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PREFACE
IN HONOUR OF PROFESSOR ILONA BÁRÁNY-KEVEI ON THE OCCASION OF HER 70TH ANNIVERSARY


Professor Ilona Bárány-Kevei

The current issue of Acta Climatologica et Chorologica is dedicated to Professor Ilona Bárány-Kevei, the former editor-in-chief of this journal and head of the Department of Climatology and Landscape Ecology at the University of Szeged, on the occasion of her 70th birthday and her retirement.

Professor Ilona Bárány-Kevei was born on 23 September 1941 in Zsadány, Hungary. After finishing the Szegedi Kiss István Secondary School in Békés, she entered the József Attila University (now University of Szeged) in 1960 and obtained an MSc as a teacher of biology and geography in 1965. In the same year she was employed at the university as a trainee in economic geography until 1966 when she obtained the University Doctor degree. Between 1966 and 1970 she took up her career as a scientific researcher at the Department of Economic Geography and from 1970 until 1972 at the Department of Climatology. In 1972 she became assistant professor at the Department of Physical Geography, where she worked as lecturer from 1974 and senior lecturer from 1983 after obtained her PhD in 1982. In the period of 1983-95 she was vice-head, while between 1992 and 1993 delegated head of the same department. In 1995 she was appointed as head of the Department of Climatology and Landscape Ecology and got it until 2006. Her habilitation took place in 1996 in Szeged and she earned the Doctor of the Hungarian Academy of Sciences degree in 2003 therefore she became the first woman geographer ever receiving such a degree in Hungary. She took over as head of the Geo Departments in 1998 and held that position until 2003.

She has been continuously teaching at the University of Szeged for more than 40 years. She either leads or takes part in such main modules and courses like Soil Geography, Biogeography, Climate and Morphology, Landscape Ecology and Planning, Geomorphology, Environmental Protection as well as Karstecology on both graduate and postgraduate levels. She is also head of the 'Geoecology' PhD program in the Doctoral School of Geosciences. She presented lectures at summer schools, led field trips and field works, as well as took part in numerous international conferences.

The wide range of her research activities like investigations in the fields of karst morphology and ecology, geo- and landscape ecology, environmental changes and their impacts on karst surfaces, landscape protection as well as the utilization possibilities of such alternative energy resources as wind in Southeast Hungary has to be especially emphasized. Her scientific works include more than 170 studies, 4 books, several research reports and articles.

Additionally, several memberships of both Hungarian and international scientific committees and societies (e.g. member of the IGU Karst Commission, elected member of the geography committee at the Academy, head of Environmental Sciences committee of the Academy in Szeged, head of Hungarian Geography Society in Szeged etc.) prove her exceptional scientific activity.

As a recognition of her excellence in teaching and research she received the price 'For Excellent Work' in 1982, 'Pro Scientia' medal in 1989, 'Pro Geographia' in 1996, the 'Széchenyi István Fellowship' in 1999-2002, 'Master Teacher' in 2001, 'For Hungary with Science' and 'For Higher Education' medals in 2002. In respect of her merits in science and teaching, in 2004 she was awarded the 'Golden Cross of Distinction of the Hungarian Republic'. Recently she received 'Lóczy Lajos' medal in 2009 and 'Prinz Gyula' medal in 2010 for her activity in geography, as well as 'Klebersberg Kunó Award' in 2010 for her activity at the university.

We dedicate this anniversary not only to the appraisal of her scientific merits – it is to be hoped lots of others will do it several times anyway but also we would like to express our respect over the immense work she spent on the numerous Master and doctoral students and colleagues – their success also reflects credit on her, the supportive teacher, whose countenance provided hundreds of former students with degrees, research places and other relevant jobs. We all hope that her scientific-educational activity continues despite her retirement still for a long period of time.

Happy Birthday to Ilona Bárány-Kevei and God bless her on her 70th anniversary.

Her colleagues from the Department of Climatology
and Landscape Ecology, University of Szeged

LIST OF PUBLICATIONS OF ILONA BÁRÁNY-KEVEI

TEXTBOOKS

1. Keveiné Bárány I (1991) Biogeográfia. [Biogeography. (in Hungarian)] JATE Press, Szeged. 190 p
2. Keveiné Bárány I (1998) Talajföldrajz. [Soil geography. (in Hungarian)] Nemzeti Tankönyvkiadó, Budapest. 146 p
3. Keveiné Bárány I, Farsang A (1998) Terep- és laborvizsgálati módszerek a földrajzban. [Methods of field and laboratory analysis in geography. (in Hungarian)] JATE Press, Szeged. 122 p

BOOKS

1. Keveiné Bárány I (2009) A karsztok ökológiai rendszere. Szerkezet, müködés, környezeti hatások a rendszerben. [The geoecological system of karsts. Structure, function and environmental effects in the system. (in Hungarian)] Földrajzi Tanulmányok 4. JATEPress, Szeged. 121 p

BOOKCHAPTERS

1. Jakucs L, Bárány I (1984) Ecological factors playing part in karst denudation dynamism for different geographical zones. In: Godard A, Rapp A: Process et Mesure de l'Érosion. Éditions du CNRS, Paris. 387-393
2. Bárány-Kevei I (1992) Ecological regulation of karst development. In: New Perspectives in Hungarian Geography. Studies in Geography in Hungary, 27. Akadémiai Kiadó, Budapest. 77-80
3. Bárány-Kevei I (1992) Les facteurs dans la formation du karst. In: Salomon JN, Maire R: Karst et Évolutions Climatiques. Hommage a Jean Nicod. Press. Universitaires de Bordeaux. 51-61
4. Mezősi G, Kevei Fné, Géczi R (1996) A Duna-Tisza köze néhány táji értékének prognosztizálható változása. [Predictable changes of some landscape values in the Duna-Tisza Interfluve. (in Hungarian)] In: Szabó L (ed) A termőföld védelme. [The protection of soil. (in Hungarian)] Gödöllő. 34-48

5. Keveiné Bárány I (1997) Chapters II/6.7.8. and II/2. In: Mezősi G, Rakonczai J (eds) Geoökológiai térképezés elmélete és gyakorlata. [Theory and practice of geoecological mapping. (in Hungarian)] 57-74, 81-96

6. Keveiné Bárány I (1998) A karsztok ökológiai rendszere. [The geoecological system of karsts. (in Hungarian)] In: Mészáros R, Tóth J (eds) Földrajzi Kaleidoszkóp. [Geographic Kaleidoscope (in Hungarian)] Pécs. 316-330

7. Bárány-Kevei I, Mezősi G (1999) The relationships between soil chemistry and the heavy metal content of vegetation on karsts. In: Bárány-Kevei I, Gunn J (eds) Essays in the ecology and conservation of karst. 47-53

8. Keveiné Bárány I (1999) A karsztok hasznosítása és a fenntartható fejlődés. [Utilization and sustainable development of karsts. (in Hungarian)] In: Tóth J, Wilhelm Z (eds) Változó Környezetünk. [Our changing environment. (in Hungarian)] Pécs. 285-296

9. Bárány-Kevei I (2000) Ecological investigation on some Hungarian Karsts. In: Kertész Á, Schweitzer F (eds) Physico-Geographical Research in Hungary. 111-117

10. Keveiné Bárány I (2000) Karsztos tájváltozások. [Landscape changes of karsts. (in Hungarian)] In: Schweitzer F, Tiner T (eds) Tájkutatási irányzatok Magyarországon. [Landscape research trends in Hungary. (in Hungarian)] MTA Földrajztudományi Kutatóintézet, Budapest. 13-24

11. Keveiné Bárány I (2001) A szélenergia potenciál és a farmergazdaságok vízkészlete közötti kapcsolat a Dél-Alföldön. [Relationship between the wind energy potential and the water resources of farms in the Southern Plain. (in Hungarian)] In: Mika J (ed) A légköri erőforrások hasznosításának meteorológiai alapjai. [Meteorological bases of the utilisation of atmospherical resources. (in Hungarian)] 139-147

12. Keveiné Bárány I, Gulyás Á (2001) Zákányszék természeti adottságai. [The physical geographical characteristics of Zákányszék. (in Hungarian)] In: Dúró A (ed) Zákányszék földje és népe az ezredfordulón. [The land and population of Zákányszék at the millennium. (in Hungarian)] 13-33

13. Tar K, Keveiné Bárány I, Tóth P, Vágvölgyi S (2001) A szélenergia hasznosításának lehetőségei Magyarországon. [Potential of windenergy utilisation in Hungary. (in Hungarian)] In: Mika J (ed) A légköri erőforrások hasznosításának meteorológiai alapjai. [Meteorological bases of the utilisation of atmospherical resources. (in Hungarian)] 41-54

14. Keveiné Bárány I (2002) Környezeti hatások a karsztökológiai rendszerben. [Environmental effects in the karstecological system. (in Hungarian)] In: Mészáros R, Schweitzer F, Tóth J (eds) Jakucs László, a tudós, az ismeretterjesztő és a művész. [László Jakucs: the scientist, the teacher and the artist. (in Hungarian)] 139-150

15. Keveiné Bárány I (2002) Tájszerkezeti vizsgálatok a tájökológiában. [Landscape structural investigations in landscape ecology. (in Hungarian)] In: Abonyiné Palotás J, Becsei J, Kovács Cs (eds) A magyar társadalomföldrajzi kutatás gondolatvilága. [Thoughts and ideas from the world of Hungarian social geography. (in Hungarian)] Ipszilon Kiadó és Ped Szolg Kft. 85-94

16. Bárány-Kevei I (2003) Bauxite deposits in karst. In: Gunn J (ed) Encyclopedia of Caves and Karst Science. Fitzroy Dearborn, New York, London. 135-137

17. Keveiné Bárány I (2003) A karsztok és az ember. [Karsts and man. (in Hungarian)] In: Csorba P (ed) Környezetvédelmi mozaikok. [Mosaics of environmental protection. (in Hungarian)] 161-169

18. Kaszala R, Bárány-Kevei I (2004) Heavy metal content of soils in the karstic area of North Hungary. In: Calabrese EJ, Kostecki PT, Dragun J (eds) Contaminated Soils, Sediments and Water. Science in the Real World. Volume 9. Springer. 167-175

19. Bárány-Kevei I, Horváth A (2005) Geo Ecological Aspects of the Aggtelek Karst Area Hungary. Vegetation (Typical Assotiation and Habitats Type of Vegetation) International Karstatlas. Zeitschrit für Geomorphologie. Sheet 18

20. Keveiné Bárány I (2005) A talajok szerepe a környezeti hatások semlegesítésében a karsztokon. [The role of soils in buffering the environmental effects on karsts. (in Hungarian)] In: Dövényi Z, Schweitzer F (eds) A földrajz dimenziói. [The dimensions of geography. (in Hungarian)] MTA FKI, Budapest. 449-459

21. Bárány-Kevei I, Zseni A, Hoyk E, Kaszala R (2006) Investigations of heavy metal pollution in the karst regions of Hungary. In: Halasi-Kun GJ (ed) Pollution and water resources. Columbia Univ. 2004-2006. Sustainable development in Central Europe. 181-191

22. Keveiné Bárány I (2007) A karsztos táj károsításának és védelmének sajátosságai. [Specialities in the damages and protection of the karsts. (in Hungarian)] In: Kerényi A: Tájvédelem. [Landscape conservation. (in Hungarian)]. Pedellus Tankönyvkiadó, Debrecen. 149-153

23. Keveiné Bárány I, Simon T (2007) Gondolatok a kisüzemi szélerőgépek hazai hasznosításának kérdéseiről. [Ideas and problems of windmill utilization in Hungarian farms. (in Hungarian)] In: Tóth T, Bíróné Kircsi A (eds) Kedvező széllel Kunhegyestől Debrecenig. [With a favourable wind: from Kunhegyes to Debrecen. (in Hungarian)] Magyar Szélenergia Társaság, Debrecen. 163-171

24. Keveiné Bárány I (2008) A geodiverzitás és a tájak sokszínűsége. [Geo- and landscape diversity. (in Hungarian)] In: Csima P, Dublinszki-Boda B (eds) Tájökológiai kutatások. [Landscape research. (in Hungarian)] Budapesti Corvinus Egyetem, Budapest. 139-147

25. Keveiné Bárány I (2008) A klíma-talaj-növényzet rendszer vizsgálata környezetérzékeny talajokon. [Examination of the climate-soil-vegetation system on environmentally sensitive soils. (in Hungarian)] In: Csorba P, Fazekas I (eds) Tájkutatás-Tájökológia. [Landscape research – landscape ecology. (in Hungarian)] Meridián Alapítvány, Debrecen. 309-317

26. Keveiné Bárány I (2010) Tájhasználat változások hatása a karsztokon. [Effects of landscape utilization changes on karsts. (in Hungarian)] In: Kertész Á (ed) Tájökológiai kutatások. [Landscape research. (in Hungarian)] MTA FKI, Budapest. 125-131

27. Samu A, Bárány-Kevei I (2010) Water quality characterization and determination of the environmental stress on the karstic lakes in Aggtelek and Slovak karst. In: Barančoková M, Krajčí J, Kollár J, Belčáková I (eds) Landscape ecology - methods, applications and interdisciplinary approach. Institute of Landscape Ecology, Slovak Academy of Sciences, Bratislava. 471-487. ISBN 978-80-89325-16-0

28. Tanács E, Szmorad F, Bárány-Kevei I (2010) Patterns of tree species composition in Haragistya-Lófej forest reserve (Aggtelek karst, Hungary). In: Barančoková M, Krajčí J, Kollár J, Belčáková I (eds) Landscape ecology - methods, applications and interdisciplinary approach. Institute of Landscape Ecology, Slovak Academy of Sciences, Bratislava. 767-780. ISBN 978-80-89325-16-0

EDITING OF BOOKS AND JOURNALS

1. Bárány-Kevei I (ed) (1995) Environmental Effects on Karst Terrains. A homage to László Jakucs. Special Issue of Acta Geogr Univ Szegediensis. 213 p
2. Bárány-Kevei I (ed) (1997) Acta Climatol Univ Szegediensis 31/A. 50 p
3. Bárány-Kevei I (ed) (1997) Acta Climatol Univ Szegediensis 31/B Urban Climate Special Issue. 69 p
4. Bárány-Kevei I (ed) (1999) Acta Climatol Univ Szegediensis 32-33. 122 p
5. Bárány-Kevei I, Gunn J (eds) (1999) Essays in the Ecology and Conservation of karst. Special Issue of Acta Geogr Univ Szegediensis. 218 p
6. Bárány-Kevei I (ed) (2001) Acta Climatol Chorol Univ Szegediensis 34-35. 118 p
7. Bárány-Kevei I (ed) (2003) Acta Climatol Chorol Univ Szegediensis 36-37. 131 p
8. Bárány-Kevei I (ed) (2005) Acta Climatol Chorol Univ Szegediensis 38-39. 181 p

ARTICLES

1. Bárány I (1967) Der Einfluss des Niveauunterschiedes und der Exposition auf die Luftttemperatur in einer Doline im Bükk-Gebirge. Acta Climatol Univ Szegediensis 7:85-109

2. Bárány I, Vörös E, Wagner R (1970) The influence of wind conditions of the Hungarian Alföld on the geographical distribution of mills. Acta Climatol Univ Szegediensis 9:73-81

3. Kevei-Bárány I (1970) Climatic and edaphic demands of groundnut growing in Hungary. Acta Geogr Univ Szegediensis 10:95-113

4. Bárány I (1971): Contribution to the climatological study of rice-growing in the region of Szeged. Acta Climatol Univ Szegediensis 10:57-67

5. Bárány I, Boros J (1972) Temperature conditions in the microclimate of a rice crop. Acta Climatol Univ Szegediensis 11:47-67

6. Bárány I, Boros J (1973) Characteristics of the change of temperature in rice plots of various densities. Acta Geogr Univ Szegediensis 13:105-115

7. Boros J, Bárány I (1973) Data concerning maximum temperatures in variously fertilized rice crops. Acta Climatol Univ Szegediensis 12:61-74

8. Bárány I (1974) Connections of effects of exposure relations of slopes and different denudative microforms. Acta Geogr Univ Szegediensis 14:27-32

9. Bárány I (1974) Komplex hatások tükröződése a lepusztulási mikroformákban. [The reflection of complex effects on denudation microforms. (in Hungarian)] Földrajzi Értesítő 23(2):243-247

10. Boros J, Bárány I (1974) Contribution to the knowledge of atmospheric humidity conditions in rice crops subjected to various treatment. Acta Climatol Univ Szegediensis 13:41-50

11. Bárány I (1975) Die Rolle des Mikroklimas in den denudativen Prozessen der verschiedenen Expositionen der Dolinen Karst Process and Relevant Landform. Ljubljana. 19-25

12. Bárány I (1975) Role of soil temperature in control of denudative processes of different exposures in karstic regions. Acta Geogr Univ Szegediensis 15:35-44

13. Boros J, Bárány I (1975) Néhány adat egy bükki töbör keleti és nyugati lejtőjének felmelegedéséhez. [Some data on the warming of eastern and western slopes in a Bükk doline. (in Hungarian)] Időjárás 79(5):297-300

14. Bárány I, Kajdócsy K (1976) Some microclimatic characteristics of the thermal-household processes in soils of different exposures. Acta Geogr Univ Szegediensis 16:57-64

15. Jakucs L, Bárány I, Mezősi G (1977) A geomorfológia időszerű problémái. [Actual problems of geomorphology. (in Hungarian)] Földrajzi Közlemények 101(4):345-348

16. Bárány I, Mezősi G (1978) Adatok a karsztos dolinák talajökológiai viszonyaihoz. [Data for the soil ecological conditions in karst dolines. (in Hungarian)] Földrajzi Értesítő 27(1):65-73

17. Mezősi G, Bárány I, Tóth I (1978) Karstmorphometrische Untersuchungen im Gebirge Aggtelek (Nordungarn). Acta Geogr Univ Szegediensis 18:131-140

18. Bárány I, Mezősi G (1979) Further data concerning the morphogenetical evaluation of karst dolines in Bükk. Acta Geogr Univ Szegediensis 19:105-115

19. Bárány I (1980) Some data about the physical and chemical properties of the soil of karst dolines. Acta Geogr Univ Szegediensis 20:37-49

20. Bárány I (1982) Einige Fragen der morphogenetischen Systematisierung von Karst-Dolinen. Acta Geogr Univ Szegediensis 22:101-116

21. Jakucs L, Andó M, Bárány I, Fehér J, Mezősi G, Tóth I (1982) Geoscientific interpretation of material relating to the region between the Danube and the Tisza in Hungary, obtained by remote sensing from the landsat satellites. Acta Geogr Univ Szegediensis 22:3-101

22. Jakucs L, Andó M, Fehér J, Kevei Fné, Mezősi G, Tóth I (1982) A Duna-Tisza köze műholdas földtudományi kutatása. [Geoscientific research of Duna Tisza Interfluve using satellite imagery. (in Hungarian)] Alföldi Tanulmányok 6: 87-128

23. Bárány I (1983) Some data about the composition of flora in karst dolines. Acta Geogr Univ Szegediensis 23:179-187

24. Bárány I (1983) Über das Mikroklima von Karstdolinen. In: Obreska-Starklowa B (ed) Prace Geograficzne 57. Naukowe Universytetu Jagiellonskiego, Krakow. 193-197

25. Jakucs L, Keveiné Bárány I, Mezősi G (1983) A karsztkorrózió korszerű értelmezése. [Modern interpretation of karst corrosion. (in Hungarian)] Földrajzi Közlemények 107(3-4):207-217

26. Bárány I (1984) Einige neue Angaben zur Untersuchung der Böden von Karstdolinen. Acta Geogr Univ Szegediensis 24:105-113

27. Bárány I, Jakucs L (1984) Szempontok a karsztok felszíni formáinak rendszerezéséhez, különös tekintettel a dolinák típusaira. [Principles of the systematization of karstic surface formes, with special regard to doline types. (in Hungarian)] Földrajzi Értesítő 33(3):259-265

28. Bárány I (1985) Ökologische Untersuchung der Karstdolinen unter besonderer Berücksichtigung des Mikroklimas. Acta Geogr Univ Szegediensis 25:109-130

29. Keveiné Bárány I (1985) A karsztdolinák talajainak és növényzetének sajátosságai. [Characteristics of the soils and vegetation of karst dolines. (in Hungarian)] Földrajzi Értesítő 34(3):195-207

30. Bárány I (1986) Some data about the properties of the dissolving dolines of the Bükk Mountains. Acta Geogr Univ Szegediensis 26:53-62

31. Kevei I, Zámbó L (1986) Study of the relationship between bacteria activity in karstic soils and corrosion. Annales Universitatis Scientiarum Budapestinensis de Rolando Eötvös Nominatae 20-21:325-333

32. Keveiné Bárány I (1986) Karsztmorfológiai megfigyelések Mallorcán. [Karstmorphological observaitons on Mallorca. (in Hungarian)] Karszt és Barlang (2):133-138

33. Keveiné Bárány I (1986) Újabb adatok a karszdolinák képződéséhez. [Recent data on the formation of karst dolines. (in Hungarian)] A Nehézipari Műszaki Egyetem Közleményei 1/33(1-4):149-155

34. Hajnal K, Keveiné Bárány I (1987) Geomorfológiai és növényföldrajzi vizsgálatok Kiskunhalas környékén. [Geomorphplogical and vegetation-geographical investigations in the Kiskunhalas region. (in Hungarian)] MTA RKK, Békéscsaba. 269-290

35. Kevei-Bárány I (1987) Comparative karstic soil researches in the Bükk Mountain and on the Aggtelek Karst, Hungary. In: Kunaver J (ed) Karst and Man. University Press Ljubljana, Ljubljana. 221-230

36. Kevei-Bárány I (1987) Man's impact on karst areas of Hungary. In: Kunaver J (ed) Karst and Man. University Press Ljubljana, Ljubljana. 207-219

37. Kevei-Bárány I (1987) Tendencies to change in the compositions of the karstic soil and the vegetation in the dolines in the Hungarian Bükk Mountain. ENDINS 13:87-92

38. Kevei-Bárány I (1987) Vergleichende Karstbodenuntersuchungen im Gebirge Bükk und Karst von Aggtelek in Ungarn. Acta Geogr Univ Szegediensis 27:39-50

39. Keveiné Bárány I (1988) Talajföldrajzi vizsgálatok Szeged környékén. [Soil geographical investigations in the Szeged region. (in Hungarian)] Alföldi Tanulmányok 12:5-32

40. Kevei Fné (1990) A földrajzoktatás szerepe a helyes környezetgazdálkodási szemlélet kialakításában. [The role of geographical education in developing the right environmental management approach. (in Hungarian)] Környezetvédelmi Tanulmányok 10:69-74

41. Kevei-Bárány I (1990) Further investigations on karst soils in Hungary. Acta Geogr Univ Szegediensis 28:31-41

42. Kevei-Bárány I (1990) Recent processes in the development of the surface forms of the Hungarian karst. Studia Carsologica 2:49-64

43. Bárány-Kevei I, Mezősi G (1991) Further morphomterical data from some important Hungarian karst areas. Quaderni del Dipartimento di Geografia 13:137-142

44. Keveiné Bárány I (1991) A szélerő-hasznosítás éghajlati adottságai az Alföldön. [Climatic conditions of wind power utilisation in the Hungarian Plain. (in Hungarian)] Földrajzi Értesítő 40(3-4):355-369

45. Kevei-Bárány I (1991) The importance of the ecological investigation of the karst territories. Studia Carsologica 5:7-14

46. Bárány-Kevei I (1992) Karst soil as indicators of karst development in Hungarian karsts. Zeitschrift für Geomorphologie 85:101-110

47. Keveiné Bárány I (1992) Gondolatok a karsztfelszíni formák rendszerezéséhez, különös tekintettel a bükki dolinákra. [Ideas of the systematiziation of karst surface forms, with special regard to Bükk dolines. (in Hungarian)] In: Lénárt L (ed) A Bükk karsztja, vizei, barlangjai II. [Karst, karstwater, caves of Bükk Mts 2. (in Hungarian)] Miskolci Egyetem, Miskolc. 269-277

48. Keveiné Bárány I (1992) Karsztökologiai rendszer vizsgálata bükki dolinák példáján. [Investigation of the karstecological system on the example of some Bükk dolines. (in Hungarian)] In: Lénárt L (ed) A Bükk karsztja, vizei, barlangjai. [Karst, karstwater, caves of Bükk Mts. (in Hungarian)] Miskolci Egyetem, Miskolc. 25-37

49. Keveiné Bárány I (1992) The physical geography of the Bükk Mountains. Abstracta Botanica 16(2):75-86

50. Kevei Bárány I, Farsang A (1992) Distinction of doline types based on ecological and morphometric parameters. Jósvafő. 47-53

51. Keveiné Bárány I, Mezősi G (1992) A szélerózió és szélenergia regionális különbségei az Alföldön. [Regional differences of wind erosion and wind energy in the Hungarian Plain. (in Hungarian)] Alföldi Tanulmányok 14:7-14

52. Bárány-Kevei I (1993) A study of the karst-ecological system on the example of the Bükk dolines. Acta Geogr Univ Szegediensis 31:15-20

53. Bárány-Kevei I, Mezősi G (1993) New morphometrical parameters for explanation of karst development. Acta Geogr Univ Szegediensis 31:27-33

54. Keveiné Bárány I (1993) Az Alföld agroökoszisztémán kívüli területeinek flórája és faunája. [Flora and fauna of the regions outside the agroecosystems of the Hungarian Plain. (in Hungarian)] Alföldi Tanulmányok 15:31-62

55. Mezősi G, Bárány-Kevei I, Mucsi L, Balogh I (1993) First results of GIS based geoökological mapping. Acta Geogr Univ Szegediensis 31:71-82

56. Bárány-Kevei I (1995) Factors of the environmental system of karst. Acta Geogr Univ Szegediensis 34(Special issue. Hommage to Jakucs L):155-163

57. Bárány-Kevei I (1995) Karstökologische Untersuchungen in einigen ungarischen Karstgebieten. Mitteilungen der Österreichischen Gesellschaft 137:133-140

58. Bárány-Kevei I, Mezősi G (1995) Ecological caracteristics of doline types in Aggtelek Hills (North Hungary). Acta Geogr Univ Szegediensis 34(Special Issue. Hommage to Jakucs L):35-147

59. Bárány-Kevei I, Mucsi L (1995) Acidification and other karst soil processes in Hungary. Acta Carsologica 24:69-82

60. Bárány-Kevei I (1996) Ecological condition of Hungarian karsts. Acta Geogr Univ Szegediensis 35:89-99

61. Bárány-Kevei I (1996) Umweltprobleme im Boden- und Vegetationssystem von Ungarn. Tübinger Geographische Studien 116:127-134

62. Bárány-Kevei I, Barta K, Tamási Gy (1996) Plant ecological survey of the Kataréti Stream catchment. Acta Geogr Univ Szegediensis 35:51-65

63. Bárány-Kevei I, Horváth A (1996) Survey of the interaction between soil and vegetation in a karstecological system (at Aggtelek, Hungary). Acta Geogr Univ Szegediensis 35:81-87

64. Keveiné Bárány I (1996) Szeged környéki talajok. [Soils in the Szeged region. (in Hungarian)] In: Pál Á, Szónokyné Ancsin G (ed) Határon innen - határon túl. [Within and beyond the borders. (in Hungarian)] JATE TTK, Szeged. 94-97

65. Mezősi G, Kevei Fné (1996) A Duna-Tisza köz néhány táji értékének prognosztizálható változása. [Predicted landscape value changes in the Duna Tisza Interfluve. (in Hungarian)] In: Szabó L (ed) A termőföld védelme. [The protection of soil. (in Hungarian)] OMÉK, Gödöllő. 34-48

66. Mezősi G, Bárány-Kevei I, Géczi R (1996) The future ecological value of the Hungarian landscape. Acta Geogr Univ Szegediensis 35:21-43

67. Bárány-Kevei I (1997) Tectonic and geomorphic evolution of Bükk Mountains, North Hungary, with special regard to doline formation. Zeitschrift für Geomorph 110:107-114

68. Bárány-Kevei I (1998) Connection between morphology and ecological factors of karstdolines (Aggtelek hills, Hungary). Geografia Fisica e Dinamica Quaternaria 3(4):115-119

69. Bárány-Kevei I (1998) Geoecological system of karsts. Acta Carsologica 27(1):13-25

70. Bárány-Kevei I (1998) The geo-ecology of three Hungarian karsts. Cave and Karst Science 25(3):113-117

71. Gunn J, Keveiné Bárány I (1998) Nagy-Britannia karsztvidékei. [Karst areas of Great Britain. (in Hungarian)] Földrajzi Közlemények 122(1-2):43-58

72. Mezősi G, Kevei Fné (1998) The predicted ecological changes on the Great Hungarian Plains (Hungary). Rev Geomorph

73. Bárány-Kevei I. (1999) Impact of agricultural land use on some Hungarian Karst region International Journal of Speleology 28B(1/4): 89-98

74. Bárány-Kevei I (1999) Land Degradation on some Hungarian Karst. In: Coelho C (ed) Proceed of The Int Seminar on Land Degradation and Desertification. IGU, Aveiro. 77-83

75. Bárány-Kevei I (1999) Microclimate of Karstic Dolines. Acta Climatol Univ Szegediensis 32-33:19-27

76. Bárány-Kevei I, Mezősi G (1999) The relationships between soil chemistry and the heavy metal content of vegetation on karsts. In: Bárány-Kevei I, Gunn J (eds) Essays in the ecology and conservation of karst. Special Issue of Acta Geogr Univ Szegediensis. 47-53

77. Keveiné Bárány I, Hoyk E, Zseni A (1999) Karsztökológiai egyensúlymegbomlások néhány hazai karszterületen. [Losses of karstecological equilibrum in some Hungarian karst areas. (in Hungarian)] Karsztfejlődés 3:79-91

78. Bárány-Kevei I (2000) Daten zur karstökologischen Forschung im Aggtelek-Gebirge (NE-Ungarn). Mitteilungen des Verbandes der deutschen Höhlen- und Karstforscher e.V. München 46(1-2):8-11

79. Hoyk E, Keveiné Bárány I (2000) Tájökológiai szempontú vegetáció elemzés a nyugat-Mecseki Karszton. [Vegetation analysis with special regard to landscape ecological aspects. (in Hungarian)] Karsztfejlődés 5:47-55

80. Keveiné Bárány I (2000) Természetvédelem - a klíma-talaj-növényzet rendszerének változása és a karsztok. [Nature conservation – changes of the climate – soil – vegetation system and the karsts. (in Hungarian)] ÖKO 10(1-2):49-58

81. Keveiné Bárány I, Mucsi L, Tímár B (2000) A szegedi Fehér-tó állapotváltozásai. [Changes in the condition of Lake Fehér in Szeged. (in Hungarian)] In: Frsinyák S (ed) Az Alföld történeti földrajza. [Historical geography of the Great Hungarian Plain. (in Hungarian)] Nyíregyházi Főiskola, Nyíregyháza. 53-66

82. Zseni A, Keveiné Bárány I (2000) Nagy Britannia mészkőjárdái és a talaj hatása azok fejlődésére. [Limestone pavements in Great Britain and soil effects on their development. (in Hungarian)] Karsztfejlődés 5:181-194

83. Bárány-Kevei I, Botos Cs (2001) Landscape-ecological problems in Aggtelek National Park with special regard to sustainable silviculture. Ekológia 20(4):151-156

84. Bárány-Kevei I, Goldie H, Hoyk E, Zseni, A. (2001) Heavy metal content of some Hungarian and English karst soils. Acta Climatol Chorol Univ Szegediensis 34-35:81-92

85. Keveiné Bárány I (2001) A szélenergia potenciál és a farmergazdaságok vízszükséglete közötti kapcsolat a Dél – Alföldön. [Connection between the wind energy potential and the water needs of farms in the Southern Plain in Hungary. (in Hungarian)] MSZET kiadványai 1:45-52

86. Keveiné Bárány I, Zboray Z (2001) Karszttájak változásainak vizsgálata térinformatikai módszerekkel. [Investigation of the changes of karst landscapes with GIS methods. (in Hungarian)] Karsztfejlődés 6:45-59

87. Unger J, Sümeghy Z, Mucsi L, Pál V, Kevei-Bárány I (2001) Urban temperature excess as a function of urban parameters in Szeged, Part 1: Seasonal patterns. Acta Climatol Chorol Univ Szegediensis 34-35:5-14

88. Unger J, Bottyán Z, Gulyás Á, Kevei-Bárány I (2001) Urban temperature excess as a function of urban parameters in Szeged, Part 2: Statistical model equations. Acta Climatol Chorol Univ Szegediensis 34-35:15-21
89. Keveiné Bárány I (2002) Tájszerkezeti vizsgálatok a tájökológiában. [Landscape structure investigations in landscape ecology. (in Hungarian)] In: Abonyiné Palotás J, Becsei J, Kovács Cs (eds) A magyar társadalomföldrajzi kutatás gondolatvilága. [Thoughts and ideas from the world of Hungarian social geography. (in Hungarian)] Ipszilon kiadó, Szeged. 85-94
90. Keveiné Bárány I, Zseni A, Kaszala R (2002) A talaj és a növényzet nehézfém-tartalmának vizsgálata karsztos területen. [Investigation of the heavy metal content of the soil and the vegetation in a karst area. (in Hungarian)] Karsztfejlődés 7:297-315
91. Zboray Z, Keveiné Bárány I (2002) Tájökológiai vizsgálat karsztos mintaterületen műholdfelvételek és térinformatikai módszerek segítségével. [A landscape ecological investigation with the help of satellite imagery and GIS methods. (in Hungarian)] Karsztfejlődés 7:147-159
92. Bárány-Kevei I (2003) Bauxite deposits in karst. In: Gunn J (ed) Enciclopedia of Caves and Karst Science. Fitzroy Dearborn, New York, London. 135-137
93. Bárány-Kevei I (2003) Human impact on Hungarian karst terrains, with special regard to sylviculture. Acta Carsologica 32(2):175-187
94. Kaszala R, Bárány-Kevei I, Polyák-Földi K (2003) Heavy metal content of the vegetation on karstic soils. Acta Climatol Chorol Univ Szegediensis 36-37:57-62
95. Keveiné Bárány I (2003) Tájszerkezet és tájváltozás vizsgálatok karsztos mintaterületen. [Landscape structure and landscape change investigations in karst areas. (in Hungarian)] Tájökológiai Lapok 1(2):145-151
96. Keveiné Bárány I, Botos Cs, Bódis K (2003) Erdőoptimalizációs vizsgálatok az aggteleki karszton. [Forest optimisation studies in Aggtelek Karst. (in Hungarian)] Karsztfejlődés 8:253-261
97. Kürti L, Bárány-Kevei I (2003) Landscape evaluation on sodic land of pélyi at Hungary (Ecotope-forming value). Acta Climatol Chorol Univ Szegediensis 36-37:71-78.
98. Szőke E, Keveiné Bárány I (2003) Karsztvíz vizsgálatok az aggteleki karszton, különös tekintettel a nehézfémszennyezésre. [Karstwater analysis in Aggtelek Karst with special regard to heavy metal pollution. (in Hungarian)] Karsztfejlődés 8:173-185
99. Zseni A, Goldie H, Bárány-Kevei I (2003) Limestone pavement in Great Britain and the role of soil cover in their evolution. Acta Carsologica 32(1):57-67
100. Kaszala R, Bárány-Kevei I, Polyák K (2004) Further dates of heavy metal content on the soil and vegetation of Aggtelek Karst (Hungary). Acta Carsologica 33(2):169-179

101. Kaszala R, Keveiné Bárány I (2004) Növények nehézfémtartalmának vizsgálata a Béke-barlang vízgyűjtőjén. [Investigation of the heavy metal content of vegetation in the catchment area of Béke cave. (in Hungarian)] Karsztfejlődés 9:269-278

102. Keveiné Bárány I (2004) A karsztökológiai rendszer szerkezete és működése. [Structure and function of the karstecological system. (in Hungarian)] Karsztfejlődés 9:65-76

103. Keveiné Bárány I (2004) A makro- és mikroklíma hatása a karsztökológiai rendszer változásaira. [Effects of macro- and microclimate on the changes of the karstecological system. (in Hungarian)] In: Tar K (ed) Földtudományi Tanulmányok [Geoscience studies (in Hungarian)]. Kossuth Egyetemi Kiadó, Debrecen. 77-82

104. Keveiné Bárány I, Szebellédi T, Bíró Cs (2004) Tájváltozások a Kolon-tó környékén. [Landscape changes in the region of Lake Kolon. (in Hungarian)] Földtani Kutatás 41(3-4):35-40

105. Zboray Z, Keveiné Bárány I (2004) Domborzatértékelés a Bükk-fennsíkon légifelvételek felhasználásával. [Relief evaluation in the Bükk Plateau based on aerial imagery. (in Hungarian)] Karsztfejlődés 9:207-213

106. Bárány-Kevei I (2005) Genetic types, human impact and protection of Hungarian karsts. Acta Climatol Chorol Univ Szegediensis 38-39:17-23

107. Keveiné Bárány I (2005) A karsztok védelmének aktuális kérdései. [Current issues of karst protection. (in Hungarian)] Karsztfejlődés 10:337-342

108. Kürti L, Keveiné Bárány I (2005) Néhány Bükkaljai forrás és patak összehasonlító vízkémiai vizsgálata. [Comparative analysis of the water chemistry of some springs and water courses in the Bükk foothills. (in Hungarian)] Karsztfejlődés 10:77-90

109. Tanács E, Keveiné Bárány I (2005) A karsztökológiai adottságok és az erdő kapcsolatának vizsgálata az egyes fafajok termőhelyi preferenciái alapján, Aggteleki példán. [An investigation of the relationship between the karstecological conditions and the forest on the basis of the soil preferences of tree species. (in Hungarian)] Karsztfejlődés 10:343-359

110. Zboray Z, Bárány-Kevei I, Tanács E (2005) Defining the corrosion surface of dolines by means of digital elevation model. Acta Climatol Chorol Univ Szegediensis 38-39:157-162

111. Zboray Z, Keveiné Bárány I. (2005) a dolinák korróziós felszínének meghatározása digitális domborzatmodell alapján. [Defining the corrosion surface of dolines by means of a digital elevation model (in Hungarian)]. Karsztfejlődés 10:221-228

112. Deák JÁ, Keveiné Bárány I (2006) A talaj és növényzet kapcsolata, tájváltozás, antropogén veszélyeztetettség a Dorozsma-Majsai homokhát keleti részén. [Relationship of soil and vegetation, lanscape change, anthropogenic impact on the eastern part of the Dorozsma-Majsa sand ridge. (in Hungarian)] Tájökológiai Lapok 4(1):195-209

113. Deák JÁ, Bárány-Kevei I (2006) Landscape-ecological mapping in the surroundings of Szeged. Ekológia 25(1):26-37

114. Goldie H, Keveiné Bárány I (2006) Óidei mészkövek karrjai, a „mészkőjárdák" Angliában. [Karren of carbon-age limestone; limestone pavements in England. (in Hungarian)] Karszt és Barlang 3-9

115. Keveiné Bárány I (2006) Összehasonlító karsztökológiai vizsgálat három magyar karsztterületen. [The comparative karsecological investigation of three hungarian karst areas. (in Hungarian)] Karsztfejlődés 11:223-233

116. Tanács E, Keveiné-Bárány I (2006) Terepmodellből származtatott famagasság-térkép felhasználhatóságának vizsgálata karsztos területen. [A study on the usability of a stand height map derived from a digital surface model. (in Hungarian)] Tájökológiai Lapok 4(2):291-300

117. Bárány Kevei I (2007) Rules of climate, soil sand vegetation on development of karstsystem. In: Time in Karst. Short Scientific papers. Postojna, Slovenia. 1-4

118. Keveiné Bárány I (2007) Geodiverzitás a karsztokon. [Geodiversity of karsts. (in Hungarian)] Karsztfejlődés 12:215-223

119. Keveiné Bárány I (2007) Tájökológiai adottságok és tájhasznosítás Kiskunhalas környékén. [Landscape ecological chracteristics and land use in the surroundings of Kiskunhalas. (in Hungarian)] In: Szónoky Ancsin G, Pál V, Karancsi Z (eds) A határok kutatója [A researcher of boundaries. (in Hungarian)]. Magyarságkutató Tudományos Társaság, Szabadka. 145-157

120. Tanács E, Barta K, Jármi R, Kiss M, Samu A, Keveiné Bárány I (2007) A talajtulajdonságok és a faállomány kapcsolata a Haragistya-Lófej erdőrezervátum területén (Aggteleki Karszt). [A connection of soil characteristics and forest structure in Haragistya-Lófej forest reserve. (in Hungarian)] Karsztfejlődés 12:225-240

121. Tanács E, Samu A, Bárány-Kevei I (2007) Forest structure studies in Aggtelek National Park (Hungary). Acta Climatol Chorol Univ Szegediensis 40-41:123-133

122. Tanács E, Szmorad F, Bárány-Kevei I (2007) A review of the forest management history and present state of Haragistya karst plateau (Aggtelek Karst, Hungary). Acta Carsologica 36(3)441-451

123. Vámos T, Bárány-Kevei I (2007) Land use changes in Ópusztaszer. Acta Climatol Chorol Univ Szegediensis 40-41:163-167

124. Zboray Z, Keveiné Bárány I (2007) A felszínborítás hatásainak vizsgálata a Bükk-fennsíkon légi- és műholdfelvételek felhasználásával. [Investigation of the effects of land cover on the Bükk Plateau based on aerial and satellite imagery. (in Hungarian)] Karsztfejlődés 12:241-252

125. Zboray Z, Tanács E, Bárány-Kevei I (2007) The accuracy and possible uses of a stand height map derived from a digital surface model. ForestSat. 2007. Forest and Remote sensing: Method and Operational Tools. Montpellier, France. Session VHR Studies 1-5 http://forestsat07.teledetection.fr

126. Keveiné Bárány I (2008) A klíma-talaj-növényzet rendszer vizsgálata környezetérzékeny karsztokon. [Investigation of the climate-soil-vegetation system in environmental sensitive karsts. (in Hungarian)] In: Csorba P, Fazekas I (eds) Tájkutatás-tájökológia [Landscape research – landscape ecology (in Hungarian)] 309-317

127. Keveiné Bárány I (2008) Geodiverzitás és tájdiverzitás. [Geodiversity and landscape diversity. (in Hungarian)] Földrajzi Közlemények 132(4):431-439

128. Keveiné Bárány I (2008) Tájökológiai vizsgálatok a karsztokon. [Landscape ecological investigations on karsts (in Hungarian)] In: Szabó V, Orosz Z, Nagy R, Fazekas I (eds) IV. Magyar Földrajzi Konferencia. [4th Hungarian Geographical Conference. (in Hungarian)] Meridián Táj- és Környezetföldrajzi Alapítvány, Debrecen. 226-230

129. Samu A, Keveiné Bárány I (2008) A karsztos tavak története és állapotváltozásai az aggteleki és szlovák karsztokon. [History and condition changes of karst lakes in the Aggtelek and Slovak Karsts. (in Hungarian)] Karsztfejlődés 13:117-135

130. Barta K, Tanács E, Samu A, Keveiné Bárány I (2009) Hazai rendzinák megfeleltetése a WBR nemzetközi talajosztályozási rendszerben. [Correspondance of Hungarian rendzinas to the international soil classification system WRB. (in Hungarian)] Agrokémia és Talajtan 58(1):7-18

131. Kiss M, Deák JÁ, Bárány-Kevei I (2009) Complex landscape ecotone analysis on the borderline region of two landscapes in the South Great Plain (Hungary). Acta Climatol Chorol Univ Szegediensis 42-43:67-79

132. Samu A, Bárány-Kevei I (2009) Characterization and changes in the state of lakes int he field of Aggtelek and Slovak Karst. Acta Climatol Chorol Univ Szegediensis 42-43:121-131

133. Vámos T, Keveiné Bárány I (2009) Az élőhelyek és a talajvíz összefüggése a Pusztaszeri Tájvédelmi Körzetben. [The relationship between biotopes and groundwater in Pusztaszeri Nature Reserve area. (in Hungarian)] Tájökológiai Lapok 7(1):103-115

134. Dóka R, Aleksza R, Kőhalmi F, Keveiné Bárány I (2010) A tájváltozások és a társadalmi-gazdasági viszonyok alakulásának összefüggései a Duna-Tisza köze középső részén. [Connections between landscape changes and the evolution of social and economical circumstances in the middle area of the Duna-Tisza Interfluve. (in Hungarian)] In: Szilassi P, Henits L (eds) Földrajzi Tanulmányok 5. Tájváltozás értékelési módszerei a XXI. században. [Geographical studies 5. Evaluation methods of landscape changes in the 21st century. (in Hungarian)] JATEPress, Szeged. 227-259

135. Duray B, Keveiné Bárány I (2010) Tájdinamikai vizsgálatok-a tájhasználat-változás és regenerációs potenciál összefüggéseinek modellezése. [Landscape dynamic investigations - modelling the relationship of landuse changes and regeneration potential. (in Hungarian)] In: Unger J (ed) Geoszférák 2009. [Geospheres 2009. (in Hungarian)] GeoLitera, Szeged. 99-151

136. Keveiné Bárány I (2010) Gondolatok a Közép-európai tájökológiai kutatásokról. [Thoughts on Middle-European landscape ecological research. (in Hungarian)] In: Szilassi P, Henits L (eds) Földrajzi Tanulmányok 5. Tájváltozás értékelési módszerei a XXI. században. [Geographical studies 5. Evaluation methods of landscape changes in the 21st century. (in Hungarian)] JATEPress, Szeged. 135-142

137. Koltai G, Országh J, Tegzes Z, Bárány-Kevei I (2010) Comprehensive radon concentration measurements in caves located in the area of Mecsek mountains. Acta Carsologica 39(3):513-522

138. Koltai G, Országh J, Tegzes Z, Bárány-Kevei I (2010) Radon transport measurements in Mecsek Mountains. Karst Development 1(1):18-30

139. Samu A, Keveiné Bárány I (2010) Jelenlegi és múltbeli állapot a Gömör-Tornai-Karszt tavain a Papverme-tó példáján. [Recent and past states of the karst lakes in Gömör-Torna Karst on the example of Lake Papverme. (in Hungarian)] Tájökológiai Lapok 8(1):111-121

140. Samu A, Tanács E, Bárány-Kevei I (2010) A characterization of the lakes in the Aggtelek and Slovak Karst and changes in their state. Karst Development 1(1):31-40

141. Deák JÁ, Keveiné Bárány I (2011) Csongrád megye kistájainak élőhelymintázata és tájökológiai szempontú értékelése. [Habitat pattern and landscape ecological assessment of microregions in Csongrad County. (in Hungarian)] In: Unger J, Pál-Molnár E (eds) Geoszférák 2010. [Geospheres 2010. (in Hungarian)] GeoLitera, Szeged. 79 -128

142. Galbács G, Kevei-Bárány I, Szőke E, Jedlinszki N, Gornushkin IB, Galbács MZ (2011) A study of stalagmite samples from Baradla Cave (Hungary) by laser induced plasma spectrometry with aztomatic signal correction. Microchemical Journal (Accepted 14 June 2011)

BOOK REVIEWS

1. Kordos L (1984) Magyarország barlangjai. [Caves of Hungary. (in Hungarian)] Gondolat, Budapest. Földrajzi Értesítő
2. Zentay T, Vitális Gy (1987) Magyarország talajjavító ásványi nyersanyagai. [Soil improving mineral raw materials of Hungary. (in Hungarian)] MÁFI. Módszertani Közlemények 119 p. Hidrológiai Tájékoztató [Hungarian Hydrological Bulletin (in Hungarian)]
3. Ford D, Williams P (1989) Karst Geomorphology and Hydrology. UNWIN HYMAN, Boston, Sydney, Wellington. Földrajzi Közlemények
4. Zentay T (ed) (1989) A szélerózió elleni védekezés lehetőségeinek, módszereinek feltárása Csongrád Megye homokterületein. [Exploration of the prospects of protection against the wind erosion of sand areas in Csongrad County. (in Hungarian)] MTA Szegedi Akadémiai Bizottság, Szeged. 128 p
5. Hajagos J, Illés S (1993) Természetismeret a nyolcosztályos gimnázium I. osztálya számára. [Cognition of nature for the first class of secondary school. (in Hungarian)] Gyöngyös. 230 p
6. Hajagos J (1994) Földrajz a nyolcosztályos gimnázium IV. osztálya számára. [Geography for the fourth class of 8-class secondary school. (in Hungarian)] Gyöngyös. 285 p
7. Gábris Gy (ed) (1998) Regionális természetföldrajzi atlasz. Európa. [Regional physical geography atlas. Europe. (in Hungarian)] ELTE Eötvös Kiadó, Budapest. 74 p
8. Trunko L (1998) Geology of Hungary. Betraege zur regionalen Geologie der Erde. Band 23. 462 p. Zeitschrift für Geomorphology 42. Dezember
9. Gábris Gy (ed) (1999) Regionális természetföldrajzi atlasz. Tengerentúli világrészek 1999. [Regional physical geographical atlas. Overseas continents 1999. (in Hungarian)] ELTE Eötvös Kiadó, Budapest. 124 p
10. Trunkó L (2000) Ungarn – Bergland um Budapest, Balaton-Oberland, Südbakony. Sammlung geologischer Führer 91. 158 p. Zeitschrift für Geomorphologie 266-269
11. Veress M (2000) Covered Karst Evolution in the Northern Bakony Mountains, West - Hungary. Bakonyi Természettudományi Múzeum, Zirc. 167 p. Zeitschrift für Geomorphologie 2002/269-271
12. Jónás I, Kovács Lné, Vízvári Ané (2001) Földrajz 9. Természetföldrajzi Környezetünk (Geography 9. Physical geographical environment). Mozaik, Szeged. 200 p
13. Veres M (ed) (2002) Karsztfejlődés 4. 176 p. Zeitschrift für Geomorphologie 71-272
14. Veress M (2007) Magashegységi karrok. [Karren of high mountains. (in Hungarian)] 80

REPORTS

1. Jakucs L, Bárány I, Mezősi G (1977) Beszámoló a Nemzetközi Földrajzi Unió 3. kongresszusa szekcióinak, szimpóziumainak és módszertani szemináriumainak munkájáról (1. szekció: Geomorfológia, Paleográfia. Geomorfológiai eredmények) [Report on the work of the sections, symposiums and methodological seminars at the 3rd IGU congress; section 1: Geomorphology, Paleogeography. Results of geomorphology). (in Hungarian)] Földrajzi Közlemények 25(4):345-348
2. Keveiné Bárány I (1991) Beszámoló a Nemzetközi Földrajzi Unió /IGU/ „Környezeti változások a karsztterületeken" munkacsoportjának Olaszországban megtartott üléséről. [Report on the work meeting of the „Environmental change in karst areas" IGU Workgroup in Italy. (in Hungarian)] Karszt és Barlang 1-2:71-73
3. Keveiné Bárány I (1999) Beszámoló a Nemzetközi Földrajzi Unió (IGU) „Sustainable Development and Management on Karst Terrains" Bizottságának Magyarországon tartott „Nature Conservation and Sustainable Development on Karst Terrains" szimpoziumról [Report from the conference titled „Nature Conservation and Sustainable Development on Karst Terrains" of the „Sustainable Development and Management on Karst Terrains" IGU Commission, held in Hungary. (in Hungarian)] MKBT Tájékoztató Nov.-Dec. 6-7

APPRECIATION, OBITUARIES

1. Jakucs László 70 éves. [László Jakucs is 70 years old. (in Hungarian)] Földrajzi Közlemények 120(1)
2. Jakucs L (2002) UIS (Union Internationale Spéléologie) Bulletin 48(2):12

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CHANGES IN THE VEGETATION OF DOLINES IN AGGTELEK AND BÜKK MOUNTAINS

I BÁRÁNY-KEVEI

Department of Climatology and Landscape Ecology, University of Szeged, P.O.Box 653, 6701 Szeged, Hungary
E-mail: keveibar@earth.geo.u-szeged.hu

Summary: The paper deals with the changes of vegetation on karstic landforms, with special regard to doline vegetation. The role of vegetation is very important in the karstecosystem, due to reducing the amount of runoff on the surface, ensuring the balanced infiltration of water into the karst system and increasing the quantity of aggressive carbon-dioxide in the soil. Dolines are the main sites of intensive infiltration of water into the karsts. My study evaluates the changes of vegetation in the last 70 years and diagnoses the degradation of doline vegetation.

Key words: Karsts, vegetation, Bükk Mts., Aggtelek Karst (Hungary)

1. INTRODUCTION

In our days the sustainable management of karsts is an important issue. The karstic ecosystem should be protected in order for the coming generations to enjoy its beauty and for tourists to visit and help sustain national parks. Surface vegetation is an important element of this system; it decreases surface flow, balances the process of infiltration and increases the amount of aggressive CO_2 in the soil through the function of its roots.

Dolines, considered the most typical surface features of temperate-region karsts, are important monitoring points of infiltration. Therefore it does matter whether the natural vegetation of dolines protects the karst surface from fast surface flow or whether it filters the pollution of modern age.

My earlier research was directed at the analysis of asymmetric doline development and I tried to interpret the role of vegetation in this process. In the present study I analyse the vegetation of dolines on the basis of ecological parameters in order to provide information and help for conservation efforts.

2. STUDY AREA AND METHODS

Our field survey was carried out in the summer season on the Bükk Plateau. 1x1 m quadrates were applied for sampling. A species list was created for each site, also containing species cover (%) (based on the frequently used A-D scale in botany). For the analysis the ecological indices of Zólyomi (1966) were applied. We examined temperature (T), water balance (W), soil reaction (R) and N indication (the latter based on the work of

Jakucs (1961)) for species found in the dolines. The conservation value for each species was defined according to the categories of Simon (1997): E (edaphic), K (edaphic accompanying), V (protected), TZ (tolerant to disturbance) and Gy (weed).

3. DISCUSSION

At the FAO conference in Buenos Aires in 1972 a proposal of the triple function of the forest was accepted, initiated by Hungary; these are the economic, protection and recreation functions. Natural forest management means that besides continuous timber production a healthy and functioning ecosystem is preserved as well as biodiversity. Since Hungary is not very rich in forests, karst areas cannot be withdrawn from active management even though excessive production increases the risk of soil erosion in the case of typical karstic rendzina and brown forest soils. The presence of forest cover enhances the water balance by ensuring the slow and continuous infiltration of precipitation therefore it is highly important in the protection of karst water supplies.

Xerophilic scrub woodlands (*Orno-Cotinion*), dominated by *Quercus pubescens*, are characteristic communities of Hungarian karstlands. There are two major types, separated by the presence of two species: *Cotinus coggygria* in Transdanubia and *Cerasus mahaleb* in the Northern Mountain Range. Mixed karst forests appear on the southern slopes as xerophilic scrub woodlands while on the colder northern slopes as beech forests. The high-mountain type of East-European beech forests (*Fagion medio-europaeum*) covers the limestone surfaces above 700 m as in the Bükk Mts. whereas its middle-mountain type sometimes reaches down into the climatic zone of oak forests. In Aggtelek Mts sessile oak-hornbeam forests (*Quercetum petreae-cerris*), thermophilous oak forests (*Corno-Quercetum pubescenti-petreae*) and scrub woodlands (*Ceraso-Quercetum pubescentis*) can be found.

Due to their extensive forest cover, forest management is a basic economic activity in karstlands. In smaller patches, especially in the vicinity of settlements croplands represent a fully anthropogenic landscape while forest management, together with grazing and hay-making in grasslands are considered a more natural way of management.

Deforestation in the beginning of the last century was a typical phenomenon in our mountains and the new, often planted forests meant less diversity compared to the original species composition. The traces of soil erosion and the resulting appearance of bare rock surfaces are sometimes recognisable in Hungarian karsts but they are not characteristic.

3.1. The zonality of vegetation in Bükk Mountains

With the increasing height above sea level several zonal forest types can be distinguished in Hungarian karsts. The series can be best followed in Bükk Mts.

- Turkey oak-sessile oak forests can be found up to 450 m height above sea level – on southern slopes up to 700 m. Acidofrequent oak forests are also situated in this zone.
- Sessile oak-hornbeam forests can be found on practically any kind of bedrock at 400-600 m asl.
- At 600-700 m asl middle-mountain beech forests are situated mixed with other species, e.g. ash, hornbeam and sessile oak. Beech forests with wood melick (*Melica uniflora*)

indicate a dry environment; in the case of this type even a small change in the environment can lead to fast degradation.

- On the Bükk-plateau high-mountain beech forests are characteristic (Bükk even means beech tree). The deforestation occurring in the last century caused considerable degradation in these stands; in many cases they were replaced by red fescue (*Festuca rubra*) hay meadows or *Nardus* swards. At the bottom of the dolines the extreme heat fluctuation (summer night frosts) prevents the successful regeneration of beech.

The presence of azonal associations reflects the specific characteristics of the bedrock, the relief, the soil and the microclimate. Lots of relict and endemic species are related to these communities. One of the unique associations of karsts is the limestone beech forest with rocky grassland. Linden and service forests can be found on steep rocky slopes whereas linden and ash forests usually occupy south- and west-looking slopes. As their name shows linden scree forests are usually found on rock flows whereas mesic rocky forests, rich in *Acer pseudoplatanus,* are the typical community of ravines (Vojtkó 2002). Acidofrequent oak forests occupy warm and dry sites; timber production in their case often results in the ultimate destruction of the community. Rocky beech forests occur on northern slopes, while karstic scrub woodlands prefer hot surfaces with very shallow soil on the southern slopes. The latter usually appear in mosaic with slope steppes and rocky grasslands, of which the proportion is only about 0.8%. The typical associations of dolines in this region are alpine grasslands due to the specific microclimate characterising the surface depressions.

Because of their height above sea level, Bükk Mts. are mostly covered by mesophilic beech forests, mixed rocky forests and acidofrequent forests. The high-mountain type of Middle-European beech forests (*Fagion medio-europaeum*) can be found in the areas above 700 m asl, while the other type reaches down even into the zone of oak woodlands. Hungary's biggest consistent forest area can be found on the Bükk-plateau; 95% of the area of Bükk National Park (41.197 ha in all) is covered by forests.

3.2. The vegetation of dolines

Removing the forest cover of the dolines resulted in their reforestation being either very slow or even impossible; however some species of the original forest vegetation can still be found. After the deforestation juniper (*Juniperus communis*) appeared in the dry valleys and dolines forming secondary associations, indicating a loss of nutrients in the soil.

At the same time the uniformisation of the earlier species-rich doline vegetation occurred; this phenomenon was further intensified by farming, mostly grazing and hay-making. Taking into account the extreme temperature fluctuation characteristic of the dolines after the removal of the protecting forest cover, the decrease in species diversity seems logical. In earlier investigations we found the micro- and macroflora a very important factor in the ecosystem of dolines. The species structure of macroflora in the forests and dolines of the Bükk Mts. was examined by Bacsó and Zólyomi (1934). Analysing the relationship between microclimate and vegetation they showed that the vegetation of the highly varied karst surface reflects both soil and microclimate characteristics.

During their survey of the now entirely protected doline of the Nagymező they described a xerophilic *Festucetum sulcatae* community on the south-looking slope, whereas in the bottom they found *Nardus* swards (*Nardetum montanum festucetosum ovinae*). The following species were found in this association in the course of their investigations: mat grass (*Nardus Stricta* (TZ)), sulphur cinquefoil (*Potentilla recta* (K)), sheep's fescue

(*Festuca ovinae* (K)), yellow bedstraw (*Galium verum* (K)), sweet vernal grass (*Antoxanthum odoratum* (E)), marsh gentian (*Gentiana pneumonanthe* (V)), spring sedge (*Carex caryophyllea* (K)), devilsbit scabious, (*Succisa pratensis* (K)), common wood-rush (*Luzula multiflora* (K)), stemless carline thistle (*Carlina acaulis* (V)), catsfoot (*Antennaria dioica* (K)).

Further characteristic species included: common milkwort (*Polygala vulgaris* (K)), *Gentianella livonica* (V), frog orchid (*Coeloglossum viride* (V)), moonwort (*Botrychium lunaria* (V)), *Gentiana austriaca* (V). Jakucs (1961) also found alpine pasture grasslands, formed as a result of the inversion caused by the extreme microclimate of the doline.

In the two dolines at Kurtabérc and three at Nagymező where I carried out my surveys false oat-grass (*Arrhenatherum elatius* (TZ)) and mat grass (*Nardus stricta* (TZ)) showed the highest surface cover % values. Hedge bedstraw (*Galium mollugo* (K)) and greater knapweed (*Centaurea scabiosa* (K)) were also present with high cover values nearly everywhere except for the southern slope.

I found the following further species everywhere within the dolines: yellow bedstraw (*Galium verum* (K)), *Ranunculus polyanthemos* (TZ), tall oat-grass (*Arrhenatherum elatius* (TZ)), stemless carline thistle (*Carlina acaulis* (V)), strawberry (*Fragaria vesca* (K)) and purple-stem catstail (*Phleum phleoides* (K)).

In the bottom of the dolines the following species were frequent: common nettle (*Urtica dioica* (TZ)), self-heal (*Prunella vulgaris* (TZ)), Russian dock (*Rumex confertus* (TZ)), barren strawberry (*Waldsteinia geoides* (K)) and cocksfoot (*Dactylis glomerata* (TZ). These species are ecologically neutral, common elements of tall grass communities.

Species usually present with lower percentage cover: *Iris graminea*, yarrow (*Achillea millefolium* (TZ)), strawberry (*Fragaria vesca* (K)), *Ranunculus polyanthemos* (TZ), prostrate speedwell (*Veronica prostrata* (TZ)), common valerian (*Valeriana officinalis* (V)), bloody cranesbill (*Geranium sanguineum* (K)), hoary plantain (*Plantago media* (TZ)), squinancywort (*Asperula cynnanchica* (K)), dropwort (*Filipendula vulgaris* (K)), heath dog violet (*Viola canina* (K)), saw-wort (*Serratula tinctorica* (TZ)), Russian dock (*Rumex confertus* (TZ)), Cypress spurge (*Euphorbia cyparissias* (GY)), alpestrine clover (*Trifolium alpestre* (K)) and salad burnet (*Sanguisorba minor* (K)) – the latter two are not present on southern slopes.

In the 1930's 60% of the doline species were natural accompanying species, whereas nearly 7% were edaphic, 23% protected and 7% disturbance tolerant. According to my results, nearly 70 years later, only 36% of the doline species were natural accompanying species, 12% protected, 4% weed and 40% disturbance tolerant. Comparing the survey of Bacsó and Zólyomi (1934) with my own results the degradation tendency of the dolines' vegetation becomes evident.

The different elements of the dolines' vegetation were characterised with their conservation values according to the method of Simon (1997). It is clear that although protected species can still be found, nearly half of the plants still present are disturbance-tolerant and weed species indicating degradation (Fig. 1).

The species we found in the dolines were also characterised with the ecological indicators of Zólyomi (1966). Considering the temperature index, there is no significant difference. Slightly higher values occur on the northern side (the south-looking slope) of the doline indicating that this side is drier and warmer. This specialty affects the other ecological characteristics as well; there are no weeds on the southern slopes and most of the protected species occurred here as well. On the northern slopes the disturbance-tolerant species are present in high numbers (Fig. 2).

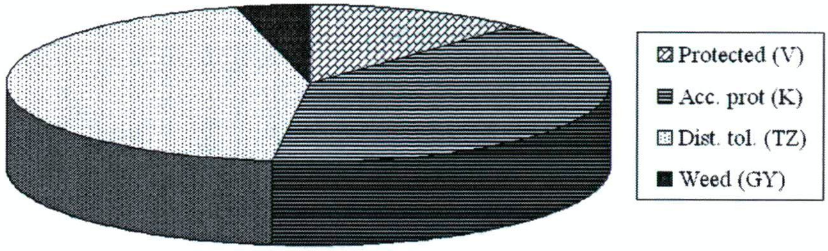

Fig. 1 Distribution of the species after the conservation values which are present everywhere in the dolines

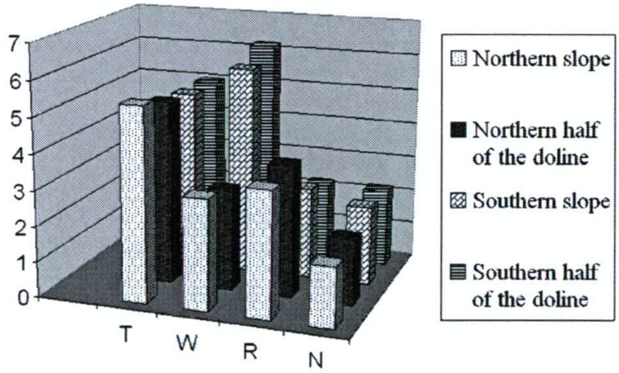

Fig. 2 Average values of ecological indicators in transect of northern and southern in the doline

There is less difference along the east-west transect. There are very few species which only grow on eastern slopes but there are several which occur on this side the most frequently. Considering the temperature index, the western slopes are less extreme than the eastern slopes. There is considerable difference in the distribution of water balance indices but it does not appear in the means (Fig. 3).

On the eastern slope the species of drier sub-mediterranean woodlands and warmer steppe climate appear. It is interesting that a few species requiring wetter conditions (*Aconitum, Colchicum*) also occur. Examining the eastern and western slopes from the conservation value's point of view, they give very similar distributions but the results come from very different species.

This draws our attention to the fact that in the east-western transect, which seems identical in many respects, species occur in very different ecological conditions because the daily distribution of radiation is significantly different on these two slopes (earlier temperature maximums on the western slope, later on the eastern). Another point of interest is the frequent appearance of the same species on the northern and western slopes.

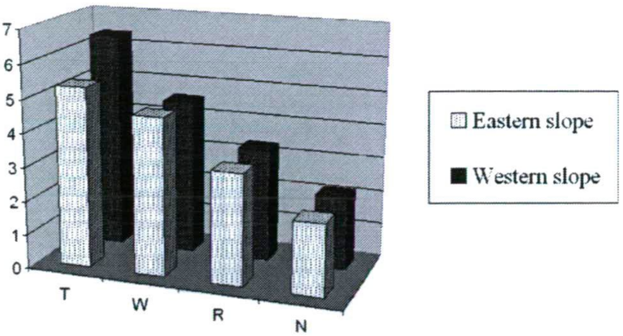

Fig. 3 Average values of ecological indicators on eastern and western slopes in the doline

4. CONCLUSION

An important objective of the survey was to investigate the changes of the dolines' vegetation over the last 70 years. Compared to the results from the 1930's the vegetation of the dolines in the Bükk Mts. shows the signs of degradation. We can also state that in the micro-environment of the open dolines (those without forest cover) the different slopes have different vegetation cover due to microclimatic differences and the resulting ecological conditions (Bárány-Kevei and Horváth 1996). Despite the fact that most of the present species are characteristic of the main associations, the rocky grasslands, slope steppes, Nardus swards and alpine meadows and that they are basically identical, in the bottom of the dolines we found tall grass associations. This is where the infiltrating waters are gathered, due to the elevation. Specific species can be found in the highest proportion on the southern and western slopes and these are the two most similar slopes as well.

There is no doubt that changes in the vegetation will have an effect on the quality of the infiltrating waters and the further development of the dolines. Since dolines are suitable monitoring points of the water in the karst system, it is important to continue the research of the vegetation cover which plays such an important role in the karstecosystem.

REFERENCES

Bacsó N, Zólyomi B (1934) Mikroklíma és növényzet a Bükk-fennsíkon. [Microclimate and vegetation on Bükk Plateau. (in Hungarian)] Időjárás 10:7-8

Bárány-Kevei I, Horváth A (1996) Survey of the interaction between soil and vegetation in a karstecological system at Aggtelek, Hungary. Acta Geogr Univ Szegediensis 35:81-87

Jakucs P (1961) Az Északi-középhegység keleti felének növényzete. [Vegetation of eastern part of Northern Middle Mountains. (in Hungarian)] Földrajzi Értesítő 10:357-377

Simon T (1997) A magyarországi edényes flora határozója. Harasztok-Virágos növények [Identifying book of Hungarian vascular plants. Moors - flowery plants. (in Hungarian)] Nemzeti Tankönyvkiadó, Budapest

Vojtkó A (2002) A hegység növénytakarója (Vegetation of Mountains). In: A Bükki Nemzeti Park. Hegyek, erdők, emberek. Bükki Nemzeti Park, Eger

Zólyomi B (1966) Einreichung von 1400 Arten der ungarischen Flora in ökologische Gruppen nach TWR - Zahlen. Fragmente Botanica Musei Historico-Naturalis Hungarici 4(1-4):101-142

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THE TEMPORAL VARIETY AND VARIABILITY OF LAND COVER FROM THE SECOND HALF OF THE 19TH CENTURY IN THE REGION OF KECSKEMÉT

R DÓKA and R ALEKSZA

Kiskunság National Park Diractorate, 19. Liszt F. street, 6000 Kecskemét, Hungary
E-mail: dokar@knp.hu

Summary: In order to understand the relationship between society and its natural environment it is crucial to research historical land use and land cover. As a result, both past and current land cover changes are more and more closely looked at – in accordance with international trends – within Hungarian geography. Through our research using a Geographical Information System, we examined the variety (diversity) and variability (land use stability) of land cover on 25x25 km urban, rural and transitional regions in the Duna-Tisza Interfluve from the second half of the 19th century to the present days, through five different time horizons. For this research we used the database previously compiled for our past landscape history and land use analysis. In this recent paper our main aim was to answer the following questions: 1. What kind of spatial characteristics can be recognized in land use stability? 2. How did the ratio of stable and transformed land cover areas, as well as the annual mean size of change affected areas vary over time? 3. What kind of conclusions can we draw from the results in terms of the driving factors and from the angle of landscape protection? By answering these questions, we would like to emphasize the driving force of the agroecological potential, while also pointing out a relationship between natural conditions and the change in land cover, as well as land use stability.

Key words: historical land use and land cover change (LULCC), land use stability, driving forces, landscape protection

1. INTRODUCTION

The GIS analysis of land use stability can also play an important role in uncovering the causes of landscape changes. From the viewpoint of understanding the landscape function it is interesting to determine when, where and why there might be significant changes in land use (Csorba 2006). Comparing the stability map that shows the spatial differences of land use stability with maps that represent other landscape characteristics can highlight that a particular landscape characteristic can play a significant role in landscape changes. This landscape characteristic can be regarded as the driver, as well as the prohibitive factor to landscape changes.

Stability maps can also be used for landscape protectional purposes, which can further increase the significance of the GIS analysis in land use stability. With regard to landscape protection and nature conservation, long-lasting and originally also natural forests, grasslands, swamps and lakes make up the most valuable parts of all landscapes, the so-called natural areas.

According to our presumptions the locations of areas with a stable or relatively stable land cover indicate areas with higher agroecological potential and with more favourable conditions from the agricultural point of view. Research shows that natural areas were best able to maintain, and abandoned areas could best regenerate in landscape parts where natural conditions were especially unfavourable from the angle of agriculture. The best natural conditions are characteristic to areas with stable land cover, which have been utilized for a long time only as arable land and where other ways of land use have not become real alternative to arable farming.

Agricultural land use is not only determined by natural conditions, but also by economical, as well as technological-infrastructural factors; therefore, the geographical position of a town can be essential to land cover change trends.

Logically, land use stability and the level of human impact, i. e. hemeroby are closely related to each other, since stable land cover means that no considerable land forming has taken place in the given area in a long period of time; therefore leaving its naturalness also unaffected as well.

When examining land cover change chronologically, we can discuss the variety and variability of the land cover or land use types. Variety means how many types of the land cover can be noticed on a given area, while variability expresses how many times the land cover has changed there. The dynamics or stability of anthropogenic activities in the environment are closer associated with the variability of the land cover. However, if we want to find out how fit a given area was to satisfy the different land use demands, we have to examine the temporal variety of the land cover.

In this study, we attempted to evaluate the land cover variety and variability (land use stability) in Kecskemét and its surroundings from the second half of the 19th century to the present days, with a retrospective approach and applying GIS methods.

2. STUDY AREA AND METHODS

Our study area – in the surroundings of Kecskemét – covered a 25x25 km area in the middle part of the Duna-Tisza Interfluve, Hungary (Fig. 1).

Its present land use is rather heterogeneous: it includes Kecskemét and other closed built-up areas (e.g. Kerekegyháza, Helvécia), more opened built-ups and garden-plots with mixed utilization, rural areas, homesteads, large agricultural fields, forest plantations, as well as meadows and pastures. Its physical geographical conditions are also diverse: characterized by loess surfaces, sand-sheets, sand dunes, swamps and intermittently flooded areas. The study area can be divided into highly protected (national parks, landscape protected areas, nature reserves), protected – and from the point of view of landscape protection – into less significant landscape details (garden-plots, built-up areas).

Vector land use and land cover data were collected from archive topographic maps, current orthophotos and digital land registry database within the following seven time horizon by visual interpretations and decodings (HIM 1783 1860-1864 1883 1940-1944 1958-59, FÖMI 1989-1996 2005 2008). We converted the vector layers of the land cover mosaics into 50, 100 and 200 meter pixel size raster files.

1. The second half of the 18th century (1783)
2. Mid 19th century (1860-1864)
3. The second half of the 19th century (1883)
4. 1940-1944
5. 1958-1959

6. 1989-1996
7. 2005-2008

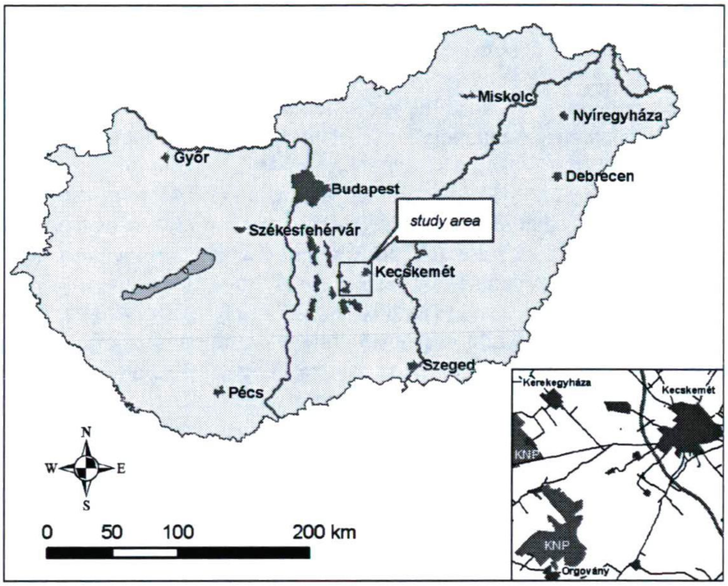

Fig. 1 The location of the study area

In our previous paper landscape historical changes were evaluated applying historical sources and scientific papers (Dóka et al. 2010). This study was also carried out with the help of the ArcGIS 9.3 software, but due to the quality limits of the raw map data in the first and second time horizons only for the period between 1883 and today (3^{rd}-7^{th} time period). With the help of GIS applications our standardized land cover classification system used in the previous landscape history research, as well as our database have been refined, and as a result we applied the following land cover types (classes):

1. Regularly and permanently water-covered areas, natural still waters, swamps
2. Grasslands, scrublands, as well as grasslands with scattered trees and scrubs
3. Closed forests, woodlands, forest plantations
4. Arable lands
5. Vineyards, orchards, gardens
6. Areas with high sparse settlement density
7. Build-ups, closed settlements
8. Artificial still water bodies

Based on our experience a standard database cannot be established in the Duna-Tisza Interfluve with the automatic application of the key codes from the 2^{nd} and 3^{rd} Military Surveys. Since military archive maps are only considered an indirect data source (Nagy 2004), it is possible that the interpretations based on the key codes provide improper information.

When evaluating the maps from the 2^{nd} Military Survey, it can be misleading that the „forests" displayed on it can represent forest plantations (from anthropogenic sources), natural closed forests, as well as spontaneous scrublands (Biró 2008). It is also true about the maps from the 3rd Military Survey. Since on later maps we categorized grasslands, scrublands, as well as grasslands with scattered trees and scrubs to be part of the land cover class 2, we had to re-categorize the areas from the 3rd Military Surveys that were marked „forest" by the key code, with consideration to the origins of their patches.

We applied landscape metrics to determine the origins of a particular area. To support our GIS application we used the base theory that natural or anthropogenic origins are present in the geometrical characteristics of the landscape structural features (Mezősi and Fejes 2004).

Since neither the analysis of the fractal dimension (FRAC) nor the investigation of the shape index (SHAPE) that display the regularity and complexity of the patches yielded acceptable results, we developed a patch index, which made natural and artificial forest and scrubland patches easier to separate. For the index we used the Patterson „Shape Geometry Extension", which supplies the inside angles of polygons (Patterson 2004).

In view of the number and the size of angles [so the number of angles close to 90° and 270° (±15°)] we can numerically define the angularity of the features. It is important to add that the result of the analysis is rather sensitive to the rules and preciseness of digitalization.

We calculated first our patch index for the „forest patches" of the 2nd Military Survey. After determining the natural or artificial origin of „forest patches" with the help of a known „reference patch", we had to separate the real forests and spontaneous scrublands. Our aid was the 1st Military Survey, which shows scrublands as part of grasslands. The forests that are identified on the 1st Military Survey and also shown on the 2nd, were categorized in land cover class 3, while the scrublands were made part of land cover class 2.

We divided the „forests" that are displayed on the map of the 3rd Military Survey into two groups, one of which consists of completely new areas, while the other includes „forests" that are present on the map of the 2nd Military Survey already. The members of the former group became part of class 3, while in case of the latter we originated the land cover type from the map of the 2nd Military Survey by applying the identity GIS function and calculating the shape indices of the „sliver" and „parent polygons". Using the ratio of the „sliver polygons" and „parent polygons" shape index we constituted three classes with the help of The Jenks Natural Breaks Classification and merged the „sliver" polygons that had a value close to 1. The remnant polygons, as well as the completely new polygons became part of land cover type 3.

In our work we separated sparsely populated areas with agricultural and forestry usage (land cover classes 2-5) from the areas with high sparse settlement density. We defined these using the raster density files from the point-database of the sparse settlements, applying mean sparse settlement density data for garden-plots from 2005 (FÖMI 2005). We used a 100 meter search radius for the calculations according to the following.

Due to the increasing level of spatial „flattening" and generalization resulting from the interpolation, only lower values can be used, which causes the higher sparse settlement density areas to better fit to the vector patch edges, and are also closer to the point-like nature of the base data used. Therefore, the search radius ($r=564.3$) of a circle with a 1 km^2 area is not appropriate for the calculations. Applying a search radius, which is significantly shorter than 100 meters (e.g. $r=50$) makes the high sparse settlement density areas much too scattered and as a result the advantage of the method (the possibility to form spatially continuous data from discrete point data) also diminishes significantly. Furthermore, we would like to add that in every such application, the spatial base data must originate from an area that is larger at least by the search radius than the analyzed reference area.

Using this method with 50, 100 and 200 meter cell size the sparse settlement density for the garden-plots yields 139 sparse settlement/km^2 after rounding the result. This value mostly represents the former garden-plots, but high sparse settlement density is possible in other regions as well. Areas with high sparse settlement density mean those where the values exceed 139 sparse settlement/km^2 in the raster files

All the methods illustrated above improve the comparability of land cover types from different time periods. Due to the different scale of the source maps, it was inevitable to generalize larger scale maps to the smallest scale (1:50 000). For these generalizations we used Töpfer's radical law.

We compared the maps with different scale and content using combination and reclassification, following the generalization, and the conversion of the vector content to 50, 100 and 200 meter pixel size raster files, then took the average of the results and analyzed it statistically.

Land cover variety was measured using the variety tool of the cell statistics tools with the help of GIS software, while variability (land use stability) was analyzed per the combined data in Microsoft Access. We filtered the variety and variability database with the use of low type „filter" functions to make the display of the results more assessable visually.

3. RESULTS AND DISCUSSION

Land cover variety and variability – according to our results – are both in close relation with the agroecological potential. The „soil quality score" expresses the natural fertility of different soils in the percentage of the fertility of the most fertile soil (Várallyay et al. 1985). Based on the soil quality score attribute of the digital agrotopographical map of Hungary (MTA TAKI 1996) we can create soil quality score categories (class 1: 0-10, class 2: 11-80 soil quality scores) using the criteria of representing roughly equal area sizes. We can generate maps that show areas with the same category based on their soil quality scores as well. If we compare the maps generated on the basis of the soil quality score to the stability and variety maps, we will see that large stability and small variety is typical for areas with high and medium soil quality scores (class 2), while on areas with low soil quality scores (class 1) there are generally more land cover changes and more land cover types occurring (Figs. 2 and 3). This spatial concurrence can be recognized even with changed cell sizes.

This can be explained with the following. The wind-blown sand which makes up within the study area – beside solonchak, solonchak-solonetz and more humic sands – the majority of the areas with low soil quality scores is barely appropriate for arable farming, as opposed to the more fertile meadow soils and chernozems with medium and high soil quality score. This region was typically agricultural-determined over more than 100 years, therefore the scale of the agroecological potential has impacted both land use stability and land cover variety. The close relation with the agroecological potential is more obvious on the variety map (Fig. 2).

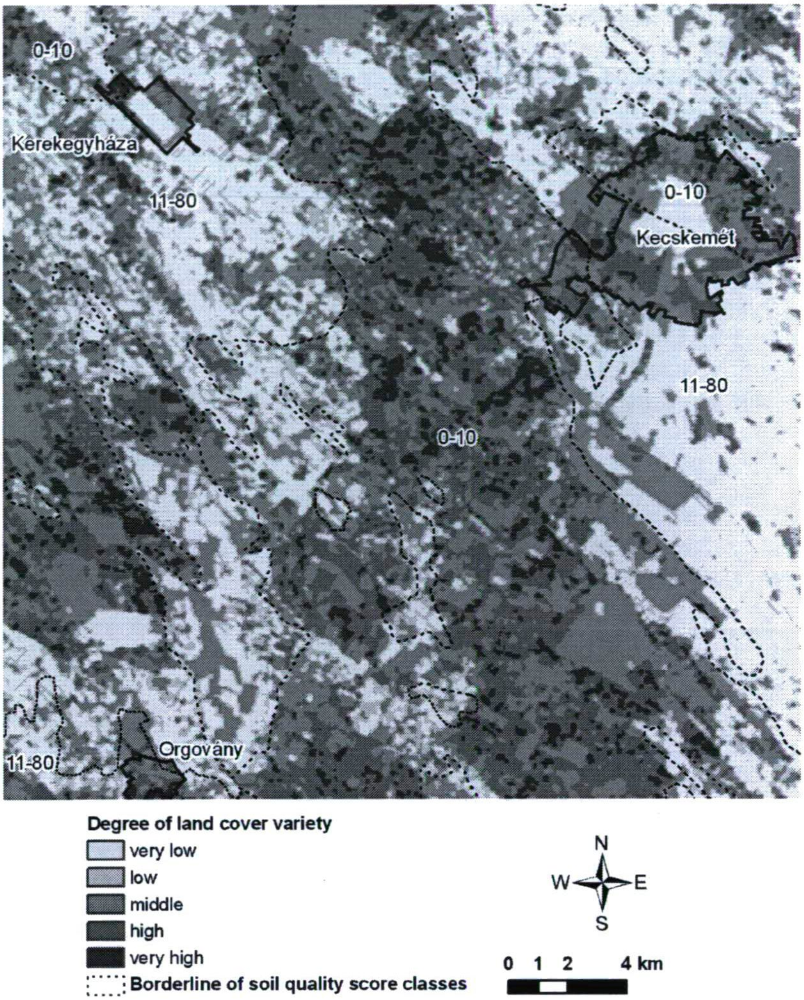

Fig. 2 Degree of land cover variety from the second half of the 19th century to the present days (50 m cell size, low type filter)

The most diverse and variable land cover areas can mostly be found with high density in the „Central Sand Region". This „Central Sand Region" as mentioned by Lettrich (1968) is situated to the east-southeast of Kecskemét, and according to its landscape history and natural conditions is a well-distinguishable part of the region in the surroundings of Kecskemét. Its typical land cover range is e.g. grassland – arable land – vineyard – grassland – forest plantation, or grassland – vineyard – area with large sparse settlement density – built-ups. It seems that some of the sandy areas, where previously agricultural production was the main form of land use, have lost their agricultural character as the conditions changed due to urbanization. Characteristically the cultivation of the land has been replaced by another land use form which is less related to the land.

From the results we can conclude that the agroecological potential in this region has operated as driving force over the past 130 years. Recent research concerning a Hungarian study area has also found that soil quality has a relevant role in the transformation of the rural landscape in Hungary (Szilassi et al. 2010).

Besides this close relation to the agroecological potential, another geographical regularity can be seen on the variability map, namely that in the zone surrounding the 19th century Kecskemét, where mostly built up areas are present nowadays, the result map displays a diverse land cover. The reason behind this is that the exterior parts of historical cities were utilized in the past in many different ways in accordance with the different urban and agricultural demands, like in the case of Kecskemét.

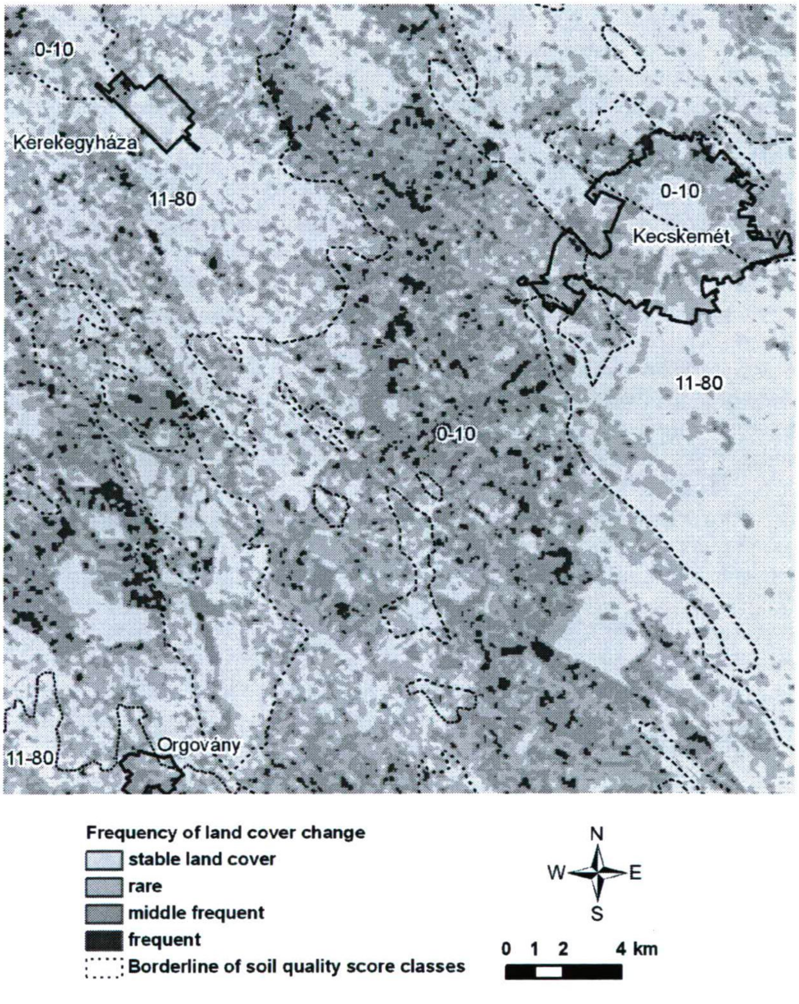

Fig. 3 Frequency of land cover change from the second half of the 19th century to the present days (50 m cell size, low type filter)

Our numerical results can only be considered estimates, as precise evaluation is impossible for several reasons. Results can be slightly affected by the preciseness of georeferencing and digitalization, the algorithms used in the origination of the data, as well as by the quality of the source maps. For example, natural still water bodies and swamps were mapped with a different extent at different times, partially for objective (drier climate period), partially for subjective (the determination of the borderlines of surface waters, the time of the mapping) reasons. In our statistical evaluation the alterations of 1) and 2) land cover types between two different time horizons were not considered an anthropogenic change.

According to our data, in the study area 44-45% of the land cover changed during the six decades following 1883, while this ratio was 28-29% from the first half of the 1940s to the end of the '50s. If we calculate the annual mean size of the transformed land area, we get a value 2.5 times larger than in the earlier period, which can be explained by the sweeping changes in socio-economical conditions that took place following World War 2.

From 1958-59 to the early years of post-communist transformation 44-45% of the study area was affected by land cover change. The annual mean size of the transformed land area is slightly more than half of the same value from the previous period, indicating a decrease in the extent of changed land cover.

During the time period between the early years of post-communist transformation and our present day 27-28% of the land cover has been changed. The annual mean size of the transformed land area doubled compared to the previous period, which refers to a much more intense land use change after the early years of post-communist transformation related to the altered socio-economic conditions.

The significant variation in the annual mean size of the transformed land area shows that the rate of land cover transformation and the intensity of land evolution are both rather irregular. According to our experience, land cover and land use change substantially after significant socio-economical changes compared to more stable socio-economical periods, in our study area as well.

It is remarkable from the viewpoint of landscape protection that since the early years of post-communist transformation stable grasslands, scrublands, still waters and swamps, which are valuable from the standpoint of nature conservation, were considerably affected by land cover change. 5% of the total area of these land cover types has been transformed, which represents 1.5-2% of the total transformed land cover area. Stable forests and woodlands haven't changed recently.

The most significant transformations were the alterations of grasslands and scrublands caused by new ploughings (around 53%), afforestations and self-reforestations (around 34%). In addition building up (6-7%) and transformation into vineyard or orchard (4%) or into reservoir (2%) also occurred in the case of them. Change of natural still waters and swamps by ploughings and the creation of reservoirs also occurred, though obviously not as frequently and extensively as in the case of grasslands.

Negative changes have lately been characteristic to every part of the study area, but as a matter of course they rather occurred in places where the wetlands, grasslands and scrublands had pre-condemned a greater area. Unfortunately these transformations didn't entirely avoid the protected areas either.

REFERENCES

Biró M (2008) A Duna-Tisza köze fásszárú vegetációjának átalakulása a 18. század óta, különös tekintettel a száraz homokterületekre. [The changes of woody plant vegetation in the Duna-Tisza interfluve since the 18th century, with special emphasis on dry sand territories. (in Hungarian)] In: Kröel-Dulay Gy, Kalapos T, Mojzes A (eds) Talaj-vegetáció-klíma kölcsönhatások. Köszöntjük a 70 éves Láng Editet. MTA ÖBKI, Vácrátót. 23-38

Csorba P (2006) Indikátorok az ökológiai tájszerkezet és tájműködés jellemzésére. [Indicators for the analysis of ecological landscape structure and landscape functions. (in Hungarian)] In: Kiss A, Mezősi G, Sümeghy Z (eds) Táj, környezet és társadalom. Ünnepi tanulmányok Keveiné Bárány Ilona professzor asszony tiszteletére. SZTE Éghajlattani és Tájföldrajzi Tanszék, SZTE Természeti Földrajzi és Geoinformatikai Tanszék, Szeged 117-122

Dóka R, Aleksza R, Kőhalmi F, Keveiné Bárány I (2010) A tájváltozások és a társadalmi-gazdasági viszonyok alakulásának összefüggései a Duna-Tisza köze középső részén. [Connections between landscape changes and alteration of socio-economical circumstances in the middle section of Duna-Tisza interfluve. (in Hungarian)] In: Szilassi, P, Henits L (eds) Tájváltozás értékelési módszerei a XXI. században. Földrajzi Tanulmányok 5:227-259

FÖMI (1989-1996) EOTR és Gauss-Krüger vetületű topográfiai térképek. Méretarány 1:10 000, 1:25 000 [Topographic maps with EOTR and Gauss-Krüger projection. Scale 1:10 000, 1:25 000] Földmérési és Távérzékelési Intézet, Budapest

FÖMI (2005) Ortofotók. Méretarány ≈ 1:10 000 [Orthophotos. Scale ≈ 1:10 000] Földmérési és Távérzékelési Intézet, Budapest

FÖMI (2008) Külterületi és belterületi vektoros ingatlan-nyilvántartási adatbázis (KÜVET, BEVET). Méretarány 1:4 000, 1:1 000 [Vectorial land registry of clear and periphery (KÜVET, BEVET). Scale 1:4 000, 1:1 000] Földmérési és Távérzékelési Intézet, Budapest

HIM (1783) I. Katonai Felmérés. Méretarány 1:28 800 [First Military Survey. Scale 1:28 800] Hadtörténeti Intézet és Múzeum Térképtára, Budapest

HIM (1860-1864) II. Katonai Felmérés. Méretarány 1:28 800 [Second Military Survey. Scale 1:28 800] Hadtörténeti Intézet és Múzeum Térképtára, Budapest

HIM (1883) III. Katonai Felmérés. Méretarány 1:25 000 [Third Military Survey. Scale 1:25 000] Hadtörténeti Intézet és Múzeum Térképtára, Budapest

HIM (1940-1944) Katonai topográfiai térképek. Méretarány 1:50 000 [Military topographic maps. Scale 1:50 000] Hadtörténeti Intézet és Múzeum Térképtára, Budapest

HIM (1958-1959) Katonai Újfelmérés. Méretarány 1:25 000 [Military Re-survey. Scale 1:25 000] Hadtörténeti Intézet és Múzeum Térképtára, Budapest

Lettrich E (1968) Kecskemét és tanyavilága. [Kecskemét and its surroundings. (in Hungarian)] Földrajzi Tanulmányok 8. Akadémiai Kiadó, Budapest

Mezösi G, Fejes Cs (2004) Tájmetria. [Landscape metrics. (in Hungarian)] In: Dövényi Z, Schweitzer F (eds) Táj és környezet. Tiszteletkötet a 75 éves Marosi Sándornak. MTA FKI, Budapest. 229-242

MTA TAKI (1996) AGROTOPO-adatbázis. Méretarány 1:100 000 [AGROTOPO-database. Scale 1:100 000] Magyar Tudományos Akadémia

Nagy D (2004) A történeti tájhasználat és felszínborítás rekonstrukciójának lehetőségei archív térképek feldolgozásával. [The possibilities of reconstruction the historical land use and land cover with the use of archive maps. (in Hungarian)] Környezetállapot értékelés program, Pályázati tanulmányok (manuscript) 22-36

Patterson DE (2004) Shape Geometry Extension (SG_10.avx, Version 1.0) http://arcscripts.esri.com/details.asp?dbid=13556

Szilassi P, Jordan Gy, Kovacs F, Rompaey Van A, Dessel Van W (2010) Investigating the link between soil quality and agricultural land use change. A case study in the lake Balaton catchment, Hungary. Carpathian Journal of Earth and Environment Sciences 5:61-70

Várallyay Gy, Szücs L, Zilahy P, Rajkai K, Murányi A (1985) Soil factors determining the agroecological potential of Hungary. Agrokémia es Talajtan 34:90-94

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Universitatis Szegediensis, Tomus 44-45, 2011, 41-49

ECOSYSTEM SERVICES IN HUNGARIAN KARST AREAS

M KISS, E TANÁCS and I BÁRÁNY-KEVEI

Department of Climatology and Landscape Ecology, University of Szeged, P.O.Box 653, 6701 Szeged, Hungary
E-mail: kiss.marton@geo.u-szeged.hu

Summary: Ecosystem service assessments provide a new and effective methodology in environmental management with several good experiences worldwide. In our study, we surveyed the services of a special landscape type, the karst areas in Hungary. Special characteristics of the karstecosystem are the high vulnerability and the three-dimensional and very fast processes. The importance of karsts is indicated primarily by drinking water provision, but they provide several other services with high economic value like soil formation, habitat function, timber production, climate regulation, recreation and aesthetic value. Hungarian karst areas are mainly in bad condition from a socio-geographical point of view, thus we propose that ecosystem services should be better incorporated in regional development processes.

Key words: ecosystem services, karsts, environmental management, vulnerability

1. INTRODUCTION, METHODS

Valuing ecosystem services could prove a comprehensive environmental evaluation method, dealing with both the animate and inanimate goods of nature. Its innovation is, among others, that the different factors and their value can be connected to social demands and present or future anthropogenic use (Costanza et al. 1997, MEA 2003). It can express such functions of natural factors that have not been taken into account or only without regard for their true importance. The analysis of landscapes' functions emerged years before in landscape ecological research (Leser 1986, Mezősi and Rakonczai 1997). With the help of valuing ecosystem services the structure→function→value approach can be completed and therefore could be used in practice easier. The complex systems approach enables overviewing the environmental factors' connections, recognizing contradictory or exclusive functions and optimizing land use. The study is based, besides other literature sources, on the previous results of karst ecological studies at University of Szeged. These studies focused on describing the landscape system of karsts as precisely as possible, with methods of different fields. By proposing the evaluation of ecosystem services, we would like to unify these results and make them more suitable for use in environmental decision making.

2. RESULTS AND DISCUSSION

2.1. *The karstecological system*

Karst areas are among the most valuable landscapes of Hungary, and they are also very vulnerable. Karstic rocks (limestone, dolomite) have good transmissibility and water holding capacity, therefore specific surface and sub-surface geomorphologic forms can be found on them; the higher geodiversity results in the diversity of living organisms. But the rocks' good solubility, the three-dimensional processes are a source of hazards as well, because harmful effects quickly induce significant changes in the whole system. Only 10% of the Earth's surface is covered with karstic rocks, but 25% of mankind's drinking water is supplied by karstic aquifers. This fact emphasizes the need for the protection of these vulnerable systems. In Hungary, parts of the Transdanubian and Northern Mountain Range and Western-Mecsek have karstic morphogenetics and special karstic landforms (Fig. 1).

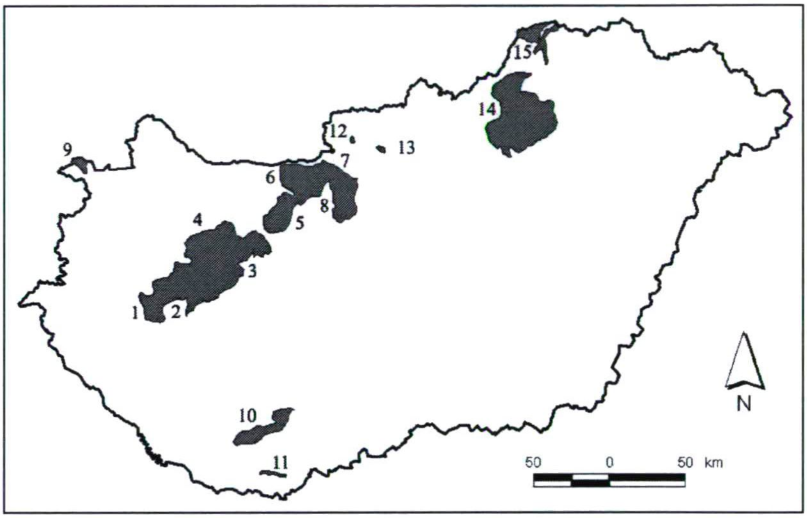

Fig. 1 Landscapes with surface karsts in Hungary
1 = Keszthely Mountains; 2 = Balaton Uplands; 3 = Southern Bakony; 4 = Northern Bakony; 5 = Vértes; 6 = Gerecse; 7 = Pilis; 8 = Buda Mountains; 9 = Surroundings of Sopron; 10 = Mecsek; 11 = Villány Mountains; 12 = Szokolya Basin; 13 = Karst of Cserhát; 14 = Bükk; 15 = Aggtelek Karst (modified after Kordos 1984)

Besides water (with transmitter function), every landscape ecological factor has an important role in the system, and they affect the special morphology and processes of the karsts. Climate is an important element in karst development through its influence on the solvent water's quantity and temperature, but it has crucial role in the formation of the soil and vegetation types as well as a zonal factor. Low temperature, despite its higher gas absorption capacity, decreases the speed of solution processes, and water migration stops entirely in the case of frost. High temperature can also moderate the intensity of corrosion, because the gas dissolving capacity of water is smaller at higher temperatures, and the aggressive carbon dioxide absorption capacity is lower in water with high temperature. The water originating from precipitation moves differently in the soil and in the parent rock, depending on the infiltration capacity of the rock and on the vegetation cover. The dilution of leaking water reduces dripstone formation. The situation is different in the case of vegetation cover, when evapotranspiration should also be taken into consideration, thus part of the precipitation is getting again in the atmosphere.

Soil is a determining element of the karstecological system. It functions as filter and buffer layer, which strains the external material of the infiltrating water. Different authors do not always formulate clearly that karstic processes depend mainly on the covering rocks, sediments or soils. According to this, we differentiate between covered, hidden-open (Bárány-Kevei and Jakucs 1984), open and bare karsts. Covered karsts are covered with non-karstic rock or sediment, thus corrosion can start where the leaking water finds way towards the soluble rock. Shallow suffusion dolines can be found on these surfaces. On bare karsts, corrosion processes are slow because of the low carbonic acid content. In soil-covered karsts, the carbon dioxide surplus, originating from organic matter decomposition and root respiration, increases the corrosion capacity of leaking water, which strengthens morphogenetical processes. Soils react and respond to external effects according to their physical and chemical properties; therefore soil is an indicator sphere of the karstecosystem. The modifying effect of non-native material coming as a result of human activities or from atmospherical deposition can cause the deterioration of near-surface soil layers. A significant sign of this is the changing acidity and, in parallel, the carbonate content. These are important factors in areas with different vegetation cover because they form the basis of investigating interactions between vegetation and soil.

The hydrogeological-hydrogeographical properties of karst areas are determined by the fact that water from precipitation and from non-carbonate areas quickly disappear in pipes and pores. Water from precipitation moves further as infiltrating water and has a crucial role in the material transport of karsts. Karsts are quite heterogenous, they are covered with soil, with vegetation, or they can be bare, thus it is not possible to give a general scheme to determine the amount of infiltrating water. Böcker (1974) differentiated infiltrating types: infiltration of open karstic surface, of surface covered with soil and vegetation, of permeable clastic deposit, and of covered karst. These types show that there are differences in the water-mediated material transport as a function of karst ecological conditions. Physical properties of the soil affect the infiltration rate. If the soil's transmissibility is greater than the parent rock's, groundwater flows in accordance with the general slope direction of the area. If the soil's transmissibility is smaller or equal to the parent rock's, then water leaks into the rock, holding all of the dissolved material from the soil.

Bio-ecological properties are important factors in the karstecosystem; karst can in fact be treated as a biological product (Jakucs 1980). Karst development strongly correlates with microbial activity; the intensity of corrosion is lower where living beings are less present in the soil. After the decomposition of organic matter, organic colloids can bind several harmful compounds e.g. heavy metals.

The strong interrelations of landscape ecological factors prevail not only in the structure and operation of the system, but in environmental effects as well, a change in one element of the system causes significant changes in the balance of other elements and subsystems (Fig. 2). Methodologically complex approaches are important in the environmental assessments of karst areas. One such approach is the evaluation of ecosystem services in karst areas, which has the advantage of managing different functions of biotic and abiotic factors of nature in a unified assessment system and presenting their value to the society. In the next chapters, we give a review of the main ecosystem services of karst areas, and, as a justification of the methodology, we assess their degradation and the value of their protection for the society.

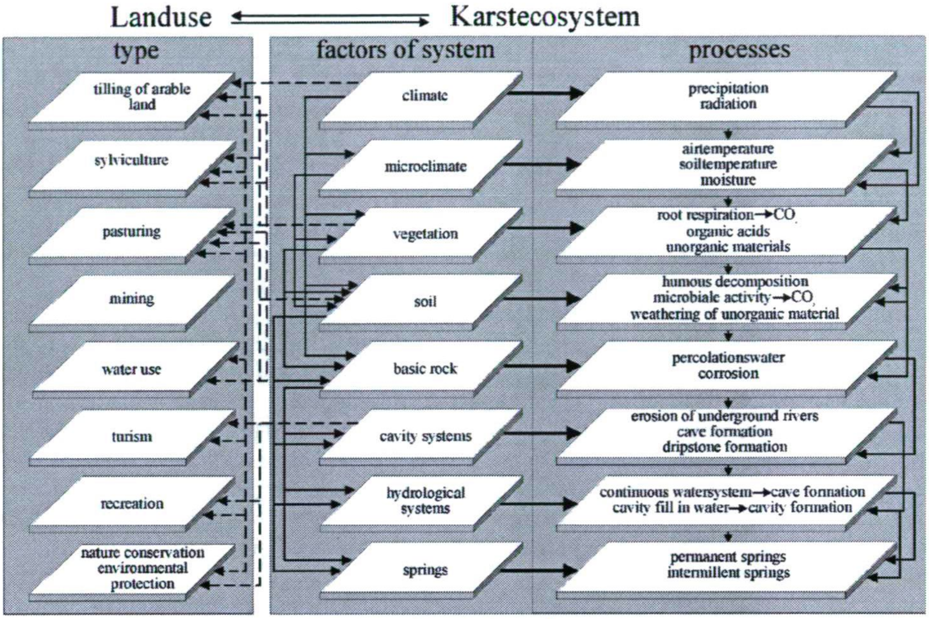

Fig. 2 The karstecological system

2.2. *Drinking water provision*

In Hungary, 14-16% of the drinking water is supplied by karstic aquifers. The quantity and quality should both be taken into account when speaking about karst waters. Karst water depletion shows a decreasing tendency and now it is approximately in balance with the supply from precipitation. But in the 1970s and 80s, in the case of Bükk mountains, the extraction was higher than the supply, which could be detected in decreasing karst water levels. The fall of karst water levels in the Transdanubian Mountain Range due to bauxite and coal mining is widely known. The pressure decrease extending to the whole aquifer resulted in the drying up of some nearby karst springs (e.g. Tata, Bodajk), while a discharge decrease was observable in the case of some thermal springs. Water level regenerated and pressure rising started owing to the closing of the mines after the political transition in 1989-90 (Csepregi 2003). Karst water levels can be expected to be influenced heavily by global climate change; former studies (e.g. Younger et al. 2002) found that significant decrease would occur in the karst water resources of low- and mid-latitudes by the middle of the century. Besides climate, karst water quantity also depends on land use, the area of built-up surfaces, through the modification of evapotranspiration, which is an important factor of the hydrological balance (Sikazwe 2008).

Karst water quality is an ecosystem service also through the drinking water supply. In Hungary, several studies dealt with the vulnerability and pollution of karst waters, mainly heavy metal pollution in different periods (Mádl-Szőnyi and Füle 1998, Mádl-Szőnyi et al. 2003, Kürti 2005, Szőke 2005, Keveiné Bárány et al. 1999, Kaszala and Bárány-Kevei 2005). The water inflow from agricultural areas can cause the redissolution of dripstones (Jakucs 1987). It is a frequent phenomenon in Central European caves (Photo 1), but this degradation process can also be observed in the Atlantic region (e.g. in Marble Arch Cave, Ireland). Meanwhile, polluted waters entering the cave cause degradation in the quality of curative aerosols.

Evaluating ecosystem services may help improve water quality, because the investments needed may be financially comparable with 'the price' of maintaining the present state. E.g. in 2006, thousands of people were taken ill because of the polluted water during a karst flood, and some karst springs were excluded from the drinking water supply in the surroundings of Miskolc, because of coli infection (Lénárt 2006). If we take into consideration the damages in other services, the total costs of interventions needed, these are financially comparable with the consequences of worse environmental status. Water Quality Trading (Boyd et al. 2004) could be a usable method in environmental management of surface and subsurface waters: it works similarly to the carbon trading system: polluters above the limit can buy emission surplus quotas from companies with less pollution.


Photo 1 Redissolution of a dripstone in the Baradla Cave (Aggtelek Karst)

2.3. Soil formation

In karst areas, all types of ecosystem services of the soils (provisioning, supporting, regulating and cultural) are being degraded. In karstic dolines the acidification of soils can be detected in a considerable part of the country (Keveiné Bárány 2002), in definite connection with acidic atmospheric deposition. The decrease in pH can result in the loss of many nutrients and a considerable amount of calcium. The soil structure may get worse, which also has an effect on the availability of nutrients. And, in extreme situations, toxic elements (aluminium, manganese, iron, heavy metals) may be mobilized. These may have an unfavourable effect on stand increment and soil biota. Soil erosion after forest clearcuts and cultivating is a problem mainly in the Mediterranean region. This is an evident example of the wide-spread process of overusing slowly or conditionally renewable resources, which may cause the degradation of services much more valuable than the exploited one. Karstic erosion badlands are not frequent in Hungary, the biggest occurrences are Ördögszántás above Aggtelek and a slope of Villány Mountains (Photo 2).

Photo 2 Erosion slope in the Villányi Mountains

2.4. Habitat function

There are several methods in the literature for evaluating biodiversity as an ecosystem service, supported by natural and semi-natural habitats. Karstic landscapes are refuges of several unique species of the flora and fauna of Hungary; the spatial distribution of the vegetation-based Natural Capital Index (Czúcz et al. 2008) shows that the quantity and quality of natural and semi-natural habitats are good in our karstlands. The InVEST modelling tool (Integrated Valuation of Ecosystem Services and Tradeoffs – Tallis et al. 2008), which was developed in the Natural Capital Project in the USA, calculates the ecosystem service of biodiversity based on habitat quantity, fragmentation, rarity and on endangering factors, which are similar criteria to those on which the Natural Capital Index is based. The number of endangering factors is limited, because almost every karst area of Hungary got territorial protection in the former decades. The management of protected areas is a typical field of land use conflicts, in most of Hungary's protected forests there is some kind of conflict between national parks and forestry companies. As most karst areas are under nature protection, and they are mostly forested, this is the main or one of the main land use conlicts in karstic national parks. A similar problem is the change in the vegetation of dolines. After forest clearcuts microclimate had turned into extreme (Bárány-Kevei 1985), and *Juniperus*-associations appeared in the place of former forests. Reforestation is very difficult in these patches; there are dead-end directions in the secondary succession of these associations (Bárány-Kevei and Horváth 2005). But it is obvious that treeless, *Juniperus*-dominated dolines have become a characteristic element of karstic landscapes, and the herbaceous associations of dolines enrich the species composition of these landscapes. Altogether, deforested dolines increase landscape diversity to some extent, which can be measured e.g. through tourism. Valuing ecosystem services manage the different natural factors in a uniform system, and thus might help to make similar land use optimizing decisions. Another example of degradation of natural and seminatural karstic habitats is the eutrophication of karstic lakes. In a number of lakes in Aggtelek Karst filling up can be detected to different, but undoubtedly faster extent than the natural process. This is one of the most obvious environmental changes in karstic areas, e.g. Aggtelek Lake has shrunk to a puddle overgrown with bulrush, from an oligotrophic lake with an open water surface of 1.3 ha (Photos 3 and 4).

Photo 3 Aggtelek lake in 1984

Photo 4 Aggtelek lake in 1999

This process can be influenced by climate change too, but the connection with agricultural and residential wastewater influx is proven (Samu and Keveiné Bárány 2008).

2.5. Other services of forests

Raw material production is the most exploited ecosystem service of forests nowadays in Hungary. Its quantitative estimation is relatively simple, because timber has real market. But in karst areas, other functions of forests should be taken into consideration compared with some other landscapes, e.g. in the Aggtelek National Park, proportion of protection-oriented forests is 62.9%, opposed to the average of 33.1% of the country (Tanács 2005). Although in the 21st century forestry is not the main employer, but in some areas its proportion in the structure of employment is above the average level in Hungary (KSH 2001). As karst areas are more densely forested than other landscape types of the country, climate regulation, which is among the most important services of forests nowadays, should be taken into account seriously in the case of these areas.

2.6. Recreation and aesthetic value

Owing to the special morphology and scenery of the surface and caves, tourism appeared relatively early in karsts; Baradla Cave was frequently visited already in the 19th century. Two of the first four national parks of the country were established in karstic landscapes (Bükk National Park 1977, Aggtelek National Park 1984), and nowadays there are practically no karstlands out of territorial protection. The ecosystem service of recreation potential has been principally exploited by the economy of these microregions: Aggtelek National Park is the main employer of the area, and, through the income from cave visitors, it has the best economic potential among Hungarian national parks. Even so, many of these areas can be considered as periphery, from a social geographical point of view. Many problems of Hungarian rural areas appear in these regions: unemployment, communal services breaking off, the ageing of native inhabitants owing to the migration of those of working age. A parallel process is the immigration of gypsies. The reasons of these are mainly the same as in many other rural areas: the migration to urban areas was at first induced by agriculture losing dominance in the country's economy, and later this was strengthened by forced industrialization in the socialist era. The repression of public services is a consequence partly of the settlement structure of these regions, which are characterized by small villages (up to 500 inhabitants). A special factor in the case of Gömör-Torna Karst is that this region was cut off from the original settlement system, most of the villages got far away from towns remaining in Hungary. In developing countries, poverty and bad living conditions are strongly connected to the degradation of ecosystem services (Duraiappah 2004, WRI 2007). In fact, our karst areas are provisioning a huge amount of ecosystem services, but they are mostly neglected by the current economic, regional development policy. This contradiction appears in other landscapes of Hungary too, drawing attention to an urgent need of changes.

3. CONCLUSIONS, FURTHER STEPS

In this paper, we would like to draw scientists' and decision makers' attention to this new methodology in the environmental management of karst areas. For the single elements of the Total Economic Value, methods of different disciplines should be used, but complex landscape ecological approaches can be justified with regard to the factors' relationships. Our examples, the Hungarian karst areas are specific because of their vulnerability and the fast and three-dimensional processes. Changes in each factor cause changes in the whole system. The extent of fluctuations is influenced by the climate-soil-vegetation system. As further steps, we feel it necessary to define these connections numerically, probably in model-based assessments. Significant differences in the spatial patterns of ecosystem services and socio-economical characteristics (economical indicators of well-being) account for further research on investigating the phenomenon, and in practice, to incorporate the sustainable use of ecosystem services more efficiently in regulations and regional development policy.

REFERENCES

Bárány-Kevei I (1985) Ökologische Untersuchung der Karstdolinen unter besonderer Berücksichtigung des Mikroklimas. Acta Geogr Univ Szegediensis 25:109 -130

Bárány-Kevei I, Horváth A (2005) Typical association and habitat types in the Aggtelek Karst Area. International Atlas of Karst Phenomena – Zeitschrift für Geomorphologie 139 Suppl:18

Bárány-Kevei I, Jakucs L (1984) Szempontok a karsztok felszíni formáinak rendszerezéséhez, különös tekintettel a dolinák típusaira. [Some aspects of systematizing karst surface landforms, with special regard to doline types. (in Hungarian)] Földrajzi Értesítő 33:259-265

Boyd B, Dowell K, Greenwood R, Hall L, Korb B, Mitchell M, Roufs T, Schary C (2004) Water Quality Assessment Handbook. US Environmental Protection Agency, Washington D.C.

Böcker T (1974) A beszivárgás meghatározása karsztvidéken a negyedévi határcsapadékok módszerével. [Determining infiltration in karsts with quarterly marginal precipitation method. (in Hungarian)] VITUKI Report, Budapest. 207-216

Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P, van den Belt M (1997) The value of the world's ecosystem services and natural capital. Nature 387:253-260

Csepregi A (2003) A Dunántúli-középhegység főkarsztvíztárolója vízforgalmának modellezése [Modelling the water regime of the main karstic aquifer of the Transdanubian Mountain Range. (in Hungarian)] In: Felszín alatti vizeink kutatása, feltárása, hasznosítása és védelme. Volume IA : Karsztvízkutatás Magyarországon. http://www.fava.hu/publikaciok/jubileumi_kiadvanyok/tanulmanyok_pdf/csepregi_dkh.pdf

Czúcz B, Molnár Zs, Horváth F, Botta-Dukát Z (2008) The natural capital index of Hungary. Acta Botanica Hungarica 50(Suppl):161-177

Duraiappah AK (ed) (2004) Exploring the links – Human well-being, poverty and ecosystem services. The United Nations Environment Programme and International Institute for Sustainable Development, Winnipeg, Canada

Jakucs L (1980) A karszt biológiai produktum. [Karst is a biological product (in Hungarian)] Földrajzi Közlemények 28:331-339

Jakucs L (1987) Traces of effects of acidic rain (sedimentation) in the re-dissolution of cave dripstones. ENDINS, Mallorca. 49-59

Kaszala R, Bárány-Kevei I (2005) Heavy metal content of soils in the karstic area of North Hungary. In: Calabrese EJ, Kostecki PT, Dragun J (eds) Contaminated Soils, Sediments and Water Science in the Real World. Vol. 2. Springer. 167-174

Keveiné Bárány I (2002) A karsztökológiai rendszer szerkezete, működése, környezeti hatások a klíma-talaj-növényzet rendszerben. Akadémiai doktori értekezés. [Structure, function and environmental effects in the karstecological system. Academic doctoral dissertation. (in Hungarian)] University of Szeged

Keveiné Bárány I, Hoyk E, Zseni A (1999) Karsztökológiai egyensúlymegbomlások néhány hazai karsztterületen. [Alterations in karstecological balance in some Hungarian karst areas. (in Hungarian)] Karsztfejlődés 3:79-91

Kordos L (1984) Magyarország barlangjai. [Caves of Hungary (in Hungarian)] Gondolat Kiadó, Budapest

KSH (Hungarian Central Statistical Office) (2001) Népszámlálás adatai – Területi adatok. [Census of Hungary – Local data. (in Hungarian)]

Kürti L (2005) Some karst spring analysis at the piedmont of Bükk Mountains. Acta Climatol Chorol Univ Szegediensis 38-39:171-180

Lénárt L (2006) A Bükk-térség karsztvízpotenciálja – A hosszú távú hasznosíthatóságának környezetvédelmi feladatai. [Karst water potential of Bükk area – Environmental tasks for long term sustainability. (in Hungarian)] In: G Fekete É (ed) Észak-Magyarországi Stratégiai Füzetek. MTA RKK, Miskolc. 17-28

Leser H (1986) A geoökológiai tájszerkezetkutatás problémái. [Problems in geoecological landscape structure research. (in Hungarian)] Földrajzi Értesítő 35:1-15

Mádl-Szőnyi J, Füle L (1998) Groundwater vulnerability assessment of the SW Trans-Danubian Central Range, Hungary. Environmental Geology 35:9-18

Mádl-Szőnyi J, Nyúl K, Mindszenty A, Halupka G (2003) Veszprém-Kádárta Plateau Test Site, Transdanubian Central Range (Hungary). In: Zwahlen F (ed) Vulnerability and risk mapping for the protection of Karst Aquifers. EU, Brussels. 274-286

MEA (Millennium Ecosystem Assessment) (2003) Ecosystems and Human Well-Being: A Framework for Assessment. Island Press, Washington DC

Mezősi G, Rakonczai J (eds) (1997) A geoökológiai térképezés elmélete és gyakorlata. [Geoecological mapping - Theory and practice. (in Hungarian)] JATE Természeti Földrajzi Tanszék, Szeged

Samu A, Keveiné Bárány I (2008) Karsztos tavak vízminősítése néhány vízkémiai paraméter alapján. [Water qualification of karstic lakes, based on some hydrochemical parameters. (in Hungarian)] 4. Magyar Földrajzi Konferencia, Debrecen

Sikazwe K (2008) The impact of land use change on karst groundwater quantity in Shentou spring Basin, Shanxi Province, China. Environemental Research Journal 2:232-237

Szőke E (2005) Research on the heavy metal pollution of some cave waters of the karsts of Aggtelek from 2000 until now. Acta Climatol Chorol Univ Szegediensis 38-39:135-142

Tallis HT, Ricketts T, Ennaanay D, Nelson E, Vigerstol K, Mendoza G, Wolny S, Olwero N, Aukema J, Foster J, Forrest J, Cameron D (2008) InVEST 1.003 beta User's Guide. The Natural Capital Project, Stanford. http://www.naturalcapitalproject.org/InVEST.html

Tanács E (2005) The role of forest in the karstecosystem. Acta Climatol Chorol Univ Szegediensis 38-39:143-156

WRI (World Resources Institute) (2007) Nature's Benefits in Kenya - An Atlas of Ecosystems and Human Well-Being. World Resources Institute, Washington DC - Nairobi

Younger PL, Teutsch G, Custodio E, Elliot T, Manzano M, Sauter M (2002) Assessments of the sensitivity to climate change of flow and natural water quality in four major carbonate aquifers of Europe. In: Hiscock KM, Rivett MO, Davison RM (eds) Sustainable Groundwater Development. Geol Soc Special Pub 193:303-323

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TEMPERATURE AND PRECIPITATION TRENDS IN AGGTELEK KARST (HUNGARY) BETWEEN 1958 AND 2008

E TANÁCS

Department of Climatology and Landscape Ecology, University of Szeged, P.O.Box 653, 6701 Szeged, Hungary
E-mail: nadragulya@geo.u-szeged.hu

Summary: The study examines the temperature and precipitation data series of Jósvafő meteorological station (situated in the Aggtelek Karst region) in the period between 1958 and 2008 and analyses the characteristics of droughts and humid periods based on the Standard Precipitation Index. The results were interpreted on the basis of earlier forest historical investigations and forest structure analysis of nearby Haragistya-Lófej forest reserve as well as the ecological characteristics of the main tree species of the area. Annual mean temperature shows an increase from the mid-1980's while there is no detectable tendency in annual precipitation sums. After the droughts of the 1980's and 1990's, the 2000's show the presence of both extremities, sometimes shortly following each other. Ellenberg's Climate Quotient shows the transitional nature of the area (between oak- and beech-dominated forests), slightly favouring oak. However a small increase in the dominance of beech and the retreat of sessile oak is shown by historical records (and recently the evidence of deadwood) throughout the examined period. This emphasizes the modifying effect of earlier management activity and the role of local site characteristics, which strongly influence the reaction of species to changes in the climate and thus the dominance conditions.

Key words: climate change, Standard Precipitation Index, species dominance, forest reserve, Aggtelek Karst

1. INTRODUCTION

Forests are especially vulnerable to climate change, due to the longevity of trees. Through its impact on forest growth, climate change will affect both long-term wood supply and carbon sequestration in trees, forest soils and wood products (Kramer and Mohren 2001). Hungary being situated on the climatic boundary between forests and forest steppe vegetation there are concerns that many of our current forest areas would in the future be unable to fulfil their functions with the present species composition (see e.g. Mátyás 2008, Czúcz et al. 2011). However, as the mentioned authors also emphasize, this is a complex issue. On a smaller scale the forests of ecotones are not (only) affected by changes in annual means of climatic variables like precipitation sums or temperature, but by interannual climate variations (Bugmann and Pfister 2000). The 'edge' of the climatically determined range of tree species depends on the occurrences of shorter unfavourable (e.g. extremely dry) periods which cause significant damage in many individuals. The effect of drought on the vegetation is often postponed (Csóka et al. 2007); besides its direct effects on the plants, it is also a major factor in the outbreaks of forest pests (Csóka et al. 2007, Mátyás 2008). On the other hand the effect of these can be modified by the soil conditions (Gärtner et al. 2008). Efficient local adaptation and mitigation measures are only possible if the local trends and characteristics of the change are revealed. It is also yet unclear how the different species would react to the changes, which is especially important in the case of economically significant species like beech (*Fagus sylvatica*) or sessile oak (*Quercus petraea agg.*) (Rennenberg et al. 2004, Ammer et al. 2005).

Aggtelek Karst is one of the southern foothill regions of the Carpathians (Fig. 1). It is a highly diverse transitional area where continental, alpine and Mediterranean species occur together within short distances (Varga et al. 1998), which makes it especially sensitive to change. Karstic habitats are in many cases quite extreme due to erosion from previous management, further increasing this vulnerability. This makes the area suitable as an indicator of the effect of climatic change. Research in Haragistya-Lófej forest reserve suggests a recent shift in the tree species composition (Tanács et al. 2007, Tanács et al. 2010) but the reasons could be anthropogenic as well as natural, since the studied reserve had been heavily managed for centuries until its designation in 1993. In this paper I review what is known about the area's climate and analyse the trends of some ecologically important climatic variables in the vicinity of Haragistya-Lófej forest reserve between 1958 and 2008. Finally I would discuss the results with regard to the two main tree species of the area and their ecological characteristics.

2. MATERIAL AND METHODS

2.1. The study area

Gömör-Torna Karst is one of the southern foothill regions of the Carpathians. It is located in the northeast of Hungary, divided by the Hungarian-Slovakian border (the Hungarian side is called Aggtelek Karst) (Fig. 1). The area was placed under protection on both sides, its largest cave, the Baradla-Domica system being designated a UNESCO World Heritage Site in 1995. Aggtelek Karst mainly consists of a series of karst plateaus, elevated to a different extent. Their height above sea level varies between 400-600 m, while the valleys separating them are situated at about 200 m asl. The surface of the plateaus is dry; the vegetation's only source of water is precipitation. Because of its height and the nearby mountainous regions it is one of the coldest areas in Hungary. According to Trewartha's classification its climate is humid continental with a long summer and a strong mountainous influence (Fig. 2).

Several more or less detailed descriptions of the area's climate can be found in different publications (Jakucs 1975, Ujvárosy 1998, Maucha 2000). Maucha (1998) published a book about the water balance of the Aggtelek Karst area, including the daily temperature and precipitation data from 1958 until 1993 as well as the water yields of some springs. Some calculations were carried out concerning the probabilities of high precipitation days and certain annual precipitation sums, but apart from that none of the above studied the temporal changes of the variables.

In the different descriptions the average mean annual temperature values vary between 8.5°C and 9.1°C. The hottest month is July with an average mean monthly temperature of 19.2°C, the coldest is January (-2.8°C). The area is characterised by a long winter, the last frosty days usually occur at the end of April (Ujvárosy 1998).

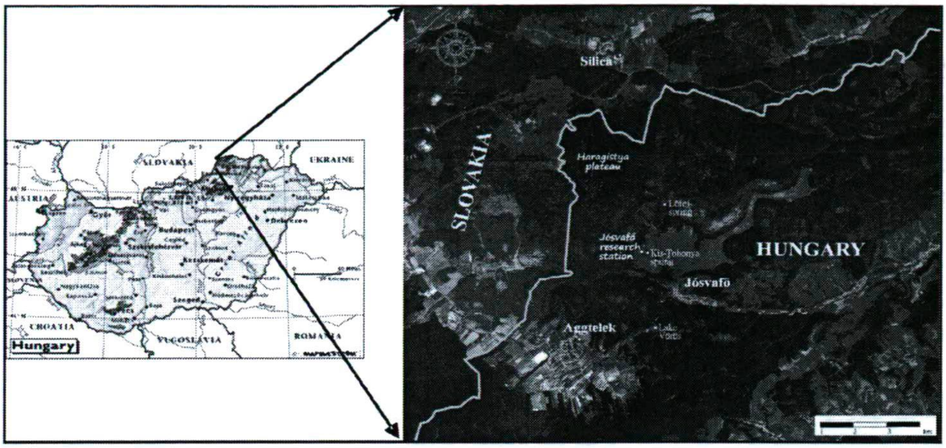


Fig. 1 The study area

The different mean annual precipitation values provided by the different authors vary depending on the period they used for the calculations (Table 1). It is interesting that after 1950, as the examined dataset gets longer (or is related to a later period), the mean values get lower. On the other hand Jakucs (1975) examined an earlier dataset and gave a mean value of 612 mm for the period 1901-1950. He stated that the precipitation in this area was less than in other similar regions in Hungary due to the surrounding higher mountains.

The driest months are February and March, the most humid June and July. There is a second precipitation maximum in November, which is a sign of sub-Mediterranean influence.

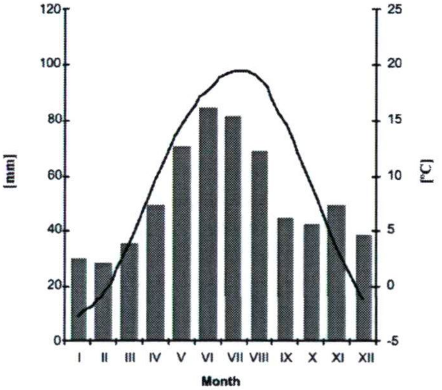


Fig. 2 Average mean monthly precipitation (columns) and temperature (line) at Jósvafő research station in the period 1958-2008

Table 1 Mean annual precipitation according to different authors

Author	Period	Mean annual precipitation (mm)
Jakucs (1975)	1901-1950	612
Ujvárosy (1998)	1940-1970	680
Maucha (2000)	1940-1998	648
The author's calculations based on data from Maucha (1998) and the Hungarian Meteorological Service	**1958-2008**	**620**

2.2. The dataset

The analysis is based on data from the meteorological station of Jósvafő, situated on a lower karst plateau at a latitude of 48°29'43"N and longitude of 20°32'10"E 270 m above sea level. 5 types of data were used:

- for the period 1958-1993 daily temperature and precipitation data published by Maucha (1998)
- for the period 1994-2000 only monthly precipitation and temperature data were available (courtesy of the Hungarian Meteorological Service)
- for the period 2001-2008 daily temperature and precipitation data from the daily weather report of the Hungarian Meteorological Service
- The daily discharge of two springs (Kis-Tohonya and Lófej) from January 1961 and 1965 respectively until December 1993 from the work of Maucha (1998)
- The water levels of Lake Vörös from 2004 to 2008 – data provided by the Directorate of Aggtelek National Park, extended by own measurements

The daily weather reports always relate to 7 am and contain data from the previous 24 hours: the minimum and maximum air temperature and the amount of precipitation. Daily mean temperatures for the period 2001-2008 were therefore calculated based on these two available values.

3. METHODS OF ANALYSIS

3.1. Climatic variables and Ellenberg's Climate Quotient

We used PASW Statistics 18 software for the analysis. Daily data were aggregated and monthly mean temperature was calculated as well as precipitation sums. There is no information about missing data from the period 1958-1993. In 1995, 1996 and 1997 some monthly means and yearly precipitation sums could not be directly calculated, these were replaced with the help of data from the nearby Silica station (Slovakia). After applying seasonal adjustment a linear trend was fitted on the adjusted data to see if there is a significant change over time and spectral analysis was carried out to trace further cycles. Makra's test (Makra et al. 2002, Makra et al. 2005) was applied on the annual precipitation sum and mean temperature data in order to identify sub-periods of which the means were significantly different from the overall mean. Ellenberg's Climate Quotient, a variable suitable to demonstrate the interplay of temperature and precipitation from the ecological point of view was calculated for each year with the following formula: mean July temperature/annual precipitation*1000 (Ellenberg 1988).

3.2. Drought

We studied the occurrence and length of drought and humid periods using the Standard Precipitation Index (McKee et al. 1993). The values of the SPI index are in fact standard deviation values (Table 2) calculated for a period defined by the user according to the time frames of the process to be studied. The main advantage of SPI is its simplicity: only monthly precipitation data are required for its calculation. Although it ignores temperature Hayes et al. (1999) found that the SPI identified the onset and severity of drought earlier than the widely used Palmer's Drought Severity Index (PDSI) (Palmer 1965).

Table 2 The meaning of SPI values

SPI value	Category
>2	Extremely wet
1.5 - 1.99	Very wet
1 - 1.49	Moderately wet
(-0.99) - 0.9	Normal
(-1) - (-1.49)	Moderately dry
(-1.5) - (-1.99)	Very dry
< (-2)	Extremely dry

In this study we first chose to examine the 3-month SPI, commonly used for agricultural predictions (Hayes et al. 1999). However, in order to specify the period related to the karst water supply, we compared the discharges of two springs (Lófej and Kis-Tohonya) and the water levels of one lake (Lake Vörös) with the SPI values calculated for periods of different lengths (Fig. 3). Since the distribution of the water data was not normal, we used Spearman's rank correlation for the comparison.

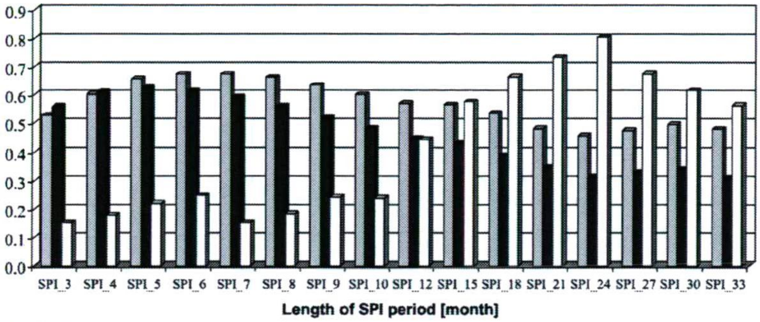


Fig. 3 Spearman's rho correlations between the discharge (or water level, in the case of Lake Vörös) and the values of SPI calculated for different periods (grey: Kis-Tohonya-spring, dark grey: Lófej-spring, white: Lake Vörös)

Lófej-spring has the lowest correlation values; the maximum is at the 5-month SPI. Kis-Tohonya is similar, but it shows the highest correlation with the 6- and 7-month SPI values. The water levels of Lake Vörös seem to have a rather stronger relationship with the precipitation trends of a longer period; the maximum is at the 24-month SPI. Based on these results, besides the 3-month SPI index, we chose to also examine the 6-month SPI values because the karst water supplies seem to depend on the precipitation trend of the previous 5-7 months and the 24-month SPI values because karst lakes seem to be most affected by these.

The 50 years time series was divided into 5 ten-year periods and we examined the number, average length and maximum magnitude of the dry and humid periods.

4. RESULTS

4.1. Temperature

According to our dataset the average annual mean temperature of the period between 1958 and 2008 is 8.9°C.

Makra's test identified one period with a significantly lower mean, which basically divides the dataset in 3 different parts (Fig. 4). The first period from 1958 to 1974 is characterised by an annual mean temperature of 8.9°C including both warmer and colder years. From the year 1974 a colder period started with an average of 8.4°C and the annual mean temperature never exceeded 9.3°C. The change was caused by cooler summers. The test marked the end of this period in 1992; the mean of the last 16 years is 9.6°C. The higher mean covers an increase in both the maximum and minimum values: while in some years (1995, 2007) the annual mean temperatures exceeded 10°C and almost reached 11°C there were no really cold years (annual mean under 8°C) and from 1998 there were hardly any values under 9°C. There is an apparent warming trend from the beginning of the 1980's.

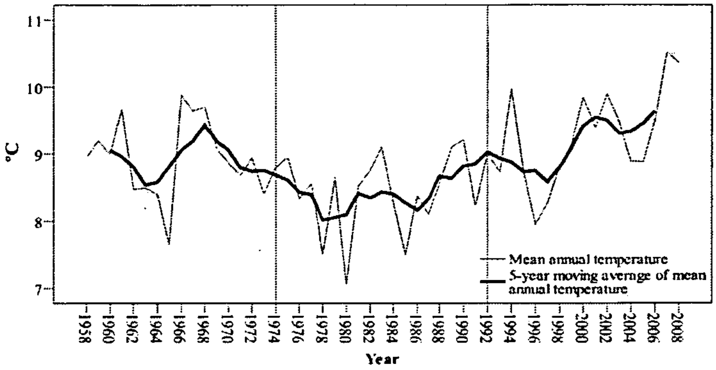


Fig. 4 Annual mean temperatures (1958-2008)

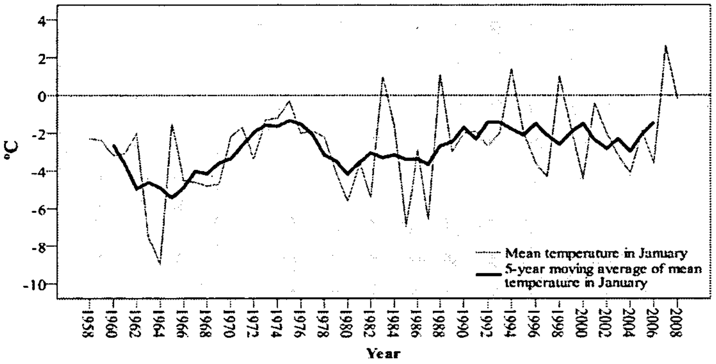


Fig. 5 Mean monthly temperatures in January (1958-2008)

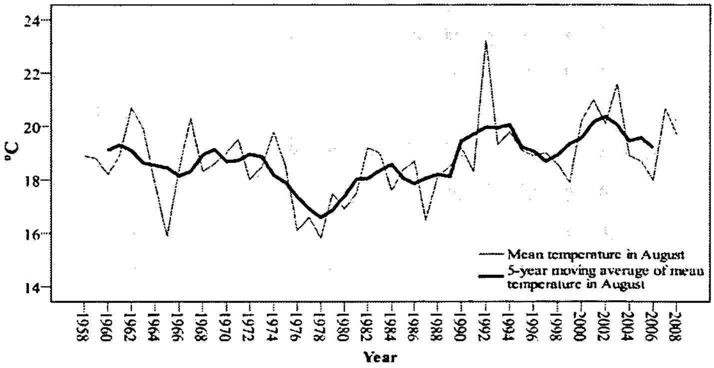


Fig. 6 Mean monthly temperatures in August (1958-2008)

There are two individual months with a significant linear trend: January and August. In both cases an increase seems to be occurring (Fig. 5, Fig. 6); the increase in January is almost continuous over the studied period (with higher averages in the first half of the

1970's) whereas in August the cooler period identified in the annual data appears and thus the warming trend seems to start in the second half of the 1970's.

4.2. Precipitation

In accordance with data from the literature a decrease could be expected in the mean annual precipitation in the Aggtelek area. Besides the authors presented in Table 1, Barančok (2001) also studied the climate of this area (based on data from Silice, Slovakia, approximately 6 km from Jósvafő meteorological station) and found that the annual mean precipitation in the period between 1981 and 1998 was 20-70 mm less than in the base period between 1931 and 1960. However our results show that there is no significant change based on the examined 50-year dataset (Fig. 7). One possible reason for this is that the datasets of the other authors (including Barančok) contained the data of a very humid period between 1947 and 1955 when the mean annual precipitation reached 760 mm whereas the measurements at Jósvafő meteorological station only started in 1958. This could mean that it was the middle of the 20th century which was uncharacteristically humid rather than the area recently becoming drier. It is also the lack of the occasional high-precipitation years (with an annual sum exceeding 750 mm) since the 1980's which could negatively influence the mean.

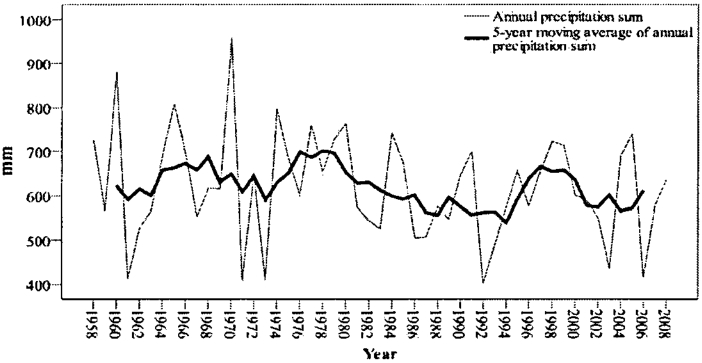


Fig. 7 Annual precipitation sums (1958-2008)

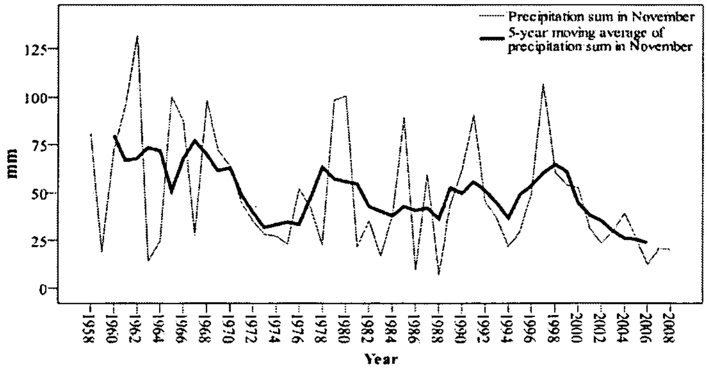


Fig. 8 Precipitation sums in November (1958-2008)

Fig. 7 shows no apparent changes in the length of dry spells, nor in the minimum values or their frequency. There is also an apparent decrease in the short-term fluctuation; the differentces between the sums of following years are smaller. Regarding single months, only the precipi-tation sums in November seem to have a downward trend (Fig. 8) probably caused by the low values of the 2000's.

4.3. Ellenberg's Climate Quotient

According to Ellenberg (1988) this index corresponds to the climatic boundary between beech and oak dominated forests; above 30, the latter become dominant. Gálhidy et al. (2006) found that it corresponded well with the current occurrence of beech forests in Hungary. Fig. 9 shows the values of the quotient calculated for the study area; it clearly indicates that Aggtelek Karst is indeed a transi-tional area between the two types of forests, since the values fluctuate around 30 with a mean of 32.6. Whereas there is no clear trend of increase or decrease, the occasional lower values (under 25), which were common before, are missing since the late 1980's.

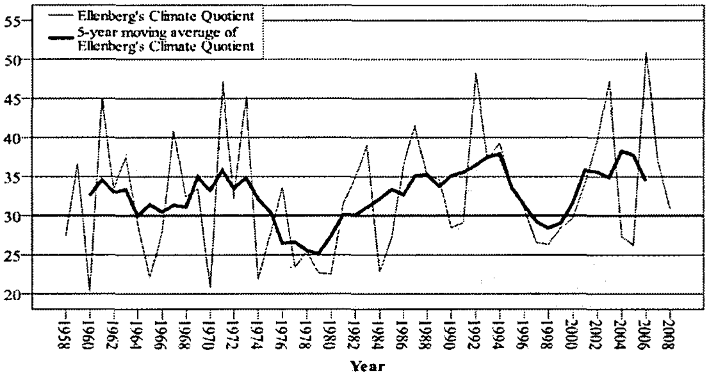
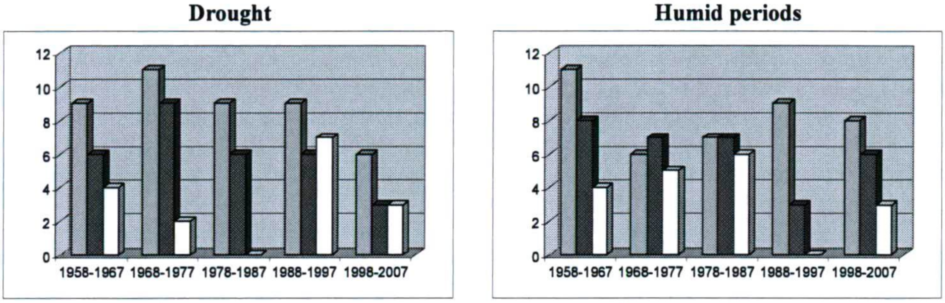


Fig. 9 Ellenberg's Climate Quotient (1958-2008)

4.4. SPI

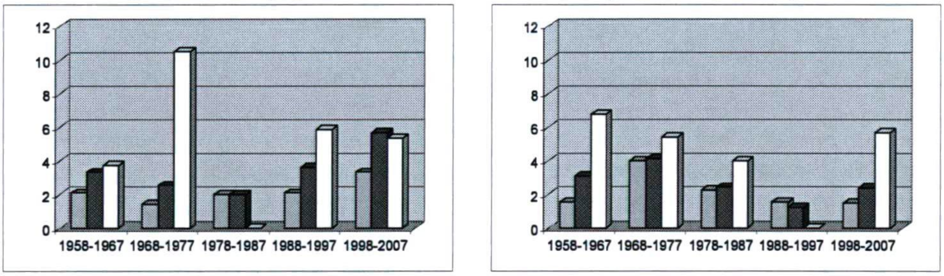
The number of dry spells (Fig. 10a) seems to be quite stable most of the time (around 6 times/10 years), it only increased from period I (1958-1967) to period II (1968-1977) and drought occurred less frequently in the last 10 years (1998-2007). The number of humid periods (Fig. 10d) differs in the case of all the 3 SPI indices used: 6-month humid periods (SPI6) are fairly stable, their number only decreased between 1988 and 1997. 3-month SPI (SPI3) first shows a sudden decrease compared to the first examined period, then a gradual increase and a slight decrease again in the last 10 years. According to the 24-month SPI (SPI24) the number of humid periods increased until the period of 1978-1987, and then came a dry spell between 1988 and 1997 and a slight improvement in the last 10 years.

The average length of dry periods (Fig. 10b) for the 3- and 6-month SPI show a small gradual decrease until period III (1978-1987) and then a stronger increase; drought in the last 10 years lasted on average for double the time than before. The average length of humid periods (Fig. 10e) in the case of the 6-month SPI has continuously decreased from period II (1967-1978). 6- and 24-month SPI behave similarly but show a slight increase in the last 10 years.



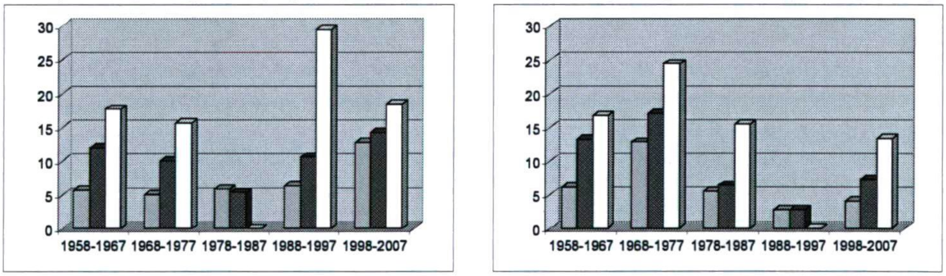
a) Number of dry spells

d) Number of humid periods



b) Average length of dry spells [month]

e) Average length of humid periods [month]



c) Maximum magnitude of drought

f) Maximum magnitude of humid periods

Fig. 10 Characteristics of dry and humid periods over the last 50 years
(grey: SPI3; dark grey: SPI6; white: SPI24)

The maximum magnitude of drought (Fig. 10c) in the case of the 3-month SPI was fairly stable in the first four examined periods and increased in the last 10 years. In the case of the 6-month SPI drought intensity first decreased, then increased from the period 1978-1987. Drought events based on the 24-month SPI seem to be more drastic; whereas there was no drought event occurring in the period 1978-1987, the next decade produced a very high maximum magnitude, which decreased a bit in the last decade but is still higher than before. All the 3 indices give the same results for the maximum magnitude of humid periods (Fig. 10f): after an initial increase they decreased continuously until the period 1988-1997 and produced a slight increase in the last 10 years.

The period between 1968 and 1977 included two of the driest years of the last 50 years and the wettest as well. These extremities are shown well by the drought index calculated for 24-month periods: both the highest average length of drought and the highest magnitude of humid periods occurred in this decade. The following ten years were fairly normal, without extremities. A really dry decade followed, lasting from 1988 till 1997 with very few humid periods and a high number of strong droughts. The last ten years brought a bit of relief but also another series of extremities. While the frequency of dry spells dropped, the magnitude of drought increased drastically, parallel with an increase in the average length and magnitude of the humid periods.

5. DISCUSSION

The most common tree species in the Aggtelek area is sessile oak (Quercus petraea agg.) and (considering the values of the Ellenberg climate index) the macroclimatic conditions seem to have been favourable for this species to be dominant in the last 50 years. However the oak decline beginning in the end of the 1970's reached this area as well and according to the forest inventory the proportion of sessile oak in the stands of the Haragistya plateau started to decrease at this time (Tanács et al. 2007). Several studies discussed the phenomenon (e.g. Jakucs 1984, Igmándy et al. 1984, 1986, Vajna 1989, Jakucs 1990, Berki 1993) and in the end it was agreed that the drivers behind it were complex and mainly related to the severe droughts in the 1980's (Führer 1998). According to Berki (1993)'s investigations in the Northern Mountain Ranges, sessile oak forests on dry sites were more affected, due to a latent lack of nitrogen in connection with the lack of water. Recent studies on the changes of species composition in such sites indicate that Turkey oak (*Quercus cerris*) is less affected by extreme periods (Mészáros et al. 2007) and also that sessile oak is in many places slowly being replaced with shade-tolerant species such as field maple (*Acer campestre*) or hornbeam (*Carpinus betulus*) and common ash (*Fraxinus excelsior*) (Kotroczó et al. 2007, Krakomperger et al. 2008, Mázsa et al. 2009, Misik és Kárász 2009). Our findings in Haragistya-Lófej forest reserve, based on the evidence of deadwood, also show a similar trend (Tanács et al. 2010). This can be explained by former management practices, which aimed to favour sessile oak. Recruitment of the species is also unfavourably affected by heavy browsing due to the ever increasing numbers of game.

According to Ellenberg (1988) European beech (*Fagus sylvatica*) should play a dominant role in most European temperate forests due to its high physiological tolerance and competitiveness. In the east, the north and at higher elevations its range is limited by winter and late spring frosts (Standovár és Kenderes 2003), while in the south and at lower elevations the major limiting factor is the lack of water. However its wood could not be used as building material before the late 19th century, therefore beech was artificially suppressed and sessile oak favoured in its sites (Csesznák 1985, Bartha 2001). Probably this is an important reason for the current debate (see Geßler et al. 2007) on how its range would be affected by climate change – its current distribution reflects anthropogenic impact rather than natural tolerance limits. On one hand ecophysiological experiments prove that the growth and competitiveness of young beech trees decreases as drought events become more frequent (Rennenberg et al. 2004), on the other hand some researchers found that the species tolerates drought much better than previously supposed (Peters 1997). Ammer et al. (2005) found that although the rate of growth of beech does indeed decrease in times of water stress, competitiveness does not.

The data from Jósvafő Research Station, situated 2 km south of Haragistya-Lófej forest reserve, at a slightly lower elevation suggest that although it is a transitional area the macroclimatic conditions in the last 30 years rather favoured the dominance of oak species. The Ellenberg Climate Quotient did not much decrease even in the cooler period at the end of the 1970's because the annual precipitation sums were also lower at this time. The frequent and strong drought events of the late 1980's and the 1990's should have caused a retreat of beech whereas the forest inventories show a small but constant increase in dominance, mainly where the bedrock is dolomite (Tanács et al. 2007). Our more recent results based on the species composition of dead wood and the spatial distribution of young trees show that beech seems to be spreading rather than retreating (Tanács et al. 2010) however it is only dominant in sites with favourable soil and microclimatic conditions, such as valleys, dolines and northern slopes. Czájlik et al. (2003) studied changes in the species composition of beech-dominated forests in Alsóhegy forest reserve (about 10 km to the west, also situated in Aggtelek Karst) between 1993 and 2003 and did not experience changes related to drought either.

The forecasts of different regional climate models for the Carpathian basin for the period 2071-2100 unambiguously predict an increase in temperature. There are different predictions concerning the annual precipitation sums, but increase is not very probable (Bartholy et al. 2008). The models also predict an increasing frequency of extreme events (Szépszó 2008), which could result in a growing importance of single disturbance events, such as droughts or windstorms. According to the bioclimatic distribution model of Czúcz et al. (2011) 56-99% of current zonal beech forests and 82-100% of sessile oak forests may be outside their present bioclimatic niche by 2050. However our experiences in Aggtelek Karst suggest that such results should be handled carefully. Since the current ranges and dominance conditions are not only defined by the ecophysiological characteristics of the different tree species, we might be in for some surprise concerning their behaviour in the future. It also draws attention to the fact that even in the case of stands near the xeric limit the site conditions (soil and microclimate) play an important role in the survival of the stands.

6. CONCLUSION

While annual mean temperature shows an increase from the mid-1980's there is no detectable tendency in annual precipitation sums. Ellenberg's Climate Quotient shows the transitional nature of the area (between oak- and beech-dominated forests), slightly favouring oak. After severe droughts and lack of humid periods in the 1980's and 1990's, the 2000's show the presence of both extremities, sometimes shortly following each other. Despite the conditions apparently favouring oak, a small increase in the dominance of beech and the retreat of sessile oak is shown by historical records (and recently the evidence of deadwood) throughout the examined period. While there are serious concerns about the future of economically important tree species in Hungary, these results emphasize the modifying effect of earlier forest management and the role of local site characteristics, which strongly influence the reaction of species to changes in the climate and thus the dominance conditions.

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REFERENCES

Ammer C, Albrecht L, Borchert H, Brosinger F, Dittmar C, Elling W, Ewald J, Felbermeier B, Gilsa H, Huss J (2005) Future suitability of beech (Fagus sylvatica L.) in Central Europe: critical remarks concerning a paper of Rennenberg, et al. 2004. Allgemeine Forst- und Jagdzeitung 176: 60-67

Barančok P (2001) Karst lakes of the protected landscape area – biosphere reserve Slovensky Kras Karst and Aggtelek National Park. Ekológia 20:157-190

Bartha D (2001) Veszélyeztetett erdőtársulások Magyarországon. [Endangered forest communities in Hungary. (in Hungarian)] WWF füzetek 18

Bartholy J, Pongrácz R, Gelybó G, Szabó P (2008) Analysis of expected climate change in the Carpathian Basin using the PRUDENCE results. Időjárás 112(3-4):249-264

Berki I (1993) Az Északi-középhegységi kocsánytalan tölgy-pusztulás néhány okának vizsgálata. [Investigation of some reasons of sessile oak decline in the Northern Mountain Ranges. (in Hungarian)] Doctoral dissertation, University of Debrecen. Manuscript.

Bugmann H, Pfister C (2000) Impacts of interannual climate variability on past and future forest composition. Regional Environmental Change 1:112-125

Csesznák E (1985) A kocsánytalantölgy-pusztulás az erdőművelő szemével. [Sessile oak decline with the eyes of the forester. (in Hungarian)] Az Erdő 34/120(8):347-350

Csóka G, Koltay A, Hirka A, Janik G (2007) Az aszályosság hatása kocsánytalan tölgyeseink és bükköseink egészségi állapotára. [The effect of drought on the health of Hungarian sessile oak and beech forests. (in Hungarian)] Erdő és klíma 5:229-241

Czájlik P, Gálhidy I, Kenderes K, Mihók B, Ódor P, Standovár T, Tímár G (2003): Report on Site-based Permanent Plot, Second-phase and New Mapping Studies: Alsóhegy Forest Reserve. Working report. Forest & Landscape Denmark (NAT-MAN project)

Czúcz B, Gálhidy L, Mátyás Cs (2011) Present and forecasted xeric climatic limits of beech and sessile oak distribution at low altitudes in Central Europe. Annals of Forest Science (in print)

Ellenberg H (1988) Vegetation Ecology of Central-Europe. Cambridge University Press, Cambridge, New York

Führer E (1998) Oak Decline in Central Europe: A Synopsis of Hypotheses. In: McManus ML, Liebhold AM (eds) Proceedings: Population Dynamics, Impacts, and Integrated Management of Forest Defoliating Insects. USDA Forest Service. 7-24

Gálhidy L, Czúcz B, Torre F (2006) Zonal forest types, climatic variables and effect of changes for Hungary. Lesnícky časopis 51(1-2):99-105

Gärtner S, Reif A, Xystrakis F, Sayer U, Bendagha N, Matzarakis A (2008) The drought tolerance limit of Fagus sylvatica forest on limestone in southwestern Germany. Journal of Vegetation Science 19:757-768

Geßler A, Keitel C, Kreuzwieser J, Matyssek R, Seiler W, Rennenberg H (2007) Potential risks for European beech (Fagus sylvatica L.) in a changing climate. Trees - Structure and Function 21:1-11

Hayes MJ, Svoboda MD, Wilhite DA, Vanyarkho OV (1999) Long-term effects of climate change on carbon budgets of forests in Europe. Bulletin of the American Meteorological Society 80(3):429-438

Igmándy Z, Pagony H, Szontagh P, Varga F (1984) Beszámoló a kocsánytalan tölgyeseinkben fellépett pusztulásról 1978-1983. [Report on the decline in Hungarian sessile oak forests between 1978-1983. (in Hungarian)] Az Erdő 33/119(8):334-341

Igmándy Z, Béky A, Pagony H, Szontagh P, Varga F (1986) A kocsánytalan tölgypusztulás helyzete hazánkban 1985-ben. [The state of sessile oak decline in Hungary in 1985. (in Hungarian)] Az Erdő 38/124(6):255-259

Jakucs L (1975) Aggteleki karsztvidék útikalauz. [Aggtelek Karst guide. (in Hungarian)] Sport Kiadó, Budapest

Jakucs P (1984) A kocsánytalan tölgyek pusztulásának ökológiai magyarázata. [The ecological explanation of sessile oak decline. (in Hungarian)] Az Erdő 33/119(8):342-344

Jakucs P (1990) A magyarországi erdőpusztulás ökológiai megközelítése. [The ecological apprach of the Hungarian forest dieback. (in Hungarian)] Fizikai Szemle 40(8):225

Kotroczó Zs, Krakomperger, Zs, Koncz G, Papp M, Bowden RD, Tóth JA (2007) A síkfőkúti cseres-tölgyes fafaj-összetételének és struktúrájának hosszú távú változása. [Long-term changes in the species composition and structure of the Turkey oak-sessile oak stands at Síkfőkút. (in Hungarian)] Természetvédelmi Közlemények 13:93-107

Krakomperger Zs, Kotroczó Zs, Koncz G, Papp M, Veres Z, Tóthmérész B, Tóth JA (2008) Egy cseres-tölgyes erdő fa-megújulási dinamikájának vizsgálata. [Recruitment dynamics in a Turkey oak-sessile oak forest. (in Hungarian)] In: Molekuláktól a globális folyamatokig V. Magyar Természetvédelmi Biológiai Konferencia programme and abstracts

Kramer K, Mohren GMJ (2001) Long-term effects of climate change on carbon budgets of forests in Europe. Alterra-report 194. Green World Research, Wageningen

Makra L, Horváth Sz, Pongrácz R, Mika J (2002) Long term climate deviations: an alternative approach and application on the Palmer drought severity index in Hungary. Physics and Chemistry of the Earth, Part B - Hydrology, Oceans and Atmosphere 27:1063-1071

Makra L, Juhász M, Béczi R, Borsos E (2005) The history and impacts of airborne *Ambrosia* (Asteraceae) pollen in Hungary. Grana 44(1):57-64

Mátyás Cs (2008) Valóban vándorolni fognak-e erdeink a klímaváltozás következtében? [Will Hungarian forests really move as a consequence of climate change? (in Hungarian)] Erdészeti Lapok 143(1):18-20

Maucha L (1998) Az Aggteleki-hegység karszthidrológiai kutatás eredményei és zavartalan hidrológiai adatsorai, 1958-1993. [Results of the karst hydrological research in Aggtelek Mts and its unbiased hydrological data 1958-1993. (in Hungarian)] Vízgazdálkodási Tudományos Kutató Részvénytársaság Hidrológiai Intézete, Budapest

Maucha L (2000) Éghajlati viszonyok. [Climate conditions. (in Hungarian)] In: Szablyár P, Szmorad F (eds) Jósvafő: Település a források és barlangok völgyében. Jósvafő település önkormányzat, Jósvafő

Mázsa K, Horváth F, Balázs B, Bölöni J, Aszalós R (2009) A felsőtárkányi Vár-hegy erdőrezervátum faállományának korosztály viszonyai erdőtörténeti összefüggésben. [The age structure of the stands in Vár-hegy Forest Reserve in the context of forest history. (in Hungarian)] Természetvédelmi Közlemények 15:347-357

McKee TB, Doesken NJ, Kleist J (1993) The relationship of drought frequency and duration to time scales. In: 8th Conference on Applied Climatology, Anaheim, US

Mészáros I, Koncz P, Kanalas P, Veres S, Sárvári É, Oláh V, Szöllősi E (2007) A kocsánytalan tölgy és a csertölgy ökofiziológiai sajátosságai kontrasztos időjárású években. [Ecophysiological characteristics of sessile oak and Turkey oak in years with contrasting weather. (in Hungarian)] Erdő és klíma 5:183-197

Misik T, Kárász I (2009) A síkfőkúti erdő cserjeszintjének struktúra változásai 2002 és 2007 között – egyedszám és méret. [Structural changes in the shrub layer of the Síkfőkút project getween 2002 and 2007 – number and size. (In Hungarian)] Természetvédelmi Közlemények 15:358-368

Palmer WC (1965) Meteorological Drought. Research Paper 45 US Weather Bureau, Washington, DC

Peters R (1997) Beech forests. Springer.

Rennenberg H, Seiler W, Matyssek R, Geßler A, Kreuzwieser J (2004) Die Buche (Fagus sylvatica L.) – ein Waldbaum ohne Zukunft im südlichen Mitteleuropa? Allgemeine Forst- und Jagdzeitung 175(10-11):210-224

Standovár T, Kenderes K (2003) A review on natural stand dynamics in beechwoods of East Central Europe. Applied Ecology and Environmental Research 1(1-2):19-46

Szépszó G (2008) Regional change of climate extremes over Hungary based on different regional climate models of the PRUDENCE project. Időjárás 112(3-4):265-284

Tanács E, Szmorad F, Kevei-Bárány I (2007) A review of the forest management history and present state of the Haragistya karst plateau (Aggtelek Karst, Hungary). Acta Carsologica 36(3):441-451

Tanács E, Szmorad F, Bárány-Kevei I (2010) Patterns of tree species composition in Haragistya-Lófej forest reserve (Aggtelek karst, Hungary). In: Barančoková M, Krajčí J, Kollár J, Belčáková I (eds) Landscape ecology - methods, applications and interdisciplinary approach. Institute of Landscape Ecology, Slovak Academy of Sciences, Bratislava. 767-780

Ujvárosy A (1998) Földrajzi helyzet, éghajlati viszonyok. [Geographical position, climate. (in Hungarian)] In: Baross G (ed) Az Aggteleki Nemzeti Park. Mezőgazda Kiadó, Budapestl. 22-26

Vajna L (1989) A kocsánytalan tölgy pusztulásának kórok és járványtani kérdései. [Causal and epidemiological questions of sessile oak decline. (in Hungarian)] Az Erdő 38/124(4):149-153

Varga Z, Vargáné Sipos J, Horváth R, Tóth E (1998) Az Aggteleki-karszt élővilága. [The wildlife of Aggtelek Karst. (in Hungarian)] In: Baross G (ed) Az Aggteleki Nemzeti Park. Mezőgazda Kiadó, Budapest. 254-333

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ASSESSMENT OF BIOCLIMATIC COMFORT USING ARTIFICIAL NEURAL NETWORK MODELS – A PRELIMINARY STUDY IN A REMOTE MOUNTAINOUS AREA OF SOUTHERN GREECE

KI CHRONOPOULOS[1], IX TSIROS[2] and N ALVERTOS[1]

[1] Department of Chemical and Physical Sciences, Faculty of Sciences, Agricultural University of Athens, Iera Odos 75, 11855, Athens, Greece, E-mail: kchrono@aua.gr
[2] Department of Geologic Sciences and Atmospheric Environment, Faculty of Sciences, Agricultural University of Athens, Iera Odos 75, 11855, Athens, Greece

Summary: This work presents an artificial neural network (ANN) model-based approach to assess bioclimatic conditions in remote mountainous areas using a relatively limited number of microclimatic data from easily accessible meteorological stations. Seven meteorological stations were established in the mountainous area of Samaria Forest canyon (Greece). ANN models were developed to predict air temperature and relative humidity for the five most remote stations of the area using data only from two stations located in more easily accessible sites. Measured and model-estimated data were compared in terms of the determination coefficient, the mean absolute error and residuals normality. Then, the developed ANN models were used to predict values of the thermohygrometric (THI) bioclimatic index on hourly basis for the five most remote stations using the model-predicted air temperature and humidity data and to evaluate the comfort THI categories. These results were then compared to THI classes obtained using the measured air temperature and relative humidity data recorded at the stations. Results showed that appreciable percentages of successful forecasts were achieved by the ANN models, indicating therefore that ANNs, when adequately trained, could successfully be used in practical applications of bioclimatic comfort in remote mountainous areas.

Key words: microclimate, artificial neural networks, thermal comfort, thermohygrometric (THI) index

1. INTRODUCTION

Human thermal comfort conditions may be assessed through a number of theoretical and empirical indices requiring usually a larger or smaller number of input microclimate parameters (Mayer 1993). In several cases, however, meteorological data in the desired or required spatial resolution are not readily available, e.g., in mountain regions due to the complex terrain, or due to the sparse network of the meteorological stations. In such cases, there is a need to estimate data for meteorological parameters not recorded at several locations from observations of the same variable recorded at other sites. Spatial data interpolation and process-based techniques have, however, important limitations in complex terrain areas (e.g. Tveito and Schöner 2002) whereas sometimes much simpler methods are used (e.g. Tang and Fang 2006).

Recently, artificial neural network (ANN) models have been started to be used for spatial data interpolation (Chronopoulos et al. 2008, Cheng et al. 2002, Rigol et al. 2001). ANN applications to various bioclimatic aspects is, however, still limited (e.g. Grinn-Gofroń and Strzelczak 2008, Incerti et al. 2007, Sánchez Mesa et al. 2005) despite their increasing use in various atmospheric studies (e.g. Tsiros et al. 2009, Wang and Lu 2006, Dimopoulos et al. 2004, Chaloulakou et al. 2003). In general, ANNs contain no critical assumptions about the nature of spatial data and are well suited to processing noisy data and handling non-linear modeling tasks (Openshaw and Openshaw 1997). The purpose of the present preliminary study is to illustrate the development and application of ANN models to assess bioclimatic comfort in a series of sites inside a remote mountainous canyon based on meteorological values recorded at reference stations located in easily accessible areas.

2. MATERIALS AND METHODS

2.1. Study area and microclimatic data

The application site is the canyon of Samaria, a mountainous forest, located in the southwest part of Crete Island in southern Greece. The canyon extends from 35°18'27"N and 23°55'06"E to 35°14'40"N and 23°58'01"E, covering a total distance of about 18 km. The only way to cross the canyon is on foot and only during the summer. The entrance of the canyon is closed during the winter, because of the danger of falling rocks and flood. The dataset used consists of measured mean hourly temperature and humidity data for 7 meteorological stations established in the canyon for the purposes of the present study and for the following time periods: 12/6/2003 – 4/8/2003, 6/8/2004 – 15/9/2004 and 20/6/2005 – 27/10/2005. Fig. 1 shows the terrain of the study area and the locations of the meteorological stations along the canyon. The geographic coordinates of the locations of the stations are given in Table 1 whereas typical statistics of the measured air temperature and relative humidity data are shown in Table 2.

Table 1 The geographic coordinates of the locations of the stations

Station	Longitude (Eastern)	Latitude (Northern)	Elevation
S_1	23°55'06"	35°18'27"	1200 m
S_2	23°56'10"	35°18'24"	640 m
S_3	23°56'53"	35°18'00"	490 m
S_4	23°57'31"	35°17'29"	340 m
S_5	23°57'44"	35°16'56"	290 m
S_6	23°58'04"	35°15'29"	190 m
S_7	23°58'01"	35°14'40"	120 m

Table 2 Statistics of the measured air temperature (°C) and relative humidity (%) data: mean and standard deviation (S.d.) values

Station		12/06/2003 to 04/08/2003		06/08/2004 to 15/09/2004		20/06/2005 to 27/10/2005	
		Mean	S.d.	Mean	S.d.	Mean	S.d.
S_1	Temp. (°C)	22.0	3.0	18.8	4.5	18.1	4.8
	RH (%)	38.3	9.5	51.9	19.8	59.9	16.0
S_2	Temp. (°C)	28.1	3.6	24.4	5.3	23.2	6.1
	RH (%)	33.8	12.4	37.6	15.4	44.0	19.6
S_3	Temp. (°C)	26.8	3.9	24.9	4.4	23.4	5.4
	RH (%)	34.7	12.3	38.4	13.4	45.8	20.5
S_4	Temp. (°C)	26.5	3.8	24.9	4.0	23.7	4.3
	RH (%)	35.2	12.2	38.3	12.2	51.0	23.1
S_5	Temp. (°C)	26.8	4.1	25.3	4.1	23.8	5.7
	RH (%)	39.0	14.1	40.0	13.0	50.8	24.5
S_6	Temp. (°C)	26.3	3.3	25.4	3.2	24.2	4.6
	RH (%)	46.9	15.5	46.1	13.5	47.6	17.2
S_7	Temp. (°C)	27.2	2.8	25.9	3.0	25.5	4.5
	RH (%)	44.1	13.4	45.5	12.9	48.3	15.4

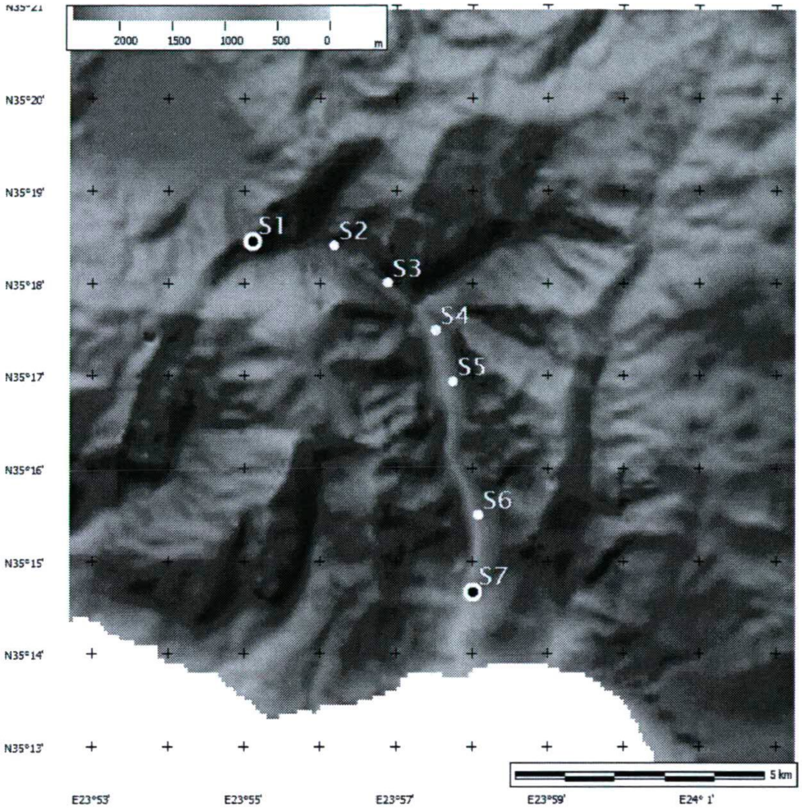

Fig. 1 Terrain of the study area and locations of the meteorological stations along the canyon

2.2. The biometeorological index

To assess human thermal comfort, the well known thermohygrometric (THI) index was used. THI was developed by Thom (1959) and was supported by a later work of Clarke and Bach (1971). THI is a simple index suitable for open spaces. For the calculations, the THI equation with air temperature (°C) and relative humidity was used along with the THI categories according to Kyle (1994):

$$\mathrm{THI} = \mathrm{T} - (0.55 - 0.0055 \cdot \mathrm{RH}) \cdot (\mathrm{T} - 14.5) \qquad (1)$$

where T: ambient air temperature (°C); RH: ambient relative humidity (%).

2.3. The Artificial Neural Network (ANN) models

An artificial neural network involves a network of simple processing elements (artificial neurons) which can exhibit complex global behavior, determined by the connections between the processing elements and element parameters. For modeling, the multilayer perceptron (MLP) artificial neural network model was adopted whereas for model training the back propagation algorithm was used (Rumelhart et al. 1986). Figure 2 shows a rough schematic figure of the MLP ANNs that were used in the present study. There is an input layer, a hidden layer of five units and the output layer. The connections between the layers are feedforward only and their weights and thresholds are determined by the training procedure of the neural network. The training set consisted of ½ of the data, the selection set of ¼ of the data and the test set of the remaining ¼ of the data, randomly assigned.

For the MLP, the output with one hidden layer is given by:

$$f(x)=\phi^{s}\left(\sum_{i=1}^{I} w_{is}\phi^{i}\left(\sum_{e=1}^{n} w_{ei}x_{e}+w_{0}\right)+w_{s}\right) \tag{2}$$

where I is the number of hidden nodes, n is the number of input variables, w_{ei} and w_{is} are the weights of the input-to-hidden and hidden-to-output layer, w_0 and w_s are the corresponding thresholds (bias), ϕ^i and ϕ^s are the units' activation functions.

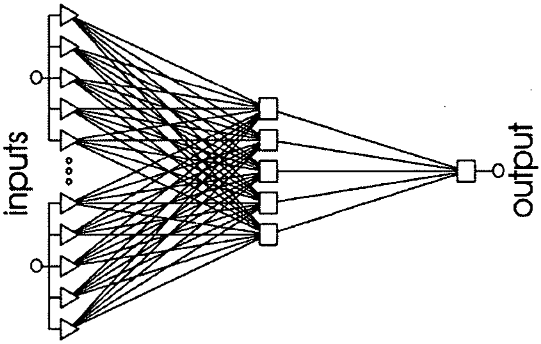

Fig. 2 General schematic figure of the MLP Artificial Neural Networks that were used.

The activation function for the hidden units as well as the output unit is the logistic sigmoid function $\phi(x)=\left(1+e^{-x}\right)^{-1}$. A major consideration in the use of MLP for model building is the determination of the optimal architecture of the network (number of inputs, number of layers and number of nodes per layer). Usually, a trial-and-error method is applied to test various alternative models. The model networks developed in the present study use one hidden layer with 5 nodes since it was found that this is the number of layers that gives the best results on the selection set.

3. RESULTS AND DISCUSSION

The first step was to develop ANN models to predict air temperature and humidity for the most remote stations of the area, $S_2 - S_6$, using data only from stations S1 (entrance of the canyon) and S_7 (end of the canyon), located in more easily accessible areas. Measured and estimated data of both air temperature and relative humidity were compared in terms of the determination coefficient (R^2) and the mean absolute error (MAE). It was found that R^2 values range from 0.7 to 0.9 for air temperature and from 0.7 to 0.8 for relative humidity; MAE values range from 0.9 to 1.8 °C and 5 to 9%, for air temperature and relative humidity, respectively. The normality of the residuals was also examined using the Shapiro-Wilk normality tests and it was found that residuals have a normal distribution. In addition, the results of the ANN models were compared to results obtained from regression analyses. The multiple linear regression was used just to compare the ANN results with this widely accepted methodology and to examine the efficiency of ANNs. The multiple linear regression had the same inputs as the neural networks used in this study.

The values of the determination coefficients and the mean absolute errors for the two different modelling techniques are shown in Tables 3 and 4, for the air temperature and the relative humidity, respectively. The comparison indicates, in general, the superiority of the ANN models, especially in the case of the relative humidity estimations.

Table 3 Air temperature estimations at the remote stations: determination coefficients (R^2) and mean absolute error (MAE) of the linear regression and the ANN models

Station	**Multiple Linear Regression Model**		**ANN Model**	
	R^2	**MAE, °C**	**R^2**	**MAE, °C**
S_2	0.89	1.5	0.90	1.4
S_3	0.89	1.4	0.89	1.3
S_4	0.69	1.9	0.72	1.8
S_5	0.85	1.6	0.86	1.6
S_6	0.91	1.0	0.92	0.9

Table 4 Relative humidity estimations at the remote stations: determination coefficients (R^2) and mean absolute error (MAE) of the linear regression and the ANN models

Station	**Multiple Linear Regression Model**		**ANN Model**	
	R^2	**MAE, %**	**R^2**	**MAE, %**
S_2	0.79	6.7	0.83	5.6
S_3	0.75	7.3	0.80	6.3
S_4	0.65	9.7	0.73	8.6
S_5	0.65	10.3	0.73	8.9
S_6	0.79	4.7	0.80	4.6

The next step was to use the developed ANN models to predict bioclimatic data values using the model-predicted air and humidity data for the five most remote stations S_2 – S_6. The ANN-predicted values of THI were then used to estimate the THI categories of human comfort; results in terms of relative frequencies are shown in Table 5. The final step was to compare these results to the THI classes obtained using the measured air temperature and relative humidity data recorded at the five stations S_2 – S_6 (Table 5). The comparison in Table 5 shows that appreciable percentages of successful forecasts were achieved by the ANN models. The highest successful rate is achieved for station S_6 located in the vicinity of the sea. In addition, five THI classes were found in both cases, with the largest percentage to be associated with the 'Cool' class. With the exception of the 'Comfortable' class, all other classes appear in small percentages in both cases. It should be noted, however, that the parameters of wind speed and radiation were not considered in the present study since reliable data of those parameters are not always available for remote areas despite the fact that their variability is expected to affect significantly the thermal stress conditions. Reliable data of those parameters were not available for the study area so there was no other way of using another biometeorological index. This is also the reason that a simple, yet widely applied, biometeorological index was used in the present study.

Table 5 The relative frequencies of the THI classes for the various stations (a) calculated using the ANN model-estimated air temperature and humidity data values and (b) calculated using the measured air temperature and humidity data values. THI classes are according to Kyle (1994).

Station	**Very Hot** **26.5≤THI≤29.9**		**Hot** **20≤THI≤26.4**		**Comfortable** **15≤THI≤19.9**		**Cool** **13≤THI≤14.9**		**Cold** **-1.7≤THI≤12.9**	
	(a)	**(b)**	**(a)**	**(b)**	**(a)**	**(b)**	**(a)**	**(b)**	**(a)**	**(b)**
S_2	0.8	2.1	1.5	3.6	24.4	31.1	56.2	61.0	1.7	2.2
S_3	0.2	0.9	2.2	3.3	19.9	26.8	62.7	68.6	0.4	0.4
S_4	0.0	0.2	0.3	1.2	16.7	28.8	64.9	69.1	0.0	0.7
S_5	0.2	1.1	1.5	3.3	16.2	25.0	64.9	69.6	0.5	1.0
S_6	0.0	0.0	0.1	0.8	18.8	21.5	74.2	77.0	0.4	0.7

4. CONCLUSION AND RECOMMENDATIONS

The results of the present study revealed that there was a satisfactory capability to estimate, through the use of ANN models, the level of thermal comfort in remote mountainous areas using relatively limited data of air temperature and humidity from easily accessible meteorological stations, assuming ANNs were adequately trained. The present study focused on estimating actual conditions at five remote stations from the actual conditions at two reference stations; a future study should investigate the development of appropriate ANN procedures to make timely extrapolations into the future in order for the models to be used for forecasts of bioclimatic conditions. In addition, future studies should focus mainly on comparing ANN model results to results obtained from the use of more complex bioclimatic indices since in several cases the variability of wind speed and radiation fluxes is expected to modify more the thermal stress conditions than air temperature and humidity.

REFERENCES

Chaloulakou A, Grivas G, Spyrellis N (2003) Neural network and multiple regression models for PM10 prediction in Athens: A comparative assessment. J Air & Waste Manage Assoc 53:1183-1190

Cheng SY, Jin YQ, Liu L, Huang GH, Hao RX, Jansson CRE (2002) Estimation of atmospheric mixing heights over large areas using data from airport meteorological stations. J Environ Sci Health A 37:991-1007

Chronopoulos K, Tsiros IX, Dimopoulos IF, Alvertos N (2008) An application of artificial neural network models to estimate air temperature data in areas with sparse network of meteorological stations. J Environ Sci Health Pt A 43:1752-1757

Clarke JF, Bach W (1971) Comparison of the comfort conditions in different urban and suburban microenvironments. Int J Biometeorol 15:41-54

Dimopoulos IF, Tsiros IX, Serelis K, Chronopoulou A (2004) Combining neural network models to predict spatial patterns of airborne pollutant accumulation in soils around an industrial point emission source. J Air & Waste Manage Assoc 54:1506-1515

Grinn-Gofroń A, Strzelczak A (2008) Artificial neural network models of relationships between Alternaria spores and meteorological factors in Szczecin (Poland). Int J Biometeorol 52:859-868

Incerti G, Feoli E, Salvati L, Brunetti A, Giovacchini A (2007) Analysis of bioclimatic time series and their neural network-based classification to characterize drought risk patterns in South Italy. Int J Biometeorol 51:253-263

Kyle WJ (1994) The human bioclimate of Hong Kong. In Brazdil R, Kolář M (eds) Proceedings of the Contemporary Climatology Conference, Brno. TISK LITERA, Brno. 345-350

Mayer H (1993) Urban bioclimatology. Experientia 49:957-963

Openshaw S, Openshaw C (1997) Artificial Intelligence in Geography. John Wiley and Sons Ltd, Chichester

Rigol JP, Jarvis CH, Stuart N (2001) Artificial neural networks as a tool for spatial interpolation. Int J Geogr Inf Sci 5(4):323-343

Rumelhart DE, Hinton GE, Williams RJ (1986) Learning representations by back-propagating error. Nature 323:533-536

Sánchez Mesa JA, Galán C, Hervás C (2005) The use of discriminant analysis and neural networks to forecast the severity of the Poaceae pollen season in a region with a typical Mediterranean climate. Int J Biometeorol 49:355-36

Tang Z, Fang J (2006) Temperature variation along the northern and southern slopes of Mt. Taibai, China. Agric Forest Meteorol 139:200-207

Thom EC (1959) The discomfort index. Weatherwise 12:57-60

Tsiros IX, Dimopoulos IF, Chronopoulos K, Chronopoulos G (2009) Estimating airborne pollutant concentrations in vegetated urban sites using statistical models with microclimate and urban geometry parameters as predictor variables: a case study in the city of Athens. J Environ Sci Health A 44:1496-1502

Tveito OE, Schöner W (eds) (2002) Applications of spatial interpolation of climatological and meteorological elements by the use of geographical information systems (GIS), report no 28/02 Klima, Norwegian Meteorological Institute. ISSN 0805-9918

Wang D, Lu, WZ (2006) Forecasting of ozone level in time series using MLP model with a novel hybrid training algorithm. Atmos Environ 40:913-924

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AREA USAGE OF TWO OUTDOOR PUBLIC PLACES WITH REGARD TO THE THERMAL CONDITIONS – OBSERVATION-BASED HUMAN THERMAL COMFORT STUDY IN THE CENTRE OF SZEGED

L ÉGERHÁZI and N KÁNTOR

Department of Climatology and Landscape Ecology, University of Szeged, P.O.Box 653, 6701 Szeged, Hungary
E-mail: egerhazi@geo.u-szeged.hu

Summary: The long-term observations of urban public parks and other green places provide useful information to estimate the impacts of the climatic and other factors on the area usage as well as on the thermal sensation of the people. This paper presents a thermal comfort investigation carried out in two squares located in the city centre of Szeged (Hungary). The survey which consisted of three study periods (three times 5 weeks in transient seasons) applied a complex methodology: the subjective approach included the investigation of the human attitude and the objective method was based on the measurement of the microclimatic parameters. The thermal conditions were quantified by one of the most popular human comfort index, Physiologically Equivalent Temperature (PET), calculated by the bioclimate model RayMan from measured meteorological parameters. The results confirm that actual thermal conditions have an effect on the attendance of the public places: the utilization of the squares increases with higher PET values, although exposure to the sun becomes lower with warmer conditions. The experienced tendencies draw attention to the importance of the detailed analyses of thermal comfort conditions in urban outdoor places.

Key words: city squares, area usage, Physiologically Equivalent Temperature (PET), behavioural adaptation

1. INTRODUCTION

Due to a rapidly growing global population more and more people need to live and work in cities. Therefore, the question of urban thermal comfort, i.e. which thermal conditions are the most comfortable and enjoyable in urban environments, becomes of even higher importance. The increasing number of cities transform the natural areas, and inhabitants unavoidably become subjects of the strain of the new environment such as noise, air pollution, accelerated lifestyle and last but not least thermal stress (Unger 1999). Since the 'green islands' in settlements have significant positive effects on life quality, the role of human comfort investigations in these places grows permanently. These public areas provide not only an aesthetical and pleasant environment for the citizens, but also increase the duration of their outdoor activities (Nikolopoulou et al. 2001, 2003, Thorsson et al. 2004).

A relationship can be detected between the utilization of open public places and the thermo-physiologically comfortable microclimate offered by them (Mayer 2008). Therefore it should be a very important part of city planning and development to take into account the well-being of people in urban areas. This task assumes bioclimatological approaches, i.e. the analysis of cities from a physiological point of view (Jendritzky 1993).

The presented investigations were carried out in Szeged, where extensive urban climate and human thermal comfort research has been conducted for several years (Unger at al. 2001, Gulyás et al. 2006, Unger 2006, Kántor et al. 2007) In this study, the relationship between a bioclimatic comfort index, PET (physiologically equivalent temperature) and the (relative) attendance of two local open public places (Ady square and Honvéd square) is presented. PET was calculated by a bioclimate model (RayMan) using objective meteorological parameters (air temperature, air humidity, wind velocity, and global radiation) to evaluate the thermal stress affecting the human body. In addition, the behavioural adaptation of people in accordance with the thermal comfort conditions was also examined.

2. MATERIAL AND METHODS

2.1. Study areas

The two investigated squares are located in a Central-European city, Szeged (Southeast Hungary, 46°N, 20°E), situated at 75-85 m above sea level, having a population of 160,000 and an administration district of 281 km^2. The city belongs to the climatic region *Cf* according to Köppen's classification (temperature warm climate with uniform annual distribution of precipitation) or to the climatic region D.*1* according to Trewartha's classification (continental climate with a long warm season) (Péczely 1979).

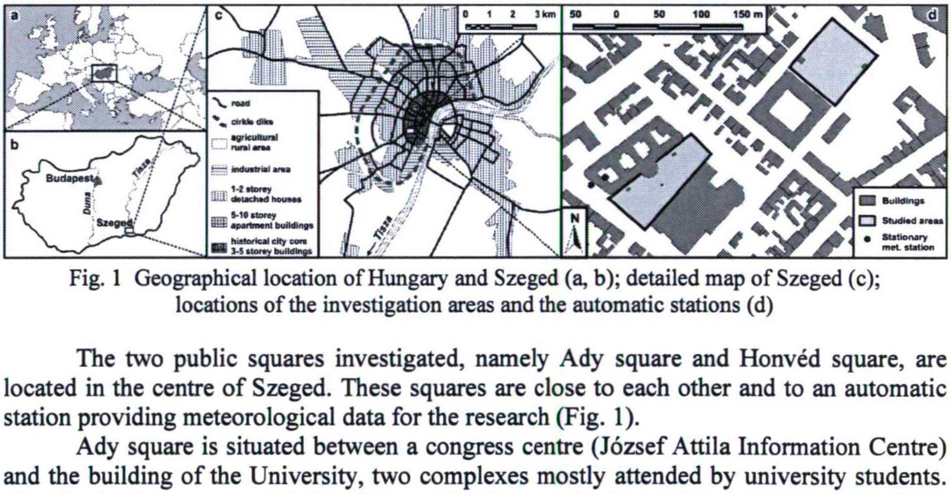

Fig. 1 Geographical location of Hungary and Szeged (a, b); detailed map of Szeged (c); locations of the investigation areas and the automatic stations (d)

The two public squares investigated, namely Ady square and Honvéd square, are located in the centre of Szeged. These squares are close to each other and to an automatic station providing meteorological data for the research (Fig. 1).

Ady square is situated between a congress centre (József Attila Information Centre) and the building of the University, two complexes mostly attended by university students. Thereby in the warmer periods of the academic year (spring and autumn), these students form the largest group of the visitors of Ady square (Kántor and Unger 2010). The area of Ady square is about 5500 m^2, almost entirely covered by grass. A small paved pathway runs across the large grassy sector, along which a few 4-5 m tall trees have been planted. These trees provide only scanty shade in the vegetation period. The large grassy sector is belted by a morphological step hence the centre surface of the square is located about 1 m lower than the ambient areas. The northwestern side of the park is bordered by a group of about 20-30 m tall trees providing shading to this area, and causing a quite different microclimate here. 10 benches offer seating places for the visitors: 8 of them are situated along the pathway, and 2 benches are on the northeastern and southwestern ends of the large grassy sector.

The second investigated public area, named Honvéd square, is slightly greater and has an area of 6000 m^2 (Fig. 1). The main reason people visit Honvéd square is the playground equipment installed in the middle of the square. Therefore the age of the visitors of Honvéd square shows larger variety than that of the visitors of Ady square, since the latter is mostly attended by students in their twenties. The shading conditions of Honvéd square are also appreciably diffent from that of the first area due to the numerous old trees offering shadow and penumbra to almost the whole park (Fig 2).

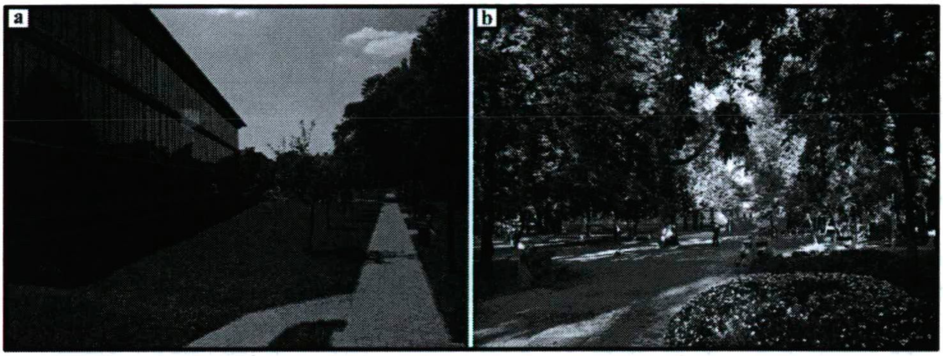

Fig. 2 Photographs of the two investigated areas: small parks in (a) Ady square and (b) Honvéd square

2.2. Methods

The examinations were carried out in three study periods to get an overall picture of the bioclimatological conditions during transient seasons. These periods were: spring of 2008 and 2009 (from the second week of April to the middle of May) and autumn 2009 (between 8 September and 8 October) (Table 1).

To estimate the area usage of the squares as a function of thermal comfort and bioclimatological features environmental and human monitoring are required (Nikolopoulou and Steemers 2003, Thorsson et al. 2004). The environmental monitoring i.e the objective approach used in our studies is based on human thermal comfort index calculation from a set of meteorological variables measured at regular intervals. As a subjective method, human attitude was observed in the afternoon hours (12–3 p.m.) each Thuesday, Wednesday and Thursday within the frame of a 5-week long systematic study in every period.

2.2.1. Objective method – Environmental monitoring

As an objective measure of thermal comfort sensation, a widely used biometeorological index, PET (Physiologically Equivalent Temperature) was selected (Mayer and Höppe 1987). PET is a popular index, which describes the thermal conditions in a physiologically relevant manner, and it is able to indicate the thermal stress of the body in a widely known unit (°C). PET is defined as the air temperature at which the heat budget of the human body in a typical indoor setting is balanced with the same core and skin temperature as under the actual, complex outdoor conditions to be assessed (Höppe 1999). This index provides an assessment of the thermal environment by values according to a comfort scale where PET values around 20°C correspond to neutral, comfortable thermal conditions. PET values higher than 23°C and lower than 18°C indicate increasing probability of thermal discomfort as well as physiological stress due to hot and cold conditions, respectively (Höppe 1999, Matzarakis et al. 1999) (Fig. 3).

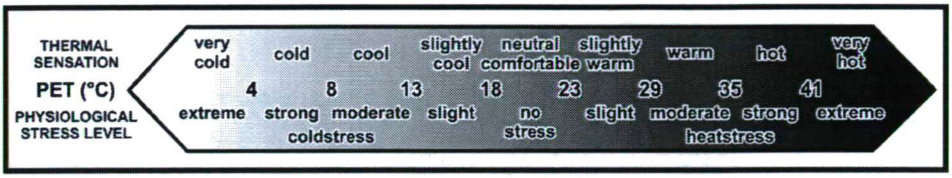

Fig. 3 PET scale for various thermal sensation and stress levels (according to Matzarakis et al. 1999)

As a first step to calculate the PET index, the 10-minute values of air temperature, relative humidity, wind velocity, and global radiation were recorded by a QLC 50 type automatic climate station. The air temperature and the relative humidity values were observed in a Stevenson screen at street level near the university building, while wind velocity and global radiation were measured on the roof of the university building near the green areas (Figs. 1 and 4). The measured wind speed data were transformed to the reference height of 1.1 m with the help of a special formula according to Matzarakis et al. (2009), but the measured global radiation data were applied without reduction. Using these measured parameters as input, the PET comfort index was calculated by means of a radiation and bioclimate model, RayMan, developed according to the guideline 3787 of the German Engineering Society (VDI 1998, Gulyás et al. 2006). The calculated PET values refer to a standard person (1.75 m, 75 kg, 35 year-old standing male) who stays in the sun.

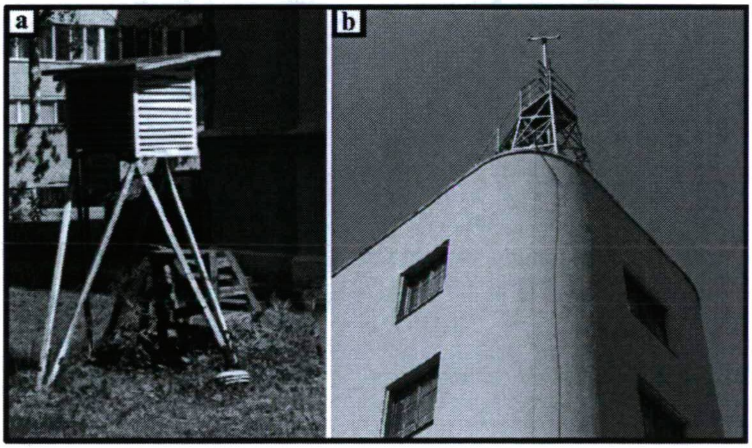

Fig. 4 Parts of the automatic station: the Stevenson screen (a) at the street level and (b) on the roof of the university building

2.2.2. Subjective method – Human monitoring

In the frame of the subjective method, the visitors' area usage and their individual features were observed in the two public places. The Ady-square survey began one year earlier resulting in data obtained from three study periods, while data for Honvéd square are available only from the past two periods (Table 1).

Table 1 The outdoor study periods of the two green areas

Study area	**Human monitoring**			
	Momentary attendance		**Cumulative attendance**	
Ady Square	spring 2008 spring 2009 autumn 2009	13 + 14 + 14 days	spring 2008 spring 2009 autumn 2009	14 + 14 + 14 days
Honvéd square	spring 2009 autumn 2009	15 + 15 days	spring 2009 autumn 2009	15 + 15 days

Human monitoring consisted of observing the attendance momentarily and cumulatively in given time-intervals between 12 and 3 p.m. Momentary attendance was derived from counting people hanging around in the studied parks in every 10 minutes. In Ady square the visitors were registered according to their solar exposure, namely whether they stayed in the sun, in penumbra or in shade. In the case of the other green area, the people were counted according to their activity-type as passive (standing, sitting, lying) or active (playing, walking around).

In the frame of the cumulative measurements, the location and some personal features of the visitors were also recorded (Table 2). The cumulative measurements were carried out in 30-minutes intervals (i.e. 6 times per days) in Ady square and in 15-minutes intervals (i.e. 12 times per days) in Honvéd squre.

Table 2 Observed parameters during the outdoor thermal comfort research

	Ady square		**Honvéd square**	
Momentary attendance		*every 10 minutes*		*every 10 minutes*
		according to **exposure** (sun / penumbra / shade)		according to **activity** (active / passive)
Cumulative attendance		*in 30-minutes intervals*		*in 15-minutes intervals*
	location	(marked on a map with ID number)	**location**	(number of a bench)
	gender	(male / female)	**gender**	(male / female)
	age-group	(child / young / middle aged / old)	**age-group**	(child / young / middle aged / old)
	clothing	(<0.45 clo / 0.45-0.9 clo / 0.9 clo<)	**clothing**	(<0.45 clo / 0.45-0.9 clo / 0.9 clo<)
	activity	(active / passive)		
	exposure	(sun / penumbra / shade)		(only visitors sitting on benches)

In Ady square, the locations of the people staying at least five minutes long were marked by means of ID numbers on the map of this area. An own map and an associated table belonged to each half-hour interval on each day in the monitoring periods. The table contained the registered individuals' gender, age-category (determined by the look), description of clothing, type of activity and solar exposure (if the presence of direct solar radiation allowed distinguishing sunny, semi-shady and shady sites). In thermal comfort studies, the insulation value of clothing is measured with the 'clo-units', where 1 clo (= 0.155 m^2KW^{-1}) corresponds to a person wearing a typical business suit and 0 clo means a naked body. Since the observations were carried out in transient seasons, the following three clo-categories were distinguished based on the registered clothing elements: (1) under 0.45 clo e.g. short and T-shirt, (2) 0.45-0.9 clo e.g. trousers and light pullover and (3) above 0.9 clo e.g. additional jacket or thick vest.

As the presented "cumulative-observation" method can cope only with "resting place conditions" and mainly sedentary visitors, in the case of Honvéd square we ignored the crowds of children milling in the playground and registered only the visitors sitting on benches. The locations of these subjects were not marked on a map, but the table of personal characteristics contained a plus item to describe the bench-number where the individuals were seated. Overall the observation periods, 6775 and 5668 visitors' data were collected in Ady square and Honvéd square, respectively.

3. RESULTS AND DISCUSSION

3.1. Momentary attendance

In the first part of the analysis the momentary attendances were examined as the function of the measured air temperature (T_a) and the calculated PET values (Fig. 5). Fig. 5 clearly shows that in the case of low air temperature and PET values, the momentary attendance approximated zero, while the number of visitors increased with warming conditions. Quadratic functions were fitted on the datasets, which in Ady square indicate a stronger correlation between attendance and PET values (R^2 = 0.36) than with T_a (R^2 = 0.32). Contrary to this, in Honvéd square the coefficient of determination R^2 is larger for T_a (R^2 = 0.18) than for PET (R^2 = 0.12). The maxima of the fitted functions for Honvéd square can be found in the examined T_a and PET domains (Fig. 5b). However, according to the fitted curves for Ady square, the maximum number of visitors may be expected under very hot conditions (Fig. 5a).

Fig. 6 shows that the PET values influenced the physical adaptation, i.e. the preference for sunny or shady position (Ady-square survey), as well as the activity-type of the visitors (Honvéd-square survey). This process confirms the fundamental behavioural changes, which can be observed during an increasing thermal load (Thorsson et al. 2004). Namely, with rising PET values, the visitors increasingly prefer the outdoor places in shadow as well as passive behaviour.

However, in Ady square there were several occasions when despite the hot conditions (PET > 35°C) a relatively large percentage of the subjects lingered in the sun (more than 50%, Fig. 6a). This can be explained by the fact that after a long cold winter season people enjoy staying outdoors; therefore in springtime they can bear a higher level of thermal stress than in autumn. In the spring of 2008 and 2009, a larger percentage of the visitors stayed in the sunny parts of the green areas (despite PET values above 36°C) than in the autumn study period (Fig. 6a).

The ratio of the active subjects as the function of PET values decreased also in the other square due to the smaller utilization of the square in the cooler thermal conditions (Fig. 6b). Although the correlation is significant at 1% level, the coefficient of determination R^2 is relatively small (R^2 = 0.0538) indicating that this decreasing tendency is not so obvious.

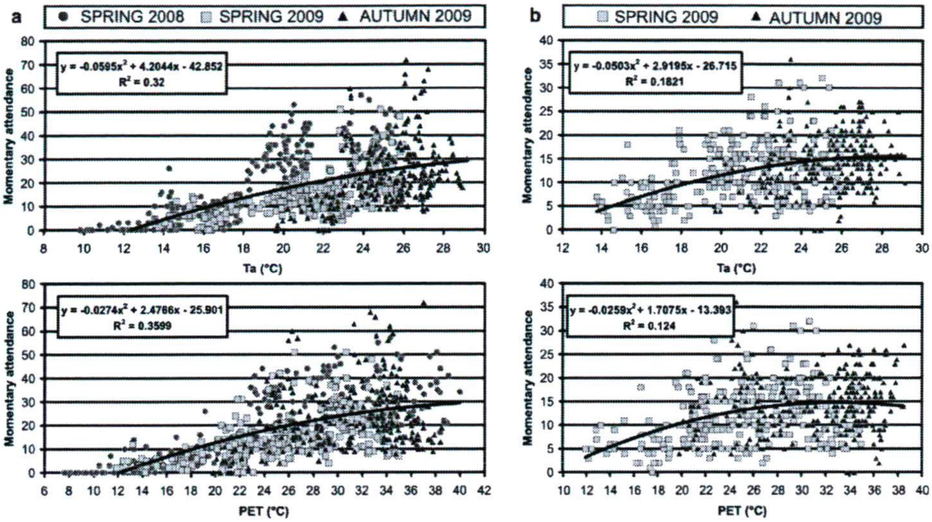

Fig. 5 Momentary attendance of Ady square (a) and Honvéd square (b) as a function of air temperature (T_a) and PET

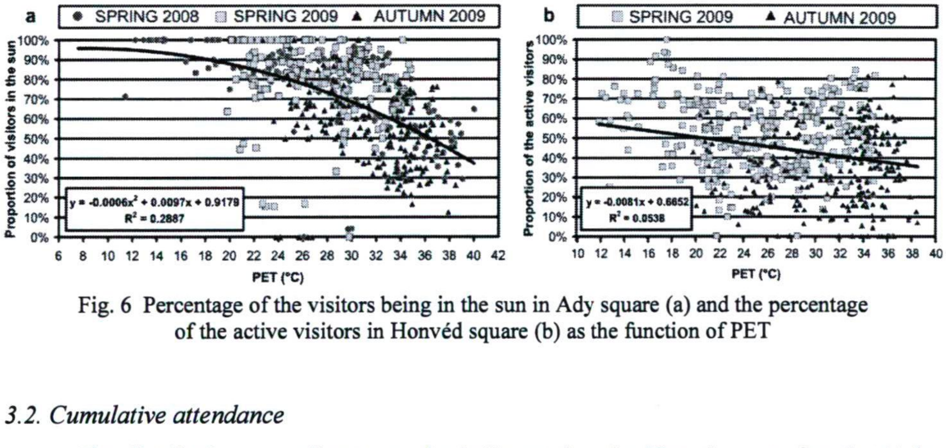

Fig. 6 Percentage of the visitors being in the sun in Ady square (a) and the percentage of the active visitors in Honvéd square (b) as the function of PET

3.2. Cumulative attendance

The distribution according to gender indicates that significantly more females (Ady: 65.3%, Honvéd: 59.7%) attended these public places than males (Ady: 34.7%, Honvéd: 40.3%) in the examined periods. Another observation was that passive (standing, sitting, lying) behaviour was more dominant, especially in Ady square. In case of both green areas, the large majority of the visitors belonged to the 'young' age group (students in their twenties), which can be explained by the educational buildings nearby. However, it should be emphasized that if each visitor had been observed in Honvéd square (and not only sedentary people on the benches), the ratio of actively and passively behaving people would be probably higher.

In this study, from the results of the cumulative analysis only the percentages of the clo-categories as a function of PET values will be presented. According to Fig. 7 an increasing portion of visitors wore ligther clothings with higher PET values in both public places.

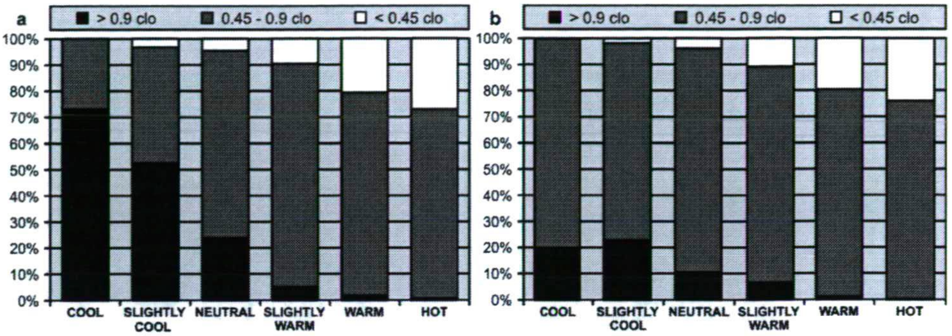

Fig. 7 Percentages of clo-categories as a function of the thermal conditions (based on the PET values) in Ady (a) and Honvéd (b) square

The relationship between the PET values and the clothing insulation is statistically significant and the Spearmen's rho rank-correlation coefficient (ρ) indicates a bit stronger link in the case of the Honvéd square (Ady square ρ = -0.388, Honvéd square: ρ = -0.450). However, if air temperature (T_a) values are examined as predictor variable (instead of PET), the statistical relationship is somewhat stronger (Ady square: ρ = -0.402, Honvéd square: ρ = -0.485). This can be explained by the fact that in everyday life the selection of clothes is based on rather the information on air temperature than PET.

4. CONCLUSIONS

The paper presented some selected results of a long-term (3 study periods) research project carried out in two public places (Ady square and Honvéd square) in the city centre of Szeged (Hungary). The study investigated the usage of the mentioned green areas under various thermal conditions by means of human and environmental observations. From measured meteorological parameters a popular human bioclimatological comfort index, PET, was calculated in order to characterize the thermal conditions.

The obtained results of our observations confirmed the dependence of the attendance of outdoor places on the thermal conditions. It is prominent that the preference of the outdoor places generally increases with warming thermal conditions and in many cases the visitors tolerate a higher level of the thermal stress. This tendency, namely the toleration of unconvenient thermal conditions, is a good example of the mechanism of behavioural adaptation. The quantitative analysis revealed that a higher percentage of the visitors was exposed to the Sun in spring than in autumn, because people apparently desire warmer thermal conditions after the cold wintertime. In addition, the results clearly show that the generally dominant passive behaviour (lower activity level) becomes more frequent with increasing PET values, and visitors wear lighter clothes in warmer weather conditions.

The main objective of the present study was to give a hand, furthermore provide useful information for city planning and development in the processes of the design of public places in order to develop a comfortable environment and an attraction of these public places to increase their attendance.

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REFERENCES

Gulyás Á, Unger J, Matzarakis A (2006) Assessment of the microclimatic and human comfort conditions in a complex urban environment: Modelling and measurements. Build Environ 41:1713-1722

Höppe P (1999) The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment. Int J Biometeorol 43:71-75

Jendritzky G (1993) The atmospheric environment – an introduction. Experientia 49:733-740

Kántor N, Unger J (2010) Benefits and opportunities of adopting GIS in thermal comfort studies in resting places: An urban park as an example. Landscape Urban Plan 98:36-46

Kántor N, Unger J, Gulyás Á (2007) Human bioclimatological evaluation with objective and subjective approaches on the thermal conditions of a square in the centre of Szeged. Acta Climatol et Chorol Univ Szegediensis 40-41:47-58

Matzarakis A, Mayer H, Iziomon M (1999) Applications of a universal thermal index: physiological equivalent temperature. Int J Biometeorol 43:76-84

Matzarakis A, De Rocco M, Najjar G (2009) Thermal bioclimate in Strasbourg - the 2003 heat wave. Theor Appl Climatol 98:209-220

Mayer H (2008) KLIMES – a joint research project on human thermal comfort in cities. Ber Meteorol Inst Univ Freiburg 17:101-117

Mayer H, Höppe P (1987) Thermal comfort of man in different urban environments. Theor Appl Climatol 38:43-49

Nikolopoulou M, Steemers K (2003) Thermal comfort and psychological adaptation as a guide for designing urban places. Energy Build 35:95-101

Nikolopoulou M, Baker N, Steemers K (2001) Thermal comfort in outdoor urban spacers; understanding the human parameter. Sol Energy 70:227-235

Péczely Gy (1979) Éghajlattan. [Climatology. (in Hungarian)] Nemzeti Tankönyvkiadó, Budapest

Thorsson S, Lindqvist M, Lindqvist S (2004) Thermal bioclimatic conditions and patterns of behaviour in an urban park in Göteborg, Sweden. Int J Biometeorol 48:149-156

Unger J (1999) Comparisons of urban and rural bioclimatological conditions in the case of a Central-European city. Int J Biometeorol 43:139-144

Unger J (2006) Modelling of the annual mean maximum urban heat island with the application of 2 and 3D surface parameters. Climate Res 30:215-226

Unger J, Sümeghy Z, Zoboki J (2001) Temperature cross-section features in an urban area. Atmos Res 58:117-127

VDI (1998) VDI guideline 3787, Part 1: Environmental Meteorology, Methods for the human biometeorological evaluation of climate and air quality for urban and regional planning. Beuth, Berlin. 29

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INTRODUCING A SCRIPT FOR CALCULATING THE SKY VIEW FACTOR USED FOR URBAN CLIMATE INVESTIGATIONS

M HÄMMERLE[1], T GÁL[2], J UNGER[2] and A MATZARAKIS[1]

[1]*Meteorological Institute, Albert-Ludwigs-University of Freiburg, 79085 Freiburg, Germany*
E-mail: martin.haemmerle@meteo.uni-freiburg.de
[2]*Department of Climatology and Landscape Ecology, University of Szeged, P.O.Box 653, 6701 Szeged, Hungary*

Summary: The sky view factor (SVF) is a parameter widely used in several research fields, applied research and planning. It is of crucial importance concerning the energy budget of a certain location. Many methods for calculating the SVF have been developed. In the present study, a selection of methods and models is analyzed in order to find out about possible improvements. Also, a new method using GIS software is introduced. In the city of Szeged fisheye pictures were taken along transects and evaluated. For the images' coordinates, SVF was calculated by numerical models which use a 3D-building database as input. Also, a set of artificial fisheye pictures was created and used for validating the applied methods. The calculations were performed with the models SkyHelios (Matuschek and Matzarakis 2010, Matzarakis and Matuschek 2010), SOLWEIG (Lindberg et al. 2008) and the ArcView SVF-Extension (Gál et al. 2009). The evaluation of the fisheye pictures was done according to the manual Steyn-method (Steyn 1980), RayMan (Matzarakis et al. 2007 2010) and with BMSkyView (Rzepa and Gromek 2006). Additionally, a new ArcView-script has been developed in order to enhance the only manual method (Steyn 1980). The comparison of the obtained results showed a systematic deviation of the SVF values. After including a cosine weighting factor in the differing models, all SVF values corresponded to each other.

Key words: urban climate, SVF-calculation methods, comparison

1. INTRODUCTION

The sky view factor (SVF or ψ_s) is a dimensionless parameter with values between zero and one. It represents the fraction of visible sky on a hemisphere which lays centred over the analyzed location (Oke 1981).

Different sky view factors mean different radiation budgets and accordingly different energy budgets: On a point with a SVF of 1 (the complete sky is visible) under clear sky conditions neither reflected short-wave radiation, nor additional long-wave radiation is received. The radiation budget for an "ideal" site can thus be written as in Fig. 1 (left side) and accordingly the energy budget corresponds to Fig. 1 (right side).

In Fig. 1, Q^* stands for the net radiation budget, $S\downarrow$ is the incoming short-wave radiation (direct solar and diffuse), $S\uparrow$ the outgoing short-wave radiation (reflection), $L\downarrow$ the incoming long-wave radiation (atmospheric downward-radiation), $L\uparrow$ the outgoing long-wave radiation (emission of the surface); Q_G stands for the soil heat flux (energy stored in volumes, e.g. soil, buildings), Q_H is the sensible heat flux (air temperature) and Q_E the latent heat flux (evaporated water).

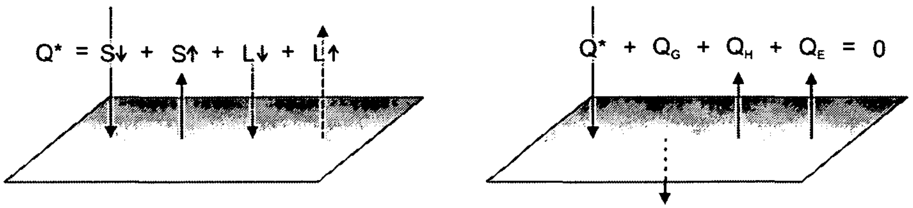


Fig. 1 Schematic summary of the fluxes involved in the radiation budget (left) and energy balance (right) of an "ideal" site (modified after Oke 1987)

If, in contrast, the analyzed location is situated for example in a valley or street canyon (Fig. 2), the radiation budget and the energy budget are changed by

- reflections of short-wave radiation as shown Fig. 2a,
- a decrease in outgoing long-wave radiation as shown Fig. 2b,
- an increase in received long-wave radiation that is emitted by the surfaces which obstruct the sky and consequently
- an altered soil heat flux.

The sky view factor thus plays a crucial role e.g. in urban climatology (Oke 1987), forest climatology (Holmer et al. 2001), human biometeorology (VDI 1998, Matzarakis 2001) etc. It is widely used as an important parameter in modelling thermal phenomena, such as the urban heat island (Unger 2004). Further it can be and it is used in a variety of new fields, e.g. the modeling of ventilation paths, research concerning renewable energy sources (Richert 2010) or urban planning (Lin et al. 2010).

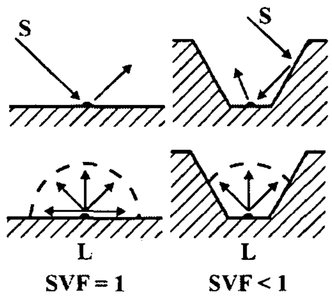


Fig. 2 The role of surface geometry in radiation exchange. Comparison of horizontal and convoluted surfaces. S = short-wave radiation, L = long-wave radiation. (modified after Oke 1987)

Several numerical models for calculating the sky view factor and several methods for evaluating the SVF have been developed. The aim of this work is to compare and to validate some of these models and methods (see section 3) in order to find out about possible differences in the results and thus to offer a background for improvements.

2. STUDY AREA

For calculating the sky view factor with the different models and for validating the calculations, a city on flat terrain would be most convenient. Where there is no noteworthy relief, the computations can be done without including data about the topography and are thus less time-consuming and less prone to errors.

As there was already a 3D-database and a collection of fisheye pictures available (Unger 2006, 2009, Gál et al. 2009), the city of Szeged in South-Hungary (Fig. 3) was chosen for this work.

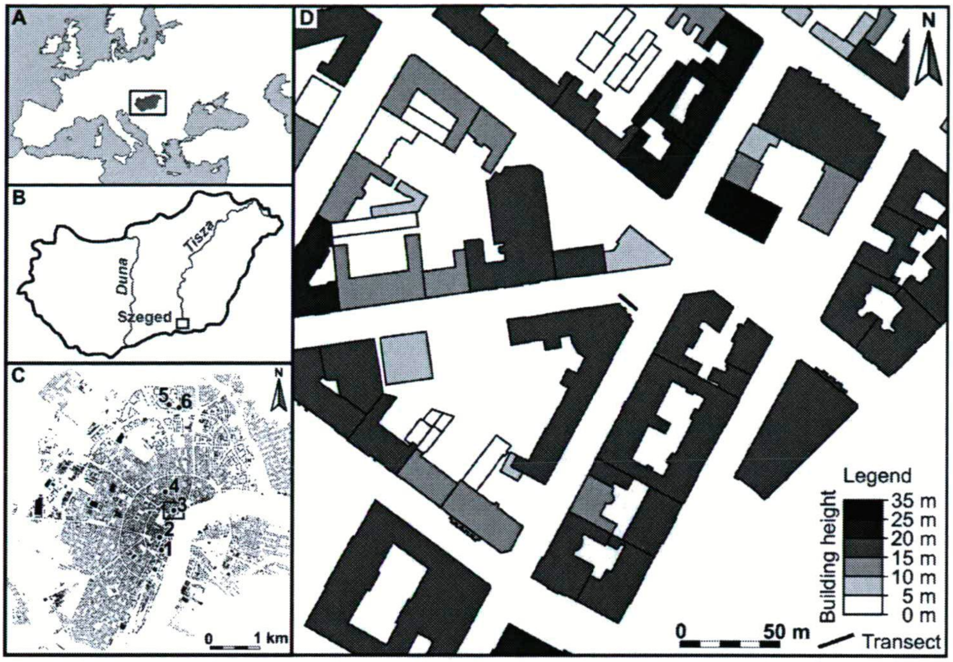


Fig. 3 The location of Hungary in Europe (A), the location of Szeged in Hungary (B), the footprint of Szeged and the locations of transects (C) and the surroundings of transect 3 (D)

Fig. 4 Views of transect 3, from the west (right), from the east (left)

It was intended to cover a variety of different building structures in order to find out how the methods react. As a guideline, the local climate zones (LCZ) as introduced by Stewart (2009) were used. In this paper, only transect 3 is presented (Fig. 3), since all of the important findings can be demonstrated here. The transect lies in the north-eastern intersection of Horváth Mihály street and Deák Ferenc street and consists of the pictures nr. 3023 to 3043 (Fig. 7). It was classified in the LCZ "compact midrise". From the first observing points, some vegetation in its "leaf on" phase is viewable. The images were taken equidistantly every 0.5 meters.

Fig. 3d shows the surroundings of transect 3 and is intended to be an overview and a help for interpreting and understanding the results. The typical building height in this area is around 15-20 m and the vegetation is represented by only a few trees (Fig. 4).

3. METHODS

3.1. *Fisheye images*

The fisheye images were taken with a Nikon Coolpix 4500 digital camera and a Nikon Fisheye Converter FC-E8 0.21x. The camera was mounted on a Gorillapod original tripod. For leveling the camera, a Lenspen panamatic bubble level (Parkside Optical Inc.) was also mounted on the tripod (Fig. 5). This configuration is quite convenient and practical, it can be moved fast and easily and uneven surfaces like gutters are no obstacle for the measurements.

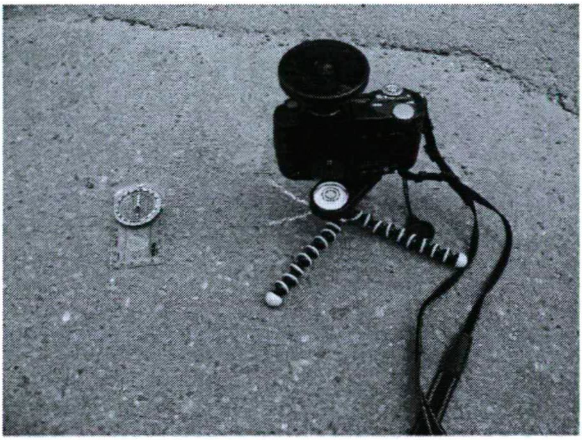


Fig. 5 Equipment for taking the fisheye pictures

A mask was created to cut the fisheye pictures to 180°. Cutting the images was necessary because the FC-E8 lens have a field of view (FOV) of 189° (Grimmond et al. 2001).

The positions of the images of transect 3 were marked with chalk on the street and then were measured with a Sokkia SET310 theodolite. As reference points, edges of the surrounding buildings were used. The building's coordinates were already available from the 3D building database (Gál et al. 2009).

3.2. *SVF evaluation methods using fisheye photoes*

3.2.1. *Manual method according to Steyn*

This is a very basic method of evaluating fisheye pictures. First, the fisheye picture is printed with an overlain polar grid. In the print, the obstacles are then to be delineated manually. With the help of the polar grid the viewing angle of each annulus is to be counted. After the SVF is calculated for each annulus according to the formulas in Steyn (1980) the values are summed up for the total SVF.

3.2.2. "Edit free sky view factor"-tool of RayMan

This RayMan-module (Matzarakis et al. 2007 2010) calculates the SVF after obstacles are digitized in a fisheye picture or loaded directly into the module. After digitizing, the SVF is calculated by counting the sky-pixels and relating them to the total number of pixels in the image.

3.2.3. BMSKyView

This software (Rzepa and Gromek 2006, Gál et al. 2007) colours all pixels which are to a certain degree similar to the clicked pixel. A threshold has to be chosen that groups not too many and not too few pixels which are to be coloured. The sky pixels are to be chosen. Some pixels in buildings (e.g. sky-reflecting windows) have to be unmarked after the selection of all sky pixels. The marked pixels are used for the SVF-calculation which is based on the Steyn-method.

3.3. New approach: Steyn-method implemented in an ArcView script

To overcome the disadvantages of the manual Steyn-method (material used for the prints, low contrast, tedious and time consuming), an Avenue script was developed in order to evaluate fisheye pictures more easily using GIS-software.

The main difference to the manual Steyn-method is the shift from manual work to digitizing the fisheye images on the computer. For a convenient programming of the ArcView Avenue script, not the obstructed areas are used for the calculation, but the area of visible sky, which is thus to be digitized.

The method uses the same formula as the manual Steyn-method. It first creates a theme of n annular rings (n is user defined, the default is 36) and then calculates the maximum value of SVF for each annular ring ($SVF_{\max i}$) with

$$SVF_{\max i} = \frac{\pi}{2} \cdot \sin\left(\frac{\pi \cdot (i - 0.5)}{2n}\right) \cdot \cos\left(\frac{\pi \cdot (i - 0.5)}{2n}\right) \tag{1}$$

where n is the count of annular rings, i the number of the actual ring and π the mathematical constant Pi.

In the next step, the visible sky is digitized as a new theme. Via intersecting the annular rings with the digitized visible sky theme, α_i (obstructed angle in ring i) is calculated with

$$\alpha_i = \frac{T_{total} - T_{obs}}{\pi \cdot r_2^2 - \pi \cdot r_1^2} \tag{2}$$

where T_{total} is the total area of the annular ring, T_{obs} is the obstructed area in the same ring, r_1 and r_2 are the radii of the inner and outer limits of the ring, respectively.

Each ring's SVF is then calculated via

$$SVF_i = SVF_{\max i} \cdot \frac{\alpha_i}{2\pi} \tag{3}$$

and finally, all SVF_i are summarized, which results in the total SVF. After this calculation the software writes the SVF value to the screen.

Digitizing the sky is done fast and easily with the script because vegetation can be more easily separated from rooftops on an actively light emitting screen. In addition, zooming in and out of the image is very helpful. The SVF-calculation for the digitized image is done with one click. This method is estimated the fastest for evaluating fisheye images.

As the script is customized for the original pictures of FC-E8 lens with its FOV of 189°, the use is restricted to a certain set of equipment. On the other hand, an extension to meet other general conditions can easily be introduced in the source code of the Avenue script.

3.4. SVF compution methods using a 3D building database

3.4.1. SkyHelios

The calculations with SkyHelios (Matuschek and Matzarakis 2010, Matzarakis and Matuschek 2010) were done twice for each transect: First with a raster input file (resolution 0.5x0.5 m), second with a vector input file, both extracted from the 3D building database. SkyHelios works in a similar way to RayMan: A virtual fisheye picture for each observation point is generated based on the 3D input. The image is evaluated following the steps as done by RayMan.

3.4.2. ArcView SVF-Extension

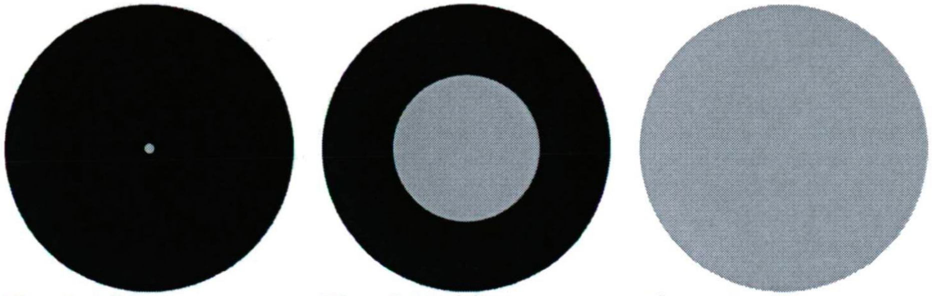
The extension (Unger 2009, Gál et al. 2009) uses a vector-based 3D building data base as input. A point shapefile has been created using the coordinates of the pictures and the SVF-calculation is done for each point in this file. The calculation method is based on Oke's SVF formula for a basin (Oke 1987). The software scans the horizon stepwise by drawing a line and searching for intersections between this line and the buildings. A step size of 1° was chosen and the scanned distance was 200 meters which gives the best results with quite a low calculation time (Unger 2009). The detected obstacles' height is read from the 3D database and the highest building that intersects the scan line is taken for the calculation (Gál et al. 2009).

3.4.3. SOLWEIG

SOLWEIG (Lindberg et al. 2008) calculates the sky view factor on the basis of a shadow casting algorithm as introduced by Ratti and Richens (1999). Due to problems with the software or the computing equipment, the resolution for all transects was 1x1 m.

3.5. Method for validation

In addition to the evaluation of real fisheye photos and model runs, some "ideal" fisheye photos were generated. For this purpose, a set of 36 pictures with 36 circles each was created. The pictures simulate an "opening sky": Each consecutive picture has one more additional white ring. This set of pictures stands for a stepwise virtual opening of the sky and leads to a cumulative SVF-calculation from one single visible ring in the centre to full visibility which means a SVF of 1 (Fig. 6).



Ring 1 visible Rings 1-18 visible Rings 1-36 visible

Fig. 6 Cumulatively „visible" rings as input for validating

The artificial sky rings were evaluated with the three methods RayMan (workflow as above except digitizing the obstacles: the produced artificial fisheye picture was used directly), BMSkyView (workflow as above) and the manual Steyn-method (SVF was calculated in a spread sheet).

4. RESULTS

First follows a description of the comparison results for transect 3. Then, the results of the evaluation based on the artificial images are shown and described.

4.1. Results for the fisheye images

A line chart was drawn for the transect (Fig. 7). As the points of the transect are equidistantly following a line, a continuous change in SVF can be assumed.

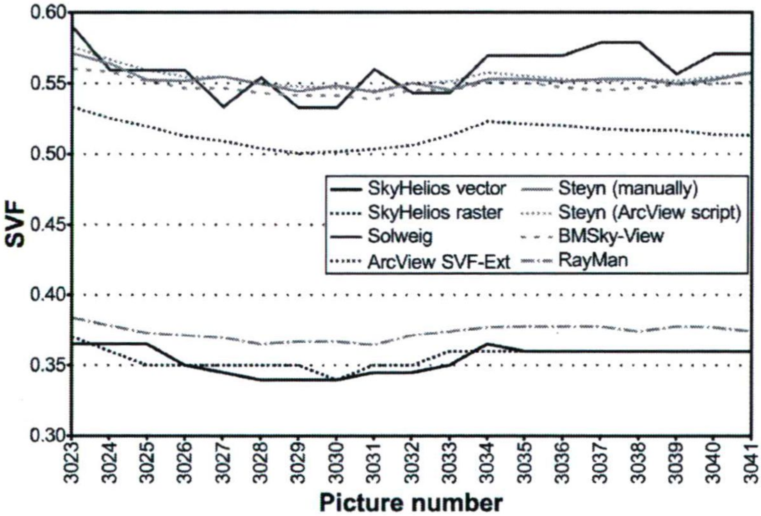


Fig. 7 SVF-diagram for transect 3

Regarding the SVF values, two groups are to be seen: group 1 consists of RayMan and SkyHelios on the one side, group 2 of the SVF-Extension for ArcView, the Steyn-Script for ArcView, Solweig and BMSky-View on the other side.

The range of SVF values is surprisingly small. The minimum value is to find at point 3029 from which the two streets going to the south and west (Fig. 3) are most obstructed by the building along which runs the transect (Fig. 4). On both the starting and ending part of the transect, always one of the intersecting streets is to see which results in higher SVF values.

4.2. Results of the validation

The values of the well established Steyn-method are used as reference. They are considered appropriate because the values were calculated in a spreadsheet and are thus "virtual", means: not influenced by any deviations and errors which can occur in fisheye pictures or the evaluation process.

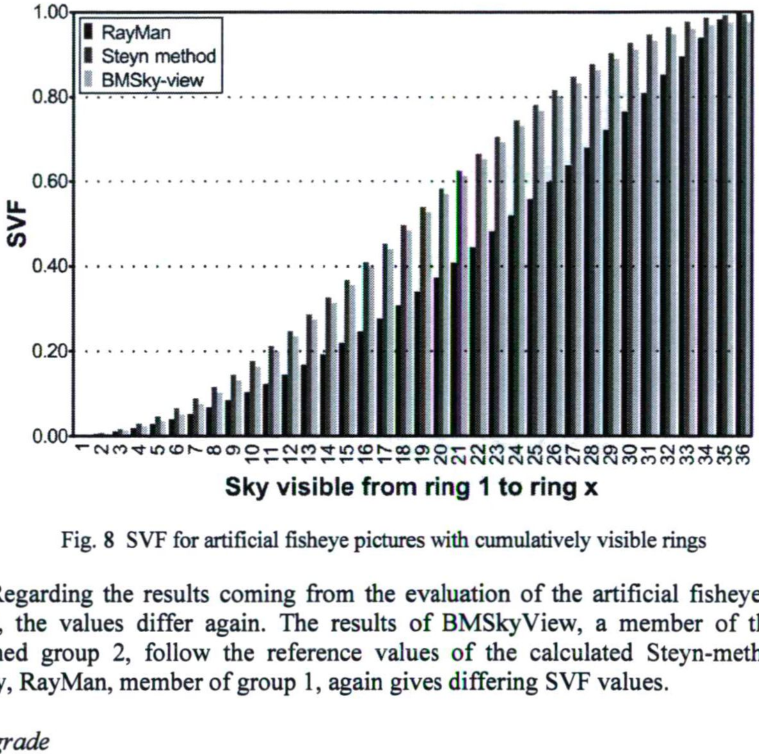


Fig. 8 SVF for artificial fisheye pictures with cumulatively visible rings

Regarding the results coming from the evaluation of the artificial fisheye pictures (Fig. 8), the values differ again. The results of BMSkyView, a member of the above established group 2, follow the reference values of the calculated Steyn-method quite precisely, RayMan, member of group 1, again gives differing SVF values.

4.3. Upgrade

After the evaluation of the real and artificial fisheye pictures, the results pointed to a systematic deviation between the used software. As the members of group 2 were developed independently and correspond also very well to the mathematical reference, the members of group 1 were to be checked. It was found that Lambert's Law of radiation (also known as the cosine-law), was not included in RayMan and SkyHelios because of a different interpretation of SVF. After providing a possibility to include Lambert's law via activating a checkbox, the same calculations were done once more with SkyHelios and the two groups are no longer to be distinguished (Fig. 9).

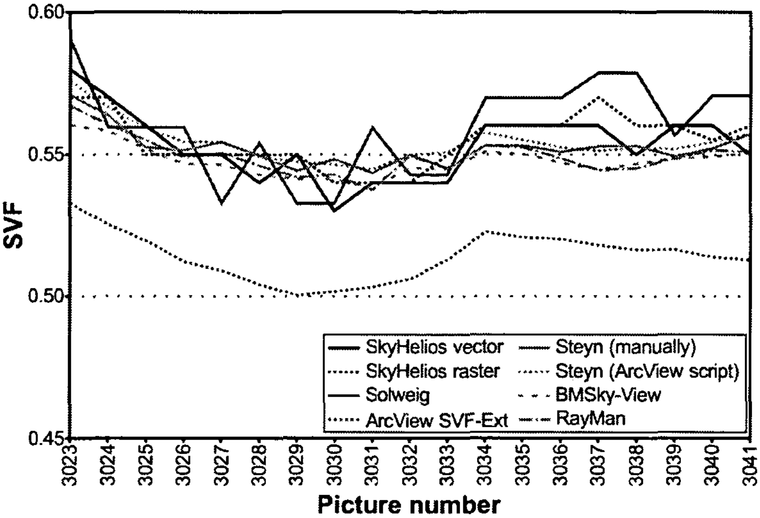


Fig. 9 SVF-diagram for transect 3 with extended SkyHelios and RayMan

5. CONCLUSION

In order to compare different methods and models which calculate the sky view factor, a set of already available programs were used as well as a manual method. To dispose of the manual method's disadvantages, a new Avenue Script was developed that can be used easily as a supplement for the ArcView GIS-software. The Script offers a fast and handy way of evaluating fisheye pictures directly on the computer screen and delivers reasonable results corresponding well to the other methods.

Also, a systematic gap in the obtained SVF values was found. After adjusting the respective software, all results show high accordance.

Considering the above results, a discussion has been started about the understanding and use of the sky view factor: Would it make sense to define the sky view factor in different ways, depending on the task and field of use?

In urban climatology for example, the cosine weighting is crucial because in urban environments it is mainly plain areas which are analyzed (streets, squares, etc.). Horizontally incoming radiation passes by without adding energy to the observed area, i. e. it plays an insignificant role.

Biometeorology on the other hand deals with bodies which receive for a big part radiation via horizontal radiation fluxes. A cosine weighting would neglect horizontal energy fluxes which in this case is inappropriate.

In any case it can be stated that controlling and cross-checking SVF-calculations is indispensable. This goes above all for checking theoretical models using virtual data by the help of real fisheye pictures. In models and in virtual data there can always be some errors, but fisheye pictures offer an inventory of the real situation.

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REFERENCES

Gál T, Rzepa M, Gromek B, Unger J (2007) Comparison between sky view factor values computed by two different methods in an urban environment. Acta Climatol Chorol Univ Szegediensis 40-41:17-26

Gál T, Lindberg F, Unger J (2009) Computing continuous sky view factors using 3D urban raster and vector databases: comparison and application to urban climate. Theor Appl Climatol 95:111-123

Grimmond CSB, Potter SK, Zutter HN, Souch C (2001) Rapid methods to estimate sky view factors applied to urban areas. Int J Climatol 21:903-913

Holmer B, Postgård U, Eriksson M (2001) Sky view factors in forest canopies calculated with IDRISI. Theor Appl Climatol 68:33-40

Lin TP, Matzarakis A, Hwang RL (2010) Shading effect on long-term outdoor thermal comfort. Build Environ 45:213-211

Lindberg F, Thorsson S, Holmer B (2008) SOLWEIG 1.0 – Modelling spatial variations of 3D radiant fluxes and mean radiant temperature in complex urban settings. Int J Biometeorol 52:697-713

Matuschek O, Matzarakis A (2010) Estimation of sky view factor in complex environment as a tool for applied climatological studies. In: Matzarakis A, Mayer H, Chmieliewski FM (eds) Proceed 7th Conf on Biometeorology. Berichte des Meteorologischen Instituts der Albert-Ludwigs-Universität Freiburg 20:534-539

Matzarakis A (2001) Die thermische Komponente des Stadtklimas. Berichte des Meteorologischen Institutes der Universität Freiburg. Nr. 6

Matzarakis A, Matuschek O (2010) Sky view factor as a parameter in applied climatology – rapid estimation by the SkyHelios model. *Meteorol Zeitschrift* 20:39-45

Matzarakis A, Rutz F, Mayer H (2007) Modeling radiation fluxes in simple and complex environments – application of the RayMan model. Int J Biometeorol 51:323-334

Matzarakis A, Rutz F, Mayer H (2010) Modeling radiation fluxes in simple and complex environments – basics of the RayMan model. Int J Biometeorol 54:131-139

Oke TR (1981) Canyon geometry and the nocturnal urban heat island: comparison of scale model and field observations. J Climatol 1:237-254

Oke TR (1987) Boundary layer climates. Methuen, London

Ratti C, Richens P (1999) Urban texture analysis with image processing techniques. In: Augenbroe G, Eastman Ch (eds) Proceed 8th Int Confon Computer Aided Architectural Design Futures held in Atlanta, Georgia

Richert C (2010) GIS-gestützte Analyse des klimatischen Potentials der Windenergie in der Region Freiburg im Breisgau auf der Grundlage von Messungen und Klimasimulationen. Magister Scientiarum Thesis, unpublished, Albert-Ludwigs-University of Freiburg, Freiburg

Rzepa M, Gromek B (2006) Variability of sky view factor in the main street canyon in the center of Łódź. Preprints Sixth Int Conf on Urban Climate, Göteborg, Sweden. 854-857

Stewart I (2009): Classifying urban climate field sites by "Local Climate Zones". IAUC Urban Climate News 34:8-11

Steyn DG (1980) The calculation of view factors from fisheye-lens photographs. Atmos-Ocean 18:245-258

Unger J (2004) Intra-urban relationship between surface geometry and urban heat island: review and new approach. Climate Res 27:253-264

Unger J (2006) Modelling the annual mean maximum urban heat island with the application of 2 and 3D surface parameters. Climate Res 30:215-226

Unger J (2009) Connection between urban heat island and sky view factor approximated by a software tool on a 3D urban database. Int J Environ Pollution 36:59-80

VDI (1998) VDI 3787, Part I: Environmental Meteorology, Methods for the human biometeorological evaluation of climate and air quality for the urban and regional planning at regional level. Part I: Climate. Beuth, Berlin

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CHANGING THERMAL BIOCLIMATE IN SOME HUNGARIAN CITIES

Á NÉMETH

Climatology Division, Hungarian Meteorological Service, Kitaibel P. u. 1., 1024 Budapest, Hungary
E-mail: nemeth.a@met.hu

Summary: Today we can say that the climate change is a scientific fact. The majority of climate change research analyzes only the future conditions. However, we need to know that the future changes cannot be determined without knowledge of the past changes. In this paper the detected changes of thermal bioclimate are analyzed. For this analysis two different bioclimate indices were used. The first one is the Physiologically Equivalent Temperature, the well known bioclimate index, calculated by the RayMan model. The second one is a newly developed bioclimate index, the Universal Thermal Climate Index. Both indices have been calculated for Budapest, Debrecen, Szeged and Siófok, for 12 and 18 UTC. According to the results the annual means increased at both examined times of day. The seasonal means in spring and in summer increased unambiguously. In autumn and in winter the change is different. In winter the 1971-2000 averages are higher than the 1981-2010 averages. In autumn, the 1971-2000-s averages are generally lower than the previous 30-year average. But the last averages exceed all the 1971-2000 averages.

Key words: thermal bioclimate, climate change, Physiologically Equivalent Temperature, Universal Thermal Climate Index

1. INTRODUCTION

Thermal comfort is one of the determining factors of human health and quality of life. The heat balance of human body is very complicated; it depends on many external and internal factors. One of the most important external factors is the atmospheric environment. The characteristics of the physical condition of the atmosphere can be described by meteorological observations. What kind of role do these meteorological parameters play concerning human heat balance? However, it is important to know that certain facts should not be examined separately, but these facts affect our body in a complex way, co-operating with each other. For this reason these meteorological parameters determining the thermoregulation process of the human body are termed “thermal complex” in human bioclimatology. This thermal complex includes long-wave radiation, air temperature, wind speed and air humidity (Jendritzky 1993). The analysis of the thermal complex is possible with different bioclimate indices.

Human bioclimate has been present for a relatively long time in urban environment research in Hungary. A number of excellent studies were born in the field of urban bioclimate (Unger 1999, Gulyás et al. 2006). But the number of large-scale or regional human bioclimate research were rather small (Gulyás and Matzarakis 2007, 2009). Researches related to the changes of thermal bioclimate have started only in recent years, particularly the aspects of tourism climatology (Németh et al. 2007, Németh and Mika 2009).

We have more or less exact knowledge about the climate changes detected in our country. This knowledge provides correct background information for climate change research. We know the regional climate model results: in all seasons the air temperature is expected to increase in the Carpathian basin (Bartholy et al. 2008, Csima and Horányi 2008, Szépszó and Horányi 2008). With the thermal complex we can evaluate mainly how our life will be affected by these changes. For this it is necessary to recognize the changes of the thermal complex in the past.

The knowledge of thermal bioclimate and its changes is useful in the everyday life in many cases. Bioclimatological research provides essential information for the development of adaptation strategies especially in the urban environment where the human body is under stronger thermal stress which increases health risks. Modern urban planning and sustainable tourism development cannot be imagined without bioclimatological analysis. This study aims to demonstrate a changing thermal bioclimate in four cities in Hungary as an example. Although bioclimatological studies based on the adopted methodology are generally carried out at 12 UTC, but the thermal bioclimate conditions in the evening (18 UTC) are also examined in the interests of practical applications. The latter is important from the aspects of the environment, health or tourism.

2. MATERIAL AND METHODS

2.1. Study area

The cities (Fig. 1) selected for this research are Budapest-Pestszentlőrinc (47°25'N, 19°11'E, 139 m asl), Debrecen (47°29'N, 21°37'E, 105 m asl), Siófok (46°54'N, 18°2'E, 107 m asl) and Szeged (46°15'N, 20°5'E, 82 m asl). At the selection of the settlements, the following properties have been taken into account. All meteorological stations have exact long-time data series. The places of measurements have not been changed significantly in the last 50 years, so the data series are homogenous. This is particularly important for analyzing long data series. In addition, these towns are located in important touristic regions of Hungary.

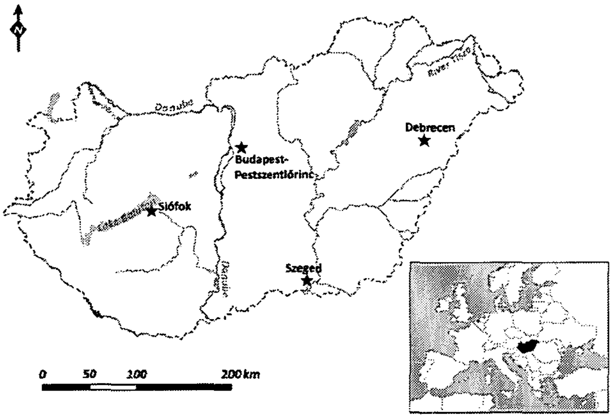

Fig. 1 Geographical location of the selected cities

2.2. Methods

The change of thermal bioclimate practically means the change of thermal sensation or comfort climate. We can analyze it by way of bioclimate indices. In human bioclimatology more and more indices are available, from simple ones, which use only meteorological input parameters, to more complex indices which take into account the human energy balance. In this paper two complex bioclimate indices were applied.

The Physiologically Equivalent Temperature (PET) is one of the most common bioclimate indices. It is derived from the Munich Energy-balance Model for Individuals (MEMI) (Höppe 1984, 1999). The MEMI models the thermal conditions of the human body physiologically. Besides meteorological parameters (air temperature, relative humidity, wind speed and cloudiness) some physiological and geographical inputs are required for calculating PET. For the calculation the RayMan software was used (Matzarakis et al. 1999 2007). The calculation was carried out for a 35 years old, 175 cm tall man with a weight of 75 kg who is sitting and wears normal clothing (0.9 clo).

The PET values were defined according to different thermal perceptions for temperate climate (Matzarakis and Mayer 1996). Because of this the original PET scale (Table 1) can not be used worldwide, so for example for (sub)tropical climate another PET scale is usually applied (Lin and Matzarakis 2008).

Contrarily, the most recent bioclimate index is the Universal Thermal Climate Index (UTCI) which is developed by COST Action 730 (Jendritzky et al. 2009). After model comparisons it became a consensus to base UTCI on Fiala's multi-node model (Fiala et al. 2001). This model simulates the heat transfer inside the body and at its surface taking into account the anatomical, thermal and physiological properties of the human body. The UTCI is the air temperature which, under reference conditions, would produce the same thermal strain as in the actual thermal environment (Blazejzcyk et al. 2010).

Table 1 Ranges of the Physiologically Equivalent Temperature (PET) and the Universal Thermal Climate Index (UTCI) for different levels of physiological stress and thermal sensation (Matzarakis and Mayer 1996, Blazejczyk et al. 2010)

PET (°C)	UTCI (°C)	Grade of physiological stress	Thermal sensation
above +41	above +46	extreme heat stress	very hot
-----	+38 to +46	very strong heat stress	strongly hot
+35 to +41	+32 to +38	strong heat stress	hot
+29 to +35	+26 to +32	moderate heat stress	warm
+23 to +29	-----	slight heat stress	slightly warm
+18 to +23	+9 to +26	no thermal stress	comfortable
+13 to +18	0 to +9	slight cold stress	slightly cool
+8 to +13	-13 to 0	moderate cold stress	cool
+4 to +8	-27 to -13	strong cold stress	cold
-----	-40 to -27	very strong cold stress	strongly cold
below +4	below -40	extreme cold stress	very cold

Both meteorological and non-meteorological (metabolic rate and thermal resistance of clothing) reference conditions were defined (Jendritzky et al. 2009, Blazejczyk et al. 2010):

- a wind speed of 0.5 m/s at 10 m height (approximately 0.3 m/s in 1.1 m),
- a mean radiant temperature equal to air temperature and,
- vapour pressure that represents a relative humidity of 50%; at high air temperatures (>29°C) the reference humidity was taken constant at 20 hPa.

- a representative activity to be that of a person walking with a speed of 4 km/h (1.1 m/s). This provides a metabolic rate of 2.3 MET (135 Wm^{-2}).

For calculating the UTCI the air temperature, mean radiant temperature, water vapour pressure and wind speed are required (Jendriztky et al 2010). A pre-alfa version of the software was used for calculation. This software can be downloaded from the COST Action 730's website (www.utci.org/cost.php).

The PET and UTCI values were calculated for 12 and 18 UTC, for the period 1961-2010 and for the mentioned four meteorological stations. Then these values were averaged for climatological standard periods: 1961-1990, 1971-2000 and 1981-2010.

3. RESULTS AND DISCUSSION

3.1. Variation of annual averages

According to the 50-year average of the annual mean PET at 12 UTC, the thermal bioclimate of the examined cities is "slightly cool" (PET_{YEARLY} = 13.2 - 14.2°C) with "slightly warm" summer (PET_S = 27.2 - 28.9°C) and "very cold" winter (PET_W = -2.5 - (-1.8)°C). On the basis of UTCI at 12 UTC, the thermal bioclimates of selected cities are "comfortable" ($UTCI_{YEARLY}$ = 12.9 - (13.9)°C) with "warm" summer ($UTCI_S$ = 26.7 - 28.3°C) and "cool" winter ($UTCI_W$ = -3.5 - (-1.9)°C).

The 30-year average of the annual means of PET and UTCI, calculated for 12 UTC, increased on a slightly different scale (Fig. 2). The averages grew significantly in Szeged and Budapest, but the change in Siófok is negligible. The average PET in Budapest was the lowest in the period 1961-1990. However, in the last 30 years the average PET of Budapest was the second highest. According to the results the UTCI changes more than the PET. The many-year average of UTCI increased from 13°C to about 15°C during the investigated period in Budapest. Meanwhile, the UTCI average in Siófok increased with only 0.5°C over this period, and reached just over 13°C.

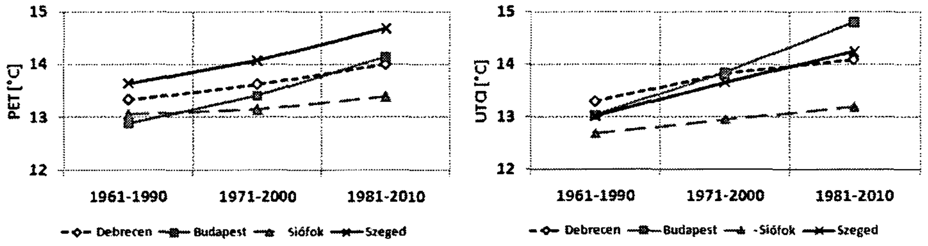

Fig. 2 Variation of 30-year averages of annual means of Physiologically Equivalent Temperature (left) and Universal Thermal Climate Index (right) at 12 UTC

If we analyze the bioclimate indices at 18 UTC, the difference between the two indices is clear (Fig. 3). The PET indices of the different stations are changing almost to the same extent. Interestingly, the highest average of PET occurs in Siófok. Then the sequence of Budapest, Szeged and Debrecen follows. The UTCI curves run somewhat different. The

UTCI changes in Siófok and Debrecen are not equable in the examined periods, in the third 30-year period the growth is lower.

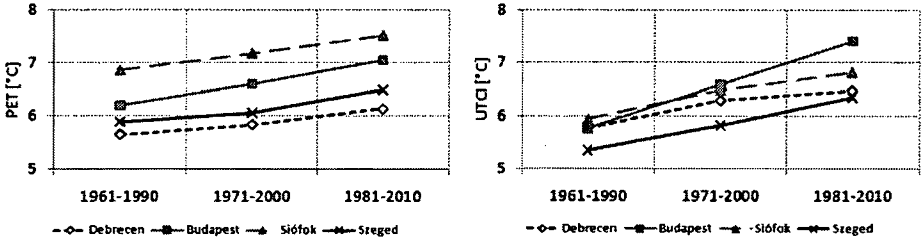

Fig. 3 Variation of 30-year averages of annual means of Physiologically Equivalent Temperature (left) and Universal Thermal Climate Index (right) at 18 UTC

3.2. Variation of seasonal averages

Analyzing the seasonal means of PET at 12 UTC (Fig. 4) in spring and summer a clear increase occurs. The change of PET average in summer is significant between the periods of 1961-1990 and 1981-2010, it is about 2°C in all stations. In autumn the situation is different. The autumn averages are lower in period 1971-2000 than the previous period, but after this the average increases. In winter the PET averages changed in the opposite direction than in autumn. The average of PET for period 1971-2000 is higher than the previous period however the averages of 1981-2010 lag behind from this. Only Budapest does not fit to in this trend because the seasonal averages of PET in winter increase permanently.

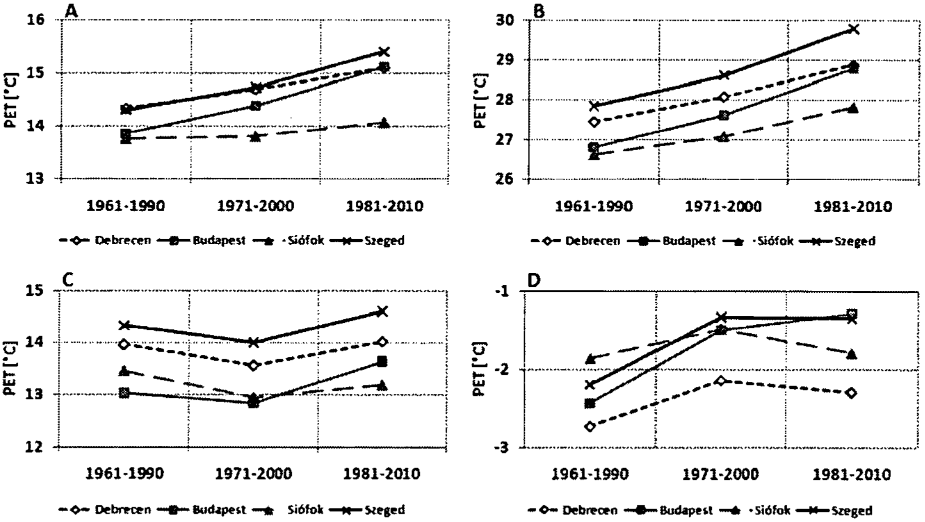

Fig. 4 Variation of 30-year averages of spring (A), summer (B), autumn (C) and winter (D) means of Physiologically Equivalent Temperature at 12 UTC

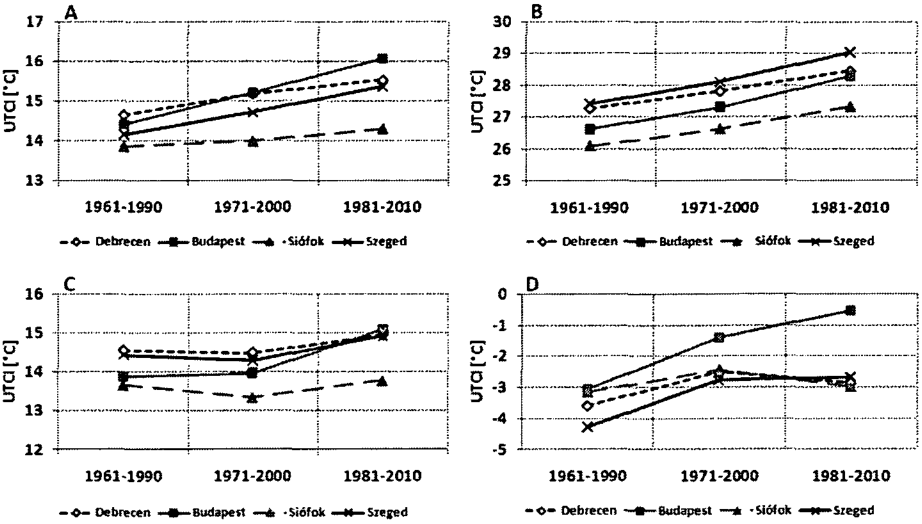

Fig. 5 Variation of 30-year averages of spring (A), summer (B), autumn (C) and winter (D) means of Universal Thermal Climate Index at 12 UTC

The variations of the UTCI averages at 12 UTC (Fig. 5) are similar to PET but the extent of change in this case is smaller. In autumn it can be observed that the differences between the averages of 1971-2000 and 1961-1990 are rather small (< 0.4°C). The averages of 1981-2010 exceed the past periods' averages in all station. The change is significant in Budapest especially; here the average of the last 30 years exceeds the averages of the previous periods with more than 1°C. In winter, it is notable that the values in Budapest behave differently from the other stations.

The thermal bioclimate is only slightly different from this in the evening hours. The averages of PET in spring at 18 UTC increased in all stations (Fig. 6). It is noticeable that the averages in Szeged and Debrecen move together in every period and these values are lower with about 1°C than the averages in Siófok and Budapest. In summer, the situation is the same as in the case of the values at 12 UTC, the seasonal averages are changed to the same extent in the examined stations. As we have already observed, in autumn the average initially decreases, and in the third 30-year period at each station an increase of PET occurs. Changes in the winter period are a reverse of this tendency.

According to the average UTCI (Fig. 7) in spring Budapest shows a higher increase than the other three stations. The 1981-2010 average in Budapest was about one degree higher than the average of the other stations. In summer, the UTCI values in each of the four examined cities were almost equal. The differences between the individual stations do not reach a half degree. In autumn, usually the 1971-2000's averages are lower than in the previous 30 years, except in Budapest. Then, large and small increases occur in the averages. Meanwhile, in Budapest the average of many years' UTCI increased at an accelerating rate. The winter averages of UTCI for 1971-2000 increased compared to the 1961-1990's averages, and then a slight decrease occurs.

Budapest is the exception in this case too, because in winter the average UTCI has not decreased in the last 30-year period.

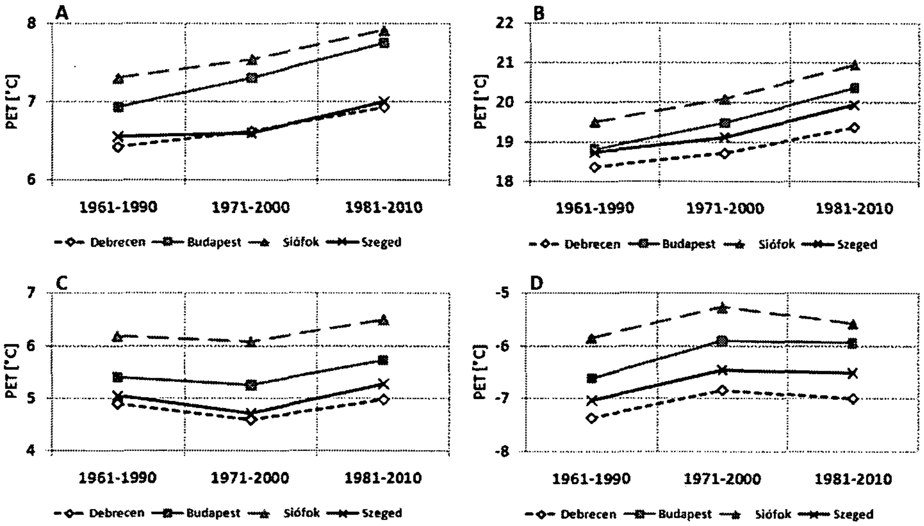

Fig. 6 Variation of 30-year averages of spring (A), summer (B), autumn (C) and winter (D) means of Physiologically Equivalent Temperature at 18 UTC

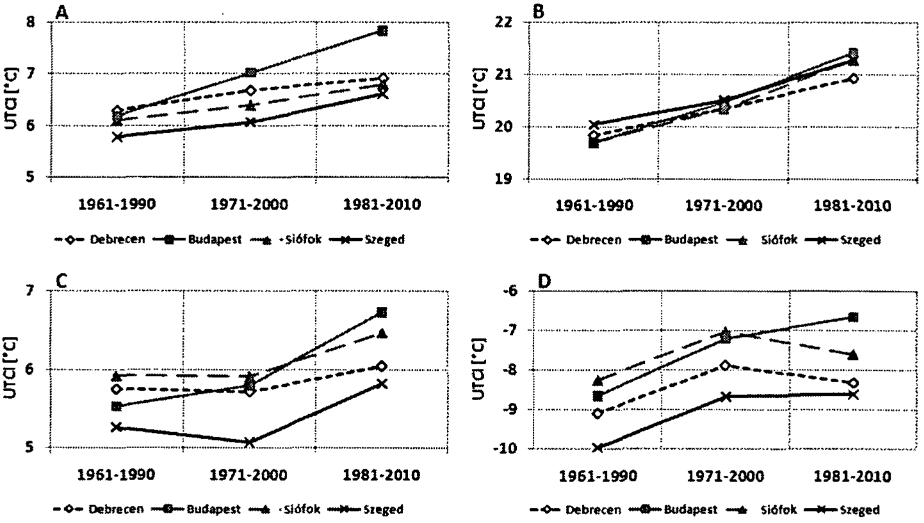

Fig. 7 Variation of 30-year averages of spring (A), summer (B), autumn (C) and winter (D) means of Universal Thermal Climate Index at 18 UTC

4. CONCLUSIONS

Based on the results the following conclusions can be drawn.

- The annual means of PET and UTCI increased in the last three 30-year periods at 12 and 18 UTC, too.
- The spring and summer average of PET and UTCI increased at both times, and the direction of changes was the same as in the case of the annual means. The extent of increase is significant in summer.
- In autumn the thermal bioclimate changed in a different way. The 1971-2000 averages are lower than the 1961-1990 averages. But in the last 30-year period the autumn averages increased significantly, especially in Budapest.
- In winter the bioclimate indices changed in an opposite way to autumn. After a heavy increase in the last 30-year period the winter averages were lower than in the antecedent period.

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REFERENCES

Bartholy J, Pongrácz R, Gelybó Gy, Szabó P (2008) Analysis of expected climate change in the Carpathian Basin using the PRUDENCE results. Időjárás 112:249-264

Blazejczyk K, Broede P, Fiala D, Havenith G, Holmér I, Jendritzky G, Kampmann B, Kunert A (2010) Principles of the new Universal Thermal Climate Index (UTCI) and its application to bioclimatic research in European scale. Miscellanea Geographica 14:91-102

Csima G, Horányi A (2008) Validation of the ALADIN-Climate regional climate model at the Hungarian Meteorological Service. Időjárás 112:155-177

Fiala D, Lomas KJ, Stohrer M (2001) Computer prediction of human thermoregulatory and temperature responses to a wide range of environmental conditions. Int J Biometeorol 45:143-159

Gulyás Á, Matzarakis A (2007) Selected examples of bioclimatic analysis applying the physiologically equivalent temperature in Hungary. Acta Climatol Chorol Univ Szegediensis 40-41:37-46

Gulyás Á, Matzarakis A (2009) Seasonal and spatial distribution of physiologically equivalent temperature (PET) index in Hungary. Időjárás 113:221-231

Gulyás Á, Unger J, Matzarakis A (2006): Assessment of the microclimatic and thermal comfort conditions in a complex urban environment: modeling and measurements. Build Environ 41:1713-1722

Höppe P (1984) Die Energiebalanz des Menschen. Dissertation. Wissenschaftlicher Mitteilung Nr. 49. Universität München

Höppe P (1999) The physiological equivalent temperature in an universal index for the biometeorological assessment of the thermal environment. Int J Biometeorol 43:71-75

Jendritzky G (1993) The atmospheric environment - an introduction. Experientia 49:733-738

Jendritzky G, Havenith G, Weihs P, Batchvarova E (eds) (2009) Towards a Universal Thermal Climate Index UTCI for assessing the thermal environment of the human being. Final Report COST Action 730

Jendritzky G, Bröde P, Fiala D, Havenith G, Weihs P, Batchvarova E, DeDear R (2010) The Universal Thermal Climate Index UTCI. Berichte des Meteorologischen Instituts der Albert-Ludwigs-Universität Freiburg 20:184-188

Lin TP, Matzarakis A (2008) Tourism climate and thermal comfort in Sun Moon Lake, Taiwan. Int J Biometeorol 52:281-290

Matzarakis A, Mayer H (1996) Another kind of environmental stress: Thermal stress. WHO Newsletters 18:7-10

Matzarakis A, Mayer H, Iziomon MG (1999) Applications of a universal thermal index: physiological equivalent temperature. Int J Biometeorol 43:76-84

Matzarakis A, Rutz F, Mayer H (2007) Modeling radiation fluxes in easy and complex environments – Application of the RayMan model. Int J Biometeorol 51:323-334

Németh Á, Mika J (2009) Climate as a risk factor for tourism. AGD Landscape & Environment 3(2):113-125

Németh Á, Schlanger V, Katona Á (2007) Variation of thermal bioclimate in the Lake Balaton Tourism Region (Hungary). In: Matzarakis A, de Freitas CR, Scott D (eds) Developments in Tourism Climatology, ISB Commission on Climate, Tourism and Recreation, Freiburg. 37-42

Szépszó G, Horányi A (2008) Transient simulation of the REMO regional climate model and its evaluation over Hungary. Időjárás 112:203-231

Unger J (1999) Comparisons of urban and rural bioclimatological conditions in the case of Central-European city. Int J Biometeorol 43:139-144

www.utci.org/cost.php

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Universitatis Szegediensis, Tomus 44-45, 2011, 103-110

BUILDINGS' HEAT OUTPUT AND URBAN CLIMATE

M SEPRŐDI-EGERESI[1] and A ZÖLD[2]

[1]*Department of Environmental Economics, Budapest University of Technology and Economics*
Magyar tudósok krt. 2. 1117 Budapest, Hungary, E-mail: egeresi.marta@gmail.com
[2]*Faculty of Technology, University of Debrecen, Ótemető u. 2-4. 4028 Debrecen, Hungary*

Summary: Both winter and summer "the buildings heat the street". In the typical design procedures the mutual interrelations between the buildings and the environment are neglected, the environment is supposed to be a sink of unlimited capacity. Nevertheless, the heat output of the buildings – a component of the anthropogenic heat load – has considerable effect on the urban microclimate. Mechanical cooling (air conditioning) launches a harmful self-generating process. Adequate urban design facilitates the slowing down or cease of this process and at the same time provides acceptable summer thermal comfort conditions. Dispensable mechanical cooling promotes mitigation. The effect appears on both urban and global scale.

Key words: Urban heat island, heat output of buildings, mechanical cooling, urban green areas

1. INTRODUCTION

When calculating the energy consumption of buildings, the set indoor temperature (the desired or the tolerated value) and the parameters of the environment are taken into account. The aim of the calculation is to determine the energy flux and its cumulated value. It is supposed that the environment is a sink of unlimited capacity. In other terms the energy flux from, or to, the environment does not cause any change in its parameters such as external air temperature.

These steady state balance equations are the base of the typical design procedures: the mutual interrelations between the buildings and the environment are neglected.

In reality not only the environment affects the energy balance of buildings but vice versa, the buildings influence the environment too. It's interesting that this relationship is better known on the global than on the local scale.

Knowing the scenarios of global climate change it is expected that the frequency and length of the hot periods and/or the summer temperature will be higher, thus in the temperate zone of Europe in a few decades the external conditions in summer will be similar to those of the Mediterranean area nowadays (IPCC 2007). This is why the study and the implementation of architectural solutions, the experience of vernacular architecture in the Mediterranean zone is becoming step by step the subject of interest of long-term thinking architects and engineers. In other terms it means the adaptation of the buildings to the expected new conditions.

Global climate change is the consequence of such activities of mankind as the heat and pollution emission of the building sector.

Climate change can already be felt on the local scale in urban areas where the density of buildings is high. Here the complexity of the parameters of the environment surrounded by real and virtual boundaries considerably depends on the building sector: the effect of the buildings on the environment can be felt. This is the microclimate on urban scale, the well-known phenomenon of the urban heat island (UHI) (Sümeghy and Unger 2004).

The UHI is the consequence of many factors. The albedo (the reflected fraction of the solar radiation) differs from that of rural areas. Therefore a higher fraction of the incoming solar radiation is trapped. At the same time, the incoming radiation is less, due to the higher air pollution. Considerable difference can be found in the intensity of the long-wave infra-red radiation towards the sky since the sky view factor of the rural areas is high, while that of the urban surfaces (building envelope, street etc.) is limited as the buildings obstruct the mutual visibility between the urban surfaces and the sky. This effect is augmented by the above-mentioned fact, namely the more polluted air over the cities.

It is evident that the thermal characteristics of the building envelope have some effect on the radiation balance. The interrelation of the albedo of the surface and the surface temperature is obvious, the importance of the thermally light colours and the cool roofs is well known. The buildings have a considerable heat storage capacity. The heat accumulated during the day is released after sunset.

The buildings influence air movement: they accelerate or slow down the wind depending on their height and layout, the width, depth and orientation of the streets and the direction of the wind. These effects form the passive role of the buildings in the development of the UHI.

Besides the radiant heat exchange there is a great difference between urban and rural areas regarding the latent heat exchange. Due to the restricted green areas in the cities the evapotranspiration of the vegetation does not represent a significant component in the energy balance.

The sewage system and the cleaning of the streets means that the melted snow and the channelling of rainwater further decrease the evaporative cooling in urban areas.

The urban heat island is intensified by the anthropogenic heat output. The heat output of the industry and traffic seems to be obvious however the heat output of buildings must not be forgotten: it should be considered as the “active role of the buildings” in the development of UHI.

2. THE ACTIVE ROLE OF THE BUILDINGS

Certainly it is not the building itself that is active, but the anthropogenic heat output due to buildings is spoken of. It is to be understood that the buildings heat the street in both winter and summer. In winter it is due to the heat loss. In summer the mechanical cooling of buildings is equivalent to the heating of the street since mechanical cooling systems extract the heat from the building and release it just nearby via the condensers on the façades and the roofs, the cooling towers on the roof and next to the building.

In both cases we have to consider the internal gains in the buildings due to the household devices, lighting, metabolic heat, etc. these are transferred to the environment as heat loss (even in summer!) or with mechanical cooling (Egeresi 2009).

The significant and basic difference between the winter and summer situation can be seen at the first glance. In winter a dynamic balance is achieved: the higher the heat loss, the more intensive the UHI is, and the more intensive UHI decreases the heat loss, thus an equilibrium state will develop. In summer a catastrophic self generating process develops: the more heat is extracted from the building, the more intensive is the UHI and as a consequence even more mechanical cooling will be needed (Santamouris 2001).

In order to compare the heat output of the buildings and the most important "natural" component of the energy balance we attempted to estimate the active role of the buildings in a case study of a downtown district of Budapest.

3. CASE STUDY

The effect of the urban heat island peaks above the city centre (Probáld 1974). The 5th District is a well-known area in Hungary in the centre of Budapest. Table 1 contains the basic parameters of the 5th District and other areas of the city.

Table 1 Population, area and density in conurbation of Budapest (www.studiometropolitana.hu 1998)

	5th District	**Budapest, total**	**Outskirts**
Population (person)	27 732	1 860 000	620 000
Area (km^2)	2.59	525	2013
Density of population (person/km^2)	10 666	3544	309

The number of flats is 19180 in the 5th District and the total floor area of flats is 1.3 million m^2. Besides residential buildings there are a lot of offices, hotels and other service areas. The total floor area of the buildings in this district is 6.5 million m^2. The ratio of built-up areas and the total area of the district is 80%. In order to estimate the specific heat output of the buildings per unit urban area the following data and approximations have been made. The ratio of the floor area and urban area is 2.52 m^2/m^2 (Table 2).

Table 2 Built-in areas in the 5th District of Budapest (2009)

Ratio to each m^2 of urban area	**m^2/m^2**
total built-in floor area	2.52
road or covered surfaces	0.36
park or green area	0.07

Taking an average ceiling height the specific heated volume of the buildings is 7.5 m^3/m^2. Taking into account the typical surface to volume ratio of the buildings (block of flats, hotel, office) in the downtown the exposed surface of the buildings per unit urban area is 4.5 m^2/m^2 (Table 3). The ratio of the cooling surface and the heated volume (A/V) determines basically the energetic quality of building. Considering the age of this building stock the heat loss coefficient of walls, roofs, windows and the transparent ratio of the building envelope, the average U value is 1.6 W/m^{2}K.

The estimated air change rate is one 1/h in winter – higher than the regulation value, because of the poor air tightness of old buildings. The internal heat gain is 5 W/m^2 floor areas, according to the design value (prescribed in the regulation) for calculation of building energy needs. 0°C external and 20°C indoor temperatures have been taken into account as the average for January. With this input data set the calculation shows that the heat output of this building stock is 4.716 kWh/d for 1 m^2 horizontal area.

Table 3 Data of different built-in areas in Budapest

	1 = City centre	**2 = Suburbs**	**3 = Single houses**
built-in ratio (%)	80	50	30
A/V (m^2/m^3)	0.6	0.8	1
floor surface per unit urban area (m^2/m^2)	2.5	0.8	0.1
built-in volume per unit urban area (m^3/m^2)	7.5	2.4	0.3
building envelope superficies A (m^2)	4.5	1.92	0.3
windows and doors (N or obstructed) (%)	75	50	25
windows and doors (E-S-W, insolated) (%)	25	50	75

The incoming solar radiation in a clear day in January is 1.45 kWh/d for 1 m^2 horizontal area. (Szabó and Tárkányi 1969) Thus the specific heat output of this building stock is not only comparable with the incoming solar radiation on an average winter day but considerably exceeds it (Fig. 1). The same calculation has been carried out for the other areas of the city as we can see in Table 4.

Table 4 Heat surplus data of different built-in areas in winter

	1 = City centre	**2 = Suburbs**	**3 = Single houses**
Solar radiation pro day ($kWh/m^2/d$)	1.450	1.450	1.450
Heat output of heating ($kWh/m^2/d$)	4.716	1.878	0.281

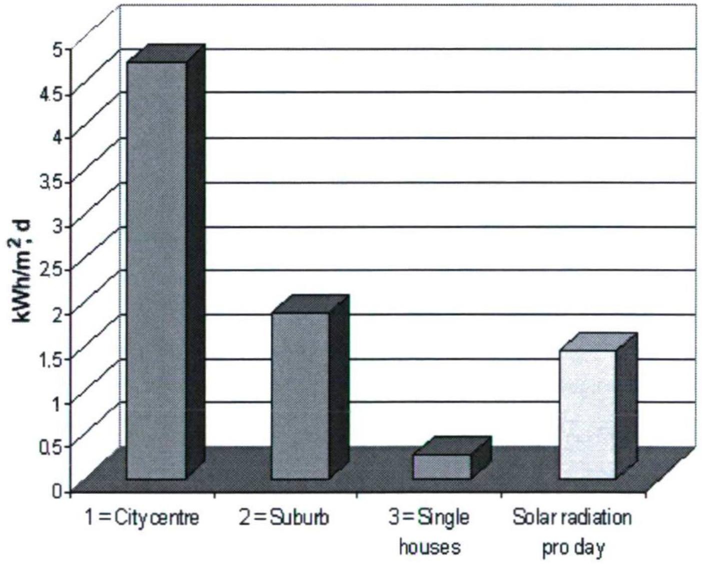

Fig. 1 Daily heat output of buildings on an average winter day and the incoming radiation

Soon a new thermal mapping system will be available covering winter-time heat loss data on Budapest and the 5th District. EnergyCity is a European-funded project aiming the reduction of energy consumption and CO_2 emission of towns and cities in Central Europe (www.energycity2013.eu). High resolution airborne infrared pictures will support the analysis of heat losses from buildings (among others) – one of the target areas will be the here investigated district of Budapest.

For summer the following conditions have been taken into account: the geometry and topology of the buildings is the same. Mechanical cooling is applied to maintain an indoor set temperature of 24°C, which coincides with the design value of the daily mean external temperature. The internal gain remains unchanged: 5 W/m^2. Whilst calculating the solar gain the total radiant energy transmittance of the windows (the *g* value) is 0.8. With regard to the high density of buildings in the downtown area it is supposed that 75% of the windows are obstructed, thus only the diffuse radiation can be taken into account. The remaining 25% (mainly on the top floors) has solar access and is evenly distributed for different orientations (Table 3). The input data set can be seen in Table 5.

Table 5 Heat surplus data of different built-in areas in summer

	1 = City centre	**2 = Suburbs**	**3 = Single houses**
Solar radiation pro day (kWh/m^2,d)	7.300	7.300	7.300
Heat output of cooling (kWh/m^2,d)	1.080	0.385	0.053

The mechanical cooling extracts the cumulated gain, the sink is the outdoor air. The results are shown in Fig. 2 with the daily heat output of buildings on an average summer day and the incoming radiation.

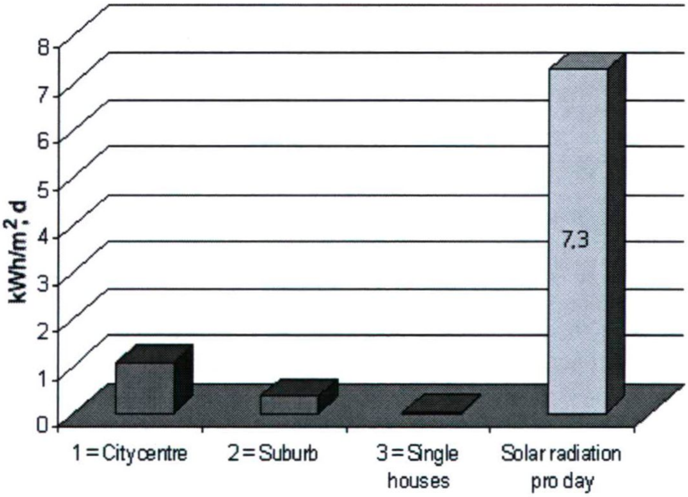

Fig. 2 Daily heat output of buildings in an average summer day and the incoming radiation

All data relates to the daily energy balance. Certainly at a given time the ratios may considerably differ from the daily average and around sunset and the evening hours the buildings' heat output exceeds the actual value of the radiation.

4. THE WAY OUT

If the buildings and the urban environment are adapted to the more severe summer conditions energy consumption and emission will decrease, mitigation may be realised. Here the interrelation shows a "positive feedback", the better the buildings are adapted, the better the mitigation is.

On an urban scale a well-proven solution is the vegetation. Among other favourable effects the cooling potential of the vegetation is very high.

Fig. 3 illustrates the temperature distribution in the neighbourhood of the City Park of Budapest (Gábor and Jombach 2006).

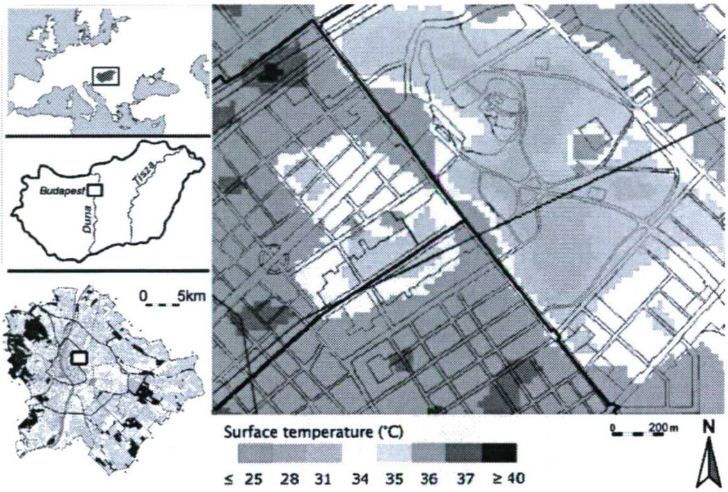

Fig. 3 The city Park of Budapest (Gábor and Jombach 2006)

One can see that the temperature in the park is low. The cooling effect can be observed around the buildings, the perimeter of the park and along the axis of the two main roads: the latter two channel the air movement, and by having trees along them, the shading and evaporative cooling effect is improved.

It is to be emphasized that the positive effects of the green areas can not only be felt within the park itself but in the buildings around the green area, too.

As a cooler part of the city a green area generates air movement: the urban breeze, which affects the surrounding buildings. In Szeged, Hungary, Gulyás (2005) reported another light-breeze measurement in which the magnitude of breeze was 0.5-1.5 m/s at a height of 1.1 m and 0.5-2 m/s at a height of 30 m. We can estimate the parameters of urban breeze with simulation tools. In the following results are shown from a PCI (Park Cool Island) examination. This research studies an average park in 1 ha and the surrounding buildings with the help of computational tools (FLUENT).

In Fig. 4 it can be seen, that even a modest temperature difference between the park and the built-in area can generate the expected light breeze mainly due to the high surface temperature of roofs and surrounding facades. The vertical component is the consequence of the buoyancy effect and has a maximum along the vertical edges at the buildings' corners. Nevertheless the horizontal components achieve a maximum of 0.7 m/s at the corners of the park and in the street – parallel with the street axis the velocity is 0.82 m/s (Egeresi and Zöld 2009).

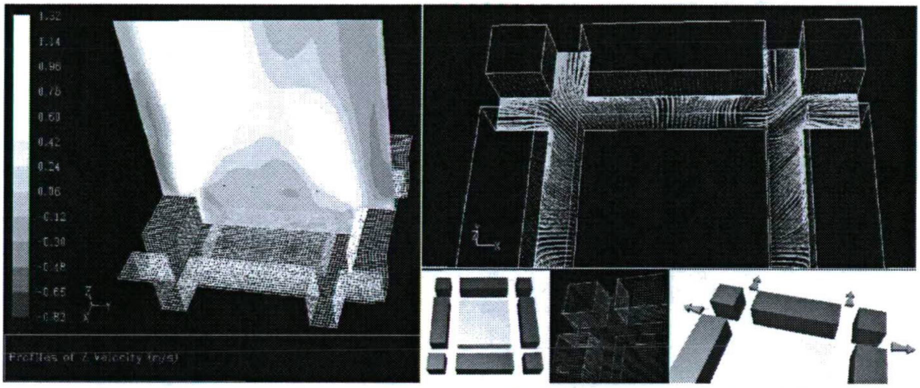

Fig. 4 PCI effect in a computational model (FLUENT) (Egeresi and Zöld 2009)

The air movement parallel with the facades is less intensive in the middle of the edge of the park, and increases approaching the corners. Comparing the different forms of the park it can be stated that a more intensive air movement is expected if the park layout is elongated.

The breeze from the park towards the built-in area has different effects. Although the internal and solar gain remains unchanged the cooling load of the building will be less since the temperature of the incoming air is lower, thus even if mechanical cooling is applied, the energy consumption will be less.

More important is the possibility of natural ventilation. In this respect two facts should be considered: on the one hand the temperature of the outdoor air is lower, and on the other hand the air movement along the facades intensifies the air movement inside the buildings. The higher air change rate accompanied with lower temperature may fulfil the expected thermal comfort conditions without mechanical cooling. Even if only a small decrease of temperature is realized, the effect of 1-2°C difference may be dramatic in the interval of 26-29°C. Last but not least the street comfort improves.

5. CONCLUSIONS

The interrelation of heat output of buildings in winter and the UHI is well-known, however the same phenomenon in summer is worthy of much more interest due to its self-generating character.

The harmful self-generating process of energy consumption and climate change on urban and global scale can and should be slowed down or prevented not only by adapting buildings to the more serious summer conditions but with conscious urban design. Urban green areas decrease the need in mechanical cooling. Without mechanical cooling the heat output of the buildings is less. Providing all buildings are air conditioned the cumulated daily heat output in dense urban area may be comparable with the daily energy income from the solar radiation.

A better adaptation of buildings and urban areas results in the mitigation of harmful emission, there is a "positive feedback" between them.

Obviously it is not disputable that there are buildings where mechanical cooling is inevitable even if the design and the urban environment is energy conscious. In some cases the technology or the high internal gains make air conditioning necessary, e.g. in a theatre, or in a hospital, but a well designed residential building in a well designed urban environment will provide acceptable thermal comfort conditions in summer without mechanical cooling.

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REFERENCES

Egeresi M (2009) Hőbuborék az épület körül. [Heat-bubble around the building. (in Hungarian)] Építés–Építészettudomány 37(3-4):371-381

Egeresi M, Zöld A (2009) Green area generated breeze: modelling of breeze generating potential of Park Cool Island. Energy Efficiency and New Approaches, International Building Physics Conference. ISBN 978-975-561-350-5 Istanbul Technical University. 931-936

Gábor P, Jombach S (2006) A zöldfelület intenzitás és a városi hősziget jelenségének összefüggései Budapesten. [Connections of intensity of green area and phenomenon of urban heat island in Budapest. (in Hungarian)] www.vati.hu

Gulyás Á (2005) Differences in human comfort conditions within a complex urban environment: a case study, Acta Climatol Chorol Univ Szegediensis 38-39:71-84

IPCC (2007) Intergovernmental Panel of Climate Change, 2007 Report. www.ipcc.ch

Probáld F (1974) Budapest városklímája. [Urban climate of Budapest. (in Hungarian)] Akadémiai Kiadó, Budapest

Santamouris M (2001) The role of green spaces. Energy and climate in the built environment. London. 145-157

Sümeghy Z, Unger J (2004) Az épített környezet léghőmérséklet-módosító hatása. [Air-temperature modifying effect of building environment. (in Hungarian)] Építész spektrum 3(6):14-17

Szabó Gy, Tárkányi Zs (1969) Napsugárzási adatok az építőipari tervezés számára. [Solar-radiation data for building industry. (in Hungarian)] Építéstudományi Intézet, Budapest

www.energycity2013.eu EnergyCity, Central Europe Programme co-financed by the ERDF.

www.studiometropolitana.hu (1998) A Budapesti Agglomeráció adottságai, fő folyamatai. [Conditions and main *processes in conurbation of Budapest. (in Hungarian)*]

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TRENDS IN THE CHARACTERISTICS OF ALLERGENIC POLLEN IN SZEGED, HUNGARY

L MAKRA[1] and I MATYASOVSZKY[2]

[1]*Department of Climatology and Landscape Ecology, University of Szeged, P.O.Box 653, 6701 Szeged, Hungary*
E-mail: makra@geo.u-szeged.hu
[2]*Department of Meteorology, Eötvös Loránd University, Pázmány Péter st. 1/A. 1117 Budapest, Hungary*

Summary: The aim of the study is to analyse trends of the pollination season with its start and end dates, as well as trends of annual total pollen count and annual peak pollen concentration for Szeged, Hungary. The data set covers an 11-year period (1999-2007) and includes one of the largest spectra, with 19 taxa, as well as five meteorological variables. After performing Mann-Kendall tests, the annual cycles of slopes of daily pollen concentration trends and annual cycles of slopes of daily climate variable trends are calculated. Representing the strength of their relationship an association measure was introduced. Total annual pollen count calculated by linear trends and annual peak pollen concentrations indicate a small number of trends, while total annual pollen count calculated by daily linear trends show significant trends (71% of them positive) for almost all taxa. However, phenological characteristics are free of significant changes except for *Urtica*. We received that the association measure performs well when comparing it to the climate change related forces. Furthermore, significant changes in pollen characteristics are also in accordance with the risk and expansion potential due to the climate change.

Key words: pollen, pollination season, trend, climate change, respiratory allergy

1. INTRODUCTION

The warming of the climate system is obvious, as is now evident from observations of increases in global average air and ocean temperatures, the widespread melting of snow and ice and rising global average sea level. Observational evidence shows that many natural systems are being affected by regional climate changes, particularly temperature increases. In terrestrial ecosystems, earlier timing of spring events and poleward and upward shifts in plant ranges are with very high confidence linked to recent warming. There is medium confidence that other effects of regional climate change on natural and human environments are emerging. They include effects of temperature increases on change in land use and parameters (start and end dates, as well as the length of the pollen season, daily peak pollen level, the incidence of peak day and the total annual pollen count) of allergenic pollen in Northern Hemisphere high and mid-latitudes (IPCC 2007).

Recent changes of the aforementioned pollen characteristics have been reported considering earlier onset (Jäger et al. 1996, Emberlin et al. 1997, Emberlin et al. 2002, Clot 2003, Teranishi et al. 2006, Emberlin et al. 2007a, Stach et al. 2007, Frei 2008, Frei and Gassner 2008), earlier end date (Jäger et al. 1996, Stach et al. 2007, Recio et al. 2010), longer pollen season (Stach et al. 2007), an increase in the daily peak pollen counts (Jäger et al. 1996, Frei 2008, Frei and Gassner 2008, Recio et al. 2010), earlier incidence of peak day (Jäger et al. 1996, Stach et al. 2007) and higher annual pollen concentration (Jäger et al. 1991, Jäger et al. 1996, Damialis et al. 2007, Frei 2008, Frei and Gassner 2008, Cristofori et al. 2010, Recio et al. 2010). However, for certain taxa, either no trends are experienced (Jäger et al. 1996, Frenguelli et al. 2002, Emberlin et al. 2007b) or being sensitive against warming an opposite change in pollen parameters is observed (Latorre and Belmonte 2004, Ridolo et al. 2007, Jato et al. 2009). Predominant changes in timing-related pollen parameters are due to higher temperatures associated with global warming, while those in quantity-related pollen characteristics are in association with both higher temperatures and change in land use (urbanisation and giving up or modifying cultivation) (Frei and Gassner 2008).

Over the last three decades, parallel to the global warming, an increasing effect of aeroallergens on allergic patients has been observed which may imply a greater likelihood of the development of allergic respiratory diseases in sensitized subjects (Damialis et al. 2007, Stach et al. 2007). Together with the aforementioned changes in pollen production and timing further factors may contribute to the development of respiratory diseases, including both indoor and ambient air pollution, as well as reduced exposure to microbial stimulation (Frei and Gassner 2008). Furthermore, chemical air pollutants increase exposure to the allergens, their concentration and/or biological allergenic activity (Just et al. 2007).

Pollen analyses rarely produce a comprehensive picture on quantity- and timing-related pollen parameters of all taxa that occur in a region studied. Many studies consider just one taxon (Emberlin et al. 2002, Latorre and Belmonte 2004, Tedeschini et al. 2006, Emberlin et al. 2007a, Stach et al. 2007, Jato et al. 2009, Recio et al. 2010), or at most a small number of taxa (up to four taxa e.g. Jäger et al. 1991, Emberlin et al. 2007b, Ridolo et al. 2007, Frei and Gassner 2008, García-Mozo et al. 2010). Altogether three studies, namely Clot (2003, 25 plant taxa), Damialis et al. (2007, 16 plant taxa) and Cristofori et al. (2010, 63 plant taxa) analysed a comprehensive spectrum of the regional pollen flora. An overall analysis of pollen characteristics for a given source area provides a more reliable picture of the local pollen trends for each taxon considered in accordance with their different optimum environmental conditions.

The knowledge of important dates of the pollination season, as well as parameters of the pollen production are very important since they make patients suffering from pollen induced respiratory diseases prepare in time for the unfavourable conditions. Climate change may, however, influence the pollination characteristics of different taxa diversely. The aim of our study is to analyse a comprehensive spectrum of airborne pollen data (19 plant taxa) for the Szeged agglomeration in Southern Hungary. Namely, trends of the pollination season with its start and end dates, as well as trends of annual total pollen count and annual peak pollen concentration are calculated for each taxon considered. After performing Mann-Kendall tests, the annual cycles of slopes of daily pollen concentration trends and annual cycles of slopes of daily climate variable trends are calculated and their association is analysed. This kind of trend analysis is a novel approach, providing information on annual cycles of trends. Results received for the pollen characteristics are compared with two novel climate change related categories, namely risk and expansion potential due to the climate change for each taxon.

2. MATERIALS AND METHODS

2.1. Location and data

Szeged (46.25°N, 20.10°E), the largest settlement in South-eastern Hungary is located at the confluence of the rivers Tisza and Maros. The area is characterised by an extensive flat landscape of the Great Hungarian Plain with an elevation of 79 m asl. The city is the centre of the Szeged region with 203,000 inhabitants. The climate of Szeged belongs to Köppen's Ca type (warm temperate climate) with relatively mild and short winters and hot summers (Köppen 1931). The pollen content of the air was measured using a 7-day recording "Hirst-type" volumetric trap (Hirst 1952). The air sampler is located on top of the building of the Faculty of Arts at the University of Szeged some 20 m above the ground surface (Makra et al. 2010). Daily meteorological variables include the mean temperature (T, °C), mean global solar radiation (GSR, Wm^{-2}), mean relative humidity (RH, %), mean wind speed (WS, ms^{-1}) and precipitation total (P, mm). They were collected in a monitoring station located in the inner city area of Szeged.

The database consists of daily mean pollen counts (pollen grains$\cdot m^{-3}$ of air) of altogether 24 taxa over the 11-year period 1997-2007. Due to incomplete data sets five taxa were omitted. The 19 taxa retained for further consideration with their Latin (English) names are as follows: *Alnus* (alder), *Ambrosia* (ragweed), *Artemisia* (mugwort), *Betula* (birch), *Cannabis* (hemp), Chenopodiaceae (goosefoots), *Juglans* (walnut), *Morus* (mulberry), *Pinus* (pine), *Plantago* (plantain), *Platanus* (platan), Poaceae (grasses), *Populus* (poplar), *Quercus* (oak), *Rumex* (dock), *Taxus* (yew), *Tilia* (linden), *Ulmus* (elm) and *Urtica* (nettle). Missing values in the data sets, not exceeding a one week term for any taxa, were estimated by interpolating on either sides of the gap (Damialis et al. 2007). The number of daily missing values runs less than 5% of the total pollen data. The 19 taxa considered produce 93.2% of the total pollen amount for the given period. Taxa with the highest pollen levels include *Ambrosia* (32.3%), Poaceae (10.5%), *Populus* (9.6%) and *Urtica* (9.1%), making up altogether 61.5% of the total pollen.

Considering the most frequent taxa, *Ambrosia* species appear both in the urban environment and in the countryside. Ragweed occurs especially frequently west of Szeged city. The ruling north-western winds can easily transport its pollen into the city. Since in the sandy region, north-west of Szeged, stubble-stripping is not necessary for ground-clearance due to the mechanical properties of sandy soils, *Ambrosia* can cover large areas. Owing to highway buildings around Szeged, several farmlands have been abandoned that also favoured the expansion of *Ambrosia*. Poaceae species represent a substantial ratio in the city, while *Urtica* and *Ulmus* have a high frequency in the floodplain forest undergrowth of the Tisza River, as well as in those of the Tisza and Maros Rivers, respectively. *Urtica* also occurs in neglected lawns of the city area. On the contrary, *Betula* has no natural habitat in the Szeged region; all individuals in the public places have been planted.

The remaining species occur sparsely. *Alnus* species are only found in the Botanical Garden of Szeged. The pollen of *Artemisia, Cannabis,* Chenopodiaceae and *Rumex* can come from neglected areas of both the city and its surroundings, as well as from stubbles. *Juglans, Pinus, Platanus, Taxus* and *Tilia* species are planted exclusively in public places and gardens; they have no natural habitats in the Szeged region.

However, since the 1960s *Pinus* species have been extensively planted in the sandy regions north-west of Szeged in the frame of an afforestation programme. Their pollen can easily reach Szeged through the north-western winds. *Morus* is planted in boulevards and in public places. *Plantago* species occur in natural lawns of both the city and its surroundings. Natural and domesticated species of *Populus* are characteristic in the sallow and poplar floodplain forests along the Tisza and Maros rivers, forming continuous green corridors there. Furthermore, these species are frequently planted into public places and beyond the city along public roads as forest belts. *Quercus* species are planted along the embankment surrounding the city, as well as north of the city (Horváth et al. 1995, Parker and Malone 2004).

The pollen season is defined by its start and end dates. For the start (end) of the season we used the first (last) date on which 1 pollen grain$\cdot$m^{-3} of air is recorded and at least 5 consecutive (preceding) days also show 1 or more pollen grains$\cdot$m^{-3} (Galán et al. 2001). In the case of a given pollen type, the longest pollen season during the 11-year period was considered for each year.

2.2. Methods

Linear trend analysis is a common way for estimating trends in the data. The existence of trends is examined generally by the *t*-test based on the estimated slopes and their variances. This technique, however, can be used only for data distributed nearly normally. Data having probability distributions far from normality can be tested against monotone trends by nonparametric tests such as the Mann-Kendall (MK) test. For highly skewed data, such as the annual total number of pollen counts or annual peak pollen concentration, the latter technique has substantially higher power than the *t*-test (Önöz and Bayazit 2003). Therefore, this method is used here, although the slopes are also calculated.

Frequently, trends might have too complex forms to be well-approximated by global linear fits, thus nonparametric methods should be preferred. Nonparametric methods require some smoothness of the trends to be estimated. Each version of these techniques results in linear combinations of observations lying within an interval around the points where trends are estimated. The size of this interval is controlled by a quantity called bandwidth. There are several versions of such estimators but local linear fittings using weighted local regression (WLR) have nice properties. They possess high statistical efficiency (Fan 1993) and are design adaptive (Fan 1992). Further, they automatically correct edge effects at boundaries of data sets (Fan and Gijbels 1992). The choice of the bandwidths has a crucial role in the accuracy when estimating the trends. A large bandwidth delivers small variances with large biases of the estimates, while a small bandwidth results in large variances with small biases. Thus, an optimal bandwidth producing relatively small variances and small biases needs to be found. Such a bandwidth minimizes the expected mean squared error of estimates. A technique proposed by Francisco-Fernández and Vilar-Fernández (2004) is used to estimate bandwidths, because the method provides autoregressive (AR) models to describe the autocorrelations of the underlying data sets, too. These AR models will be important in Sections 3.2 and 3.3. Note that the local linear fits become globally linear with infinite bandwidths.

3. RESULTS

3.1. Pollination season, annual total pollen count and annual peak concentration

In the order of descending strength of the significance based on the MK test *Populus, Taxus* and *Urtica* show a significant increase of the annual total pollen count (Table 1). Concerning the annual peak pollen concentration the similar order of taxa are *Populus, Alnus* and *Juglans*. *Populus* and *Juglans* are characterised by growing, while *Alnus* with declining peak concentrations. Only Poaceae and *Urtica* show significant rising of the duration of the pollination season. The most substantial changes emerge in the behaviour of *Urtica*, because both the annual total pollen count and the duration (with significantly earlier start and later end) of the pollination season are strongly increasing. *Populus* does not have any change concerning its pollination season, however both the annual total pollen count and annual peak pollen concentration increase significantly. The majority of test statistics for the pollination season is not statistically significant, nevertheless the beginning seems to occur earlier and the end tends to happen later thus extending the duration of this period.

Table 1 Change of total annual pollen count (TAPC) (pollen grains·m^{-3}/10 years), annual peak pollen concentration (APP) (pollen grains·m^{-3} / 10 years), start, end and duration of the pollination season (days / 10 years) calculated by linear trends. Significant values for the Mann-Kendall test are denoted by **bold** (1%), ***bold italic*** (5%) and light-faced (10%) letters.

Taxa	**TAPC**	**APP**	**Pollination season**		
			Start	**End**	**Duration**
Alnus	*-207*	*-59*	*18*	*16*	*-2*
Ambrosia	*229*	*230*	14	*-9*	*-22*
Artemisia	*-61*	*-133*	*-4*	*15*	*19*
Betula	*-60*	*0*	*-1*	*2*	*3*
Cannabis	*47*	*-4*	*8*	*36*	*28*
Chenopodiaceae	*-175*	*-9*	*-2*	*3*	*5*
Juglans	*253*	30	*-8*	*-7*	*1*
Morus	*400*	*44*	*-7*	*-4*	*3*
Pinus	*-194*	*-20*	*-2*	*-1*	*0*
Plantago	*91*	*3*	***-23***	*19*	*4*
Platanus	*271*	*48*	*-7*	*-3*	*4*
Poaceae	*176*	*43*	*-1*	17	**27**
Populus	***2981***	***610***	*-2*	*3*	*4*
Quercus	*236*	*25*	*4*	*9*	*5*
Rumex	*-505*	*-45*	***-11***	*3*	*15*
Taxus	697	*59*	*-4*	**29**	*32*
Tilia	*-65*	*-1*	*-4*	*-1*	*3*
Ulmus	*-160*	*-12*	*5*	*-13*	*-18*
Urtica	1183	*25*	***-13***	*18*	**31**

Note that only a few trends have been detected significant as compared to the total number of tests performed, which is however not surprising as the interannual variability (variance) of the characteristics examined is quite high and the length of data sets is quite short. In order to get a deeper insight into the tendencies of pollen concentrations a detailed trend analysis is introduced on a daily basis.

3.2. Trends on a daily basis

MK tests are performed and slopes of linear trends are estimated for every particular day of each pollination season using 11 pollen concentration data corresponding to the 11 years. This kind of trend analysis provides information on annual cycles of trends. In the absence of trend on every day of the pollination season the MK test values are distributed normally with expectation zero and variance unit. Therefore, deciding on the existence of trend is identical with the problem of deciding whether the annual mean of daily MK test values correspond to the expectation zero. The classical *t*-test is simplified as the variance is known (unit), but modified according to the autocorrelations among the consecutive MK test values. First order autoregressive (AR(1)) models are used to describe these autocorrelations as mentioned in Section 2.2. Averaging daily slopes over the pollination seasons gives rates of the change of total annual pollen counts. Table 2 shows that only 5 out of the 19 taxa do not exhibit significant change. However, it can happen that the pollination season consists of time intervals with both positive and negative trends, and this is why the mean of MK test values are close to zero. This possibility is examined by the following way (Fig. 1a-b).

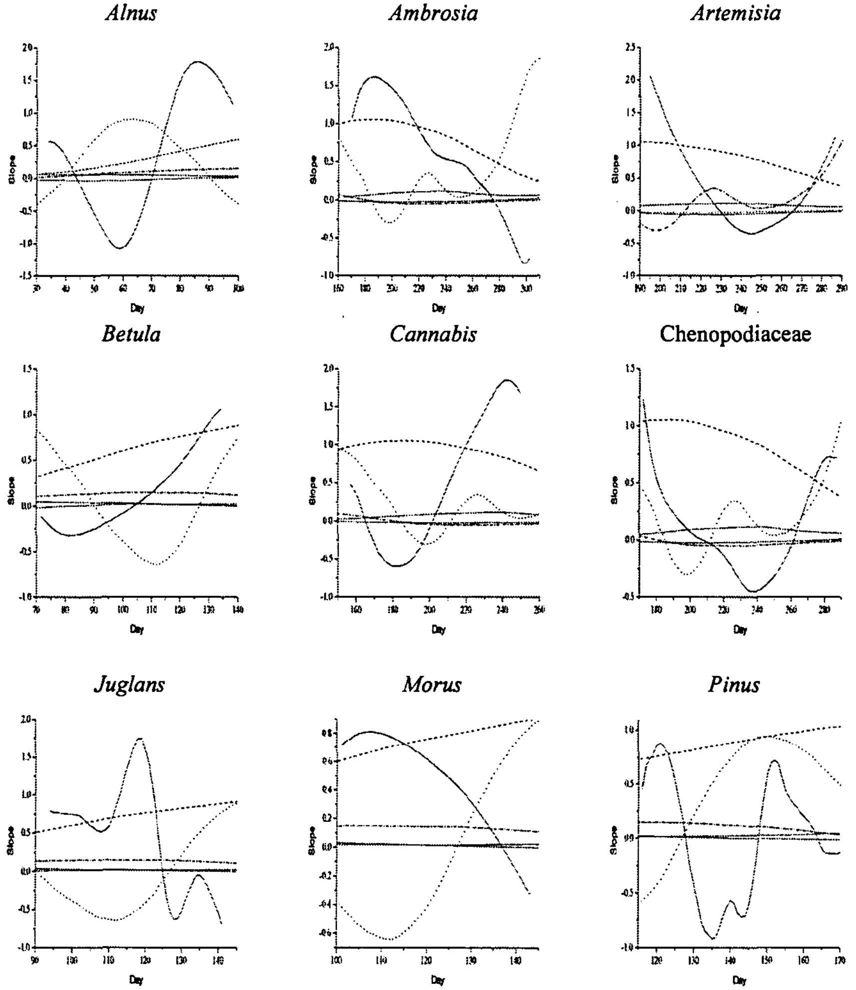
Table 2 Change of total annual pollen count (TAPC) (pollen grains·m^{-3}/10 years) calculated from daily linear trends. Significant values for the modified *t*-test performed with daily Mann-Kendall test values are denoted by **bold** (1%), ***bold italic*** (5%) and light-faced (10%) letters.

Taxa	TAPC
Alnus	*-214*
Ambrosia	*-1170*
Artemisia	*-60*
Betula	*-60*
Cannabis	47
Chenopodiaceae	***-175***
Juglans	**253**
Morus	**400**
Pinus	**-194**
Plantago	***91***
Platanus	***271***
Poaceae	*176*
Populus	**2981**
Quercus	236
Rumex	**-505**
Taxus	**678**
Tilia	-65
Ulmus	**-160**
Urtica	**1183**

Evidently, the daily MK test statistics exhibit big variability. In order to estimate the annual cycles of daily trends, daily MK test values are smoothed with the nonparametric regression technique outlined in Section 2.2. In the absence of trend for every day the estimated bandwidth would be extremely large (practically infinite) producing a line close to zero, because the local linear approximation to the annual cycle of the trend becomes globally linear. However, well-defined finite bandwidth has been obtained for each taxon indicating trends even for *Alnus, Ambrosia, Artemesia, Betula* and Poaceae.

3.3. Relationships with climate variables

MK tests are performed and slopes of linear trends are estimated for every particular day of the entire year using 11 data corresponding to the 11 years for each climate variable. Averaging daily MK test values show significant (even at 0.1% probability level) growth of global solar radiation, relative humidity and wind speed. In contrast, temperature and precipitation do not exhibit overall trends at any reasonable significance level. However, the smoothing of daily MK test values indicates stages of positive and negative trends within the year for these latter two variables.



Alnus *Ambrosia* *Artemisia*

Betula *Cannabis* Chenopodiaceae

Juglans *Morus* *Pinus*

Fig. 1a Annual cycles of slopes of global solar flux (10 Wm^{-2}/year, dash), relative humidity (%/year, dot), precipitation (mm/year, dash dot), temperature (°C/year, short dot), wind speed (ms^{-1}/year, short dash) and pollen concentration (pollen grain·m^{-3}/year, solid) of the 19 taxa examined

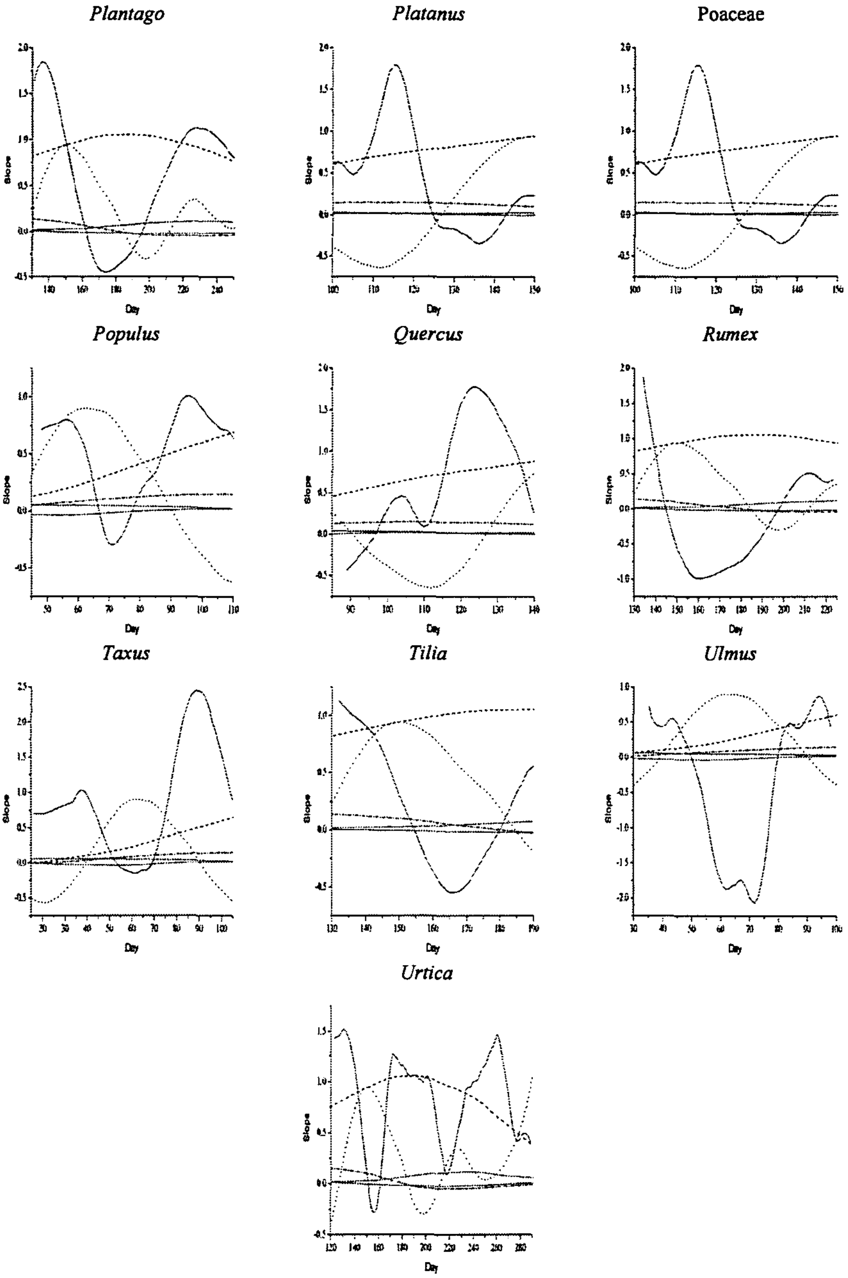


Fig. 1b Annual cycles of slopes of global solar flux (10 Wm^{-2}/year, dash), relative humidity (%/year, dot), precipitation (mm/year, dash dot), temperature (°C/year, short dot), wind speed (ms^{-1}/year, short dash) and pollen concentration (pollen grain·m^{-3}/year, solid) of the 19 taxa examined

The question now is how the annual cycles of slopes of pollen concentration trends and annual cycles of slopes of climate variable trends are related. An association measure is used to characterise these relationships calculating the correlations between the annual cycles of slopes obtained by the nonparametric trend estimation procedure of Section 2.2. This quantity, hereafter, will not be labelled correlation because a correlation is defined for random variables, but now similarities between deterministic functions (annual cycles) have to be quantified. This quantity is tabulated in Table 3.

An association between the annual cycles of slopes of pollen concentration trends and annual cycles of slopes of climate variable trends is considered strong (weak) if the measure is higher (lower) than 0.5. According to climate sensitivity, the individual taxa are counted into three categories; namely, (1) high sensitivity (annual cycles of slopes of pollen concentration trends are in strong association with annual cycles of slopes of four or five climate variable trends), (2) medium sensitivity (annual cycles of slopes of pollen concentration trends are in strong association with annual cycles of slopes of two or three climate variable trends), (3) indifferent (annual cycles of slopes of pollen concentration trends are in strong association with annual cycles of slopes of zero or one climate variable trends) (Table 3). According to this classification, *Alnus*, *Juglans Morus*, *Platanus*, Poaceae and *Taxus* have high sensitivity to climate; *Ambrosia*, *Betula*, *Cannabis*, Chenopodiaceae and *Tilia* indicate medium sensitivity; while *Artemisia*, *Pinus*, *Plantago*, *Populus*, *Quercus*, *Rumex*, *Ulmus* and *Urtica* are indifferent.

Table 3 Association measure between annual cycles of pollen concentration trends and annual cycles of climate variable trends

Taxa	**Precipitation**	**Temperature**	**Global solar flux**	**Relative humidity**	**Wind speed**
Alnus	0.603	0.910	0.725	-0.672	-0.725
Ambrosia	-0.203	0.210	0.974	-0.817	-0.910
Artemisia	0.093	-0.397	0.286	-0.259	-0.134
Betula	0.378	0.623	0.899	-0.157	-0.944
Cannabis	-0.825	0.731	-0.951	0.133	0.041
Chenopodiaceae	0.879	-0.956	-0.192	0.389	0.484
Juglans	0.651	-0.636	-0.553	-0.786	0.600
Morus	0.980	-0.745	-0.920	-0.987	0.939
Pinus	0.005	-0.075	-0.133	-0.381	0.143
Plantago	0.252	0.017	-0.779	0.289	0.498
Platanus	0.476	-0.523	-0.573	-0.720	0.599
Poaceae	0.839	-0.868	-0.621	-0.036	0.960
Populus	0.140	0.238	0.276	-0.544	-0.351
Quercus	0.012	0.465	0.749	0.181	-0.727
Rumex	-0.064	0.260	-0.586	-0.244	0.116
Taxus	0.482	0.785	0.600	-0.565	-0.614
Tilia	0.516	-0.372	-0.746	-0.029	0.644
Ulmus	-0.017	0.408	0.169	-0.876	-0.230
Urtica	0.056	0.007	-0.056	-0.531	0.115

The association between the annual cycles of slopes of total annual pollen count trends and the annual cycles of slopes of climate variable trends are only analysed in detail for those of the 19 taxa that comprise the highest total annual pollen counts for the examined 11 years, namely for *Ambrosia* (32.3%), Poaceae (10.5%), *Populus* (9.6%) and *Urtica* (9.1%) (Fig. 1a-b). For all taxa, the annual cycles of slopes of global solar flux trends and those of relative humidity trends are the most characteristic, while the annual cycles of slopes of the remaining meteorological variables are not substantial. *Ambrosia* and Poaceae indicate high climate sensitivity according to the above classification, while *Populus* and *Urtica* are indifferent in this respect (Table 3). For *Ambrosia*, the annual cycle of slopes of total annual pollen count trends indicates a clear decreasing tendency, presenting definite positive and negative associations with those of the global solar flux and relative humidity, respectively. For Poaceae, the annual cycle of slopes of the total annual pollen count shows a strong negative connection with that of the global solar flux and a disturbed and in this way non-important association with the annual cycle of slopes of relative humidity. Furthermore, for *Populus*, slopes of the total annual pollen count show a definite positive connection with those of the relative humidity, while the role of the global solar flux is not characteristic here. For *Urtica* a strong negative association can be observed between the slopes of the total annual pollen counts and those of the relative humidity (Fig. 1a-b; Table 3). The knowledge of the annual cycle of slopes of total pollen count trends in association with those of the meteorological parameters are important, since it draws the attention not only to potential changes of pollen characteristics within a given year but clearly reveals to a potential increase of pollen stress in the case of a given taxon for a given day of the year as an example of a potential short term climate change.

4. DISCUSSION AND CONCLUSIONS

Climate change can modify pollen characteristics of different taxa diversely and can exert a substantial influence on habitat regions. The present study analyses a comprehensive spectrum of the pollen flora in Szeged region. In our best knowledge, altogether three studies (Clot 2003, Damialis et al. 2007, Cristofori et al. 2010) have analysed the most comprehensive spectra of the regional pollen flora. The present study analyses one of the largest spectra with 19 taxa. Our study can be considered unique in the sense that we calculate trends of pollen concentration data for each taxon and those of all five climate variables on a daily basis. Hereby, this kind of trend analysis provides information on annual cycles of trends.

It was found that in descending order, *Populus*, *Taxus* and *Urtica* show a significant increase of the annual total pollen count. Furthermore, *Populus* and *Juglans* are characterised by the most important increase, while *Alnus* with the most substantial decrease of the annual peak pollen concentration. Only Poaceae and *Urtica* show a significant increase in the duration of the pollination season. In addition, 14 of the 19 taxa exhibit significant change of the total annual pollen count, while 9 of these 14 significant changes indicate increasing trends. Averaging daily Mann-Kendall tests, values indicate significant increasing trends of the global solar radiation, relative humidity and wind speed. However, temperature and precipitation do not exhibit significant trends. Nevertheless, smoothing of daily Mann-Kendall test values show stages of positive and negative trends within the year for these latter two variables. An association measure (AM) was introduced to characterise the strength of the relationship between the annual cycles of slopes of daily pollen concentration trends and annual cycles of slopes of daily climate variable trends. According to climate sensitivity, the individual taxa were sorted into three categories: (1) high sensitivity (characterised by *Alnus, Juglans Morus*, *Platanus*, Poaceae and *Taxus*), (2) medium sensitivity (including

Ambrosia, Betula, Cannabis, Chenopodiaceae and *Tilia*) and (3) indifferent (with *Artemisia, Pinus, Plantago, Populus, Quercus, Rumex, Ulmus* and *Urtica*).

Furthermore, results received are evaluated by applying a new approach, namely trends for the pollen characteristics, as well as the association measure (AM) introduced representing the strength of the relationship between annual cycles of slopes of pollen concentration trends and annual cycles of slopes of climate variable trends are compared with two novel climate change related forces, namely risk and expansion potentials due to the climate change for each taxon.

Risk due to the climate change describes the endangerment of the species of different taxa. It indicates survival potential of the species with three categories in their present habitat. The non-endangered taxa (*) can survive the anticipated climate change for the Charpatian Basin as they comprise species for warmer and drier conditions, whereas the climatically endangered taxa (***) have no species in the present flora for the awaited changed conditions. At the same time, moderately endangered taxa (**) could survive partly in their place, but populations of some species may decrease regionally. The expansion potential (EP) due to the climate change shows the capability of the species to move in the landscape and rescue themselves or to increase their distribution area with their adaptation. This feature is described with five categories as a wide range of response is awaited due to the different climate-tolerance of the species-pool of taxa (Table 4). The categories have been defined using a flora database provided by Horváth et al. (1995).

Risk and expansion potential (EP) due to the climate change are compared to the AM for each taxon (Table 4). If there is no higher than one unit difference between the AM and the above two climate change related forces, then we say that the AM is in accordance with the risk and EP due to the climate change. Otherwise there is no correspondence between them. We received that 14 of the 19 taxa indicate risk due to the climate change, while 15 of the 19 taxa for EP agree well with their AM. Namely, this newly introduced measure performs well when comparing it to the climate change related forces (Table 4).

Considering pollen characteristics, change of total annual pollen count (TAPC) calculated by daily linear trends indicates the most significant values; namely, 9 positive of the 14 significant daily linear trends. On the contrary, for the pollination season only two significant trends were received, namely both for Poaceae and *Urtica* a definite increase were observed. Based on all pollen characteristics for all taxa, 17 of the 24 significant values were positive indicating a positive tendency in their trends. Next, the connection between the climate change related forces and the above significant pollen characteristics was examined separately for each taxon. An agreement is excepted if the tendencies are similar in each comparison. We received that 22 cases from the 24 significant changes in pollen characteristics were in accordance with the climate change related forces (Table 4).

Urtica, being principally a northern temperate belt origin taxon from the taiga to the Mediterrannean (Parker and Malone 2004), shows the most significant changes. The increase of its total annual pollen count (TAPC) calculated by both linear trend and daily linear trends was substantial. Furthermore, the duration (with significantly earlier start and latter end) of its pollination season is strongly increasing. This result is in accordance with its AM and the climate change related forces (Table 4).

Table 4 Climate change related forces and significance of the different pollen characteristics for the individual taxa

Taxa	**[1]Risk due to the climate change**	**[2]EP**	**[3]AM**	**[4]TAPC by linear trend**	**[5]APP**	**[6]Pollination season**			**[7]TAPC by daily linear trend**
						start	end	duration	
Alnus	***	-2	+++		-10				
Ambrosia	*(potential increase)	2	++						
Artemisia	*(potential increase)	2	+						
Betula	***	-2	++						
Cannabis	*	0	++						+10
Chenopodiaceae	*(potential increase) **(few taxa)	1	++						-5
Juglans	*(potential increase)	2	+++		+10				+1
Morus	*	0	+++						+1
Pinus	**	-1	+						-1
Plantago	*(potential increase) **(few taxa)	1	+						+5
Platanus	*(potential increase)	2	+++						+5
Poaceae	*(potential increase) **(few taxa) ***(few taxa)	1	+++					+1	
Populus	* **(few taxa)	1	+	+5	+5				+1
Quercus	* **(few taxa)	1	+						+10
Rumex	*(potential increase) **(few taxa)	1	+						-1
Taxus	***	-2	+++	+10					+1
Tilia	* **(few taxa)	1	++						-10
Ulmus	* **(few taxa)	1	+						-1
Urtica	* **(few taxa)	1	+	+10		-5	+5	+1	+1

[1]**Risk due to the climate change:** * non-endangered taxa; ** moderately endangered taxa (population of some species may decrease regionally); *** endangered taxa

[2]**Expansion Potential due to the climate change:** 0: non-influenced by global warming; 1: for some species area-increase, while for some others area-decrease is possible; 2: significantly influenced by global warming; for some species area-increase is awaited; -1: for some species regional area-decrease is possible; -2: significantly influenced by global warming; for the majority of species area-decrease is awaited;

(The effect of global warming is indifferent or mostly favourable for families and genus classified into categories 0, or 1 and 2, while for those listed into categories -1 and -2 changes are unfavourable. Taxa grouped into categories 0, 1 and -1 are not influenced substantially but those in categories 2 and -2 are significantly influenced by global warming.)

[3]**Association Measure:** + indifferent; ++ medium sensitivity; +++ high sensitivity;

[4]**TAPC by linear trend:** change of total annual pollen count calculated by linear trends;

[5]**APP:** change of annual peak pollen concentration calculated by linear trends;

[6]**Pollination season:** change of start end and duration of the pollinations season calculated by linear trends;

[7]***TAPC by daily linear trend:*** *change of total annual pollen count calculated by* daily linear trends;

[4,5,6,7]: ±1, ±5, ±10: significant increasing/decreasing trend for 1%, 5% and 10% probability levels;

According to our results annual pollen counts indicate strong increasing trends for a number of taxa. Nevertheless, phenological characteristics (onset, end and duration of the pollination season) are free of significant changes except for *Urtica*. Hence, the increasing trends in annual pollen levels can be explained by increasing diurnal pollen concentrations. Our conclusions are in accordance with those of several researchers. For Thessaloniki (Greece), total annual pollen levels, as well as daily peak pollen counts show significant increasing trends for the majority of taxa. At the same time, there were no any important changes for the phenological characteristics (Damialis et al. 2007). Considering the wider surroundings of Central Europe, for Zurich, Switzerland (Frei 2008, *Betula*; Frei and Gassner 2008, *Betula*), as well as for Vienna, Austria (Jäger et al. 1996, *Alnus, Corylus, Betula, Pinus* and *Ulmus*) the pollen counts for most of the pollen types have been increasing. Furthermore, for Zurich (Frei 2008, *Betula*), Poznań, Poland (Stach et al. 2007, *Artemisia*) and Vienna (Jäger et al. 1996, *Alnus, Corylus, Betula, Pinus* and *Ulmus*) the pollination season starts earlier, in addition the daily maximum pollen level increases (Frei 2008, *Betula*) and the days of peak pollen levels occur earlier (Stach et al. 2007, *Artemisia*).

While in our study only annual pollen counts indicate definite increasing trends and phenological characteristics do not change substantially, but for Switzerland, Austria and Poland both annual pollen levels increase remarkably and the pollination season starts substantially earlier. Note that arboreal plants appear to react stronger to the climate change than herbaceous plants (Clot 2003). We received significant increasing trends for global solar radiation, relative humidity and wind speed; while of the above-mentioned studies Frei (2008) reported a notable increasing trend for temperature. Several papers have reported evidence of ecological changes due to a potential climate change (Dose and Menzel 2004), like shifts in plant and animal phenology for the boreal and temperate zones of the northern hemisphere (Menzel and Fabian 1999). Phenological characteristics, like earlier start of the pollination season, are very simple bio-indicators to track climate changes (Ahas et al. 2002).

The knowledge of the annual cycle of slopes of total pollen count trends in association with those of the meteorological parameters trends are important, since it draws the attention not only to potential changes of pollen characteristics within a given year but clearly reveals to a potential increase of pollen stress in the case of a given taxon for a given day of the year as an example of a potential short term climate change.

Note, that all taxa examined in the study are families or genus involving a number of species. Accordingly, analysing pollen and phenological characteristics of a family or genus instead of a given species involves high variability of pollen data. An observed trend in the above characteristics incorporates variability of a given parameter for all species belonging to a given taxon. This variability is influenced by meteorological variables. An important positive role of global solar flux is stressed here, since its high values enhance pollen production (Valencia-Barrera et al. 2001, Kasprzyk and Walanus 2010).

As the ratio of local and medium-range transport in the total pollen level is higher than the ratio of long range transport (Makra et al. 2010), it is important to consider further factors of local pollen production for Szeged region. Besides meteorological variables, pollen levels are influenced also by agricultural and social factors (Makra et al. 2005) including urbanisation, so called "green meadow investments" (new investments over originally agricultural areas) and highway buildings. Land eutrophication facilitating higher pollen production is not characteristic over the agricultural area consisting of small private parcels for Szeged agglomeration. At the same time, as more important factors, large industrial areas were put on operation; housing estates as well as highways were built in the region during the study period. Stripping agricultural lands for building purposes involves the possibility for expanding neglected areas that contributes to the increase of habitat regions of weeds and hence to the increase of pollen production.

The results received indicate suggestions to public health services. The prevalence and severity of respiratory diseases has increased worldwide during the past three decades, especially in industrialised countries. This increase may be explained by changes in environmental factors (D'Amato et al. 2005), as well as by increasing levels of biological and chemical air pollutants. Furthermore, an interaction between pollen and chemical air pollutants in the atmosphere can also exacerbate respiratory allergy (Emberlin 1995). The observed changes in the pollen characteristics have important consequences. They provide substantial information for pollen-sensitive people, especially for prevention and pre-seasonal therapy purposes. They could also make possible to update input parameters for a more accurate pollen forecast.

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REFERENCES

Ahas R, Aasa A, Menzel A, Fedotova G, Schleifinger H (2002) Changes in European spring phenology. Int J Climatol 22:1727-1738

Clot B (2003) Trends in airborne pollen: an overview of 21 years of data in Neuchâtel (Switzerland). Aerobiologia 19(3-4):227-234

Cristofori A, Cristofolini F, Gottardini E (2010) Twenty years of aerobiological monitoring in Trentino (Italy): assessment and evaluation of airborne pollen variability. Aerobiologia 26(3):253-261

D'Amato G, Liccardi G, D'Amato M, Holgate S (2005) Environmental risk factors and allergic bronchial asthma. Clin Exp Allergy 35(9):1113-1124

Damialis A, Halley JM, Gioulekas D, Vokou D (2007) Long-term trends in atmospheric pollen levels in the city of Thessaloniki, Greece. Atmos Environ 41(33):7011-7021

Dose V, Menzel A (2004) Bayesian analysis of climate change impacts in phenology. Global Change Biology 10:259-272

Emberlin J (1995) Interaction between air pollutants and aeroallergens. Clin Exp Allergy 25:33-39 Suppl. 3

Emberlin J, Mullins J, Corden J, Millington W, Brooke M, Savage M, Jones S (1997) The trend to earlier Birch pollen seasons in the UK: A biotic response to changes in weather conditions? Grana 36(1):29-33

Emberlin J, Detandt M, Gehrig R, Jäger S, Nolard N, Rantio-Lehtimäki A (2002) Responses in the start of Betula (birch) pollen seasons to recent changes in spring temperatures across Europe. Int J Biometeorol 46(4):159-170

Emberlin J, Laaidi M, Detandt M, Gehrig R, Jäger S, Myszkowska D, Nolard N, Rantio-Lehtimäki A, Stach A (2007a) Climate change and evolution of the pollen content of the air in seven European countries: The example of Birch. Rev F Allergol 47(2):57-63

Emberlin J, Smith M, Close R, Adams-Groom B (2007b) Changes in the pollen seasons of the early flowering trees Alnus spp. and Corylus spp. in Worcester, United Kingdom, 1996-2005. Int J Biometeorol 51(3):181-191

Fan J (1992) Design-adaptive nonparametric regression. J Am Stat Assoc 87:998-1004

Fan J (1993) Local linear regression smoothers and their ninimax efficiency. Ann Stat 21:196-216

Fan J, Gijbels I (1992) Variable bandwidth and local linear regression smoothers. Ann Stat 20:2008-2036

Francisco-Fernández M, Vilar-Fernández JM (2004) Weighted local nonparametric regression with dependent data: study of real private residential fixed investment in the USA. Stat Inference for Stochastic Proc 7:69-93

Frei T (2008) Climate change and its impact on airborne pollen in Basel, Switzerland 1969-2007. Allergologie 31(5):165-169

Frei T, Gassner E (2008) Climate change and its impact on birch pollen quantities and the start of the pollen season an example from Switzerland for the period 1969-2006. Int J Biometeorol 52(7):667-674

Frenguelli G, Tedeschini E, Veronesi F, Bricchi E (2002) Airborne pine (Pinus spp.) pollen in the atmosphere of Perugia (Central Italy): behaviour of pollination in the two last decades. Aerobiologia 18(3-4):223-228

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(2):59-63

García-Mozo H, Mestre A, Galán C (2010) Phenological trends in southern Spain: A response to climate change. Agr Forest Meteorol 150(4):575-580

Hirst JM (1952) An automatic volumetric spore trap. Ann Appl Biol 39(2):257-265

Horváth F, Dobolyi ZK, Morschhauser T, Lökös L, Karas L, Szerdahelyi T, (1995) Flóra adatbázis 1.2. [Flora database 1.2. (in Hungarian)] MTA-ÖBKI, Vácrátót, Hungary

IPCC (2007) Intergovernmental Panel of Climate Change, 2007 Synthesis Report

Jäger S, Spieksma FTM, Nolard N (1991) Fluctuations and trends in airborne concentrations of some abundant pollen types, monitored at Vienna, Leiden, and Brussels. Grana 30(2):309-312

Jäger S, Nilsson S, Berggren B, Pessi AM, Helander M, Ramfjord H (1996) Trends of some airborne tree pollen in the Nordic countries and Austria, 1980-1993 – A comparison between Stockholm, Trondheim, Turku and Vienna. Grana 35(3):171-178

Jato V, Rodríguez-Rajo FJ, Seijo MC, Aira MJ (2009) Poaceae pollen in Galicia (NW Spain): characterisation and recent trends in atmospheric pollen season. Int J Biometeorol 53(4):333-344

Just J, Nikasinovic L, Laoudi Y, Grimfeld A (2007) Air pollution and asthma in children. Rev F Allergol 47(3):207-213

Kasprzyk I, Walanus A (2010) Description of the main Poaceae pollen season using bi-Gaussian curves, and forecasting methods for the start and peak dates for this type of season in Rzeszow and Ostrowiec Sw. (SE Poland). J Environ Monitor 12(4):906-916

Köppen W (1931) Grundriss Der Klimakunde. Walter De Gruyter & Co., Berlin

Latorre F, Belmonte J (2004) Temporal and spatial distribution of atmospheric Poaceae pollen in Catalonia (NE Spain) in 1996-2001. Grana 43(3):156-163

Makra L, Juhász M, Béczi R, Borsos E (2005) The history and impacts of airborne *Ambrosia* (Asteraceae) pollen in Hungary. Grana 44(1):57-64

Makra L, Sánta T, Matyasovszky I, Damialis A, Karatzas K, Bergmann KC, Vokou D (2010) Airborne pollen in three European cities: Detection of atmospheric circulation pathways by applying three-dimensional clustering of backward trajectories. Geophysical Research-Atmospheres 115, D24220, doi:10.1029/2010JD014743

Menzel A, Fabian P (1999) Growing season extended in Europe. Nature 397:659

Önöz B, Bayazit M (2003) The power of statistical tests for trend detection. Turkish J Engineering and Environ Sci 27:247-251

Parker J, Malone M (2004) Flora I-II. Global Book Publishing Pty Ltd, Willoughby

Recio M, Docampo S, García-Sánchez J, Trigo MM, Melgar M, Cabezudo B (2010) Influence of temperature, rainfall and wind trends on grass pollination in Malaga (western Mediterranean coast). Agr Forest Meteorol 150(7-8):931-940

Ridolo E, Albertini R, Giordano D, Soliani L, Usberti I, Dall'Aglio PP (2007) Airborne pollen concentrations and the incidence of allergic asthma and rhinoconjunctivitis in Northern Italy from 1992 to 2003. Int Arch Allergy Imm 142(2):151-157

Stach A, García-Mozo H, Prieto-Baena JC, Czarnecka-Operacz M, Jenerowicz D, Silny W, Galán C (2007) Prevalence of Artemisia species pollinosis in western Poland: Impact of climate change on aerobiological trends, 1995-2004. J Invest Allerg Clin 17(1):39-47

Tedeschini E, Rodríguez-Rajo FJ, Caramiello R, Jato V, Frenguelli G (2006) The influence of climate changes in Platanus spp. pollination in Spain and Italy. Grana 45(3):222-229

Teranishi H, Katoh T, Kenda K, Hayashi S (2006) Global warming and the earlier start of the Japanese-cedar (Cryptomeria japonica) pollen season in Toyama, Japan. Aerobiologia 22(2):91-95

Valencia-Barrera RM, Comtois P, Fernández-González D (2001) Biogeography and bioclimatology in pollen forecasting - An example of grass in Leon (Spain) and Montreal (Canada). Grana 40(4-5):223-229

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CONNECTION BETWEEN METEOROLOGICAL ELEMENTS AND POLLUTANTS CONCENTRATIONS AT SZEGED, HUNGARY

L. MAKRA[1], I. MATYASOVSZKY[2], I. IONEL[3], F. POPESCU[3] and Z. SÜMEGHY[1]

[1]Department of Climatology and Landscape Ecology, University of Szeged, P.O.Box 653, 6701 Szeged, Hungary
E-mail: makra@geo.u-szeged.hu
[2]Department of Meteorology, Eötvös Loránd University, Pázmány Péter st. 1/A, 1117 Budapest, Hungary
[3]University Politehnica Timisoara, Faculty of Mechanical Engineering,Department of Thermodynamics, Thermal Machines & Road Vehicles, Timisoara 300222, Romania

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

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

1. INTRODUCTION

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

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

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

2. CLIMATIC CHARACTERISTICS AT SZEGED

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

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

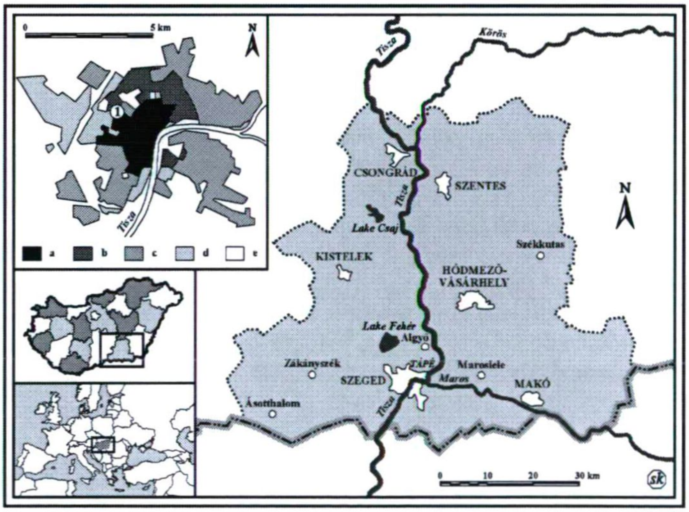

Fig.1 Geographical position of Szeged, Hungary and built-in types of the city [a: centre (2-4-storey buildings); b: housing estates with prefabricated concrete slabs (5-10-storey buildings); c: detached houses (1-2-storey buildings); d: industrial areas; e: green areas; (1): monitoring station]

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

3. DATA

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

4. METHOD

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

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

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

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

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

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

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

5. RESULTS

5.1 Winter months

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

5.2. Summer months

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

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

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

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

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

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

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

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

6. CONCLUSIONS

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

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REFERENCES

Bartzokas A, Metaxas DA (1993) Covariability and climatic changes of the lower troposphere temperatures over the Northern Hemisphere. Nuovo Cimento della Societa Italiana di Fisica C-Geophysics and Space Physics 16C:359-373

Bartzokas A, Metaxas DA (1995) Factor Analysis of Some Climatological Elements in Athens, 1931-1992: Covariability and Climatic Change. Theor Appl Climatol 52:195-205

Horváth Sz, Makra L, Zempléni A, Motika G, Sümeghy Z (2001) The Role of Traffic in Modifying Air Quality in a Medium-Sized City, The Third International Conference on Urban Air Quality and Fifth Saturn Workshop. Measurement, Modelling and Management. Canopus Publishing Limited, Loutraki, Greece. Institute of Physics, Extended Abstracts CD-ROM

Jolliffe IT (1990) Principal component analysis: A beginner's guide – I. Introduction and application. Weather 45:375-382

Jolliffe IT (1993) Principal component analysis: A beginner's guide – Pitfalls, myths and extensions. Weather 48:246-253

Sindosi OA, Katsoulis BD, Bartzokas A (2001) An objective assessment of the relation between meteorological parameters and the main air pollutants in Athens on a daily basis. 7th International Conference on Environmental Science and Technology, Ermoupolis, Syros Island, Greece

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MULTIVARIATE ANALYSIS OF RESPIRATORY DISORDERS IN RELATION TO ENVIRONMENTAL FACTORS

Z GUBA[1], I MATYASOVSZKY[2], L MAKRA[1] and Z SÜMEGHY[1]

[1]*Department of Climatology and Landscape Ecology, University of Szeged, P.O.Box 653, 6701 Szeged, Hungary*
E-mail: makra@geo.u-szeged.hu
[2]*Department of Meteorology, Eötvös Loránd University, Pázmány Péter st. 1/A. 1117 Budapest, Hungary*

Summary: The aim of the study is to analyse the joint effect of biological and chemical air pollutants, as well as meteorological variables, on the hospital admissions of respiratory problems for Szeged, Southern Hungary. The data set used covers a nine-year period (1999-2007). The analysis was performed using three age categories for the pollen season of *Ambrosia* and the pollen-free season. Two novel procedures are applied here: factor analysis, including a special transformation and a time-varying multivariate linear regression that makes it possible to determine the rank of importance of the influencing variables in respiratory hospital admissions, and also to compute the relative importance of the parameters affecting respiratory disorders. Both techniques revealed that *Ambrosia* pollen, O_3 and wind speed are important variables that influence hospital admissions. The role of chemical and meteorological parameters vary according to the seasons and the methods. Wind speed is a surprisingly important meteorological variable.

Key words: air pollution, respiratory hospital admissions, cluster analysis, factor analysis including a special transformation, time-varying multivariate linear regression

1. INTRODUCTION

Air pollution, as a major and permanently rising hazard for the environment, is associated with large increases in medical expenses, morbidity and is estimated to cause about 800,000 annual premature deaths worldwide (Cohen et al. 2005). The prevalence of allergic respiratory diseases has also increased during the last three decades, especially in industrialized countries. This increase may be explained by changes in environmental factors: urbanization, the ever increasing automobile traffic with its high levels of vehicle emissions, and the changing lifestyle are linked to the rising frequency of respiratory allergic diseases (D'Amato et al. 2005). Weather conditions can also affect both the biological and chemical air pollutants. There are evidences on the effect of air pollution upon allergens, increasing exposure to the latter, their concentration and/or biological allergenic activity (Just et al. 2007). Habitat regions and levels of pollen are changing in Europe, as a result of cultural factors, more international travel and climate change (Kiss and Béres 2006).

Air pollution in Hungary is one of the highest in Europe. Around 16,000 annual premature deaths attributable to exposure to ambient PM_{10} concentrations are estimated in the country (Ågren 2010). Furthermore, airborne pollen levels are also high. The Carpathian basin, including Hungary is considered the most polluted region with airborne ragweed *(Ambrosia)* pollen in Europe. *Ambrosia* in Hungary discharges the most pollen of all taxa; the ratio of its pollen release compared to the total pollen release in the late summer period is around 60-71% (Juhász and Juhász 2002). About 30% of the Hungarian population has some type of allergy, 65% of them have pollen-sensitivity, and at least 60% of this pollen-sensitivity is caused by *Ambrosia* (Járai-Komlódi 1998).

The substantial increase in respiratory diseases in industrialized countries is attributable to a combination of chemical air pollution and the allergens existing in the air of big cities. Several papers have analysed separately the effects of either chemical air pollutants (Alves et al. 2010) or pollen (Diaz et al. 2007) to hospital admissions of respiratory diseases; however, only very few studies have yet examined the effect of these two kinds of variables together (e.g. Andersen et al. 2007). Such papers revealed a significant connection between partly pollen taxa and chemical compounds and partly health for admitted respiratory patients, and this relationship was stronger than that detected separately either for the chemical air pollutants or pollen.

The purpose of this study is to analyse the joint effect of biological (pollen) and chemical air pollutants, as well as meteorological variables on the hospital admissions of respiratory diseases of different age groups during different seasons in Szeged region, Southern Hungary. The data set applied is unique in the sense that it includes all of the above three categories of influencing variables. Meteorological elements and air pollutants are clustered in order to define optimum environmental conditions for high patient numbers. Afterwards, analysis of variance is used to determine whether cluster related mean patient numbers differ significantly. Then a factor analysis including a special transformation is applied, as well as a time-varying multivariate linear regression making it possible to determine the rank of importance of the influencing variables in respiratory hospital admissions and to compute the relative importance of the parameters affecting respiratory disorders. The study examines one of the largest data sets used in the literature on respiratory hospital admissions.

The following meteorological and pollutant variables will be considered in our study. (1) Temperature. Inhalation of cold air in hyper-reactive bronchia induces the inflammation of the mucous membrane. (2) Relative humidity. Repeated exposition to dry air may produce the inflammation, obstruction and hyper-reactivity of the small respiratory tracts. (3) Global solar flux. This parameter develops its effect through influencing the values of temperature and relative humidity. (4) Wind speed. Strong winds make good ventilation conditions resulting in low pollutant levels. Additionally, winds desiccate and cool the air (see: hyper-reactivity occurring by the influence of cold and dry air). (5) Air pressure. In general, air pressure is not a direct reason for respiratory symptoms but is an indicator of certain atmospheric processes influencing the occurrences of respiratory diseases. (6) Air pollution. (6a) Inhalative chemical and physical substances (industrial and cigarette smoke, soot, carcinogenic and oxidizable substances, e.g. nitrogen-monoxide, etc.). For instance, after inhaling NO_x, an inflammation of mucous membrane in the bronchia will develop by the transmission of different mediators. (6b) Pollen. In the respiratory tracts of individuals sensitive to the given pollen, inflammation mediated by IgE will develop (IgE, the Immunoglobulin E plays an important role in allergy) (Parsons and Mastronarde 2005).

2. MATERIALS AND METHODS

2.1. Location and data

Szeged (46.25°N; 20.10°E) is the largest settlement in South-eastern Hungary. The area is characterised by an extensive flat landscape of the Great Hungarian Plain with an elevation of 79 m AMSL. The built-up area covers a region of about 46 km^2. The city is the centre of the Szeged region with 203,000 inhabitants. In the Köppen system the climate of Szeged is the Ca type (warm temperate climate) with relatively mild and short winters and hot summers (Köppen 1931). The pollen content of the air was measured using a 7-day recording "Hirst-type" volumetric trap. The air sampler is located about 20 m above the ground (Makra et al. 2008).

Meteorological variables and chemical air pollutants were collected in a monitoring station located in the downtown of Szeged at a distance of about 10 m from the busiest main road. Daily values of the above-mentioned 5 meteorological variables are: mean temperature (T, °C), mean global solar flux (GSF, Wm^{-2}), mean relative humidity (RH, %), mean sea-level air pressure (P, hPa) and mean wind speed (WS, ms^{-1}).

Chemical air pollutants include the daily average mass concentrations of CO, NO, NO_2, SO_2, O_3 and PM_{10} (μgm^{-3}) (Alves et al. 2010). When selecting biological air pollutants special emphasis is put on *Ambrosia* due to its above-mentioned characteristics in Hungary. Besides ragweed (*Ambrosia)*, further 23 relevant taxa are also taken into account. The taxa with their Latin (English) names are as follows: *Acer* (maple), *Alnus* (alder), *Artemisia* (mugwort), *Betula* (birch), *Cannabis* (hemp), *Carpinus* (hornbeam), Chenopodiaceae (goosefoots), *Corylus* (hazel), *Fraxinus* (ash), *Juglans* (walnut), *Morus* (mulberry), *Pinus* (pine), *Plantago* (plantain), *Platanus* (platan), Poaceae (grasses), *Populus* (poplar), *Quercus* (oak), *Rumex* (dock), *Salix* (willow), *Taxus* (yew), *Tilia* (linden), *Ulmus* (elm) and *Urtica* (nettle). Two pollen variables corresponding to taxa were formed for our analysis: pollen of *Ambrosia* due to its extremely high levels during its short pollination period, and total pollen excluding the pollen of *Ambrosia*. Both pollen variables were considered for the pollen season of *Ambrosia* (July 15 – October 16).

The daily number of hospital admissions registered with respiratory diseases comes from the Thorax Surgery Hospital, Deszk, Csongrád County located about 10 km from the monitoring station in Szeged downtown. This is the only hospital in Csongrád County hosting patients exclusively with respiratory symptoms. Most of the patients were treated as out-patients. Age, date of admission and disease type were available for each patient. Three age groups were considered in the research: young patients (0-14 years), adult patients (15-64 years) and elderly patients (equals to or older than 65 years) because some respiratory illnesses, such as the diagnostic category of asthma, may include different syndromes in children, adults and elderly people (Ko et al. 2007). Due to the very small patient number in the younger age group, the categories of adults and elderly people as well as all patients including the younger age group were analyzed. The population consists of 133,464 hospital admissions of subjects' residents in Szeged.

The analysis was performed for a nine-year term 1999-2007 with two data sets according to the pollen season of *Ambrosia* (July 15 – October 16) and to the pollen-free season (October 17 – January 13). Note that Saturdays, Sundays and holidays as days without hospitalization were excluded from the analysis. Furthermore, there were no remarkable flu epidemics during the periods examined.

The pollen season is defined by its start and end dates. For the start (end) of the season we used the first (last) date on which 1 pollen grain·m^{-3} of air is recorded and at least 5 consecutive (preceding) days also show 1 or more pollen grains·m^{-3} (Galán et al. 2001). Evidently, the pollen season varies from year to year, here the longest observed pollen season during the nine-year period was considered for each year.

2.2. Methods

2.2.1. Cluster analysis

Cluster analysis is a common statistical technique to objectively group elements. The aim is to maximise the homogeneity of elements within the clusters and to maximise the heterogeneity among the clusters. Here a non-hierarchical cluster analysis with k-means algorithm using a Mahalanobis metric (Mahalanobis 1936) was applied. Data to be clustered include daily values of the 13 explanatory variables (5 meteorological elements, 6 chemical pollutants and 2 pollen types). The homogeneity within clusters was measured by RMSD defined as the sum of the root mean square deviations of cluster elements from the corresponding cluster centre over clusters. The RMSD value usually decreases with an increasing number of clusters. Thus, this quantity itself is not very useful for deciding the optimal number of clusters. However, the change of RMSD (CRMSD) or even the change of CMRSD (CCRMSD) versus the change of cluster numbers is much more informative (Makra et al. 2010). Clustering with the k-means algorithm was performed by using MATLAB 7.5.0. The remaining statistical computations were performed with SPSS (version 16.0) software.

2.2.2. Analysis of variance (ANOVA)

The one-way analysis of variance (ANOVA) is used to determine whether the inter-group variance is significantly higher than the intra-group variance of a data set. After performing ANOVA on the averages of the groups in question, a post-hoc Tukey test is applied to establish which groups differed significantly from each other (Tukey 1985). Significant differences between mean hospital admissions corresponding to different cluster pairs may reveal an important influence of the meteorological elements, chemical air pollutants and pollen types considered on daily number of respiratory diseases.

2.2.3. Factor analysis and special transformation

Factor analysis (FA) identifies linear relationships among subsets of examined variables which helps to reduce the dimensionality of the initial database without substantial loss of information. First, a factor analysis was applied to the initial dataset consisting of 14 variables (13 explanatory variables and 1 resultant variable defined by the number of daily hospital admissions with respiratory diseases) in order to transform the original variables to fewer variables. These new variables called factors can be viewed as latent variables explaining the joint behaviour of weather-pollutant-hospital admission variables. The optimum number of retained factors is determined by the criterion of reaching 80% of the total variance (Jolliffe 1993). After performing the factor analysis, a special transformation of the retained factors was performed to discover to what degree the above-mentioned explanatory variables affect the resultant variable, and to give a rank of their influence (Jahn and Vahle 1968).

2.2.4. Time-varying multivariate linear regression with time lags

The task is to establish a relationship between explanatory variables and the resultant variable. As both kinds of variables exhibit annual trends, regression coefficients in the linear relationship have annual courses described by sine and cosine functions with one year and one half year period lengths. This latter cycle was introduced to describe the asymmetries of the annual courses. Coefficients of these periodic functions were estimated using the least square principle.

It is reasonable to allow time lags between pollutants concentrations and number of hospital admissions. Therefore, the univariate version of the above mentioned time-varying linear regression was carried out with every individual explanatory variable with different time lags including the zero lag. The time lags minimising the mean square errors were taken as optimal.

3. RESULTS

3.1. Cluster analysis and ANOVA

Two clusterings were performed according to the two periods excamined (pollen season of *Ambrosia* and pollen-free season). The cluster analysis for the pollen season of *Ambrosia* and for the pollen-free season resulted in five and four clusters, respectively. The cluster-related mean values of the explanatory and resultant variables are shown in Tables 1a-b.

Table 1a Cluster-related mean values of the meteorological and pollutant parameters as well as patient numbers for the pollen season of *Ambrosia* (**bold**: maximum; *italic:* minimum)

Cluster	**1**	**2**	**3**	**4**	**5**
Parameter			**Mean values**		
Total number of days	68	41	*26*	94	**137**
Frequency (%)	18.6	11.2	*7.1*	25.7	**37.4**
Temperature (°C)	23.3	16.9	20.5	**24.9**	*16.4*
Global solar flux (Wm^{-2})	211.1	155.3	176.4	**223.6**	*126.7*
Relative humidity (%)	66.1	72.2	68.6	*59.3*	**75.0**
Air pressure (hPa)	1002.7	**1009.4**	*1001.7*	1005.3	1005.9
Wind speed (ms^{-1})	0.8	*0.5*	0.9	**1.1**	0.9
CO (μgm^{-3})	468.9	**700.5**	*425.1*	444.5	463.8
PM_{10} (μgm^{-3})	*36.3*	**52.8**	40.4	44.0	40.2
NO (μgm^{-3})	10.8	**44.7**	14.1	*9.5*	15.1
NO_2 (μgm^{-3})	32.9	**48.8**	33.2	34.0	*31.8*
O_3 (μgm^{-3})	41.8	*26.2*	36.3	**58.4**	29.2
SO_2 (μgm^{-3})	*4.0*	5.5	4.9	4.9	**6.0**
Ambrosia (pollen·m^{-3}·day^{-1})	91.7	*43.3*	**593.2**	46.2	57.9
Total pollen excluding *Ambrosia* (pollen·m^{-3}·day^{-1})	**111.9**	16.8	48.7	49.9	*14.1*
Adults (15-64 years) (person)	101.6	76.7	**114.3**	*74.5*	78.2
The elderly (≥65 years) (person)	12.8	11.8	**13.3**	*10.5*	12.2
All age groups (person)	114.5	88.7	**127.9**	*85.1*	90.6

The analysis of variance revealed a significant difference at least at a 95% probability level in the mean values of patient numbers among the individual clusters. The Tukey test indicated 6 (60.0%) and 4 (66.7%) significant differences for adults, while 4 (40%) and 5 (83.3%) significant differences for the elderly in the pairwise comparisons among the possible 10 and 6 cluster pairs for the pollen season of *Ambrosia* and pollen-free season, respectively. Similar results for the mean patient numbers of the cluster pairs for all age groups were obtained. Namely, 5 (50.0%) and 5 (83.3%) significant differences were found among the possible 10 and 6 cluster pairs. Only clusters accompanied with significantly different means were then analysed in detail, principally the clusters with extreme patient numbers.

For the pollen season of *Ambrosia*, patient numbers are the highest in cluster 3, of which the most characteristic components are the highest and medium levels of *Ambrosia* and the remaining pollen, respectively (Table 1a). Furthermore, cluster 4 involving a substantial part of summer with the highest temperature (24.9°C), global solar flux (223.6 Wm^{-2}) and O_3 level (58.4 μgm^{-3}), as well as the lowest relative humidity (59.3%) and NO concentration (9.5 μgm^{-3}) provides the lowest patient numbers. Moderate levels of the two pollen types and of the chemical pollutants (except for O_3) contribute to the lowest number of hospital admissions (Table 1a).

Table 1b Cluster-related mean values of the meteorological and pollutant parameters as well as patient numbers for the pollen-free season (**bold:** maximum; *italic:* minimum)

Cluster	**1**	**2**	**3**	**4**
Parameter		**Mean values**		
Total number of days	75	**137**	*44*	108
Frequency (%)	20.6	**37.6**	*12.1*	29.7
Temperature (°C)	**10.8**	3.2	*-2.7*	5.7
Global solar flux (Wm^{-2})	**62.1**	38.9	*36.2*	44.8
Relative humidity (%)	*82.1*	87.6	**93.1**	87.1
Air pressure (hPa)	1010.6	*1004.3*	**1020.3**	1008.5
Wind speed (ms^{-1})	0.6	*0.5*	*0.5*	**1.4**
CO (μgm^{-3})	788.2	**812.4**	729.7	*652.2*
PM_{10} (μgm^{-3})	**79.2**	53.2	61.6	*52.6*
NO (μgm^{-3})	35.9	**40.6**	*28.0*	31.9
NO_2 (μgm^{-3})	**40.4**	38.0	*5.2*	36.0
O_3 (μgm^{-3})	**19.6**	15.2	16.8	*11.3*
SO_2 (μgm^{-3})	10.4	*6.6*	**15.2**	7.4
Adults (15-64 years) (person)	61.4	59.2	*50.2*	**64.6**
The elderly (≥65 years) (person)	11.7	11.6	*10.1*	**13.9**
All age groups (person)	73.2	71.0	*60.3*	**78.5**

For the pollen-free season, the highest patient numbers for each age category are associated with cluster 4 characterised by high temperature, the strongest wind speed, as well as low air pressure. These values of the meteorological parameters assume a cyclonic weather situation facilitating the dilution of the pollutants' concentrations (CO, PM_{10} and O_3 take their minimum levels of all four clusters) (Table 1b). Contrary to the low levels of the chemical air pollutants, relatively high temperature favours reproducing bacteria and viruses, while strong winds desiccating the air may produce inflammation in the small respiratory tracts. Both effects substantially contribute to the highest patient numbers for this cluster in this part of the year. Cluster 3 delivers the lowest patient numbers for each age category. This cluster covers a cold part of the winter period (temperature is -2.7°C) involving an anticyclonic ridge weather situation featured by clouds (global solar flux is the lowest: 36.2 Wm^{-2}), while relative humidity (93.1%) and air pressure (1020.3 hPa) are the highest and wind speed (0.5 ms^{-1}) is the lowest. A possible reason of the lowest patient numbers is that very low temperatures in winter time contribute to restrict respiratory infections. Furthermore, in spite of the highest SO_2 level, the lowest NO and NO_2 concentrations, especially the latter one, may substantially contribute to decreasing respiratory admissions (Table 1b).

3.2. Optimal time lags

Time-varying univariate linear regressions of the resultant variable on every individual explanatory variable were performed in order to determine optimal time lags defining the delay of patient number response to explanatory variables based on the two seasons and the three age categories, respectively.

A wide range of candidate time lags are applied in the literature for finding the optimal time delay. Although there are examples for time lags up to 5 days (Ko et al. 2007) and even 8 days (Nascimento et al. 2006), the literature generally shows delays up to 3 days in patient response to pollution exposure (Alves et al. 2010). It is likely that the explanatory variables develop their effects until the formation of the respiratory diseases within 3 days (Knight et al. 1991). For instance, immediate allergic reactions of pollen can occur within 15-20 minutes, in certain cases 8-10 hours, while all immune reactions in cells can occur 48-72 hours following the exposure (Petrányi 2000).

Our optimal time lag varies from zero to three days. There is a tendency with the increasing age for more non-zero lags. The global solar flux has the largest number of positive time shifts from meteorological variables (typically 2-3 days) for elderly, while the relative humidity has the largest number of non-zero delays (2-3 days) for adults. However, the role of relative humidity in positive delays is substantially smaller than the role of the global solar flux. Within the chemical pollutants, positive lags (0-3 days) are mostly associated with CO and SO_2 for both age groups, and then with NO for adults and PM_{10} for elderly, in agreement with other studies (e.g. Schwartz and Dockery 1992). No time shift is typical for the pollen season of *Ambrosia* in any disease groups.

3.3. Factor analysis and special transformation

Factor analysis was performed for adults, elderly and all age groups based on the two seasons considered. Thus, altogether 3x2=6 factor analyses were carried out. After performing factor analysis 7 and 6 factors were retained for the pollen season of *Ambrosia* and the pollen-free season, respectively. In order to calculate the rank of importance of the explanatory variables in determining the resultant variable, the loadings of the retained Factors were projected onto Factor 1 (special transformation) (Table 2a-b) (Jahn and Vahle 1968).

In the pollen season of *Ambrosia*, temperature and global solar flux for adults, as well as global solar flux for all age groups are proportional to the patient numbers (Table 2a). In the pollen-free season only temperature for all three age groups and wind speed for elderly change proportionally to the number of hospital admissions (Table 2b). These results are confirmed by other authors (Freitas et al. 2010). Furthermore, relative humidity tends to be inversely proportional to the patient numbers for both periods. Air pressure is in significant positive association with the patient numbers only for adults and elderly in the pollen-free season, while its role is negligible for the remaining cases (Table 2a-b). Wind speed is inversely proportional to the number of hospital admissions for all three age groups in the pollen season of *Ambrosia*, while it is proportional to the patient numbers for elderly in the pollen-free season. Wind speed involves a dual character; namely, strong winds facilitate decreasing hospital admissions through reducing levels of the pollutants all over the year. On the other hand, they contribute to desiccating the air and hence to an increase of respiratory diseases. The latter effect seems to be higher in the pollen-free season since in this period wind speed changes proportionally to the elderly patient numbers (Table 2b). In the pollen season of *Ambrosia*, the inverse connection of wind speed with the number of hospital admissions suggests that here the pollutant diluting effect of wind is predominant (Table 2a). In the cold pollen-free season, relatively high temperatures and strong wind speeds are associated to typical cyclonic air masses. This kind of weather can raise the number of hospital admissions of elderly since repeated exposition to dry air desiccated by winds may produce the inflammation of the small respiratory tracts (Table 2b) (Strausz 2003). Furthermore, bacteria and viruses causing respiratory diseases have optimal relative humidity and temperature to multiply. While Mycoplasma bacteria generating pneumonia and other respiratory inflammations favour relative humidity below 40%, adenoviruses provoking upper respiratory infections and conjunctivitis are more infectious at higher than 70% relative humidity. Hence, high relative humidity may also be a reason of respiratory hospital admissions (Dilaveris et al. 2006).

Table 2a Special transformation. Effect of the explanatory variables on respiratory diseases as resultant variables and the rank of importance of the explanatory variables on their factor loadings transformed to Factor 1 for determining the resultant variable; pollen season of *Ambrosia* (thresholds of significance: *italic:* $x_{0.05} = 0.056$; **bold:** $x_{0.01} = 0.074$)

Explanatory variables	**Adults (15-64 years)**		**The elderly (≥ 65 years)**		**All age groups**	
	weight	**rank**	**weight**	**rank**	**weight**	**rank**
Patient number	**0.914**	–	**-0.983**	–	**0.918**	–
Temperature (°C)	**0.081**	10	0.021	13	0.067	10
Global solar flux (Wm^{-2})	**0.168**	7	*0.134*	4	**0.146**	8
Relative humidity (%)	-0.163	8	0.057	10	**-0.152**	7
Air pressure (hPa)	-0.042	13	-0.103	7	-0.018	13
Wind speed (ms^{-1})	**-0.220**	5	**0.142**	2	**-0.228**	5
Total weight	0.675	–	0.457	–	0.611	–
CO (μgm^{-3})	**-0.255**	3	0.095	8	**-0.251**	4
PM_{10} (μgm^{-3})	**-0.314**	2	*0.119*	5	**-0.304**	2
NO (μgm^{-3})	-0.058	11	-0.032	12	-0.041	12
NO_2 (μgm^{-3})	0.047	12	*-0.134*	3	0.059	11
O_3 (μgm^{-3})	**-0.230**	4	**0.272**	1	**-0.252**	3
SO_2 (μgm^{-3})	*-0.115*	9	0.070	9	*-0.119*	9
Total weight	1.018	–	0.722	–	1.025	–
Ambrosia ($pollen \cdot m^{-3} \cdot day^{-1}$)	**0.553**	1	*-0.117*	6	**0.520**	1
Total pollen excluding *Ambrosia* ($pollen \cdot m^{-3} \cdot day^{-1}$)	**0.199**	6	-0.041	11	**0.177**	6
Total weight	0.752	–	0.158	–	0.697	–

Both for the pollen season of *Ambrosia* and the pollen-free season, the total weight of the chemical pollutants is the highest for all three age groups considering all variable types and is substantially higher than that of the meteorological variables. This latter result may be due to the fact that anticyclonic weather situations, being the most frequent during the above seasons, favour the enrichment of chemical pollutants and, in this way, high pollutant levels exert a higher effect on respiratory patient numbers (Table 2a-b).

Table 2b Special transformation. Effect of the explanatory variables on respiratory diseases as resultant variables and the rank of importance of the explanatory variables on their factor loadings transformed to Factor 1 for determining the resultant variable; pollen-free season (thresholds of significance: *italic:* $x_{0.05} = 0.105$; **bold:** $x_{0.01} = 0.138$)

Explanatory variables	**Adults (15-64 years)**		**The elderly (≥ 65 years)**		**All age groups**	
	weight	**rank**	**weight**	**rank**	**weight**	**rank**
Patient number	**0.993**	–	**0.943**	–	**0.992**	–
Temperature (°C)	**0.168**	2	**0.165**	4	**0.188**	2
Global solar flux (Wm^{-2})	0.048	8	-0.004	11	0.047	9
Relative humidity (%)	0.009	10	-0.083	9	-0.020	11
Air pressure (hPa)	*0.110*	7	*0.124*	7	0.055	7
Wind speed (ms^{-1})	0.035	9	**0.273**	2	0.022	10
Total weight	0.370	–	0.649	–	0.331	–
CO (μgm^{-3})	-0.009	11	*-0.126*	6	-0.049	8
PM_{10} (μgm^{-3})	**0.147**	3	0.092	8	**0.138**	4
NO (μgm^{-3})	*0.120*	6	**0.148**	5	0.104	5
NO_2 (μgm^{-3})	**0.175**	1	**0.186**	3	**0.197**	1
O_3 (μgm^{-3})	*-0.121*	5	**-0.351**	1	**-0.158**	3
SO_2 (μgm^{-3})	*-0.124*	4	-0.073	10	-0.091	6
Total weight	0.696	–	0.977	–	0.737	–

For the pollen season of *Ambrosia*, pollen variables indicate the second highest weight for adults and all age groups, basically due to the very high *Ambrosia* pollen levels (Table 2a). For adults, the first three explanatory variables influencing most the patient numbers in decreasing order are *Ambrosia*, PM_{10} and CO, while for all age groups *Ambrosia*, PM_{10} and O_3, respectively. For the elderly, there are much less significant associations between the explanatory variables and the number of respiratory diseases; furthermore, pollen variables show the smallest total weight in this case. Here, influencing variables ranked highest in decreasing order are O_3, wind speed and NO_2. *Ambrosia* pollen is yet in significant connection with the number of respiratory diseases, however it is ranked only 6 (Table 2a).

For the pollen-free season, the chemical variables are ranked highest (Table 2b). The sequence of the most important influencing variables in decreasing order for adults is NO_2, temperature and PM_{10}, for the elderly O_3, wind speed and NO_2, while for all age groups NO_2, temperature and O_3 (Table 2b).

CO and photochemical pollutants (NO_2, O_3) can be considered as determinants of acute respiratory conditions. Since CO and NO_2 are good indicators of combustion products from traffic-related sources the detected effect may be due to unmeasured fine and ultrafine particles (Fusco et al. 2001). We received a statistically significant negative association between daily hospital admissions for respiratory causes and CO levels for adults and all age groups in the pollen season of *Ambrosia*, as well as for elderly in the pollen-free season. CO has been associated to respiratory conditions in several investigations. Freitas et al. (2010) did not find any statistically significant relationship between respiratory hospital admissions and CO, while Kassomenos et al. (2008), Fusco et al. (2001), Migliaretti et al. (2007) and Chiu et al. (2009) confirmed the role of CO on respiratory health effects. The impacts of long-lasting but low level exposure to CO on the respiratory system are thus still uncertain (Table 2a-b).

For the pollen season of *Ambrosia*, we found significant negative associations between the number of respiratory admissions and PM_{10} levels for all three age groups, while for the pollen-free season significant positive associations were detected between these variables for adults and all age groups (Table 2a-b). Time-series analysis conducted in the scope of the "Air Pollution and Health, European Approach" (APHEA) project involving 15 European cities, 10 different countries and 25 million people (Katsouyanni et al. 1996), as well as other epidemiological studies in Europe (Fusco et al. 2001) have suggested that gaseous air pollutants, in particular CO and NO_2, are more important predictors of acute hospitalisation for respiratory conditions than particulate matter. On the contrary, in Athens (Kassomenos et al. 2008) elevated PM_{10} levels seem to play a dominant role among the main air pollutants. Furthermore, some studies (Tenías et al. 1998, Fusco et al. 2001) showed the association between particulate matter and health conditions not to be significant, while others (Andersen et al. 2007, Ko et al. 2007, Chiu et al. 2009) found that the number of admissions for respiratory causes rose significantly with increased exposure to particulate matter. Additionally, Freitas et al. (2010) detected but Alves et al. (2010) did not detect associations between the number of respiratory diseases and PM_{10} levels in Lisbon. It should be noted that the impact of particulates on health is complex, since their biological effect can be influenced by the particle size and composition. It is also possible that PM_{10} itself is a by-product of some chemical reactions involving other pollutants and that these precursors are the real cause of hospital admissions (Alves et al. 2010).

For the pollen season of *Ambrosia*, we received a significant positive association between respiratory causes and NO_2 levels for the elderly, while for the pollen-free season significant positive associations were found between NO concentrations and respiratory admissions for adults and elderly, as well as between NO_2 levels and admissions for all three age groups, respectively (Table 2a-b). Although NO and NO_2 are considered to increase predisposition to respiratory diseases, results of different studies concerning the association between NO_x and respiratory causes still show discrepancies. For example, both Alves et al. (2010) and Freitas et al. (2010) found no significant association between respiratory diseases and NO levels. Spix et al. (1998) observed no significant relationship between NO_2 and respiratory admissions for adults and elderly from five West-European cities. Atkinson et al. (1999) reported no significant associations between NO_2 and respiratory admissions in London for each three age groups (children, adults and elderly) and for all ages. Similarly, no significant association between NO_2 and hospital admissions for respiratory morbidity was found in Dab et al. (1996). On the contrary, Luginaah et al. (2005) found a significant association between NO_2 levels and respiratory admissions only for females, 0-14 years of age. Further examples for significant impact of NO_2 levels on respiratory causes are in Fusco et al. (2001), Wong et al. (2006), Nidhi and Jayaraman (2007), Kassomenos et al. (2008), Cadum et al. (2009). In Lisbon, due to the dual role of NO_2, its high levels partly indicate no significant association with respiratory admissions (Alves et al. 2010), and partly increase the susceptibility for respiratory disorders (Freitas et al. 2010).

Several studies suggest that high concentrations of O_3 are harmful to human health and have indicated a positive association between O_3 and respiratory hospital admissions (Kassomenos et al. 2008). In particular, individuals exposed to higher than common ambient O_3 levels develop reversible reductions in lung function often associated with symptoms such as airway hyper-reactivity and lung inflammation (Uysal and Schapira 2003). In contrast, we observed a statistically significant negative effect of ozone for all three age categories in both seasons (Table 2a-b). This was the most characteristic connection between the number of respiratory disorders and levels of chemical pollutants. The aforementioned role of O_3 is confirmed in Lisbon for children and elderly people (Alves et al. 2010), as well as for all ages (Freitas et al. 2010). Some further studies (Karr et al. 2007) found that, sometimes low levels of ozone appear to be more harmful to health than moderate values. As there is no evidence that low levels of ozone are really harmful, this association seems paradoxical. The phenomenon called Paradoxical Ozone Association, i.e. POA (Joseph 2007) could be due to methyl nitrite from combustion of methyl ethers or esters in engine fuels. Methyl nitrite is known to be highly toxic, and closely related alkyl nitrites are known to induce respiratory sensitivity in humans (Joseph and Weiner 2002). Since sunlight is essential for ozone formation by photochemical oxidation a probable explanation for POA would be the existence of this nitrite pollutant that is rapidly destroyed by solar radiation. Hence, methyl nitrite is negatively correlated with O_3. Days with low solar radiation are likely to be days with both low ozone and high methyl nitrite, so that low ozone would be a marker for low solar radiation and high methyl nitrite. Since sunlight has opposing effect on ozone and methyl nitrite, one would expect the most acute methyl nitrite effect in winter (Joseph 2007). Negative association between O_3 levels and respiratory disorders in the summer period (pollen season of *Ambrosia*) can be explained by the fact that our monitoring station is found at a junction with heavy traffic (Table 2a-b).

SO_2 reacts with other chemicals in the air to form tiny sulphate particles. When these are breathed in, they gather in the lungs and are associated with increased respiratory symptoms together with decreased lung functions (Alves and Alvim-Ferraz 2005). We received a significant negative association between SO_2 levels and respiratory admissions for adults in both seasons and all age groups in the pollen season of *Ambrosia* (Table 2a-b, Matyasovszky et al. 2011). For the remaining cases the connection is not characteristic. Previous findings regarding the association between SO_2 levels and the number of respiratory causes have been inconsistent, since in some studies the pollutant was not significantly associated with respiratory diseases but other papers have reported positive relationships. Atkinson et al. (1999), Martins et al. (2002), Sunyer et al. (2003) or Alves et al. (2010) associated SO_2 levels with visits to the emergency departments. Contrarily, studies performed by the APHEA project (Katsouyanni et al. 1996), Tenías et al. (1998), Fusco et al. (2001), Galán et al. (2003), Ko et al. (2007) or Chiu et al. (2009) found no relationship between SO_2 concentrations and the hospital admissions for respiratory diseases.

Ambrosia pollen levels are in significant positive association with the number of hospital admissions for all three age categories (Table 2a). Furthermore, the remaining pollen is positively associated with respiratory disorders only for adults and all age groups. Similar results can be found e.g. in Carracedo-Martinez et al. (2008). However, factor loadings belonging to the remaining pollen are much smaller indicating their substantially weaker connection with hospital admissions (Table 2a).

Results received for elderly differ substantially from the remaining age categories for both periods (Table 2a-b). Though the sign of the associations betwen elderly patient number and the explanatory variables is the same for the most variables, the explanatory variables indicate generally smaller (higher) factor loadings, and the total weight of the variable types is also smaller (higher) than that for the remaining age categories in the pollen season of *Ambrosia* (pollen-free season). Furthermore, the sensitivity of the elderly to pollen seems to be definitely smaller than that of the remaining age groups. Accordingly, respiratory diseases for elderly people depend less on the explanatory variables in the pollen season of *Ambrosia.* Some of elderly habits, as social factors, contribute to this result as they tend to underestimate chronic diseases and consider them as natural attendant of age. Hence, the elderly do not turn to physician and do not partake in medical attendance in time (Johnson 2005), which may result in a weaker connection of the number of respiratory admissions with the explanatory variables in the pollen season of *Ambrosia.* At the same time, in the pollen-free season inhalation of generally colder air induces inflammation of the respiratory tracts especially for the elderly (Strausz 2003), who may be more sensitive to inflammation due to colder air. This may be the reason of the fact that the respiratory hospitalization of the elderly peaks in the winter months (Table 2a-b) (McCoy et al. 2005).

3.4. Time-varying multivariate linear regression

In order to measure the role of the explanatory variables in the number of hospital admissions the relative variances explained by these variables are used. Three questions can be addressed here. What is the order of explanatory variables with regard to the strength of the influence on patient number? What is the relative contribution of these variables to the variance explained by all of the variables? How do the patient numbers answer to a unit change in the explanatory variables? Concerning the first question, the selection of the importance of explanatory variables in the formation of patient numbers was performed by the well-known stepwise regression (Draper and Smith 1981).

The ratio of the variance of patient numbers explained by explanatory variables to the variance of patient numbers is considerably larger for adults than for elderly people. Also, the annual cycle of adult patient numbers is substantially larger (Table 3) suggesting that hospital visit of elderly people depends on pollutants and meteorological conditions to a lesser degree. This might be due to the social factor mentioned before (Table 3).

Table 3 Relative variance (%) of patient numbers accounted for by explanatory variables including and omitting (in parentheses) the annual cycle of patient numbers

Patients	**Pollen season of *Ambrosia***	**Pollen-free season**
Adults	26.8 (50.0)	17.8 (21.2)
The elderly	19.9 (23.9)	9.9 (13.9)
All age groups	26.5 (48.1)	13.8 (17.7)

The answer to the second question is more difficult due to the multicollinearity among the explanatory variables. Namely, the sum of variances explained by individual variables is larger than the variance explained by all of the variables. Therefore, neither univariate regressions with individual explanatory variables nor the multivariate regression performed with all of the variables is appropriate to quantify the individual explained variances. However, elementary consideration shows that the variance percentage explained by the ith variable is between V-V_i and v_i, where V is the total explained variance, and v_i and V_i are the variances explained by the ith variable and all of the variables excluding the ith variable, respectively. Therefore, only the ranges of variances explained by the explanatory variables corresponding to V-V_i and v_i can be shown in Table 4. The most important explanatory variables influencing patient numbers in the pollen season of *Ambrosia* are O_3

and temperature for every age category. The order of the remaining variables is the same for adults and all of ages: global solar flux, NO, wind speed, PM_{10}, air pressure, and *Ambrosia.* Almost the same variables are considered to be most substantial for the elderly group, but with a slightly different order. It is remarkable that *Ambrosia* is only the sixth-eighth most important explanatory variable influencing patient numbers. For the pollen-free season, O_3 is the second main factor for adults and all age groups, but is just the fifth for the elderly. The order is rather variable under different age groups. For instance, the most significant variable is PM_{10}, NO and global solar flux for adults, elderly and all age category, respectively.

Table 4 Ratio (%) of variances accounted for by explanatory variables to variance accounted for by all of the explanatory variables. Variables are indicated in an order of importance obtained via a stepwise regression. Only variables with a joint contribution just exceeding 90% of the total explained variance are shown. (in *X:* significant for $p < 0.1$, in **X**: significant for $p < 0.05$, in ***X***: significant for $p < 0.01$)

Pollen season of *Ambrosia*			**Pollen-free season**		
Adults	**The elderly**	**All ages**	**Adults**	**The elderly**	**All ages**
O_3: 15.8-31.7	**O_3: 20.1-36.7**	***O_3: 16.8-46.6***	**PM_{10}: 14.6-18.5**	*NO: 10.0-17.1*	**GSF: 8.0-12.3**
T: 1.5-10.9	T: 1.0- 5.0	*T: 1.5-10.4*	*O_3: 7.9- 9.0*	CO: 8.0-18.1	*O_3: 10.9-12.3*
GSF: 2.3- 6.4	NO_2: 5.0-10.0	GSF: 2.2- 6.0	*RH: 3.4-19.1*	SO_2: 8.0-14.1	*RH: 4.3-20.3*
NO: 3.8- 6.4	WS: 5.0- 6.0	NO: 3.7- 6.3	T: 7.9- 8.4	RH: 3.0-16.1	*CO: 4.3-11.6*
WS: 6.8-10.2	PM_{10}: 3.5-10.1	*WS: 7.1-10.1*	P: 0.2- 9.6	*O_3: 13.1-16.1*	*NO_2: 12.3-13.8*
PM_{10}: 6.0- 7.9	A: 2.5- 4.0	PM_{10}: 6.0- 8.2	*GSF: 8.4-10.7*	WS: 5.0- 9.0	P: 0.1- 9.4
P: 0.1- 5.3	GSF: 4.5- 5.0	P: 0.1- 5.0	SO_2: 5.6- 6.2	NO_2: 8.0-13.1	*NO: 8.0-16.7*
A: 5.7- 6.4	P: 0.0- 3.5	A: 4.9- 6.3	*NO: 7.3-12.9*	PM_{10}: 5.0- 5.1	T: 5.1- 9.4
RH: 1.1- 4.2	CO: 2.0- 4.0	RH: 0.7- 3.7			

T = Temperature (°C); GSF = Global Solar Flux (Wm^{-2}); RH = Relative humidity (%); P = Air pressure (hPa); WS = Wind speed ($m \cdot s^{-1}$); CO = Carbon-monoxide (μgm^{-3}); PM_{10} = Particulate matter smaller size than 10 μm (μgm^{-3}); NO = Nitrogen-monoxide (μgm^{-3}); NO_2 = Nitrogen-dioxide (μgm^{-3}); O_3 = Ozone (μgm^{-3}); SO_2 = Sulphur-dioxide (μgm^{-3}); *A* = *Ambrosia* ($pollen \cdot m^{-3} \cdot day^{-1}$)

Additionally, the order of importance of explaining variables identified by the stepwise regression is not the same as the order of level of the statistical significance (Table 4). The significance depends not only on the strength of the relationship but also on data length and autocorrelations of the different variables. Significance levels were determined by a Monte-Carlo simulation experiment. Approximating the autocorrelations of an explaining variable by a first order autoregressive model fitted to observed values of this variable, a time series independent of patient numbers was generated according to the time-varying empirical probability distribution function of the underlying explaining variable. The observed values were then substituted by this simulated data and the time-varying multivariate linear regression was performed. Finally, the mean squared error for patient numbers obtained from this regression was calculated. These steps were repeated 1,000 times, and the appropriate quantiles of the empirical probability distribution function of these 1,000 simulated mean squared errors delivered the critical value for checking the null-hypothesis of this explaining variable being uncorrelated with patient numbers. The procedure was applied to every explaining variable separately.

The answers of the patient numbers to unit changes in the explanatory variables exhibit annual cycles as the regression coefficients depend on dates within the year. There are evidences that confirm different effects of the explanatory variables in different periods of the year. For instance, wind speed is inversely proportional to the patient numbers in the pollen season of *Ambrosia* since this period is characterized by pollutant diluting effect of wind due to an intense vertical exchange in the boundary layer. In the pollen-free season, however, wind speed is mainly in positive association with respiratory diseases, especially for the elderly, since repeated exposition to strong winds may produce an inflammation of the small respiratory tracts (Strausz 2003). Furthermore, the role of bacteria and viruses affecting respiratory hospital admissions may be different under given meteorological conditions. While, for example, Mycoplasma bacteria generating pneumonia and other respiratory inflammations favour low relative humidity (pollen season of *Ambrosia*), adenoviruses provoking upper respiratory infections and conjunctivitis are more infectious at higher relative humidity (pollen-free season). Hence, not only low but also high relative humidity may contribute to an incraese in respiratory hospital admissions (Dilaveris et al. 2006).

Minima and maxima of regression coefficients during the year are shown in Table 5.

Table 5 Minima and maxima of regression coefficients during the year

Variable	Pollen season of Ambrosia						Pollen-free season					
	Minimum			Maximum			Minimum			Maximum		
	Adults	The elderly	All	Adult	The elderly	All	Adults	The elderly	All	Adults	The elderly	All
T	-3.61	-0.27	-3.96	5.28	0.01	5.83	-0.52	-0.55	-0.59	2.26	0.08	1.58
GSF	-0.03	-0.02	-0.03	0.38	0.01	0.40	-0.20	-0.02	-0.13	0.13	0.00	0.13
RH	-0.54	-0.06	-0.56	0.17	0.01	0.18	-0.77	-0.21	-0.82	0.29	0.05	0.35
P	-0.04	-0.01	-0.05	0.01	0.01	0.07	-0.03	0.00	-0.03	0.06	0.02	0.08
WS	-35.1	-2.61	-37.7	0.26	0.33	0.17	-4.11	0.00	-3.50	4.49	3.72	6.06
CO	-0.04	-0.01	-0.04	0.00	0.01	0.00	-0.01	-0.01	-0.02	0.01	0.01	0.00
PM_{10}	-0.50	-0.03	-0.55	0.14	0.03	0.18	0.00	-0.04	-0.05	0.24	0.04	0.13
NO	-1.00	-0.11	-1.07	0.25	0.01	0.23	-0.15	-0.03	-0.18	0.27	0.09	0.38
NO_2	-0.26	-0.07	-0.31	0.13	0.09	0.16	-0.42	-0.14	-0.68	0.21	0.08	0.47
O_3	-1.20	-0.16	-1.37	0.60	0.03	0.10	-0.47	-0.20	-0.70	0.24	0.02	0.00
SO_2	-1.54	-0.20	-1.75	0.63	0.18	0.99	-1.24	-0.09	-0.54	0.00	0.21	0.47
A	-0.08	-0.03	-0.11	2.78	0.24	3.05						
TP	-0.02	-0.13	0.00	0.34	0.02	0.59						

T = Temperature (°C); GSF = Global Solar Flux (Wm^{-2}); RH = Relative humidity (%); P = Air pressure (hPa); WS = Wind speed (ms^{-1}); CO = Carbon-monoxide (μgm^{-3}); PM_{10} = Particulate matter smaller size than 10 μm (μgm^{-3}); NO = Nitrogen-monoxide (μgm^{-3}); NO_2 = Nitrogen-dioxide (μgm^{-3}); O_3 = Ozone (μgm^{-3}); SO_2 = Sulphur-dioxide (μgm^{-3}); *A* = *Ambrosia* ($pollen \cdot m^{-3} \cdot day^{-1}$); TP = Total pollen ($pollen \cdot m^{-3} \cdot day^{-1}$)

These values mean boundaries of how the patient number changes with a unit change in different explanatory variables. The comparison of the main results of the factor analysis including special transformation (Table 2a-b) with stepwise regression (Table 4) and with the regression coefficients (Table 5) clearly indicates the difficulty of quantifying the importance of the explanatory variables due to multicollinearity among variables. The most evident example is *Ambrosia* in the pollen season of *Ambrosia*. It is considered to be the most important variable influencing patient numbers by the factor analysis for adults and all age groups, while stepwise regression takes it as only the sixth-eigth most significant parameter. However, Table 5 shows that a rise of 10 pollen grains·m^{-3} in the *Ambrosia* level may imply an increase of 28-30 patient numbers (24%) except for elderly people. This is because temperature, global solar flux, relative humidity and wind speed being important meteorological variables influencing the patient numbers well correlate with *Ambrosia* levels and so the stepwise regression prefers the aforementioned variables instead of *Ambrosia*. Another essential circumstance is that when using factor analysis, the relationship between two variables is due partly to the similarity of their annual cycles and partly to the correlation between centralized (difference between data and their annual cycle) data. Additionally, this relationship is constant in time for factor analysis, while time-varying linear regression allows different types of relationships during the year. Finally, a time lag between actual explanatory variables and patient numbers not introduced in the factor analysis is allowed for the regression approach. To sum up, time-varying regression produces a refinement of the overall picture provided by the factor analysis not discriminating between annual cycles and variations around these cycles. Considering O_3 (the most significant variable during the pollination season of *Ambrosia*), a 10 μgm^{-3} rise results in a relative patient number change from -17% (beginning of the season) to +11% (end of the season). Temperature and wind speed, weakly significant explaining variables, may imply a 7-8% increase at the beginning and 5% decrease at the end of the pollination season against a 1°C temperature rise and up to a 42-45% decrease of patient numbers under a 1 ms^{-1} wind speed growth (except for elderly people). The number of significant explaining variables is larger for the pollen-free season. The relative contribution of the influencing variables to all patient number varies during the year between the following ratios: -1.5% - +1.5% for global solar flux, 0% - +8% for O_3, -10% - +5% for relative humidity, -9% - +6% for NO_2 and -3% - +6% for NO under a rise of 10 Wm^{-2}, 10 μgm^{-3}, 10%, and 10 μgm^{-3} of the aforementioned variables, respectively.

Note that regression results coincide with the findings of factor analysis including special transformation according to which the connection of the number of respiratory admissions for the elderly age group with the explanatory variables is substantially weaker than for adults.

4. DISCUSSION AND CONCLUSIONS

The analysis of hospital admissions due to respiratory disorders originating in meteorological conditions and air pollutant levels is a very important issue of public health. The present study analyzes one of the largest databases in the field. Our study can be considered unique in the sense that it concurrently includes three categories of influencing variables with 5 meteorological, 6 chemical and 2 biological (pollen) parameters. We know of only one study (Kassomenos et al. 2008) that made an attempt to quantify the impact of different chemical pollutants together with meteorological elements on the incidence of respiratory diseases. However, pollen has not been studied from this point of view.

A large variety of statistical methods has been used to quantify the relationship of meteorological and air pollutant variables on the one hand and respiratory disorders on the other. The most frequently used procedures include stepwise regression (Kassomenos et al. 2008), artificial neural networks (Kassomenos et al. 2008), generalized additive Poisson regression (e.g. Alves et al. 2010), logistic regression (Heinrich et al. 2005), or case-crossover analysis as an alternative to Poisson regression (Yang et al. 2004). In our study, cluster analysis and factor analysis including special transformation, as well as a time-varying multivariate linear regression were applied in order to explore the role of influencing variables in respiratory hospital admissions and to determine the rank of importance of these variables as well as to quantify their effects. The aforementioned two methods are novel procedures in the subject.

The clustering of the pollen season of *Ambrosia* produced five clusters. It was found that for each age category, patient numbers were the highest in cluster 3, most probably due to the highest and medium levels of *Ambrosia* and the remaining pollen, respectively (Table 2a). Furthermore, cluster 4 involving a substantial part of summer provides the lowest patient numbers. It can be explained by moderate levels of both the two pollen types and the chemical pollutants (except for O_3) (Table 2a). Concerning the pollen-free season, four clusters were retained. The highest patient numbers for each age category are associated with cluster 4; that can be explained by the relatively high temperature facilitating the reproduction of bacteria and viruses, as well as by strong winds promoting inflammation in the small respiratory tracts by desiccating the air. On the other hand, cluster 3 having an anticyclonic character exhibits the lowest patient numbers for each age category, probably due to the very low temperatures in winter time that contribute to restricting respiratory infections (Table 2b).

In the pollen season of *Ambrosia*, factor analysis including special transformation revealed that the most important factors influencing respiratory diseases in decreasing order include *Ambrosia*, PM_{10}, CO, O_3 and wind speed for adults; furthermore, O_3, wind speed, NO_2, global solar flux and PM_{10} for the elderly, as well as *Ambrosia*, PM_{10}, O_3, CO and wind speed for all age groups. The sign of the relationship between patient numbers and the above variables is negative except for *Ambrosia* in every age group and NO_2 for elderly group (Table 2a). The most significant variables for this season obtained with time-varying linear regression are O_3 for every age group with its negative effect on patient numbers, furthermore temperature, global solar flux, NO and wind speed for both the adults and all age groups, while temperature, NO_2, wind speed and PM_{10} for elderly people. The sign of their effects are variable during the season (Table 4). Regression coefficients of the wind speed are rather large indicating the importance of this variable (Table 5). In the pollen-free season, factor analysis including special transformation showed the following explanatory variables to be most important: NO_2, temperature, PM_{10}, SO_2 and O_3 for adults; O_3, wind speed, NO_2, temperature and NO for elderly people; while NO_2, temperature, O_3, PM_{10} and NO for all age groups (Table 2b). The sign of these relationships is now positive except for O_3 and SO_2. The order of importance of explanatory variables obtained by time-varying linear regression is highly variable among age groups, but O_3 is again a main explaining variable. The role of wind speed is essentially smaller, while relative humidity is more important compared to the pollen season of *Ambrosia*.

Note that rank of the importance of the explanatory variables is different when using factor analyses and time-varying linear regressions due to three reasons. Specifically, factor analysis explores relationships among variables coming from two sources. Namely, the relationship between two variables is partly due to the similarity (or dissimilarity) of their annual cycles but partly due to the correlation between variations around these annual cycles. Additionally, this relationship is constant in time for factor analysis, while time-varying linear regression allows different types of the relationships between the explanatory variables and patient numbers during the year. Finally, a time lag between the actual explanatory variables and patient numbers not introduced for factor analysis is allowed for the regression approach. Hence, factor analysis shows an overall picture, while time-varying linear regression characterises the relationship between daily variations of explaining variables and number of daily hospital admissions.

Additional reasons make further difficulties in determining direct association between the explanatory variables and the number of respiratory diseases. A major concern is a dual character, namely different effects of specific explanatory variables on the respiratory admissions in the two periods examined or even during the same period. A typical example is the inverse role of O_3; see section 3.3 discussing the Paradoxical Ozone Association. Another case is temperature that is proportional to the patient numbers in both seasons. In the pollen season of *Ambrosia*, it affects patient numbers possibly purely. Namely, higher temperature contributes to the intense reproduction of bacteria and viruses that raises the number of hospital admissions. On the other hand, in the pollen-free season the effect of temperature increase occurs jointly with wind speed during a cyclonic activity. Concerning wind speed in the pollen season of *Ambrosia* it is in inverse connection with the number of hospital admissions as here the pollutant diluting effect of wind is predominant (Table 2a). In the cold pollen-free season, however, wind speed together with temperature is proportional to the number of hospital admissions, especially for elderly, since repeated exposition to dry air desiccated by winds may produce an inflammation of the small respiratory tracts (Table 2b) (Strausz 2003). Bacteria and viruses indicate also a dual effect. While, for example, Mycoplasma bacteria generating pneumonia and other respiratory inflammations favour relative humidity below 40%, adenoviruses provoking upper respiratory infections and conjunctivitis are more infectious at higher than 70% relative humidity. Hence, not only low but also high relative humidity may contribute to an incraese in respiratory hospital admissions (Dilaveris et al. 2006).

In the knowledge of the weight of the explanatory variables determined in developing respiratory diseases, age categories of high risk, as well as vulnerable groups with specific activity patterns can be warned by authorities, especially before and during given weather situations that favour extreme values of meteorological and pollutant variables.

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REFERENCES

Ågren C (2010) Particles killing half a million. Acid News 2:1-5 http://www.airclim.org/acidnews/2010/AN2-10.php#1

Alves CA, Alvim-Ferraz MCM (2005) Effects of Air Pollution on Emergency Admissions for Chronic Obstructive Pulmonary Diseases in Oporto, Portugal. Int J Environ Pollut 23:42-64

Alves CA, Scotto MG, Freitas MC (2010) Air Pollution and Emergency Admissions For Cardiorespiratory Diseases in Lisbon (Portugal). Quim Nova 33(2):337-344

Andersen ZJ, Wahlin P, Raaschou-Nielsen O, Scheike T, Loft S (2007) Ambient particle source apportionment and daily hospital admissions among children and elderly in Copenhagen. J Exposure Sci Environ Epidemiology 17(7):625-636

Atkinson RW, Anderson HR, Strachan DP, Bland JM, Bremner SA, Ponce de Leon A (1999) Short-term associations between outdoor air pollution and visits to accident and emergency departments in London for respiratory complaints. Eur Respir J 13(2):257-265

Cadum E, Berti G, Biggeri A, Bisanti L, Faustini A, Forastiere F (2009) The results of EpiAir and the national and international literature. Epidemiologia & Prevenzione 33(6):113-119 Suppl 1

Carracedo-Martinez E, Sanchez C, Taracido M, Saez M, Jato V, Figueiras A (2008) Effect of short-term exposure to air pollution and pollen on medical emergency calls: a case-crossover study in Spain. Allergy, 63(3):347-353

Chiu HF, Cheng MH, Yang CY (2009) Air Pollution and Hospital Admissions for Pneumonia in a Subtropical City: Taipei, Taiwan. Inhal Toxicol 21(1):32-37

Cohen AJ, Anderson HR, Ostro B, Pandey KD, Krzyzanowski M, Künzli N, Gutschmidt K, Pope A, Romieu I, Samet JM, Smith K (2005) The global burden of disease due to outdoor air pollution. J Toxicol Environ Health A 68(13-14):1301-1307

D'Amato G, Liccardi G, D'Amato M, Holgate S (2005) Environmental risk factors and allergic bronchial asthma. Clin Exp Allergy 35(9):1113-1124

Dab W, Medina S, Quénel P, Le Moullec Y, Le Tertre A, Thelot B, Monteil C, Lameloise P, Pirard P, Momas I, Ferry R, Festy B *(1996) Short term respiratory health effects of ambient air pollution: results of the* APHEA project in Paris. J Epidemiol Commun H 50 Suppl 1 S42-S46

Diaz J, Linares C, Tobias A (2007) Short-term effects of pollen species on hospital admissions in the city of Madrid in terms of specific causes and age. Aerobiologia 23(4):231-238

Dilaveris P, Synetos A, Giannopoulos G, Gialafos E, Pantazis A, Stefanadis C (2006) Climate impacts on myocardial infarction deaths in the Athens territory: the climate study. Heart 92:1747-1751

Draper N, Smith H (1981) Applied Regression Analysis. 2nd edition. John Wiley & Sons, New York

Freitas MC, Pacheco AMG, Verburg TG, Wolterbeek HT (2010) Effect of particulate matter, atmospheric gases, temperature, and humidity on respiratory and circulatory diseases' trends in Lisbon, Portugal. Environ Monit Assess 162(1-4):113-121

Fusco D, Forastiere F, Michelozzi P, Spadea T, Ostro B, Arca M, Perucci CA (2001) Air pollution and hospital admissions for respiratory conditions in Rome, Italy. Eur Respir J 17:1143-1150

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(2):59-63

Galán I, Tobias A, Banegas JR, Aranguez E (2003) Short-term effects of air pollution on daily asthma emergency room admissions. Eur Respir J 22(5):802-808

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(2):240-249

Jahn W, Vahle H (1968) Die Faktoranalyse und ihre Anwendung. Verlag die Wirtschaft, Berlin. 231

Járai-Komlódi M (1998) Ragweed in Hungary. In: Spieksma FThM (ed) Ragweed in Europe. Satellite Symposium Proceedings of 6th International Congress on Aerobiology. Perugia, Italy. Alk-Abelló A/S, Horsholm, Denmark. 33-38

Johnson ML (ed) (2005) The Cambridge Handbook of Age and Ageing. Cambridge University Press, Cambridge. 770 ISBN 9780521826327

Jolliffe IT (1993) Principal component analysis: A beginner's guide – II. Pitfalls, myths and extensions. Weather 48:246-253

Joseph PM (2007) Paradoxical ozone associations could be due to methyl nitrite from combustion of methyl ethers or esters in engine fuels. Environ Int 33(8):1090-106

Joseph PM, Weiner MG (2002) Visits to physicians after the oxygenation of gasoline in Philadelphia. Arch

Juhász M, Juhász IE (2002) A hazai gyomnövények aeropollinológiai jelentősége. [Aeropollinological importance of domestic weeds. (in Hungarian)] In Szabó T, Bártfai I, Somlai J (ed) Környezeti ártalmak és a légzőrendszer. Vol 12. F & G Press, Zalaegerszeg. 149-160

Just J, Nikasinovic L, Laoudi Y, *Grimfeld A (2007) Air pollution and asthma in children.* Rev Fr Allergol 47(3):207-213

Karr C, Lumley T, Schreuder A, Davis R, Larson T, Ritz B, Kaufman J (2007) Effects of subchronic and chronic exposure to ambient air pollutants on infant bronchiolitis. Am J Epidemiol 165:553-560

Kassomenos P, Papaloukas C, Petrakis M, Karakitsios S (2008) Assessment and prediction of short term hospital admissions: the case of Athens, Greece. Atmos Environ 42(30):7078-7086

Katsouyanni K, Zmirou D, Spix C (1996) Short-term effects of urban air pollution on health: a European approach using epidemiologic time series data. The Aphea protocol. J Epidemiol Commun H 5 Suppl 1 S12-S18.

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

Knight A, Drouin MA, Yang WH, Alexander M, Delcarpio J, Arnott WS (1991) Clinical-evaluation of the efficacy and safety of noberastine, a new H1 antagonist, in seasonal allergic rhinitis - a placebo-controlled, dose-response study. J Allergy Clin Immun 88(6):926-934

Ko FWS, Tam W, Wong TW, Lai CKW, Wong GWK, Leung TF, Ng SSS, Hui DSC (2007) Effects of air pollution on asthma hospitalization rates in different age groups in Hong Kong. Clin Exp Allergy *37(9):1312-1319*

Köppen W (1931) Grundriss Der Klimakunde. Walter De Gruyter & Co., Berlin

Luginaah IN, Fung KY, Gorey KM, Webster G, Wills C (2005) Association of ambient air pollution with respiratory hospitalization in a government-designated "Area of concern": The case of Windsor, Ontario. Environ Health Perspectives 113(3):290-296

Mahalanobis PC (1936) On the generalized distance in statistics. Proceedings of the National Institute of Sciences of India 12:49-55

Makra L, Tombácz Sz, Bálint B, Sümeghy Z, Sánta T, Hirsch T (2008) Influences of meteorological parameters and biological and chemical air pollutants to the incidence of asthma and rhinitis. Climate Res 37(1):99-119

Makra L, Sánta T, Matyasovszky I, Damialis A, Karatzas K, Bergmann KC, Vokou D (2010) Airborne pollen in three European cities: Detection of atmospheric circulation pathways by applying three-dimensional clustering of backward trajectories. J Geophys Res 115, D24220, doi:10.1029/2010JD014743

Martins LC, Latorre MDDD, Saldiva PHD, Braga ALF (2002) Air pollution and emergency room visits due to chronic lower respiratory diseases in the elderly: An ecological time-series study in Sao Paulo, Brazil. J Occup Environ Med 44(7):622-627

McCoy L, Redelings M, Sorvillo F, Simon P (2005) A Multiple Cause-of-Death Analysis of Asthma Mortality in the United States, 1990-2001. J Asthma 42:757-763

Migliaretti G, Dalmasso P, Gregori D (2007) Air pollution effects on the respiratory health of the resident adult population in Turin, Italy. Int J Environ Heal R 17(5):369-379

Nascimento LFC, Pereira LAA, Braga ALF, Modolo MCC, Carvalho JA (2006) Effects of air pollution on children's health in a city in Southeastern Brazil. Revista de Saude Publica 40(1):77-82

Nidhi and Jayaraman G (2007) Air quality and respiratory health in Delhi. Environ Mon Assess 135(1-3):313-325

Parsons JP, Mastronarde JG (2005) Exercise-Induced Bronchoconstriction in Athletes. Chest 128:3966-3974

Petrányi Gy (ed) (2000) Klinikai Immunológia. [Clinical Immunology. (in Hungarian)]. Medicina Könyvkiadó, Budapest. ISBN: 9789632425610

Schwartz J, Dockery DW (1992) Particulate air pollution and daily mortality in Steubenville, Ohio. Am J Epidemiol 135:12-19

Spix C, Anderson HR, Schwartz J, Vigotti MA, LeTertre A, Vonk JM, Touloumi G, Balducci F, Piekarski T, Bacharova L, Tobias A, Ponka A, Katsouyanni K (1998) Short-term effects of air pollution on hospital admissions of respiratory diseases in Europe: a quantitative summary of APHEA study results. Arch Environ Health 53(1):54-64

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

Sunyer J, Atkinson R, Balleste, F, Le Tertre A, Ayres JG, Forastiere F, Forsberg B, Vonk JM, Bisanti L, Anderson RH, Schwartz J, Katsouyanni K (2003) Respiratory effects of sulphur dioxide: a hierarchical multicity analysis in the APHEA 2 study. Occup Environ Med 60(8) e2-e2

Tenías JM, Ballester F, Rivera ML (1998) Association between asthma emergency room visits and air pollution in Valencia, Spain. Occup Environ Med 1998:55:541-547

Tukey JW (1985) The problem of multiple comparisons (1953) (unpublished manuscript). In The Collected Works of John W. Tukey. Vol 2. Wadsworth Advanced Books & Software, Monterey, CA. 1965-1984

Uysal N, Schapira RM (2003) Effects of ozone on lung function and lung diseases. Curr Opin Pulm Med 9(2):144-150

Wong TW, Tam W, Yu ITS, Wun YT, Wong AHS, Wong CM (2006) Association between air pollution and general practitioner visits for respiratory diseases in Hong Kong. Thorax 61(7):585-591

Yang CY, Chang CC, Chuang HY, Tsai SS, Wu TN, Ho CK (2004) Relationship between air pollution and daily mortality in a subtropical city: Taipei, Taiwan. Environ Int 30(4):519-523

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ASSESSMENT OF DAILY POACEAE POLLEN LEVELS BY LINEAR REGRESSION FOR TWO HUNGARIAN CITIES IN ASSOCIATION WITH DIFFERENT WEATHER TYPES

F TÓTH[1], I MATYASOVSZKY[2], L MAKRA[1], Z GUBA[1] and Z SÜMEGHY[1]

[1]*Department of Climatology and Landscape Ecology, University of Szeged, P.O.Box 653, 6701 Szeged, Hungary*
E-mail: makra@geo.u-szeged.hu
[2]*Department of Meteorology, Eötvös Loránd University, Pázmány Péter st. 1/A. 1117 Budapest, Hungary*

Summary: Objectively defined clusters of meteorological elements and weather types described by weather fronts and precipitation occurrences are produced in order to classify Poaceae pollen levels. The Poaceae pollen concentration was then estimated one day ahead for each categories of days in Szeged and in Győr in Hungary. The database describes an 11-year period from 1997-2007. We find that both for Szeged and Győr, as well as both for the subjective and objective classifications, high daily mean Poaceae pollen levels are favoured by anticyclone ridge weather situations. Taking clusters into account, the objective classification for the original data, and the subjective classification for days with a warm front and precipitation were most effective.

Key words: Poaceae, grass pollen, pollination period, weather front, factor analysis, cluster analysis, ANOVA, linear regression

1. INTRODUCTION

Pollen allergy became a widespread medical problem by the end of the 20th century. Nowadays, some 20% of the inhabitants on average suffer from this immune system problem in Europe (D'Amato et al. 2007). In Hungary, about 30% of the population has some type of allergy and 65% has a pollen-sensitivity (Járai-Komlódi and Juhász 1993, Makra et al. 2004). The pollen from grasses (Poaceae) is one of the most important airborne allergen sources worldwide (Mohapatra et al. 2005). For sensitive people the threshold value is 30 grains·m^{-3}, above which the symptoms of pollinosis occur (Puc and Puc 2004). In many countries grass pollen is the main cause of pollinosis (Subiza et al. 1995). For example, 56.7%, 40.4% and 24% of people are allergic to grasses in Szeged in Hungary (Kadocsa and Juhász 2000), Thessaloniki in Greece (Gioulekas et al. 2004) and Hamburg in Germany (Nowak et al. 1996), respectively. The Poaceae pollen season usually begins when the average daily temperature exceeds 13.5°C (Peternel et al. 2006). In Hungary, Poaceae has the longest blooming period of all species: it lasts from the middle of April till the middle of October (Makra et al. 2006) and, after *Ambrosia*, discharges the second biggest amount of pollen of all taxa. The ratio of its pollen release to the total pollen release in Hungary is around 17% (Juhász 1996).

Poaceae pollen is considered to be the result of medium-range transport involving local pollen dispersion (Makra et al. 2010). The main grass pollen season is generally double-peaked. The pattern of successive flowering in grass species and meadow cutting dates appear to be the factors which cause the characteristic bimodal behaviour of the grass pollen season (Kasprzyk and Walanus 2010). In Hungary, the first peak occurs from February to April, while the second peak is from May to July (Juhász 1996).

Finding a connection between the daily Poaceae pollen concentration and daily meteorological elements is of great practical importance. Applying simple statistical analyses, several studies found significant positive correlations between daily Poaceae pollen concentration and daily maximum temperature (Valencia-Barrera et al. 2001, Green et al. 2004, Kasprzyk and Walanus 2010), daily minimum temperature (Green et al. 2004), daily mean temperature (Puc and Puc 2004, Peternel et al. 2006, Kasprzyk and Walanus 2010) and daily global solar flux (Valencia-Barrera et al. 2001, Kasprzyk and Walanus 2010). Relative humidity (Valencia-Barrera et al. 2001, Puc and Puc 2004, Peternel et al. 2006, Kasprzyk and Walanus 2010) and rainfall (Fehér and Járai-Komlódi 1997, Valencia-Barrera et al. 2001, Green et al. 2004, Puc and Puc 2004, Peternel et al. 2006, Kasprzyk and Walanus 2010), however, had a negative effect. Wind speed has an ambivalent role, partly having a positive impact by increasing pollen shed from the anthers, partly a negative association by diluting pollen from the air (Valencia-Barrera et al. 2001).

Meteorological elements affect pollen concentration not by means of their individual effects, but through their interrelationships and so it is useful to study the connection between daily Poaceae pollen concentrations and the daily values of meteorological elements as a whole. Only relatively few papers have reported results of approaches like these using multivariate statistical analysis techniques. Makra et al. (2006) objectively defined weather types with factor and cluster analyses in order to associate given daily pollen concentrations with their representative meteorological parameters. Hart et al. (2007) analysed the influence of weather elements on pollen concentrations for Sydney, producing a synoptic classification of pollen concentrations using principal component analysis and cluster analysis. Tonello and Prieto (2008) classified pollen data of 17 taxa and climate parameters using principal component analysis and cluster analysis to identify relationships between potential natural vegetation, pollen and climate.

The purpose of this paper is to determine the most homogeneous groups of meteorological elements by cluster analysis, and then Poaceae pollen levels are examined by conditioning on these clusters. Another aim is to utilise the possible information of meteorological elements on Poaceae pollen concentration when cold and warm weather fronts pass through a city. Furthermore, those days with a front but no rain and those days with rain but no front will also be considered. Lastly, we attempt to estimate the Poaceae pollen concentration one day ahead for each of the above day categories at Szeged and Győr. These medium-sized cities are located in South-eastern and North-western Hungary, respectively, about 340 km apart.

2. MATERIALS AND METHODS

2.1. Location and data

Szeged (46.25°N, 20.10°E), the largest settlement in South-eastern Hungary is located at the confluence of the rivers Tisza and Maros. The area is characterised by an extensive flat landscape of the Great Hungarian Plain with an elevation of 79 m asl. The city is the centre of the Szeged region with 203,000 inhabitants. The pollen content of the air was measured using a 7-day recording "Hirst-type" volumetric trap (Hirst 1952). The air sampler is located on top of the building of the Faculty of Arts at the University of Szeged some 20 m above the ground surface (Makra et al. 2010).

Győr (47.68°N, 17.63°E) lies in Northern Transdanubia, in Hungary. The city is located in the Rába valley with an elevation of 123 m asl at the confluence of the Rába, Rábca and Mosoni-Duna rivers. Győr is the sixth largest city in Hungary with a population of 132,000. The air sampler is situated on the roof of the Oncology Department building, Petz Aladár County Hospital, south of the centre of Győr, approximately 20 m above ground level.

Meteorological data were collected in monitoring stations (operated by the Environmental and Natural Protection and Water Conservancy Inspectorates of the Lower-Tisza Region, Szeged and Northern Transdanubia, Győr respectively) located in the downtown of Szeged and Győr at a distance of about 10 m from the busiest main roads.

For weather front recognition purposes, the ECMWF (European Centre for Medium-Range Weather Forecasts) ERA-INTERIM database was used on the grid network with a density of 1°x1°. Only those grid points (for Szeged: 46°N, 20°E; for Győr: 48°N, 18°E) were selected that were nearest to the geographical coordinates of both Szeged (46.25°N, 20.10°E) and Győr (47.68°N, 17.63°E). Meteorological parameters considered are as follows: RT 500/850 hPa relative topographies (for calculating the thickness of the air-layer), 700 hPa temperature fields (for calculating the temperature advection in order to determine the sign of the front) and 700 hPa wind fields (to include advection when calculating the Thermal Front Parameter, TFP).

In order to estimate actual daily Poaceae pollen concentrations, the previous-day values of five meteorological variables (mean temperature, mean global solar flux, mean relative humidity, mean sea-level pressure and mean wind speed) and previous-day Poaceae pollen concentrations as candidate predictors were applied. The statistical relationship between the predictors and the pollen concentration was conditioned on the clusters as well as frontal and precipitation information. The rationale behind this approach is that the existence of fronts and precipitation is forecasted at a high accuracy, but the forecast of the above meteorological variables is much less reliable. Hence, previous-day values were considered instead of their values forecasted for the actual days in question.

The longest pollination period of the two cities (April 4 – October 16, 1997-2007) was used for our study. This interval covers most of the Poaceae pollination period both in Szeged and Győr using the criterion of Galán et al. (2001). Namely, the start (end) of the pollen season is the earliest (latest) date on which at least 1 pollen grain m^{-3} is recorded and at least 5 consecutive (preceding) days also have 1 or more pollen grains m^{-3}. The mean of this annually varying period was selected for the 11-year period examined.

2.2. *Objective identification of weather fronts*

The objective identification of weather fronts is a difficult task due to the lack of a unique definition described in mathematical terms. In addition, different fronts can be characterised by different sets of meteorological parameters. The contribution of Renard and Clarke (1965) is a classic advance in this area. They analysed the horizontal gradient of magnitude of the horizontal potential temperature gradient at an air pressure of 850 hPa. Later, Hewson (1998) improved the procedure, resulting in a quantity called the Thermal Front Parameter (TFP). Using this methodology, Yan et al. (2008) produced an automatic weather system identification method that can identify weather systems with 80-100% accuracy and provide objective information on identifying and positioning weather systems. There is a clear relationship between the TFP as frontal analysis parameter and the well-known basic front definition that fixes a cold front where the temperature begins to fall and a warm front where the rise in temperature ends. This definition corresponds to the maximum of the TFP.

Frequently the relative topography is used for simplicity (www.satreponline.org) instead of the potential temperature. This is because there is a close connection between the thickness and the average potential temperature of an air-layer. Therefore, the relative topography (RT 500/850 hPa) was used in our calculations. The algorithm was run for 6-hourly datasets within the period examined for both cities. Dates when fronts passed through the cities were thus produced with a 6-hour resolution.

2.3. Statistical methods

Factor analysis (FA) explains linear relationships among the variables examined and reduces the dimensionality of the initial database without a substantial loss of information. In particular, the 6 variables (5 climate variables and the previous-day pollen concentration) were trasformed into *m* number of factors. These factors can be viewed as the main latent variables potentially influencing daily pollen concentration. The optimum number *m* of the retained factors is defined such that the total variance of the *m* factors reaches a prespecified portion (80% in our case) of the total variance of the original variables (Jolliffe 1993).

A cluster analysis was applied to the original data sets that objectively classifies the days of the given groups with similar climate conditions. We applied hierarchical cluster analysis using Ward's method on the climatic variables of the period April 4 – October 16 over the 11-year period examined. Ward's method attempts to minimise the sum of squares of elements within clusters forming at each step during the procedure (Ward 1963). The procedure works with the Mahalanobis metric, which is deemed better than the Euclidean metric (Mahalanobis 1936). The Mahalanobis metric takes into account the different standard deviations of the components of the vectors to be clustered as well as the correlations among the components. We select the number of clusters under possible cluster numbers from 3 to 30 so as to ensure nearly uniform occurrence frequencies of the clusters. Intuitively, the final system of clusters produces a small variation of occurrence frequencies of the clusters constrained on forming these clusters by Ward's method (Anderberg 1973, Hair et al. 1998).

Another classification is based on frontal information. In particular, the following six weather types were defined: warm front with rain, warm front with no rain, cold front with rain, cold front with no rain, no front with rain, no front with no rain.

The one-way analysis of variance (ANOVA) was then used to decide whether the inter-cluster variance was significantly higher than the intra-cluster variance of daily Poaceae concentrations. A post-hoc Tukey test was applied to find the clusters which differ significantly from others (Tukey 1985) from the viewpoint of the cluster-dependent mean pollen levels.

A further task was to establish a relationship between the predictors and the pollen concentration. As both kinds of variables exhibit annual trends, standardised data sets were used. Denoting an underlying data set by x_t, $t = 1, \dots, n$ the expected value function $m(t)$ of x_t is approximated by a linear combination of cosine and sine functions with periods of one year and one half year. (Note that the latter cycle was introduced to describe the asymmetries of the annual courses.) Namely, $m(t) = a_0 + a_1 \cos(w_1 t) + a_2 \cos(w_2 t) + b_1 \sin(w_1 t) + b_2 \sin(w_2 t)$ with $w_1 = 2\pi/365.25$ and $w_2 = 2w_1$. Unknown coefficients in this linear combination were estimated via the least squares technique. Then the standardised, and thus annual course-free data set is $y_t = (x_t - m(t))/d(t)$, $t = 1, \ldots, n$, , where the unknown coefficients in $d^2(t) = a_0 + a_1 \cos(w_1 t) + a_2 \cos(w_2 t) + b_1 \sin(w_1 t) + b_2 \sin(w_2 t)$ were estimated like those in $m(t)$, except that x_t was replaced by $x_t^* = (x_t - m(t))^2$, $t = 1, \ldots, n$ when applying the least squares technique. Linear regressions for both the entire data set and data sets corresponding to both systems of weather types were performed. The order of importance of predictors in the formation of pollen concentration was determined by the well-known stepwise regression method (Draper and Smith 1981). The mean squared error obtained for the entire data set was compared to the weighted sum of mean squared errors obtained for the weather types. The weights were the relative frequencies of these types.

3. RESULTS

3.1. Cluster analysis and ANOVA

The days of the 11-year period for both Szeged and Győr (Tables 1a and 2a) were classified into the above-mentioned six categories (warm front with rain, warm front with no rain, cold front with rain, cold front with no rain, no front with rain, no front with no rain). Afterwards, cluster analyses were carried out for the two cities using the original and standardised data sets. Hence altogether 4 cluster analyses were performed. The mean values of the 6 influencing variables (5 meteorological and 1 pollen variables) and the resultant variable (Poaceae pollen level) for both the frontal categories and the clusters are tabulated in Tables 1 and 2.

The analysis of variance revealed a significant difference at least at a 95% probability level in the mean values of Poaceae pollen levels among the individual clusters. For Szeged, using frontal categories, the pairwise comparisons of the cluster averages found 2 significant differences among the possible 15 cluster pairs of 6 clusters (13.3%). In this case, only the mean values of clusters 4 and 5, as well as 4 and 6 differed significantly from each other. The clustering of original variables resulted in 14 significant pairwise differences among the mean pollen levels of all 21 cluster pairs of 7 clusters (66.7%). Clusters defined with standardised variables revealed 7 significant differences among the possible 21 cluster pairs of 7 clusters (33.3%). The role of Cluster 2 is important because its average differed significantly from those of the remaining clusters.

For Győr, using frontal categories, only 3 significant differences were found among the possible 15 cluster pairs of 6 clusters (20%). An objective classification of original variables resulted in 7 clusters. Here, with the exception of clusters 2 and 5, 2 and 6, as well as 4 and 7, the means of all remaining cluster pairs notably differed from each other (85.7%). For standardised variables, 6 objective clusters and 11 significant pairwise differences among the mean pollen levels of all 15 cluster pairs (73.3%) were obtained.

Below only clusters of the significantly different cluster averaged pollen levels will be considered and analysed in detail, principally the clusters with extreme pollen levels

(Tables 1a-b and 2a-b). Comparing the results obtained by frontal categories (Table 1a) and objective clusters (Table 1b) defined on the original data for Szeged, the following key conclusions can be drawn. The category (cluster) displaying the highest mean pollen level includes a medium (fewest) number of days. The frontal category (cluster) involving the highest mean pollen level includes (does not include) extreme values of the influencing variables. For the subjective classification, the category of the highest mean pollen level (class 4: cold front with no rain) is influenced by high previous-day mean Poaceae pollen concentration, the highest mean values of temperature and air pressure, as well as low relative humidity and the lowest wind speed. These values of the meteorological parameters assume an ante – cold front weather situation that is a possible anticyclone ridge weather situation which facilitates high pollen levels (Table 1a). For the objective classification, the cluster of the highest mean Poaceae pollen concentration (cluster 5) is affected by the highest previous-day pollen level, low temperature, as well as high global solar flux, relative humidity, air pressure and wind speed. These values suppose a weak anticyclone ridge weather situation promoting the enrichment of Poaceae pollen (Table 1b). A similar comparison for Győr (Table 2a-b) reveals the following main points. The subjective category involving the highest mean pollen concentration occurs frequently, while the frequency of the objective cluster having the highest mean pollen level is the smallest. The subjective category having the highest mean pollen level is associated with the second highest previous-day mean Poaceae pollen concentration, while the objective cluster displaying the highest value of the resultant variable involves the highest mean previous-day pollen level as its apparently most important influencing variable. For the subjective classification, the category of the highest mean pollen level (class 2: warm front with no rain) is influenced by the highest temperature and wind speed, high global solar flux and air pressure, as well as low relative humidity. These values assume an ante – warm front weather situation that is possibly again an anticyclone ridge weather situation that aids high pollen levels (Table 2a). For the objective classification, the cluster of the highest mean Poaceae pollen concentration (Cluster 3) is probably mostly affected by the highest previous-day pollen level, since no meteorological variables have extreme values. Nevertheless, the temperature and global solar flux are high, while the relative humidity is low; furthermore air pressure and wind speed assume medium values. Accordingly, this cluster is supposed to be prevailed by a weak anticyclone ridge weather situation that assists the enrichment of Poaceae pollen (Table 2b).

Table 1a Mean values of the meteorological and pollutant parameters, according to subjective categories for Szeged, original data (**bold:** maximum; *italic:* minimum)

Cluster	**1**	**2**	**3**	**4**	**5**	**6**
Parameter	**Mean values**					
Total number of days	123	320	*46*	203	211	**484**
Frequency (%)	8.9	23.1	*3.3*	14.6	15.2	**34.9**
Temperature (°C)	19.4	20.8	19.0	**20.9**	*17.8*	19.5
Global solar flux (Wm^{-2})	259.3	**361.6**	270.1	340.5	*250.1*	357.5
Relative humidity (%)	75.2	*63.7*	77.6	64.7	**80.7**	65.8
Air pressure (hPa)	1000.6	**1006.1**	1002.1	**1006.1**	*1001.1*	1004.5
Wind speed (ms^{-1})	**1.1**	1.0	**1.1**	*0.9*	1.0	1.0
Poaceae pollen, previous-day*	16.7	14.7	**18.2**	17.7	14.5	*14.4*
Poaceae pollen, same day*	15.8	15.9	17.2	**17.7**	*13.2*	14.6

1: warm front with rain; 2: warm front with no rain; 3: cold front with rain; 4: cold front with no rain; 5: no front with rain; 6: no front with no rain; *: (pollen·m^{-3}·day^{-1})

Table 1b Cluster-related mean values of the meteorological and pollutant parameters, Objective clusters for Szeged, original data, whole database (**bold**: maximum; *italic*: minimum)

Cluster	1	2	3	4	5	6	7
Parameter				**Mean values**			
Total number of days	174	249	232	137	*82*	**343**	170
Frequency (%)	12.5	18.0	16.7	9.9	*5.9*	**24.7**	12.3
Temperature (°C)	**22.4**	16.2	*15.8*	22.3	19.3	23.3	18.2
Global solar flux (Wm^{-2})	285.7	*165.3*	386.3	349.1	350.5	**413.5**	329.9
Relative humidity (%)	54.8	**89.5**	64.4	*49.5*	68.3	69.3	72.3
Air pressure (hPa)	**1012.7**	1000.3	1007.5	*997.1*	1005.0	1003.2	1003.9
Wind speed (ms^{-1})	0.9	0.9	*0.8*	1.0	1.0	0.9	**1.7**
Poaceae pollen, previous-day*	14.7	*8.7*	9.1	12.1	**66.6**	14.7	13.2
Poaceae pollen, same day*	14.9	*8.4*	10.8	12.9	**55.3**	15.4	14.9

*: (pollen·m^{-3}·day^{-1})

Table 2a Mean values of the meteorological and pollutant parameters, according to subjective categories for Győr, original data (**bold**: maximum; *italic*: minimum)

Cluster	1	2	3	4	5	6
Parameter			**Mean values**			
Total number of days	90	264	*53*	145	168	**416**
Frequency (%)	7.9	23.2	*4.7*	12.8	14.8	**36.6**
Temperature (°C)	17.8	**19.9**	18.1	19.8	*16.6*	18.7
Global solar flux (Wm^{-2})	*145.1*	196.5	154.7	193.8	149.0	**201.7**
Relative humidity (%)	72.8	*60.7*	69.8	60.4	**74.8**	61.2
Air pressure (hPa)	1002.2	1004.8	1003.5	1005.1	*1001.7*	**1006.1**
Wind speed (ms^{-1})	**1.2**	**1.2**	**1.2**	*1.1*	**1.2**	*1.1*
Poaceae pollen, previous-day*	7.1	7.7	**9.3**	7.7	*5.8*	6.1
Poaceae pollen, same day *	6.6	**7.9**	6.2	7.4	*5.2*	7.0

1: warm front with rain; 2: warm front with no rain; 3: cold front with rain; 4: cold front with no rain; 5: no front with rain; 6: no front with no rain; *: (pollen·m^{-3}·day^{-1})

Table 2b Cluster-related mean values of the meteorological and pollutant parameters, Objective clusters for Győr, original data, whole database (bold: maximum; italic: minimum)

Cluster	1	2	3	4	5	6	7
Parameter				**Mean values**			
Total number of days	214	102	*80*	139	195	**217**	189
Frequency (%)	18.8	9.0	*7.0*	12.2	17.2	**19.1**	16.6
Temperature (°C)	20.1	17.3	20.6	*14.1*	18.2	**23.6**	15.3
Global solar flux (Wm^{-2})	**295.8**	168.6	224.2	118.3	178.7	187.0	*105.2*
Relative humidity (%)	59.8	69.2	61.9	75.6	*49.9*	60.2	**78.9**
Air pressure (hPa)	1008.2	999.5	1004.3	**1012.8**	1003.7	1003.9	*999.1*
Wind speed (ms^{-1})	*1.0*	**1.9**	1.2	1.1	1.1	1.1	1.1
Poaceae pollen, previous-day*	7.1	3.9	**37.2**	*2.3*	5.4	4.1	3.5
Poaceae pollen, same day*	10.0	5.0	**24.6**	*2.2*	6.9	5.0	2.7

*: (pollen·m^{-3}·day^{-1})

3.2. Linear regression

Predictors significant at least at a 90% level were retained and evaluated. These include previous-day pollen concentration, previous-day mean temperature and previous-day mean global solar flux for Győr, but only previous-day pollen concentration for Szeged when the entire data set was used. The previous-day concentration is apparently the best predictive parameter for both locations and for each weather type defined either by clustering or fronts with rain occurrences. The rank of importance of temperature and global solar flux for Győr is variable under both sets of clusters and even the wind speed has a slight (although statistically significant) role in types with fronts.

The ratio of the variance explained by these variables to the variance of the pollen concentration is 12.8% and 29.9% for Győr and Szeged, respectively, using all the data sets. With cluster-dependent regressions, Győr provides an explained variance of 27.9%, 17% and 16.3% using clusters with original data, clusters with standardised data and subjective weather types, respectively. The most effective classification is, therefore, the clustering with original data. A subjective classification and clustering with standardised data do not make any substantial difference. The corresponding values for Szeged under cluster-dependent regressions are 31%, 29.6% and 29.7%. Here, the different classifications perform quite similarly, especially the subjective classification and clustering with standardised data. Note that the estimation of daily Poaceae pollen concentration is more reliable for Szeged than for Győr because it has a warmer and dryer climate. However, the cluster-dependent regression for Szeged, in contrast to Győr, yields only a slight gain under clustering with original data and yields no gain under subjective classification and clustering with standardised data.

For the subjective classification, the best estimates can be obtained for days of warm front with precipitation (39% and 70.4% explained variance for Győr and Szeged, respectively), while the poorest estimates occur on days of cold front with no precipitation. Under this type, the mean squared error is larger than this quantity defined for the entire data set (by 20% and 13% for Győr and Szeged, respectively). For clustering with original data, the best estimates can be obtained for Cluster 4 and Cluster 3 for Győr (42.8% explained variance and Szeged (74.6% explained variance), respectively. The poorest estimates are associated with Cluster 3 for Győr and Cluster 7 for Szeged. The corresponding mean squared error increases by 106.5% (Győr) and 55.4% (Szeged) relative to the quantity defined for the entire data set.

The variability of mean pollen concentrations among clusters is wider than the similar range under subjective weather types. This is due to the fact that a subjective grouping might consider fewer influencing variables or selects the types arbitrarily, while an objective classification makes it possible to select an optimum number of groups of weather types, providing a higher explained variance of the pollen level (Makra et al. 2009). The category of warm front with precipitation involves very similar days of a relatively stable weather situation. Though the wind speed is high, the influencing variables display a small variablity, producing a higher explained variance of the Poaceae pollen concentration. On the contrary, on days of cold front with no rain in spite of low winds the higher variability of the influencing variables involves a lower explained variance of the pollen level (Tables 1 and 2). The estimation of the pollen level for Szeged is more reliable than for Győr. The warm and temperate climate (Köppen's Ca type) of Szeged fits the climate optimum of Poaceae better than temperate oceanic climate (Köppen's Cbfx type) of Győr (Köppen 1931). This is why the explained variance of the 6 influencing variables to the variance of the pollen level is higher for Szeged than for Győr.

4. CONCLUSIONS

Both for Szeged and Győr, as well as for the subjective and objective classifications, high daily mean Poaceae pollen levels are facilitated by anticyclone ridge weather situations, as we expected.

When estimating Poaceae pollen level, the previous-day pollen concentration, previous-day mean temperature and previous-day mean global solar flux for Győr, but only previous-day pollen concentration for Szeged were significant at least at a 90% level using the entire data set. As regards clusters with original data, clusters with standardised data and subjective weather types, the objective classification with original data proved the most effective.

For the subjective classification, the best estimates can be obtained for days of warm front with precipitation for Győr and Szeged, respectively. The poorest estimates are obtained on days of cold front with no precipitation. The ratio of the variance explained by the 6 variables to the variance of the pollen concentration was higher for the objective than for the subjective classification of the weather types, which confirms our expectations. The difference between explained variances of the Poaceae pollen concentration under the category of warm front with precipitation and under cold front with no precipitation can be explained by the different variability of the influencing variables. The estimates of the pollen level for Szeged is much more reliable than those for Győr, since the warm and temperate climate of Szeged fits the climate optimum of Poaceae better than the temperate oceanic climate of Győr.

The above-mentioned relationship between the pollen level and the six influencing variables allow us to perform a preliminary, cluster related analysis of variable dependencies for the pollen level. In order to get a reliable forecast of the Poaceae pollen concentration a more advanced methodology will be needed. However, both the objectively and subjectively defined weather types produce useful information on the accuracy of the forecast. For instance, the Poaceae pollen concentration following a warm front with rain can be accurately forecasted, while a cold front with no rain involves highly uncertain factors.

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REFERENCES

Anderberg MR (1973) Cluster Analysis for Applications. Academic Press, New York

D'Amato G, Cecchi L, Bonini S, Nunes C, Annesi-Maesano I, Behrendt H, Liccardi G, Popov T, van Cauwenberge P (2007) Allergenic pollen and pollen allergy in Europe. Allergy 62(9):976–990

Draper N, Smith H (1981) Applied Regression Analysis. 2nd Edition. John Wiley & Sons, New York

Fehér Z, Járai-Komlódi M (1997) An examination of the main characteristics of the pollen seasons in Budapest, Hungary (1991-1996). Grana 36(3):169–174

Galán C, Cariñanos P, García-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(2):59-63

Gioulekas D, Papakosta D, Damialis A, Spieksma F, Giouleka P, Patakas D (2004) Allergenic pollen records (15 years) and sensitisation in patients with respiratory allergy in Thessaloniki, Greece. Allergy 59:174–184

Green BJ, Dettmann M, Yli-Panula E, Rutherford S, Simpson R (2004) Atmospheric Poaceae pollen frequencies and associations with meteorological parameters in Brisbane, Australia: a 5-year record, 1994-1999. Int J Biometeorol 48(4):172-178

Hair JF, Anderson RE, Tatham RL, Black WC (1998) Multivariate data analysis. Prentice Hall, New Jersey

Hart MA, de Dear R, Beggs PJ (2007) A synoptic climatology of pollen concentrations during the six warmest months in Sydney, Australia. Int J Biometeorol 51(3):209-220

Hewson TD (1998) Objective fronts. Meteorol Appl 5(1):37-65

Hirst JM (1952) An automatic volumetric spore trap. Ann Appl Biol 39(2):257-265

Járai-Komlódi M, Juhász M (1993) Ambrosia elatior (L.) in Hungary (1989-1990). Aerobiologia 9:75-78

Jolliffe IT (1993) Principal component analysis: A beginner's guide – II. Pitfalls, myths and extensions. Weather 48:246-253

Juhász M (1996) A pollen, mint környezetszennyezést jelző indicator. [Pollen as an indicator of environmental pollution. (in Hungarian)] The 2nd Symposium on Analytical and Environmental Problems. SZAB, Szeged, Hungary. 4 November, 1996. Book of Abstracts 152-159

Kadocsa E, Juhász M (2000) A szénanáthás betegek allergénspektrumának változása a Dél-Alföldön (1990-1998). [Change of allergen spectrum of hay-fever patients in Southern Great Plain (1990-1998). (in Hungarian)] Orvosi Hetilap 141(29):12617-12620

Kasprzyk I, Walanus A (2010) Description of the main Poaceae pollen season using bi-Gaussian curves, and forecasting methods for the start and peak dates for this type of season in Rzeszow and Ostrowiec Sw. (SE Poland). J Environ Monitoring 12(4):906-916

Mahalanobis PC (1936) On the generalised distance in statistics. Proceedings of the National Institute of Sciences of India 12:49-55

Makra L, Juhász M, Borsos E, Béczi R (2004) Meteorological variables connected with airborne ragweed pollen in Southern Hungary. Int J Biometeorol 49(1):37-47

Makra L, Juhász M, Mika J, Bartzokas A, Béczi R, Sümeghy Z (2006) An objective classification system of air mass types for Szeged, Hungary with special attention to plant pollen levels. Int J Biometeorol 50(6):403-421

Makra L, Mika J, Bartzokas A, Béczi R, Sümeghy Z (2009) Comparison of objective air-mass types and the Péczely weather types and their ability to classify levels of air pollutants in Szeged, Hungary. Int J Environ Pollut "Air Pollution" Special Issue 36(1-3):81-98

Makra L, Sánta T, Matyasovszky I, Damialis A, Karatzas K, Bergmann KC, Vokou D (2010) Airborne pollen in three European cities: Detection of atmospheric circulation pathways by applying three-dimensional clustering of backward trajectories. J Geophys Res 115, D24220, doi:10.1029/2010JD014743

Mohapatra SS, Lockey RF, Shirley S (2005) Immunobiology of grass pollen allergens. Current Allergy and Asthma Reports 5(5):381-387

Nowak D, Heinrich J. Jorres R, Wassmer G, Berger J, Beck E, Boczor S, Claussen M, Wichmann HE, Magnussen H (1996) Prevalence of respiratory symptoms, bronchial hyperresponsiveness and atopy among adults: West and East Germany. Eur Respir J 9(12):2541-2552

Peternel R, Smec L, Čulig J, Hrga I, Hercog P (2006) Poaceae pollen in the atmosphere of Zagreb (Croatia), 2002-2005. Grana 45(2):130-136

Puc M, Puc MI (2004) Allergenic airborne grass pollen in Szczecin, Poland. Ann Agr Env Med 11(2):23-244

Renard RJ, Clarke LC (1965) Experiment in numerical objective frontal analysis. Monthly Weather Review 93(9):547-556

Subiza J, Jerez M, Jiménez JA, Narganes MJ, Cabrera M, Varela S, Subiza E (1995) Allergenic pollen and pollinosis in Madrid. J Allergy Clin Immun 96(1):15-23

Tonello MS, Prieto AR (2008) Modern vegetation-pollen-climate relationships for the Pampa grasslands of Argentina. J Biogeogr 5:926-938

Tukey JW (1985) The problem of multiple comparisons (1953) (unpublished manuscript). In The Collected Works of John W. Tukey. Vol. 2. Wadsworth Advanced Books & Software, Monterey, CA. 1965-1984

Valencia-Barrera RM, Comtois P, Fernández-González D (2001) Biogeography and bioclimatology in pollen forecasting - An example of grass in Leon (Spain) and Montreal (Canada). Grana 40(4-5):223-229

Ward JH (1963) Hierachical grouping to optimise an objective function. J Am Stat Assoc 58:236-244

Yan WK, Lap YC, Wah LP (2008) Automatic identification of weather systems from numerical weather prediction data using genetic algorithm. Expert Syst Appl 35(1-2):542-555

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