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Determining the impact of motor vehicles on atmospheric air using existing predictive models

Motor vehicle emissions have become a significant air pollution problem, especially in cities with high industrial concentrations like Kryvyi Rih. Despite ongoing air quality monitoring, assessing the direct impact of vehicles is challenging. Vehicle emissions, primarily released in the lower atmosphere, affect areas where human activity is most concentrated. To evaluate the impact of motor vehicles on air pollution, mathematical models are used to estimate pollutant concentrations based on traffic volume, intensity, fuel type, and other factors. In Kryvyi Rih, areas with the highest traffic intensity were identified, and CO and NO_2 dispersion models were developed. The CALRoads View software, using the CALINE4 model, and "EOL Plus," based on the OND-86 methodology, were applied. A comparison of the results helped determine the suitable applications of each model for analyzing vehicle emissions in large urban areas.

Keywords: motor vehicles, air pollution, pollutant emissions, forecasting models, mathematical models

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Introduction

Atmospheric air is a critical component of human life, and its degradation due to anthropogenic factors adversely affects both quality of life and public health. In industrial cities such as Kryvyi Rih, air quality often fails to meet established permissible concentration limits due to emissions from industrial enterprises and motor vehicles.

With the continual increase in the number of vehicles in urban areas, emissions from road transport have become the dominant source of air pollution. Moreover, the rising vehicle count intensifies the load on urban infrastructure, resulting in traffic congestion at interchanges and intersections, which in turn leads to increased emissions. Therefore, it is crucial to conduct emission forecasting to develop effective strategies aimed at reducing air pollution.

Review of Recent Studies and Publications

Modeling the environmental impact of road transport is a vital tool for forecasting ecological consequences, and it is extensively explored in numerous scientific studies. Various methodological approaches and models are employed to address different objectives, including the prediction of transport emission levels. These models often comprise complex, multifactorial mathematical solutions that account for a multitude of variables [1,2].

Special attention is given to the development of mathematical models for assessing the dispersion of pollutants in the air. Regression models analyzing the impact of motor vehicles on atmospheric air pollution not only assess the current situation but also offer effective tools for forecasting emission trends, taking into account traffic intensity, vehicle type, and operational conditions [2,3].

Several studies actively utilize statistical forecasting methods to identify general emission trends and their correlation with transport flow parameters. Additionally, software packages for simulating the dispersion of pollutants in the atmosphere are widely applied. These tools allow for accurate evaluation of the impact of transport emissions on air quality in specific urban settings [4].

Given the continuous growth of the vehicle fleet and the heterogeneous structure of traffic flows, integrating such models into environmental monitoring systems is essential for formulating strategies to mitigate environmental harm.

Identification of Gaps in Existing Research The heavy industrial burden in Kryvyi Rih places significant pressure on the local environment, and emissions from motor vehicles further exacerbate air pollution. The concentration of pollutants frequently exceeds regulatory limits for individual substances emitted by both industrial facilities and vehicles. However, accurately quantifying the contribution of motor transport to overall pollution levels is challenging due to the mixed nature of emission sources.

In this context, it is imperative to conduct comprehensive research and develop predictive emission models that enable precise assessment of transport-related environmental impacts. The development of integrated environmental protection measures, the establishment of monitoring systems for vehicle emissions, and appropriate legal regulation are essential steps toward reducing ecological risks and safeguarding public health.

Furthermore, the introduction of modern technologies into the transportation infrastructure—such as electric vehicles and advanced emission control systems—can substantially improve environmental conditions and contribute to sustainable urban development.

Problem Statement

The aim of this study is to analyze the contribution of motor transport to the overall air pollution levels in Kryvyi Rih and to develop a predictive model for assessing this impact, along with measures to mitigate its negative environmental effects.

Research Objectives:

- analyze air pollution sources in Kryvyi Rih, with a specific focus on categorizing motor transport as a separate emission source.
- develop a model for forecasting the impact of road transport on air quality in various city zones, considering traffic flows and operational conditions.
- formulate recommendations for comprehensive environmental measures aimed at reducing the negative impact of motor transport on air quality.

Main Content and Results

Motor transport is one of the primary contributors to environmental pollution, particularly of the atmospheric environment. Various predictive modeling approaches are widely used to assess its impact on air quality. The primary methods for evaluating transport emissions include:

- *emission modeling* and *statistical methods* – involving specialized software tools to estimate the volume of pollutants emitted by vehicles.
- *emission models* – designed to quantify emissions of pollutants from vehicles, aiming to calculate the total mass of harmful substances released over a given period, depending on input parameters.
- *dispersion models* – used to determine the distribution of pollutants in the atmosphere based on meteorological conditions and emission source characteristics.
- *traffic models* – focus on analyzing traffic flow and forecasting future changes in transport systems, incorporating data on traffic, road infrastructure, and urban planning.
- *field research methods* – involve direct measurements of pollutant concentrations on-site.

These approaches allow for accurate evaluation of the scope and nature of transport-related environmental impacts.

Transport Emission Modeling. Emission modeling involves calculating the amount of pollutants released by vehicles into the atmosphere during operation. Specialized software solutions employ emission models that account for factors such as:

- vehicle type – different vehicle categories (passenger cars, trucks, buses) exhibit varied emission profiles.
- engine technologies and fuel type – diesel, gasoline, and electric vehicles differ in their environmental impacts.
- road conditions and traffic regimes – speed, stops, congestion, and other factors influence emission volumes.
- vehicle count – traffic intensity directly affects total emissions in a specific area.

Specialized transport emission modeling tools, such as MOVES, EMFAC, and COPERT, facilitate calculations that support the development of transport policies aimed at reducing air pollution. These tools are used to assess the environmental impact of motor vehicles, including the estimation of emissions of pollutants and greenhouse gases. Each model has specific features and is used in different regions and contexts.

- *MOVES* (Motor Vehicle Emission Simulator) – developed by the U.S. Environmental Protection Agency (EPA), it is used for calculating emissions from motor vehicles [5].
- *EMFAC* (Emission Factor Model) – developed by the California Air Resources Board (CARB), it is employed exclusively within the state of California for evaluating vehicle emissions and air quality management [6].
- *COPERT* (Computer Programme to Calculate Emissions from Road Transport) – a European model created under the auspices of the European Environment Agency to assess road transport emissions in EU countries [7].

COPERT uses data from the EMEP/EEA Emission Inventory Guidebook (2019 edition) [8], which outlines standards and methodologies for emission calculations based on European environmental regulations and EMEP research findings. This enables EU countries to effectively evaluate transport systems' environmental impact and develop sound environmental policies.

EMEP is a program established under the Convention on Long-Range Transboundary Air Pollution (CLRTAP) and coordinated by the United Nations Economic Commission for Europe (UNECE). It focuses on air quality monitoring and assessment across Europe, supporting international efforts to reduce air pollution.

The results of vehicle emission impact assessments obtained using the *COPERT* software are available via the interactive Emisia emission map [9] (Fig. 1).

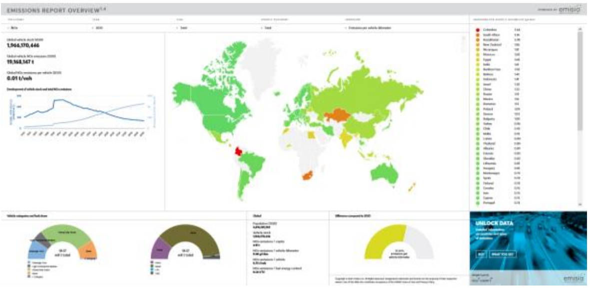

Figure 1 – Interactive emissions map "Emisia" from the COPERT software tool

Various approaches and methods are employed to determine the concentrations of pollutants in the atmosphere, including field measurements and mathematical modeling.

Field measurements are conducted using networks of stationary and mobile monitoring stations, which directly measure the concentrations of pollutants in the air. These systems provide real-time data on pollution levels but may be limited in terms of spatial coverage and typically account for emissions from all sources, such as industrial discharges and motor vehicle emissions.

Dispersion models are mathematical tools used to simulate how pollutants released into the atmosphere are transported and dispersed in space. These models allow estimation of pollutant concentrations at various distances from emission sources, taking into account several factors, including:

- *meteorological conditions* – wind speed and direction, temperature, humidity, and precipitation influence the dispersion of pollutants;
- *topography* – terrain features (mountains, hills, plains) affect airflow and the movement of pollutants;
- *type of emission source* – different sources (e.g., point or line sources, such as roadways) produce different dispersion patterns.

Examples of dispersion models include *CALRoads View* (Lakes Environmental), *CALINE4, AERMOD* (Lakes Environmental), *ADMS*, and *EOL+*, which are commonly used to assess the impact of road transport on air quality in specific areas. These models enable the prediction of pollutant concentration levels at defined locations, which is essential for planning environmentally sustainable infrastructure and minimizing health risks to the population.

- *CALRoads View* is used for modeling the impact of vehicular emissions on air quality. The software integrates the *CALINE4, CAL3QHC*, and *CAL3QHCR* models.
- *CALINE4* is specifically designed to estimate pollutant concentrations from roadway traffic and considers various road types and meteorological factors. The *CAL3QHC* and *CAL3QHCR* models are enhanced versions of *CALINE3*, incorporating the ability to simulate traffic queue effects on pollutant concentrations and account for temporal variations in meteorological conditions and traffic volumes.
- *AERMOD* is an atmospheric dispersion model developed by the United States Environmental Protection Agency (EPA) for regulatory purposes.
- *ADMS-Roads* is used for modeling vehicular emissions on urban roads and highways.
- *EOL+* is based on the *OND-86* regulatory methodology ("Organizational Normative Document 1986"), which provides a framework for calculating pollutant dispersion in the atmosphere from both industrial and vehicular sources. The *OND-86* method remains a foundational guideline for estimating ground-level concentrations from industrial emissions, although its outdated nature may limit compliance with modern environmental standards and requirements.

To investigate the impact of motor vehicles on atmospheric air pollution, we identified areas with the highest traffic intensity within the city of Kryvyi Rih and developed pollutant dispersion models for those locations.

Three high-traffic intersections were selected for detailed analysis:

- 95th Quarter Roundabout, one of the busiest traffic hubs in Kryvyi Rih, recorded a traffic volume of 1,258 vehicles in 20 minutes, equivalent to 3,855 vehicles per hour. Traffic flow was nearly uniform from all directions, with a high proportion of public transportation.
- Vilna Ichkeria Street recorded a traffic volume of 1,548 vehicles in 20 minutes, or 4,641 vehicles per hour, also featuring evenly distributed flow and significant public transport presence.
- Intersection of Metallurgiv Avenue and Nikopolske Highway recorded 1,204 vehicles in 20 minutes, or 3,609 vehicles per hour, with similarly balanced traffic from all directions and heavy public transportation use.

For further modeling, nitrogen dioxide (NO_2) and carbon monoxide (CO) were selected as the most common and representative pollutants. Emission power values (g/s) were determined for these substances based on daily traffic intensity, and a graphical representation of their dependence was developed [12].

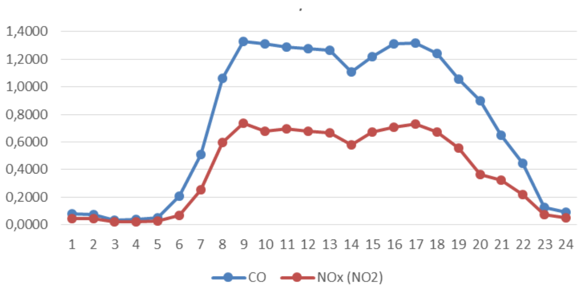

Figure 2 – Pollutant emissions during the day g/s

The graph (Fig. 2) shows that traffic intensity begins to increase from 6:00 a.m. to 9:00 a.m., after which it gradually decreases throughout the day. Between 2:00 p.m. and 6:00 p.m., traffic intensity rises again, followed by a subsequent decline. Peak traffic hours are observed at 9:00 a.m. and 6:00 p.m., corresponding to the periods of population mobility from home to work and from work to home. As traffic volume increases, emissions of air pollutants also rise accordingly.

To assess the impact of motor vehicle emissions, the *CALRoads View* software suite was used, employing the *CALINE4* dispersion model. This model was selected for its high accuracy in simulating the dispersion of pollutants emitted by motor vehicles within urban road networks. *CALINE4* enables the estimation of pollutant emissions and their concentrations while accounting for various influencing factors, including wind speed, local topography, meteorological conditions, and traffic intensity.

The model was configured to simulate dispersion under worst-case wind direction conditions, where the software automatically identifies the direction that results in the maximum pollutant concentration.

The modeling domain was defined as a square area measuring 3,000 × 3,000 meters.

The road type was categorized as urban, with a surface roughness length of 400 cm, which reflects the local turbulence of the air and affects pollutant dispersion.

The wind speed was assumed to be 3 m/s across all sections of the study area, with an air temperature of 20°C.

At the selected site, the roadway consists of three traffic lanes in each direction, amounting to a total width of 22 meters, with an additional 3 meters on each side. Thus, the total mixing zone width was set to 28 meters.

Based on these parameters, dispersion models were constructed for carbon monoxide (CO) and nitrogen dioxide (NO_2) emissions. The highest predicted concentrations were found within the 95th Quarter roundabout, Vilna Ichkeria Street, the intersection of Metallurgiv Avenue and Nikopolske Highway, as well as at other nearby intersections within the vicinity of the study area.

The 95th Quarter roundabout, a large circular intersection, is not equipped with traffic lights and connects major city avenues, each comprising three lanes in both directions. This location experiences high traffic density, including a significant volume of private vehicles and public transport.

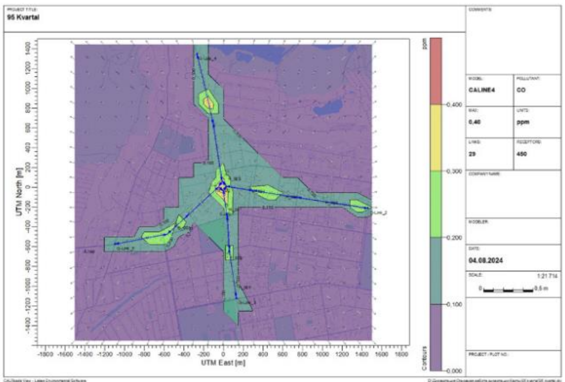

Figure 3 – CO distribution model 95 quarter.

As we can see (Fig. 3), according to the results of calculations, CO emissions do not exceed the established MPC values. Within the limits of highways, the maximum value for this section is 0.458 mg/m3 (0.4 ppm) or 0.09 MPC.

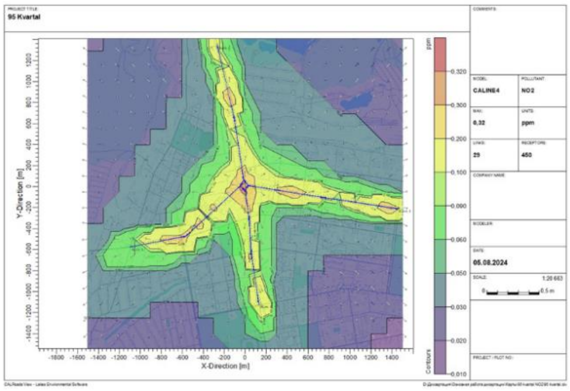

Figure 4 – Distribution model NO2 95 quarter.

The results of NO_2 emission calculations (Fig. 4) indicate that the concentration values exceed the established maximum permissible concentrations (MPC) within the intersection area under investigation. The maximum concentration recorded for this section is 0.61 mg/m³ (0.32 ppm), which corresponds to 3.04 MPC.

A pollutant dispersion model was also developed for the section of V. Ichkeria Street. This street originates in the vicinity of the 95th Quarter and terminates at a Y-shaped intersection near Artem 1 mine, Volodymyr Velykyi Street, and Mariyska Street. The primary research focus was on the intersection with Darwin Street, which functions as a bypass route for heavy-duty vehicles and is characterized by high traffic volumes, including public, passenger, and freight transport.

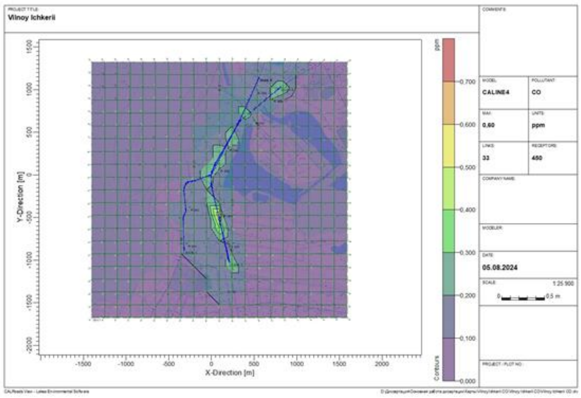

Figure 5 – CO distribution model on Vilna Ichkeria Street

In this section (Fig. 5), CO emissions do not exceed the established MPC values along the roadways. The maximum value recorded for this location is 0.687 mg/m³ (0.6 ppm), or 0.14 MPC.

The results of NO_2 emission calculations (Fig. 6) again indicate that concentration values exceed the established MPC within the intersection where the study was conducted. The maximum recorded concentration for this site is 1.2 mg/m³ (0.64 ppm), which is equivalent to 6.02 MPC.

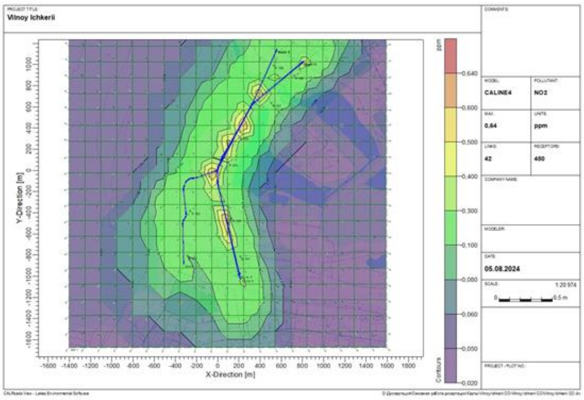

Figure 6 – Distribution model NO_2 Vilnoi Ichkerii Street

The intersection of Metalurhiv Avenue and Nikopolske Highway represents a location where one of the city's central avenues intersects with a bypass route that carries major transit highways H23, H11, and P74. This area is characterized by heavy traffic flow, including public, passenger, and heavy-duty transport.

As shown in the **CO emissions calculation results (Fig. 7)**, the values do not exceed the established MPC along the roadways. The maximum concentration observed for this section is 0.573 mg/m³ (0.5 ppm), or 0.115 MPC.

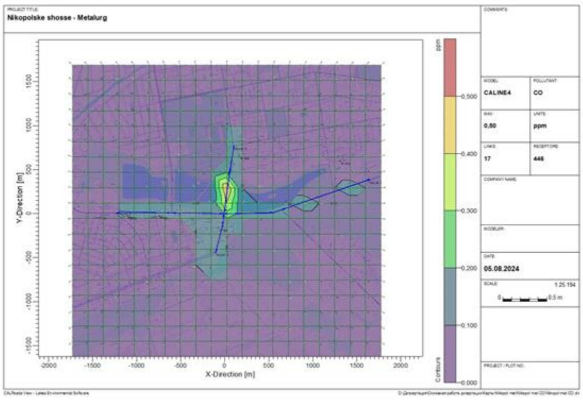

Figure 7 – CO distribution model Intersection of Metallurg Avenue and Nikopol Highway

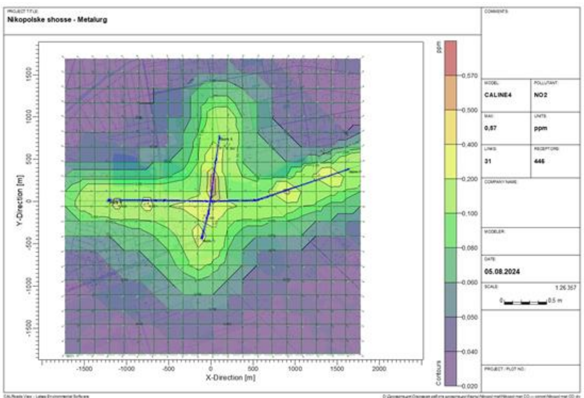

Figure 8 – NO_2 Distribution Model Intersection of Metallurg Avenue and Nikopol Highway

The NO_2 emission results (Fig. 8) show that concentration levels once again exceed the MPC at the studied intersection. The highest value recorded for this section is 1.07 mg/m³ (0.64 ppm), or 5.36 MPC.

Additionally, dispersion calculations for pollutants in the ground-level atmospheric layer were conducted for the analyzed areas using the "EOL Plus" software package, which implements the OND-86 methodology *("Method for Calculating the Concentrations of Harmful Substances in Ambient Air Emitted by Industrial Facilities")*.

The maximum concentration values based on the calculations for the investigated sections are summarized in Table 1.

Analysis of the results of ground-level pollutant dispersion calculations revealed that nitrogen dioxide (NO_2) concentrations exceed the established environmental safety standards (maximum permissible concentrations – MPC). For other substances present in vehicular emissions within the studied sections, no exceedances of MPC were recorded.

It should be noted that the pollutant dispersion calculations in the atmospheric air were performed under the worst-case meteorological conditions for each calculation point and for each pollutant, taking into account the simultaneous maximum possible emission values.

Table 1 Maximum concentration values

Research area	A polluting substance	Concen-tration mg/m3	Concen-tration, portion of MPC
95th Quarter Ring	CO	1,9	0,38
	NO_2	1,09	5,49
Vilnoi Ichkerii St.	CO	2,21	0,44
	NO_2	1,15	5,75
Intersection of Metallurgists Ave. and Nikopol Highway	CO	2,21	0,44
	NO_2	1,16	5,78

When comparing the two pollutant dispersion models, it is observed that the results for carbon monoxide (CO) differ, while nitrogen dioxide (NO_2) emissions are highly similar. This discrepancy may be attributed to differences in the calculation algorithms and emission input parameters of the respective models. Nevertheless, the general trends observed in both models remain consistent.

Conclusions.

The conducted study has established that road transport has a significant impact on the ambient air quality in the city of Kryvyi Rih. The developed models show that CO emissions do not exceed the MPC values along roadways, though they still contribute to overall air pollution. In contrast, NO_2 emissions exceed the MPC values at intersections across all studied sites.

Both dispersion modeling methods—based on the OND-86 methodology and the CALINE4 model—can be applied in future studies. However, CALINE4 offers a key advantage due to its ability to account for complex meteorological conditions and road geometries, which is particularly important in urbanized areas such as Kryvyi Rih, where numerous roads are located in close proximity to residential areas. Furthermore, the model effectively handles various types of pollutants, such as nitrogen oxides (NO_x) and carbon monoxide (CO), making it a versatile tool for analyzing the impact of road transport on air quality.

Due to its accuracy and adaptability to local conditions, CALINE4 not only supports assessment of current pollution levels but also enables the development of predictive models for designing effective environmental protection measures.

In contrast, the OND-86 model is better suited for simulating emissions from stationary sources, such as industrial facilities. While it can also be applied to assess the impact of road transport by treating it as a linear emission source, this approach limits its accuracy because vehicular emissions have dynamic characteristics influenced by changes in vehicle speed, type, and other factors.

Unlike CALINE4, which is specifically designed to model linear pollution sources such as roadways, OND-86 does not consistently account for the specific features of vehicular movement and meteorological conditions that influence pollutant dispersion along transport corridors. Therefore, although OND-86 remains useful for general pollution analysis, its precision in evaluating the environmental impact of road transport is lower compared to more specialized models like CALINE4.

Thus, the modeling of vehicular emissions provides a valuable tool for assessing the current road infrastructure, developing predictive models for the expansion or construction of new roads and transport interchanges.

The importance of predictive models lies in their ability to evaluate future environmental consequences under various scenarios of transportation infrastructure development and traffic dynamics. These models help forecast how changes in traffic volume, vehicle types, or regulatory measures may affect air pollution levels. This, in turn, enables the timely development of strategies to reduce emissions, improve the effectiveness of urban environmental initiatives, and minimize health risks for the population.

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Визначення впливу автотранспорту на атмосферне повітря за допомогою існуючих прогнозних моделей

Останнім часом викиди від автотранспорту стають дедалі серйознішою проблемою забруднення атмосферного повітря, особливо в містах із високою концентрацією промислових підприємств, таких як Кривий Ріг. Хоча в таких містах постійно здійснюється моніторинг якості повітря, визначити безпосередній вплив автотранспорту залишається складним завданням. Особливістю автомобільного забруднення є те, що шкідливі викиди, що містяться у відпрацьованих газах, потрапляють у найнижчі, приземні шари атмосфери – саме там, де відбувається основна життєдіяльність людини. Для оцінки впливу автотранспорту на забруднення повітря використовують різні методи прогнозування, які ґрунтуються на математичних моделях. Ці моделі дозволяють оцінити концентрації забруднювальних речовин у повітрі в залежності від кількості транспортних засобів, інтенсивності руху, типу палива та інших факторів.

Для проведення дослідження в пливу автотранспорту на стан забруднення атмосферного повітря міста Кривий Ріг визначено ділянки з найбільшою інтенсивністю руху та побудовані моделі розповсюдження CO та NO2. Для визначення впливу автотранспорту використано програмний комплекс CALRoads View із застосуванням моделі CALINE4 та програмний комплекс «ЕОЛ Плюс», який реалізує методику ОНД-86. На основі співставлення результатів розрахунків встановлено можливі сфери застосування кожної з моделей для аналізу викидів автомобільного транспорту в умовах крупних міських агломерацій.

Ключові слова: автотранспорт, атмосферне повітря, викиди забруднюючих речовин, прогнозні моделі математичні моделі.

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