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Innovative Principles of Urban Greening: Adaptation to Climate Change and Biodiversity Conservation

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Abstract

This article explores current approaches to urban greening under increasing anthropogenic pressure and climate change. Using the case of Ivano-Frankivsk, it analyzes the impact of rising annual temperatures, droughts, air pollution, and soil compaction on the resilience of traditional plant species. Special attention is given to the problem of invasive and allergenic species, their ecological effects, and the unsuitability of their use in modern urban landscapes. The article presents criteria for selecting adaptive, pollution-tolerant, and stress-resistant plants, as well as the prospects for implementing vertical greening, meadow lawns, phytoremediation filters, and filtering trees. Recommendations are summarized for developing a scientifically grounded greening strategy that enhances urban environmental resilience and preserves biodiversity.

Keywords: greening, urban environment, climate change, biodiversity, adaptive species, sustainable development.

1. INTRODUCTION

The rapid expansion of urbanized areas, combined with global climate change, presents new challenges for shaping an environmentally sustainable urban environment (Geletukha & Zherebchuk, 2020; European Environment Agency, 2020). In particular, the increase in average annual temperatures, prolonged drought periods, rising air pollution levels, and soil degradation significantly reduce the viability of traditional urban green plant species (Melnychuk & Andrusiv, 2022; Kuzemko, 2021). As a result, many settlements, including Ivano-Frankivsk, are experiencing a gradual decline in the ecosystem services provided by green spaces, such as air purification, temperature regulation, increased comfort, and biodiversity conservation (European Parliament and Council, 2014).

Under these conditions, there is a growing need for scientifically grounded, adaptive approaches to selecting plant species for urban greening. This primarily involves the use of species resistant to drought, pollution, soil compaction, and temperature stress, while posing no allergenic or invasive threat to the local ecosystem (Nowak et al., 2014; Stepanenko & Ostapchuk, 2021).

Modern technologies are also becoming increasingly relevant, including vertical greening, phytofilters, and the creation of biodiverse herbaceous coverings aligned with the principles of sustainable development (Kavchuk & Riznychuk, 2022; Kavchuk & Riznychuk, 2025).

2. RESEARCH OBJECTIVE, METHODOLOGY AND DATA

The purpose of this work is to summarize modern approaches to greening urbanized areas, define criteria for plant selection in the context of climate change and anthropogenic impacts, and analyze the case of Ivano-Frankivsk as a model region for implementing innovative solutions in urban landscape planning. The aim of the study is to analyze the environmental, climatic, and anthropogenic factors influencing the effectiveness of urban greening and to develop practical recommendations for selecting adaptive plant species suitable for urban conditions, using Ivano-Frankivsk as an example.

To achieve this goal, the following objectives were defined:

- to characterize climate changes and urban factors affecting urban greening;
- to analyze common invasive and allergenic species and assess their impact on the urban environment;
- to outline criteria for selecting resilient and ecologically appropriate plant species;
- to present modern eco-technologies for urban greening and compare their effectiveness.

The research methodology is based on:

- analysis of literature sources and regulatory documents related to urban greening;
- use of climate data for Ivano-Frankivsk over the past 30 years;
- assessment of the adaptive potential of specific plant species based on bioecological parameters (drought resistance, pollution tolerance, allergenicity, ornamental value);
- comparative analysis of the implementation of ecological solutions in European cities (Vienna, Kraków, Lyon).

The data used in the study included climate observations, presentation and analytical materials on the state of greening in Ivano-Frankivsk, information from botanical studies on introduced and native plant species, as well as practical examples of applying sustainable approaches to the formation of urban green environments.

3. RESULTS AND DISCUSSION

The research results indicate a significant transformation in the conditions for greening urbanized areas due to climate change and anthropogenic pressure. In Ivano-Frankivsk, an increase in the average annual temperature by 1.4 °C has been recorded over the past decades (Fig. 1).

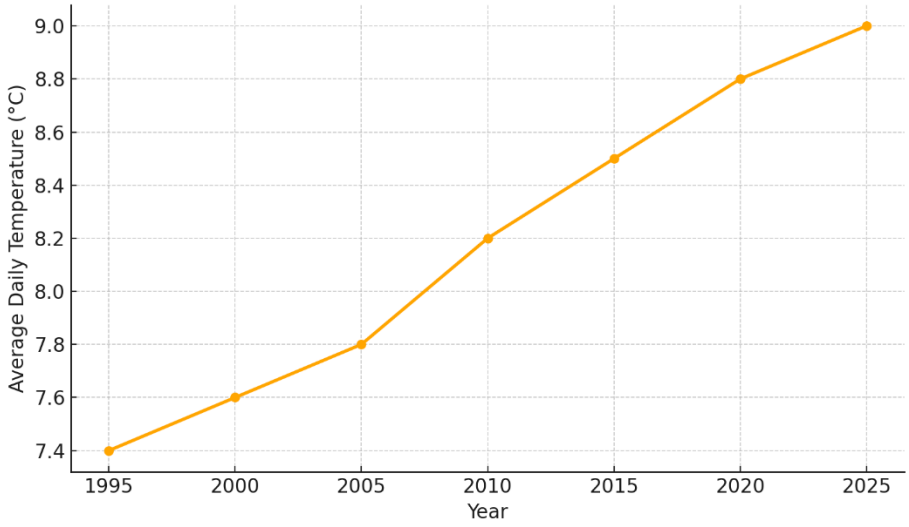

Fig. 1. Dynamics of average annual temperature in Ivano-Frankivsk (1995–2025).

The increasing frequency of heatwaves and prolonged drought periods, as well as deteriorating air quality and soil compaction (Fig. 2), critically reduce the viability of traditionally used urban greening species such as *Tilia cordata*, *Betula pendula*, and *Aesculus hippocastanum*.

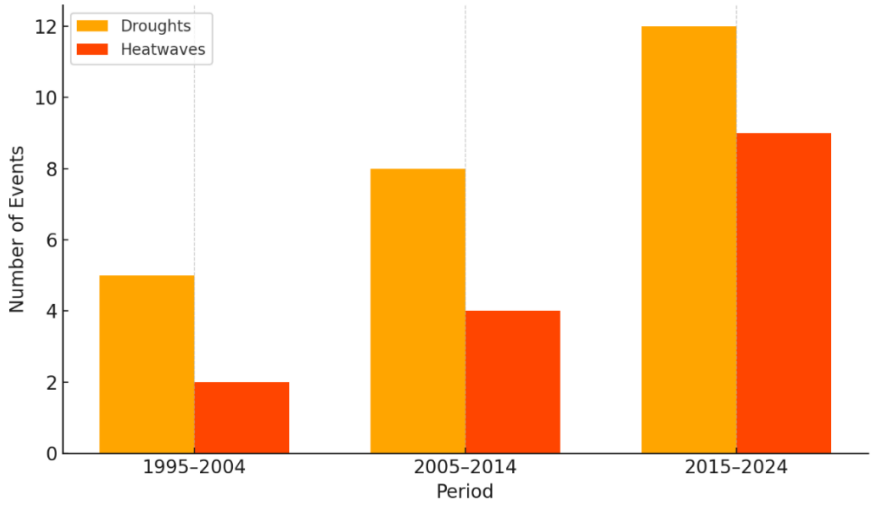

Fig. 2. Dynamics of drought and heatwave frequency in Ivano-Frankivsk (1995–2024).

Invasive species, particularly *Acer negundo*, *Robinia pseudoacacia*, and *Quercus rubra*, are actively spreading, displacing native flora, altering soil chemical composition, and reducing biodiversity. They cause biocenotic, phytosanitary, and landscape disruptions, complicating the management of urban ecosystems. These species are not recommended for use in urban greening, especially in the conditions of Western Ukraine.

Allergenic species (*Tilia cordata*, *Betula pendula*) exhibit high seasonal pollen activity and pose health risks to residents with respiratory conditions. Replacing them with less allergenic plants is a priority measure for sustainability-oriented greening.

The study identifies a list of recommended species with high adaptability to urban conditions (Fig. 3):

- *Gleditsia triacanthos* – drought-resistant, pollution-tolerant, and ornamental;
- *Carpinus betulus* 'Fastigiata' – compact form, heat-tolerant;
- *Quercus robur*, *Amelanchier lamarckii*, *Ginkgo biloba* – ecologically efficient, low-allergenic, long-living, and undemanding species.

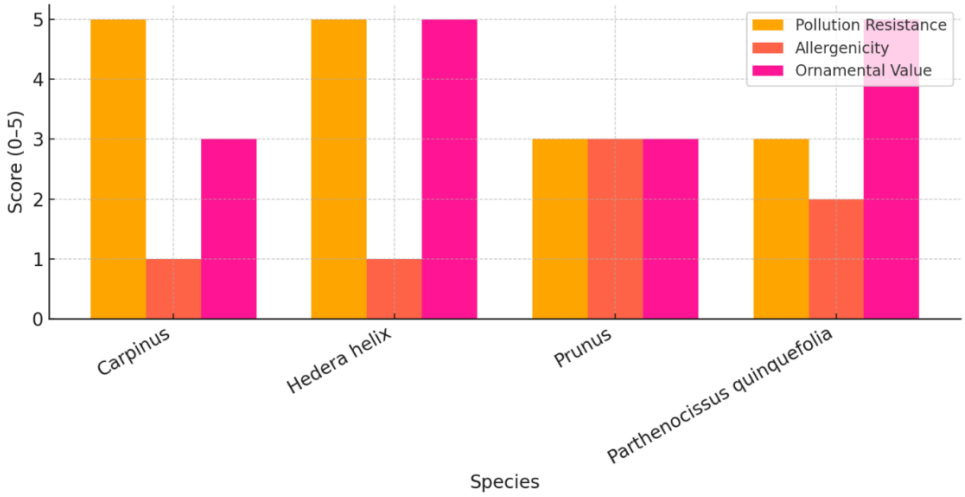

Fig. 3. Comparison of plant species by pollution resistance, allergenicity, and ornamental value (0 – low, 5 – high).

Special attention is given to innovative approaches: vertical greening using *Parthenocissus quinquefolia*, *Hedera helix*, and *Lonicera*; Mauritanian lawns with high potential for preserving entomofauna; phytofilters and filter trees (*Carpinus*, *Corylus*, *Prunus*), which purify the air and improve the microclimate.

A comparative analysis with European greening practices (Vienna, Kraków, Lyon) demonstrates the effectiveness of integrated solutions using phytoremediation technologies, green roofs, vertical greening, and local plant selection standards. These approaches have been successfully implemented and can serve as a model for Ukrainian cities.

Thus, scientifically grounded formation of urban plant composition, taking into account ecological function, allergenicity, invasive potential, and climate resilience, is key to the sustainable development of urbanized areas.

4. Conclusions

Urbanized areas require a new greening strategy that takes into account the realities of climate change, increasing anthropogenic pressure, and the need to preserve biodiversity. Using the example of Ivano-Frankivsk, it has been shown that rising temperatures, increased frequency of droughts and heat waves, air pollution, and soil degradation significantly reduce the effectiveness of traditional plant species. The use of invasive and allergenic plants that have low adaptability or pose ecological risks should be limited or completely discontinued. Instead, it is advisable to implement adaptive, pollution-tolerant, and ecologically resilient species such as *Gleditsia triacanthos*, *Carpinus betulus*, *Ginkgo biloba*, and *Amelanchier lamarckii*, along with innovative approaches such as vertical greening, Mauritanian lawns, and phytofilters. The formation of a scientifically grounded urban greening strategy should be based on the following principles:

- adaptation to local climate conditions;
- prioritization of native and resilient introduced species;
- consideration of allergenicity and invasive potential;
- implementation of ecological infrastructure solutions aimed at sustainable development.

The proposed approaches create conditions for enhancing urban ecological resilience, improving residents' quality of life, and ensuring the long-term preservation of urban ecosystems.

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Анотація

У статті розглянуто актуальні підходи до озеленення урбанізованих територій в умовах зростаючого антропогенного тиску та кліматичних змін. На прикладі Івано-Франківська проаналізовано вплив підвищення середньорічних температур, посух, забруднення повітря та ущільнення ґрунтів на стійкість традиційних видів зелених насаджень. Особливу увагу приділено проблемі інвазійних та алергенних видів, їх екологічному впливу та небажаності використання в сучасному міському ландшафті. Наведено критерії добору адаптивних, малочутливих до забруднення, стресостійких рослин, а також перспективи впровадження вертикального озеленення, мавританських газонів, фітофільтрів і дерев-фільтрів. Узагальнено рекомендації щодо створення науково обґрунтованої стратегії озеленення, яка забезпечує підвищення екологічної стійкості міського середовища та збереження біорізноманіття.

Ключові слова: озеленення, міське середовище, зміни клімату, біорізноманіття, адаптивні види, сталий розвиток.