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Mathematical Model for Forecasting the Influence of Atmospheric Pollution on Population Morbidity in Stara Zagora Municipality (Bulgaria)

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Abstract

AIM: This paper aims to create a mathematical model for forecasting the morbidity of the population in the Republic of Bulgaria and the Stara Zagora Municipality in particular as a consequence of the atmospheric pollution.

SUBJECTS AND METHODS: This model is based on a formula which determines the correlation between the average annual concentrations of atmospheric pollutants SO_2, PM_{10}, Pb aerosols, NO_2 and H_2S) and the morbidity of the population based on the number of people who visited their GPs in a relation with a chronic health problem or emergency condition and the number of hospitalisations in two age groups (newborn to 17 years olds and 18 and older) as well as for the entire population in the period 2009-2013, making it possible to predict morbidity levels.

RESULTS: The expected morbidity level predictions based on the number of people who visited their GPs in Municipality are lower, while hospitalisation level predictions are higher. This model has been created and tested and is applicable in all residential areas.

CONCLUSIONS: A new, very sensitive, mathematical model has been created and tested (average margin of error from 0.61% to 2.59%) and is applicable in all residential areas.

Introduction

Stara Zagora Municipality is situated in the central part of South Bulgaria, in the Upper Thracian Plain, on the south hills of Sredna Sarnena Gora mountain (N 42° 25 ', E 25° 37'). It covers an area of 1019.1 square km and is located at 240 m above sea level. It comprises 52 towns and villages with a total of 156,662 residents, 137,834 of whom live in the city of Stara Zagora. Stara Zagora Municipality is amongst the most industrially developed municipalities in Bulgaria, which is the main cause of air, water and soil pollution. One of the key threats to public health associated with the environment in Stara Zagora is atmospheric air pollution. Its protection is governed by the Clean Air Act [1] as well as by its associated regulations – Regulation No. 14/1997 [2]; Regulation No. 11/2007 [3]; Regulation No. 12/2010 [4], where all Bulgarian rules and regulations are harmonised with those of the EU (Directive 2008/50/EC). Atmospheric air quality monitoring and control are carried out throughout the year by the Regional Inspectorate of Environment and Water Directorate.

In the past 20 years, the atmospheric air in Stara Zagora Municipality has been amongst the most polluted in the country [5] [6] [7]. The atmospheric air quality in the municipality is contingent upon the operation of numerous local (industrial enterprises, domestic heating, heavy traffic) and regional (the three thermal power stations of the Maritza East power complex situated 40 km south of Stara Zagora and Zmeevo, a military testing ground 7 km to the southwest) emission sources. These sources mainly generate sulphur dioxide (SO_2), breathable PM_{10}, nitrogen dioxide (NO_2), lead aerosols and hydrogen sulphide (H_2S). Two trans-European corridors go through the territory of the municipality. These characteristics coupled with weather conditions and the topography of the area facilitate the migration of pollutants and affect the morbidity of the population. An ecological task of top priority is to prevent atmospheric air pollution from the major pollutants (PM_{10}, sulphur and nitrogen oxides, ozone), given their role as a risk factor in the aetiology, pathogenesis and spreading of some diseases (cardiovascular diseases, respiratory diseases etc.)

The purpose of this study is to analyse air pollution and its impact on the morbidity amongst the population of Stara Zagora Municipality in the period 2009 - 2013, as well as to create a mathematical model of predicting morbidity levels.

Subjects and Methods

On the territory of Stara Zagora Municipality, sample-taking and analyses of the atmospheric pollutants (sulphur dioxide, PM_{10}, nitrogen oxides, lead aerosols and hydrogen sulphide) are conducted in an automatic measuring station, two differential optical absorption spectroscopic systems and one unit for the manual taking of samples. Standards in compliance with European law are used in the analysis of the pollutants. Information about the morbidity based on the number of people who visited their GPs in a relationship with a chronic health problem or emergency condition and the number of hospitalisations has been obtained from the Regional Health Inspectorate – form 365, 1A, appendices 5 and 6. The study covers the two age groups (from 0 to 7-year-olds, 18 and older) and the entire population of Stara Zagora Municipality.

The influence of atmospheric pollution on the morbidity of the population in Stara Zagora Municipality in the period 2009-2013 is based on disease class according to the International Classification of Diseases, revision X.

The correlation between the examined atmospheric pollutants and morbidity can be calculated using the following formula:

$$Y_i = e^{\varepsilon i} K_0 \prod_{j=1}^{n} X_{i;j}^{Kj}$$

Where:

Y_i - the dependant variable (result = the number of predicted diseases);

i - the year;

n – number of factors;

$X_{i;j}$ - the value of factor j for the period i;

K_j – powers (coefficients) – the constants of each dependence;

K_0 - the module (the equaliser of the dimensions of each dependence);

ε_i - statistical error.

Module K_0 and the powers K_j are obtained using an integral exponential function by applying the least squares method used by Frenkely and described in Multifactor correlation model for labour productivity [8].

In this particular case, the factors (pollutants) are $X_{i;1}$-SO_2, $X_{i;2}$-PM_{10}, $X_{i;3}$-NO_2, $X_{i;4}$-Pb aerosols). The magnitude of each factor ($X_{i;}$) is calculated in μg/m^3.

Results

The analysis of systemically controlled pollutants (SO_2, PM_{10}, NO_2, H_2S and lead aerosols) by months and years for the period 2009-2013. Showed that the mean monthly concentrations of SO_2, NO_2, H_2S and lead aerosols did not exceed the permissible levels. The only observed pollutant in which there are cases of exceeding mean monthly concentrations relative to the threshold value is PM_{10}. At only one of the measurement points, all PM_{10} average annual PM_{10} values for 2009, 2010 and 2011 are above the limit value of 40 μg/m^3. Contributing to this is probably the lively traffic on the boulevard where the points are located. About the annual average concentrations, the results for all atmospheric pollutants indicate that they are within the boundaries of the norm and safety for human health. The complex assessment of atmospheric pollution in the municipality of Stara Zagora shows a slight fluctuation of the aggregate indices by years, without any sudden changes, and confirms the tendency to reduce the systemically observed pollutants: sulfur dioxide, PM_{10} nitrogen oxides, lead aerosols and hydrogen sulphide for the period 2009-2013.

As regards the morbidity based on the number of people who visited their GPs in a relationship with a chronic health problem or emergency condition, the greatest share for the entire population take the cardiovascular diseases (22.99%). They are more frequent (27.77%) in the age group of 18 and older, or more as compared to the age group 0-17 (0.97%). Second are respiratory diseases

(17.34%) for the entire population. In age group 0-17, the relative share is rather high, 47.20%. Third, come to the diseases of the genitourinary system (9.76%).

As regards incidence of diseases that require hospitalisation, the leading diseases with almost the same share are the diseases of the digestive system (11.90%) and cardiovascular diseases (11.85), followed by respiratory diseases (10.86%) and genitourinary systems (8.88%). In age group 0-17, the greatest share is the share of the respiratory diseases (36.93%). Most common in this disease class is pneumonia (82.44%). Children most frequently suffer from infectious diseases where disturbed immune balance is observed. Cardiovascular diseases are most common amongst adults (14.26%).

During the examined period, there is a tendency in Stara Zagora Municipality towards decreasing the incidence of diseases based on the number of people who visited their GPs in a relationship with a chronic health problem or emergency condition and an increase based on hospitalisation as compared to the base year (2009).

The correlation between atmospheric pollution and the morbidity of the population as well as tracking the influence of each pollutant on morbidity is determined using the values of the mathematical expression $X_{i;j}^{Kj}$ based on the mathematical model used. The data analysis after the computations shows that PM_{10} has the greatest influence on the morbidity of the population in Stara Zagora Municipality based on the number of people who visited their GPs in a relationship with a chronic health problem or emergency condition and the number of hospitalisations. The correlation is particularly strong in the age group 0-17 by the number of people who visited their GPs in a relationship with a chronic health problem or emergency condition ($r = 0.762$, $p < 0.05$).

Sulphur dioxide exhibits a positive correlation with morbidity based on the number of hospitalisations in the age group 18 and older at the beginning of the studied period (2009-2013) ($r = 0.430$, $p < 0.05$), and at the end of the period it is negative. Lead aerosols too have a pronounced influence on morbidity based on the number of hospitalisations amongst the population aged 18 and older in Stara Zagora Municipality ($r = 0.501$, $p < 0.05$).

We found the additive action of some pollutants as SO_2+PM_{10} on malignant diseases for the whole population by hospitalisation [9] [10] [11] [12] [13] and cardiovascular diseases for the whole population is affected by the additive effect of PM_{10}+Pв aerosols [14] [15] [16].

After applying the Least squares method on the morbidity based on the number of hospitalisations and on the number of people who visited their GPs in a relationship with a chronic health problem or emergency condition amongst the entire population in Stara Zagora Municipality, the following coefficients are obtained as an independent variable:

$K_0\ e^{19.7723}$ K_1 - 0.1039 K_2 - 1.8949 K_3 - 1.5106 K_4 - 0.2254

The following formula will be used to calculate the predicted future morbidity count:

$$Y_{prognosis} = e^{19:7723} X_{i,1}^{0:1039} X_{i,2}^{1:8949} X_{i,3}^{1:5106} X_{i,4}^{0:2354}$$

The result calculated based on the formula above makes it possible to forecast morbidity with a significant precision-the average margin of error for the studied period ranges from 0.61 to 2.59%. The expected morbidity level predictions based on the number of people who visited their GPs in a relationship with a chronic health problem or emergency condition in Stara Zagora Municipality are lower, while hospitalisation level predictions are higher as compared to the numbers obtained during the period of the study (Table 1).

Table 1: Registered and projected morbidity of the population in Stara Zagora Municipality by the number of people who visited their GPs in a relationship with a chronic health problem or emergency condition and the number of hospitalisations for the period 2009-2013

Year	Number of registered diseases	Number of projected diseases	Error for the year %
	Diseases by the number of people who visited their GPs in a relationship with a chronic health problem or emergency condition		
2009	333425	105396	0.68
2010	339482	196226	0.42
2011	402741	108831	0.72
2012	321726	141328	0.56
2013	321968	104115	0.67
	The average margin of error for the period = 0.61%		
Year	Number of registered diseases	Number of projected diseases	Error for the year %
	Diseases by the number of hospitalisations		
2009	34038	105396	2.09
2010	37277	196226	4.26
2011	37194	108831	1.92
2012	32019	141328	3.41
2013	45777	104115	1.27
	The average margin of error for the period = 2.59%		

Discussion

The majority of cardiovascular diseases can be explained by the fact that people older than 65 are more vulnerable as regards hypertonic disease, cerebrovascular diseases and ischemic heart disease. These diseases, in particular, indirectly associated with air pollution, seasons and climate factors, increase the possibility of the occurrence of thrombosis [17] [18] [19]. The respiratory system is affected to no lesser extent, and data shows that it is the most sensitive to atmospheric pollutants and children are the most sensitive group [20] [21] [22]. This is correlated to the immature immunity, high vulnerability and the body's predisposition to different respiratory diseases, especially in the early childhood years. Frequent pneumonia in hospitalised children are influenced by meteorological factors, which is confirmed by the studies of some authors [23] [24]. It is established that atmospheric pollutants have a suppressive effect on the production of immunoglobulin for this age group [25] [26] [27].

Similar to our observations of the effect of nitrogen dioxide on the respiratory system, described Nickmilder M. et al., 2007 which establish the inflammatory changes in the airways, but they bind them to the low-level contamination with nitrogen oxides and ozone [28].

Numerous studies of this age group show a positive relationship even between low concentrations of lead aerosols and damage to hemopoiesis, nervous tissue, hearing, changes in neurobehavioral functions, and intellectual [29] [30] [31] [32]. Reports of blocking the bioactivity of porphyrin synthesis enzymes, impaired haem- synthesis and the development of anemia by the action of lead is found in research by de Carvalho RP et al., 2006; Zimmermann M. B. et al., 2006; Muwakkit S. et al., 2008; Rondó P. K. et al., 2011, Park S. et al., 2014 [33] [34] [35] [36] [37]. A lot of studies show a relationship between atmospheric pollution and malignant diseases. The analyzing of the data in morbidity by the number of people who visited their GPs in a relation with a chronic health problem or emergency condition of the groups from 0 to 17 years, 18 and more and the whole population shows high correlation dependence between sulphur dioxide and the increasing of bladder and lung cancer leading to high mortality [38] [39] [40] [41]. For the influence of PM_{10} on all diseases, report Raaschou-Nielsen O. et al., 2013; Ponomareva L. A et al. V.V. Inogamova, 2013; Jevtić M. et al., 2014 [42] [43] [44]. Some factors like quality of water, food and feeding can affect the occurrence of diseases of the genitourinary system.

Using the mathematical model formula, it is possible to calculate the predicted value of the number of diseases based on all average annual concentrations of the pollutants for the years in question. The formula is a multiplication product because all pollutants together affect the morbidity and since the concentrations of each factor (pollutant) change over time, an integral exponential function is included too. The calculation of the average development rate for the different pollutants makes it possible to predict the level of atmospheric pollution for each coming year and, hence, the morbidity for the same period. The decrease in atmospheric pollution for the studied period is associated with the commissioning and effective operation of desulphurisation in Maritza East power complex, the efforts directed toward maintaining the road infrastructure, the gasification of Stara Zagora City, reduced use of wood and coal for heating in the municipality, the use of more environmentally-friendly fuels. Determining the projected morbidity levels confirms the tendencies in the dynamics and structure of morbidity based on the number of people who visited their GPs in a relationship with a chronic health problem or emergency condition and the number of hospitalisations amongst the population in Stara Zagora Municipality for the period 2009-2013.

In conclusion, the main methods of medical, mathematical statistics (regression, correlation analysis etc.) do not make it possible to cover fully and precisely the actual correlations between the different factors and the result. In fact, these connections are non-linear which is why it is necessary to use a multi-factor correlation model with non-linear dependences. The functions used in the current study constitute a connection between two factors (atmospheric pollutant and morbidity) and exclude the interaction of all factors. The proposed dependence provides a theoretical model of the interaction, which is quite close to the real one. Determining the dependences makes it possible to realise and control the fluctuations of the result through the impact of one factor or another. A disadvantage of the model can be assumed to be the implicit nature of the functional interdependencies. In reality, this does not have a considerable effect on the practical application of the model in every residential area.

Using the created mathematical model and the atmospheric pollution data, it is possible to forecast the morbidity in every residential area.

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