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Ambient air quality assessment in the Kremenchuk Territorial Community based on the environmental risk concept

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✓ **Abstract.** Under conditions of urban transformation and increasing anthropogenic pressure, the assessment of ambient air quality and associated environmental risks is becoming increasingly important. A significant role in the formation of environmental hazards is played by short-term peaks in pollutant concentrations, which are often not taken into account by conventional monitoring methods. The aim of this study was to substantiate an approach to the operational assessment of environmental hazard states of ambient air at the territorial community level, taking into account natural and anthropogenic factors. The study employed methods of logical analysis of scientific research findings, system analysis of factors influencing air quality formation, elements of mathematical modelling of pollutant dispersion processes, and a risk-oriented approach to assessing the impact of pollution on the population. The concept of natural-anthropogenic fluctuations in ambient air quality within a territorial community was substantiated, taking into account natural factors, emergency and war-related events, and anthropogenic hazard sources. An Increased Environmental Risk Index (IER) was introduced as an analytical indicator for assessing the short-term effects of air pollution on public health. An integrated model for environmental assessment was proposed, combining mathematical modelling (Gaussian, jet, and energy models) with instrumental measurements. Regularities in the formation of local zones of ingredient and acoustic pollution under conditions of intensive use of individual power generators were identified. The proposed approach makes it possible to promptly identify periods of increased risk and assess the spatial heterogeneity of environmental hazards. The obtained results may be used by local authorities to improve ambient air monitoring systems, develop measures for managing anthropogenic pressure, and implement early warning mechanisms for informing the population about increased levels of environmental hazard.

✓ **Keywords:** ambient air quality; environmental risk; anthropogenic pressure; natural-anthropogenic fluctuations; mathematical modelling

✓ Introduction

Under conditions of increasing anthropogenic pressure, ensuring adequate ambient air quality has become an important area of environmental safety management. The impact

of emergency and war-induced factors leads to the emergence of new types of environmental hazards. This necessitates the assessment of ambient air quality within territorial

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communities based on the concept of a health-oriented environment, which is interpreted by T.Ye. Ryhas (2026) as a dynamic socio-ecological-economic system capable of adapting to external challenges, including climate change, anthropogenic threats, and crisis situations, by enhancing environmental safety, increasing the resilience of urban ecosystems, and improving the quality of life of the population. In this context, environmental safety serves not only as a prerequisite for environmental protection but also as a fundamental basis for health-oriented urban development.

Contemporary studies focus not only on annual average concentrations of air pollutants but also on short-term pollution episodes, which may cause significant adverse health effects. B. Hoffmann *et al.* (2021) analysed current scientific evidence regarding the impact of air pollution on human health, which formed the basis for updating the World Health Organization air quality guidelines. The study demonstrated that adverse health effects associated with fine particulate matter (PM_{2.5}), nitrogen dioxide, and other air pollutants may occur even at concentrations previously considered relatively safe. The authors emphasised the need to revise existing approaches to ambient air quality management in light of current knowledge regarding risks to public health.

S. Khomenko *et al.* (2021) assessed the impact of air pollution on premature mortality in nearly one thousand European cities. The analysis revealed that a substantial proportion of premature deaths could be prevented if the recommended air quality levels were achieved. The authors also identified significant intercity differences in environmental risk levels, highlighting the need to develop localised air quality management strategies. In a subsequent study, S. Khomenko *et al.* (2023) analysed the spatial and sector-specific contributions of various emission sources to ambient air pollution and associated mortality in European cities. Using a health impact assessment approach, the authors evaluated the contribution of individual economic sectors to particulate matter pollution and related health risks. The results demonstrated that the structure of emission sources varies considerably among cities, while the effectiveness of environmental protection measures largely depends on the appropriate identification of priority emission sources.

Particular attention has recently been paid to the concept of short-term exposure, which focuses on assessing the health effects associated with short-term episodes of elevated pollutant concentrations. Unlike traditional approaches based mainly on annual average pollutant concentrations, contemporary studies indicate that short-term pollution peaks play a significant role in environmental risk formation and the occurrence of acute adverse health outcomes. Thus, W. Yu *et al.* (2024) performed a global assessment of mortality associated specifically with short-term exposure to air pollution. Based on data analysis from more than 13,000 cities worldwide, the authors estimated that short-term exposure to fine particulate matter is associated with approximately one million premature

deaths annually, accounting for nearly 2% of total global mortality. These findings confirmed that short-term pollution episodes make a substantial contribution to the global burden of disease and should therefore be considered in environmental risk assessment.

Y. Ma *et al.* (2024) analysed the relationship between short-term changes in particulate matter and NO₂ concentrations and mortality based on nearly nine million death records from four countries. Using advanced causal modeling methods, the authors identified a statistically significant association between increased pollutant concentrations and higher all-cause mortality. The findings emphasised the importance of considering short-term variations in ambient air quality when assessing environmental risks. C. Demoury *et al.* (2024) investigated the effects of short-term exposure to PM_{2.5}, PM₁₀, NO₂, O₃, and black carbon on natural mortality in Belgium. The study demonstrated a significant association between increased pollutant concentrations and the risk of death from natural causes. Particular attention was paid to the identification of vulnerable population groups for whom short-term pollution episodes pose an increased health risk.

Therefore, the findings of contemporary studies convincingly demonstrate that short-term peaks in pollutant concentrations represent an important factor in the formation of public health risks. However, most existing approaches focus primarily on the epidemiological and statistical assessment of the consequences of short-term exposure, whereas the integration of short-term pollution indicators, meteorological conditions, local emission sources, and the natural self-purification capacity of a territory into a unified environmental risk assessment framework remains insufficiently explored. This necessitates the development of risk-oriented approaches to ensuring adequate ambient air quality at the territorial community level.

The aim of this study was to apply the environmental risk concept to the operational assessment of ambient air quality in the Kremenchuk Territorial Community (KTC) under the influence of natural and anthropogenic factors contributing to environmental hazards. To achieve this aim, the following objectives were addressed: to analyse the factors affecting ambient air quality formation in an urbanised area; to assess the influence of short-term pollution peaks on the level of environmental risk to the population; and to substantiate approaches to ambient air quality management, taking into account anthropogenic pressure and the bioregulatory potential of the territory.

▼ Materials and Methods

The KTC, characterised by a specific structure of environmental hazards, was selected as the study area. The urban environment should be considered as a complex urban geosystem in which natural conditions, features of spatial organisation, and anthropogenic pressures determine the course of ecological processes (Serohin & Kostrikov, 2024). The uniqueness of the environmental situation in the KTC is determined by the combination of natural conditions,

transformation of natural landscapes during urbanisation, and the presence of numerous anthropogenic facilities. The interaction of these factors forms a complex system of environmental risks manifested in changes in ambient air quality, soils, surface and groundwater quality, as well as in the formation of noise pollution within the community. The combination of valley relief, the extensive water surface of the Kremenchuk Reservoir, and temperature inversions creates air stagnation zones where pollutants accumulate. Thus, the natural environment of the territory is not only affected by anthropogenic impacts but also actively contributes to their manifestation. These conditions determine the occurrence of natural-anthropogenic fluctuations in ambient air quality.

The study employed methods of analysis and synthesis of scientific findings, system analysis of factors influencing air quality formation, elements of mathematical modelling of pollutant dispersion processes, and a risk-oriented approach to assessing the impact of pollution on the population. Current approaches to assessing the impact of air pollution on public health are based on the concept of short-term exposure. Quantitative methods for assessing health risks associated with ambient air pollution rely on the use of Relative Risk (RR) and Population Attributable Fraction (PAF) indicators, as well as AirQ and AirQ+ software tools recommended by the World Health Organization (Amini *et al.*, 2024). Quantitative assessment of such impacts at the territorial community level was performed using the Relative Risk (RR) indicator of adverse health outcomes, which is widely applied in epidemiological studies investigating the effects of ambient air pollution on public health (Khomenko *et al.*, 2021):

$$RR = e^{\beta \Delta C}, \quad (1)$$

where β is the population sensitivity coefficient to changes in pollutant concentration (for $PM_{2.5}$, approximately 0.0008-0.0012 per $1 \mu g/m^3$); ΔC is the increase in pollutant concentration relative to the background level, $\mu g/m^3$.

To assess the proportion of health risk attributable to ambient air pollution, the Population Attributable Fraction (PAF) indicator was used:

$$PAF = \frac{RR-1}{RR}. \quad (2)$$

The reduction in the increase of pollutant concentrations in the near-surface atmospheric layer under the influence of natural purification mechanisms can be described by the following generalised relationship:

$$\Delta C_{adj} = \Delta C - \frac{M_{dep}}{V_{mix}}, \quad (3)$$

where ΔC_{adj} is the adjusted increase in pollutant concentration taking into account natural deposition processes; M_{dep} is the mass of pollutant particles deposited by vegetation (kg); V_{mix} is the volume of air within the atmospheric mixing layer (m^3).

For the operational assessment of environmental hazard levels in the near-surface atmospheric layer under conditions of short-term fluctuations in pollutant concentrations, the Increased Environmental Risk Index (IER) was applied:

$$IER = \frac{\Delta C \cdot F_{met} \cdot F_{src}}{B_{reg}}, \quad (4)$$

where F_{met} is an indicator characterising the atmospheric dispersion capacity and accounting for meteorological conditions (wind speed, the occurrence of temperature inversions, and the height of the atmospheric mixing layer); F_{src} is an indicator of anthropogenic pressure intensity reflecting the cumulative impact of major emission sources (transport, stationary sources, autonomous diesel generators, emergency and war-induced emissions); B_{reg} is an indicator of the bioregulatory potential of the territory characterising the ability of green infrastructure to reduce pollutant concentrations in the near-surface atmospheric layer (the main contributing factors include the area of green spaces, leaf surface area, and the capacity of vegetation to deposit fine particulate matter).

The structure of the index is based on the principles of risk-oriented assessment, according to which the level of environmental risk increases with increasing pollutant concentrations, unfavourable meteorological conditions, and the intensity of local emission sources. At the same time, the presence of green spaces and other natural ecosystem elements contributes to the self-purification of ambient air and reduces the level of risk, which is accounted for through the indicator of the territory's bioregulatory potential. The proposed approach makes it possible to consider the specific features of urbanised areas, where local short-term pollution peaks frequently occur and are not always reflected by conventional air quality indices.

The processes of sound wave propagation in ambient air were described using a fragment of the integrated model of ecological safety and sustainable development of a health-oriented urban territorial community developed by the authors (Ryhas, 2026):

$$\frac{\partial^2 P}{\partial t^2} - c^2 \nabla^2 P = 0, \quad (5)$$

where P is the sound pressure (acoustic load); c is the speed of sound in air; and ∇^2 is the Laplace operator.

This equation describes the propagation of acoustic waves in an elastic medium. Its solutions take the form of wave functions characterising the propagation of sound energy in space. However, for practical engineering calculations, a simplified energy-based model is used, which accounts for the attenuation of sound intensity with distance:

$$\frac{dP}{dr} = -\frac{2I}{r} - \alpha I. \quad (6)$$

The solution of this equation is given by:

$$P(r) = P_0 \cdot \frac{1}{r^2} \cdot e^{-\alpha r}. \quad (7)$$

This equation was used to calculate noise pollution levels. The integrated pollution index was determined as the average value of the relative concentrations of the investigated pollutants with respect to their maximum permissible concentrations. This approach makes it possible to comprehensively assess the state of ambient air within the study area and determine the level of anthropogenic pressure. To describe the processes of transport, dispersion, and transformation of pollutants in ambient air, a corresponding fragment of the mathematical model within the concept of environmentally safe functioning of a health-oriented territorial community was employed (Ryhas, 2026):

$$\frac{\partial c}{\partial t} + u \frac{\partial c}{\partial x} + v \frac{\partial c}{\partial y} + w \frac{\partial c}{\partial z} = \frac{\partial}{\partial x} \left(k_x \frac{\partial c}{\partial x} \right) + \frac{\partial}{\partial y} \left(k_y \frac{\partial c}{\partial y} \right) + \frac{\partial}{\partial z} \left(k_z \frac{\partial c}{\partial z} \right) + S - R, \quad (8)$$

where C denotes the pollutant concentration; u , v , and w represent the components of air flow velocity; K_x , K_y , and K_z are the turbulent diffusion coefficients in the x , y , and z directions, respectively; S is the emission source strength; R represents the rate of chemical transformations and pollutant deposition. One of the most commonly used approaches for solving Equation (8) is the Gaussian plume model, widely applied in atmospheric pollution studies (Johnson, 2022):

$$C(x, y, z) = \frac{S}{2\pi u \sigma_y(x) \sigma_z(x)} \exp\left(-\frac{y^2}{2\sigma_y^2(x)}\right) \exp\left(-\frac{(z-H)^2}{2\sigma_z^2(x)}\right), \quad (9)$$

where the main parameters are the emission rate, wind speed, and dispersion coefficients characterising turbulent air mixing.

Maximum pollutant concentrations are observed along the plume centerline (at $y=0$) and near the effective source height ($z \approx H$). As the distance from the source (x) increases, the plume expands, resulting in a decrease in pollutant concentrations. Physically, this model describes the formation of a so-called "plume" – an elongated cloud of pollutants transported by wind and gradually expanding in both horizontal and vertical directions (Khomenko *et al.*, 2023).

The following assumptions were adopted when applying the Gaussian plume model: emissions are continuous and stationary over time; wind speed and direction remain constant during the calculation period; atmospheric conditions are homogeneous within the study area; turbulent mixing of pollutants is described by the dispersion coefficients σ_y and σ_z ; and chemical transformations of pollutants during transport are neglected. The Gaussian model was applied to assess pollutant dispersion at distances greater than 10 m from the emission source.

Despite its widespread applicability, the Gaussian model has several limitations when applied to low-height emission sources, such as power generators. First, the model assumes that pollutants are instantaneously distributed according to a Gaussian profile immediately after

release. In real conditions, a generator produces a directed exhaust jet characterised by its own velocity, temperature, and flow structure. Second, the Gaussian model is generally valid at distances ranging from tens to hundreds of meters, whereas the impact zone of generators is typically limited to 1-10 m. Third, the model does not account for the influence of local obstacles (buildings, fences, and trees), which substantially affect turbulence characteristics in the near-surface atmospheric layer.

Thus, the application of the Gaussian model for describing pollutant dispersion from autonomous power generators in the near-field zone is limited. This is because, in the immediate vicinity of the source (within several meters), turbulent mixing processes between the exhaust jet and the surrounding air dominate and are not adequately represented by the classical Gaussian approach. To adequately describe processes occurring in the immediate vicinity of the emission source, the use of a jet model is considered appropriate. In this case, emissions are treated as a turbulent jet that gradually expands due to mixing with the surrounding air (Johnson, 2022). In a simplified form, the solution of Equation (8) can be expressed as:

$$C(x) = \frac{S}{u \cdot A(x)}, \quad (10)$$

where $A(x)$ is the cross-sectional area of the expanding jet. Typically, $A(x) \sim (\alpha x)^2$; therefore:

$$C(x) \sim \frac{S}{u \cdot x^2}. \quad (11)$$

Unlike traditional approaches, this study proposes the combined use of Gaussian, jet, and energy-based models for assessing natural-anthropogenic fluctuations in ambient air quality. The authors' approach is based on the differentiated application of these models depending on the spatial scale of the process: the jet model is used to describe pollutant dispersion in the near-field zone (up to 10 m) from autonomous power generation sources; the Gaussian model is applied to assess pollutant dispersion at greater distances; and the energy-based model is employed to evaluate acoustic load. In addition, the modelling results are integrated with the Increased Environmental Risk Index (IER), which accounts for meteorological conditions, the intensity of local emission sources, and the bioregulatory potential of the territory. Such an approach makes it possible to consider the specific features of short-term pollution peak formation under the conditions of the KTC.

Instrumental studies within the KTC were carried out in several urban areas characterised by intensive use of electric generators. The study objects included gasoline and diesel generators with a capacity of 2-5 kW, which are most widely used as backup power sources in the residential sector. Ambient air sampling and noise level measurements were performed at distances of 1, 5, 10, and 15 m from an operating generator, taking into account the prevailing wind direction. Monitoring points were located at

a height of 1.5 m above ground level, corresponding to the average height of the human breathing zone. Concentrations of carbon monoxide (CO), nitrogen dioxide (NO₂), sulfur dioxide (SO₂), and fine particulate matter were determined in ambient air. Each measurement cycle lasted 20 min. Measurements were recorded every 2 min, resulting in 10 consecutive readings at each monitoring point. Average values of pollutant concentrations and noise levels were subsequently used for analysis.

Measurements were conducted in the absence of atmospheric precipitation and at wind speeds ranging from 0.5 to 2.0 m/s. The obtained experimental data were used to verify mathematical models of pollutant dispersion and to assess environmental risk. Particular attention was paid to areas characterised by a high concentration of commercial infrastructure facilities, including retail stores, catering establishments, and other service sector enterprises, where generators were used as backup power sources (Fig. 1).

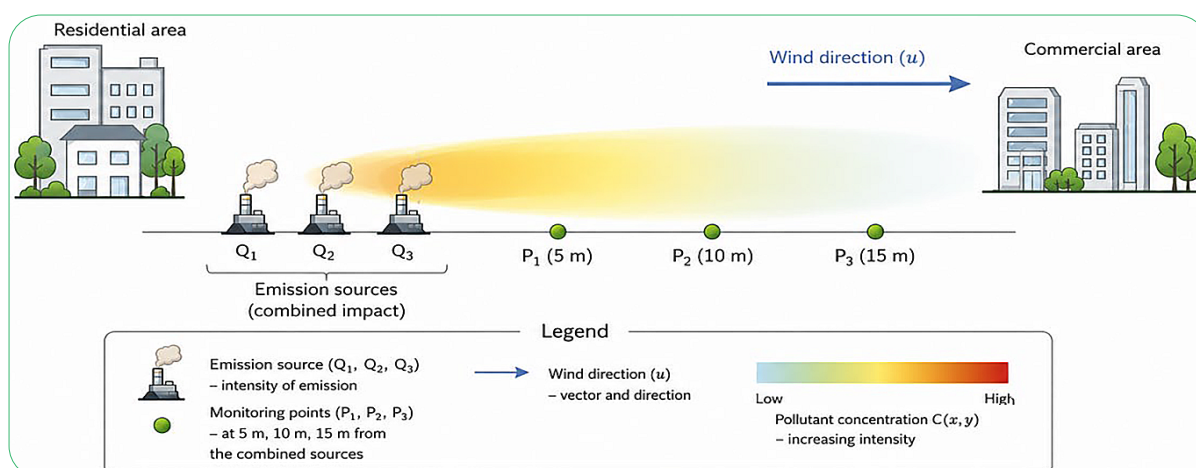


Figure 1. Schematic representation of the spatial arrangement of emission sources and monitoring points with consideration of pollutant dispersion in the near-surface atmosphere

Source: created by the authors

The assessment of acoustic load was carried out at the same monitoring points where pollutant concentration measurements were performed. Noise level measurements were conducted at different distances from the generators, taking into account the spatial arrangement of noise sources and the direction of sound wave propagation. The main parameter determined during the study was the equivalent continuous A-weighted sound pressure level (LAeq, dBA).

Results and Discussion

Contemporary fluctuations in ambient air quality are formed not only under the influence of traditional

emission sources (industry, heat and power facilities, and transport) but also as a result of the widespread use of electric generators at critical infrastructure facilities, commercial establishments, healthcare institutions, and in the residential sector due to regular damage to energy infrastructure, as well as emergency- and war-induced fires and the destruction of fuel and energy facilities. A generalised model describing the interaction between natural and anthropogenic factors and emergency events that determine short-term fluctuations in pollutant concentrations in the near-surface atmospheric layer was proposed (Fig. 2).

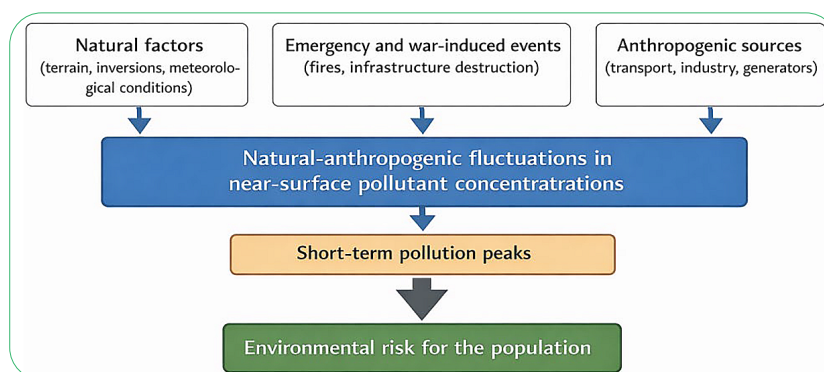


Figure 2. Conceptual scheme of the formation of natural-anthropogenic fluctuations in ambient air quality within a territorial community

Source: created by the authors

An assessment of the Relative Risk (RR) was carried out for the conditions of the KTC. For a short-term increase in $PM_{2.5}$ concentration by $20 \mu g/m^3$ relative to the background level and assuming $\beta = 0.001$, Equation (1) yields $RR \approx 1.02$. Thus, the relative risk of adverse health effects may increase by approximately 2% during periods of peak ambient air pollution. For the KTC, with $RR = 1.02$, Equation (2) gives $PAF \approx 0.0196 \approx 1.96\%$, indicating that approximately 2% of adverse health outcomes in the population may be associated with short-term peaks in ambient air pollution. Since the RR value is determined by the concentration increment (ΔC), a key objective of environmental safety management is to reduce the amplitude of peak pollutant concentrations.

One of the natural mechanisms for reducing ΔC is the deposition of pollutants by urban vegetation. Assessment of the bioregulatory potential of vegetation showed that green spaces within the KTC annually remove hundreds of tons of fine particulate matter from the atmosphere. In addition, based on the area characteristics of green spaces and the average biological productivity of vegetation, the integrated bioregulatory potential of urban vegetation was determined. The calculations demonstrated that the annual oxygen production amounts to approximately 130 thousand tonnes per year. This value was used as an integral indicator of the biological activity of vegetation and its potential capacity for phytoremediation of ambient air and does not characterise changes in atmospheric oxygen concentrations. According to J. Liao & H.Y. Kim (2024), urban green spaces contribute to pollutant deposition, regulation of microclimatic conditions, and enhancement of the environmental resilience of urbanised areas. Similar conclusions were reported by P. Kumar *et al.* (2024), who considered green infrastructure as one of the key natural mechanisms for reducing anthropogenic pressure on ambient air quality.

Thus, the presence and spatial distribution of green spaces can significantly affect the concentration regime of ambient air. Through the processes of dry deposition of aerosol particles and the absorption of gaseous pollutants by vegetation, green infrastructure functions as a natural regulator of both the gaseous composition of ambient air and the amplitude of short-term fluctuations in pollutant concentrations, thereby directly influencing the level of environmental risk for the population. Analysis of the spatial distribution of emission sources and green spaces within the KTC revealed pronounced spatial asymmetry. The northern industrial district is characterised by a high concentration of pollution sources and insufficient greening, which enhances concentration increments (ΔC) and, consequently, increases RR values. In contrast, central urban areas with well-developed green infrastructure exhibit lower amplitudes of concentration fluctuations. Therefore, environmental risk within the territorial community is spatially differentiated and depends on the interplay among the following factors: the intensity of anthropogenic emissions, meteorological conditions affecting pollutant dispersion, and the bioregulatory potential of the territory.

Quantitative assessment of RR makes it possible to move from a descriptive analysis of ambient air quality to environmental risk modelling and the development of an early warning system. It should be noted that the actual level of environmental hazard is determined not only by pollutant concentrations but also by the combined influence of natural and anthropogenic factors affecting the formation of short-term pollution peaks. These factors include, in particular, meteorological conditions, the intensity of anthropogenic emissions, the spatial distribution of pollution sources, and the natural self-purification capacity of the environment. The need for an integrated consideration of such factors as ambient air quality, noise exposure, the availability of sufficient green infrastructure, and other characteristics of the urban environment in assessing the condition of territorial communities is confirmed by recent studies on the impact of urban environments on public health (Arriazu-Ramos *et al.*, 2025). For the operational assessment of environmental hazard levels in the near-surface atmospheric layer under conditions of short-term concentration fluctuations, it is advisable to use an integral indicator that summarises the influence of the main natural and anthropogenic risk factors, namely the Increased Environmental Risk Index (IER) (Equation 4).

Existing air quality assessment indices, particularly the Air Quality Index (AQI), are widely used to inform the public about current levels of ambient air pollution. Analysis of contemporary approaches to calculating such indices indicates that they are primarily based on pollutant concentrations and are used for the operational assessment of ambient air quality and the potential health impacts of pollution (Shihab, 2023). However, conventional indices only partially reflect environmental risk under conditions of short-term natural-anthropogenic fluctuations, since they do not account for meteorological dispersion conditions, the intensity of local emission sources, or the natural self-purification capacity of the environment. As demonstrated by recent studies on short-term exposure (Yu *et al.*, 2024; Demoury *et al.*, 2024), the combination of short-term pollutant concentration peaks and unfavourable accumulation conditions may substantially increase health risks.

In this regard, the proposed Increased Environmental Risk Index (IER) should not be considered an alternative to traditional air quality indices but rather as a complementary tool. Unlike AQI, the IER is aimed at assessing the potential environmental risk associated with hazardous short-term pollution episodes and takes into account not only changes in pollutant concentrations but also the conditions governing their accumulation and dispersion in ambient air, the intensity of local emission sources, and the bioregulatory potential of the territory. This approach makes it possible to use the IER for analysing scenarios of environmental change and forecasting periods of elevated environmental hazard at the territorial community level.

As follows from Equation (4), the IER value increases with increasing pollutant concentration increments,

deterioration of meteorological dispersion conditions, and increasing anthropogenic pressure, whereas it decreases with increasing bioregulatory potential of the territory. For the practical application of the IER and the operational assessment of changes in environmental hazard levels under short-term fluctuations in ambient air quality, a tentative

risk scale was proposed (Table 1). The boundaries of the proposed categories were determined based on the analysis of typical scenarios characteristic of the KTC, including background conditions, calm weather episodes, temperature inversions, widespread use of autonomous generators, and accidental emissions during fires at fuel and energy facilities.

Table 1. Tentative scale of environmental risk levels under conditions of short-term fluctuations in ambient air quality

IER Value	Environmental Risk Level
$IER < 15$	Background
$15 \leq IER < 30$	Elevated
$30 \leq IER < 60$	High
$IER \geq 60$	Critical

Note: the proposed scale is tentative and intended for the comparative assessment of environmental risk levels under different ambient air quality scenarios. The threshold values between risk categories were established based on expert analysis of IER calculation results and may be refined during further validation of the methodology in other territorial communities

Source: developed by the authors

Thus, the IER is determined by pollutant concentrations in the near-surface atmospheric layer, meteorological conditions affecting their dispersion, the intensity of anthropogenic pressure, and the bioregulatory potential of the territory. Therefore, it can be considered an integral indicator characterising the cumulative influence of natural and anthropogenic factors on the formation of short-term peaks in ambient air pollution. Analysis of ambient air quality data and meteorological conditions during temperature inversion episodes revealed a short-term increase in PM_{10} concentrations of approximately $20 \mu\text{g}/\text{m}^3$ above the background level ($\Delta C = 20 \mu\text{g}/\text{m}^3$). Under unfavourable meteorological conditions (low wind speed and temperature inversion), the meteorological coefficient was assumed to be $F_{met} \approx 2$. During periods of intensive use of electric generators and increased traffic load, the anthropogenic pressure coefficient was estimated as $F_{src} \approx 1.5$. The bioregulatory potential of the territory, determined by the presence of green infrastructure, was estimated by the coefficient $B_{reg} \approx 1.2$. According to Equation (4), the calculated value of the Increased Environmental Risk Index was $IER \approx 50$. This value indicates a high level of short-term environmental risk resulting from the combined effects of unfavourable meteorological conditions and significant anthropogenic pressure. The findings of R.S. Sokhi *et al.* (2021) also confirmed that

even under conditions of substantial reductions in anthropogenic emissions, pollutant concentrations remain strongly dependent on meteorological factors and atmospheric transport conditions, highlighting the importance of considering these factors in environmental risk assessment.

It should be noted that, in the proposed model, ΔC is used as a normalised indicator of concentration increase; therefore, the IER is considered a dimensionless conditional index reflecting the integrated influence of natural and anthropogenic factors on environmental risk levels. Considering these circumstances, the following indicative ΔC values were adopted for scenario modelling: 10, 15, 20, 25, and $40 \mu\text{g}/\text{m}^3$. These values represent different levels of short-term increases in fine particulate matter concentrations in the near-surface atmospheric layer, ranging from moderate increases typical of ordinary traffic-related pollution to extreme situations that may occur under unfavorable meteorological conditions or during accidental emissions. Using the above-mentioned ΔC values, together with the adopted coefficients of meteorological conditions (F_{met}), anthropogenic pressure (F_{src}), and the bioregulatory potential of the territory (B_{reg}), a scenario-based assessment of the Increased Environmental Risk Index (IER) was performed for the conditions of the KTC. The results of this analysis are presented in Table 2.

Table 2. Scenarios of IER formation for the KTC

Scenario	$\Delta C, \mu\text{g}/\text{m}^3$	F_{met}	F_{src}	B_{reg}	IER	Risk level
Normal dispersion conditions	10	1.0	1.0	1.2	8.3	Moderate
Calm conditions (low wind speed)	15	1.5	1.0	1.2	18.8	Elevated
Temperature inversion	20	2.0	1.0	1.2	33.3	High
Widespread use of diesel generators	25	2.0	1.5	1.2	62.5	Very high
Fire at an oil refinery	40	2.5	2.0	1.2	166.7	Critical

Source: developed by the authors

The obtained results indicate that the highest IER values are formed under the combined influence of unfavourable meteorological conditions and intensive anthropogenic emissions, which is typical of periods characterised

by temperature inversions, widespread use of diesel generators, or accidental events at industrial facilities. The application of this indicator makes it possible to: promptly assess changes in environmental hazard levels; predict periods of

elevated risk; establish early warning systems for the population; and support management decisions aimed at reducing anthropogenic pressure.

The obtained IER values for the scenario involving widespread use of diesel generators ($IER = 62.5$) indicate the formation of a critical level of environmental risk. Similar trends were reported by R. Zalakeviciute *et al.* (2024), who demonstrated that during the energy crisis in Quito, concentrations of major air pollutants in the urban environment increased by 15-35% compared to background conditions. In the present study, the IER value for the scenario involving a fire at an oil refinery reached 166.7, indicating a substantial increase in environmental risk under accidental emission conditions. These findings are consistent with contemporary approaches to risk-oriented ambient air quality management and short-term exposure assessment proposed by the World Health Organization (2021a; 2021b) and by S. Khomenko *et al.* (2021; 2023).

Thus, the IER can be used as an analytical tool within environmental monitoring systems and ambient air quality management frameworks for urbanised areas. High IER values for the KTC can be explained by the combined influence of natural and anthropogenic factors. Valley topography, the extensive water surface of the Kremenchuk Reservoir, and the occurrence of temperature inversions create favourable conditions for pollutant accumulation in the near-surface atmospheric layer. Additional impacts are associated with the high concentration of local emission sources, particularly road transport, which contributes to the formation of short-term pollution peaks.

The application of the concept of natural-anthropogenic fluctuations in ambient air quality and the determination of IER provide an analytical basis for the development of an ambient air quality management system at the territorial community level. Unlike conventional air quality indices, particularly the Air Quality Index (AQI), which is primarily based on current pollutant concentrations (Shihab, 2023), the IER simultaneously accounts for short-term variations in pollutant concentrations, meteorological dispersion conditions, the intensity of local emission sources, and the bioregulatory potential of the territory. In addition, the study proposes a combined modelling approach involving the application of jet, Gaussian, and energy-based models. Such an approach makes it possible not only to assess the current state of ambient air quality but also to predict the occurrence of short-term hazardous pollution episodes, which are not considered by conventional air quality indices.

The ambient air quality management mechanism was considered as a system of interrelated components, including reduction of anthropogenic pressure, optimisation of the spatial distribution of emission sources, development of green infrastructure, and improvement of operational environmental monitoring and environmental risk forecasting systems. One of the key directions for improving ambient air quality is the reduction of anthropogenic emissions. The analysis of the collected empirical data demonstrated that, within the KTC, the most significant pollution sources are

road transport, industrial enterprises, and autonomous electric generators, which are widely used during periodic power outages.

The reduction of transport-related emissions can be achieved through the optimisation of traffic flows, development of public transportation, establishment of low-emission or restricted traffic zones in central urban areas, and implementation of advanced traffic management systems. Restrictions on heavy-duty vehicle traffic in residential areas are also applied. In authors opinion, effective measures for reducing the adverse impacts of autonomous electric generators include strict compliance with technical requirements for their placement, the use of noise mitigation and exhaust filtration systems, and a transition to alternative backup energy sources that exert minimal impacts on the environmental safety of territorial communities.

An important direction for reducing pollutant concentrations is the spatial regulation of emission source placement and the formation of a rational urban structure. This approach may be considered a form of mitigating the unfavourable positioning of pollution sources through the use of natural environmental factors. Natural features of the territory, including topography, prevailing wind directions, and the presence of water bodies or green spaces, can be used as additional regulators of the spatial distribution of pollutants. One of the most effective approaches to optimising the spatial positioning of emission sources is urban greening, which contributes to reducing pollutant transport towards residential areas. A rational combination of technical measures, spatial organisation of the urban environment, and the development of green infrastructure creates the prerequisites for establishing an adaptive ambient air quality management system for the territorial community, capable of reducing the amplitude of short-term fluctuations in pollutant concentrations and minimising environmental risks to the population. Within the KTC, the principles of functional zoning are applied, providing for the separation of residential, industrial, and transport areas. Based on the above-mentioned findings, an integrated ambient air quality management system for the KTC is proposed (Fig. 3). The proposed system is based on the integration of environmental monitoring, analytical risk assessment, and the implementation of management decisions. The initial stage involves environmental monitoring using a network of stationary monitoring stations, a mobile laboratory, and mobile sensor units, which provide operational data on actual pollutant concentrations. Subsequently, the obtained data are analysed, and concentration increments relative to background levels (ΔC) are determined, after which the IER is calculated to characterise the current level of environmental hazard to the population. The assessment results are further used to predict periods of elevated environmental risk and to support appropriate management decisions, including traffic regulation, restrictions on the operation of specific emission sources, or limitations on the use of autonomous generators. The system also accounts the implementation of long-term measures aimed at the

development of green infrastructure, thereby enhancing the bioregulatory potential of the environment and contributing to the reduction of pollutant concentrations.

Collectively, these components form an adaptive management system aimed at ensuring adequate ambient air quality within the territorial community.

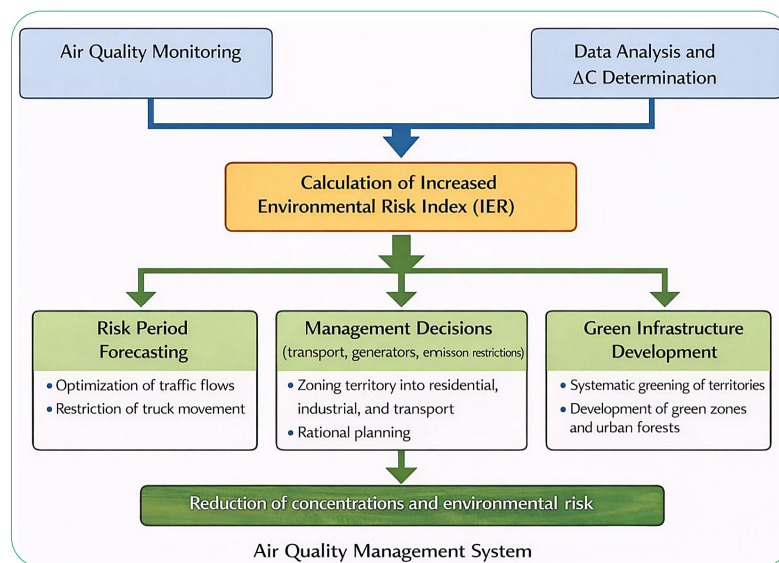


Figure 3. Structural framework of the air quality management system for a territorial community

Source: developed by the authors

At present, there is an urgent need for comprehensive monitoring of the impacts of individual power generation sources on ambient air quality and the acoustic environment of territorial communities. The application of instrumental methods for measuring pollutant concentrations in ambient air and assessing noise levels makes it possible to determine the nature and magnitude of anthropogenic pressure generated by the widespread use of generators in urban areas. In cases where generators are densely

distributed within a limited area, for example, along specific street sections or near clusters of commercial facilities, overlapping zones of pollutant dispersion and noise propagation may occur. This results in the formation of a complex anthropogenic load manifested simultaneously through ambient air pollution and increased acoustic impacts. The results of measurements of the concentrations of major air pollutants at the monitoring sites within the KTC are presented in Table 3.

Table 3. Concentrations of air pollutants at ambient air monitoring sites and their compliance with regulatory standards

Monitoring site	Distance, m	CO, mg/m ³	MAC*	NO ₂ , mg/m ³	MAC	SO ₂ , mg/m ³	MAC	PM ₁₀ , mg/m ³	MAC	K	Z	I
1	1	4.8	5.0	0.19	0.20	0.03	0.5	0.14	0.15	0.92	2.90	0.73
2	5	2.9	5.0	0.13	0.20	0.02	0.5	0.10	0.15	0.58	1.94	0.49
3	10	1.6	5.0	0.08	0.20	0.015	0.5	0.07	0.15	0.33	1.22	0.31
4	15	1.1	5.0	0.05	0.20	0.012	0.5	0.05	0.15	0.23	0.82	0.21

Note: *MAC – Maximum Allowable Concentration

Source: authors' own research findings

The obtained values approached the maximum allowable concentrations at some monitoring sites. The most pronounced impact was observed in areas characterised by a high density of generators, where

overlapping emission dispersion zones occurred. To generalise the monitoring results, an integrated assessment of ambient air quality at the monitoring sites was performed (Table 4).

Table 4. Integrated assessment of ambient air pollution levels at the monitoring sites

Monitoring site	C(CO)/MAC	C(NO ₂)/MAC	C(PM ₁₀)/MAC	Integrated pollution index (Ip)	Pollution level
1	0.84	0.90	0.87	0.87	Elevated
2	0.52	0.60	0.60	0.57	Moderate
3	0.30	0.35	0.40	0.35	Low
4	0.18	0.20	0.27	0.22	Background

Source: authors' own research findings

As the calculations demonstrated, the application of the Gaussian model at short distances leads to an overestimation of calculated pollutant concentrations. To illustrate the specific features of the model, a hypothetical generator was considered with the following parameters: emission rate of 200 mg/s, wind speed of 1 m/s, source height of 1.5 m, and a distance of 5 m from the source. The calculations showed that pollutant concentrations may reach values on

the order of hundreds of mg/m³. Such values are physically unlikely under open-air conditions and indicate the limited applicability of the Gaussian model in the near-field zone. Using Equation (11), calculations were performed for carbon monoxide, one of the major combustion products emitted by generators. The following parameters were adopted: $S = 200$ mg/s and $u = 1.0$ m/s. The results are presented in Table 5.

Table 5. Calculated pollutant concentrations according to the jet model

Distance x, m	Concentration C(x), mg/m ³
2	50.0
5	8.0
10	2.0
15	0.89
20	0.50

Source: authors' own research findings

As can be seen from Table 5, carbon monoxide concentration rapidly decreases with increasing distance from the emission source. The most pronounced reduction in concentrations is observed within the near-field zone of jet dispersion, which is consistent with the mechanisms of turbulent mixing between the exhaust plume and the surrounding

air. At distances of 10-20 m, concentrations decrease by more than one order of magnitude compared to their initial values, indicating the significant influence of dispersion processes on ambient air quality within the impact zone of an autonomous emission source. A comparison between calculated and experimental data is presented in Table 6.

Table 6. Comparison of calculated and experimental data

Distance, m	Calculated concentration, mg/m ³	Measured concentration, mg/m ³	Error, %
5	8.0	6-10	≤20
10	2.0	1.5-3.0	≤20

Source: authors' own research findings

The obtained error values did not exceed 20%, indicating satisfactory agreement between the calculated and experimental results. Thus, the application of the jet model provides an adequate description of pollutant dispersion processes in the near-surface atmospheric layer. The calculated results are in good agreement with the experimental data, confirming the reliability of the proposed model. The obtained relationships can be used to assess local environmental pressure under urban conditions. Considering the characteristics and limitations of the different modelling approaches, the

use of a combined modelling framework appears to be appropriate: the jet model should be applied in the near-field zone (up to 10 m from the source), whereas the Gaussian model is recommended for the far-field zone. Such an approach combines the physical adequacy of describing processes in the immediate vicinity of the source with the possibility of assessing pollutant dispersion over larger distances. The assessment of acoustic load was carried out at the same monitoring sites where pollutant concentration measurements were performed. The results are presented in Table 7.

Table 7. Acoustic load levels in areas with electric generator operation

Monitoring site	Distance from generator, m	LAeq, dBA
1	1	90
2	5	76
3	10	70
Reference site	20-30	60-65

Source: authors' own research findings

The acoustic load was calculated using Equation (7), which corresponds to the energy-based model accounting for sound intensity attenuation with distance. The following parameters were adopted: $L_0 = 90$ dBA and $\alpha = 0.02$ (a

typical attenuation coefficient for air). A comparison between the calculated values and the results of instrumental noise measurements in areas with generator operation is presented in Table 8.

Table 8. Comparison of calculated and experimentally determined noise levels

Monitoring site	Distance, m	Measured noise level, dBA	Calculated noise level, dBA	Deviation
1	1	90	90	≈0%
2	5	76	76	≈0%
3	10	70	69.8	<1%
Reference site	20-30	60-65	62	Within the measured range

Source: authors' own research findings

Comparison of the noise levels calculated using the energy-based model with the results of instrumental measurements demonstrated a high degree of agreement. The discrepancy between the calculated and experimental data did not exceed 1-5%, indicating the adequacy of the applied model for describing noise propagation processes in the near-surface atmospheric layer. Importantly, the model accurately reproduced both high noise levels at short distances from the source (1-5 m) and their attenuation at greater distances (10-25 m), confirming that both geometric spreading and atmospheric sound absorption were appropriately taken into account.

Under contemporary conditions, the structure of ambient air pollution sources is undergoing significant transformation (State of Global Air, 2024). Whereas stationary industrial sources previously made the largest contribution to pollutant concentrations, the role of mobile and localised sources has increased considerably in recent years. The study by S. Khomenko *et al.* (2021) demonstrated that the transport sector is one of the key sources of ambient air pollution in European cities and substantially affects health risk levels. Subsequent research by S. Khomenko *et al.* (2023) showed that the contribution of transport emissions to concentrations of nitrogen oxides and fine particulate matter differs considerably among cities but remains one of the priority factors of urban air pollution. Transport emissions exhibit a spatially localised pattern and are concentrated along major roads and in densely built-up areas, forming local hotspots of elevated pollution and environmental risk.

Under conditions of martial law and energy instability, the use of individual power generation sources, including gasoline, diesel, and inverter generators, has increased significantly. This is particularly evident in the KTC, where some of the longest periods of centralised power outages in Ukraine were recorded, resulting in additional anthropogenic pressure predominantly localised within residential areas. Similar trends have also been observed in other countries during energy crises. In particular, R. Zalakeviciute *et al.* (2024) found that the widespread use of diesel generators was accompanied by substantial increases in concentrations of CO, NO₂, SO₂, and fine particulate matter in urban environments, thereby creating additional health risks. W.K. Ahmed *et al.* (2020) confirmed that the operation of diesel generators leads to increased concentrations of PM_{2.5}, PM₁₀, and gaseous pollutants, as well as higher noise levels. Comparable findings were reported by D. Del Pozo *et al.* (2025), who identified increased acoustic pressure on the urban environment resulting from the widespread use of diesel generators during an energy crisis.

Thus, autonomous power generation sources can be considered a significant factor contributing to local short-term fluctuations in ambient air quality and the acoustic environment of urbanised territories. These factors generate extreme peak emissions and impacts that abruptly alter both the pollutant concentration regime and the acoustic regime of ambient air over short periods and may result in substantial short-term exceedances of hygienic standards. To minimise ambient air pollution and reduce acoustic risk associated with individual power generation sources, a system of measures integrating organisational, technical, and spatial planning approaches was proposed. It was established that the operating conditions of generators, particularly their location relative to residential areas, operating regimes, and the density of emission sources, have a significant influence on the formation of short-term fluctuations in ambient air quality. Increasing the distance between generators and residential buildings, considering prevailing wind directions, limiting continuous operating time, and dispersing emission sources contribute to reducing local peaks in pollutant concentrations and noise levels.

Technical measures aimed at reducing emissions and mitigating noise also play an important role. The use of inverter generators, catalytic converters or exhaust gas purification systems, fuels with low impurity content, as well as timely maintenance of equipment, can reduce emissions of carbon monoxide, nitrogen oxides, fine particulate matter, and other pollutants. Additional benefits may be achieved through the installation of acoustic enclosures, silencers, vibration-absorbing supports, and anti-vibration foundations. The effectiveness of such engineering solutions was confirmed by the meta-analysis conducted by A. Montazeri *et al.* (2025), which summarised the results of experimental and field studies on noise control structures, acoustic materials, and active noise control systems for generator installations. The authors reported high effectiveness of the combined use of acoustic enclosures, silencers, and sound-absorbing materials in reducing noise levels in residential and industrial environments. This is also consistent with the findings of H.M. Buluklu *et al.* (2022), who demonstrated that the reduction in noise pollution from generators depends to a large extent on design and noise insulation solutions, confirming the importance of taking the technical characteristics of the source into account when planning measures to reduce the acoustic impact on the local community.

Spatial planning solutions also play a substantial role in the functioning of the management system. The creation of open and well-ventilated spaces improves pollutant

dispersion conditions within the near-surface atmospheric layer, while the use of green spaces and buildings as natural barriers contributes to noise attenuation and partial deposition of airborne pollutants. At the same time, avoiding the placement of generators near windows, air intake systems, and building ventilation openings reduces the risk of combustion products entering residential and public premises directly. The integrated implementation of these measures ensures reductions in pollutant concentrations and noise levels, decreases the extent of areas characterised by elevated environmental risk, and enhances the environmental safety of territorial communities under conditions of widespread use of autonomous power generation sources.

✓ Conclusions

It was established that the specific natural conditions of the KTC, including valley topography, the extensive water surface of the Kremenchuk Reservoir, and the periodic occurrence of temperature inversions, contribute to the formation of local air stagnation zones and the occurrence of short-term natural-anthropogenic fluctuations in ambient air quality. A model describing the formation of natural-anthropogenic fluctuations in ambient air quality within a territorial community was proposed. The model incorporates natural factors, emergency and war-related events, and anthropogenic sources of environmental hazards. To provide an operational assessment of environmental hazard levels, the Increased Environmental Risk Index (IER) was developed. It was found that under normal conditions the IER value equals 8.3 (background risk level), increases to 33.3 under temperature inversion conditions (high risk level), reaches 62.5 during the widespread use of diesel generators (critical risk level), and may attain 166.7 under accidental emission scenarios at industrial facilities. From the perspective of ensuring an environmentally safe territorial community, a system for assessing the health impacts of ambient air pollution was proposed. The system is based on the short-term exposure concept and employs both the Relative Risk (RR) indicator and the Increased Environmental Risk Index (IER).

A structural framework for an ambient air quality management system at the territorial community level was developed. The proposed framework integrates

environmental monitoring, analytical risk assessment, and the implementation of management measures. Instrumental monitoring of pollutant and acoustic contamination under conditions of widespread use of autonomous power generation sources revealed the formation of local zones of elevated pollution within 5-10 m from the source. The maximum carbon monoxide concentration measured at a distance of 1 m reached 4.8 mg/m³, approaching the maximum allowable concentration (5.0 mg/m³). The integrated pollution index decreased from 0.73 at a distance of 1 m to 0.21 at a distance of 15 m from the source. Verification of the mathematical model of environmentally safe functioning of the territorial community was performed using Gaussian, jet, and energy-based models. The results demonstrated that the jet model provides the most adequate description of pollutant dispersion within the near-field zone (up to 10 m from the generator), whereas the Gaussian model is more suitable for assessing pollutant dispersion over longer distances. The discrepancy between calculated and experimental concentration values did not exceed 20%, indicating satisfactory agreement between modelling results and instrumental measurements. A system of measures aimed at managing the risks associated with ambient air pollution and acoustic impacts from individual power generation sources was proposed. The system includes a set of interconnected organisational, technical, and spatial planning instruments designed to minimise the impacts of environmental hazard sources. Further research will focus on the development of a geoinformation system for operational forecasting of natural-anthropogenic fluctuations in ambient air quality and on the integration of the proposed IER index into environmental monitoring systems at the territorial community level.

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Оцінювання якості атмосферного повітря Кременчуцької територіальної громади на основі концепції екологічного ризику

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✔ **Анотація.** В умовах трансформації урбанізованих територій та зростання техногенного навантаження питання оцінювання якості атмосферного повітря та пов'язаних з ним екологічних ризиків набуває особливої ваги. Значну роль у формуванні екологічної небезпеки відіграють короточасні піки концентрацій забруднювальних речовин, які часто не враховуються традиційними методами моніторингу. Мета роботи полягала в обґрунтуванні підходу до оперативного оцінювання станів екологічної небезпеки атмосферного повітря на рівні територіальної громади з урахуванням природних і антропогенних чинників. У дослідженні використано методи логічного аналізу результатів наукових досліджень, системного аналізу факторів формування якості повітря, елементів математичного моделювання процесів розсіювання забруднювальних речовин, а також ризик-орієнтований підхід до оцінювання впливу забруднення на населення. Обґрунтовано концепцію природно-антропогенних флуктуацій якості атмосферного повітря у межах територіальної громади, що враховує природні чинники, аварійні та воєнні події, антропогенні джерела небезпеки. Введено індекс підвищеного екологічного ризику як аналітичний показник для оцінювання короточасного впливу забруднення на здоров'я населення. Запропоновано інтегровану модель оцінювання екологічного стану, що поєднує: математичне моделювання (гаусівська, струменева та енергетична моделі), інструментальні вимірювання. Встановлено закономірності формування локальних зон інгредієнтного та акустичного забруднення за умов масового використання індивідуальних електрогенераторів. Запропонований підхід дозволяє оперативно ідентифікувати періоди підвищеного ризику та оцінювати просторову неоднорідність екологічної небезпеки. Отримані результати можуть бути використані органами місцевого самоврядування для вдосконалення систем моніторингу атмосферного повітря, розроблення заходів управління техногенним навантаженням та впровадження механізмів раннього попередження населення про підвищення рівня екологічної небезпеки

✔ **Ключові слова:** механізми управління; техногенне навантаження; здоров'я-орієнтоване середовище; природно-антропогенні флуктуації; моделювання