ABSTRACT

of the dissertation work submitted for the degree of Doctor of Philosophy (PhD) in the specialty 6D070300 - Information Systems (by industry)

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DEVELOPMENT OF INFORMATION SYSTEM FOR MODELING OF ATMOSPHERIC POLLUTION BY AUTOMOBILE TRANSPORT

By the direction of the state program "Digital Kazakhstan", approved by the Government of the Republic of Kazakhstan (RK) No. 827 of December 12, 2017, the pace of economic development of the republic and the improvement of the quality of life of the population is accelerated through the use of digital technologies in the medium term, and conditions are being created for the transition of Kazakhstan's economy to a fundamentally new development trajectory. This will ensure the creation of a digital economy of the future in the long term, an important element of which becomes automated means for monitoring air pollution.

The timeliness of the problem for our country is based on the Environmental Code of the Republic of Kazakhstan (dated January 9, 2007, No. 212), which defines state measures for sustainable environmental development of the country. The Code assumes monitoring as an integrated system for monitoring the state of the environment, natural resources, for the purpose of assessing, forecasting and monitoring changes in their state under the influence of natural and anthropogenic factors.

Article 141 assumes the implementation of observations of the state of atmospheric air pollution in the settlements of the Republic of Kazakhstan by the authorized body in the field of environmental protection.

The annual amount of atmospheric pollution produced in Kazakhstan varies between 5-7 million tons, of which the transport sector (mainly road transport) accounts for more than a third. According to the national environmental authorities, almost all regional and large industrial centers of the republic have elevated levels of air pollution.

Impurities of harmful substances in the atmosphere and the features of their spatial and temporal distribution are the basis for an objective assessment of the state and trends of air pollution. In this regard, it is necessary to develop measures to ensure the purity of the atmosphere in order to normalize harmful emissions in the atmosphere. The results of the research should be taken into account in the design of the location of enterprises and residential areas and in establishing the maximum permissible emissions into the atmosphere.

In cities, there is a high level of air pollution, which is certainly connected to the release of carbon dioxide from fuel combustion in the transport sector. To date, in our cities with heavily polluted air, such as Almaty, Karaganda, Ust-Kamenogorsk and Shymkent, up to 80-90 percent of harmful emissions polluting

the atmosphere are generated by automobile transport. In this regard, it is imperative to control and reduce emissions of harmful substances generated by vehicles.

In connection with the introduction of norms for emissions of harmful substances by road transport and the transition to Euro-4 and Euro-5 standards in accordance with the Technical Regulations of the Customs Union of the Customs Union of Customs Union 018/2011 "On the safety of wheeled vehicles", it is expected to tighten the control methods for emissions of harmful substances from automobile transport .

Research in the field of environmental protection in the Republic of Kazakhstan is one of the elements of the state's efficiency in determining the ways of sustainable development of the country, which implies the development of environmental monitoring, as well as information technologies for public administration in the field of environmental protection. (The Strategic Development Plan of the Republic of Kazakhstan until 2025 was approved by the Decree of the President of the Republic of Kazakhstan No. 636 of February 15, 2018).

The basis of an objective assessment of the state and trends of air pollution are the study of patterns of atmospheric impurities and the development of measures that ensure the purity of the atmosphere. In modern science there is a tendency to characterize atmospheric pollution from the position of meteorological values. Of course, the creation of software applications for monitoring air pollution, interpreting the results of numerical analysis of calculations of the amount of emissions of pollutants from vehicles, is directly related to meteorological problems. Carrying out activities that improve the environmental situation and normalize the amount of harmful emissions into the atmosphere, the establishment of maximum permissible emission standards, must necessarily take into account the conditions of dispersion of harmful emissions in the atmosphere, which is an important factor in planning the placement of enterprises and residential areas.

The development of a new direction in meteorological work related to atmospheric air pollution suggests the prediction of conditions for achieving high concentrations of impurities in the surface layer of the atmosphere. At the same time, the greatest interest in practical application is represented by short-term forecasts (within a day), where a sharp increase in the concentrations of harmful impurities in the surface air layer is possible.

Investigations of the distribution patterns of atmospheric admixtures for the purpose of obtaining a space-time distribution are the basis for an objective assessment of the state and trends of changes in air pollution, and the development of possible measures to ensure the purity of the atmosphere. The characteristics of atmospheric pollution are now increasingly regarded as meteorological quantities. The creation of software applications for monitoring air pollution, interpreting the results of a numerical analysis of the calculation of the emission of pollutants from vehicles, are directly related to meteorological tasks. Carrying out activities that improve the ecological situation by normalizing

harmful emissions, establishing maximum permissible emissions into the atmosphere, directly depends on taking into account the conditions of their dispersion in the atmosphere, which is also used in planning the location of enterprises and residential areas.

In the departments of town-planning enterprises that have a large number of vehicles, automotisation of their activities to monitor emissions of pollutants from vehicles is based on the calculation of their number and forecast emissions in order to develop recommendations for undertaking activities that improve the environmental situation. The motorization of the country directly causes scientific and technical, economic, social and environmental problems. Along with many benefits, motorization is accompanied by a number of negative phenomena, causing significant damage to society and nature, which can manifest itself either directly or in the form of waste of resources. It is necessary to carry out measures to reduce emissions of harmful substances in the atmosphere of cities.

All emissions of substances from human production activities are concentrated in the atmospheric boundary layer, where energy in the form of heat and moisture is transferred from the underlying surface to the atmosphere and back. That is why the value of the boundary layer structure serves as the basis for establishing the ability of the atmosphere to be cleared of harmful impurities.

The structure of this layer is extremely complex. The variety of characteristics of the underlying surface (the difference in roughness, albedo, relief form) and atmospheric conditions lead to great variability of conditions at the boundaries of these media; of great importance is the rotation of the earth. In mathematical modeling, all these factors can not be taken into account in a single model, as the air flow in the boundary layer of the atmosphere is almost always turbulent. Turbulence is the main source of difficulties in the study of the boundary layer of the atmosphere, but it facilitates the transfer of heat, the amount of movement of various impurities that pollute the air.

Many years of experience in the study of air pollution have been accumulated, a series of field experiments have been conducted to control the spread of impurities, and their basic laws of transport and deposition have been obtained. Conducting environmental protection measures places increased demands on the accuracy of models designed to calculate the distribution of impurities in the atmosphere. The method of calculating impurity scattering is mainly suitable for the conditions of thermally uniform and even relief.

However, a significant number of industrial facilities are located on the coast of water bodies or in hilly areas. In such cases, the use of kinematic models, where components of wind speed and other meteorological characteristics are assumed to be given, leads to large errors in the dispersion of impurities in the atmosphere. Therefore, the emerging interest in studying the process of transport and scattering of impurities using hydrodynamic models, which describe physical processes in more detail, is quite understandable.

In this thesis, it was proposed to use the probabilistic-statistical approach for modeling the distribution of harmful impurities in the atmosphere from vehicles using the example of the Ust-Kamenogorsk city.

By using a simplified methodology of stochastic modeling it is possible to construct effective numerical computational algorithms that significantly reduce the amount of computation without losing their accuracy.

The idea of work - to model the impact of road traffic flows on the environment, taking into account the terrain, the road network and the number of vehicles in a particular region.

The object of the study is the process of description of the transport of harmful impurities in the atmosphere by mathematical modeling of the variability of the gas and aerosol composition of the atmosphere, as well as the assessment of the effect of atmospheric contaminants on the environment.

The subject of the study are methods and algorithms of probabilistic-stochastic modeling for constructing an effective numerical algorithm for calculating the transport of harmful impurities from linear sources on a horizontal cross-section.

The main goal of the study is to create the computer model of the microclimate of the air basin of the city for the monitoring system on the basis of the probabilistic-statistical modeling of the processes of air pollution and dispersion of contaminants.

The process of creating information systems for the process of dispersion of harmful impurities in atmospheric air is based on studies on computer graphics, expert systems and digital mapping systems. Recently such research was conducted by Zakarin E.A. with his students and Spivak LF. (1998). The results of these studies are used in the development of information systems for environmental monitoring.

In order to achieve the goal, the following tasks are set and solved in the thesis:

1) An analysis of the energy and environmental impact of road traffic on the environment;

2) Adapted mathematical models for transferring impurities of harmful emissions from vehicles in the city atmosphere;

3) Development of methods and algorithms for the transport of harmful impurities from vehicles in the atmosphere on the basis of probabilistic modeling;

4) Testing and implementation of a system for monitoring the dispersion of harmful impurities in the city's atmospheric air.

Research Methods. Research Methods are based on the use of systems analysis, simulation, information technology. Modular Web-programming methods, information technologies of object-oriented programming using design patterns have been used in the development of software tools.

The scientific novelty of the dissertation research is the use of probabilistic-statistical modeling of the transport of harmful impurities from vehicles in the atmosphere, the development of an information system for recording harmful emissions into the atmosphere by vehicles, which makes it possible to model the transfer of impurities from point and linear sources.

The main scientific provisions to be defended are:

1) Method for calculating the power of emissions of pollutants from vehicles on the road network represented as a graph;

2) Algorithm for calculation of emissions based on probabilistic statistical modeling of the transport of harmful substances in the atmosphere;

3) The system for modeling the process of scattering of harmful impurities in the atmosphere is adapted to any locality using the free web map service OpenStreetMap.

Practical significance of the study. The algorithms and software developed in the thesis work are intended for use in monitoring air pollution in the city's air basin. On the basis of a probabilistic-statistical model, dynamic processes of impurities of harmful substances in the atmosphere have been studied. A computer system has been created that allowes us to calculate the amount of emissions of harmful substances into the atmosphere from moving vehicles along the street-road network (SRN).

In the atmosphere, a particle of an impurity can move together with air currents or under the influence of external forces or through turbulent diffusion under the influence of turbulent pulsations of the atmosphere. Accordingly, the trajectory of the motion of the impurity particles can be considered as a total random path: any of its coordinates at any time can be represented as the sum of the deterministic and random components.

The developed Web-based system for monitoring the process of dispersion of harmful impurities in the city's atmospheric air simulates the spread of harmful substances emissions from road transport in the city atmosphere and will be useful in the development of routes and timetables for public transport and their assessment from an environmental point of view.

The developed Web-based monitoring system meets all the requirements for automated information systems, can be effectively used in carrying out activities to protect the environment.

Implementation of the results. The system was introduced to the East Kazakhstan branch republican state enterprise on the right of economic ownership of «Kazgidromet» in August 2018 and has been successfully used in the work of an environmental engineer in the field of atmospheric air protection.

Approbation of work. The main results of the thesis are reported and discussed at International Scientific Conference «Computational and Informational Technologies in Science, Engineering and Education (CiTech-2015)», September 24-27, 2015, KazNU, Almaty, Kazakhstan; 16th Conference on Optical Fibers and Their Applications, 17 December 2015, Lublin and Naleczow, Poland; Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments 2016, 29 May – 6 June, 2016 - Wilga, Poland; International Conference GEOMED 2016 4th International Geography Symposium, May 23 - 26, 2016 - Kemer, Antalya, Turkey; International conference of students, undergraduates and young scientists «Творчество молодых – инновационному развитию Казахстана», 12.13 April 2017, EKSTU, Ust-Kamenogorsk, Kazakhstan; in the VI Congress of the Mathematical Society of the Turkic World (TWMS 2017), October 2-5, 2017,

ENU, Astana, Kazakhstan, at the international conference «Computational and Informational Technologies in Science, Engineering and Education (CiTech-2018)», September 25 - 28, 2018. EKSTU, Ust-Kamenogorsk, Kazakhstan.

Publications. 13 research papers have been published on the topic of the thesis, including 1 article in the journal indexed in the Thomson Reuters database, 1 article in the conference materials indexed in the Thomson Reuters database, 1 article in the journal indexed in the Scopus database, 4 articles in the conference materials indexed in the Scopus database, 3 works in the editions recommended by the Education and Science Control Committee of the Ministry of Education and Science of the Republic of Kazakhstan, 4 works in collections of international conferences.

Structure of the thesis. The thesis consists of an introduction, three chapters, conclusion, a list of literature containing 131 titles, applications. The work is presented in 117 pages of typewritten text, contains 50 figures, 9 tables and 5 annexes.