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EVALUATION OF THE AIR QUALITY OF SZEGED WITH SOME ASSESSMENT METHODS

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Összefoglalás – A légkör emberre gyakorolt hatásainak becsléséhez a humán biometeorológia módszereit kell alkalmazni. A humán biometeorológia összetevői közül a termikus komponens, valamint a levegőminőségi komponens játssza a legfontosabb szerepet. A légszennyező anyagok koncentrációinak vizsgálatához szükséges küszöbértékeik mindenütt rendelkezésre állnak. A levegőminőségi komponens értékelése céljából egyrészt statisztikai alapú ún. levegőterhelési indexeket, másrészt hatás alapú ún. levegőminőségi indexeket fejlesztettek ki. A dolgozatban egy Szeged-belvárosi forgalmi csomópontban működő monitoring állomás ötéves 30 percenkénti adatbázisa alapján összehasonlítottuk a statisztikai alapú ASI_{Sz} levegőterhelési index, valamint egy újonann előállított hatás alapú levegőminőségi index (DAQx) értékeinek gyakorisági eloszlásait. Mindkét indexet német kutatók fejlesztették ki, s napi adatbázis alapján számíthatók. A két index gyakorisági eloszlás görbéinek eltérő alakja az egyes légszennyező anyagok hatás alapú koncentrációinak megadott tartományaira vezethető vissza, melyek a levegőminőségi indexek jellmezői. Az adatbázis alapján a levegőminőségi indexek értékeiben elsősorban a szén-monoxid és a PM_{10} részesedése számottevő.

Summary – Methods of human-biometeorology have to be applied for the assessment of atmospheric impacts on human beings. Among the human-biometeorological effective complexes two are of great importance in the regional scale: the thermal effective complex and the air quality effective complex. With respect to the air quality effective complex, standards for the assessment of single air pollutants exist worldwide. In addition, approaches for statistical air stress indices and impact-related air quality indices were developed. In this study, based on a five-year air pollutant data set from the downtown of a middle-sized Hungarian city, Szeged, the frequency distribution of the air stress index ASI_{Sz} is compared with the frequency distribution of the new air quality index DAQx. Both indices were developed by German researchers and are on a daily basis. The varying forms of both frequency distributions are mainly caused by the impact-related concentration ranges of single air pollutants, which are typical of air quality indices. Especially carbon-monoxide and PM_{10} have a stronger influence on the determination of values of air quality indices.

Key words: air pollution, air stress index (ASI), air quality index (DAQx)

INTRODUCTION

There are a lot of questions on the impacts of the atmospheric environment on human beings which are focussed on the regional scale (e.g. landscape planning). To get answers, methods of human-biometeorology have to be applied (*Mayer,* 1993). Among the human biometeorological effective complexes two are of great importance in the regional scale: the thermal effective complex (*Matzarakis and Mayer*, 1997; *Matzarakis et al.*, 1999; 2000) and the air quality effective complex (*Mayer et al.*, 2002a, 2002b). They have to be assessed in a human biometeorologically significant manner. Assessment of air quality developed only a few studies in Hungary (e.g. *Makra and Horváth,* 2001). The objective of this article is twofold: on the one hand, to give a brief overview of assessment methods; and, on the other hand, to discuss exemplary results for air pollution data basis of Szeged.

METHODS

Standards for the assessment of single air pollutants exist in almost every country of the world, e.g. in EU directives. However, these standards are insufficient in view of the persistent demands (e.g. from planners) for the assessment of the air quality, which is not limited to a single air pollutant. Therefore, indices on the basis of routinely monitored air pollutants were developed. They can be categorized into two groups (*Mayer et al.,* 2002b). The first group includes indices, which are only statistical and have no direct relation to the well-being and health of human beings. They indicate mainly the content of air pollution in the ambient air and, therefore, are called air stress indices ASI. They can be calculated according to the following formulas:

$$ASI = \frac{1}{n} * \sum_{i=1}^{n} \left[\frac{C_i}{R_i} \right]_i \tag{1}$$

with a symbol description in *Table 1.*

Table 1 Description of the air stress index ASI in formula (1)

	mean stress (year, day)	**short-term stress**
n	number of air pollutants	number of air pollutants
C	time specific concentration of the air pollutant i	number of cases per calendar year: air pollutant specific limit values are exceeded
R	time specific reference (limit) value of the air pollutant i	number of cases per calendar year: air pollutant specific limit values are not to be exceeded

Planning-related air stress index ASI_1 for mean stress, developed by the Office of Environmental Protection, Division Urban Climate, City of Stuttgart, Germany:

$$ASI_1 = \frac{1}{4} * \left(\frac{C(SO_2)}{20\mu g/m^3} + \frac{C(NO_2)}{40\mu g/m^3} + \frac{C(PM_{10})}{40\mu g/m^3} + \frac{C(benzene)}{5\mu g/m^3} \right) \tag{2}$$

where C: arithmetical annual mean values ($\mu g/m^3$); reference values (denominators of the addable sums): air pollutant specific EU standards.

Planning-related air stress index ASI_2 for short-term stress, developed by the Office of Environmental Protection, Division Urban Climate, City of Stuttgart, Germany:

$$ASI_2 = \frac{1}{4} * \left(\frac{N(SO_2)}{24} + \frac{N(NO_2)}{18} + \frac{N(PM_{10})}{35} + \frac{N(CO)}{1} \right) \tag{3}$$

where N: number of cases per calendar year, air pollutant specific EU limit values are exceeded; reference values (denominators of the addable sums): number of cases per calendar year, air pollutant specific EU limit values are not to be exceeded [SO_2: 350 μg/m^3 (1 h mean value), NO_2: 200 μg/m^3 (1 h mean value), PM_{10}: 50 μg/m^3 (daily mean value), CO: 10 mg/m^3 (highest daily running 8 h mean value)] (*Mayer et al.*, 2002b).

A graded assessment scale (*Table 2*) is available for the air stress indices ASI_1 and ASI_2 (*Mayer et al.*, 2002b), which e.g. can serve as basis for planning specific recommendations with respect to the air quality.

Table 2 Assessment of the air quality conditions on the basis of ASI_1 and ASI_2 (*Mayer et al.*, 2002b)

ASI_1: no single air pollutant exceeds the corresponding limit value		
ASI_2: no single air pollutant shows a higher number of cases per calendar year with air pollutant specific limit values are exceeded than the permitted number		
level I	very low air stress	ASI_1, $ASI_2 < 0.2$
level II	low air stress	$0.2 \le ASI_1$, $ASI_2 < 0.4$
level III	moderate air stress	$0.4 \le ASI_1$, $ASI_2 < 0.6$
level IV	distinct air stress	$0.6 \le ASI_1$, $ASI_2 < 0.8$
level V	strong air stress	ASI_1, $ASI_2 \ge 0.8$
ASI_1: no less than one air pollutant exceeds the corresponding limit value		
ASI_2: no less than one air pollutant shows a higher number of cases per calendar year with air pollutant specific limit values are exceeded than the permitted number		
level VI	extreme air stress	independent of ASI_1 and ASI_2

Air stress index ASI_{Sz} on a daily basis, developed by the Federal State Institute for Environmental Protection Baden-Wuerttemberg, Karlsruhe, Germany:

$$ASI_{Sz} = \frac{C(SO_2)}{350\mu g/m^3} + \frac{C(CO)}{10mg/m^3} + \frac{C(NO_2)}{200\mu g/m^3} + \frac{C(O_3)}{180\mu g/m^3} + \frac{C(PM_{10})}{50\mu g/m^3} \tag{4}$$

Lower index $_{Sz}$ indicates data sets of Szeged city, to which this air stress index is applied). $C(SO_2)$, $C(NO_2)$, and $C(O_3)$: highest daily 1 h mean values (μg/m^3), C(CO): highest daily running 8 h mean value (mg/m^3), $C(PM_{10})$: daily mean value (μg/m^3); limit values from EU directives.

ASI_{Sz} classes and ranges are as follows: I: $ASI_{Sz} < 0.5$; II: $0.5 \le ASI_{Sz} < 1.1$; III: $1.1 \le ASI_{Sz} < 1.7$; IV: $1.7 \le ASI_{Sz} < 2.3$; V: $2.3 \le ASI_{Sz} < 2.9$; VI: $ASI_{Sz} \ge 2.9$.

Impact-related indices, which are called air quality indices, constitute the second group of indices for the assessment of the air quality effective complex. Such indices are very rare, because it is difficult to quantify the impacts of air pollutants on the well-being and health of human beings. The methodology of air quality indices is to assign concentrations of ambient air pollutants to different air pollutant specific ranges. The air quality index itself is represented by the highest index class among the considered air pollutants. The relation to the impact on human beings is given by different classified ranges of air pollutant concentrations, which are derived from epidemiological and toxicological investigations.

A new impact-related air quality index obtained on a daily basis and abbreviated as DAQx (Daily Air Quality Index) was recently developed and tested by the Meteorological

Institute, University of Freiburg, and the Research and Advisory Institute for Hazardous Substances, Freiburg, Germany (*Mayer et al.*, 2002a, 2002b). DAQx considers the air pollutants SO_2, CO, NO_2, O_3, and PM_{10}. To enable a linear interpolation between index classes, DAQx is calculated for each air pollutant by

$$DAQx = \left[\left(\frac{DAQx_{up} - DAQx_{low}}{C_{up} - C_{low}} \right) * (C_{inst} - C_{low}) \right] + DAQx_{low} \tag{5}$$

with $C_{inst.}$: highest daily 1 h concentration of SO_2, NO_2, and O_3, highest daily running 8 h mean concentration of CO, and mean daily concentration of PM_{10}; C_{up}: upper threshold of specific air pollutant concentration range (*Table 3*); C_{low}: lower threshold of specific air pollutant concentration range (*Table 3*); $DAQx_{up}$: index value according to C_{up} (*Table 3*); $DAQx_{low}$: index value according to C_{low} (*Table 3*).

Table 3 Assignment of ranges of specific air pollutant concentrations to DAQx values and DAQx classes inclusive of classification names according to school marks (*Mayer et al.*, 2002a, b)

SO_2 (µg/m³)	**CO (mg/m³)**	**NO_2 (µg/m³)**	**O_3 (µg/m³)**	**PM_{10} (µg/m³)**	**DAQx value**	**DAQx class**	***Classification***
0–24	0.0–0.9	0–24	0–32	0.0–9.9	0.5–1.4	1	*very good*
25–49	1.0–1.9	25–49	33–64	10.0–19.9	1.5–2.4	2	*good*
50–119	2.0–3.9	50–99	65–119	20.0–34.9	2.5–3.4	3	*satisfactory*
120–349	4.0–9.9	100–199	120–179	35.0–49.9	3.5–4.4	4	*sufficient*
350–999	10.0–29.9	200–499	180–239	50.0–99.9	4.5–5.4	5	*poor*
≥ 1000	≥ 30.0	≥ 500	≥ 240	≥ 100	≥ 5.5	6	*very poor*

DATA BASIS

The data basis of the study is formed by 30-minute air pollutants concentrations (SO_2, NO_2, CO, O_3, PM_{10}) of the monitoring station in the downtown of Szeged, for the five-year period between 1997-2001. The considered pollutants and the existing concentration data in percentage are shown in *Table 4*.

Table 4 Existing data for calculation of ASI_1 and ASI_2, %

Year	**[1]SO_2**	**[1]NO_2**	**[2]PM_{10}**	**[3]PM_{10}**	**[4]CO**
1997	6.11	67.24	85.56	83.56	90.14
1998	78.38	89.01	73.20	73.15	88.49
1999	99.81	95.53	72.76	72.60	99.18
2000	98.90	89.34	99.01	98.08	98.36
2001	98.65	98.95	96.36	95.07	98.08

[1] 1 h mean values; used for calculation of ASI_1 and ASI_2;
[2] 1 h mean values; used for calculation of ASI_1;
[3] daily mean values; used for calculation of ASI_2. It was calculated if at least 20 one-hour mean was at disposal on a given day;
[4] highest daily running 8 h mean value. It was calculated if at least 20 one-hour mean was at disposal on a given day.

RESULTS

As benzene (considering for calculation of ASI_1) is not measured at the monitoring station, the fourth addable sum in the parenthesis of formula (2) is omitted. The data basis of SO_2 was rather scanty in 1997. Hence, both ASI_1 and ASI_2 were calculated on the basis of the rest two and three parameters, respectively.

The reason of high values of ASI_1 and ASI_2 in 1997 is as follows. On the one hand, sulphur-dioxide in 1997 was taken out of consideration; hence, division in their formulas occurred by one number less. On the other hand, SO_2 concentration was very low in the rest of the years, which reduced values of these two indices substantially in years 1998-2001. The reason of the extremely high values of ASI_2 is the fact that number of exceedings for carbon-monoxide per calendar year is extremely high in each examined year. Neither values of ASI_1 nor those of ASI_2 show clear tendency (*Fig. 1-2*).

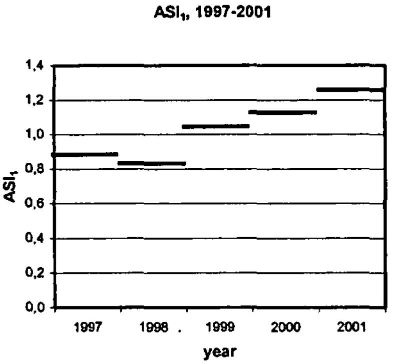

Fig. 1 Annual values of ASI_1, 1997-2001

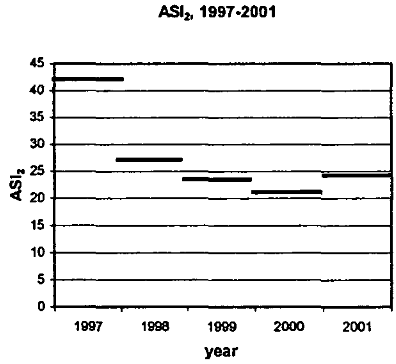

Fig. 2 Annual values of ASI_2, 1997-2001

An assessment scale was developed for ASI_1 and ASI_2 in order to characterise the air quality (*Table 2*). Considering only values of either ASI_1, or ASI_2, air quality of Szeged can be characterised by strong air stress (level V) in each examined year. For further analysis (see *Table 2*): on the one hand, concentration of PM_{10} (considering for calculation of ASI_1) exceeds its limit value in each five year; on the other hand, both for PM_{10} and CO the number of actual exceedings of the specific limit values (considering for calculation of ASI_2) is several times higher than that of the permitted exceedings in each five year. Consequently, independently from the actual values of either ASI_1 or ASI_2, air quality of Szeged city can be characterised by extreme air stress (level VI) (*Table 2*).

To investigate the sensitivity of indices for the assessment of the air quality conditions, frequency distributions for ASI_{Sz} as an exponent of air stress indices and DAQx as an exponent of air quality indices were calculated for Szeged downtown. ASI_{Sz} as well as DAQx are indices on a daily basis. Since ASI_{Sz} has no relation to the impact on human beings, six classes were statistically defined on the results of five-year (1997-2001) daily values (*Table 3*).

Daily values of both ASI_{Sz} air stress index and DAQx air quality index were calculated for the examined five-year period. Further, results for the year 2001 are only shown (*Fig. 3-4*). Empty sections on the figures indicate lack of data. ASI_{Sz} values – exceeding level III – presenting increased air stress as well as peak values are concentrated in the winter half-year or in the winter months (*Fig. 3*). This can be explained by climatic reasons. Standard deviation of DAQx values is less than that of ASI_{Sz} values. Peak values of DAQx are also concentrated in the winter half-year (*Fig. 4*); however, this is not as characteristic as in the case of ASI_{Sz} values. The reason of this is that the vertical axis of the diagram for ASI_{Sz} is linear, while that of the diagram for DAQx is not.

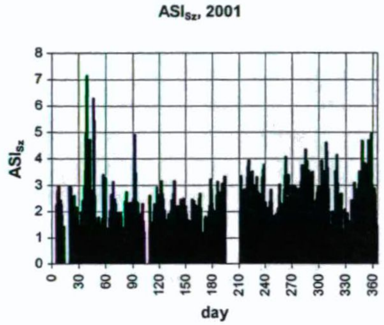

Fig. 3 Annual course of ASI_{Sz}, 1997-2001

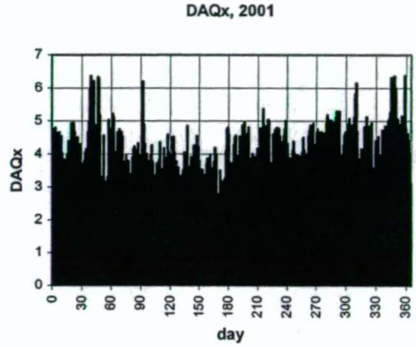

Fig. 4 Annual course of DAQx, 1997-2001

Frequency distribution of ASI_{Sz} and DAQx according to both classes and years are different. DAQx values have generally well higher frequencies in levels 4 and 5; and, on the other hand, have less ones in the rest levels comparing to frequency distribution of ASI_{Sz} values in levels I-VI (*Fig. 5-6*).

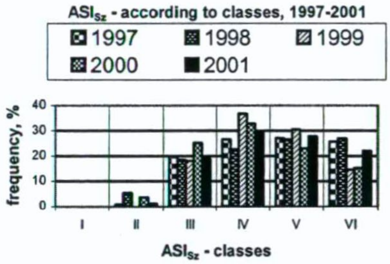

Fig. 5a Frequency distribution of ASI_{Sz} values according to classes, 1997-2001

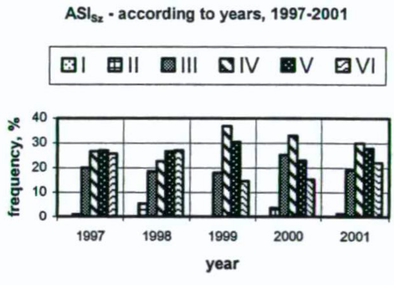

Fig. 5b Frequency distribution of ASI_{Sz} values according to years, 1997-2001

Carbon-monoxide and PM_{10} are mainly responsible for the changed form of the frequencies of DAQx classes (*Fig. 7*).

There were selected those 3 days in each July and January in the examined five-year period, on which air pressure was the highest in the month. Afterwards, ASI_{Sz} and DAQx values of these days were calculated. In July values of ASI_{Sz} share of PM_{10}, ozone and carbon-monoxide are the largest, while its January values are mostly determined by concentrations of CO and PM_{10} (*Fig. 8a, c*). When calculating DAQx values in July, highest index categories are shown by PM_{10} on 10 days, by O_3 on 3 days and by CO on

2 days, respectively (*Fig. 8b*). While in January PM_{10} and carbon-monoxide indicate the highest index categories on 10 and 5 days, respectively (*Fig. 8d*).

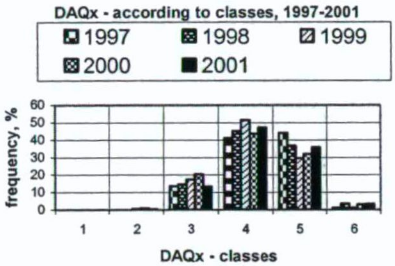

Fig. 6a Frequency distribution of DAQx values according to classes, 1997-2001

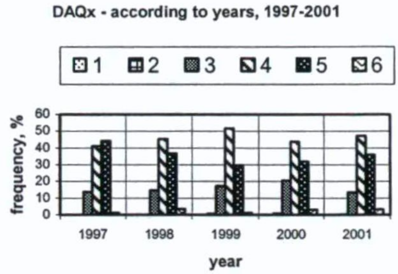

Fig. 6b Frequency distribution of DAQx values according to years, 1997-2001

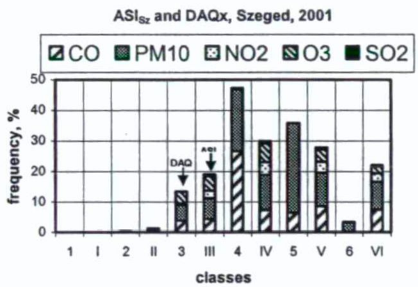

Fig. 7 Frequency distribution of ASI_{Sz} and DAQx values according to classes, with the share of the pollutants, 1997-2001

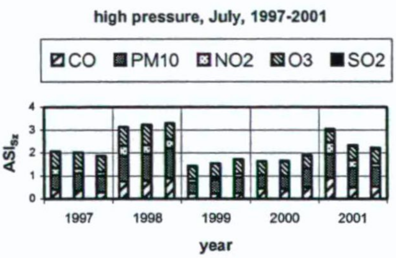

Fig. 8a Share of the pollutants in ASI_{Sz} values of 3 selected days, respectively, July, 1997-2001

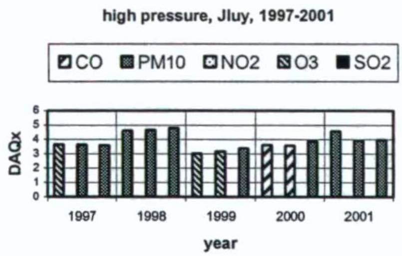

Fig. 8b DAQx values of 3 selected days, July, 1997-2001

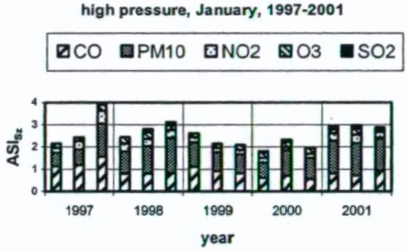

Fig. 8c Share of the pollutants in ASI_{Sz} values of 3 selected days, respectively, January, 1997-2001

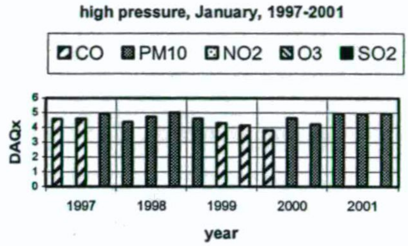

Fig. 8d DAQx values of 3 selected days, January, 1997-2001

Analysis of both ASI_{Sz} and DAQx values represents high pollution load of PM_{10} and carbon-monoxide. Examined parameters of PM_{10} and CO – which are several times higher than standards of their EU directives – substantially modifiy air quality of Szeged.

CONCLUSIONS

Aside from single air pollutant standards, air stress indices and air quality indices enable an additional assessment of the air quality conditions, which is primarily not limited to single air pollutants. The application of air stress indices or air quality indices depends on the specific objectives of the investigation.

Temporal course of ASI_1 and ASI_2 is not clear. High values of mean air stress (indicated by $ASI_1 \approx 1$) as well as extremely high values of short-term air stress (indicated by $ASI_2 > 20$) suppose high air pollution load in Szeged.

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