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Wheather related ragweed pollen levels and prediction of ragweed pollen concentration for Szeged, Hungary

Theses of PhD dissertation

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2018

1. Introduction

Air pollution, as a major and permanently rising hazard to the environment, is associated with a large increase in medical expenses and morbidity, and it 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 (D'Amato, 2002; Asher, 2006; Lundback, 1998; ECRHS, 1996; ARIA, 2008). Furthermore, an examination of historical records indicates that the prevalence of allergic rhinitis (AR) and allergic asthma have significantly increased over the past two centuries. Although the reasons for this increase are not fully elucidated, epidemiologic data suggest that certain pollutants produced from the burning of fossil fuels may have played an important role in the prevalence changes (Peterson and Saxon, 1996; Saxon and Diaz-Sanchez, 2005). This increase may be partly explained by changes in environmental factors. Urbanization, the ever increasing automobile traffic with its high levels of vehicle emissions (diesel exhaust is able to enhance IgE production, Peterson and Saxon, 1996; Krämer et al., 2000) 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 biological and chemical air pollutants. There are evidences on the effect of air pollution upon allergens, on their increasing exposure and/or biological allergenic activity to the latter, (Pénard-Morand et al., 2005; Bartra et al., 2007; Just et al., 2007). Habitats and levels of pollen are changing in Europe as a result of cultural factors, growing international travel and climate change (Vogl et al., 2008; Ariano et al., 2010; Cecchi et al., 2010; Kiss and Béres, 2006). Now there is considerable evidence to suggest that climate change will have, and has already had, impacts on aeroallergens. These include impacts on pollen amount, pollen allergenicity, pollen season, plant and pollen distribution, and other plant attributes (Beggs, 2004; Williams, 2005; D'Amato et al., 2007; Reid and Gamble, 2009; Kaminski and Glod, 2011). Hence, due to the continually increasing air pollution, respiratory diseases are of major concern worldwide.

The air pollution of 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; Barrett et al., 2008). Furthermore, airborne pollen levels are also high. The Carpathian Basin, where Hungary is located, is considered to be the most polluted region with airborne ragweed *(Ambrosia)* pollen in Europe. *Ambrosia* discharges the most pollen of all taxa in Hungary; the ratio of its pollen release compared to the total pollen release in the late summer period exceeds 40% (Fig. 1) (Juhász and Juhász, 1997). The highest counts on peak days in Szeged, Southern Hungary, are about one order of magnitude higher than those in other cities of Europe (Makra et al., 2005). The ratio (or percentage) of ragweed-sensitive patients is 83.7% in Szeged (Kadocsa and Juhász, 2000).

The seasonal drug cost of a ragweed-pollen-sensitive patient with hay fever in Hungary is around 100 EUR (Harsányi, 2009). For patients suffering from asthma, a 50% increase in treatment days involves an increase of 230% in the value of drugs spent for treatment (Harsányi, 2009).

According to conservative estimates, patients suffering from pollen allergy in Hungary spend a total of about 90 million EUR for allergy or asthma drugs (Mányoki et al., 2011). At the same time, drug costs represent only a portion of the direct costs incurring in health care. Furthermore, ambulatory and hospital treatment costs for patients suffering from pollen allergy amount to an additional 53-67 million EUR annually (Basky, 2009). Hence, the total amount is 143-157 million EUR annually (Fig. 3).

2. Objectives

The statistical analysis of ragweed pollen concentration and the study of its meteorological associations have great practical importance. They may effectively help in preparing for the periods of severe pollen loads and facilitating their health consequences. According to the above, the objectives of the dissertation are as follows.

a) To analyze the potential reasons of the day-to-day variations of *Ambrosia* pollen counts for the region of Szeged in Southern Hungary in association with meteorological elements. For this purpose, a factor analysis with special transformation is performed on the daily meteorological and *Ambrosia* pollen data in order to find out the strength and the sign of the associations between meteorological (explanatory) variables and the *Ambrosia* pollen (resultant) variable.

b) To study the relationship between pollen characteristics of *Ambrosia* and meteorological variables, furthermore, between the rank of the ordered *Ambrosia* pollen characteristics and the rank of the ordered annual values of meteorological variables for Szeged in Southern Hungary.

c) To analyze how previous-day values of meteorological elements relate to actual-day values of extreme *Ambrosia* pollen load.

d) To separate the weight of the current and past climate conditions in determining the pollen concentrations of *Ambrosia* for the region of Szeged in Southern Hungary applying two procedures, namely multiple correlation and factor analysis with special transformation.

e) Based on different statistical procedures i) to develop accurate forecasting models for operational use, ii) to evaluate Computational Intelligence (CI) methods that have not been previously applied for *Ambrosia* pollen, such as Multi-Layer Perceptron and regression trees and iii) to obtain a forecast of highest accuracy among CI methods based on input data of former prediction algorithms.

3. Database

Data sets concerning the given analyses in the dissertation cover different periods. Its reasons are as follows: (1) shorter data sets available in former studies; (2) incomplete data sets of certain taxa; (3) when performing some tasks, shorter data sets proved to be sufficient.

The database of the meteorological elements used involves daily values of 8 meteorological variables [mean temperature (T_{mean}); minimum temperature (T_{min}); maximum temperature (T_{max}); temperature range, as the difference of maximum and minimum temperatures, $\Delta T(=T_{max}-T_{min})$; irradiance (I) or total radiation (TR); relative humidity (RH); wind speed (V or WS) and rainfall (R)] for different periods (daily values for each day of the year or the term July 15-October 15, regarding the periods 1997-2006; 1997-2010 or 1999-2007).

The pollen database involves the daily mean pollen concentration of *Ambrosia* (pollen grain/m^3 of air) for different periods (term July 15-October 15, regarding the periods 1997-2006; 1997-2010 or 1999-2007).

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 at least 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. The longest observed pollen season during the ten-year period was considered here for each year, even if the remaining years involve substantially different pollen seasons with either remarkably later start or notably earlier end of the pollen release (Makra et al., 2010; Matyasovszky et al., 2012; Makra et al., 2014a).

4. Methods

t-test (Section 7): The Student *t*-test (Zimmerman, 1997) was used to decide whether pollen-category-related means of each meteorological variable (*Ambrosia* pollen load as well as the total pollen load excluding *Ambrosia* pollen) differ significantly under each quantile for *Ambrosia* pollen. *Nearest neighbour (NN) technique (Section 7):* An NN technique was developed and applied in order to decide which of the two categories of the next-day pollen load occurs under actual values of the 5 meteorological variables. A nearest neighbour of the actual daily meteorological variables is identified with the day where the explaining variables are the most similar to the actual explaining variables. Then the decision on the pollen load category for this case is the category being present on the selected day. *Regression (Section 8):* Linear regressions are used as follows. The explaining variables are divided into two parts, and the daily pollen concentrations are regressed separately against these two groups of meteorological variables for every day of the pollen season. *Factor analysis (Sections 5, 7, 8):* In order to reduce the dimension of the initial data set, and to explain the associations of the variables examined, the multivariate statistical method of factor analysis is applied. *Factor analysis with special transformation (Sections 5, 7, 8):* After having performed factor analysis, all weights of the retained factors, both on the place of the explaining variables and the place of the target variable, are transformed into one factor in order to determine to what extent the explanatory variables influence the target variable, furthermore, to give the rank of importance of their influence. *Computational Intelligence (CI) (Section 9):* The following CI methods are evaluated in the dissertation: *Multi-layer perceptron (MLP)* (Haykin, 1999) models are artificial neural network models capable of modelling complex and highly non-linear processes. Two types of neural networks are applied: a complex (MLP with more than one hidden layer) and a less complex (MLPRegressor with only one hidden layer) version. MLP can model complex and highly non-linear processes through the topology of the network. Multi-Layer Perceptron comprises an input and an output layer with one or more hidden layers of non-linear-activation functions. For predicting both the daily pollen concentrations and the daily alarm levels of ragweed, several tree algorithms (M5P, REPTree, DecisionStump and

J48) are used. These algorithms have not been used for the above tasks in scientific literature yet. The models have been developed in Matlab environment with WEKA implementation of the above algorithms as described in Hall et al. (2009). *MLPRegressor and MLPClassifier:* Both classes are built-in WEKA modelling softwares (Hall et al., 2009). These algorithms are special parts of Multi-Layer Perceptrons. They always have only one hidden layer where the number of neurons is user-specific. Both use optimization by minimizing the squared error plus a quadratic penalty with the BFGS method. Both MLPRegressor and MLPClassifier are applied for predicting the daily pollen concentrations and daily alarm thresholds of ragweed, respectively. *Tree-based algorithms: M5P:* This procedure is a reproduction of Quinlan's M5 algorithm (Quinlan, 1992) being a combination of decision trees and multivariate regression models. Contrary to other regression trees, the leaves of the M5P tree structure consist of MLR models. As a result, it is possible to model local linearity within the data, similarly to piecewise linear functions. This is the first occasion for applying M5P to model daily ragweed pollen data. *DecisionStump:* This model builds a decision tree with a single split point. It makes (1) regression based on mean-squared errors, or (2) classification based on entropy, depending on the data type to be forecasted. *REPTree:* this model is a fast decision tree learner. It builds a decision tree using information gain or makes a regression tree from the variance. It applies pruning with backfitting to reduce error. *J48:* this model is an implementation of C4.5 algorithm in the WEKA data mining pool. C4.5 builds decision trees from a set of training data in the same way as ID3 uses the concept of information entropy. J48 classifier achieves fast execution times and adequate scales of large datasets (Quinlan, 1993).

5. Results and Conclusions

The statistical analysis of the associations of phenological and quantitative characteristics of different taxa combined with meteorological elements is a relatively new area of science, since observations with pollen traps only started in Europe in the 1960s, and the first papers in the field were published about 3 decades later (Declavijo et al., 1988; Emberlin and Norrishill, 1991; Peeters et al., 1994). In Hungary, this area of science is completely new; no one has dealt with pollen climatology so far.

The topic of weather-related ragweed pollen levels has great literature due to its high practical importance. Results of this kind of research may effectively help sensitive individuals in preparing for the periods of severe pollen loads, and for facilitating their health consequences.

The results of the dissertation are obtained by using different statistical procedures. Among them, factor analysis with special transformation has not been applied for studying this kind of relationships yet. In addition, this procedure has never been used for studying meteorological processes before in the special literature. This method has only been applied in economics so far. Furthermore, for predicting future daily ragweed pollen concentrations, the methods of Computational Intelligence are used in the dissertation. For predicting both the daily pollen concentrations and the daily alarm levels of ragweed, several tree algorithms (M5P, REPTree, DecisionStump and J48) are used here. These algorithms have not been applied for the above mentioned tasks in the special literature yet. These models have been developed in Matlab environment with WEKA implementation of the above algorithms, described in Hall et al. (2009).

The major findings of the dissertation are as follows.

1) When analyzing the potential reasons of the day-to-day variations of *Ambrosia* pollen counts for Szeged region in Southern Hungary in association with meteorological elements, daily differences in meteorological variables (value on the given day – value on the day before) were assigned to the daily ratios of *Ambrosia* pollen counts (A) (value on the given day per value on the day before) for each day of the analysis. Three data sets were subjected to analysis: (1) the total data set, (2) those daily differences in meteorological variables for which $A \leq 1$, and (3) those for which $A > 1$, respectively. For all three data sets, the days examined were classified into four categories, which are as follows: (a) a rainy day preceded by a rainy day; (b) a rainy day preceded by a non-rainy day; (c) a non-rainy day preceded by a rainy day; (d) a non-rainy day preceded by a non-rainy day.

A unique procedure, namely factor analysis with special transformation was performed on the daily meteorological and *Ambrosia* pollen data in order to find out the strength and sign of associations between meteorological (explanatory) variables and *Ambrosia* pollen (resultant) variable.

When using factor analysis with special transformation, for all four categories examined in the three data sets, wind speed (V), rainfall (R), and temperature range (ΔT) were the most important parameters with 5 (for the total data set), 8 (for those daily differences in meteorological variables for which A ≤ 1) and 4 (for those for which A > 1) significant associations with daily ratios of *Ambrosia* pollen counts, respectively. At the same time, minimum temperature (T_{min}) and irradiance (I) were the least important meteorological variables influencing the resultant variable. After dividing the total data set into two groups, a tendency of stronger associations between the meteorological variables and the pollen variable was found in the data set for which A ≤ 1.00, compared to the one for which A > 1. This is due to the difference in the behaviour of the plant to endure environmental stress. Namely, the data set for which A ≤ 1.00 can be associated with lower summer temperatures with near-optimum phyto-physiological processes, while the category of A > 1.00 is involved with high and extreme high temperatures modifying life functions, and, hence, interrelationships of the meteorological and pollen variables (Csépe et al., 2012a; Matyasovszky et al., 2012; Makra et al., 2014c).

2) When analyzing the relationship between Ambrosia pollen characteristics and meteorological variables, furthermore, between the rank of ordered Ambrosia pollen characteristics and the rank of ordered annual values of meteorological variables for Szeged in Southern Hungary, the following results were obtained.

Ambrosia pollen is sensitive to either temperature or precipitation. Furthermore, it is reversely related to temperature (negative correlations). On the whole, due to a warming and drying climate, pollen count characteristics (total annual pollen amount and annual peak pollen concentration) indicate a decrease for Ambrosia.

Based on the daily pollen counts of *Ambrosia* depending on both extreme temperatures and extreme precipitations, we established that the coldest and the wettest years highly facilitate pollen production.

Increasing temperature may benefit spatial distribution and abundance, while it interferes pollen release in the lack of rainfall. Although overall trends of *Ambrosia* pollen counts can be explained partly by landscape-use changes, seasonal changes reflect weather conditions, which can enhance or suppress (hide, blunt) the overall trends. The genetic background of *Ambrosia* gives a special response to the changing weather conditions that can determine their potential distribution influenced by landscape use (Csépe et al., 2012b; Makra et al., 2012b).

3) In order to determine how previous-day values of meteorological elements relate to actual-day values of extreme *Ambrosia* pollen load, we performed factor analysis with special transformation and found that four meteorological variables (mean temperature, mean global solar flux, mean relative humidity, and mean sea-level pressure) except for mean wind speed display significant associations with *Ambrosia* pollen load. Temperature and global solar flux indicate positive proportional associations, while air pressure and relative humidity inversely proportional associations with *Ambrosia* pollen loads. The explaining variables in decreasing order of their substantial influence on *Ambrosia* pollen load are temperature, air pressure, global solar flux, and relative humidity.

Factor analysis gave a first insight into the relationship between pollen load variables and meteorological variables, and the *t*-test showed the possibility of distinguishing between extreme and non-extreme pollen events using meteorological elements as explaining variables. Using selected low and high quantiles corresponding to the probability distributions of *Ambrosia* pollen, the quantile and beyond-quantile averages of pollen loads were compared and evaluated. As a result, the number of events exceeding the quantile of 90% and those not exceeding the quantile of 10% are strongly underestimated. However, the procedure works well for quantiles of 20% and 80%, and even better for those of 30% and 70%.

A nearest neighbour (NN) technique was applied to discriminate between extreme and non-extreme pollen events using meteorological elements as explaining variables. It was found that the explaining variables, in decreasing order of their influence on *Ambrosia* pollen load, are temperature, global solar flux, relative humidity, air pressure, and wind speed. Furthermore, the relative frequency of good decisions for exceeding/not exceeding the different quantiles shows that the five meteorological elements as explaining variables are informative to discriminate between extreme and non-extreme pollen events. Note that the larger the percentages in above-above or below-

below rows-columns in Tables 9 and 10 are, the better the estimation is delivered by the NN technique (Csépe et al., 2012c).

4) Although several studies have been published to explore the relationship between meteorological conditions and pollen loads as well as past weather conditions and certain phenological phases of different taxa, neither of them aimed at distinguishing between the effect of current and past weather on current pollen concentrations. In this section, we separated the weight of the current and past climate conditions in determining the pollen concentrations of *Ambrosia* for Szeged region in Southern Hungary by applying two procedures, namely multiple correlation and factor analysis with special transformation.

Using the two methods, results revealed characteristic similarities. For *Ambrosia*, the continental rainfall peak and additional local showers in the growing season can strengthen the weight of the current meteorological elements. However, due to the precipitation, big amount of water can be stored in the soil contributing to the effect of the past climate elements during dry periods. The high climate sensitivity (especially water sensitivity) of *Ambrosia* as a herbaceous taxon can be definitely established.

We found that extreme differences in the effects of the current and past weather elements, featured by different shades of grey, indicate pronounced coincidences. This assumes that there are real associations between phyto-physiological processes on the one hand, and the current and past meteorological elements for given parts of the year and given accumulation lengths of days, on the other.

The separation of the weight of the current and past climate conditions for different taxa presented in the study involves practical importance not only for pollen-sensitive people but also for agricultural production. Namely, the knowledge of taxon specific effects of the time-based past weather may help to predict future pollen levels well ahead in time; furthermore, it may contribute to reduce the weather dependence of agricultural production (Matyasovszky et al., 2014a; 2014b).

5) We performed predictions in order to assess ragweed pollen concentrations several days ahead. For this aim, we used factor analysis with special transformation, a novel tech-

nique for detecting the importance of the influencing variables in defining the pollen levels for 1-7 days ahead. In addition, further procedures were applied, such as (1) data-driven modeling methods including neural networks that have never been used in forecasting daily *Ambrosia* pollen concentration, (2) daily alarm thresholds are first time predicted in the aerobiological literature; furthermore, (3) algorithm J48 has never been used in palynological forecasts.

We applied Computational Intelligence procedures in order to predict the daily values of *Ambrosia* pollen concentrations and alarm levels for Szeged (Hungary) and Lyon (France). Contrary to the difficulties in the availability of daily pollen levels (they are available only once a week), the forecasts of daily ragweed pollen concentrations and alarm levels were successful for 1-7 days ahead for both cities. The importance of the influencing variables (the serial number of the day in the year, meteorological and pollen variables) in forming the resultant variable (pollen levels or alarm levels for 1-7 days ahead) was analysed. The weights of *Ambrosia* pollen level emerge extraordinarily from all variables indicating its high significance in determining pollen levels (alarm levels) for 1-7 days ahead for both cities. The weights of the rest of the influencing variables are different for the two cities. For instance, the most important variables are temperature-related ones for Szeged, while relative humidity and wind speed have the most important roles in forming pollen concentrations in Lyon.

For Szeged, Multi-Layer Perceptron models provide results similar to tree-based models for predicting pollen concentration 1 and 2 days ahead, while they deliver better results for more than two days ahead than tree-based models. For Lyon, only Multi-Layer Perceptron gives acceptable result for predicting pollen levels 1 and 2 days ahead. Concerning the alarm levels, the efficiency of the procedures differs substantially.

When fitting the models to the days of the highest pollen levels, the more complex CI methods proved better for both cities. MLP and M5P methods provided the best results for Szeged and Lyon, respectively. We showed that the selection of the optimal method depends on climate as a function of geographical location and relief.

The results can be utilized for the national pollen information services. The total medical costs of ragweed pollen can be substantially reduced if sensitive people can be prepared for serious ragweed pollen episodes in time. Decision-makers are responsible for introducing regulations and actions in order to facilitate the problem caused by ragweed pollen. Furthermore, it is the responsibility of aero-biologists to develop personalized information services in order to improve the overall quality of life of sensitive people. Note, however, that due to the restrictions of the sampling procedure used (daily pollen counts are available only after a 7-day period), the applicability of the methods presented is limited in terms of operational use. Accordingly, the methodology introduced here can only be used as supportive means to the original forecasting methods (models) for the time-being. This problem can only be solved if low-cost, automatic pollen samplers based on a totally new principle will be introduced by "in situ" recognizing of pollen types and measuring pollen counts.

The methods applied here are sensitive to the number of the influencing parameters. A further aim is to use much more influencing parameters (including further meteorological parameters, and, in addition, chemical air pollutants, land use, relief, etc.) in order to develop a general model for different locations (Csépe et al., 2014a; 2014b).

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Csépe Zoltán's Scientometric data based on the publication data base MTMT				
MTA X. Department of Earth Sciences (2018.03.02.)				
Type of publications	**Number**		**Reference**	
	Total	Details	Independent	Total
I. Scientific publications	27	---	---	---
Full article in international journal	---	15	79	88
Full article in a domestic foreign language journal	---	10	6	6
Full article, on Hungarian language in Hungarian journal	---	2	0	0
II. Book	0	---	---	---
a) Book (monography, professional book, encyclopedia or handbook)	0	---	---	---
Reference book, manual, in foreign language	---	0	0	0
Reference book, manual, in Hungarian language	---	0	0	0
Higher education book	---	0	0	0
b) Book parts or chapters	0	---	---	---
Edited book, in foreign language	---	0	---	---
Edited book, in Hungarian language	---	0	---	---
Higher education book	---	0	---	---
III. Book chapter, specialist study	5	---	---	---
Book chapter, in foreign language	---	4	0	0
Book chapter, in Hungarian language	---	1	0	0
Chapters written in course book	---	0	0	0
IV. Journal papers	5	---	0	0
Foreign language	---	3	1	2
Hungarian language	---	2	0	0
V. Maps	0	---	0	0
Total scientific publications (I-V.)	37	**---**	86	96
VI. Other scientific	11	---	---	---
Other scientific works, including the non-complete articles and the articles in unknown peer-reviewed journal	---	11	2	2
Editorial correspondence, comments, answers	---	0	0	0
Citation	---	---	88	98
Hirsch index[1]	5	---	---	---

Special Scientometric data	Number			
The number of full scientific publications by the first author	6			
Number of scientific journals published in WOS and / or Scopus	16			
Citation in WOS and / or Scopus referenced journal	53			