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Influences of meteorological parameters and biological and chemical air pollutants on the incidence of asthma and rhinitis

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ABSTRACT: We studied the relationship among (1) the characteristic weather types found in the Carpathian Basin in the summer to early autumn period (July 15 to October 15) and in the winter months (December, January and February), (2) the levels of chemical (CO, NO, NO_2, NO_2/NO, O_3, O_{3max}, SO_2, PM_{10}) and biological (pollen) air pollutants, and (3) their effect on respiratory diseases. The database comprises daily values of 13 meteorological parameters, 8 chemical and 8 biological pollutants, and the number of patients for the period from 1999 to 2003, in Szeged, Hungary. Altogether, 9 symptom groups of respiratory diseases and their occurrences were taken into account. In the summer to early autumn period a total of 26 703 patients, while in the winter months a total of 14 507 patients, registered with respiratory diseases were considered. An objective definition of the characteristic weather types was carried out by using factor and cluster analysis. In the winter months, there was no relationship between the 8 defined weather types and patient numbers. On the other hand, in the summer to early autumn period, Weather Type 7, with a weak anticyclonic ridge character and the highest patient numbers, was linked to high temperature parameters (T_{mean}, T_{max}, T_{min}), low relative humidity, as well as high chemical and biological pollutant levels. At the same time, Type 2 (anticyclonic ridge character) was associated with the lowest patient numbers and was characterized by high temperature and medium relative humidity parameters, as well as high levels of chemical and low levels of biological air pollutants. Results on the relationships of the meteorological parameters and chemical air pollutants, as well as weather types, will be built into a model to predict, and in this way to prepare for, days of severe risk of respiratory illness.

KEY WORDS: Weather types · Pollen · Chemical air pollutants · Respiratory diseases · Lorenz diagram · ANOVA weather classification · Tukey test

1. INTRODUCTION

Over the last decades, a worldwide increase of respiratory diseases has been experienced. In the United States the estimated number of people with self-reported asthma during the preceding 12 mo increased from approximately 3.0% of the total US population in 1970 and 3.1% in 1980 to 5.5% in 1996. Furthermore, for the 3 yr period from 2001 to 2003, an average annual incidence of asthma of at least 6.7% in the population was determined (Moorman et al. 2007). Rimpela et al. (1995) describe a 3-fold increase of physician-diagnosed asthma and allergic rhinitis among Finnish adolescents in the period from 1977 to 1991. Studies indicate that asthma and allergic conditions are most prevalent in the UK (Canonica et al. 2007), Australia (Watson et al. 2007) and New Zealand (Epton et al. 2007). An increasing trend of respiratory symptoms has also been reported for Chile (Luque et al. 2006). Lundback (1998) shows the lowest rates of asthmatic

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diseases are in Central Europe; however, this is not the case in the Carpathian Basin (Makra et al. 2004, 2005). In Hungary, about 30% of the population has some type of allergy, 65% of them have a pollen sensitivity, and at least 60% of the cases of pollen sensitivity are generated by pollen of the ragweed genus, *Ambrosia* (Járai-Komlódi 1998). Over the 40 yr preceding the late 1990s, the number of patients with registered allergic illnesses doubled and the number of cases of allergic asthma quadrupled in southern Hungary (Mezei et al. 1992, Farkas et al. 1998). However, it is important to note that the diagnosis of asthma has also certainly developed a great deal during this period (Rimpela et al. 1995, Makra et al. 2004). Aerobiological and allergological studies show that the pollen map of Europe is changing as a result of cultural factors (for example, importation of plants such as birch and cypress for urban parklands), more international travel (e.g. colonization by ragweed in France, northern Italy, Austria, Hungary) and climate change (Kiss & Béres 2006).

Respiratory diseases in adults frequently result in death. The roles of meteorological or environmental factors in the development of respiratory diseases have long been observed, but only partially proved, and many controversial results, especially concerning the effect of weather variables, still exist. General characteristics of the weather, such as temperature, atmospheric humidity, wind direction and air pollution, can influence the development of respiratory diseases. Due to these effects, acute diseases (e.g. upper and lower respiratory catarrh and inflammation of nasal accessory cavity) and the worsening of stages of existing chronic respiratory diseases (e.g. asthma, chronic obstructive pulmonary disease [COPD], allergies) can, in part, develop (ZuWallack et al. 2004). These diseases are characterised by an increased sensitivity (hyper-reactivity) of the bronchia to the harmful substances inhaled. Asthmatic symptoms are most frequently caused by allergies, but they may also be generated by respiratory viral infection, air pollution, physical load, stress and change of weather (Freed 1995).

The following influencing factors should be taken into account. (1) Temperature: inhalation of cold air in hyper-reactive bronchia induces inflammation of the mucous membrane. Furthermore, the inhalation of dry and cold air also activates the so-called cold receptors on the nasal mucous membrane, which contribute to the development of the respiratory hyper-reactivity. (2) Atmospheric humidity: after inhaling dry air, neutrophil, eosinophil and leukotriene contents in the bronchial lavatory fluid increase, thus, repeated exposition to dry air produces inflammation, obstruction and hyper-reactivity of the small respiratory tracts. (3) Wind direction: winds influence air pollution and desiccate and cool the air (i.e. hyper-reactivity from the influence of cold and dry air). (4) Air pollution: (a) inhalative chemical and physical substances (industrial and cigarette smoke, soot, carcinogenic and oxidizable substances, e.g. nitrogen monoxide, peroxynitrite). The concentrations of these substances also depend on the weather circumstances, and the severity of the symptoms is correlated with the severity of the air pollution. After inhaling NO_x, inflammation of mucous membranes in the bronchia, depending on the qualities of the irritating substances, will lead to a stricture of the bronchioluses (bronchoconstriction). This is aggravated by the anatomical and associated functional damage of cilia, which are responsible for self-purification. The resulting plentiful and stagnant bronchus secretion is an excellent substrate for pathogens and for respiratory infections. (b) Pollen: its concentration is influenced, among other things, by meteorological parameters, and the symptoms depend on pollen levels. In this case, in the respiratory tracts of the individuals sensitive to a given pollen, inflammation mediated by immunoglobin E (IgE) develops. After antigen-antibody linkage, mediator substances (e.g. histamine, serotonin, prostaglandins, leukotrienes) multiply, which generate inflammation of the bronchial mucous membrane and cause bronchiospasm. As a result of this, bronchoconstriction can develop, which is reversible in the case of asthma (Millqvist 1999, Strausz 2003, Parsons & Mastronarde 2005).

The most important consequence of the stricture of the respiratory tracts is that the air is prevented from flowing out; hence, it is trapped and as a result the lungs gradually puff up. Consequential symptoms are coughing, an increased quantity of spit and dyspnoea at an early stage in case of physical loading, while later even during rest as well (Strausz 2003).

The connections between meteorological parameters, weather types and respiratory diseases have already been widely studied (e.g. Danielides et al. 2002). Bucher & Haase (1993) describe and critically discuss causal correlations between conditions in the lower atmosphere and reactions of the human organism, but also the combined or synergistic effects of different weather situations. The effects of meteorological factors (Schlink et al. 2002), climate conditions (Serda et al. 2005), including air temperature and absolute humidity (Kotaniemi et al. 2002, Avino et al. 2004, Nastos & Matzarakis 2006), wind parameters (Avino et al. 2004) and weather types (Nastos et al. 2006), as well as geographical factors (Kurt et al. 2007) and chemical air pollutants (Schlink et al. 2002, Lee et al. 2003, Avino et al. 2004, Heinrich et al. 2005), influence the risk of respiratory symptoms. Furthermore, there is considerable evidence to suggest that climate change impacts on aeroallergens. These include impacts on pollen amount, pollen allergenicity, pollen season, plant and pollen distribution, and other plant attributes (Beggs 2004, Beggs & Bambrick 2005). Hence, considering also the ever increasing air pollution, respiratory diseases are of major concern worldwide.

On the basis of the weather type classification for the Szeged region, southern Hungary, we aimed to identify those weather types that are either influential in increasing patient numbers of respiratory diseases or are negligible in triggering asthma and rhinitis. For this purpose, the joint effects of the meteorological variables setting up the weather types, as well as levels of chemical and biological air pollutants influenced by the given weather types were considered. In this way a more comprehensive and simple analysis could be performed on the number of patients with respiratory disease dependent on weather and ambient air quality.

2. MATERIALS AND METHODS

2.1. Study area

The city of Szeged (46° 15′ N, 20° 06′ E), the largest settlement in SE Hungary, is located at the confluence of the Tisza and Maros Rivers. The area is characterised by an extensive flat landscape, with an elevation of 79 m above sea level (a.s.l.). The developed area covers a region of about 46 km^2, with approximately 155 000 inhabitants (Fig. 1).

The mean annual temperature is 11.2°C, while mean January and July temperatures are −1.2 and 22.4°C, respectively. Annual average precipitation is 573 mm, relative humidity is 71 %, wind speed is 3.2 m s^{-1}, and sunshine duration is 2102 h.

The city is arranged in a boulevard–avenue street system crossed by the Tisza River. In this way, the structure of the city is simple; however, due to this system, motor vehicle traffic, as well as air pollution, are concentrated in the city centre. The industrial area is located mainly in the north-western part of the town; thus, the prevailing westerlies and northerlies also transport pollutants originating from this area towards the centre of the city.

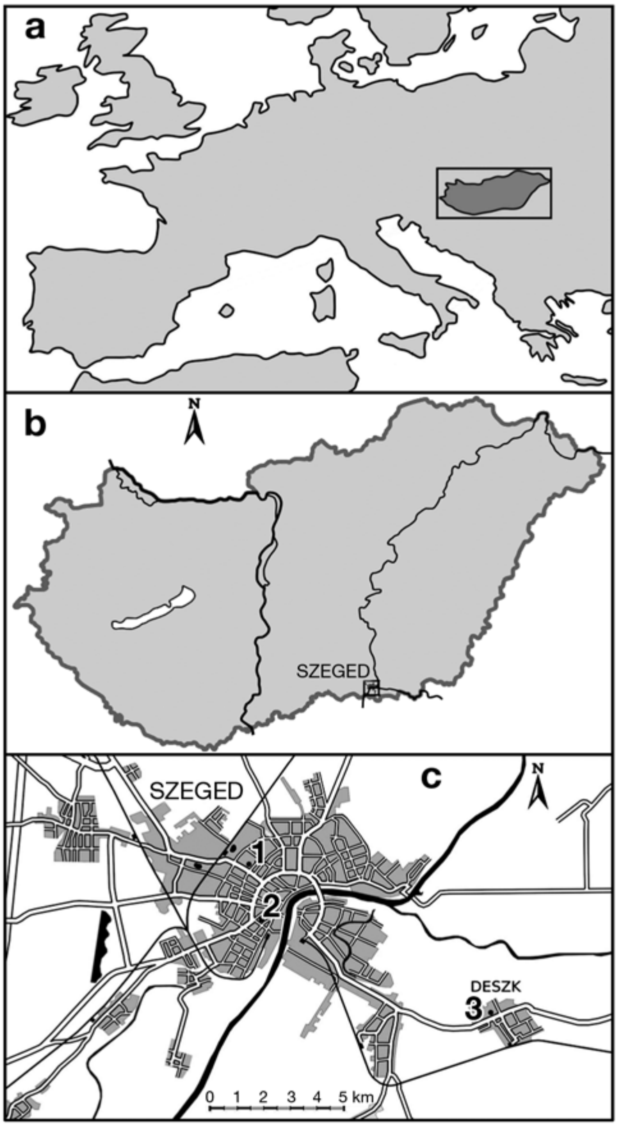

Fig. 1. (a) Location of Hungary within the Carpathian Basin in Europe, (b) Hungary and the location of Szeged, (c) the urban web of Szeged, with the position of the data sources. 1: monitoring station, measuring climate parameters and chemical air pollutants; 2: pollen trap, measuring biological air pollutants; 3: Thorax Surgery Hospital, Deszk

2.2. Sources of air pollutants

The total urban spread extends well beyond the city limits and, north of the town, includes the largest oil field in Hungary, with several oil torches. This oil field is a significant source of NO_x and SO_2. The power station, located in the north-western part of the town (in the downtown area), and motor vehicle emissions largely contribute to the NO_x levels in Szeged. The main sources of industrial CO, NO_x and CO_2 in Szeged are district heating, heat supply and energy production using gas motors, while sources of industrial solid material emissions are the production of rubber, iron moulding and asphalt, as well as metal processing. It should be noted that industrial emission data only include quantities of air pollutants released through measurable air pollution point sources, that are required to be reported according to the 21/2001 (II. 14.) Government statute. Air pollutants released into the air in a diffuse (non-measurable) way have been omitted from the above inventory. In Szeged, the total emission ratios (kg yr^{-1}) for the main air pollutants of industrial origin in the year 2006 are: solid materials: 0.0047 %; NO_x: 0.1277 %; CO: 0.1157 %; CO_2: 99.7519 %. This means that CO_2 emissions highly predominante all pollutant release of industrial origin.

2.3. Location of the monitoring station

All the weather data were collected by the air pollution monitoring station (under the auspices of the Environmental and Natural Protection and Water Conservancy Inspectorate of the Lower Tisza Region, Szeged, belonging to the Ministry of Environment and Water, Hungary), which is located in downtown Szeged at a crossroads with heavy traffic (Kossuth Avenue and Damjanich Street), at a distance of about 10 m from Kossuth Avenue. This is one of the busiest crossroads in Szeged. The monitoring station was put into operation on September 1, 1996. Wind and irradience parameters are affected by a 2-storey building located ~10 m from the station. Sensors, measuring concentrations of the chemical air pollutants, are located 3 m above the surface.

2.4. Representativeness of the location of the station

The monitoring station is influenced by the urban heat island in anticyclonic weather situations, especially in summer and winter. Hence, values of the meteorological parameters measured here differed from those for the wider surroundings. The station was placed at a crossroads to evaluate the levels of pollutants due to traffic. In this way, the pollutant concentrations measured here were not representative of Szeged on the whole.

Pollen traps were usually located on the roof of a suitably accessible building, about 2 or 3 storeys high. Traps were placed at this height to enable monitoring of the general ambient airflow, which contains a good mix of the local and more distant pollen sources gathered on the wind. If the trap had been at ground level, it would mainly have collected pollen from the immediate vicinity and results between sites would not have been comparable. In this way, the representativity of the pollen trap was ensured.

The Thorax Surgery Hospital, Deszk, is situated about 10 km from the city centre of Szeged (Fig. 1). For such a short distance, the meteorological values for Szeged can be assumed to also represent those for Deszk. The hospital is located on road No. 43, which is characterised by heavy traffic, similar to road No. 5 (of which Kossuth Avenue is part) at the crossing where the monitoring station is located, though comparative traffic census data are not available. Hospital admissions with respiratory diseases are primarily from Szeged. Nevertheless, this is the only hospital in Csongrád County (the capital of which is Szeged) that treats patients with respiratory symptoms.

2.5. Study period

Both the meteorological and pollution data come from the monitoring station. The meteorological parameters and the chemical air pollutant data consist of 30 min averages of the 5 yr term from 1999 to 2003, for the summer to early autumn period (July 15 to October 15) and the winter months (December, January and February). The daily counts of pollen grains of different species, as biological air pollutants, were considered for the summer to early autumn period of the above 5 yr term.

The summer to early autumn period was chosen with respect to the main pollination period of ragweed (*Ambrosia*), which is considered the most dangerous aeroallergen in Hungary (Járai-Komlódi 1998, Makra et al. 2004, 2005). In this period of the year, further species release their pollen, which may also exacerbate symptoms of respiratory diseases. Winter is a special season in the sense that during the 3 winter months, pollen is rarely observed. Thus, hospital admissions with respiratory diseases in winter can only be explained by other reasons. Spring and late autumn have not been tested, since we focussed our attention on the ragweed pollination and pollen-free periods. The choice of the period, of course, influences the results. While the levels of chemical air pollutants are uniform over the entire year, the effect of pollen depends on the term of pollen dispersion, which is strongly related to the climate/weather-related phenological phases of the plant. In Szeged, the pollen of some species can cause increased sensitivity from the beginning of February until the end of October (Makra et al. 2007).

2.6. Meteorological parameters and types of instruments

The meteorological parameters come from the monitoring station, and the daily values of 13 meteorological variables were used: mean, maximum and minimum temperature (T_{mean}, $T_{\max}$ and $T_{\min}$ in °C, respectively), diurnal temperature range ($T_{\mathrm{range}} = T_{\max} - T_{\min}$ in °C), day-to-day change of mean, maximum and minimum temperature (ΔT_{mean}, $\Delta T_{\max}$ and $\Delta T_{\min}$ in °C, respectively), mean and day-to-day change of relative humidity (RH and ΔRH, %), mean and day-to-day change of mean atmospheric pressure (P and ΔP, hPa), mean and day-to-day change of mean vapour pressure (VP and ΔVP, hPa). Considering humidity parameters, water vapour pressure is the most important in assessing the effect of humidity on the human body, since it involves the total amount of water in the air and, unlike RH, is not dependent on temperature.

Wind speed and wind direction were not included in the study, although both influence the distribution of pollen and air pollutants. However, wind promotes high pollen concentrations in some cases and not in others. Airborne pollen concentrations depend on the conditions under which plants release the pollen but the higher concentration of airborne pollen sometimes depends less on phenological phases and meteorological conditions than on transportation by the wind. So, pollen concentration depends both on wind speed and wind direction. Namely, if winds blow from a source area, the pollen concentration increases; on the other hand, coming from other directions, the wind would decrease the pollen count. However, wind parameters measured at the monitoring station were omitted from the analysis, because they were disturbed by the urban background (buildings). Pollen concentration may also increase due to the deposition of high-atmosphere pollen that could have been released several hours earlier (Giner et al. 1999, Fehér & Járai-Komlódi 1997, Makra et al. 2004).

The types of instruments at the station measuring the meteorological parameters considered are HMP-10 for temperature and humidity (HW1) and 501-A for irradiation (Solar Light Co. Inc.). Temperature and humidity values were measured 3 m above the surface, while irradiation was recorded at a height of 6 m above the ground level.

2.7. Air pollutants

2.7.1. Chemical pollutants and types of instruments

The variables measured at the monitoring station and those considered were the daily average mass concentrations of CO, NO, NO_2, SO_2, O_3 and particulate matter < 10 µm in diameter (PM_{10}) (µg m^{-3}) calculated from 30 min averages, the daily ratios of NO_2/NO and the daily maximum mass concentrations of O_3 (µg m^{-3}).

The concentration of CO was measured by non-dispersive infrared absorption (CO11M-LCD; Environment S.A.). The measurements of NO and NO_2 concentrations were based on the principle of chemiluminescence; the concentrations of NO_x were obtained so that the instrument (42C; Thermo Environment Instruments Inc.) added up the latest NO and NO_2 values automatically. SO_2 concentrations were measured using UV fluorescence emission (AF21M-LCD; Environment S.A.). O_3 concentration measurements were based on UV absorption by the 254 nm wavelength (49C; Thermo Environment Instruments. Inc.). PM_{10} concentrations were recorded by absorption of β-radiation (FH-62-I-N; Eberline).

Gas analysers were calibrated using 2 methods: (1) 0-point adjustment, which occurred automatically every 24 h and (2) adjustment by a verified sample every 2 wk. Measurements of PM_{10} were verified once in every quarter of the year. All instruments were regularly calibrated, and the data gathered were stored on a personal computer. From the 10 s measurements, 1 min averages were derived; then, from the latter data, 30 min averages were calculated.

2.7.2. Biological pollutants and types of instruments

Special emphasis was placed on the ragweed *Ambrosia* as a biological air pollutant, since its pollen counts well exceed those of other types of pollen (Makra et al. 2004, 2005, Béres et al. 2005). According to the annual totals of pollen counts of different plants measured between 1990 and 1996 in southern Hungary, ragweed produces about half of the total pollen production (47.3%). Furthermore, the short (or common) ragweed, *Ambrosia artemisiifolia* = *Ambrosia elatior* has the most aggressive pollen of all. Clinical investigations have proven that its allergenic pollen is the main source of the most massive, most serious and most long-lasting pollinosis (Járai-Komlódi 1998). Other relevant genera with pollination periods overlapping that of ragweed were also considered. These were mugwort (*Artemisia*), hemp (*Cannabis*), goosefoot (*Chenopodium*), plantain (*Plantago*), grasses (*Poaceae*), dock (*Rumex*) and nettle (*Urtica*) (Fig. 2).

In Szeged, the pollen content in the air has been measured since 1989 using a 7 d Hirst-type volumetric pollen trap (Hirst 1952) (Lanzoni VPS 2000). The air sampler is located on top of the building of the Faculty of Arts, University of Szeged (20 m above the ground). The building is located in the downtown area, and is one of the highest in the city (Fig. 1).

Pollen sampling was performed as follows. A specific tape was made adhesive by washing with silicone oil. The sampler absorbed air at a rate of 13 l min^{-1} and was supplied with a timer to which a rotating drum was fitted. The drum moved the adhesive tape (2 mm h^{-1}) to which pollen grains adhered. After a week's exposure, the tape was removed, then cut to a length corresponding to 24 h pollen sampling, covered with a gel mounting agent containing a stain (fuxin) and put onto a microscope slide. Samples were then examined

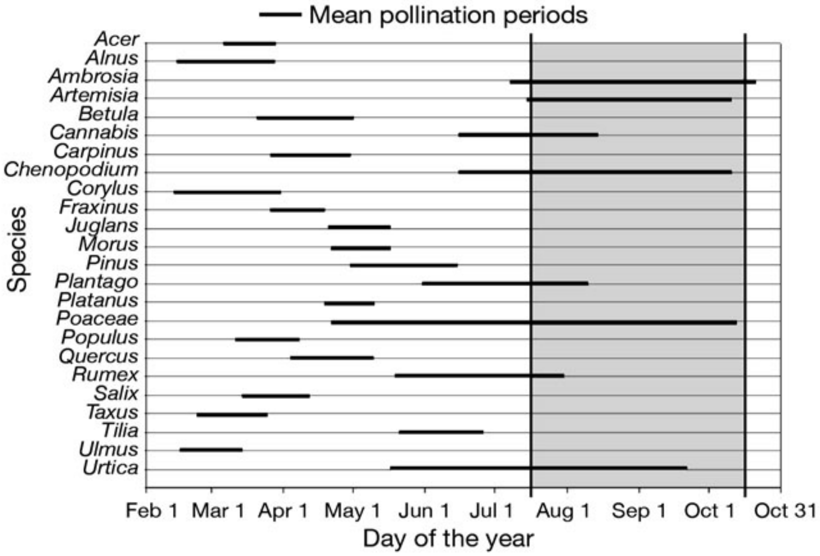

Fig. 2. Mean pollination periods of plant genera in Szeged, with special attention to those of ragweed (*Ambrosia*), mugwort (*Artemisia*), hemp (*Cannabis*), goosefoot (*Chenopodium*), plantain (*Plantago*), grasses (*Poaceae*), dock (*Rumex*) and nettle (*Urtica*). Shaded area: 1999 to 2003, summer to early autumn period (July 15 to October 15)

under a light microscope at a magnification of ×400, to determine pollen type and counts. Five horizontal sweeps were analysed on each slide. Horizontal sweeps were used because the variation in the concentration during the day can be observed along this axis (the direction of the tape shifts in the sampler). The accuracy of the measurement was proportional to the number of sweeps and the concentration of particles. Counting was done using a standard sampling procedure. Pollen concentrations were expressed as number of pollen grains m^{-3} of air (Käpylä & Penttinen 1981, Peternel et al. 2006).

2.8. Characteristics of the respiratory diseases

The daily number of patients registered with asthma and rhinitis for the period examined came from the Thorax Surgery Hospital, Csongrád County, Deszk, southern Hungary. Altogether, 9 symptom groups of respiratory diseases and their cumulative occurrences, indicated with their ICD codes, were taken into account (Table 1).

ICD is the abbreviation of the WHO International Statistical Classification of Diseases and Related Health Problems. Use of this classification system has been compulsory in the Hungarian Public Health sector since January 1, 1993 when the 9/1993 NM order of the Ministry of Health came into effect. Until the end of 1998, diseases were categorized using the 9th revision of the International Classification of Diseases (ICD-9) (WHO 1977); the 10th revision (ICD-10) was implemented in 1999 (WHO 1999).

In the summer to early autumn period, for the whole five-year term, a total of 26 703 patients were registered with respiratory diseases, while in the winter months this number was 14 507 patients. Most of the patients registered live in Szeged or in the neighbouring villages. The medical part of the study was based on the ratio of the different respiratory diseases (Table 2) and basic statistical parameters of both the individual respiratory diseases (Table 3) and the totals across the 10 yr age intervals for men and women for the analysed periods (Table 4) and their 30 d subperiods.

The Thorax Surgery Hospital, Deszk, is situated about 10 km from the monitoring station in downtown Szeged, where the data for the meteorological variables and those of the chemical air pollutants originated. Most of the patients were treated as out-patients; only a fraction of them were registered as in-patients. To study the relationship of respiratory diseases to meteorological parameters and air pollutants, the registration dates of the patients were used.

2.9. ERA 40 database

Daily sea-level pressure fields measured at 00:00 UTC came from the ECMWF (European Centre for Medium-Range Weather Forecasts) Re-Analysis ERA 40 project. The investigated area is in the North Atlantic–

Table 1. Types and symptoms of respiratory diseases indicated with codes by the WHO International Statistical Classification of Diseases and Related Health Problems (ICD)

ICD code	Definition
J3000	Vasomotor rhinitis (= hay-fever; rhinitis = cold, vasomotor = related to increased release of histamine)
J3010	Allergic rhinitis from pollen (allergic hay-fever)
J3020	Other seasonal allergic rhinitis
J3030	Other allergic rhinitis
J3040	Allergic rhinitis without specification
J4500	Mainly allergic asthma (asthma extrinsic; it occurs under the influence of external factors)
J4510	Non-allergic asthma (intrinsic asthma; it occurs under the influence of internal factors; e.g. from some medicines)
J4580	Mixed asthma
J4590	Asthma without specification (the type of the asthma is not known, only the process)

Table 2. Ratios (%) of the types of respiratory diseases for the years 1999–2003 in Szeged/Deszk, Hungary by the time of the year and ICD codes (see Table 1)

	J3000	J3010	J3020	J3030	J3040	J4500	J4510	J4580	J4590
Summer to early autumn	0.0	29.6	1.2	9.1	2.6	41.2	12.7	1.9	1.6
Winter	0.0	8.0	0.6	5.3	1.7	53.5	24.5	3.5	2.9

Table 3. Hospital admissions with respiratory diseases for the years 1999–2003, in Szeged/Deszk, Hungary, by time of year and ICD codes (see Table 1)

ICD code	Summer–early autumn		Jul 15–Aug 14		Aug 15–Sep 14		Sep 15–Oct 15	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
J4500	2198.6	1.9	684.6	153.5	832.2	64.7	681.8	99.5
J4510	680.2	142.4	206.8	39.6	222.6	18.7	250.8	28.4
J4580	102.6	21.4	32.4	5.6	35.6	5.0	34.6	8.6
J4590	86.6	94.2	22.0	6.6	31.6	9.5	33.0	9.0
J3000	2.2	20.5	0.4	0.5	1.2	1.3	0.6	0.8
J3010	1582.6	291.2	522.0	16.5	803.6	10.7	257.0	37.6
J3020	63.0	76.3	22.8	8.0	28.8	12.0	11.4	7.2
J3030	486.8	16.5	151.6	39.1	225.2	42.8	110.0	19.3
J3040	138.0	23.9	37.4	5.7	63.8	14.8	36.8	7.6
ICD code	Winter		Dec		Jan		Feb	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
J4500	1552.4	216.4	498.8	68.3	559.8	80.6	493.8	74.6
J4510	710.4	42.7	225.6	10.6	259.4	23.3	225.4	18.1
J4580	100.8	19.8	30.4	10.6	40.6	4.6	29.8	5.6
J4590	83.6	27.7	29.8	10.1	29.4	9.5	24.4	9.8
J3000	0.6	1.3	0.2	0.4	0.0	0.0	0.4	0.8
J3010	231.6	25.3	72.4	11.7	75.8	15.0	83.4	16.0
J3020	17.6	10.3	2.8	1.7	7.0	4.4	7.8	4.5
J3030	154.6	24.4	47.8	16.1	52.2	6.5	54.6	10.0
J3040	49.8	12.4	13.8	5.1	19.4	10.0	16.6	3.6

Table 4. Hospital admissions with respiratory diseases (mean ± SD) for the years 1999–2003, in Szeged/Deszk, Hungary, by time of year, sex and age group (yr), over all ICD codes (see Table 1)

Age interval	Summer–early autumn	Jul 15–Aug 14	Aug 15–Sep 14	Sep 15–Oct 15	Winter	Dec	Jan	Feb
Men								
0–10	2.0 ± 1.0	0.4 ± 0.5	0.8 ± 0.8	0.8 ± 0.8	0.4 ± 0.5	0.0 ± 0.0	0.4 ± 0.5	0.0 ± 0.0
11–20	193.4 ± 23.7	44.8 ± 5.7	74.6 ± 11.2	74.0 ± 10.0	89.4 ± 21.5	27.6 ± 9.8	31.2 ± 8.3	30.6 ± 5.2
21–30	555.0 ± 15.4	167.6 ± 13.0	236.0 ± 22.8	151.4 ± 15.5	254.2 ± 17.7	79.4 ± 14.3	83.0 ± 15.2	91.8 ± 17.3
31–40	396.0 ± 36.2	131.8 ± 19.9	176.4 ± 6.8	87.8 ± 12.7	172.2 ± 22.8	61.4 ± 15.1	57.6 ± 8.3	53.2 ± 13.1
41–50	397.6 ± 15.1	125.4 ± 4.5	184.6 ± 15.7	87.6 ± 7.7	186.4 ± 5.6	55.2 ± 2.3	70.4 ± 4.0	60.8 ± 3.3
51–60	361.2 ± 57.9	116.6 ± 35.0	147.6 ± 6.3	97.0 ± 19.9	243.8 ± 46.4	77.2 ± 15.0	88.8 ± 15.7	77.8 ± 25.1
61–70	207.6 ± 15.0	64.0 ± 12.7	81.8 ± 11.2	61.8 ± 5.3	159.6 ± 22.6	55.2 ± 15.2	57.8 ± 7.6	46.8 ± 10.1
71–80	113.8 ± 27.6	36.0 ± 10.6	40.6 ± 8.5	37.2 ± 10.6	97.2 ± 19.6	35.4 ± 11.2	31.4 ± 8.7	30.4 ± 6.8
> 80	18.0 ± 9.2	4.6 ± 2.6	6.2 ± 4.0	7.2 ± 3.2	19.0 ± 8.5	6.8 ± 5.2	6.0 ± 1.4	6.2 ± 2.4
Women								
0–10	0.6 ± 0.5	0.6 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.8	0.0 ± 0.0	0.2 ± 0.4	0.2 ± 0.4
11–20	121.8 ± 17.8	36.4 ± 5.1	52.4 ± 11.2	33.0 ± 3.7	64.8 ± 14.1	19.6 ± 4.6	25.4 ± 7.1	19.8 ± 5.0
21–30	458.6 ± 17.3	155.2 ± 10.2	210.4 ± 27.1	93.0 ± 2.9	185.0 ± 16.4	65.8 ± 8.1	62.8 ± 6.5	56.4 ± 6.4
31–40	511.2 ± 15.9	173.4 ± 13.8	230.6 ± 22.0	107.2 ± 11.1	186.6 ± 21.6	55.8 ± 6.7	69.6 ± 10.7	61.2 ± 6.5
41–50	857.6 ± 39.9	274.4 ± 33.7	363.6 ± 30.5	219.6 ± 12.5	443.0 ± 40.1	137.6 ± 8.5	163.2 ± 14.5	142.2 ± 21.9
51–60	613.6 ± 102.0	183.6 ± 36.5	251.6 ± 30.2	178.4 ± 38.7	372.6 ± 68.4	118.2 ± 27.5	138.0 ± 28.1	116.4 ± 17.4
61–70	334.0 ± 31.7	101.6 ± 17.9	119.0 ± 8.2	113.4 ± 10.9	267.6 ± 36.8	80.6 ± 13.5	96.0 ± 15.0	91.0 ± 18.2
71–80	174.8 ± 40.9	57.0 ± 20.9	61.2 ± 6.7	56.6 ± 16.7	139.0 ± 41.8	40.4 ± 16.4	53.0 ± 17.7	45.6 ± 11.3
> 80	23.8 ± 9.5	6.6 ± 2.6	7.2 ± 3.1	10.0 ± 4.9	20.2 ± 3.4	5.6 ± 2.8	8.8 ± 4.2	5.8 ± 1.4

European region, between 30 and 70.5° N latitude and 30° W and 45° E longitude. The grid network was established with a density of 1.5° × 1.5°, which indicates $28 \times 51 = 1428$ grid points for the region.

ERA-40 data were available with a better resolution (1.125° × 1.125°). However, the resolution of 1.5° × 1.5° for the sea-level pressure field is sufficient to determine the large-scale weather situations that are characteristic of the North Atlantic–European region, i.e. macrosynoptic types should reflect large-scale (planetary or synoptic scale) processes, and the resolution we used was satisfactory for this aim. The finer resolution would not have provided significant additional information. On the other hand, if the major goal was to study smaller scale (sub-synoptic or meso-scale) processes for a smaller region, even this finer resolution would have been insufficient.

2.10. Data analyses

2.10.1. Lorenz curve

The Lorenz curve is a graphic representation of the cumulative distribution function of a probability distribution that shows the proportion of the distribution assumed by the bottom y% of the values (Lorenz 1905). Let us interpret the Lorenz curve of the cumulative number of admissions (i.e. the total number of patients, y, %) as the function of mean temperature (x) (see Fig. 3a). The total number of patients decreases if mean temperature is low, since on these days (first and second quintiles) the gradient of the Lorenz diagram is the lowest; furthermore, its gradient increases with increasing mean temperature (see Fig. 3a).

2.10.2. Gini coefficient

The Gini coefficient is a measure of statistical dispersion. It is defined as a ratio, with values between 0 and 1: the numerator is the area between the Lorenz curve of the distribution and the uniform distribution line; the denominator is the area under the uniform distribution line. Thus, taking the example in 2.10.1, the very low Gini coefficient of the mean temperature dependent cumulative number of admissions (see Fig. 3a) indicates near to equal distribution of the total number of patients (Gini 1921, Wessa 2008).

2.10.3. Definition of the weather types

Factor analysis was applied to the data set consisting of 13 columns (13 meteorological variables) and 450 rows (days) both for the summer to early autumn period and the winter period. Then, cluster analysis was applied to the factor-score time series of the retained factors (in our case to the 5-factor factor-score time series; see Section 4.2.1), in order to generate groups of days (namely, clusters) with homogeneous meteorological conditions.

Subsequently, for each cluster (weather type), the mean daily concentrations of the air pollutants, as well as disease parameters were estimated. In order to reveal the possible relationships to the prevailing weather conditions, the spatial distribution of the mean daily sea-level pressure fields and the mean daily concentrations of the air pollutants and disease parameters in the area of Szeged were calculated for the different weather types experienced in the North Atlantic–European region.

Finally, for each objective weather type, mean daily isobar maps on the basis of daily sea-level pressure data calculated for each grid point of the investigated region were constructed by applying the Surfer v.7.00 software. Isobars for an average day, i.e. for an average objective type, were drawn by using the standard kriging method (Makra et al. 2006a,b).

When determining the weather types, only meteorological parameters are taken into account, excluding pollution and disease data. Hence, the differences in the calculated means of the air pollutants and the disease data between the resultant weather types needed further statistical evaluation. This was performed by 1-way analysis of variance (ANOVA) for each pollutant and disease parameter with Tukey's honestly significant difference test applied in order to quantitatively compare the means of pollution and disease parameters between each pair of synoptic types (i.e. pairwise multiple comparisons) (Tukey 1985, McGregor & Bamzelis 1995, Sindosi et al. 2003).

All statistical computations were performed with SPSS v.15.0 software. According to the procedure the original data, but not the deviations from the expected value, were considered as input parameters.

3. RESULTS

3.1. Relationship with respiratory diseases

During the 5 yr term (1999 to 2003) analysed, the number of hospital admissions with respiratory conditions showed definite fluctuations. However, a 5 yr database may not be sufficient to detect clear trends. (Hereafter, the number of hospital admissions or the total number of patients denote the number of respiratory admissions and the total number of respiratory patients.)

A comparison of the patients' age and sex data in Csongrád County to those of Szeged[1] using the χ^2-test for homogeneity showed a significant difference in both patients' age and sex data. In a more detailed analysis of the patients' age and sex data for Szeged, 21 to 30 yr old men and 41 to 50 yr old women (Table 4) seemed to be the most sensitive to respiratory symptoms. On the other hand, young people (0 to 20 yr olds) were the least susceptible (Table 4). Hence, patients' age-groups are not uniformly sensitive to respiratory diseases. Information on the occupation structure of the patients was not available.

The values of the meteorological and pollution parameters were classified into 5 and 5 quintiles, respectively, so that the first quintile comprised the lowest 20 % of the ranked data for a given variable, while the fifth quintile comprised the highest 20 %. Then, the frequencies of the meteorological and pollution parameters were calculated in the given quintiles. In this way, contingency tables were prepared for each meteorological and pollution parameter for the summer to early autumn period and for the winter months. Pearson's χ^2-test was applied both to the contingency tables of the 13 meteorological and 9 pollution parameters in the summer to early autumn period and to those of the 13 meteorological and 8 pollution parameters in the winter months. Subsequently, the null hypothesis of independence was tested between the parameters' quintiles and the total number of patients. If the independence was true, it meant that the meteorological and pollution parameters did not influence the total number of patients, while, in the reverse case, a relationship was indicated between them. The reason for applying contingency tables instead of Pearson's correlation was that the distribution of the total number of patients was not normal. As a result of the χ^2-test, among the 13 meteorological variables in the summer to early autumn period, 4 variables (T_{mean}, T_{max}, T_{min}, RH) showed statistically significant relationships with the total number of patients (namely, independence was not fulfilled at the $p = 0.99$ significance level), while, in the winter months, no variables showed significance. In the winter months, mainly day-to-day change in the maximum temperature (ΔT_{max}) and the mean atmospheric pressure (P) influenced the total number of patients; however, this relationship was not significant in either case. On the basis of the χ^2-test, in the summer to early autumn period, 5 (PM_{10}, NO, NO_2, NO_2/NO, O_{3max}) of the 8 chemical air pollutants, as well as 1 (ragweed) of the 8 biological air pollutants, showed significant relationships with the total number of patients (probability of independence was >99 % but <95 %), while, in the winter months, only NO showed such a relationship (only at the 95 % significance level).

The relationships between the total number of patients and the meteorological and pollution parameters indicating significant connection are illustrated as Lorenz diagrams (Fig. 3) (Lorenz 1905, King 1912, Danielides et al. 2002). Only the Lorenz diagrams of those meteorological variables which, according to the χ^2-test, showed significant relationships with the total number of patients (T_{mean}, T_{max}, T_{min}, RH; summer to early autumn period; Fig. 3a) were analysed. The total number of patients decreased if mean temperature was low, since on these days (first and second quintiles), the gradient of the Lorenz diagram was the lowest; furthermore, its gradient increased with increasing mean temperature (Fig. 3a). T_{max} and T_{min} covary highly with T_{mean}; hence, low values of these parameters also decreased chances of illness (Fig. 3a). At the same time, respiratory diseases frequently occurred during times of low relative humidity (the gradient of the Lorenz diagram was highest in the first quintile) (Fig. 3a). In the winter months, there were no significant relationships between the total number of patients and the meteorological variables; hence, the Lorenz diagrams were not analysed in this case. Gini coefficients of the above relationships were low. Even the highest Gini coefficient between RH and the total number of patients, indicating the most unequal distribution, was very low (–0.0797) (Fig. 3a; Gini 1921, Wessa 2008).

With regards to the chemical and biological air pollutants, Lorenz diagrams of PM_{10}, NO, NO_2, NO_2/NO, O_{3max} and the pollen of the ragweed *Ambrosia* showed significant connection with the total number of patients in the summer to early autumn period (Fig. 3b). The total number of patients decreased if the concentrations of PM_{10}, NO, NO_2 and O_{3max} were low, and, in turn, it increased if they were high (Fig. 3b). In the case of NO_2/NO, the situation was a bit different: the total number of patients decreased with either low or high values of the ratio. A low ratio of NO_2/NO was basically determined by a low NO_2 level, while a high ratio of NO_2/NO was resolved by a low NO level (Fig. 3b). At the same time, it was shown that the total number of patients decreased with both low NO_2 concentrations and low NO levels (Fig. 3b). On the other hand, the total number of patients changed in parallel to the ragweed pollen levels: low (high) patient numbers are related to low (high) *Ambrosia* pollen levels (Fig. 3b). Values of the Gini coefficients were low. The highest Gini coefficient of all (0.1339) with the most unequal distribution belongs to the *Ambrosia*-dependent total patient numbers (Fig. 3b; Gini 1921, Wessa 2008). Since in the winter months a significant relationship

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[1] Statistical yearbooks of Hungary from 1999 to 2003, published in Hungarian by the Central Statistical Office, Budapest

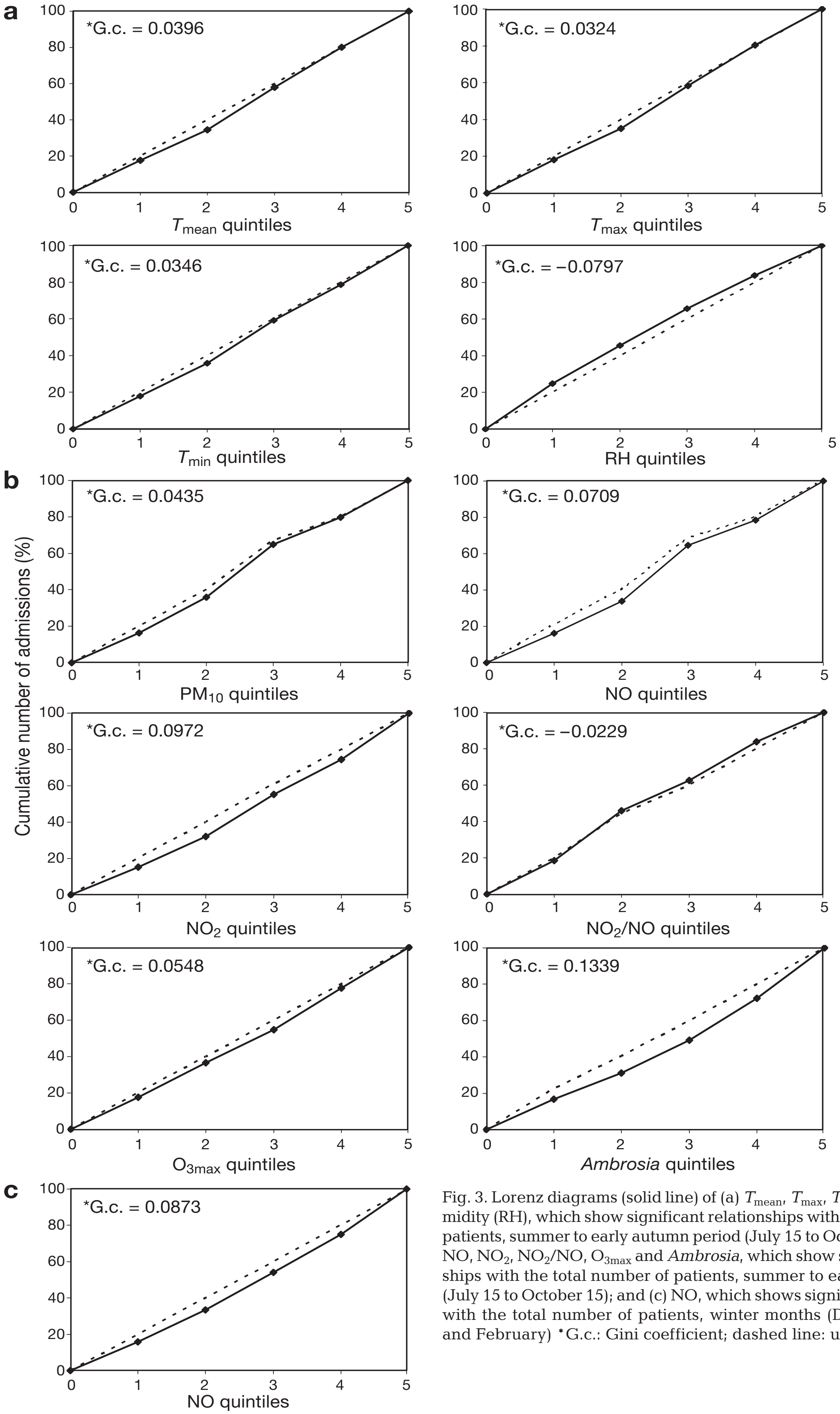


Fig. 3. Lorenz diagrams (solid line) of (a) T_{mean}, T_{max}, T_{min} and relative humidity (RH), which show significant relationships with the total number of patients, summer to early autumn period (July 15 to October 15); (b) PM_{10}, NO, NO_2, NO_2/NO, $O_{3\text{max}}$ and *Ambrosia*, which show significant relationships with the total number of patients, summer to early autumn period (July 15 to October 15); and (c) NO, which shows significant relationships with the total number of patients, winter months (December, January and February) *G.c.: Gini coefficient; dashed line: uniform distribution

was only detected between NO concentrations and the total number of patients, the Lorenz diagrams of only these 2 variables were analysed. In the winter months, similar to in the summer to early autumn period, the total number of patients was low (high) when NO levels were low (high) (Fig. 3c). This latter relationship has the second highest Gini coefficient (0.0873) (Fig. 3c; Gini 1921, Wessa 2008).

3.2. Weather types and the connection with pollution and pollen

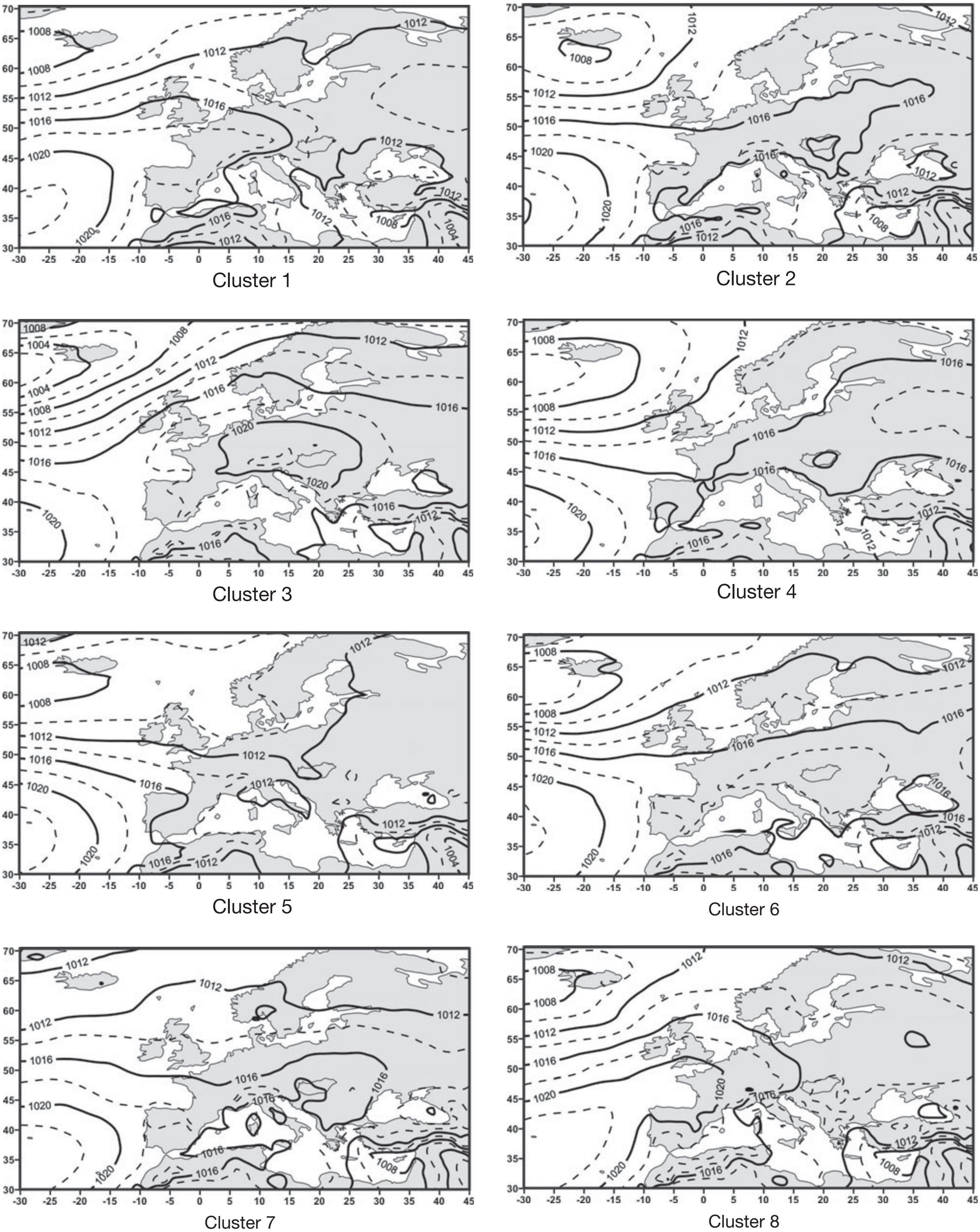
3.2.1. Summer to early autumn period (July 15 to October 15)

The application of factor analysis to the meteorological variables resulted in 5 factors, which explained 86.71% of the total variance. Then, cluster analysis was applied to the 5-factor factor-score time series (465 factor scores = 465 d) in order to classify them objectively into groups of days with characteristic weather types. Cluster analysis resulted in 8 weather types (clusters). Each cluster contained at least 5.6% of all the days examined. Throughout the summer, only 2 main pressure systems rule the weather of the Carpathian Basin: the Icelandic Low and the Azores High. The difference between these pressure systems is fairly small, both in terms of the mean values of the parameters examined and the spatial distribution of the atmospheric pressure. Subsequently, daily mean sea-level pressure fields of the 8 weather types (clusters) and 30 d frequencies of the days of types were determined. Mean sea-level pressure fields and occurrences of the 8 weather types are presented in Fig. 4, Table 5. Furthermore, mean values of meteorological and pollution parameters, as well as the patient numbers were calculated (Appendix 1, Table A1).

As a result of the previously described analysis (Section 4.1), after applying the χ^2-test, in the summer to early autumn period, 4 of the 13 meteorological variables (T_{mean}, $T_{\max}$, $T_{\min}$, RH) showed statistically significant relationships with the total number of patients. If some of the meteorological variables also indicated significant relationships with the patient numbers, we thought this might confirm a real statistical connection; namely, a physically interpretable relationship between weather types and patient numbers, too. Accordingly, the aim of using weather types to classify patient numbers was the possibility of simplifying the meteorological relationships of the total patient numbers with respiratory symptoms.

In order to decide whether the total number of patients depended on weather types on a statistical basis, Pearson's χ^2-test was applied. If the null hypothesis of independence was fulfilled, then patient numbers did not depend on weather types; while, in the opposite case, a relationship did exist between them. As a result, we determined that the probability of independence was 0; namely, patient numbers were closely related to weather types (Fig. 5, Table 6). The total number of patients was the highest during Weather Types 7 and 8. Both types were characterised by a weak anticyclonic ridge, with high temperature and low relative humidity parameters and occurred almost exclusively between July 15 and September 15 (Fig. 5, Table 6). The lowest values appeared during Type 2 (anticyclonic ridge character, occurrence between July 15 and August 15), with high temperature and low relative humidity. It should be noted that the pollen release of ragweed culminated only following this period, and this was an important fact in the low patient numbers associated with Type 2 (Fig. 5, Table 6).

According to the above argument, one might think that the weather types were not responsible for high respiratory morbidity, but only the pollen counts, with special emphasis on ragweed. However, this was not the case. Within the period examined in Szeged, daily pollen numbers of species fluctuated notably. This fluctuation can only be explained by daily changes in the meteorological variables. There have been many studies analysing the effect of meteorological parameters on the pollen concentration of various plants (e.g. Giner et al. 1999, Galán et al. 2000, 2001, Jato et al. 2000). According to them, the most important parameters were temperature, humidity and precipitation. The role of temperature was clear; it was in direct proportion with pollen concentration. On the other hand, the effect of humidity might be complex. According to Giner et al. (1999), nightly relative humidity in excess of 60% appeared to negatively influence the atmospheric pollen concentration during the day, but when relative humidity was >80% in the morning, pollen concentrations increased again. Another factor might be that, in the case of high relative humidity, pollen grains with an uneven surface may stick together easier. Hence, the sampler may trap more pollen grains (Makra et al. 2004). Also, it has been observed in Szeged that on the day following a rainy day (when relative humidity is higher), pollen concentration suddenly increases (Makra et al. 2004). Furthermore, pollen concentration depends on wind speed and wind direction (see Section 2.6). Anticyclonic weather situations with undisturbed sunshine and calm weather favoured the increase of pollen levels, due to the resuspension of high-atmosphere pollen that could have been released several hours earlier (Makra et al. 2004). According to the above, meteorological parameters, as variables of weather types, were closely related to pollen concentrations. Hence, in this case, we also



Cluster 1 Cluster 2

Cluster 3 Cluster 4

Cluster 5 Cluster 6

Cluster 7 Cluster 8

Fig. 4. Mean sea-level pressure fields of the 8 weather types determined, North Atlantic–European region, summer to early autumn period (July 15 to October 15)

Table 5. Occurrences of the 8 weather types (clusters), North-Atlantic–European region, summer–early autumn period (July 15–October 15)

Cluster	n (%)	No. of days for weather type (cluster) 15 Jul–14 Aug	15 Aug–14 Sep	15 Sep–15 Oct
1	15.27	37	34	30
2	11.61	36	17	1
3	11.83	7	14	34
4	18.28	25	20	40
5	16.56	24	25	28
6	8.39	1	12	26
7	12.47	23	32	3
8	5.59	13	11	2

aimed at using weather types to classify pollen levels to simplify their meteorological relationships.

In order to decide whether the mean sea-level pressure fields of the 8 weather types (clusters) determined for the North Atlantic–European region differ significantly from each other, a χ^2-test was applied with the assumption of independence (null hypothesis). As a result, mean sea-level pressure fields for half of the possible 28 cluster pairs can be considered independent. The null hypothesis of independence in each of the 3 relationships of Weather Types 2, 7 and 8 (2 vs. 7, 2 vs. 8 and 7 vs. 8) is 1, which means that these weather types can be considered independent of each other. With regards to their sea-level pressure fields, Type 2 is ruled by a developed Icelandic low-pressure system, while, at the same time, an Azores high-pressure centre pushes far over the East European Plains; Type 7 is characterised by a less-developed Azores High, while the Icelandic Low disappears; and finally, in Type 8, the Azores High passes further west compared to Type 7. Selecting the region of the Carpathian Basin, Types 2, 7 and 8 indicate an anticyclonic ridge character with decreasing strength (Fig. 4, Tables 5 & 6).

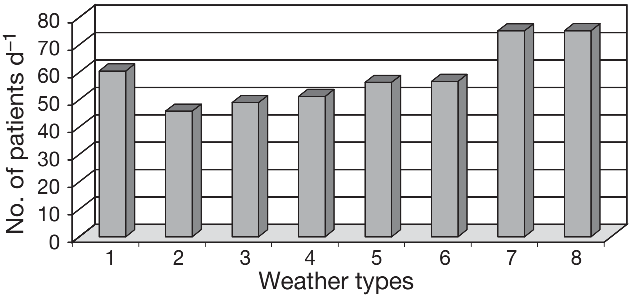


Fig. 5. Daily total number of patients in the individual weather types, summer to early autumn period (July 15 to October 15)

The significance of the differences of the calculated means for each pollutant and disease parameter between the resultant weather types was evaluated by ANOVA (Appendix 1, Table A2). Differences of means were found for CO, PM_{10}, NO, NO_2, O_3, O_{3max}, SO_2, ragweed (*Ambrosia*), mugwort (*Artemisia*), hemp (*Cannabis*), goosefoot (*Chenopodium*), plantain (*Plantago*), grasses (*Poaceae*), dock (*Rumex*) and nettle (*Urtica*), as well as for the average patient numbers for the following asthmatic and allergic diseases (with their ICD codes): allergic rhinitis from pollen (allergic hay-fever) (J3010), other seasonal allergic rhinitis (J3020) and other allergic rhinitis (J3030) (Table 1, see also Table A2). Furthermore, the average of the total number of patients and that of the 10 yr age categories of men and women patients between the weather types considered were significant at the 99% significance level (Table A2). Accordingly, we found a significant difference between group means. Then, in order to detect exactly between which means there was a significant difference, Tukey's HSD test was performed.

Performing pairwise ('between-clusters') comparisons of the parameter means (Tukey's HSD tests), significant differences were found at both the 95 and 99% significance levels. There were no 2 weather types for which the means of each variable differed significantly (Appendix 1, Table A3). Clusters (weather types) 7 and 2 differed most from the others (in decreasing order), since they showed significant differences in the great-

Table 6. Main characteristics of the 8 weather types (clusters) determined for the Szeged region, summer to early autumn period (July 15 to October 15)

Cluster	Main meteorological characteristics	Occurrences in the period examined
1	Low maximum temperature	Uniformly
2	High minimum temperature and absolute humidity	Mainly in the first two-thirds
3	Low mean temperature and high air pressure	Mainly in the last two-thirds
4	High relative humidity	Near uniformly, with peak in the last third
5	Low air pressure	Uniformly
6	Low mean temperature and absolute humidity	Mainly in the last two-thirds
7	High mean and maximum temperature, high temperature range and low relative humidity	Mainly in the first two-thirds
8	High absolute humidity	Mainly in the first two-thirds

est number of parameter means. On the other hand, Clusters 1 and 6 were the most similar to the others (in decreasing order), since they indicated significant pairwise differences in the least number of parameter means (Fig. 4, Tables 5, 6 & A2). The most specific clusters in separating parameter means from those of the other clusters were as follows: Cluster 1: in separating PM_{10}; Cluster 3: CO and NO; Clusters 2 and 7: O_3, O_{3max} and biological air pollutants except for *Ambrosia*; Cluster 8: O_3 and O_{3max}; Cluster 7: allergic diseases with their ICD codes, namely allergic rhinitis from pollen (allergic hay-fever) (J3010), other seasonal allergic rhinitis (J3020) and other allergic rhinitis (J3030). Cluster 7 was the most specific in separating averages of the total patient numbers and their classes according to 10 yr age groups both for men and women patients. Mean pollen numbers of *Ambrosia* differed significantly only between Clusters 2 and 3 (Fig. 4, Tables 5, 6 & A2).

The differences in the means of variables between weather types can mainly be attributed to synoptic factors. With regards to the sea-level pressure fields of the clusters (weather types), during Cluster 1, Hungary, lying between 2 high-pressure formations, was characterised by northerlies. Cluster 2 was ruled by a developed Icelandic low-pressure system and the Azores high-pressure centre pushed far over the East European Plains, indicating an anticyclonic ridge character for the Carpathian Basin. Cluster 3 indicated a developed high-pressure centre over the Carpathian Basin. Cluster 4 showed a weak high-pressure formation over Hungary. Cluster 5 indicated low pressure with cyclonic activity over the country. During Cluster 6, a weak high-pressure formation ruled the continent, except for Scandinavia and NW Russia. Weather Type 7 (cluster 7) was characterised by a less-developed Azores High, while the Icelandic Low disappears. Furthermore, in Type 8 (cluster 8), the Azores High passed further west compared to in Type 7. Over the Carpathian Basin Types 7 and 8 showed a weak anticyclonic ridge character (Fig. 4, Tables 5, 6, A2 & A3).

3.2.2. Winter months (December, January and February)

The application of factor analysis to the time series of meteorological variables resulted in 5 factors, which explained 85.39% of the total variance. Afterwards, cluster analysis was applied to the 5-factor factor-score time series, as a result of which 9 homogeneous clusters of the days were determined and their main characteristics were established. The clusters comprised at least 6% of the days examined. Since in the winter months the intertropical convergence zone (ITCZ) draws southward, Central Europe becomes the running field of the weather fronts. The ITCZ is an area of low pressure that forms where the Northeast Trade Winds meet the Southeast Trade Winds near the Earth's Equator. As these winds converge, moist air is forced upward. This causes water vapour to condense, as the air cools and rises, resulting in a band of heavy precipitation around the globe. This band moves seasonally, always being drawn toward the area of most intense solar heating, or warmest surface temperatures.

The dependence of the total number of patients from the weather types was calculated by using Pearson's χ^2-test. If the null hypothesis of independence is fulfilled, it means that the total number of patients does not depend on the weather types and, in the reverse case, there is a relationship between them. As a result, the probability of the null hypothesis of independence was very high: 0.7210. Hence, in the winter months, there was no relationship between the weather types and the patient numbers. Due to this, their relationship with the synoptic background and meteorological characteristics of the weather types in the winter months were not analysed in detail.

4. DISCUSSION

Asthma and rhinitis are common respiratory diseases both for children and adults. Asthma happens when the airways to the lungs get irritated. They then become tight and inflamed. This makes the area inside the airways narrower than it should be, making it harder to get air through. Rhinitis covers irritation and inflammation of some internal areas of the nose. The primary symptom of rhinitis is a runny nose. It is caused by chronic or acute inflammation of the mucous membrane of the nose due to viruses, bacteria, or irritants. The inflammation results in the generation of excessive amounts of mucus producing a runny nose, nasal congestion and post-nasal drip.

Meteorological factors, mostly temperature and humidity parameters, have been reported to affect the occurrence of respiratory diseases. However, chemical and biological air pollutants also influence the meteorological parameters, and their joint effect might exacerbate the symptoms.

It should be noted that the meteorological parameters (especially T_{mean}, T_{max}, T_{min} and RH in the summer to early autumn period, which show significant relationships with the total number of patients; Fig. 3a), as well as the air pollutants, are not independent. Dependent data provide more ambiguous estimates (higher standard deviations) than independent data, and this increase in standard deviations is determined by the degree of dependence. It is most straightforward to consider the dataset as one that originated from a Markov process and to follow the effect of the dependence in this way. In case of hypothesis testing, for example, neglecting dependence might in fact involve a causeless rejection of the null hypothesis, because for dependent data the acceptance interval of the null hypothesis is wider than for independent data.

Our motivation was to discover the most comprehensive system of relationships between the objective weather types and the means of the pollution and disease parameters. This was achieved by performing ANOVA and the Tukey test. With the application of the Tukey test, when performing pairwise comparison of the means of the pollution and disease parameters between 2 objective weather types, besides the so-called 'individual' effect of the 2 given weather types, the 'joint' effect of the rest of the objective weather types is also taken into account. On the other hand, the simple correlations include only the 'individual' effects of the 2 weather types considered. Because of this, typical correlation of the means of the pollution and disease parameters between 2 weather types gives false results, since it does not take into account the 'joint' effect of the rest of the objective weather types (Tukey 1985).

Cross reactivity of the pollen of different species may heighten the allergic reactions. This phenomenon, especially between ragweed *Ambrosia* and mugwort *Artemisia*, is experienced in southern Hungary. The mean pollination period of ragweed overlaps with that of mugwort (Fig. 2). The pollen of mugwort is another main agent of allergic reactions in late summer and autumn, not only in Hungary, but also in many countries of Europe, and it affects about 10 to 14 % of the patients suffering from pollinosis (Wopfner et al. 2005). Amb a 1 and Art v 1, the major allergens of ragweed and mugwort, respectively, are unrelated proteins. As described for other pollen, ragweed and mugwort pollen also contain the pan-allergen profilin and calcium-binding proteins, which are responsible for extensive cross-reactivity among pollen-sensitized patients (Hirschwehr et al. 1998, Wopfner et al. 2005).

Determination of pollen threshold levels that elicit an allergy response is a complex task, since allergy depends on the combined effects of several factors: the patient, the allergens, the timing, the duration of exposure and on the qualities of the environment. On the other hand, a higher pollen load acts somehow like a specific immunotherapy, so that higher pollen loads result also in higher thresholds in different areas. It was proven that the highest sensitization rates in children occur in countries with lowest pollen loads and vice versa (Thibaudon & Oliver 2007).

Although interesting results have been determined for children (Jaklin et al. 1971, Beer et al. 1991) and adult populations (Goldstein 1980) concerning the effects of meteorological parameters on respiratory diseases, the joint effects of meteorological parameters, chemical and biological air pollutants on the development of respiratory diseases have not yet been studied.

Kljakovic & Salmond (1998) found that, with regards to meteorological variables, asthma was most closely related to temperature and relative humidity. This conclusion coincides with our results, according to which respiratory diseases can be attributed to high temperature and low relative humidity parameters. Jaklin et al. (1971) showed that a continental air mass from the east (cold and dry in winter, hot and dry in summer) was associated with an increased incidence of croup. Effects of hot and dry weather (high temperature and low relative humidity) are in agreement with our results. Wang & Yousef (2007) found that asthma-related diseases were associated with aeroallergens and climatic factors and not air-quality factors. This statement differs from our conclusion, according to which air-quality factors also play an important role in the incidence of respiratory diseases.

McGregor et al. (1999) used a synoptic climatological approach to investigate linkages between air mass types (weather situations), the daily mean PM_{10} concentrations and all respiratory hospital admissions for the Birmingham area, UK. They showed distinct differential responses of respiratory admission rates to the 6 winter air mass types identified. Two of the 3 air masses associated with above average admission rates (continental anticyclonic gloom and continental anticyclonic fine and cold) also favour high PM_{10} levels. This association is suggestive of a possible linkage between weather, air quality and health. The remaining admissions-sensitive air mass type (cool moist maritime) does not favour high PM_{10} levels. This is considered to be indicative of a direct weather–health relationship (McGregor et al. 1999). Comparing our results with those of McGregor et al. (1999), we found that in the winter months there is no relationship between weather types and patient numbers. On the other hand, in the summer to early autumn period Weather Type 7, with a weak anticyclonic ridge character and with the highest patient numbers, is linked to high temperature parameters (T_{mean}, T_{max}, T_{min}), low relative humidity, as well as high chemical and biological pollutant levels (Table A1). At the same time, Type 2 (anticyclonic ridge character) indicates the lowest patient numbers (Table A1) and is characterised by high temperature and medium relative humidity parameters, in addition to high levels of the chemical and low levels of the biological air pollutants. Summing up, we found that both the highest and the lowest patient numbers occur during anticylonic ridge weather situations, during high temperatures. However, their differences in relative humidity and in levels of biological air pollutants lead to the significant difference in patient numbers.

5. CONCLUSIONS

The present paper analyses the relationships of daily values of meteorological parameters, chemical and biological air pollutants and the daily frequency values of respiratory diseases for Szeged, southern Hungary, during characteristic sea-level pressure systems. First, weather types were determined based on meteorological parameters; then, sea-level pressure fields were derived from these weather types. The weather types, defined for the summer to early autumn period, play an important role in separating daily air pollutant levels and daily frequency values of respiratory diseases; however, they are negligible in the winter months.

The meteorological and air pollutant parameters, their variation and covariation indicate their strong relationship to respiratory diseases. With regards to the meteorological parameters, in the summer to early autumn period 4 variables (T_{mean}, T_{max}, T_{min}, RH) show a statistically significant relationship with the total number of patients. Namely, the total number of respiratory diseases changes proportionally to the mean, maximum and minimum temperatures; on the other hand, hospital admissions occur more frequently during low relative humidity. At the same time, in the winter months there is no relationship between the meteorological variables and the total number of patients. In the summer to early autumn period, the total patient numbers decrease if PM_{10}, NO, NO_2 and O_{3max} concentrations are low, and they increase if they are high. On the other hand, the total number of patients decreases with either a low or high ratio of NO_2/NO. Ragweed *Ambrosia* pollen levels are the most sensitive of all the variables to the total number of patients, and their relationship is characterised by direct proportionality. In the winter months, similar to in the summer to early autumn period, low NO concentrations parallel a low total number of patients, while high NO concentrations parallel increases in the total number of patients.

In the summer to early autumn period, concentrations of the chemical and biological air pollutants, as well as the data on patient numbers are closely related to weather types. Types 1 (a weak anticyclonic ridge situation), 3 (a developed high pressure centre) and 7 (a weak anticyclonic ridge character) (in decreasing order) show the most significant differences in means of chemical air pollutants; Types 2 (anticyclonic ridge character) and 7 show the most significant differences in the means of biological air pollutants; Types 7 and 3, in the means of ICD codes of the respiratory diseases; and Type 7, in the means of both the total patient numbers and 10 yr age groups of respiratory diseases for men and women (Table A3). At the same time, the highest (and the only 3 above average) total patient numbers are observed inTypes 8 (a weak anticyclonic ridge character), 7 and 1 (in decreasing order) (Fig. 5, Tables A1 & A3). As a result, Type 7, with the highest number of patients (Table A1) is also the most important in occurrences of the total number of patients with respiratory diseases; specifically, allergic rhinitis from pollen (allergic hay-fever), other seasonal allergic rhinitis, other allergic rhinitis and allergic rhinitis without specification (indicated by their ICD codes of J3010, J3020, J3030 and J3040, respectively). Type 7 (a weak anticyclonic ridge character) with the highest number of patients is characterised by high temperature and low relative humidity parameters, as mentioned above, as well as by high mean concentrations of both the chemical and biological air pollutants. At the same time, Type 2 indicates the lowest patient number (Table A1), which is characterised by high temperature and medium relative humidity parameters, as well as high levels of chemical and low levels of biological air pollutants. On the other hand, in the winter months, there is no relationship between weather types and patient numbers.

The above results might serve as important information for illness preventive actions.

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LITERATURE CITED

Anderberg MR (1973) Cluster analysis for applications. Academic Press, New York

Avino P, De Lisio V, Grassi M, Lucchetta MC and others (2004) Influence of air pollution on chronic obstructive respiratory diseases: comparison between city (Rome) and hillcountry environments and climates. Ann Chim 94: 629–635

Beer SI, Kannai YI, Waron MJ (1991) Acute exacerbation of bronchial asthma in children associated with afternoon weather changes. Am Rev Respir Dis 144:31–35

Beggs PJ (2004) Impacts of climate change on aeroallergens: past and future. Clin Exp Allergy 34:1507–1513

Beggs PJ, Bambrick HJ (2005) Is the global rise of asthma an early impact of anthropogenic climate change? Environ Health Perspect 113:915–919

Béres I, Novák R, Hoffmanné Pathy Zs, Kazinczi G (2005) Az ürömlevelű parlagfű (*Ambrosia artemisiifolia* L.) elterjedése, morfológiája, biológiája, jelentősége és a védekezés lehetőségei. [Distribution, morphology, biology, importance and weed control of common ragweed (*Ambrosia artemisiifolia* L.)]. Gyomnövények Gyomirtás 6:1–48

Bucher K, Haase C (1993) Meteorotropy and medical-meteorological forecasts. Experientia 49:759–768

Canonica GW, Bousquet J, Mullol J, Scadding GK, Virchow JC (2007) A survey of the burden of allergic rhinitis in Europe. Allergy (CPH) 62[Suppl 85]:17–25

Danielides V, Nousia CS, Patrikakos G, Bartzokas A, Lolis CJ, Milionis HJ, Skevas A (2002) Effect of meteorological parameters on acute laryngitis in adults. Acta Otolaryngol 122:655–660

Epton MJ, Town GI, Ingham T, Wickens K, Fishwick D, Crane J (2007) The New Zealand asthma and allergy cohort study (NZA(2)CS): assembly, demographics and investigations. Art. No. 26, BMC Public Health, Vol 7, Biomed Central., London

Farkas I, Erdei E, Magyar D, Fehér Z (1998) Anti-ragweed campaign in Hungary in the frame of the National Health Action Programme. In: Spieksma FThM (ed) Ragweed in Europe. Satellite Symp Proc of the 6th Int Congr on Aerobiology. Alk-Abelló A/S, Horsholm, p 46

Fehér Z, Járai-Komlódi M (1997) An examination of the main characteristics of the pollen seasons in Budapest, Hungary (1991–1996). Grana 36:169–174

Freed AN (1995) Models and mechanisms of exercise-induced asthma. Eur Respir J 8:1770–1785

Galán C, Alcázar P, Cariñanos P, Garcia H, Domínguez-Vilches E (2000) Meteorological factors affecting daily *Urticaceae* pollen counts in southwest Spain. Int J Biometeorol 43:191–195

Galán C, Cariñanos P, Garcia-Mozo H, Alcázar P, Domínguez-Vilches E (2001) Model for forecasting *Olea europaea* L. airborne pollen in South-West Andalusia, Spain. Int J Biometeorol 45:59–63

Giner MM, Garcia JSC, Sellés JG (1999) Aerobiology of *Artemisia* airborne pollen in Murcia (SE Spain) and its relationship with weather variables: annual and intradiurnal variations for three different species. Wind vectors as a tool in determining pollen origin. Int J Biometeorol 43: 51–63

Gini C (1921) Measurement of inequality and incomes. Econ J 31:124–126

Goldstein JF (1980) Weather patterns and asthma epidemics in New York City and New Orleans. Int J Biometeorol 24: 329–339

Hair F, Anderson RE, Tatham RL, Black WC (1998) Multivariate data analysis, 5th edn. Prentice Hall, Engelwood Cliffs, NJ

Heinrich J, Topp R, Gehring U, Thefeld W (2005) Traffic at residential address, respiratory health, and atopy in adults: the National German Health Survey 1998. Environ Res 98:240–249

Hirschwehr R, Heppner C, Spitzauer S, Sperr WR and others (1998) Allergens, IgE, mediators, inflammatory mechanisms: identification of common allergenic structures in mugwort and ragweed pollen. J Allergy Clin Immunol 101: 196–206

Hirst JM (1952) An automatic volumetric spore trap. Ann Appl Biol 39:257–265

Jaklin RH, Bender SW, Becker F (1971) Environmental factors in croup syndrome. Z Kinderheilkd 111:85–94

Járai-Komlódi M (1998) Ragweed in Hungary. In: Spieksma FThM (ed) Ragweed in Europe. Satellite Symp Proc 6th Int Congr on Aerobiology. Alk-Abelló A/S, Horsholm, p 33–38

Jato MV, Rodríguez FJ, Seijo MC (2000) *Pinus* pollen in the atmosphere of Vigo and its relationship to meteorological factors. Int J Biometeorol 43:147–153

Jolliffe IT (1986) Principal component analysis. Springer-Verlag, New York

Käpylä M, Penttinen A (1981) An evaluation of the microscopial counting methods of the tape in Hirst-Burkard pollen and spore trap. Grana 20:131–141

King WI (1912) The elements of statistical method. MacMillan, New York

Kiss L, Béres I (2006) Anthropogenic factors behind the recent population expansion of common ragweed (*Ambrosia artemisiifolia* L.) in eastern Europe: Is there a correlation with political transitions? J Biogeogr 33:2156–2157

Kljakovic M, Salmond C (1998) A model of the relationship between consultation behaviour for asthma in a general practice and the weather. Clim Res 10:109–113

Kotaniemi JT, Pallasaho P, Sovijarvi ARA, Laitinen LA, Lundback B (2002) Respiratory symptoms and asthma in relation to cold climate, inhaled allergens, and irritants: a comparison between northern and southern Finland. J Asthma 39:649–658

Kurt E, Metintas S, Basyigit I, Bulut I and others (2007) Prevalence and risk factors of allergies in Turkey: results of a multicentric cross-sectional study in children. Pediatr Allergy Immunol 18:566–574

Lee YL, Shaw CK, Su HJ, Lai JS and others (2003) Climate, traffic-related air pollutants and allergic rhinitis prevalence in middle-school children in Taiwan. Eur Respir J 21:964–970

Lorenz MO (1905) Methods of measuring the concentration of wealth. Publications of the American Statistical Association 9: 209–219, doi:10.2307/2276207

Lundback B (1998) Epidemiology of rhinitis and asthma. Clin Exp Allergy 28[Suppl 2]:3–10

Luque C, Cisternas FA, Araya M (2006) Changes in the patterns of disease after the epidemiological transition in health in Chile, 1950–2003. Rev Med Chil 134:703–712

Makra L, Juhász M, Borsos E, Béczi R (2004) Meteorological variables connected with airborne ragweed pollen in southern Hungary. Int J Biometeorol 49:37–47

Makra L, Juhász M, Béczi R, Borsos E (2005) The history and impacts of airborne *Ambrosia* (Asteraceae) pollen in Hungary. Grana 44:57–64

Makra L, Juhász M, Mika J, Bartzokas A, Béczi R, Sümeghy Z (2006a) An objective classification system of air mass types for Szeged, Hungary with special attention to plant pollen levels. Int J Biometeorol 50:403–421

Makra L, Mika J, Bartzokas A, Béczi R, Borsos E, Sümeghy Z (2006b) An objective classification system of air mass types for Szeged, Hungary with special interest to air pollution levels. Meteorol Atmos Phys 92:115–137

Makra L, Juhász M, Mika J, Bartzokas A, Béczi R, Sümeghy Z (2007) Relationship between the Péczely's large-scale weather types and airborne pollen grain concentrations for Szeged, Hungary. Grana 46:43–56

McGregor GL, Bamzelis D (1995) Synoptic typing and its application to the investigation of weather air pollution relationship, Birmingham, United Kingdom. Theor Appl Climatol 51:223–236

McGregor GR, Walters S, Wordley J (1999) Daily hospital respiratory admissions and winter air mass types, Birmingham, UK. Int J Biometeorol 43:21–30

Mezei G, Járai-Komlódi M, Papp E, Cserháti E (1992) Late summer pollen and allergen spectrum in children with allergic rhinitis and asthma in Budapest. Pädiatr Pädol 27:75

Millqvist E (1999) Effect of nasal air temperature on lung function. Allergy 54[Suppl 57]:106–111

Moorman JE, Rudd RA, Johnson CA, King M and others (2007) National surveillance for asthma — United States, 1980–2004. Surveillance Summaries 56(SS08):1–14; 18–54

Nastos PT, Matzarakis A (2006) Weather impacts on respiratory infections in Athens, Greece. Int J Biometeorol 50: 358–369

Nastos PT, Paliatsos AG, Priftis KN, Kaldellis JK and others (2006) The effect of weather types on the frequency of childhood asthma admissions in Athens, Greece. Fresenius Environ Bull 15:936–942

Parsons JP, Mastronarde JG (2005) Exercise-induced bronchoconstriction in athletes. Chest 128:3966–3974

Peternel R, Culig J, Hrga I, Hercog P (2006) Airborne ragweed (*Ambrosia artemisiifolia* L.) pollen concentrations in Croatia, 2002–2004. Aerobiologia 22:161–168

Rimpela AH, Savonius B, Rimpela MK, Haahtela T (1995) Asthma and allergic rhinitis among Finnish adolescents in 1977–1991. Scand J Soc Med 23:60–65

Schlink U, Fritz GJ, Herbarth O, Richter M (2002) Longitudinal modelling of respiratory symptoms in children. Int J Biometeorol 47:35–48

Serda GJ, Navarro PC, Fernandez OA, Perez PM and others (2005) High prevalence of asthma symptoms in the Canary Islands: climatic influence? J Asthma 42:507–511

Sindosi OA, Katsoulis BD, Bartzokas A (2003) An objective definition of air mass types affecting Athens, Greece: the corresponding atmospheric pressure patterns and air pollution levels. Environ Technol 24:947–962

Strausz J (ed) (2003) Asthma bronchiale. Mediszter GlaxoSmithKline, Budapest

Thibaudon M, Oliver G (2007) Clinical and phenological data interest for the determination of the allergic risk. Allergy 62[Suppl 83]:81–81

Tukey JW (1985) The problem of multiple comparisons (1953) (unpublished manuscript). In: The collected works of John W. Tukey, Vol 2. Time series, 1965–1984. Wadsworth Advanced Books & Software, Monterey, CA

Wang HC, Yousef E (2007) Air quality and pediatric asthma-related emergencies. J Asthma 44:839–841

Watson L, Turk F, Rabe KF (2007) Burden of asthma in the hospital setting: an Australian analysis. Int J Clin Pract 61:1884–1888

Wessa P (2008) Free statistics software. Version 1.1.22-r4, Office for Research Development and Education, Antwerpen, available at: www.wessa.net/

Wopfner N, Gadermaier G, Egger M, Asero R, Ebner C, Jahn-Schmid B, Ferreira F (2005) The spectrum of allergens in ragweed and mugwort pollen. Int Arch Allergy Immunol 138:337–346

World Health Organization (1977) Manual of the international statistical classification of diseases, injuries, and causes of death, 9th revision. World Health Organization, Geneva

World Health Organization (1999) Manual of the international statistical classification of diseases, injuries, and causes of death, 10th revision. World Health Organization, Geneva

ZuWallack RL, MacNee W, Keenan JM (2004) Clinical management of chronic obstructive pulmonary disease. Professional Communications, Caddo, OK

Appendix 1. Statistical comparisons of the meteorological, pollution, health and patient parameters

Table A1. Mean values of the meteorological and pollution parameters, as well as the average total patient numbers of different respiratory diseases and those belonging to the 10 yr age groups both for men and women between the weather types (Clusters 1 to 8), summer to early autumn period (July 15 to October 15). **Bold**: maximum; *italic*: minimum

	Mean	1	2	3	4	5	6	7	8
Admissions									
Number of cases (d)	56.3	49	49	69	61	*31*	58	55	**78**
Frequency (%)	12.5	10.9	10.9	15.3	13.6	*6.9*	12.9	12.2	**17.3**
Weather									
T_{mean} (°C)	20.4	17.5	25.3	*17.0*	18.8	20.8	15.9	**25.9**	21.9
T_{max} (°C)	25.9	*21.5*	31.3	22.8	24.0	26.2	22.0	**32.7**	26.8
T_{min} (°C)	15.3	13.7	**19.6**	11.6	14.3	16.0	*10.0*	18.9	18.2
$T_{\mathrm{range}} = T_{\mathrm{max}} - T_{\mathrm{min}}$ (°C)	10.6	*7.8*	11.7	11.2	9.7	10.1	12.0	**13.8**	8.6
ΔT_{mean} (°C)	–0.4	–2.1	**1.3**	0.0	**1.3**	–0.4	0.1	0.9	*–4.3*
ΔT_{max} (°C)	–0.5	–2.7	**1.9**	0.3	1.5	–0.7	0.9	1.2	*–6.2*
ΔT_{min} (°C)	–0.3	*–2.1*	0.6	–0.3	**1.5**	0.2	–0.9	0.3	–1.6
RH (%)	67.7	75.9	63.8	68.2	**76.3**	73.4	62.5	*48.4*	73.1
ΔRH (%)	–1.0	–2.4	*–6.2*	0.6	0.0	**3.1**	–3.7	–2.6	2.9
P (hPa)	1005.8	1003.0	1008.2	**1014.7**	1005.0	*996.1*	1005.9	1004.9	1008.2
ΔP (hPa)	0.2	2.5	0.9	**2.6**	0.1	*–2.6*	–1.8	–1.6	1.1
VP (hPa)	16.7	15.6	**21.2**	13.6	17.1	18.7	*11.5*	16.6	19.5
ΔVP (hPa)	0.0	*–2.8*	–0.2	0.2	1.3	0.3	–0.6	0.1	**1.6**
Industrial pollutant									
CO (µg m^{-3})	88.5	112.3	**126.4**	*34.8*	56.5	112.3	66.7	116.3	82.8
PM_{10} (µg m^{-3})	9.2	8.6	**13.8**	5.1	*4.1*	7.2	5.5	18.1	10.8
NO (µg m^{-3})	2.3	1.7	4.5	1.1	0.8	0.7	*0.3*	**6.0**	3.5
NO_2 (µg m^{-3})	9.3	8.6	**12.9**	*5.2*	5.5	7.2	5.4	17.5	12.1
NO_2/NO	1.9	1.9	**3.8**	1.3	0.9	1.1	*0.2*	3.1	2.5
O_3 (µg m^{-3})	6.7	6.2	**10.1**	5.1	5.1	6.4	*3.5*	9.2	8.1
$O_{3\mathrm{max}}$ (µg m^{-3})	0.4	0.4	**0.9**	0.3	0.2	0.3	*0.0*	0.6	0.7
SO_2 (µg m^{-3})	12.6	13.7	**24.3**	7.3	7.0	9.5	*3.7*	20.1	15.1
Biological pollutant (pollen m^{-3} d^{-1})									
Ambrosia	501.0	*399.3*	506.6	**657.1**	481.2	459.9	466.2	569.6	467.9
Artemisia	43.1	*33.1*	45.0	46.2	42.8	42.3	44.9	**52.2**	38.0
Cannabis	14.1	8.8	9.7	**23.7**	14.7	12.3	20.5	14.8	*8.6*
Chenopodium	29.0	*22.6*	30.3	31.2	26.5	26.6	32.0	**37.2**	25.7
Plantago	5.2	6.2	**7.2**	3.1	5.8	5.3	*2.8*	5.6	5.4
Poaceae	51.4	44.0	65.6	45.9	*39.8*	45.6	40.6	**68.1**	61.8
Rumex	93.9	75.8	115.4	95.9	*74.7*	83.8	80.5	**121.5**	103.6
Urtica	5.5	4.5	*3.2*	**7.0**	6.4	5.2	6.9	6.7	3.6
ICD code									
J3000	*0.0*	*0.0*	*0.0*	**0.1**	*0.0*	**0.1**	*0.0*	*0.0*	*0.0*
J3010	17.4	17.7	14.7	*10.0*	14.4	18.1	15.3	**25.9**	23.0
J3020	0.7	0.7	*0.4*	*0.4*	0.6	1.0	0.5	**1.1**	0.7
J3030	5.5	5.2	*3.7*	4.6	4.1	4.6	5.5	**8.5**	7.8
J3040	1.5	1.5	1.5	*1.0*	1.5	1.4	1.1	1.9	**2.3**
J4500	24.3	25.5	*18.7*	23.1	21.3	22.3	24.8	27.9	**30.4**
J4510	7.4	8.2	*5.4*	7.5	7.4	7.2	7.4	7.3	**8.5**
J4580	1.1	*0.9*	*0.9*	1.2	1.1	1.2	1.2	**1.3**	1.2
J4590	1.0	0.9	0.7	1.1	0.9	*0.6*	1.1	1.2	**1.3**
Patient age and sex									
Patient number[a]	58.8	60.5	*45.9*	49.0	51.3	56.4	56.8	**75.2**	**75.2**
M00–10[b]	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
M11–20	*1.9*	**2.3**	1.2	2.1	2.0	2.2	2.1	2.2	1.9
M21–30	6.0	5.9	*4.2*	4.8	5.2	6.4	6.3	**8.2**	7.0
M31–40	4.4	4.3	*3.3*	*3.3*	3.8	3.8	4.2	**6.1**	**6.1**
M41–50	4.4	4.2	3.6	**3.1**	3.5	4.4	4.7	**5.7**	5.6
M51–60	4.0	3.9	*2.7*	3.4	3.1	3.7	4.1	5.5	**5.7**
M61–70	2.2	2.5	*1.7*	1.8	2.1	2.0	2.4	2.6	**2.8**
M71–80	1.2	*1.1*	*1.1*	1.2	*1.1*	*1.1*	1.3	1.2	**1.7**
M81–99	0.2	*0.1*	*0.1*	0.2	0.2	*0.1*	0.2	*0.1*	**0.3**
W00–10[c]	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
W11–20	1.3	1.3	*1.0*	1.1	1.2	1.4	1.1	**1.6**	1.3
W21–30	5.0	5.2	4.5	*3.5*	4.3	5.0	4.3	**6.6**	6.4
W31–40	5.5	6.1	5.0	*3.7*	4.7	6.1	4.6	**7.1**	6.6
W41–50	9.4	9.7	*7.4*	7.7	8.4	8.9	8.6	12.1	**12.2**
W51–60	6.8	7.0	*5.1*	6.6	5.8	5.5	6.6	8.6	**9.2**
W61–70	3.7	3.9	*2.7*	3.6	3.2	3.3	4.0	4.0	**4.7**
W71–80	1.9	1.9	*1.5*	1.8	1.7	*1.5*	*1.5*	2.5	**2.6**
W81–99	0.2	0.2	*0.1*	**0.3**	0.2	0.2	*0.1*	0.2	**0.3**

[a] Total number of patients with respiratory diseases, indicated by ICD codes; [b] 10 yr age groups for men starting with Years 00–10; [c] 10 yr age groups for women starting with Years 00–10

Table A2. ANOVA statistics for comparing mean concentrations of chemical and biological air pollutants, as well as the average total patient numbers of different respiratory diseases and those belonging to the 10 yr age groups both for men and women between the weather types (clusters), summer to early autumn period (July 15 to October 15)

	Mean square between groups	Mean square within groups	*F*	Level of significance (%)
Industrial pollutant				
CO	369 149.29	45 069.03	8.19	0.00
PM$_{10}$	1 915.48	200.82	9.54	0.00
NO	1 535.80	152.24	10.09	0.00
NO$_2$	1 239.43	179.51	6.90	0.00
NO$_2$/NO	110.35	88.79	1.24	27.76
O$_3$	7 587.58	333.89	22.73	0.00
O$_{3max}$	19 801.71	655.21	30.22	0.00
SO$_2$	114.02	13.67	8.34	0.00
Biological pollutant				
Ambrosia	67 216.45	21 465.64	3.13	0.31
Artemisia	1 382.86	130.77	10.57	0.00
Cannabis	250.65	15.87	15.75	0.00
Chenopodium	1 131.45	74.26	15.23	0.00
Plantago	81.24	9.94	8.17	0.00
Poaceae	259.56	38.42	6.75	0.00
Rumex	4.36	1.21	3.60	0.00
Urtica	2 702.90	310.64	8.70	0.00
ICD codes				
J4500	638.17	331.04	1.93	6.36
J4510	41.84	35.02	1.19	30.41
J4580	1.27	1.90	0.67	69.88
J4590	3.33	1.50	2.22	3.16
J3000	0.03	0.03	1.20	29.98
J3010	1 330.36	305.43	4.36	0.01
J3020	4.40	1.29	3.42	0.14
J3030	157.19	27.95	5.62	0.00
J3040	7.00	2.79	2.50	1.56
Patient age and sex				
Patient number[a]	5 955.27	2 043.05	2.91	0.54
M00–10[b]	0.01	0.02	0.61	0.74
M11–20	6.15	4.57	1.34	0.22
M21–30	88.62	28.02	3.16	0.00
M31–40	60.28	16.81	3.58	0.00
M41–50	47.33	16.41	2.88	0.00
M51–60	54.23	12.33	4.39	0.00
M61–70	7.86	4.47	1.75	0.09
M71–80	1.29	2.03	0.63	0.72
M81–99	0.20	0.20	1.00	0.42
W00–10[c]	0.01	0.01	1.03	0.40
W11–20	2.40	2.41	0.99	0.43
W21–30	55.45	24.01	2.30	0.02
W31–40	71.90	27.10	2.65	0.01
W41–50	158.37	63.74	2.48	0.01
W51–60	97.91	33.23	2.94	0.00
W61–70	17.21	10.88	1.58	0.13
W71–80	8.66	3.55	2.43	0.01
W81–99	0.24	0.29	0.82	0.56

[a] Total number of patients with respiratory diseases, indicated by ICD codes

[b] 10 yr age groups for men starting with Years 00–10

[c] 10 yr age groups for women starting with Years 00–10

Table A3. Significant differences of the parameter means between the weather types (clusters) determined, according to Tukey's honestly significant difference test (normal-face: 95% of significance, **bold-face**: 99% of significance), summer to early autumn period (July 15 to October 15). Counts in the table cells indicate clusters, which represent significant differences of the parameter means between the clusters in cells and in headings

Parameter	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8
CO	**3 7**	**3**	**12 456 8**	**3**	**3**	**3**	**1**	**3**
PM$_{10}$	**234567**	**1**	**1**	**1 7**	**1 7**	**1**	**1 45 8**	**7**
NO	**3 6**	**3 6**	**12 45 78**	**3**	**3** 6	**12** 5 **8**	**3**	**3 6**
NO$_2$	**23** 6**7**	1	**1**	**7**	**7**	1	**1 45 8**	**7**
NO$_2$ vs. NO								
O$_3$	**2 78**	**1 3456**	**2 78**	**2 78**	**2 78**	**2 78**	**1 3456**	**1 3456**
O$_{3max}$	**23 78**	**1 3456**	**12 4 7**	**23 78**	**2 7**8	**2 78**	**1 3456**	**1 4**56
SO$_2$	**3**4 67	**34 67**	**12 8**	12 8		12 8	12 8	**3**4 67
Ambrosia		3	2					
Artemisia	**7**	**34**56	**2 7**	**2 7**	2 **7**	2 **7**	**1 3456**	
Cannabis	**2 7**	**1 3456**	**2 7**	**2 7**	**2 7**8	**2 7**8	**1 3456**	56
Chenopodium	**7**	**3456**	**2 7**8	**2 7**8	**2 7**	**2 7**8	**1 3456**	34 6
Plantago	**2**	**1 3456**	**2** 7	**2 7**	**2 7**	**2 7**	3**456**	
Poaceae	2	1 **3456**	**2** 7	**2 7**	2	**2 7**	34 **6**	
Rumex		**4 6**		**2**		**2**		
Urtica	2	1 **3456**	**2 7**	**2 7**	**2** 7	**2 7**	**34**56	
J4500								
J4510								
J4580								
J4590								
J3000								
J3010		7	**7**8	**7**			2**34**	3
J3020		7	5 **7**		3		2**3**	
J3030	**7**	**7**8	**7**	**7**8	**7**		**12345**	2 4
J3040			8					3
Patient number[a]		7	7	7			234	
M00–10[b]								
M11–20								
M21–30		**7**	7	7			**2**34	
M31–40		**7**	**7**	7	7		**23**45	
M41–50			7	7			34	
M51–60		**7**8	7	**7**8			**2**3**4**	2 4
M61–70								
M71–80								
M81–99								
W00–10[c]								
W11–20								
W21–30			7				3	
W31–40			7				3	
W41–50		7					2	
W51–60		7			7		2 5	
W61–70								
W71–80								
W81–99								

[a] Total number of patients with respiratory diseases, indicated by ICD codes; [b] 10 yr age groups for men starting with Years 00–10; [c] 10 yr age groups for women starting with Years 00–10

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