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ATMOSPHERIC LOAD IN THE URBAN ECOLOGICAL DIMENSION: SPATIAL ANALYSIS OF UKRAINIAN REGIONS IN 2021–2022

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Abstract

The state of atmospheric air is one of the fundamental indicators of the quality of the urban ecological environment. The full-scale invasion that began in Ukraine in 2022 significantly altered the nature of environmental pressure: the focus shifted from traditional sources of pollution, such as industrial enterprises, to newer factors—namely, military actions, the destruction of critical infrastructure, and mass population displacement.

The comparative analysis conducted in this study enables an assessment of how atmospheric air quality in various regions has changed due to the war. The results not only document the current transformations but also provide a foundation for theoretical modeling of potential scenarios in the event of hostilities in new locations. Thus, the study may serve as a valuable tool for forecasting environmental dynamics in the context of armed conflicts.

Keywords: *air pollution, Air Pollution Index (API), waste, green zones, emergencies, urban ecological load.*

Objective – the study aims to rank the air quality across Ukrainian regions in 2021–2022 and to develop a regional Urban Ecological Load Index with a focus on the atmospheric component. **Scientific Novelty –** the research develops and tests a multifactorial integrated approach for assessing atmospheric urban ecological load in Ukrainian regions, adapted to the conditions of wartime.

Essence of the Study

In the context of increasing technogenic pressure on the environment, the assessment of urban ecological load at the regional level becomes particularly important. This study presents a comparative analysis of the environmental conditions across 24 regions of Ukraine based on an integrated approach that takes into account a set of key indicators.

The following indicators were used for the comparative analysis of Ukraine's 24 regions:

- Air Pollution Index (API).
- Number of emergencies.
- Volume of generated waste (relative coefficient).
- Actual forest cover (%).

Each of these indicators underwent normalization to ensure data comparability across regions. A distinct feature of the forest cover calculation was the use of an inverse scale: given its positive impact on environmental conditions, a higher level of forest cover was interpreted as a lower ecological load.

All indicators were normalized, after which an integrated index of atmospheric urban ecological load was calculated.

$$N = \frac{x - min(x)}{max(x) - min(x)}$$

were:
N – normalized value;
x – the measured value for the area;
min(x) – the minimum value over a given period;
max(x) – the maximum value over a given period.

An inverse scale was applied to forest cover (since a higher level of forestation corresponds to a lower ecological load):

$$N_{Forest} = 1 - \frac{x - min(x)}{max(x) - min(x)}$$

were:
N_{Forest} – normalized value for forest cover.

After normalization, all indicators were averaged, and based on them, the integral Urban Ecological Load Index I_{UEL}) was calculated using the following formula:

$$I_{UEL} = \frac{N_{API} + N_{Emergency} + N_{Waste} + N_{Forest}}{4}$$

were:
I_{UEL} – the integral Urban Ecological Load Index:
N_{API} - normalized value for air pollution index;
$N_{Emergency}$ – normalized value for quantity of emergencies;
N_{Waste} – normalized value for amount of waste generated.

This index enables the assessment of the overall level of ecological load in each region and allows for dynamic comparison. A comparative analysis was conducted for two consecutive years 2021 and 2022 which made it possible to identify both consistent trends and potential changes in the environmental conditions at the regional level. The results are visualized in the form of a chart that clearly illustrates the ecological ranking of each region.

Key Indicators

1. Air Pollution: General Trends

In 2021, the highest Air Pollution Index (API) was recorded in Ukraine's industrially developed regions—Donetsk (15.7), Dnipropetrovsk (12.8), and Odessa (12.5) oblasts. However, by 2022, a noticeable decline was observed: in Donetsk to 10.2, in Kyiv from 8.6 to 7.6, and in Kharkiv from 3.4 to 2.7.

The main reason behind this temporary improvement in air quality is the reduction of industrial activity due to ongoing hostilities in the eastern and central regions. The shutdown of factories and industrial facilities led to a decrease in emissions—an unintended yet short-term environmental effect of the war.

2. Emergencies as a Factor in Air Quality Deterioration

The oblasts with the highest number of emergencies—Kherson, Donetsk, and Mykolaiv—reported 10–11 incidents per year. Most were related to explosions, fires, and infrastructure destruction, which are direct sources of secondary atmospheric pollution. The combination of high or medium API levels with frequent emergencies indicates persistent urban ecological stress in these territories.

3. Waste: Industrial Legacy and Its Impact

Donetsk and Dnipropetrovsk oblasts top the anti-rating in terms of waste generation—over 23 million tons annually, mostly industrial waste of hazard classes I–II. The API in these regions clearly correlates with the accumulation of hazardous waste, especially in areas of intense industrial activity.

In contrast, western regions—Chernivtsi, Ivano-Frankivsk, and Zakarpattia—have low API levels and low volumes of generated waste. This confirms a direct relationship between industrial load and air quality.

4. Ukraine's Green Shields: Forest Cover as an Ecological Buffer

Forest cover emerged as a powerful natural factor capable of mitigating atmospheric pollution. Zakarpattia, Ivano-Frankivsk, and Volyn oblasts, each with over 40% forested area, show the lowest API values.

Conversely, oblasts with the lowest forest cover—Kherson, Zaporizhzhia, and Dnipropetrovsk (less than 10%)—face the highest pollution levels. This confirms that forests serve not only as landscape elements but also as critical buffers capable of absorbing harmful substances and reducing environmental pressure.

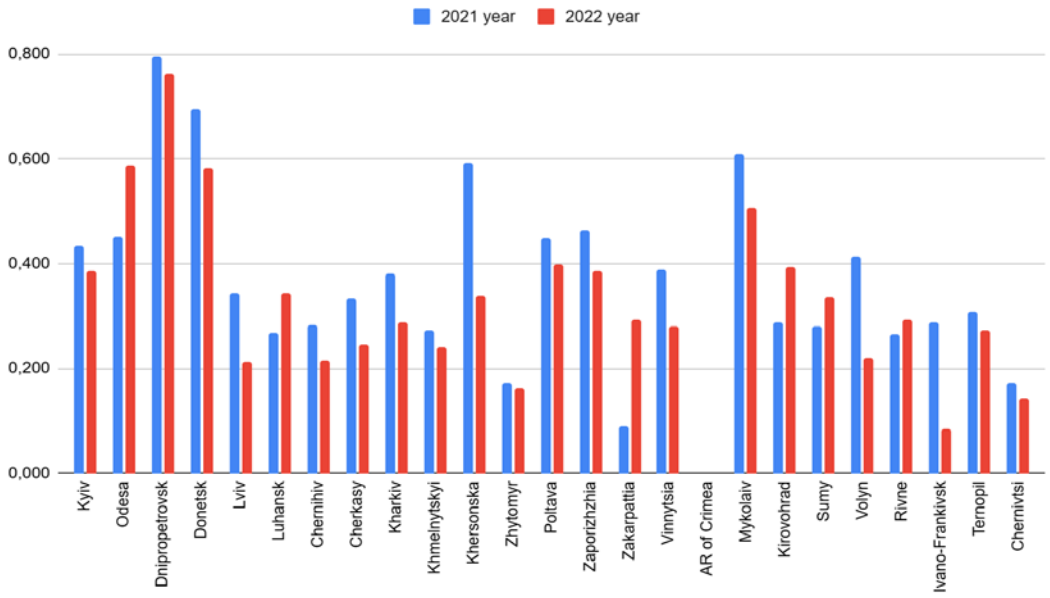

***Fig. 1**. Urban Ecological Load Index across All Regions of Ukraine*

Conclusions

- The Integral Urban Ecological Load Index (UELI) is an effective aggregated indicator for assessing the environmental condition of Ukraine's regions. It accounts for the most significant components of urban ecological pressure—air pollution, emergencies, waste generation, and forest cover.
- The normalization method enables comparison of diverse ecological indicators, while the use of an inverse scale for forest cover accurately reflects its protective role in shaping environmental conditions.
- The dynamics of indicators for 2021–2022 show a temporary improvement in air quality in certain industrial regions (particularly Donetsk and Kyiv oblasts), driven by a decline in industrial emissions. However, this does not suggest that military actions are harmless to the environment—this issue requires further research and recalculations.
- The combination of high pollution levels and a high number of emergencies in specific regions (Kherson, Donetsk, Mykolaiv) indicates sustained urban ecological pressure and increased environmental vulnerability to anthropogenic and technogenic impacts.
- A clear correlation exists between the level of industrialization and environmental risks—regions with large volumes of waste, especially of hazard classes I–II, simultaneously demonstrate higher API levels.
- Forest cover has proven to be a natural stabilizer of ecological balance—regions with extensive forested areas consistently exhibit lower levels of atmospheric pollution.

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АТМОСФЕРНЕ НАВАНТАЖЕННЯ В УРБОЕКОЛОГІЧНОМУ ВИМІРІ: ПРОСТОРОВИЙ АНАЛІЗ РЕГІОНІВ УКРАЇНИ У 2021-2022 РОКАХ

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Анотація

Стан атмосферного повітря є одним із базових індикаторів якості урбоекологічного середовища. Повномасштабне вторгнення, що розпочалося в Україні у 2022 році, суттєво змінило характер екологічного навантаження: пріоритетними стали не стільки традиційні джерела забруднення, як-от промислові підприємства, скільки новітні чинники — бойові дії, руйнування критичної інфраструктури та масове переміщення населення.

Проведений порівняльний аналіз дозволяє оцінити, яким чином змінився стан атмосферного повітря в регіонах внаслідок воєнних подій. Отримані результати не лише фіксують поточні зміни, а й створюють основу для теоретичного моделювання можливих сценаріїв розвитку ситуації в разі початку бойових дій у нових локаціях. Таким чином, дослідження може бути корисним як інструмент прогнозування динаміки екологічного стану територій у контексті збройних конфліктів.

Ключові слова: атмосферне забруднення, ІЗА, відходи, зелені зони, надзвичайні ситуації, урбоекологічне навантаження.