Informational and Mathematical Modeling of the Impact of Emissions into the Atmosphere on Public Health

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Abstract

In the article proposed methods of processing and analysis of materials of air pollution research and its impact on public health. There are developed mathematical-statistical models of the influence of environment on public health. The article aims to examine the possibility of mathematical modeling assessment of the impact of harmful emissions into the atmosphere of the industrial region on the population's health. The developed mathematical model can be used by the industries for the efficient solution of environmental problems.

Keywords: Mathematical model; Atmospheric pollution; Model for numeric variables; Model for non-numeric variable; Public health.

Introduction

To predict the occurrence of a particular environmental situation, the degree of concentration (C) of pollutants in the air has a high importance. According to its excess over the maximum permissible concentration (MPC) and the limit, there can be given the advice to reduce emissions, or the length of time the work of enterprises.

According to many authors, there are between 100 and 250 quality forecasting techniques of the atmosphere (Zonderland M.E., 2014). However, the leading experts believe that it makes sense to speak only of the three methods: the expert, extrapolating and modeling (Banks H.T., Hu Sh., Thompson W.C., 2014). And all the rest are merely variants of these methods.

Expert prediction method can be used if the forecast data cannot be processed completely or at least partially. It is based on a system of obtaining and processing of specialized assessments of the forecast of a situation by interviewing experts in the field of science.

Extrapolation and interpolation method is used mostly for short-term forecasts. It is based on the study data (both quantitative and qualitative) for a few years prior, and if the change in the environmental situation does not undergo abrupt jumps, implying a trend change in the status for the next forecast period.

In practice, the most widely used method is the method of modeling. For the preparation of the model required to fulfill three basic conditions:

- Identification of factors that are essential for the prediction;
- Determination of the actual relationship of elements to a predictable phenomenon;
- Development of algorithms and programs.

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This method is useful because it is possible to use computers for the data processing. Further, as it is not a complicated model (it is always easier for forecasting object).

Using this method does not require the involvement of highly qualified specialists. It allows taking into account the probability of occurrence of a particular environmental situation.

The method of mathematical modeling is the most representative (both in research and medical practice). It allows simulating the occurring processes realistically, highlights the most relevant and optimal values of the plurality of options, quantitatively reflects the relationship of many factors of the exposed qualitative analysis, uses of independent forecasts and dynamics of individual elements, builds a system of interconnected models (Friedman A., Kao Ch.-Y., 2014).

The modern development of humanity defines a constant transformation and change of biological processes in the entire globe. And it is worth noting that the dynamics of these processes can go both to the benefit and to the detriment of a person. In this case, it is important to be able to determine the trend of development of biological processes for a possible correction, especially in the early stages of their existence. In practice, to solve this problem, there can be used the simulation method based on a mathematical analysis of biological processes parameters method (Hritonenko A., Yatsenko Yu., 2014). Mathematical modeling in biology is becoming the increasingly common method of scientific analysis widely used to achieve other sciences, including cybernetics and mechanics. It is an excellent tool for understanding the evolutionary and genetic effects of complex processes, the development of which are difficult to predict analytically. The presence of dozens of complex customized software packages for the simulation is currently modeling an affordable option for researchers in many fields (Shahin M., 2014).

It is increasingly used in science, math, and cybernetic methods, and as a result of their synthesis with biology, there are new areas of research, such as synergetics, computer sciences, biometrics, etc. A variety of biological objects and phenomena are led to the fact that for their quantitative description from the outset is involved the submission of various mathematical disciplines (Heinz S., 2014). At the same time, depending on the nature and properties of the investigated processes for modeling, there selected a unit, discrete or continuous mathematics (Neittaanmäki P., Repin S., Tuovinen T., 2015).

The main advantage of the method of modeling is the ability to study the degree of variability of the system under the influence of individual factors and determining the fullness of relationship variables (Dudin A., Nazarov A., Yakupov R., Gortsev A., 2014).

There are exacerbated the problems of industrial pollution complexes for which the maximum permissible sanitary norms still do not meet the modern requirements. An important task of science is currently to forecast changes in ecological systems under the influence of natural and anthropogenic factors (Agarwal N., Xu K.S., Osgood N., 2015).

This problem becomes sharper in Kazakhstan. The interest in the increasing of production capacity of oil and gas industry led to a severe human impact on the environment and became a global problem with a big emergency. For the main companies of the Republic, the annual emissions amount is more than 135 thousand tons. An urgent issue is the utilization of associated gas in oil and gas fields where they are flared. Every year a growing number of complaints and fines which are currently in comparison with 2001st has increased 5 times.

For the implementation of environmental protection measures, the national company plans to spend more than 1.8 bln. tenge annually. However, this is not always accompanied by a meaningful, purposeful work to create a favorable natural environment protection management system. It takes a scientific approach for the solving of these problems.

In the connection with the noted above, the impact of pollution on human health (Table 1) needs to be addressed with the help of mathematical modeling (Greenberg R., Daniels S., Flanders W., 2015).

Table 1. The Impact of pollution on human health

Pollutants	Sources	Pathological Effect on Human Body
Aldehydes	Thermal decomposition of fats, oil or glycerol	Irritate nasal and respiratory tract
Ammonia	Chemical processes-dye making, explosives, fertilizers	Inflame upper respiratory passages
Arsenic	Processes involving	Break down red cell in blood jaundice
Carbon monoxide	Gasoline motor exhausts, burning of coal	Reduce O_2 carrying capacity of blood
Chlorine	Bleaching cotton and other chemical processes	Attack entire respiratory tract and mucous membrane of eyes, cause pulmonary oedema
Hydrogen cyanides	Fumigation blast furnaces, metal plating	Interfere with nerve cells, produce dry throat, indistinct vision, headache
Hydrogen fluorides	Glass etching, fertilizers production	Irritate and corrode all body passages
Hydrogen sulphides	Refineries and chemical industries bituminous fuels	Smell like rotten eggs, cause nausea, irritate eyes and throat
Nitrogen oxides	Motor vehicles exhaust soft coal	Inhibit ciliary action of so that soot and dust penetrate far into the lungs
Phosgene (carbon chloride ($COCl_2$))	Chemical and dye manufacturing	Induce coughing, irritation, and sometimes fatal pulmonary oedema
Sulphur	Coal and oil combustion incinerator	Causes chest constriction, headache, vomiting and death from respiratory-ailments
Suspended particles (ash, soot, smoke)	Incinerator, almost any type of manufacturing	Cause emphysema, eye irritation and possibly cancer

Materials and Methods

To assess the impact of the environment on the public health, the authors used mathematical and statistical models of 4 types: two models for numeric variables and two models for non-numeric variables (Aydosov A.A., Aydosova G.A., Zaurbekov N.S., 2015; 2010; Aydosov A.A., 2002; Alekseev S., 2000; Korovkin I.A., Pashkov E.V., 1997; Nikitin D.P., Novikov Y., 1980; Soltaganov V., Schegortsov V., 2003).

Models for numeric variables

There were distinguished the set of territories – $S^1, S^2, ..., S^l$, the set of environmental factors – $X^1, X^2, ..., X^p$, the set of parameters describing the incidence – $y_1, y^2, ..., y^m$, the gender and age groups of the population – $U^1, U^2, ..., U^q$, successive intervals of the time (typically, a calendar month) – t=1,2, ... ,n. Determined y^i (U^c, Sdt) – as the value of the incidence rate y^i for the group of the population U^c in the territory Sd in the time interval t; X^y (Sdt) – the average value of the factor X^y in the territory Sd in the time interval t. The factors $X^1, X^2, ..., X^p$ are corresponding to the characteristics of air pollution with dust, nitrogen dioxide, etc. The indicators $y^1, y^2, ..., y^m$ are representing the characteristics of health of the population formed in the special way:

- Incidence;
- Mortality, etc.

The groups $U^1, U^2, ..., U^q$ were determined by gender, age, region of residence, professional affiliations, etc.

Dependence analysis was carried out in stages in an interactive man-machine mode (Banks H.T., Hu Sh., Thompson W.C., 2014). Each step was realized by the scheme:

1. Fixes the only group U;

2. Fixes the only indicator y_i and the set of the factors $X_1, X_2, ..., X^p$ – the part or all of a set of the controllable factors;

3. Fixes a subset of the areas and a subset of the time period;

4. From the database, the files are generated by the given group of indicator factors, areas and time periods;

5. Forms the correlation field for each pair of the plurality of variables $X_1, X_2, ..., X^p, y_i$,

where the Pearson correlation coefficient is calculated according to the formula:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 (y_i - \bar{y})^2}} \quad (1)$$

where x, $\bar{y}$ – the selective arithmetic means, n – a sample size;

6. Builds the linear regression equations, where the coefficients and settings are measured:

$$y_i(USt) = a_0{}'(U) + \sum_{y=1}^{p} a_y{}'(U) X_y(S't) + \varepsilon_i(U_1 S_1 t) \quad (2)$$

Models for non-numeric variables

Let us consider measures of connection for two variables. The authors are entering designations with two outputs for the variables A and B having respectively *i* and *j* levels of the categories, where *fml* – is the frequency of occurrence of both categories *Am* and *Bl*.

f – is the general result of all considered cases or mathematically:

$$f_2 = \sum_y f_r j_1 f_0 k = \sum f_k j_1 f_{00} = \sum{}_r f_n = \sum{}_k f_{on} = \sum{}_r \sum{}_k f_n k \quad (3)$$

In contingency tables (LxJ) for the determination of connection and independence it is necessary:

- In the case of the variables independence, the following ratio should be:

$$\frac{f_i j}{f_0 j} \approx \frac{f_n}{f_{00}} \text{ for all } i,j. \quad (4)$$

Designating P_iJ, there is the probability that a randomly selected individual enters the section (ij), just get the condition of independence, namely, if A and B are independent, then $P_iJ = P_{i0} P_0 J$, $i = 1,2, ..., I; j=1,2, ..., J$. (5)

The evaluation P_iJ answers l_iJ:

$$l_iJ = \frac{f_{i0} f_{0j}}{f_{00}} \quad (6)$$

Hence, for the criterion X^2 there is a following calculation:

$$X^2 = \sum_I \sum_J \frac{(f_{ij} - l_{ij})^2}{l_{ij}} \quad (7)$$

with (i-1)x(j-1) including the degrees of freedom for independence check.

The distribution X^2 is only approximately corresponds to the X^2 placement, but it well works for $f_iJ>3$. There are following measures of connection which based on X^2:

Cramer's V and Chuprov's T (Pötzsche C., Heuberger C., Kaltenbacher B., 2014).

$$V = \left\{\frac{X^2}{f_{00} x \min[(i-1)(j-1)]}\right\}^{j^2}; \quad T = \left\{\frac{X^2 f_{00} V}{\sqrt{[(i-1)(j-1)]}}\right\}^{j^2} \quad (8)$$

From the other measures, τ - Goodman and Kruscal:

$$\tau = \frac{\sum_i \sum_j \left[(f_{00} f_{ij} - f_{0j})^2 S_{i0}\right]}{f_{00}\left(f_{00}{}^2 \sum_j f^2{}_{oj}\right)} \quad (9)$$

the measures λ_b, λ_a and λ_i.

$$\lambda_b = \frac{\sum_j f_{im} - f_{0m}}{\frac{i=1}{f_{00} - f_{0m}}} , (10)$$

where f_{im} – is a maximum input in the *i*-line, f_{0m} – the highest of the results in columns.

Results and Discussion

The analysis of contingency tables with more than two inputs is complicated and very cumbersome, so in practice it almost never used (Siddiqi A.H., Manchanda P., Bhardwaj R., 2015).

To evaluate and analyze the impact of social and health conditions of the population on the frequency of uptake of medical care in outpatient facilities, there are Sxr contingency tables, where r – the number of categories received the response of variable; S – the number of values taken by the factor variable.

To test the hypothesis of independence (not to influence socio-hygienic factors on the uptake), there used statistics with degrees of freedom:

$$X^2 c(r-1)(S-1);$$

$$X^2 = \sum_{j=1}^{r} \sum_{i=1}^{S} \frac{\left(K_{ij} - l_{ij}\right)^2}{l_{ij}} \quad (11)$$

where nij – the actual frequency of contingency tables; lij – the theoretically expected frequencies under the conditions of signs of independence.

To measure the force of connection, the authors used the following coefficients:

P= $\sqrt{\frac{x^2}{N}}$, contingency C= $\sqrt{\frac{x^2}{x^2 + N}}$, (12)

also, Cramer's V, Ksendal's τ, and Stewart's $\tau_{ñ}$.

To determine the significance of the influence of certain social factors on the incidence rate, there were applied the log-linear models for contingency tables.

Since the exact probability collectively known (Chatterjee S., Singh N.P., Goyal D.P., 2014), it stays to use the observed sections frequency as their ratings. As a result of what is extracted from the model, there can be found a reasonable explanation with the help of the differences in the observed frequencies of sections (Wang L., 2014). The model can be integrated regarding the probability of sections which, of course, are obliged to be between 0 and 1. It implies that the easiest way to build the model is not to work with probabilities, but with some functions of probabilities which are not restricted and have their minimum value - ∞ and the maximum one $+\infty$.

For dichotomizing factors at which probabilities of categories consist 1 and 2 are accordingly equal to P and (1-P), it is possible to work potentiating both parts, having got rid of l n and get $l = \frac{P}{1-P}$ or, allowing relatively P: $P = \frac{1}{1+l^k}$. The function X is known as the "logit" or the predominance of logarithms (Martcheva M., 2015).

Consider some models for 2x2 table.

Suppose, there is a 2x2 table for categorized variables A and B, and authors want to test the hypothesis:

1) A_1 is more common than A_2;

2) B_1 is more common than B_2;

3) The combinations A_1 B_2 and A_2 B_1 are more common, than would be expected if the variables A and B are independent.

Now there is a need for the mathematical method that allows quantitatively compare the relative importance of these three effects, and identify cases in which the effects should be recognized as real and when to assign them random deviations (Aydosov A.A., Aydosova G.A., Zaurbekov N.S., 2015; 2010; Aydosov A.A., 2002; Alekseev S., 2000; Korovkin I.A., Pashkov E.V., 1997; Nikitin D.P., Novikov Y., 1980). This method involves the use of models, recorded relatively natural logarithms U_{ij} of probability of sections P_{ij}.

Consider the model U_{ij} lcmI, loge from P_{ij}

$U_{ij} = M + \lambda_i^A \lambda_{ij}^B$, where M – is a middle part,

$$\sum_i \lambda_i^A = \sum_j \lambda_{ij}^B = \sum_i \lambda_{ij}^{AB} = \sum_j \lambda_{ij}^{AB} = 0 \quad (13)$$

If the model has as many parameters as sections, it is called saturated (Zonderland M.E., 2014).

Restrictions (2) have the form (in this case):

$$\lambda_r^A = -\lambda_i^B ; \qquad \lambda_r^B = -\lambda_i^B ;$$

$$\lambda_2^{AB} = -\lambda_{21}^{AB} = \lambda_n^{AB}$$

Enter the simplification and sum both parts of (1) I, AB

$$\sum_i U_{ij} = \sum_i M + \sum_i \lambda_i^A + \sum_i \lambda_j^B + \sum_i \lambda_j^{AB} \quad (14)$$

Taking into account (2) shall have:

$$Ixv_{ij} = IxM + O + \lambda_y^B + O \quad (15)$$

Summing over all observations, will get:

$$Ijv_{...} = IjM + O + \lambda + O \quad (16)$$

Consequently, M=v, substituting it in (3), will find:

$$\lambda_i^A = v_{io} - v_{io}\lambda_j^B - v_{ij}\lambda_{ij}^{AB} = v_{ij} - v_{ij} - v_i - v_{ij} + v_n \quad (17)$$

Using (4) it is possible to interpret X as an additive (or a decrease), connected to the category of factor A and in comparison with the common average. Padding light on the equation (4), concerning the tables:

$$\lambda_i^A = \frac{v_1 + v_{12} - v_{21} - v_{22}}{4} = \frac{1}{4}\sum \log O\left(\frac{P_{ij}}{P_2 j}\right);$$

$$\lambda_i^B = \frac{v_{11} - v_{12} + v_{21} - v_{22}}{4} = \frac{1}{4}\sum \log e\left(\frac{P_i j}{P_2 j}\right); \quad (18)$$

$$\lambda_i^{AB} = \frac{v_{11} - v_{12} - v_{21} + v_{22}}{4} = \frac{1}{4}\sum \log e\left(\frac{P_{11}P_{22}}{P_1 P_2}\right).$$

The two-dimensional model or the table with two inputs was considered above, and the authors need to define a mode of operation in case of many-dimensional tables.

The task consists of choosing one or several rather prime models from all variety.

The saturated model is used in the article. When was selecting the saturated model, the authors estimated the value of all λ which can be imagined to include in the appropriate simple model. Some of the values λ can be close to 0 that will indicate their small probability. Then at the choice of unsaturated model it is possible to be guided by the aspiration to include in it, first of all, those λ which significantly differ from 0.

Two simple methods were used in the building of an unsaturated model:

a) Switching method, which is that at each step is introduced into the model is the most important λ;

b) Elimination method, the essence of which is that at each step of the model excludes the least important λ.

The introduction of an additional parameter in the model may result in its improvement. One method or any combination of them can necessarily lead to the best single model (Mickens R.E., 2015).

Software problem

For the implementation of the described algorithms of the issue, the application program package of the tasks SAS-82,4 is used. For data handling and simulation, the EUNCAT procedure processing categorical variables were used.

In each equation in the first stage, the process without additional options is used; in the last step, it used with FRF Q, X, PREDICT options.

Theoretical and Practical Implications

The impact of air pollution on human health can be direct or indirect. Directly related to the effect on the human body of particles and gasses inhaled with the air. Most of these contaminants cause irritation of the respiratory tract, reduced resistance to airborne infections (remember the regular flu epidemic in the larger cities, where, along with a high frequency of contacts between people, as shown by many studies, resistance to infection in the majority of the population is reduced). Also, increase the likelihood of cancer and disorders of the hereditary system which leads to an increase in the frequency of malformations and the general deterioration of the condition of the offspring.

Many contaminants have both carcinogenic (cancer causing) and mutagenic (causing increased frequency of mutations, including violations, leading to deformities) properties, because their mechanism of action is associated with violations of the structure of DNA or cellular mechanisms of realization of genetic information. These properties are as radioactive pollution, and many chemicals organic nature - products of incomplete combustion of fuel, pesticides used for plant protection in agriculture, many organic synthesis intermediates, is partially lost in the production process.

Mediated effect, i.e. effect through the soil, vegetation and water, because the same substance into the body of animals and humans, not only via the respiratory tract but also in food and water. In this area of their influence can significantly expand. For example, pesticides preserved vegetables and fruits in dangerous quantities; affect not only the rural population but also to the inhabitants of the cities, eating these products.

The danger of the uncontrolled use of pesticides has increased and from the products of their metabolism in the soil are sometimes more toxic, than drugs used on fields.

Clean air, preventing ingress into the anthropogenic air pollution - one of the most important tasks, the solution of which is necessary to improve the ecological state of the planet and each country.

Mathematical modeling is particularly important for the analysis of biological processes which increasingly give failures under the influence of anthropogenic factors (Johnson T.P., 2014). This approach to the modeled process is widely used in ecology, population genetics, where with the help of models in the form of differential equations described as the behavior of individual populations and relationships in much more complex systems (Wahiba K., Abdessalem B., 2015).

The complexity of the biological processes and describing the behavior of mathematical models inevitably leads to the use of computer technology (Castellani B., Rajaram R., Buckwalter J.G., 2015). Computers are increasingly used not only for data processing and refinement of model parameters but also for the production of informatics experiment in many cases designed to replace expensive natural experiment (Klapp J., Chavarría G.R., Ovando A.M., 2015). Therefore, further development of mathematical modeling in biology is seen in the way of the application of modern computer mathematics as a tool for the preparation of highly qualified specialists, build content models, accumulation, and storage of information received as a result of the study of these models (Wicks A., 2014).

The use of such models in practice can contribute to improving the strategic biosphere and prevention of adverse biological processes at an early stage of their existence. For example, tracking the dynamics of life expectancy, or the appearance of immunity to pathogens some medicines (Moumtzoglou A., 2014).

Conclusion

Problems of safety and control quality of the environment give rise to a broad class of challenges associated with the search for optimal solutions in the preparation of economic projects that are related to the impact on the environment as well as the planning of environmental measures requiring emission management of existing industrial facilities, taking into account features of the hydrometeorological regime and sanitary restrictions and socio-economic nature (Yashin A.I., Jazwinski S.M., 2014). In this regard, the methods of the environmental quality improving are becoming increasingly important in the practice of management and can be attributed to these methods:

- Reconstruction and improvement of existing production lines, ensuring reduction of emissions of impurities and harmful waste;
- Development and implementation of low-waste (closed) processes that provide widespread use of all components and a minimum flow releases to the environment (Cojocaru M.,

Kotsireas I.S., Makarov R., Melnik R., Shodiev H., 2015).

Selection of management methods (of the most useful from the "environmental" and "industrial" criteria) is a challenge of which solution is hardly possible without the use of mathematical modeling method (Mansnerus E., 2014).

Currently, due to the increased capabilities of computer maintenance, the method of mathematical modeling of environmental processes is one of the most promising for incorporating technical features of the load on the environment that let to consider the sharpness of the ecological situation in the territory, depending on the incidence of the resident population (Siddiqi A.H., Manchanda P., Bhardwaj R., 2015).

The results of this simulation can be used when making decisions in the fields of ecology, health, medicine industry, investment planning, urban development and others (Alvarez M.A., 2014).

Although there is no direct link between the concepts of "ecology" and "investment", they nonetheless are complementary factors (Gilbert K.M., Blossom S.J., 2014). Businesses need to carry out investments with a constant eye on the environment (Nishii R., Ei Sh.-I., Koiso M., Ochiai H., Okada K., Saito Sh., Shirai T., 2014).

Total environmental degradation, the need to accurately forecast and make operational decisions on overcoming the consequences of pollution, require the creation of particular mathematical models which reflect the assessment of the degree of air pollution (De S., Hwang W., Kuhl E., 2014). The successful solution of the tasks of the forecast is based on the use of mathematical models (Kluever R.C., Kluever C.A., 2015).

Of course, the development of mathematical patterns in connection with the marginal incidence used to solve a variety of problems, including issues that related to the preparation of environmental measures, the health risk assessment of population which has a great scientific and practical importance (Friedman A., Kao Ch.-Y., 2014).

Analysis of the simulation results shows that the procedural decision of the enterprise and contemporary emission sources environmental characteristics of air only for some contaminants may be in the range of normative values. In general, there is a significant impact on the change in the level of pollution of the atmosphere of the city and on public health (Priti K.R., 2015).

The constructed mathematical models used to describe the processes of distribution of pollutants in the numerical models (Logan J.D., 2014). It makes it possible to estimate pollution levels at the points of the region which can be used to form the air basin quality criterion.

In this article the authors have implemented the following:

- The methods of processing and analysis of research materials;
- Development of mathematical and statistical models of the influence of the environment on public health.

The paper identified the possibility of mathematical modeling assessment of the impact of harmful emissions into the atmosphere of the industrial region on the health of the population (Table 2).

Table 2. Major industrial sources of air pollution

Industry	**Major air pollutants**
Thermal power plants	NO_2, N_2O, SO_2, particulates
Steel industries	Smoke, particulates, CO, fluoride
Petroleum refineries	SO_2, smoke, particulates
Metal smelters	SO_2, NO_2, N_2O, smoke, particulates
Fertilizer plants	SO_2, NO_2, N_2O, NH_3, fluoride
Acid plants	SO_2, NO_2, N_2O
Cement plants	SO_2, smoke, particulates
Soap and detergent plants	Particulates, odour

Paper mills	SO_2, particulates, odour

The mathematical model can be a precise tool for determining the influence of industry on the environment, analysis and assessment of anthropogenic impacts on the ecological condition of the air basin industrial region.

The developed mathematical model can be used by industry to address environmental issues effectively.

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