are as follows.

Types connected with northerly current

mCc: Hungary lies in the rear of an East European cyclone
AB: Anticyclone over the British Isles
CMc: Hungary lies in the rear of a Mediterranean cyclone

Types connected with southerly current

mCw: Hungary lies in the fore part of a West European cyclone
Ae: anticyclone in the east of Hungary
CMw: Hungary lies in the fore part of a Mediterranean cyclone

Types connected with westerly current

zC: zonal, cyclonic
Aw: anticyclone extending from the west
As: anticyclone in the south from Hungary

Types connected with easterly current

An: anticyclone in the north from Hungary
AF: anticyclone over the Fennoscandinavian region

Types of pressure centres

A: anticyclone over the Carpathian Basin
C: cyclone over the Carpathian Basin

The daily catalogue of Péczely macrosynoptic types from 1881 is available (Péczely, 1983; Károssy, 1987).

Table 1.
Results of the Kolmogorov-Smirnov fitting test to distribution functions of air pollutants' concentrations for all possible macrotype-pairs

(+: distribution functions of air pollutants' concentrations for the given macrotype pairs indicate significant difference)

CO

Péczely's macrotype	1	2	4	5	6	7	8	9	10	11	12	13
1												
2	+											
4	+	+										
5	+	+	+									
6	+	+		+								
7	+	+										
8		+	+	+	+	+						
9	+	+	+	+	+		+					
10		+	+	+	+	+		+				
11			+	+	+	+		+				
12	+	+	+	+	+		+		+	+		
13		+		+		+		+		+	+	

NO_x

Péczely's macrotype	1	2	4	5	6	7	8	9	10	11	12	13
1												
2	+											
4		+										
5	+	+										
6			+	+								
7	+	+	+	+	+							
8	+	+	+	+	+	+						
9	+	+	+	+	+		+					
10	+		+	+		+	+	+				
11	+		+	+	+	+	+	+				
12	+	+	+		+		+		+	+		
13		+	+	+		+	+	+	+	+	+	

NO

Péczely's macrotype	1	2	4	5	6	7	8	9	10	11	12	13
1												
2	+											
4		+										
5	+	+										
6			+	+								
7	+	+	+	+	+							
8	+	+	+	+	+	+						
9	+	+	+	+	+		+					
10	+		+	+		+	+	+				
11	+		+	+		+	+	+				
12	+	+	+		+	+			+	+		
13		+		+		+	+	+	+	+	+	

O_3

Péczely's macrotype	1	2	4	5	6	7	8	9	10	11	12	13
1												
2												
4												
5	+											
6	+	+										
7	+											
8	+				+	+						
9	+	+					+					
10				+	+	+		+				
11	+	+	+	+	+	+	+	+	+			
12	+							+	+	+		
13					+			+		+		

NO_2

Péczely's macrotype	1	2	4	5	6	7	8	9	10	11	12	13
1												
2												
4		+										
5	+	+	+									
6			+	+								
7	+	+			+							
8	+	+	+	+	+							
9	+	+	+		+		+					
10			+	+		+	+	+				
11	+		+	+	+	+	+	+				
12	+	+	+	+	+		+		+	+		
13		+		+		+	+	+		+	+	

SO_2

Péczely's macrotype	1	2	4	5	6	7	8	9	10	11	12	13
1												
2												
4	+	+										
5	+	+	+									
6		+	+	+								
7		+	+		+							
8	+	+	+	+	+							
9	+	+	+		+							
10				+	+		+	+				
11	+	+			+							
12	+	+	+		+	+			+	+		
13		+			+							

TSP

Péczely's macrotype	1	2	4	5	6	7	8	9	10	11	12	13
1												
2												
4	+											
5	+	+	+									
6			+	+								
7	+	+	+		+							
8	+			+	+	+						
9	+	+	+		+		+					
10				+	+	+		+				
11				+	+	+		+				
12	+	+	+		+		+		+	+		
13				+		+		+			+	

Table 2.
Probability whether partly the distribution function of pollutants' concentrations at given Péczely-macrotype, partly that for all other macrotypes are considerd the same, %

Air pollutant	**1**	**2**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**All macro-types**
CO	36	9	27	9	27	45	36	18	36	36	18	45	**29**
NO	27	27	27	18	45	9	9	18	27	27	27	27	**25**
NO_2	45	36	27	18	36	45	9	27	45	18	18	36	**30**
NO_x	27	27	18	18	36	18	0	18	27	18	27	18	**21**
O_3	36	73	91	73	45	64	55	36	45	0	64	73	**54**
SO_2	45	18	27	45	9	64	45	55	55	64	36	82	**45**
TSP	45	64	45	27	27	27	45	27	55	55	27	64	**42**

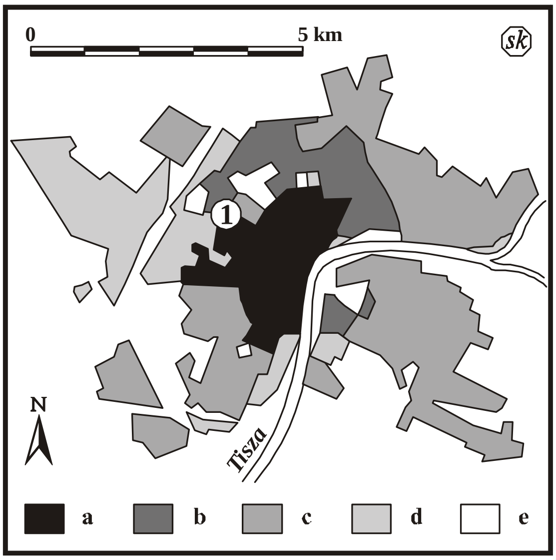

Fig. 1.
Built-up types of Szeged
a: centre (2-4-storey buildings); b: housing estates with prefabricated concrete slabs (5-10-storey buildings); c: detached houses (1-2-storey buildings); d: industrial areas; e: green areas; (1): monitoring station

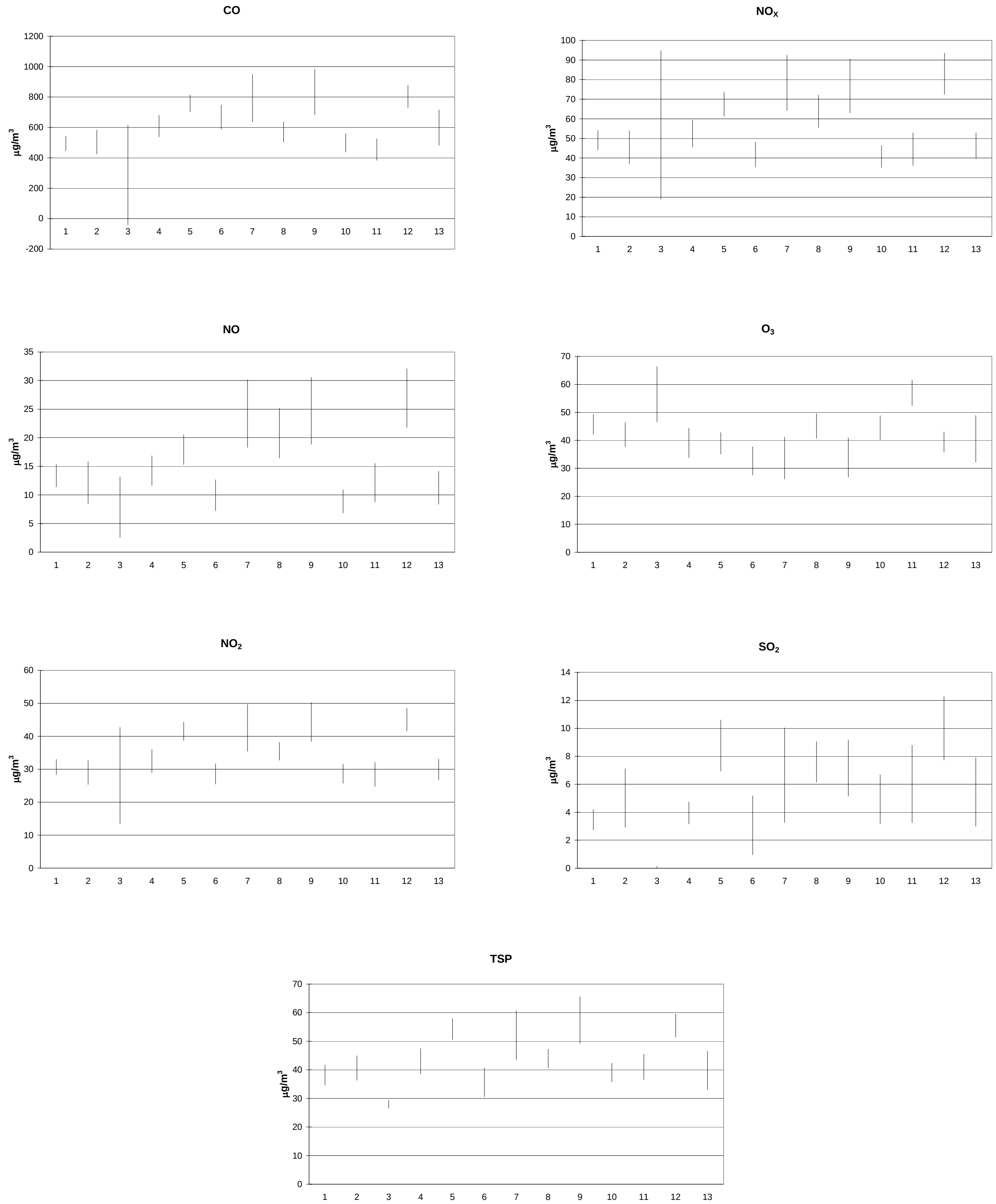

Fig. 2.
90 % confidence intervals for expected values of air pollutants' concentrations concerning Péczely's macrotypes