Relation of pollutants concentrations to the Péczely’s large scale weather situations in Szeged, Southern Hungary

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Summary  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.

Key-words: contaminating gases, large-scale weather situations, Kolmogorov-Smirnov test, central limit theorem, a new interpretation of the two sample test

Introduction

Air pollution, concentrations of air pollutants are influenced not only by physical and chemical processes but also by meteorological processes as well as by geographical and social factors. Some weather conditions like moderate wind conditions or calm air conditions together with temperature inversions caused by an anticyclone can contribute to extreme accumulations of air pollutants.

Objectives

(a) To decide whether the distribution functions of a given pollutant’s concentrations differ significantly between the thirteen Péczely’s large scale weather situations;
(b) To detect the 90 % confidence intervals for mathematical expectations (m) of the pollutants concentrations for each Péczely’s large-scale weather situations;
(c) To present and apply a new interpretation of the two-sample test (Makra-test). Namely:
   (c1) To detect whether or not average concentrations of air pollutants, calculated for each Péczely’s weather-type, differ significantly from the whole sample average?
   (c2) To detect the efficiency of the Péczely’s macrotypes in enrichment or dilution of the air pollutants examined.

Database

Since September 1996 an environmental monitoring station has been operating in Szeged. This station measures not only climatic elements (air temperature, humidity, radiation, air pressure, precipitation and wind speed and direction) but concentrations of the main air pollutants (CO, NO, NO\(_2\), NO\(_x\), O\(_3\), SO\(_2\) and PM\(_{10}\)), as well.

The data basis consists of a 30-minute data set from the three-year period between January 1\(^{st}\) 1997 and December 31\(^{st}\) 1999. The elements considered are the average mass concentrations of the main air pollutants \([\text{CO, NO, NO}_2, \text{NO}_x, \text{SO}_2, \text{O}_3\text{ and } \text{PM}_{10} (\mu g m^{-3})]\).

Geographical position, meteorology and topography of Szeged
Szeged is located in the Carpathian Basin (20°06'E and 46°15'N), at an altitude of ca. 80 m above sea level. Its population is about 155,000 inhabitants and the built-up area is around 46 km². The city is situated near the confluence of the Tisza and Maros Rivers, in southern Hungary. Szeged is the largest city in the southern part of the Great Hungarian Plain (Fig. 1.). The climate is temperate, the annual mean temperature is 11°C and the annual average sum of precipitation is 570 mm. The basis of the city structure is the boulevard-avenue system, crossed by the Tisza River. In this way, structure of the city is simple. Following to this system, motor vehicle traffic as well as air pollution are concentrated in the city.

Though Szeged is the centre of light industry in the southern part of the Great Hungarian Plain, (mill-, wood-, paprika processing industry, hemp processing, salami production), some elements of heavy industry are present as well (rubber- and paint industry, furthermore crude oil and gas mining). Industrial potential of Szeged has changed for the worse from the 1990-ies. Several companies have closed down, e.g. textile-, cable-, clothing- and canning factories, while the KÉSZ Ltd. (Light Structure Building and Servicing Ltd.) moved its centre and activity to another city. The industrial area is located mainly in the north-western part of Szeged. Thus, the prevailing westerlies and northerlies transport pollutants, originating from this area, towards the centre of the city.

Method

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.

Kolmogorov-Smirnov test

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

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

Let $\xi_{ij}$ the daily average concentration of a given contaminating gas found in the $i$-th macrotype from Péczely falling into the group $i$ ($i = 1, 2, \ldots, 13$) where $n_i$ is the number of days (measurements) ($j = 1, 2, \ldots, n_i$). The distribution functions for each macrotype are estimated by empirical 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 $k$ ($i, k = 1, 2, \ldots, 13$) ($i \neq k$), 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:

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

The test statistics is as follows:

\[ D_{1,2} = \sqrt{n_i \cdot n_k} \cdot \sup_{-\infty < x < +\infty} \left| F_{n_i}(x) - F_{n_k}(x) \right|, \]

for which

\[ \lim_{n_i, n_k \to \infty} P(D_{1,2} < x_\alpha) = \sum_{i=-\infty}^{+\infty} (-1)^i \cdot e^{-2i^2x^2} = K(x), \quad \text{if } x > 0. \]

The \( x_\alpha \) 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 \( \alpha \) 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.

**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.

\[ \lim_{n \to \infty} P(\frac{\bar{m} - m}{\sigma/\sqrt{n}} < x) = \Phi(x), \]

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

\[ P\left| \frac{\bar{m} - m}{\sigma/\sqrt{n}} \right| < x = 2\Phi(x) - 1, \quad x \geq 0. \]

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

**A new interpretation of the two sample 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., 2002). 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

\[ \frac{\bar{M} - \bar{m}}{\sqrt{\frac{N - n}{N \cdot n} \cdot \sigma}} \]

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:

\[ P\left( \frac{\bar{M} - \bar{m}}{\sqrt{\frac{N - n}{N \cdot n} \cdot \sigma}} > x_p \right) = p \cdot \]

If the absolute value of the above probability variable with N(0;1) distribution is higher than \( x_p \), then it is said that \( \bar{M} \) and \( \bar{m} \) 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 1a-g, 2.). Altogether \( \binom{n}{2} \) cases (macrotypes 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 PM\(_{10}\) (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.
Table 1.
Results of the Kolmogorov-Smirnov test. Goodness of fitting of the distribution functions of
the given pollutants concentrations for all possible pairs of the Péczely types
(+: the distribution functions indicate significant difference for the given macrotype pairs)

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Table 2.
Significant difference between distribution functions of the pollutants concentrations analysed at given Péczely’s macrotype compared to others, %

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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 (Fig. 2).

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.
Fig. 2.
90 % confidence intervals for mathematical expectation (m) of pollutants concentrations for each large scale weather situations

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.
References
Lakatos, M. and Ferenczi, Z., 1994: The background air pollution in connection with weather and circulation conditions. Manuscript

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Table 3.
Efficiency of the Péczely’s large scale weather situations in enrichment / dilution of air pollutants

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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 the Péczely’s macrosynoptic types since 1881 has been available (Péczely, 1983; Károssy, 1987) (Fig. 3a-b).
Fig. 3a
Sea level pressure fields of the typical days selected by Péczely, representing the thirteen characteristic weather types (Péczely-types)
Fig. 3b
Sea level pressure fields of the typical days selected by Péczely, representing the thirteen characteristic weather types (Péczely-types)