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Anastasiia Kahukina,
Iryna Patseva

ASSESSMENT AND FORECAST OF ATMOSPHERIC POLLUTANT DYNAMICS IN THE URBAN ECOSYSTEM OF ZHYTOMYR

The object of the study is the atmospheric air of the urban environment and the dynamics of concentrations of the main pollutants (CO, VOC (H_2CO), PM10, PM2.5, PM1.0, NH_3, NO_2) for the period 2019–2024. One of the most problematic areas is the steady upward trend in CO concentrations with a projected increase of 15–20 % every 2–3 years, which poses significant risks to public health. Also, of concern are seasonal peaks in PM1.0 concentrations in winter and a tendency to increase the baseline level of this pollutant by 5–10 %. The study used statistical analysis of time series of pollutant concentrations, graphical and mathematical data processing, analysis of seasonal fluctuations and long-term trends. Forecasting was carried out taking into account climatic, anthropogenic and technological factors that affect the distribution of pollutants in the city's air basin.

A comprehensive assessment of the temporal dynamics of atmospheric pollutants with the identification of multidirectional trends and seasonal fluctuations is obtained. This is due to the fact that the proposed approach has a number of features, in particular, taking into account the relationship between different pollutants and impact factors, as well as the introduction of predictive models taking into account seasonal cycles. This makes it possible to develop scientifically based recommendations for reducing the anthropogenic load on the urban air environment. Compared to similar known studies, this provides such benefits as the ability to more accurately predict changes in pollutant concentrations, optimize the environmental situation, reduce risks to public health and increase the effectiveness of environmental protection measures.

Keywords: *atmospheric pollutants, air quality, temporal dynamics, forecasting, environmental monitoring, PM1.0, PM10, PM2.5, CO, NO_2, NH_3, urban air basin.*

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1. Introduction

The relevance of the study is due to the environmental situation in modern urbanized environments, where air pollution poses a threat to public health and ecological systems. Air pollution is one of the most acute environmental problems in modern cities.

Assessing the state of the air in the surface layer is important when determining potential consequences for the ecosystem and assessing the risk to public health. Air pollution by pollutants from industrial plants and vehicles is one of the main environmental problems in Zhytomyr and the region [1].

Air pollution is a consequence of economic growth and urbanization. The industrial sector is the largest source of pollutant emissions, with the production and generation of electricity, gas, steam and air conditioning leading the way in terms of both emissions and energy consumption [2].

The expansion of transport infrastructure [3], industrial production and climate change [4] are increasing anthropogenic pressure on the urban atmosphere [5]. Air pollution is defined as a phenomenon in which certain substances in the air exceed certain concentrations and cause damage to ecosystems and human health.

Pollutant emissions have a negative impact on the environment and health [6], especially in urban environments [7]. Prolonged exposure to polluted air also reduces life expectancy.

The sustainability of both the environment and people is largely dependent on forests, as water cycling, carbon sequestration, and absorption of direct solar radiation by forests affect climate [8].

Particular attention should be paid to fine particles (PM1.0, PM2.5) and gases that have a significant negative impact on the respiratory system and the general condition of ecosystems. Continuous monitoring and forecasting of the dynamics of atmospheric pollutants is critical for developing effective strategies to improve air quality and protect public health.

Modern research demonstrates a variety of approaches to monitoring air pollutants [3, 9, 10]. However, there is a need for further research on the state of atmospheric air in urban areas. Further development of systematic long-term observations will contribute to more accurate forecasting of changes in pollutant concentrations and the development of effective environmental protection measures.

The aim of research includes a scientific component, which is to identify patterns of time dynamics of atmospheric pollutant concentrations (CO, VOC (H_2CO), PM10, PM2.5, PM1.0, NH_3, NO_2) and to establish the impact of climatic, anthropogenic and technological factors on their changes.

The practical component is the development of scientifically based recommendations for reducing the anthropogenic load on the urban air environment, which will optimize the environmental situation, reduce risks to public health and increase the effectiveness of environmental protection measures.

2. Materials and Methods

The object of research is the city's atmospheric air and the dynamics of pollutant concentrations. The study is based on 5 years of data according to the databases of the Ukrainian network of public air quality monitoring Eco City [11–18].

The research methodology included statistical analysis of time series of pollutant concentrations, graphical and mathematical data processing, analysis of seasonal fluctuations and long-term trends. The scatter plot widget provides visualization of a 2D scatter plot. The data is displayed as a set of points, each of which has an X-axis attribute value that determines the position of the horizontal axis, and a Y-axis attribute value that determines the position of the vertical axis. The forecast was made taking into account climatic, anthropogenic and technogenic factors.

The analysis of air quality monitoring data reveals complex patterns in the distribution and dynamics of atmospheric pollutants in the urban environment.

3. Results and Discussion

A detailed analysis of the temporal dynamics of changes in the concentrations of CO, VOC (H_2CO), PM10, PM2.5, PM1.0, NH_3 and NO_2 is carried out and their further dynamics is forecasted. Particular attention is paid to seasonal fluctuations, critical values and long-term trends in pollutant concentrations.

The effectiveness of air quality management depends significantly on understanding these patterns and their underlying causes. During the study period, various factors influenced the concentrations of pollutants, including meteorological conditions, seasonal variations, and changes in anthropogenic activity.

Fig. 1 shows a clear upward trend in CO concentration. This trend is an alarming indicator. Higher concentrations in recent years may be due to increased industrial activity, more road transport, possible changes in heating systems and climate change affecting the dispersion of pollutants. If this trend continues, it is possible to expect an increase in CO concentrations in the city's air basin.

Without the implementation of emission control measures, carbon monoxide concentrations may reach dangerous levels. In such circumstances, there is a need to develop an action plan to reduce CO concentrations.

If the current trend continues, the average values will increase by 15–20 % every 2–3 years. Seasonal fluctuations will continue, with seasonal peaks becoming more pronounced. There may be an increase in the amplitude of fluctuations and concentration spikes due to emergency situations.

The general downward trend in formaldehyde concentration in Fig. 2 indicates the introduction of environmental technologies in production. There is a possibility of seasonal fluctuations related to temperature and activity of emission sources. The presence of yellow dots in Fig. 2 indicates periodic exceedances of safe levels of this pollutant. Formaldehyde is a substance that has a negative impact on public health and the ecosystem.

Based on the data shown, it is possible to predict a continuation of the general downward trend in VOC (H_2CO) concentrations. Let's expect the average value to be around 10–12 units. Seasonal fluctuations with an amplitude of 2–3 units are possible. There is a possibility of some peak values in the summer. This forecast will be influenced by seasonality, the general trend towards improved environmental conditions and the introduction of new treatment systems.

Taking into account the trend Fig. 2 and seasonality, it is possible to expect a gradual decrease in average VOC (H_2CO) concentrations, but with the preservation of cyclicality and the possibility of individual peak values.

The scatter plot Fig. 3 has a range of values from 0 to 200 $\mu g/m^3$. During the studied years, a slight decrease in PM10 concentration levels was recorded, as indicated by a slow downward trend. The existing critically elevated concentrations of $\mu g/m^3$ may be related to anthropogenic factors such as waste incineration, industrial emissions, seasonal heating and forest fires in the Zhytomyr region. Based on the data obtained, it is possible to make a forecast of PM10 levels in the city's air basin.

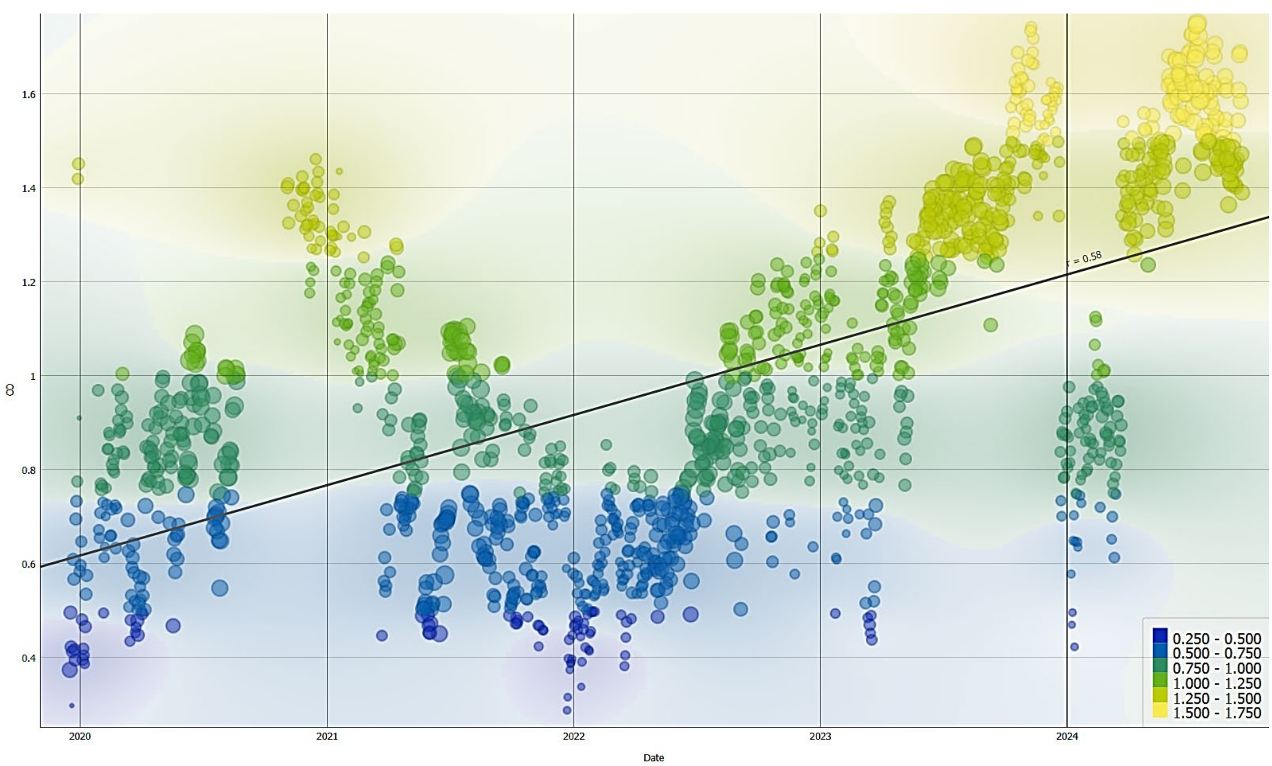

Fig. 1. Time variation of CO concentrations (based on data from [16, 18])

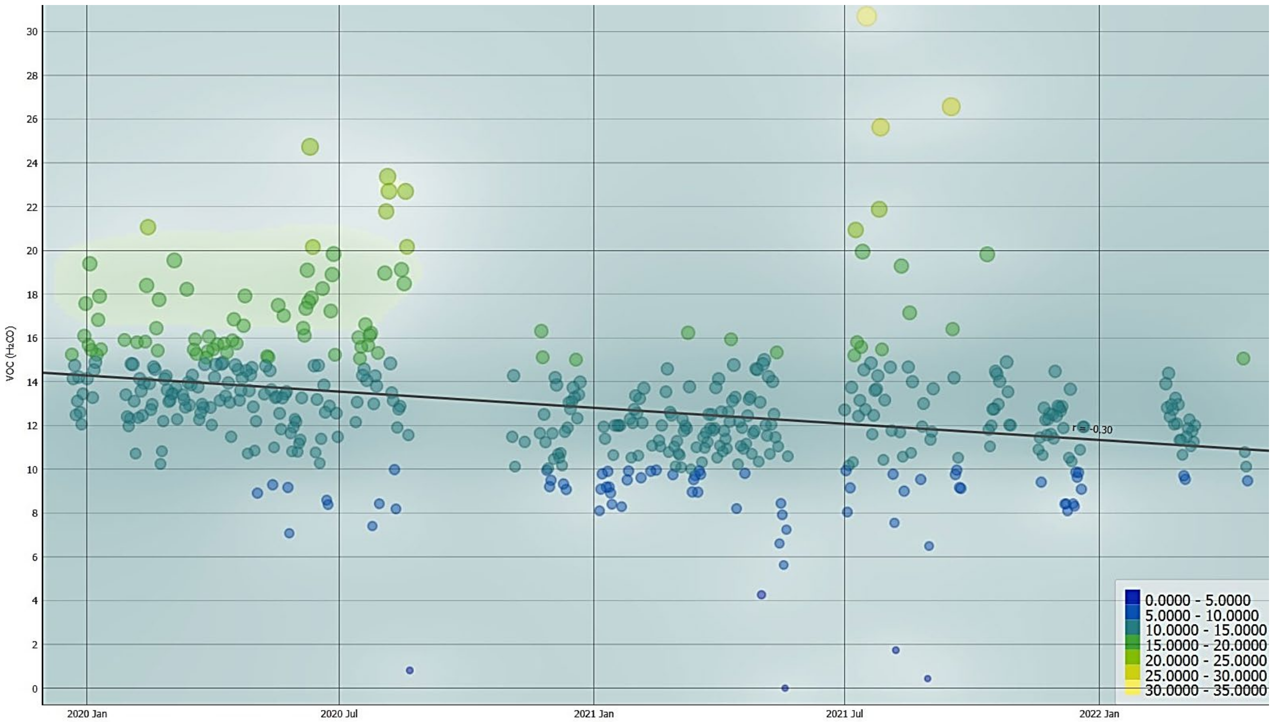

Fig. 2. Time variation of VOC (H_2CO) concentrations (based on data from [17, 18])

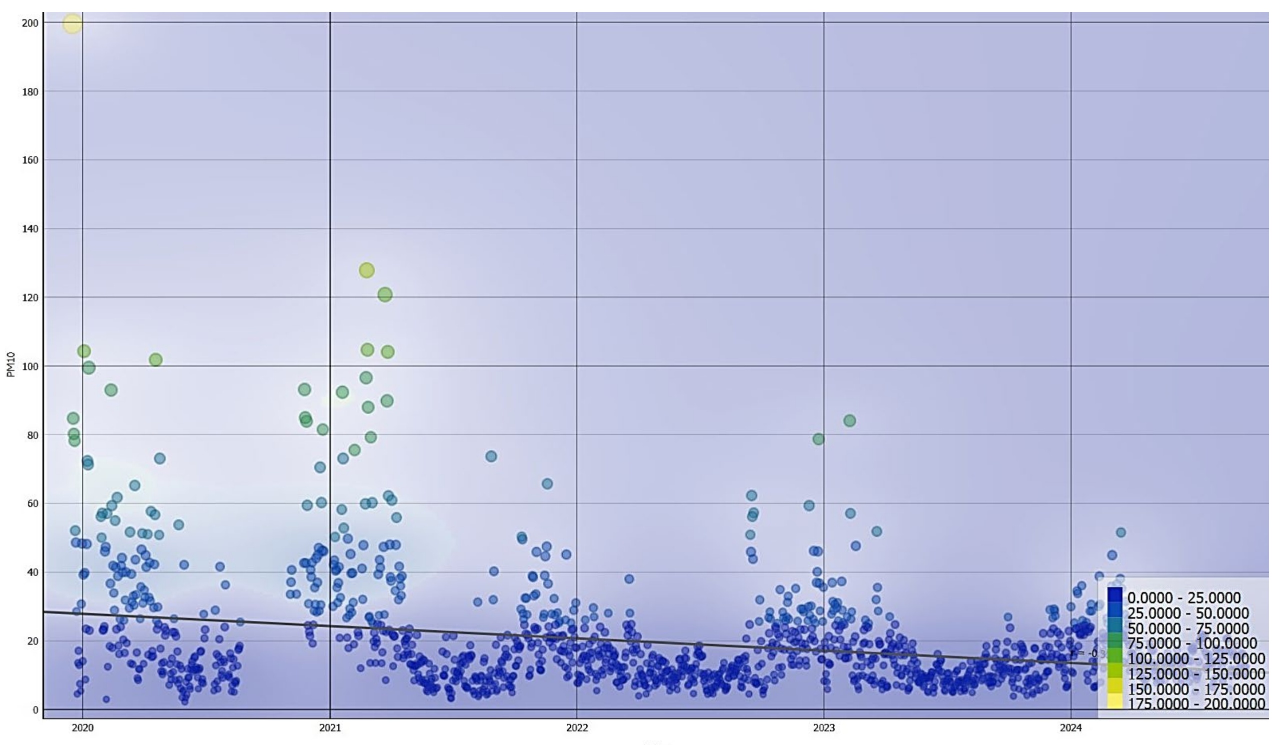

Fig. 3. Time variation of PM10 concentrations (based on data from [13, 18])

Based on the data obtained, it is possible to forecast the levels of PM10 concentrations in the city's air basin. It is possible to expect PM10 concentrations to remain at the level of 15–40 μg/m^3. There is still a risk of hazardous concentrations in the range of 80–100 μg/m^3, which will depend on the season. The general downward trend will continue in the coming years. Average PM10 values may decrease to a concentration of 15–25 μg/m^3.

There are a number of factors that may affect the forecast. These include changes in industrial activity, the introduction of new and environmentally friendly standards and technologies, climate change, urbanization processes and the development of transport infrastructure. Environmental protection measures may help to maintain the current downward trend in PM10 concentrations.

PM2.5 is a hazardous particle that adversely affects the human body. PM2.5 has the ability to penetrate the lungs causing pathological conditions. With prolonged exposure to elevated concentrations, there is a risk of respiratory and cardiovascular diseases.

Fig. 4 shows a downward trend in the level of PM2.5. The highest pollution levels were recorded in 2020–2021. Most indicators vary in the range of 0–30 μg/m^3, which indicates a moderate level of air pollution by this pollutant. Based on the data obtained, the following forecasts can be made.

It is possible to expect the downward trend in the average PM2.5 levels to continue. PM2.5 concentration in the city's air basin will fluctuate between 5–20 μg/m^3. However, concentrations of the pollutant in the range of 30–40 μg/m^3 may occur. The number of cases with concentrations above 50 μg/m^3 will decrease, but there is still a possibility of critically high concentrations.

Positive dynamics in terms of PM2.5 concentrations may be associated with the implementation of environmental standards, modernization of industrial enterprises, reduction of emissions from transport and effective control of air pollution sources in the city. It should be noted that taking into account environmental factors, both a further decrease in PM2.5 concentrations and a change in the trend line towards an increase in PM2.5 levels are possible.

Further implementation of environmental technologies, increase in the number of electric vehicles, and improvement of air quality monitoring systems will help to further reduce PM2.5 concentrations.

Growth in industrial production, an increase in the number of vehicles, and emergencies involving explosions and fires will have a negative impact on the state of the air. Such events will have a risk of high PM2.5 concentrations in the city's air basin. Climate change and adverse weather conditions also play a role.

To maintain the positive trend of reducing PM2.5 concentrations, it is necessary to continue modernizing industrial enterprises, developing the city's green infrastructure, and stimulating the transition to environmentally friendly transport. According to research [19] the widespread introduction of electric vehicles will lead to even lower vehicle emissions and further improvements in air quality.

Further improvement of warning systems for high PM2.5 concentrations will be useful to reduce the incidence of respiratory and cardiovascular diseases among the city's population.

PM1.0 dust particles are dangerous to the human body because they are small, up to 1 μm, which allows them to penetrate deeply into the lungs. Fig. 5 shows the temporal variability of PM1.0 concentrations in the city air basin. Most of the indicators range from 0–25 μg/m^3. However, there are critical increases in concentrations at the level of 100–125 μg/m^3. It is possible to predict that the peak values will remain in the range of 70–100 μg/m^3 from December to February.

The baseline level of pollution will be in the range of 0–25 μg/m^3, but there is a tendency to increase the values by 5–10 %, with an increase in the frequency of extreme values above 50 μg/m^3. Is also a possibility of increased concentrations in late autumn and early winter.

Such cyclicality is dangerous for the city's residents due to the high level of PM1.0 pollutant in the school. There is a need to strengthen air quality control measures in winter due to the recorded elevated levels during the cold season.

There are also certain risks of deterioration of the environmental situation in terms of air pollution by PM1.0 pollutant. These risks include an increase in the duration of temperature inversions, growth in industrial production, expansion of urban development, and deterioration of the existing road transport due to the increasing age of cars. To improve the environmental situation in terms of air pollution under the RM1.0, it is necessary to introduce new emission treatment technologies and develop green areas of the city for natural air filtration.

This analysis indicates the need for a comprehensive approach to solving the problems related to air pollution in the city.

Ammonia is an important indicator of air pollution. NH_3 is involved in the formation of fine particulate matter. This chemical also reacts with other pollutants such as ammonium sulphate and ammonium nitrate. Secondary aerosols of ammonium sulphate and ammonium nitrate are formed. All these particles make up a significant part of PM2.5.

NH_3 is converted to NH_4^+ in the atmosphere. This has a significant impact on the biodiversity of ecosystems. NH_3 is toxic to sensitive plant species and inhibits their growth. It can disrupt food chains and change the species composition of ecosystems. As a result, ecosystem resilience may be reduced, rare species may be lost, ecological balance may be disturbed, and the structure of natural communities may change. These effects are interrelated and can reinforce each other, creating a cascading effect on the city's environment. In Fig. 6, the bulk of the values vary around zero, but there are some peaks of increased concentrations.

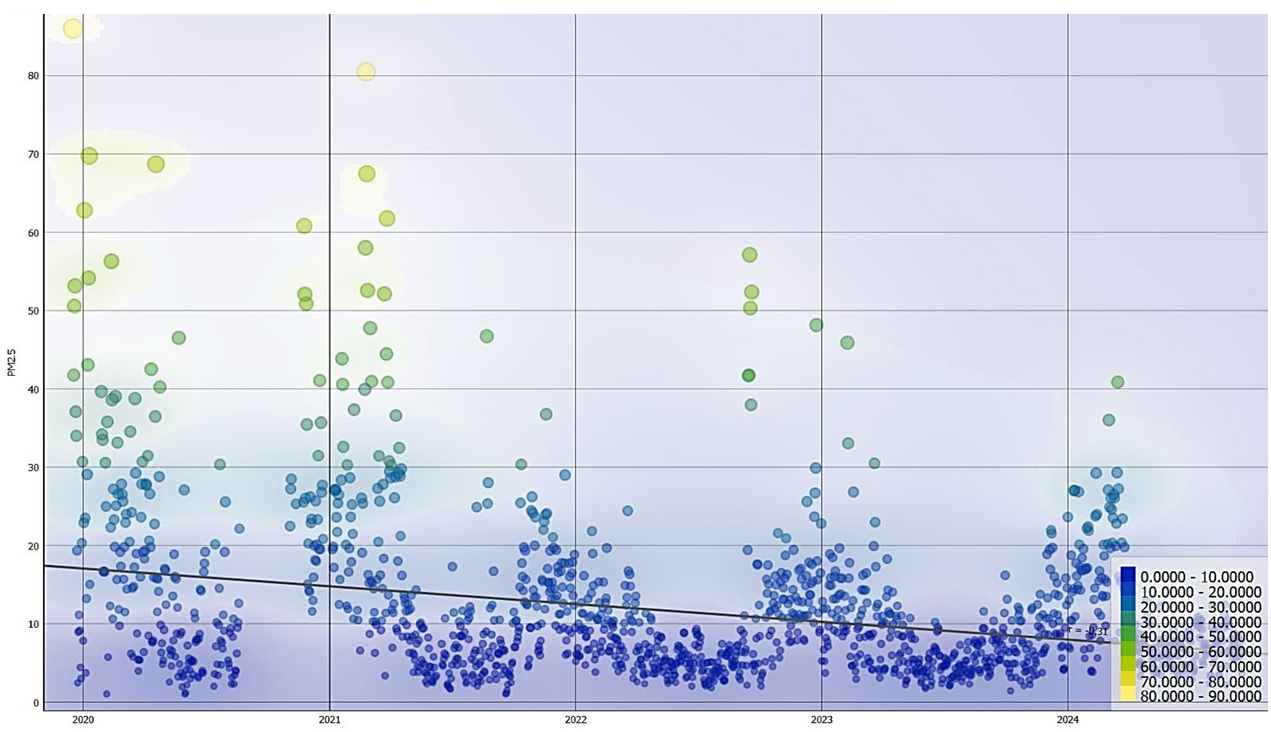

Fig. 4. Time variation of PM2.5 concentrations (based on data from [14, 18])

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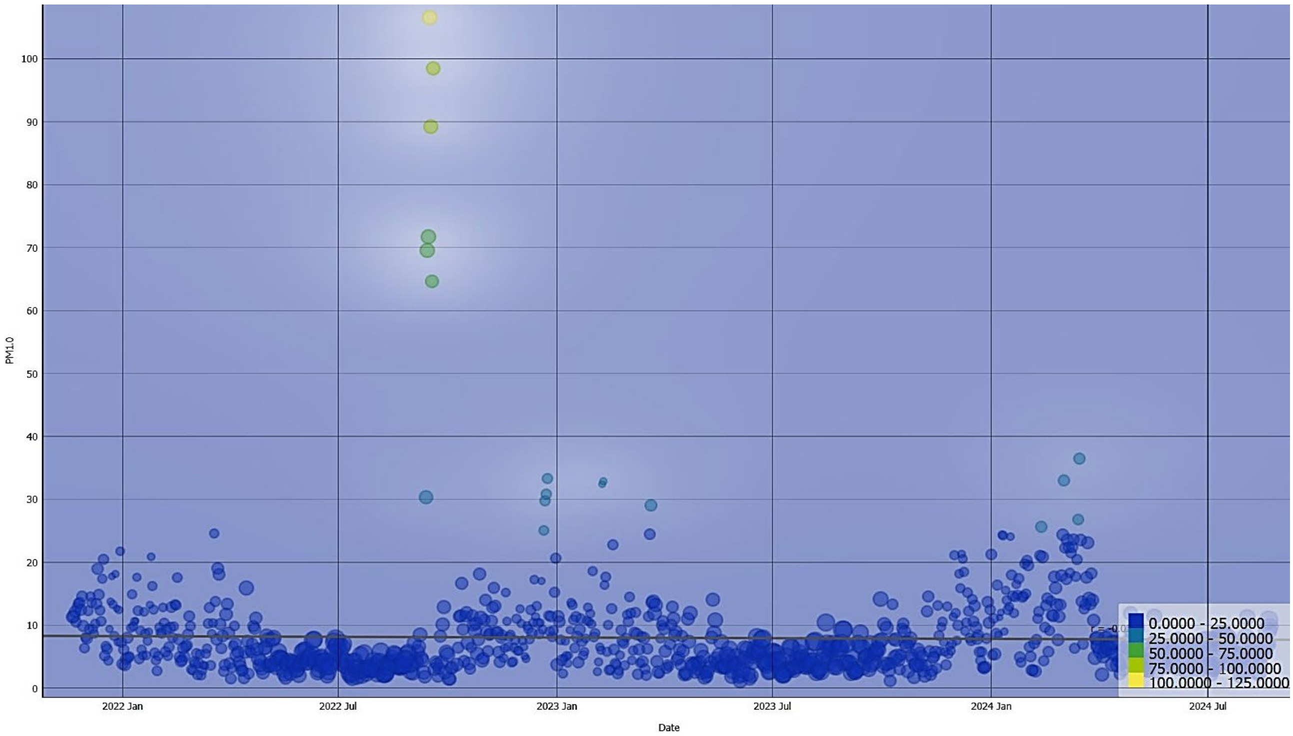

Fig. 5. Time variation of PM1.0 concentrations (based on data from [15, 18])

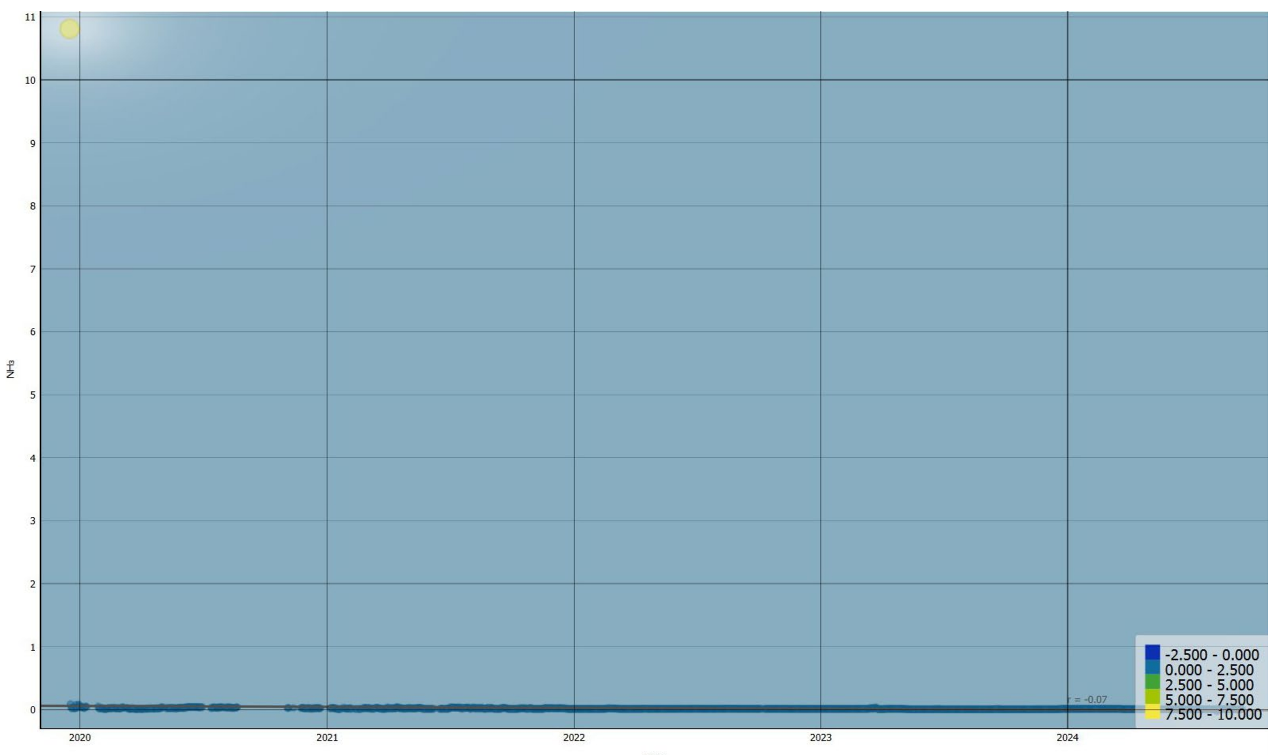

Fig. 6. Time variation of NH_3 concentrations (based on data from [12, 18])

There is a certain seasonality with small fluctuations. It is possible to predict that the seasonal fluctuations will continue and that short-term peaks in concentrations are possible. Over the next 2 years, the concentrations will remain in the range of 0–2.5 units, but if this trend continues, there is a risk of an increase. In the absence of changes in emissions regulation, a gradual increase in the average concentration of this pollutant is possible. This forecast may be affected by the introduction of new emission control technologies, climate change and innovation in the region's industrial activity.

According to scientists [20], the reason for the high content of nitrogen dioxide in the city air is not only emissions from heating and industry, but also motor transport can be identified as a source of emissions.

In Fig. 7, the highest NO_2 concentrations were recorded at the beginning of the observation period. Since 2021, there has been a general downward trend in maximum nitrogen dioxide concentrations.

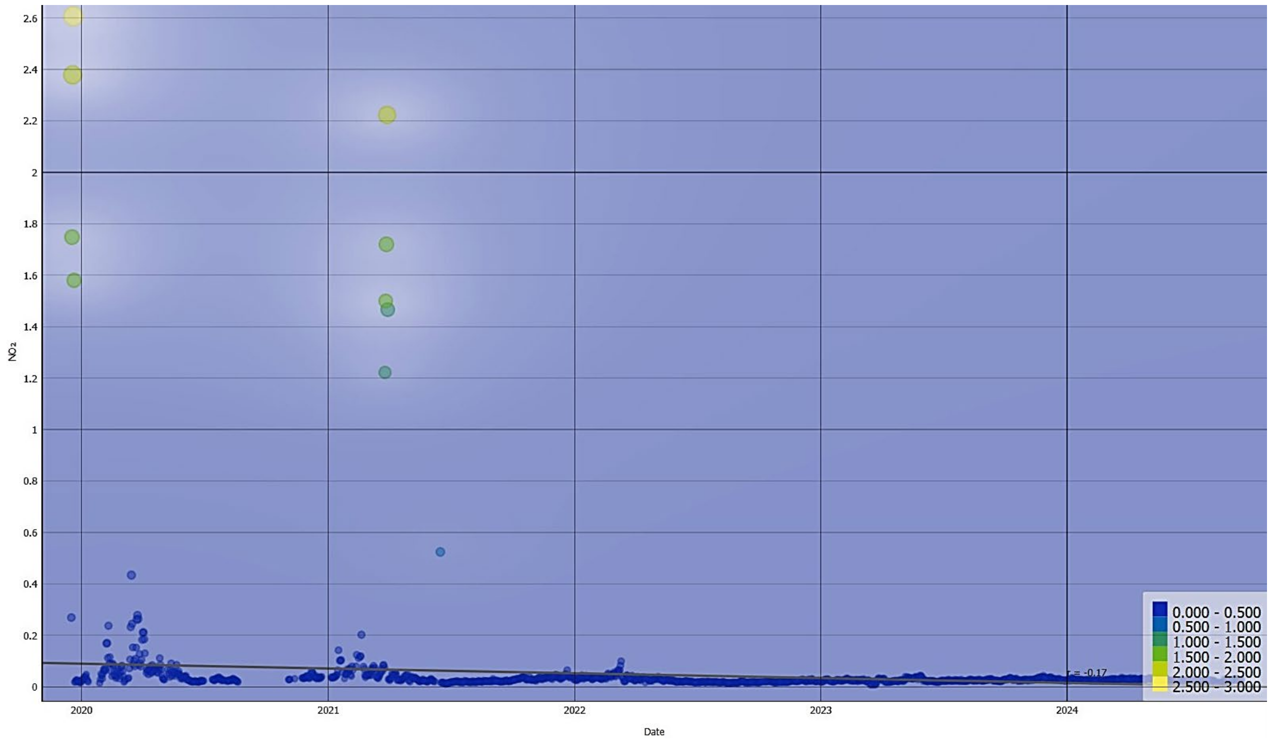

Fig. 7. Time variation of NO_2 concentrations (based on data from [11, 18])

The main sources of NO_2 are road transport and industrial emissions. For the city's environment, this pollutant is a precursor of acid rain, contributes to the formation of photochemical smog and affects the development of vegetation. For the public health, it is a pollutant that negatively affects the respiratory system, which contributes to the emergence of pathological processes.

It is possible to expect the cyclical nature of the changes to continue. The highest NO_2 concentrations are expected in the winter months, and the lowest in the summer months. The overall trend indicates that the baseline indicators will remain stable with a decrease in extreme values. There is a risk that climate change will affect the distribution of NO_2 pollution.

The measurement results show significant temporal variability in pollutant concentrations, which is attributed to both natural and anthropogenic factors.

Temperature inversions, precipitation patterns, and wind conditions significantly affected the dispersion and accumulation of pollutants in the urban atmosphere [21, 22]. Seasonal changes in meteorological parameters contributed to cyclical variations in pollutant concentrations, with distinct patterns observed during different seasons.

Urban development dynamics and changes in industrial activity also influenced pollution levels. The implementation of environmental protection measures during the study period had a noticeable impact on the concentrations of certain pollutants, although the effectiveness of these measures varied depending on local conditions and the specific characteristics of pollution sources.

The analysis of air pollutants in time dynamics indicates the need for an integrated approach to solving problems related to air pollution in the city [23]. The identified trends and patterns allow to move on to a more detailed discussion of the practical significance of the study, its limitations, the impact of martial law, and prospects for further work.

The research results of the temporal dynamics of pollutants are of significant practical importance for various fields of activity. For local governments, it is important to create a scientifically sound basis for developing and adjusting the city's environmental programmes, optimizing the location of new industrial facilities, taking into account the projected levels of pollution, and planning the development of green areas as natural air filters. For the healthcare system, the development of predictive models for the risks of respiratory and cardiovascular disease outbreaks associated with seasonal peaks in pollution (especially PM1.0, PM2.5 and CO). This will allow for the creation of an early warning system for healthcare facilities and optimize the allocation of healthcare resources. For industrial enterprises, assessing the effectiveness of implemented emission treatment systems and planning further equipment modernization. For the transport sector, to justify the need to develop electric transport and other types of environmentally friendly transport, and to optimize public transport routes, taking into account the environmental impact on different city districts. For the environmental monitoring system, to determine the optimal periods for intensifying air quality measurements and control, especially in winter, when peak pollutant concentrations are observed. For the educational sector, the creation of visual materials for environmental education of the population, formation of environmental awareness of citizens and promotion of environmentally responsible behavior.

Despite the comprehensive nature of the study, the forecasting methods used take into account past trends, but have limited accuracy in predicting sharp changes in industrial activity or the introduction of new technologies.

The conditions of martial law in Ukraine had a significant impact on both the research and the results obtained [24]. Periodic power outages and infrastructure damage led to gaps in monitoring data, which required additional statistical processing methods. The hostilities led to changes in the region's industrial activity, re-profiling of production facilities, and the use of alternative energy sources (including diesel generators) during power outages, which affected the nature and intensity of emissions. Some sharp increases in pollutant concentrations (especially particulate matter) could be related to the effects of shelling, fires, and infrastructure damage in the region, which made it difficult to analyze natural trends. Despite these challenges, the study confirms the importance of continuous air monitoring, even in times of crisis, as air quality has a direct impact on public health and the sustainability of local ecosystems.

Based on the analysis and taking into account the identified limitations, the following promising areas for further research can be outlined, namely the introduction of geospatial modelling methods to create detailed maps of pollution, taking into account the city's topography,

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urban development and green areas. Conducting a comparative analysis of pollution indicators before and after the introduction of specific environmental technologies and regulatory measures. Study of the impact of green infrastructure, namely quantitative assessment of the potential of urban green spaces to absorb pollutants and development of recommendations for optimizing green areas.

Implementation of these research areas will help to develop more effective air quality management strategies, reduce risks to public health and ensure sustainable development of the urban environment.

4. Conclusions

The temporal dynamics of pollutants in the air is characterized by multidirectional trends and pronounced seasonality. The most critical situation is with CO concentrations, which have a steady upward trend of 15–20 % every 2–3 years, requiring the development of urgent control measures. Positive dynamics are observed for VOC (H_2CO), PM10 and PM2.5, which may be a result of the introduction of environmental technologies. There is a tendency to increase PM1.0 values by 5–10 %, with an increase in the frequency of extreme values.

The bulk of NH_3 values vary around zero, but a gradual increase in the average concentration of this pollutant is possible.

It is possible to predict that the cyclical nature of changes will continue. The highest NO_2 concentrations are expected in the winter months, and the lowest in the summer months. In general, fluctuations in pollutant concentrations will continue, and concentrations will gradually decrease with the introduction of environmental technologies. However, there is a risk that concentrations could increase if environmental protection measures are not implemented.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, including financial, personal, authorship, or any other, that could affect the research and its results presented in this article.

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Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating this work.

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✉***Anastasiia Kahukina,*** *PhD Student, Depatment of Ecology and Environmental Protection Technologies; Assistant, Department of Earth Sciences, Zhytomyr Polytechnic State University, Zhytomyr, Ukraine, e-mail: ke_kham@ztu.edu.ua, ORCID: https://orcid.org/0000-0001-8932-1211*

Iryna Patseva, *Doctor of Technical Sciences, Professor, Head of Department of Ecology and Environmental Protection Technologies, Zhytomyr Polytechnic State University, Zhytomyr, Ukraine, ORCID: https://orcid.org/0000-0001-6271-7355*

✉*Corresponding author*