

ALLERGENIC WEED POLLEN FORECAST UNDER THE MATHEMATICAL MODELING METHOD IMPLEMENTATION IN UKRAINE

Maj 14, 2018 | [2018 / 03](#) |

WDRAŻANIE PROGNOZY PYLENIA CHWASTÓW NA PODSTAWIE METODY MODELOWANIA MATEMATYCZNEGO NA UKRAINIE

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ABSTRACT

Introduction: Allergies are the most common reason of the chronic diseases in developed countries and represent an important medical, social and economic issue, the relevance of which is growing both in these countries and in Ukraine. The most famous of these allergens group is the pollen of ambrosia and pollen of poaceae, which are ubiquitously distributed in the subtropical and temperate climate.

The aim: The objective of our study was to develop the mathematical models, which will be able to indicate the probability of the pollen circulation, and thus these models can simplify the forecast of symptoms risk and improve the prophylaxis of pollinosis.

Materials and methods: The research was conducted on the basis of the research center of National Pirogov Memorial Medical University, Vinnytsia in the years 2012-2014.

A volumetric sampler of the Hirst type was used for the air sampling. The observation was conducted from the first of April to the thirty-first of October.

For the initial preparation of the tables and intermediate calculations, Excel software package was used. The software STATISTICA 10.0 was applied to calculate the average coefficients values and their statistical characteristics (beta-values, errors of the mean values, Student's t-test, veracity and the factors percentage contribution into the function variation).

Results: Statistically significant correlation between pollen concentrations of herbaceous plants and individual meteorological factors was found; classificational functions were designed by which it is possible to calculate the probability of presence or absence of *Artemisia* pollen in the atmosphere; the risks of increasing of the *Artemisia* pollen concentration are determined under exceeding of the critical temperature of 18°C, relative humidity of 67% and atmospheric pressure of 980 Pa.

Conclusions. The results of the research can be used to predict the emission of potentially hazardous concentrations of weed pollen grains in the atmosphere of the central region of Ukraine using the weather forecast.

Wiad Lek 2018, 71, 3 cz. I

Introduction

Allergies are the most common reason of the chronic diseases in developed countries and represent an important medical, social and economic issue, the relevance of which is growing both in these countries and in Ukraine, where there is a steady tendency according to the constant allergic pathology increasing and the population high allergy reaction [1, 2]. An important reason of the seasonal occurrence of allergies in many world's countries is the pollen of herbaceous plants [3, 4]. The most famous of these allergens group is the pollen of ambrosia [5, 6] and pollen of poaceae, which are ubiquitously distributed in the subtropical and temperate climate [7, 8, 9]. Even though the incidence of hay fever varies in different regions of the world [10, 11], weed pollen is one of the most important reasons of seasonal allergy emergence in Europe [8, 12]. Particularly, in addition to pollen of ambrosia and poaceae, the pollen of *artemisia*, which may have cross-reactivity with ambrosia pollen [13], is the important factor of the population sensitization [14, 15]. In previous research, which was carried out in Ukraine, it was determined that the main factor of sensitization in the southern and south-eastern regions of our country is the pollen of herbaceous plants, ambrosia and *artemisia* mostly [16], whereas in the central, western, northern, and also in the northeastern regions – there is a mixed population sensitivity to the pollen of both trees and herbaceous plants [17]. Therefore, the herbaceous plants' pollen as the pollinosis agent plays a significant role for the Ukrainian population of all regions. Obviously, period of weed and poaceae pollination has the particular

importance in our country while it might be characterized by numerous outbreaks of allergic symptoms within the sensitive individuals. In addition, herbs, unlike tree flora, are characterized by a longer pollination period [18, 19], which causes their special practical significance as the seasonal allergy factor. A traditional method for the aerobiological data analysis, which proved its accuracy and efficiency during the last several decades of utility, is the regression analysis, which is used to simulate changes in the pollen concentration of plants, implemented in the modern systems of air content modelling [20, 21]. However, a disadvantage of the models, which are designed to show changes in pollen concentration on the certain location, is that the forecast is implemented simultaneously for the large area and does not show always accurately the regional features of the pollen circulation in the atmosphere. Moreover, in order to simplify the forecasting of pollen grains concentration in the air, it is important to figure out specific values of meteorological factors, when the intense pollen emission into the atmosphere may be observed during the main pollination period. The discriminant analysis can be used for this purpose as well [22].

The Aim

Therefore, the objective of our study was to develop the mathematical models, which will be able to indicate the probability of the pollen circulation, and thus these models can simplify the forecast of symptoms risk and improve the prophylaxis of pollinosis.

Materials and Methods

The research was conducted on the basis of the research center of National Pirogov Memorial Medical University, Vinnytsia in the years 2012-2014.

A volumetric sampler of the Hirst type was used for the air sampling [22, 23]. The device was installed on the roof of National Pirogov Memorial Medical University at the chemical department building, at a relative altitude of 25 m. The observation was conducted from the first of April to the thirty-first of October. The microscope slides reading was carried out by the twelve vertical transects [24, 25]. According to the hourly data of Vinnytsia regional hydro-meteorological center, from the first of May to the thirty-first of October during 2012, 2013, 2014 years, seven meteorological factors were statistically processed: wind direction (WD), wind speed (WS), average daily air temperature (T), dew point (DP), relative humidity (RH), humidity deficiency (HD), atmospheric pressure (P).

For the initial preparation of the tables and intermediate calculations, Excel software package was used. The main part of the mathematical processing was performed using the standard statistical software package STATISTICA 10.0 portable. The software STATISTICA 10.0 was applied to calculate the average coefficients values and their statistical characteristics (beta-values, errors of the mean values, Student's t-test, veracity and the factors percentage contribution into the function variation). Discriminant analysis was used to find out the classification functions between meteorological parameters and pollen concentrations of certain species.

Results and discussion

The majority of the revealed regularities were unidirectional, which were repeated year in, year out and conjugated correlation analysis was applied for estimating the relation between the pollen grain concentration and the substantial meteorological factors. The results of the correlation analysis during all three years of the research are represented in the table I. The results of the conducted research analysis during the 2012-2014 years (table I) revealed a direct correlation between the herbaceous flora's pollen distribution and the air temperature. There was not detected any correlation between the atmospheric pressure and pollen circulation of ambrosia, artemisia and poaceae. There was revealed the inverse correlation between the air relative humidity and the pollination of artemisia and poaceae. According to the literature sources, the cyclone is led by the low atmospheric pressure, wet weather with precipitation in summer. A less significant meteorological factor was the wind direction. Consequently, using a correlation analysis, it was indicated that the air temperature and the relative humidity are the main meteorological factors, which affect the pollen grain concentration and circulation. The less significant meteorological factors are: the atmospheric pressure, wind direction and wind speed, the humidity deficiency and the dew point. According to the correlation analysis results, the mathematical models were established, which represent the dependence of the pollen circulation on the meteorological factors. In this case, simple and linear multifactor regression functions were used as the mathematical models:

$$y = a_1x_1 + a_2x_2 + \dots + a_nx_n,$$

where y – pollen concentration, $x_1, x_2, \dots, x_n$ – meteorological factors, $a_1, a_2, \dots, a_n$ – models' parameters.

The model parameters values of the artemisia's pollen grain are represented in the table II. Note here and further: β – the standardized regression coefficient; $S\beta$ – a standard error of the standardized regression coefficient; a – the regression coefficient; Sa – a standard error of the a -coefficient; t_a – Student's t-test; p_a – a significance; a_0 – a free coefficient.

Thus, the model of the pollen concentration variation in the 2012-2014 years had the following formula:

$$\text{Carte} = 0,083 \times \text{Wind speed} + 0,13 \times \text{Air temperature} + 0,017 \times \text{Relative humidity} - 0,002 \times \text{Atmospheric pressure}$$

This model was adequate: $F = 285,5$; $p < 0,001$.

According to the regression analysis results during 2012-2014 years, it was established (table II) that the percentage of temperature contribution to the pollen circulation of artemisia is 66.350%, this is three times higher than the contribution of the atmospheric pressure and five times higher than the relative humidity contribution and 66 times than the air speed contribution. This is completely rational, as far as the plants pollination is directly dependent on the air temperature, relative humidity and atmospheric pressure. The model parameters values for the pollen grain of ambrosia are presented in the table. III. The model of ambrosia's pollen variation during 2012 year looked the following way:

$$\text{Cambr} = 0,06 \times \text{Air temperature} - 0,022 \times \text{Relative humidity} + 0,003 \times \text{Atmospheric pressure},$$

This model was adequate: $F = 47,203$; $p < 0,001$.

It is obvious from the table IV, that the atmospheric pressure has a significant positive effect on the pollen grain circulation of ambrosia, as the percentage contribution is 75.850%. The relative humidity (14,930%) and air temperature (9,220%) do not have a significant influence on the pollen products of ambrosia. In addition, it is indicated that the pollen concentration of ambrosia increases with the temperature increasing. The results of regression analysis of the pollen grain circulation of ambrosia during 2013, 2014 years and during 2012–2014 years are not statistically significant. The values of the model parameters of the pollen grain of poaceae are shown in the table IV. The model of the poaceae's pollen variation during 2012–2014 years looked the following way:

$$\text{Cpoac} = -0,054 \times \text{Wind speed} - 0,01 \times \text{Relative humidity} + 0,003 \times \text{Atmospheric pressure},$$

This model was adequate: $F = 393,26$; $p < 0,001$.

The most important factor of the study, which influenced the distribution of poaceae during 2012-2014 years (table IV), was the pressure, the contribution rate of which is 93.57%. In addition, it is evident that poaceae's pollen concentration decreases with the wind speed and relative humidity increasing. It is observed an increase of the pollen grain circulation with the simultaneous increasing of the atmospheric pressure. Thus, the main meteorological factors that influenced the pollen concentration of artemisia in 2012-2014 years are the air temperature, less significant is the atmospheric pressure and relative humidity; on the concentration of poaceae's pollen in 2012-2014 years is the pressure, and on the concentration of ambrosia's pollen grain in 2012 year is the pressure.

To determine the critical values of individual meteorological parameters, with deviations from which the increase in the pollen grain concentrations of ambrosia and artemisia and poaceae in the atmospheric air is expected, two samples were generated from the general data array: one sample is with appropriate pollen

grain concentration variants, which is lower than average for pollination season, in the other – with the pollen grain concentration that is higher than average. For the meteorological critical value factor was applied the average value, between the mean arithmetic values, in the comparable samples, within the presence of statistically significant differences between them. It has been established, that the increase of artemisia's pollen grain concentrations in air is expected in correspondence with the excess of the following critical values of meteorological factors: the air temperature (17,74°C), the dew point (10,62°C), the humidity deficiency (13,49 Mbar), the atmospheric pressure (980,75 hPa), and at a decrease below the critical values of relative humidity (66,955%), the wind direction (168,03°) and the wind speed (3,315 m/sec).

If we take into the consideration the pollen of ambrosia, then the pollen grain concentration increasing in the air is expected under the exceeding of such values of meteorological factors as: the wind direction (174,785°), the wind speed (3,385 m/sec), the atmospheric pressure (980,915 hPa), and within the decreasing, lower than the limit values of the dew point (9,95°C), the relative humidity (67,14%), the humidity deficiency (12,9 Mbar). Poaceae's pollen concentration increasing is expected, if the wind direction is $> 173,1^\circ$, the air temperature is $> 17,425^\circ\text{C}$, the dew point is $> 10,56^\circ\text{C}$, the humidity deficiency is $> 13,64$ Mbar, the relative humidity is $< 67,525\%$ and the atmospheric pressure is $< 980,235$ hPa. Consequently, it can be considered, that for herbaceous plants' pollen, the meteorological critical values factors, at which the expectations for a significant increase in the pollen grain concentration during the pollination season, are: the temperature, which is higher than 18°C, the pressure which is higher than 980 hPa, and the relative humidity which is less than 67%.

It was indicated, that the risk of artemisia's pollen circulation under the critical temperature increasing of 18 °C is equal to $RR = 1,19, 1,17-1,21; p<0,05$; the risk of artemisia's pollen concentration increasing, within the simultaneous decreasing of the air relative humidity less than 68 % is equal to $RR = 1,08, 1,06 - 1,10; p<0,05; p<0,05$. The low humidity causes the increase of artemisia's pollen concentration.

It has been established that the risk of artemisia's pollen concentration circulation increasing in correspondence with the exceeding of the critical pressure value of 981 hPa is equal to: $RR = 1,24, 1,21-1,27; p<0,05$. High pressure causes artemisia's pollen concentration increasing. It was statistically found out that: at the low humidity, there is a risk of the pollen grain of artemisia concentration increasing; the low temperature and pressure raises the risk of the pollen grain of artemisia concentration increasing. During the final stage of the data processing, the discriminant analysis was performed, according to which, the classificational functions were applied, which allowed to calculate the probability of the presence or absence of the herbaceous plants' pollen in the atmospheric air in Vinnytsya, in the case of the multifactorial meteorological parameters variations. The classificational functions for the standardized variables are as follows:

– the classificational functions for artemisia's pollen absence (ARTE 0):

$ARTE0 = -10419,00 + 8,51 \text{ Air temperature} + 2,64 \times \text{Relative Humidity} + 20,92 \text{ Atmospheric Pressure};$

– for artemisia's pollen presence (ARTE 1):

$ARTE1 = -10442,20 + 8,61 \text{ Air temperature} + 2,65 \times \text{Relative Humidity} + 20,94 \times \text{Atmospheric Pressure};$

– the classificational functions for ambrosia's pollen absence (AMBR0):

$AMBR0 = -10411,10 + 8,35 \text{ Air temperature} + 2,62 \times \text{Relative Humidity} + 20,91 \times \text{Atmospheric Pressure};$

– for ambrosia's pollen presence (AMBR1):

$AMBR1 = -10431,8 + 8,38 \text{ Air temperature} + 2,62 \times \text{Relative Humidity} + 20,93 \times \text{Atmospheric Pressure};$

– the classificational functions for poaceae's pollen absence (POAC0):

$POAC0 = -10401,00 + 8,30 \text{ Air temperature} + 2,62 \times \text{Relative Humidity} + 20,89 \times \text{Atmospheric Pressure};$

– for poaceae's pollen presence (POAC1):

$POAC1 = -10400,80 + 8,37 \text{ Air temperature} + 2,62 \times \text{Relative Humidity} + 20,88 \times \text{Atmospheric Pressure}.$

The overall forecast reliability during the entire observation period is 89,36% for the pollen of artemisia, for pollen of ambrosia – 92,05%, for the pollen of poaceae – 86,52%.

Thus, according to the results of the monitoring conducted in 2012-2014 (table I), it was established valid correlation between the distribution of the herbaceous flora's pollen and the air temperature ($rARTE = 0,202$, $rAMBR = -0,062$, $rPOAC = 0,074$, $p < 0,05$).

The correlation was positive for artemisia and poaceae, which is corresponding with well known trends. The correlation was negative for ambrosia, which may be related to bad adaptation of ambrosia to warm and arid weather conditions [26, 27]. An inverse correlation was revealed between the air relative humidity and the pollination of the artemisia and poaceae ($rARTE = -0,093$, $rPOAC = -0,055$, $p < 0,05$). It relates to the fact that pollen grain change its physical properties, when the relative humidity increases, becoming heavier, which causes the loss of the pollen, encumbered with moisture, from the air aerosol [28]. The less significant meteorological factors were: the wind direction ($rAMBR = -0,06$), the dew point ($rARTE = 0,067$, $rAMBR = -0,108$, $p < 0,05$) and the humidity deficiency ($rARTE = 0,064$, $rAMBR = -0,1$, $p < 0,05$). Consequently, applying the correlation analysis, it was found that the main meteorological factors, which influence the pollen grain concentration and distribution, are the temperature and relative humidity. The atmospheric pressure, wind direction, humidity deficiency and dew point are less significant meteorological factors. It coincided with the results of other research [29, 30, 31]. According to the regression analysis during the 2012- 2014 years, it was established that the partial temperature

contribution to the artemisia's pollen distribution is 66.35% (table. II). This is three times more than the contribution of the atmospheric pressure, five times – than the contribution of the air relative humidity and 66 times more than the contribution of wind speed. This is logically, as far as the pollination of plants has a direct dependence on the air temperature, the relative humidity and the atmospheric pressure [26, 27]. The most important factor, which influenced the distribution of poaceae in the 2012-2014 years, was the atmospheric pressure, the partial contribution of which, was 93.57% (table III). It seems to be connected with anticyclonic air circulation, which is characterized by the high atmospheric pressure, in Northern Hemisphere in summer [32, 33]. Another important parameter was air temperature, which is noted as important for poaceae in other research [34, 35]. Concerning the influence of the meteorological factors on ambrosia's pollination, an adequate mathematical model was obtained only according to the results during the 2012 year, which differed from 2013 and 2014 with the highest average and maximum air temperature, the lowest average relative humidity, the highest average and maximum air velocity during the research period from the first of May to the thirty-first of October. The atmospheric pressure has a significant effect on the distribution of ambrosia's pollen grain, as far as the partial contribution of this parameter is 75.85%. The relative humidity (14.93%) and temperature (9.22%) less influenced the ambrosia's pollen production (table IV). Thus, the main meteorological factors, which influenced the pollen concentration of artemisia in 2012-2014, are temperature, less significant, the atmospheric pressure and relative humidity; on ambrosia and poaceae pollen concentration – the atmospheric pressure. In addition, poaceae's pollen concentration is decreasing, at the same time with the wind speed and relative humidity is increasing. It was observed that the pollen grain distribution increases with the atmospheric pressure increasing, which may be caused by the formation of favorable weather conditions for the distribution of pollen grain under the anticyclone conditions, for which the high temperatures, low humidity and high pressures are typical in summer.

By means of the discriminant analysis, the classificational functions were calculated, which allow us to calculate the probability of the presence or absence of the artemisia, ambrosia and poaceae pollen in the air, under the individual changeable meteorological parameters (for standardized values of Air temperature, Relative Humidity and Atmospheric Pressure). These parameters, except the air pressure, are well-known factors, influencing weed pollen concentration in the atmosphere [36, 37, 38]. It is notable, that the obtained data are important for the proper allergy risk forecast and the particular control of the herbaceous plants pollination season, which are the source of the pollinosis symptoms among the population.

Conclusions

1. In our study, it was revealed, the inverse correlation between the wind speed and dew point ($r = -0.043$), the relative air humidity ($r = -0.095$) and the humidity deficiency ($r = -0.018$); the direct correlation between the air temperature and the dew point ($r = 0.530$), the humidity deficiency ($r = 0.179$) and the atmospheric pressure ($r = 0.021$); correlation between the air temperature and the relative air humidity with a negative value output ($r = -0.548$); a direct correlation between the dew point and the relative air humidity ($r = 0.15$) and the humidity deficiency ($r = 0.25$); the correlation between the relative air humidity and the humidity deficiency with positive value output ($r = 0.046$).
2. According to the research results of the correlation analysis during 2012-2014, it was found out the infallible relation ($p < 0.05$) between pollination of the herbaceous plants, related to the meteorological factors such as: the air humidity with the temperature and atmospheric pressure. Under the influence of the changeable meteorological factors, the herbaceous plants significantly transformed the pollination density.
3. According to the regression analysis results, the weather forecast models were established, nonetheless, it was revealed the dependence of the pollen distribution of artemisia on temperature, relative air humidity and pressure.
4. It was demonstrated that the distribution of ambrosia's pollen grains ($p < 0.05$) is affected by the atmospheric pressure, relative humidity and temperature.
5. The pressure and relative humidity were the most significant research factors, which caused the circulatory of poaceae in 2012-2014 years.
6. It was defined, that if the critical temperature exceeds the value of 18°C , the risk of increasing of artemisia's pollen concentration will be equal to: $\text{RR} = 1.19, 1.17-1.21, p < 0.05$. It was established, that if the critical air relative humidity decreases to the value of 67% , the risk of increasing of artemisia's pollen concentration will be equal to: $\text{RR} = 1.08, 1.06-1.10, p < 0.05$. It was found out, that when the critical pressure exceeds the value of 980 Pa, the risk of the distribution of artemisia's pollen concentration will be equal to: $\text{RR} = 1.24, 1.21-1.27; p < 0.05$.
7. According to the discriminant analysis proceeding, classificational functions were achieved, which can be used to calculate the probability of the presence or absence of artemisia's pollen in the atmospheric air.

The reliability of the probability calculation for these functions is highly tried and tested (from 86.52% for poaceae's pollen up to 92.05% for ambrosia's pollen grain).

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The article is a fragment of the scientific work “Aerobiological monitoring as the basis for the development of allergologic prognosis for the prevention of seasonal allergies among the population” (state registration number 0112U003477). The topic is performed at the department of Pharmacy as well as the department of Pharmaceutical Chemistry, General Hygiene and Ecology department of Vinnytsya National Pirogov Memorial Medical University.

Explanation to the text of the article: Note here and further: AMBR – Ambrosia; ARTE – Artemisia; POAC – Poaceae.

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Received: 10.03.2018

Accepted: 16.05.2018

Table I. The Relation between the Herbaceous Plants Pollination and the Meteorological Factors during the years 2012–2014

Meteorological factors	Statistical characteristics	Pollen's name		
		Artemisia (ARTE)	Ambrosia (AMBR)	Poaceae (POAC)
Wind direction	r	-0,029	-0,060	-0,017

	p	0,251	0,047	0,463
	r	0,010	0,004	-0,018
Wind speed	p	0,674	0,895	0,451
	r	0,202	-0,062	0,074
Air temperature	p	<0,001	0,041	0,002
	r	0,067	-0,108	0,015
Dew point	p	0,007	<0,001	0,541
	r	-0,093	-0,009	-0,055
Relative humidity	p	<0,001	0,763	0,020
	r	0,064	-0,100	0,006
Humidity deficiency	p	0,010	0,001	0,789

	r	0,007	-0,008	-0,012
Atmospheric pressure	p	0,790	0,790	0,611

Table II. The Regression Analysis Results of the Pollen Circulation of Artemisia during the years 2012–2014

The coefficients of the regression equation and their statistical characteristics							
Names of the variables	b	S β	a	Sa	ta	pa	Contribution (%)
Wind speed	0,088	0,041	0,083	0,039	2,161	0,031	1,010
Air temperature	0,713	0,100	0,130	0,018	7,145	<0,001	66,350
Relative humidity	0,304	0,093	0,017	0,005	3,261	0,001	12,070
Atmospheric pressure	-0,397	0,178	-0,002	0,001	-2,233	0,026	20,570

Table III. The Regression Analysis Results of the Pollen Circulation of Ambrosia during the year 2012

The coefficients of the regression equation and their statistical characteristics							
Names of the variables	b	S β	a	Sa	ta	pa	Contribution (%)

Air temperature	0,198	0,189	0,06	0,057	1,051	0,294	9,220
Relative humidity	-0,252	0,191	-0,022	0,016	-1,322	0,187	14,930
Atmospheric pressure	0,568	0,33	0,003	0,002	1,719	0,086	75,850

Table IV. The Regression Analysis Results of the Pollen Circulation of Poaceae during the years 2012–2014

The coefficients of the regression equation and their statistical characteristics							
Names of the variables	b	S β	A	Sa	ta	pa	Contribution (%)
Wind speed	-0,074	0,035	-0,054	0,026	-2,090	0,037	0,620
Relative humidity	-0,226	0,065	-0,010	0,003	-3,482	0,001	5,810
Atmospheric pressure	0,907	0,076	0,003	0	11,974	<0,001	93,570