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THE INFORMATION MODEL OF THE SYSTEM FOR LOCAL ATMOSPHERIC AIR POLLUTION MONITORING

The structure of the information system for estimating and modelling pollutants behaviour in the air based on multi-component probabilistic model for calculating the concentration of pollutants, which takes into account the spatial location and characteristics of pollution sources, meteorological conditions and topography, has been developed. Integration capabilities of geoinformational systems allow attaching the existing web resources as external data sources for calculating and modeling. The description of the functional blocks of the system and the optimal scenario of their interaction has been proposed in the article.

***Keywords**: the geoinformational system, environmental monitoring, atmospheric pollution, the probabilistic model, concentration of pollutants estimating.*

Introduction

Due to the permanent deterioration of the ecological situation, special attention is paid to problems of environmental monitoring and assessment of technological risks. It is in many respects caused by increase of environment anthropogenic loads. The atmosphere is exposed to the strongest influence by any forms of technical objects activity, irrespective of their type: industrial, power, transport, agricultural, household, and other types of enterprises. Features of the cities' atmosphere pollution process are connected with high concentration of the enterprises on urban area, which leads to situation when both - volumes of emissions per the territory unit, and structure (range) of emissions are repeatedly increasing. The regulation of emissions in the atmosphere is performed by establishment of the maximum permissible concentration (MPC) of harmful substances in the atmosphere, i.e. the norms determined by the condition under which the content of polluting substances in ground layer of air does not exceed standards of air quality for the human population, animals and flora. At the same time background concentration of the same substances emerging from external sources and effect of summation are surely considered. For substances with insufficiently fully studied features of impact on human body at the initial stage before development of standards of MPC approximately allowed levels of influence temporarily are established. At the level lower than MPC, risk to get disease or toxic effects signs including long-term ones is insignificant. Unlike the MPC level, threshold concentration values C_{thr} of harmful substances cause effect of toxic influence with probability of not less than 16%. Threshold concentrations C_{thr} are connected with maximal non-affecting concentration levels (MPC) by the following equation: $MPC = C_{thr}/K_s$, where K_s is the safety coefficient which depends on danger class of the substance and availability of experimental data about its danger: the first class of danger – $K_s > 7,5$; the second one – $K_s = 6,0 – 7,5$; the third – $K_s = 4,5 – 6,0$ and the fourth class – $K_s = 3,0 – 4,5$. For the characteristic of atmospheric pollution level of some territory for long time period background concentration of separate polluting substances is used as well as the generalized indicator – the atmosphere pollution index (API) that is calculated as the amount of concentration values of the leading pollutants (as a rule, five substances, API_5), normalized to the values of their MPC. For API_5 the level of pollution is considered as "Normal" when $API_5 < 5$, "Elevated" – from 5 to 6, "High" – from 7 to 13 and "Extremely high" – when $API_5 > 13$.

Quantitative evaluation and mapping of critical loads values allows defining ecosystems that are most sensitive to polluting substances (PS) admission. Comparison of the existing maps of critical loads with actual volume of incoming pollutants to the ecosystem allows estimating the existing influence level in relation to optimally permissible one. Similar comparison helps to reveal regions where it is necessary to reduce emissions of harmful substances, taking into account that the pollution source can be located spatially at some distance from the place where the precipitation level exceeds maximum permissible one.

Thus, monitoring and forecasting of the atmosphere pollution remains an actual problem therefore the block of PS concentration fields distribution modeling on the basis of the general indicators of industrial facilities operation or other pollution sources as well as the extent to their impact on the environment is of fundamental importance in the information system that provides an environmental monitoring. Such calculations are necessary in the analysis of unfavourable ecological situation in the region for the causes identification (together with the analysis of direct measurements data or instead of them when their receiving is not possible) or when forecasting ecological situation while putting into operation or reconstruction one or other type of sources of human-caused impact on environment. The accuracy of present state simulating should be sufficient to identify pollution sources and elaborate appropriate control action on the technological and economical levels. Currently there is a number of methods and software tools, which allow to define fields of polluting substances concentrations by a solution of the equations describing within certain range of accuracy the dispersion of pollutants in the atmosphere. The multi-component probabilistic model for calculation of PS concentration in the atmosphere had been proposed in the work [1], that takes into consideration the state of the atmosphere, physical properties of the emitted substances, the height and diameter of the emission source and their location.

The purpose of the work is to elaborate a structure of the information system for the assessment and modeling the content of pollutants in the atmosphere on the basis of multi-component probabilistic model for calculating the concentration level of pollutants [1, 2].

1. The mathematical modeling in the ecological risk assessment

At the environmental risk assessment following sequence of steps is performed:

– the hazards identification;

– the hazards accounting (the determination of pollutants flows and boundaries for their dissipation);

– the influence assessment (reversible and irreversible influences, dose - effect of interaction, ecosystem response, etc.);

– the risk characteristic – the assessment of frequency and severity of the probable events related to the air pollution, the comparison of chemicals concentrations (actual or potential) with the existing sanitary and hygienic standards;

– the risk management – the selection of measures for the regulation of pollutants emission and their applications (prohibitions, restrictions, preventions of air pollution), the implementation of permanent and periodic monitoring, the creation of ecological and economic optimization models to determine the direction of investments, the repetition of the process of ecological risk assessment for chemicals when their production increasing or new information incoming, in accidents, at high levels of local and regional air pollution.

When performing an environmental risk assessment it must be taken into account that some part of the required information contains uncertainty, resulting, in particular, from unreliability of experimental data due to difficulties which occur during in-the-field monitoring (sampling and chemical analyses problems), the lack of long-term series of observations, the spatial variability of most parameters of the environment, as well as due to the deficiency of data and necessity of assumptions that are underlying the environmental risk analysis.

Hence, to obtain information about the spatial variability of harmful substances concentrations in the air and to map air pollution using experimental data it is necessary to take systematically samples of air in the regular grid nodes with a step of no more than 2 km away. This task is practically impossible. Therefore, the mathematical methods simulating pollutants dissipation in atmosphere implemented on computers are used to build fields of concentration. Mathematical simulation assumes the availability of reliable data about the meteorological features and emission parameters. Any algorithmic or analog system, which allows imitating the processes of pollutions dissipation in atmospheric air, can be used as a model.

Air pollution modeling is a numerical tool used to describe the causal relationship between emissions, meteorology, atmospheric concentrations, deposition, and other factors. Air pollution measurements give important, quantitative information about ambient concentrations and deposition, but they can only describe air quality at specific locations and times, without giving clear guidance on the identification of the causes of the air quality problem. Air pollution modeling, instead, can give a more complete deterministic description of the air quality problem, including an analysis of factors and causes (emission sources, meteorological processes, and physical and chemical changes), and some guidance on the implementation of mitigation measures. Air pollution models play an important role in science, because of their capability to assess the relative importance of the relevant processes. They are the only method that quantifies the deterministic relationship between emissions and concentrations/depositions, including the consequences of past and future scenarios and the determination of the effectiveness of abatement strategies. This makes air pollution models indispensable in regulatory, research, and forensic applications [3, 4].

The most popular models are the Gaussian models based on the hypothesis that the distribution of particles in a stream or a cloud is close to normal, and the method UND-86 (all-Union Normative Document, 1986), which can be reduced into a sequence of analytical expressions, obtained as the solution of the turbulent diffusion equation by approximating evaluations.

In the work [1] for the description of pollutants concentration distribution along the axes Y and Z the normal law was adopted, and to describe the pollutants dissipation along the X-axis the S_L-Johnson distribution [5] was suggested for using. The input variables of the multi-component probabilistic model [1] are: the pollution source coordinates (x_0, y_0), the source height h, the source's mouth radius R_0, the emission intensity Q, the gases velocity w_0 at the source outlet, the temperature difference ΔT between emitted gas-air mixture and atmospheric air, the wind velocity u and the wind direction φ, the atmosphere stability class k_A; the output variables are PS concentrations at specified node points with spatial coordinates x, y, z.

2. The informational support of the system for atmosphere pollution monitoring

The main objective of environmental monitoring (EM) is to create information system that allows to obtain reliable information about the state of the environment and about the changes in its physical and biotic components caused by natural and anthropogenic factors. The information EM system can be used as an integral part of the environmental state management system for the environmental policy elaborating and region socio-economic development planning [6].

Geographic information systems (GIS) are a powerful tool for the collection, storage, systematization, analysis and representation of spatio-temporal data. GIS technology allows assembling and analyzing a variety of information about the environment which makes possible predictions and assessment of technogenic risks. The advantage of GIS is in the linking of graphic (spatial) and tabular (attributive) data as well as the opportunity to realize on this basis complex mapping queries.

At the organization of graphic and attribute data communication the following rules are observed:

– the map objects and the records in the featureattribute table are in one-to-one correspondence;

– the correspondence between the object and recording is managed by using a unique identifier assigned to each object;

– the unique identifier is physically stored in two places, namely, in the files containing pairs of X, Y coordinates, and in the corresponding record in the feature attribute table.

Such communication is created and supported in GIS automatically. After that, it is possible to address to the map for obtaining attributive information or to create the map on the basis of the objects attributes which are stored in the table. On the basis of such information modern GIS helps to solve such problems as interpolation – the reconstruction of continuous fields according to discrete data, the complex assessment of the pollution fields formed by various ingredients which impact on the ecological situation in the region, etc.

The environmental data of the region are the basis of the system informational support. Such information can be obtained from stationary automated stations for continuous environmental monitoring as well as mobile laboratories. Considering that mobile laboratories operate intermittently and research areas are changing, it is reasonable to store the obtained information in the tables corresponding to dates of the conducted researches and containing the control points addresses, the ranges and concentrations of the studied pollutants, the weather conditions while measurements was carrying out, etc. Lacking the observational data, such estimations can be found using the results of calculations according to accepted mathematical models; at the same time it is necessary to provide the possibility of the current values setting for all of the model input variables.

The thematic information about the localization and configuration of the main sources polluting environment should be represented as the relevant electronic maps. It is appropriate to store general information about the enterprises of the region in the tables associated with electronic maps. Such databases together with the relevant maps allow to get responses to the following queries:

– what is the object selected on the map;

– where it is located;

– which of the objects are emitting specific harmful substances;

– what kinds of substances are emitted by specified enterprise and what is the emission volume;

– which of the enterprises exceeds the standard MPC levels.

On the basis of such data in GIS maps of points of measurements are created and continuous fields of pollution are formed, diagrams and plots of changes in meteorological factors or concentrations of pollutants are built. GIS also allows to perform statistical processing the measurement results in different time periods of interest for the user.

Calculations and mapping of the PS ground level concentrations will allow to create ecological-economic models of optimization, in particular, to identify regions where technological precipitations exceed the critical load. This information can allow to determine the regions where it is necessary to reduce polluting substances emissions in order to decrease regional pollution level exceeding the critical load so to reduce probability of environmental risk.

3. The structure of GIS for local atmosphere pollution monitoring

The local monitoring is aimed at the control over the concentration level of pollutants, which are emitted by a specific company. The main components in the GIS structure are:

– databases and databanks of ecological, meteorological, normative, sanitary and hygienic, technical and economic orientations;

– the block for modeling and statistical analysis of post-processing results;

– the block for reconstruction the fields of ecological and meteorological factors obtained from modeling results and for forecasting propagation of them;

– the decision making block.

The structure of GIS is shown in fig. 1.

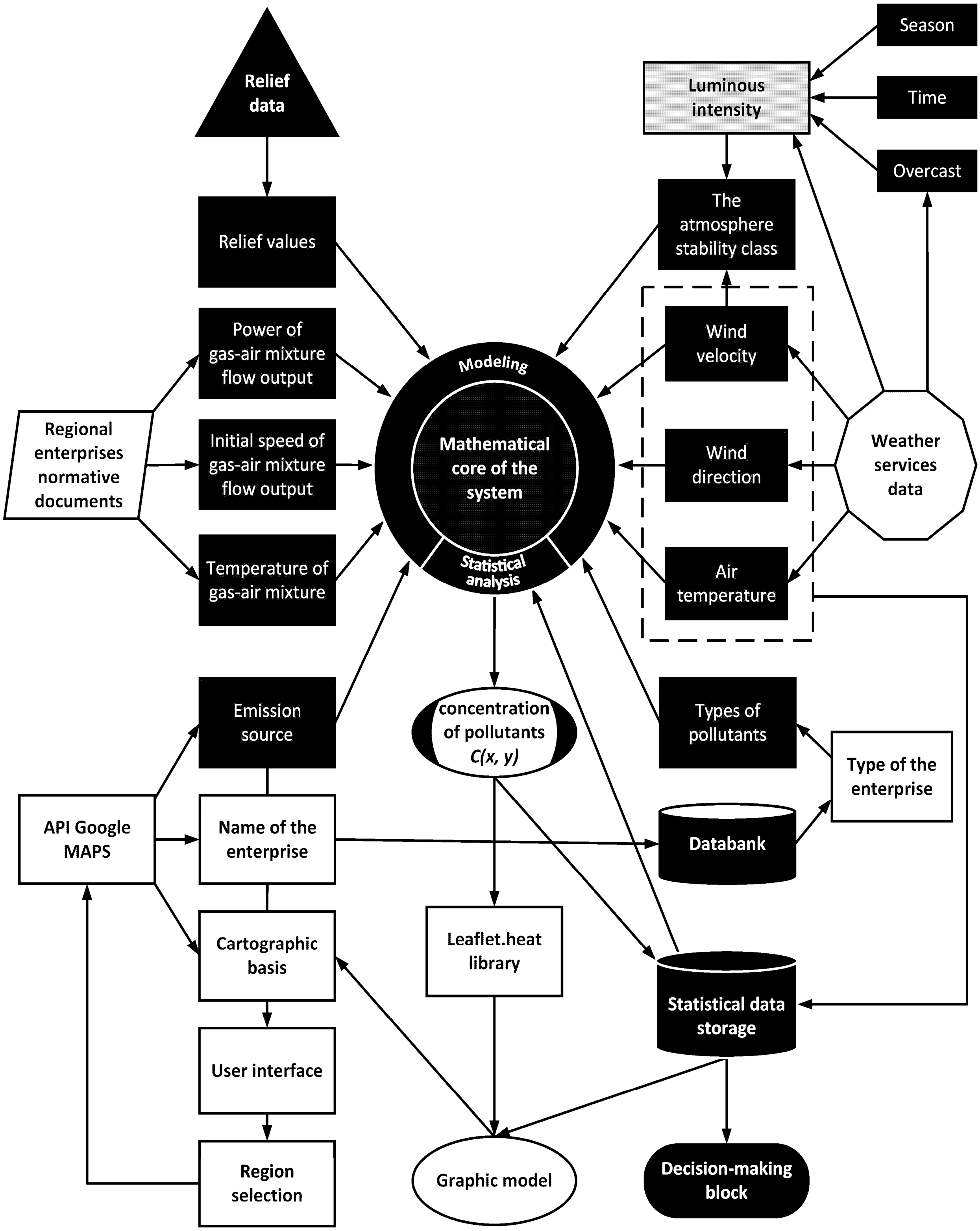

Fig. 1. GIS model for air pollution monitoring

The analytical core of GIS consists of the block for calculation of PS concentrations in the atmosphere considering data of positioning and weather conditions based on multi-component probabilistic model [1] as well as the statistical block for formation of stochastic predicative models using data that represent the long-time period of observations.

The estimated statistical indicators of air pollution are the average single concentration and the maximum single concentration, as well as the occurrence frequency of values exceeding maximum permissible concentration, in the general case, characterizing the duration of increased air pollution within a certain period of time.

A databank on industrial enterprises of the region is designed to store attribute descriptions of the enterprises: the emissions consistence, the emission sources pipes heights h_i and diameters D_i, the emission intensity Q, the velocity of the gases at the outlet of the source w_0, the temperature of outcoming gas-air mixture T_g; the values of the parameters Q, w_0 , T_g are established by the applicable technological standards for the corresponding type of production.

Fundamental regulatory documents in which the current state of the enterprises of the city is described, are the ecological passport of the city, and also the ecological passport of the enterprise, but optionally it can be any other documents that indirectly characterizes the workflow of the enterprise – ranging from summaries of the production volume and ending with the layout of the buildings of the company in schematic view.

Blocks of input data allow determining of the input variables values for the mathematical core of the system, characterizing the conditions of substances emission into the atmosphere from the specified enterprise. Surface concentration of harmful substances at any point in the area in the presence of N sources defined as the sum of the concentrations of substances emitted by the individual source for the given wind direction and speed.

When we have a joint presence of several (n) substances in the atmosphere, which have the property of harmful effects summation, for each group of these unidirectional harmful effecting substances the dimensionless total concentration q is calculated

$$q = \sum\nolimits_{i=1}^{n} \frac{C_i}{MPC_i},$$

where C_i (mg/m^3) – calculated concentrations of harmful substances in atmosphere in the same point; MPC_i (mg/m^3) – corresponding maximal single MPC of harmful substances in the air.

The relief affects the behaviour of the movement and the turbulent regime of the airflow that causes a significant change in pollutants concentrations dissipation from the emission sources. The relief data are advisable to take from dem - files generated by remote sensing satellites.

These files can be found in the archives for non-commercial use; since the relevance of these data does not change very often, quite early images and tables of relief may be used. In addition, this type of data is evaluable on a major map services such as Google Maps. Information about the relief is entering into the system in the form of a matrix of heights. The value of each cell in this matrix is linking to a square on the terrain, in accordance with the coordinate system and spatial scale. The obtained data is converted into a matrix of correction coefficients, specifying the values of PS concentrations.

The benefits of using the Google MAPS API are:

1) interactive customizable cartographic basis having its own coordinate system and a large database of geographic features.

2) no need in georeferencing;

3) an option to obtain data about the relief (as an alternative to dem-files);

4) a large number of libraries running on map-based Google APIs, in particular, support for graphic library Leaflet.heat which allows to visualize the results of calculation of concentration fields;

5) the system is easy for integration into practically any web interface.

The use of the Google MAPS API allows to provide the core of the system with the user's location data, the region of interest for the user and to list the names, types and coordinates of the enterprises operating on the territory.

In addition, the joint use of the Google MAPS API and Leaflet library.heat will allow to perform a graphical representation of the model output variables in the form of thematic maps (areas of contamination) on the cartographical substrate (map of the studying area) in real-time and statistical data (for some period).

The Google MAPS API block is associated with the enterprises databank – via the user interface of the system, it is possible to specify a certain enterprise, the geographical coordinates of which are determined by using a Google map interface and then passed into the mathematical core of the GIS. It is advisable to load the values of the input variables of the model [1], determining the climatic conditions of the pollutants dissipation process in the atmosphere, into the system core in automatic mode from the meteorological services, which providing such opportunity, for example, the weather service of "Yandex".

The implementation of continuous interaction process with the weather services will allow to determine parameters such as wind speed and direction, air temperature, time of sunrise and sunset, overcast parameter and current season systematically. The values of these parameters allow to determine the class of atmospheric stability according to Pasquill [7].

The data storage block accumulates statistical data about PS concentrations in the atmospheric surface layer C(x, y) as well as the corresponding values of meteorological factors. These data are used for graphical visualization of contamination areas, the consistent patterns identification and management decisions making for improvement of ecological situation in the region.

Conclusion

Extensive integration capabilities of GIS allow using external specialized calculation modules and web services as sources of information. Taking into account these features of the information model of the air pollution local monitoring system caused by industrial enterprises has been developed.

The mathematical core of the system contains a probabilistic model for the concentration of pollutants in the atmosphere calculation; the input variables of the model are the spatial coordinates of the pollution sources, attributes of the sources, characterizing the chemical composition of the emissions and the physical conditions of pollutants emission in the atmosphere, atmospheric conditions and topography.

Existing web resources provide the necessary input information.

The proposed GIS will allow solving such tasks of environmental monitoring as evaluation of PS concentration from stationary sources into the atmospheric surface layer for a given region; a visual representation of calculation results in the form of polluted areas for levels of concentration of substances taking into account their cumulative effects; the creation of statistical data bank for consistent patterns identification and management decisions making in order to improve the ecological situation in the region; implementation of both short-term and long-term forecasts on the environmental state (on the basis of created databank), as well as modelling eventual technological hazards to evaluate the potential effects (technological risks).

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ІНФОРМАЦІЙНА МОДЕЛЬ СИСТЕМИ МОНІТОРИНГУ ЛОКАЛЬНОГО ЗАБРУДНЕННЯ АТМОСФЕРНОГО ПОВІТРЯ

А.С. Нечаусов

Розроблено структуру інформаційної системи для оцінки та моделювання вмісту забруднюючих речовин в атмосферному повітрі на основі багатокомпонентної ймовірнісної моделі розрахунку концентрації суміші, яка дозволяє врахувати просторове розташування і характеристики джерел забруднення, метеорологічні умови та рельєф місцевості. Інтеграційні можливості геоінформаційних систем дозволяють підключати в якості джерел зовнішніх даних для розрахунків і моделювання існуючі web-ресурси. У роботі наведено опис функціональних блоків системи і запропоновано оптимальний сценарій їх взаємодії.

Ключові слова: *геоінформаційна система, моніторинг навколишнього середовища, забруднення атмосфери, імовірнісна модель, оцінка концентрації забруднюючих речовин.*

ИНФОРМАЦИОННАЯ МОДЕЛЬ СИСТЕМЫ МОНИТОРИНГА ЛОКАЛЬНОГО ЗАГРЯЗНЕНИЯ АТМОСФЕРНОГО ВОЗДУХА

А.С. Нечаусов

Разработана структура информационной системы для оценки и моделирования содержания загрязняющих веществ в атмосферном воздухе на основе многокомпонентной вероятностной модели расчета концентрации примеси, которая позволяет учесть пространственное расположение и характеристики источников загрязнения, метеорологические условия и рельеф местности. Интеграционные возможности геоинформационных систем позволяют подключать в качестве источников внешних данных для расчетов и моделирования существующие web-ресурсы. В работе приведено описание функциональных блоков системы и предложен оптимальный сценарий их взаимодействия.

Ключевые слова: *геоинформационная система, мониторинг окружающей среды, загрязнение атмосферы, вероятностная модель, оценка концентрации загрязняющих веществ.*