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Interactive system for analysis of climatic and ecological processes of urban areas

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Abstract. The relevance of the study is driven by the growing impact of climate change on the functioning of urbanised areas, manifested in rising temperatures, uneven precipitation patterns, increasing frequency of extreme hydrometeorological events, and the formation of urban heat islands. In the context of intensive urbanisation and transformation of the natural environment, the need for a comprehensive analysis of climatic and ecological processes at the local level becomes particularly significant. The aim of the study was to develop an interactive information-analytical system for comprehensive analysis of climatic and ecological processes in urban areas. The research methodology was based on statistical analysis of climatic data, geoinformation analysis, three-dimensional modelling, and software development of an interactive application. As a result of the study, the software application “EcoData” was developed, integrating modules for the analysis of temperature, precipitation, water bodies, green infrastructure, and urban heat islands. Tools for building interactive charts and three-dimensional models were implemented to analyse climatic indicators for the period 1990-2024. A trend of increasing temperature values and the presence of local thermal anomalies in the central part of the city were identified. Years with anomalously high and low precipitation levels were detected. The positive effect of green plantings on reducing the thermal load of the urban environment was demonstrated. The obtained results can be applied in scientific research, educational processes, the development of urban climate strategies, greening programs, and climate change adaptation measures

Keywords: environmental monitoring; temperature regime; urban heat island; 3D modelling; urbanised areas

Introduction

Climate change and urbanisation significantly affect the functioning of urban ecosystems. Rising air temperatures, increasing frequency of extreme weather events, transformation of green zone structures, and changes in water

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regimes require the application of modern digital tools for environmental monitoring and support of managerial decision-making. Contemporary digital platforms provide access to large volumes of climatic data; however, they are predominantly oriented toward global or regional scales, are complex to use, and do not account for the specific characteristics of individual cities. At the same time, traditional analytical methods fail to provide sufficient clarity and operational efficiency for informed managerial decision-making. In this regard, the development of integrated digital tools that combine the processing of long-term climatic data, spatial analysis, 3D visualisation, and assessment of urban factor impacts within a unified system becomes particularly relevant. Such solutions contribute to improving the effectiveness of environmental monitoring, forecasting climate risks, and shaping sustainable development strategies for urban areas.

In the study by V. Zatserkovnyi *et al.* (2024), the potential of Earth remote sensing for monitoring urban heat islands was analysed. The researchers applied Landsat satellite data and Google Earth Engine tools to assess temperature anomalies in cities, particularly Kyiv and European urbanised areas. The results demonstrated a clear relationship between building density, green space coverage, and the intensity of heat islands. The authors concluded that geoinformation technologies represent an effective tool for assessing the ecological condition of urban areas and forecasting climate risks. G. Rees *et al.* (2024) investigated spatiotemporal changes in surface temperature within urbanised environments. The authors analysed long-term satellite data and established that land use transformation and urban expansion directly contribute to the growth of temperature anomalies.

The study confirmed the importance of integrating remote sensing data and geoinformation systems for urban environment monitoring. L. Lishchenko & O. Kudryashov (2021) analysed the spatiotemporal dynamics of surface temperature in one of the largest industrial cities of Ukraine based on Landsat and Sentinel-2 satellite data. The authors examined the formation of the urban heat island, determined its spatial boundaries, and established the relationship between land use patterns and temperature anomalies. The results confirmed the effectiveness of Earth remote sensing for monitoring urbanised areas and identifying zones of elevated thermal load. In the work of N. Pazynych (2020), the influence of natural landscape complexes on the formation of the temperature regime of the city of Kyiv was investigated. Based on long-term Landsat satellite data, the author established the role of valley complexes in reducing surface temperature and mitigating the manifestations of the urban heat island effect. The findings confirmed the significant importance of natural elements of the urban environment in regulating local microclimate and maintaining the ecological resilience of urbanised areas. J. Hofierka & T. Fedor (2025) developed an approach to three-dimensional modelling of urban climate using digital elevation and building models. The study demonstrated that 3D-GIS modelling enables more detailed assessment of the spatial distribution of temperature and the effectiveness of urban climate adaptation measures.

The analysis of scientific sources indicates significant advances in methods of environmental monitoring, Earth remote sensing, geoinformation analysis, and urban heat island modelling. This confirms the feasibility of developing a localised digital tool for territorial communities that integrates long-term climatic analysis, 3D modelling, heat island assessment, water body analysis, and the evaluation of green infrastructure impact within a unified interactive system (Vasylieva *et al.*, 2024; Hramchuk, 2025; Voronkova *et al.*, 2025). The majority of existing studies focus on individual aspects of environmental analysis, particularly temperature changes, satellite monitoring, or geoinformation mapping. Insufficient attention has been given to the development of unified interactive software systems that would combine automated acquisition of climatic data, their processing, statistical analysis, three-dimensional modelling, and clear visualisation of results within a single software environment. The aim of the present study was to develop a software application for the collection of climatic data, their processing, construction of informative charts, analysis of changes over time, and identification of long-term trends in temperature regime and precipitation patterns – including determination of the direction and intensity of climate change, detection of anomalously warm or cold periods, drought-affected and excessively humid years, as well as assessment of the influence of the urbanised environment on the formation of local climatic characteristics.

Materials and Methods

The study employed a combination of general scientific and specialised research methods. Statistical analysis was applied to examine the long-term dynamics of air temperature and atmospheric precipitation. The identification of climatic trends and patterns of indicator changes over time was carried out using the time series method. Elements of geoinformation analysis were used to assess the spatial distribution of temperature anomalies and to investigate urban heat islands. Visualisation of the temperature field, water bodies, and thermal anomalies was performed using three-dimensional modelling methods. The assessment of the influence of green infrastructure on the temperature regime of the urban environment was conducted through comparative analysis. For the development of the "EcoData" software application, software engineering methods were applied, encompassing software architecture design, integration of functional modules, user interface development, and system performance testing.

Within the scope of this study, the "EcoData" software application was developed, enabling the collection, processing, and interactive analysis of historical atmospheric precipitation data. A key element of the system is an interactive precipitation chart featuring zooming functionality, display of precise values, and analysis of peak and anomalous periods (Meteostat, n.d.; IQAir, 2026). The user interface of the application is presented in the Ukrainian language, which is determined by its orientation toward local use within the framework of research on climatic and ecological indicators of the urban environment. The "EcoData" application is implemented in the Python programming language following a modular architecture. The system structure includes modules for loading climatic data, their processing and statistical analysis, two-dimensional and three-dimensional visualisation, as well as a graphical user interface. For the implementation of individual functions, the following libraries were utilised: Pandas and NumPy for data processing and analysis, Matplotlib and mpl_toolkits.mplot3d for chart construction and three-dimensional modelling, FuncAnimation for the creation of animated visualisations, mplcursors for interactive engagement with charts, and Meteostat (n.d.) for retrieving historical climatic data via API.

The primary source of information was open climatic data from the Meteostat platform (n.d.) for the territory of the city of Ivano-Frankivsk covering the period 1990-2024, including indicators of mean, maximum, and minimum air temperature, atmospheric precipitation amounts, and relative humidity. Following data import, missing values were removed, time series were constructed, data were aggregated by month and year, and the dataset was prepared for subsequent modelling and visualisation. The study was conducted in stages and encompassed analysis of the subject domain, formulation of software requirements, connection of data sources, data collection and cleaning, construction of mathematical models, development of visualisation tools, and interpretation of the obtained results. To evaluate the performance of the software application, functional testing was carried out, during which the accuracy of climatic data loading and processing, the operation of interactive interface elements, and the generation of charts and three-dimensional models were verified. Thus, the development of a digital tool for comprehensive analysis of climatic indicators is aimed at improving the effectiveness of environmental monitoring, forming scientifically grounded managerial decisions, and ensuring the sustainable development of the urban environment (Pernerovska, 2014; Arkhypova & Pernerovska, 2015; Hutnyk & Kachala, 2025).

Results and Discussion

The "EcoData" software application is constructed as an integrated multifunctional system that combines several interrelated analytical modules within a unified interface. The program structure incorporates a climatic data loading module, which ensures the import and preparation of information for subsequent analysis; a temperature analysis module for examining seasonal and long-term dynamics of temperature indicators; and an atmospheric precipitation analysis module, which enables assessment of annual and seasonal changes in precipitation amounts and identification of anomalous periods. The system also includes a 3D temperature model module, which displays long-term temperature dynamics in three-dimensional space, as well as a dedicated annual 3D temperature model module, providing the capability for detailed analysis of daily temperature fluctuations for a specific year. Spatial analysis is further complemented by a water bodies map, which displays the hydrographic structure of the city and allows examination of its influence on microclimatic conditions. An important component is the 3D heat map module, aimed at detecting and visualising urban heat islands formed under the influence of dense urban development and reduction of green space coverage. A dedicated urban greening analysis module was also implemented, enabling assessment of the role of green plantings in regulating the temperature regime and shaping a favourable urban environment. All the aforementioned modules are integrated into a unified software shell with an interactive research period management system, allowing the user to independently select the temporal boundaries of analysis within a defined range. This structure ensures a comprehensive approach to the study of climatic processes within the city and enables both temporal and spatial analysis of ecological indicators. The identification of anomalously rainy or drought-affected years is essential for forecasting climate risks, planning climate change adaptation measures, and shaping sustainable development strategies for communities. Thus, the development of a software application for the collection, processing, and interactive visualisation of atmospheric precipitation data represents a timely and scientifically grounded step that contributes to improving the effectiveness of environmental monitoring, enhancing the urban environment management system, and ensuring the ecological security of the territory (Fig. 1). A key element of the system is the interactive charts, which enable analysis of the annual dynamics of indicator changes, mean monthly values, peak periods, and other ranges. Drought periods, excessive moisture periods, and long-term trends can be tracked and analysed. Interactive features include hover tooltips displaying the precise date and precipitation values in mm, chart zooming, and navigation along the timeline (Fig. 2). The urban heat island module implements spatial analysis of thermal load distribution within the city of Ivano-Frankivsk and displays the results in the form of a three-dimensional heat map (Fig. 3). The constructed model demonstrates the variation of the temperature field depending on geographical coordinates (longitude and latitude), while the Z-axis reflects the temperature increment (ΔT, °C) relative to a conditional background value. This approach enables quantitative assessment of the intensity of local thermal overheating of areas and determination of the spatial structure of the urban heat island. Within the model, the main districts of the city were identified, namely the Center, Pasichna, Naberezhna, BAM, and Kaskad. The highest temperature increment values are observed in the central part of the city, indicating heat concentration in the zone of dense urban development, high traffic load, and a significant proportion of artificial surfaces that accumulate and slowly release heat. In districts with a greater share of green plantings and lower building density, a gradual decrease in temperature indicators is observed.

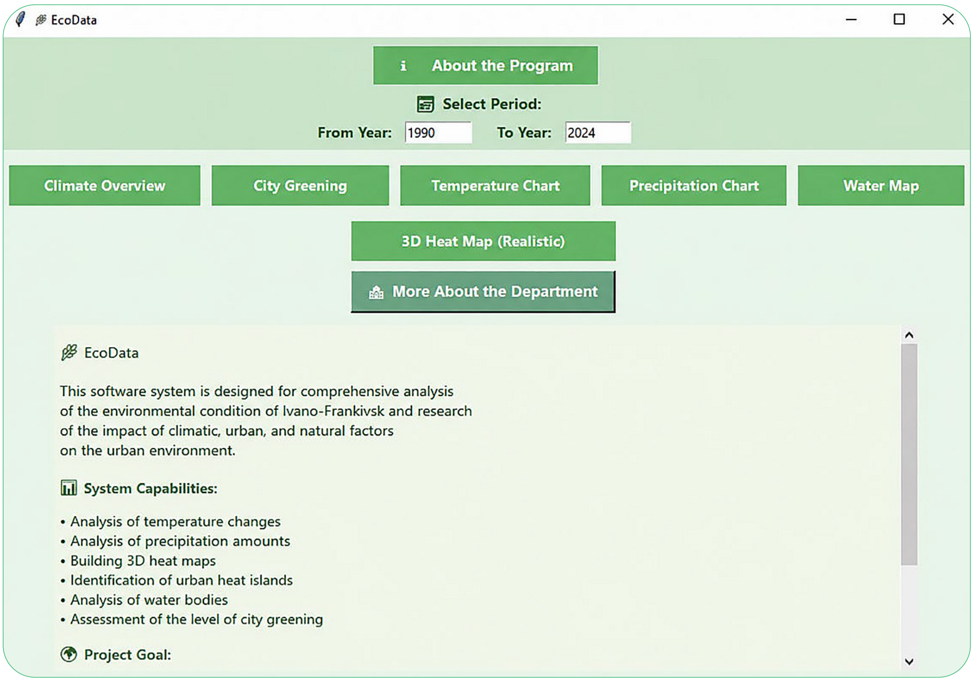

Figure 1. Main screen of the "EcoData" application

Note: the figure presents the main window of the developed EcoData software, designed for analysing the ecological condition of the city of Ivano-Frankivsk and assessing the influence of climatic, urban, and natural factors on the urban environment. The interface includes fields for selecting the research period, specifically the start and end year, as well as functional buttons for loading climatic data, analysing urban green infrastructure, constructing temperature and precipitation charts, generating a water bodies map, and producing a 3D heat map. The lower section of the window provides a brief description of the system's capabilities, explaining its core analytical functions

Source: compiled by the authors based on the results of the "EcoData" application

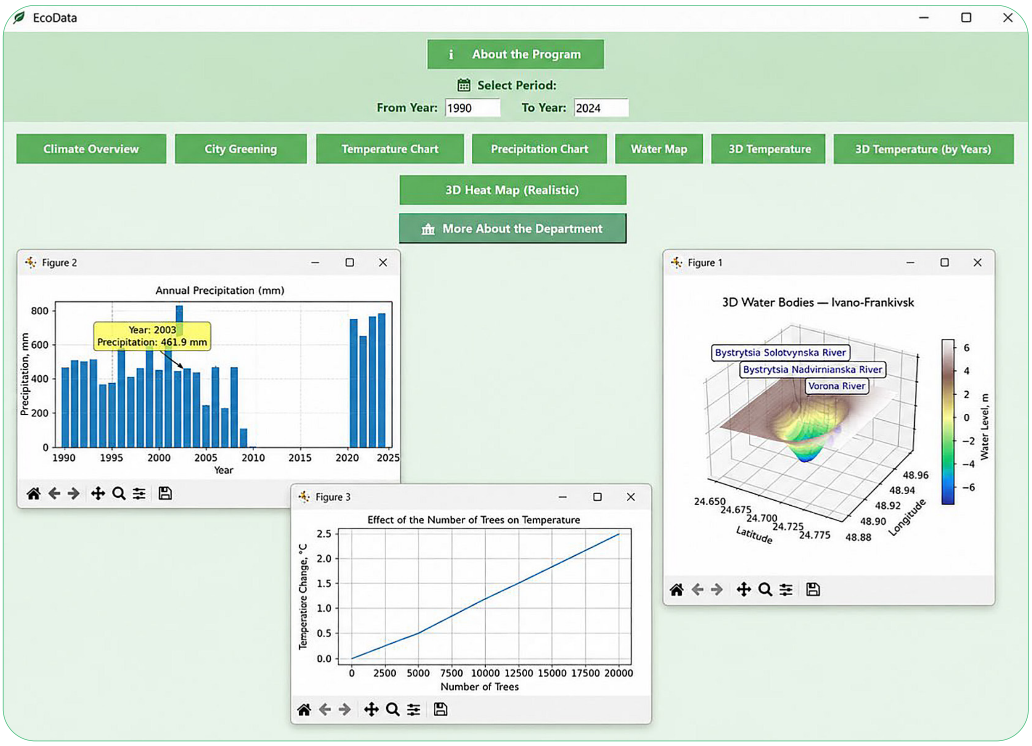

Figure 2. Example of graphical data display in the application

Source: compiled by the authors based on the results of the "EcoData" application

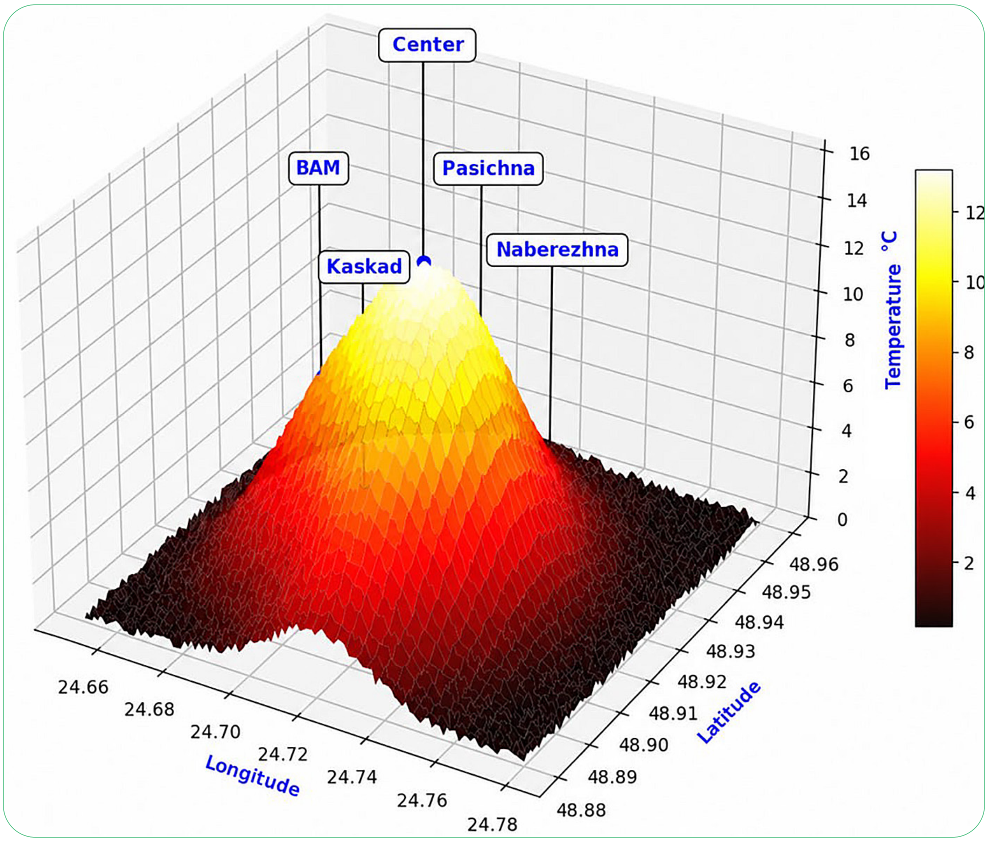

Figure 3. 3D heat islands of the city of Ivano-Frankivsk
Source: compiled by the authors based on the results of the "EcoData" application

The three-dimensional thermal model demonstrates the influence of urban factors on the formation of local temperature anomalies and confirms the manifestation of the urban heat island effect. The visualisation enables tracing of the temperature gradient from the central part to the periphery of the city, which is a characteristic feature of urbanised areas. Thus, the model provides the capability to comprehensively assess the interrelationship between building density, green infrastructure coverage, and the temperature regime. The practical significance of the module lies in the potential application of the obtained results for planning measures to expand green zones, optimise urban development policy, and form climate-adapted infrastructure. The 3D heat map data can be applied in the development of programs aimed at reducing thermal load, improving the energy efficiency of urban development, and enhancing the quality of the urban environment in accordance with the principles of sustainable development.

The "3D Water Bodies – Ivano-Frankivsk" module is designed for spatial analysis of the hydrographic structure of the city and its influence on the formation of the local microclimate (Fig. 4). Within this module, a three-dimensional terrain model was constructed incorporating the locations of the main water bodies, namely the Bystrytsya Solotvynska, Bystrytsya Nadvirnyanska, and Vorona rivers. The model displays spatial coordinates (longitude and latitude) along the horizontal axes, while the Z-axis characterises elevation or depth, enabling assessment of the terrain features and hydrological structure of the territory. The central part of the model demonstrates a surface depression corresponding to the river channel and floodplain areas. The colour scale enhances the visualisation: darker and cooler shades correspond to deeper areas, while lighter shades represent higher elevations. The three-dimensional visualisation enables tracing of the interrelationship between terrain, water body locations, and potential water accumulation zones. This is particularly important for assessing flood risk, analysing the hydrological regime, and forecasting possible changes under the influence of intensive precipitation. The presence of water bodies also affects the formation of the local microclimate, in particular contributing to temperature reduction in adjacent districts during the warm season through evaporation and air mass circulation. The practical significance of the module lies in the potential application of its results for planning water resource management measures, flood prevention, optimisation of development in coastal zones, and formation of ecologically balanced urban infrastructure. The model can be integrated with precipitation and temperature data for comprehensive analysis of the interaction between climatic and hydrological processes within the urbanised territory.

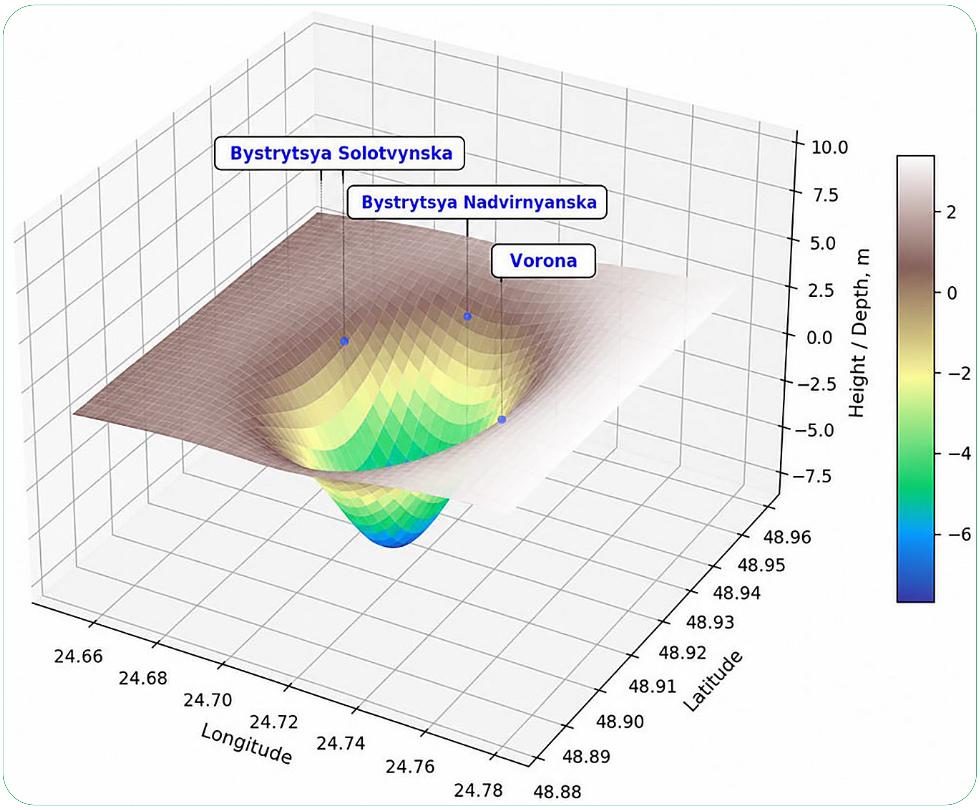

Figure 4. 3D Water Bodies – city of Ivano-Frankivsk
Source: compiled by the authors based on the results of the "EcoData" application

The module for assessing the influence of green infrastructure on the urban temperature regime demonstrates the relationship between changes in air temperature and the number of planted trees. Within this module, a chart was constructed in which the X-axis displays the number of trees and the Y-axis represents the change in air temperature (°C) (Fig. 5). The linear relationship presented in the chart shows a gradual temperature decrease with an increasing number of green plantings. The model illustrates that even a moderate increase in tree count leads to a noticeable reduction in thermal load. With an expansion of the green stock to 20,000 trees, a conditional temperature decrease of approximately 2-2.5°C is observed, which represents a significant indicator for an urbanised environment. This effect is explained by the processes of transpiration, surface shading, reduction of heat accumulation by artificial materials, and improvement of air circulation.

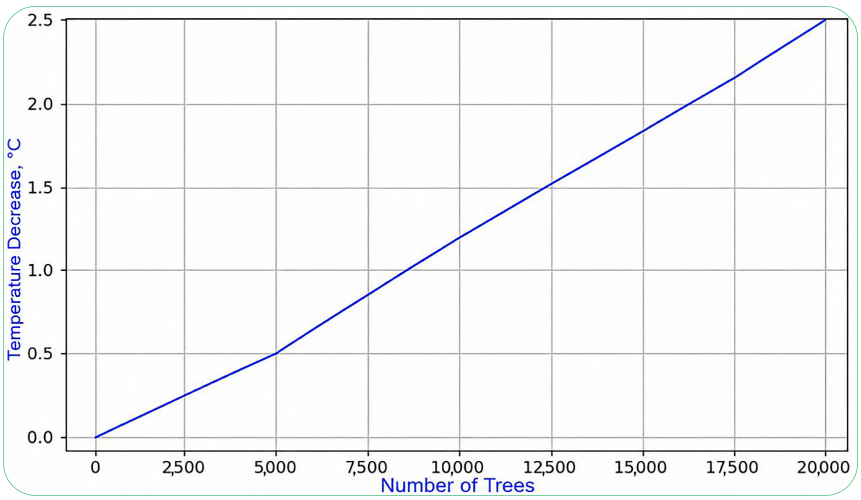

Figure 5. Influence of green infrastructure on the urban temperature regime
Source: compiled by the authors based on the results of the "EcoData" application

The chart enables assessment of the potential ecological effect of implementing mass greening programs and serves as an important tool for strategic urban development planning. Through this model, it is possible to forecast the degree to which the intensity of the heat island effect will diminish with an increase in green space coverage. The practical significance of the module lies in the potential application of the obtained results in the formulation of ecological restoration programs, development of "green city" concepts, improvement of residential comfort for the population, and adaptation of the urban environment to climate change. It can also serve as a justification for investment in the development of green plantings as one of the most effective and nature-based approaches to reducing thermal load.

The daily temperature analysis module displays the dynamics of temperature regime changes in Ivano-Frankivsk for the period 1990-2024 in the form of a continuous time series chart (Fig. 6). The horizontal axis represents the calendar scale (dates), while the vertical axis displays air temperature values in degrees Celsius. This format enables tracing not only the overall long-term trend but also detailed temperature fluctuations within each individual year. The chart clearly demonstrates the cyclical nature of temperature changes, corresponding to seasonal processes: regular peaks during the summer period and temperature decreases in winter. The recurrence of the wave-like structure indicates the stability of the seasonal rhythm, while individual deviations are also evident – sharp temperature decreases or increases that may be associated with anomalous weather events. Analysis of the long-term data array enables assessment of the frequency of extremely low temperatures during the winter period and high temperatures during the summer season. In certain years, significant temperature amplitudes are observed, which may indicate an increase in climatic variability. A gradual shift of temperature maxima toward higher values in more recent years can also be traced, which is consistent with the global warming trend. The practical significance of this module lies in the capability to identify extreme temperature periods, analyse the duration of warm and cold seasons, assess the thermal load on urban infrastructure and the population. The obtained results can be applied for forecasting climate risks, planning energy consumption, developing climate change adaptation measures, and enhancing the resilience of the urban environment to temperature extremes.

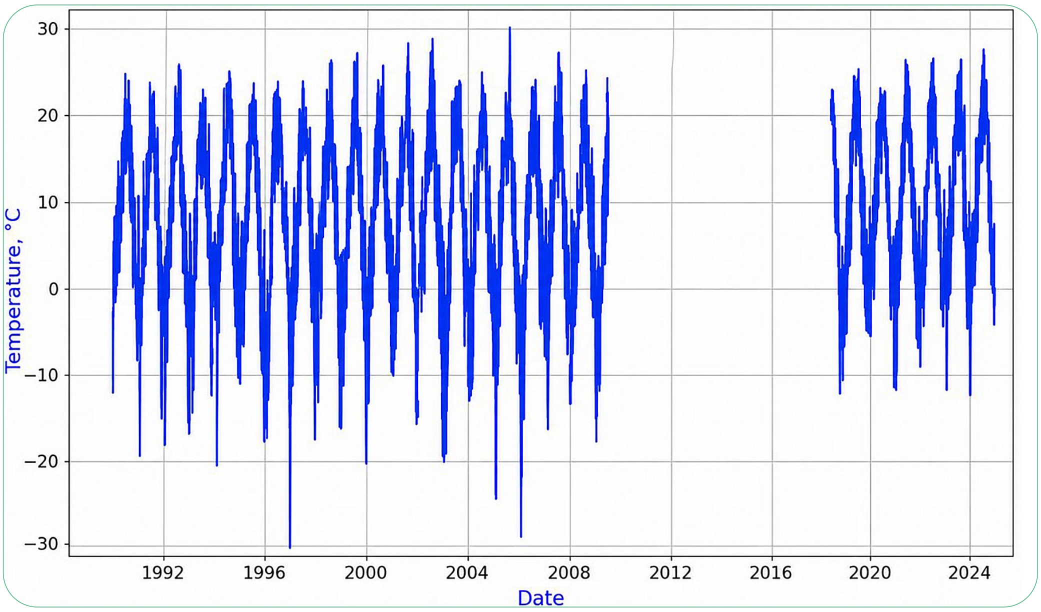

Figure 6. Analysis of daily temperature in the city of Ivano-Frankivsk for the period 1990-2024
Source: compiled by the authors based on the results of the "EcoData" application

The precipitation analysis module is one of the key components of the software system and is aimed at investigating the long-term dynamics of atmospheric precipitation within Ivano-Frankivsk (Fig. 7). Within this module, the system automatically generates a bar chart of annual precipitation totals in millimetres, covering the study period from 1990 to 2024. The visualisation enables clear tracing of changes in annual precipitation sums, assessment of their inter-annual variability, and identification of years with maximum and minimum values. The chart displays peak values that may indicate anomalously rainy years, as well as periods of reduced precipitation characterised as anomalously dry. This approach makes it possible to identify the long-term trend of changes in territorial moisture levels and assess whether a tendency toward increase or decrease in annual precipitation totals is observed in the context of climate change.

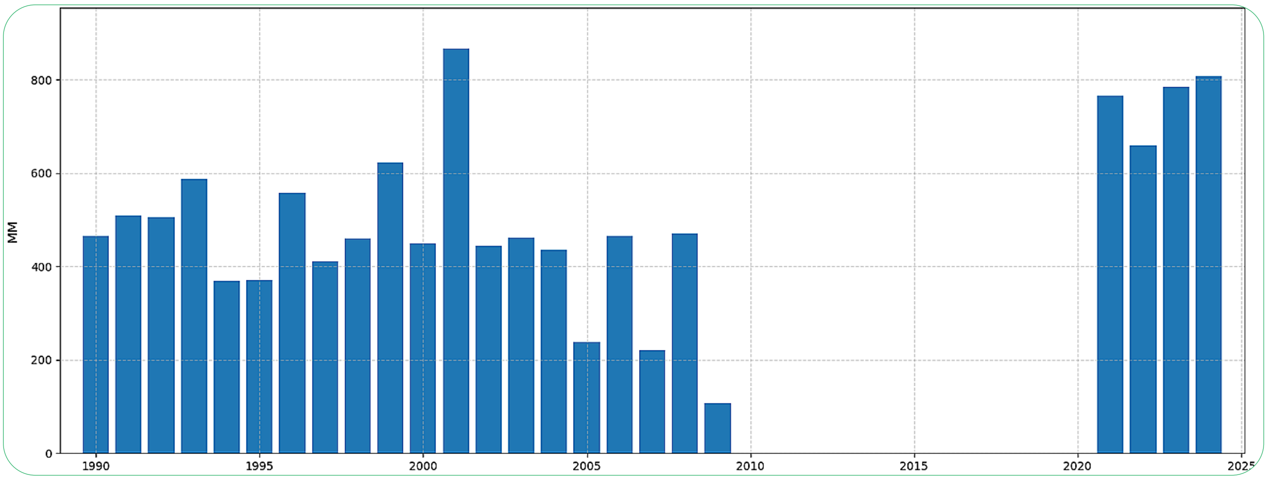

Figure 7. Annual precipitation totals – city of Ivano-Frankivsk
Source: compiled by the authors based on the results of the "EcoData" application

The analytical capabilities of the module enable comparison of any years with one another, identification of periods of elevated flood risk resulting from excessive precipitation, as well as assessment of moisture deficit periods that may negatively affect green plantings and the city's water resources. In addition, the system provides detection of climatic anomalies that are significant for ecological planning and the development of climate change adaptation measures. An important advantage of the module is its interactivity. The user has the capability to obtain precise precipitation values in millimetres through hover tooltips, zoom the chart for detailed analysis of individual periods, navigate along the timeline, and drill down into specific years. This format of data presentation enhances the usability of the system and makes the analysis process more intuitive and effective.

The module presented in Figure 8 provides comprehensive spatiotemporal analysis of the temperature regime of the city of Ivano-Frankivsk over an extended observation period (1990-2024). Within this module, a three-dimensional surface was constructed in which the X-axis represents the day of the year (from 1 to 365), the Y-axis represents the observation year, and the Z-axis displays air temperature values in degrees Celsius. This format enables simultaneous assessment of both seasonal dynamics and long-term changes in temperature indicators. The model surface demonstrates a characteristic wave-like form corresponding to the cyclical nature of seasonal processes: temperature increase during the spring-summer period and its decrease during the autumn-winter season. Through the use of a colour scale ranging from blue to red shades, temperature contrasts are clearly visualised: blue tones correspond to negative values during winter months, while red tones represent maximum summer temperatures.

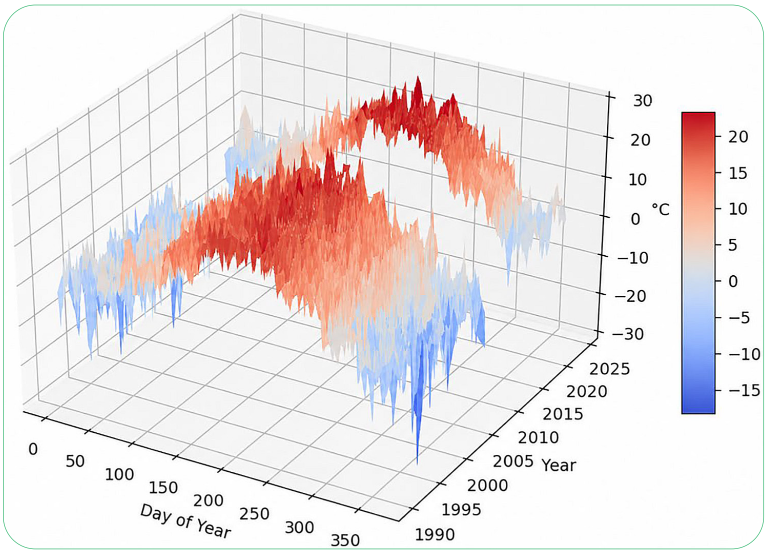

Figure 8. 3D temperature – Ivano-Frankivsk
Source: compiled by the authors based on the results of the "EcoData" application

Analysis of the model enables tracing of long-term temperature change trends, in particular the gradual increase in mean annual values in more recent observation years. Periods of extreme temperatures can also be identified – both anomalously cold winters and exceptionally hot summers. The three-dimensional visualisation assists in detecting changes in the duration of warm and cold periods, which serves as an important indicator of climatic transformations. The practical significance of the module lies in the potential application of the obtained results for assessing the impact of temperature changes on urban infrastructure, energy consumption, the condition of green plantings, and residential comfort of the population. The model represents an effective tool for scientific analysis of climatic trends and the formulation of urban adaptation measures in response to global warming conditions.

The "3D Temperature by Year" module (Fig. 9) is designed for detailed analysis of the temperature regime of an individual year with the capability of spatiotemporal visualisation. Within this tool, a three-dimensional model is generated in which the X-axis represents the day of the year (from 1 to 365), the Y-axis corresponds to the selected study year, and the Z-axis displays air temperature values in degrees Celsius. This approach enables representation of daily temperature dynamics within a specific year and tracing of the character of seasonal fluctuations. Using 1992 as an example, a gradual temperature increase from winter negative values to summer maxima is clearly visible, followed by a characteristic temperature decrease during the autumn-winter period. The colour scale ranging from blue to red shades enhances the clarity of analysis: cold periods are represented by blue tones, while warm periods are depicted in orange-red hues. This enables rapid visual identification of temperature peak periods, cold waves, or atypical seasonal deviations.

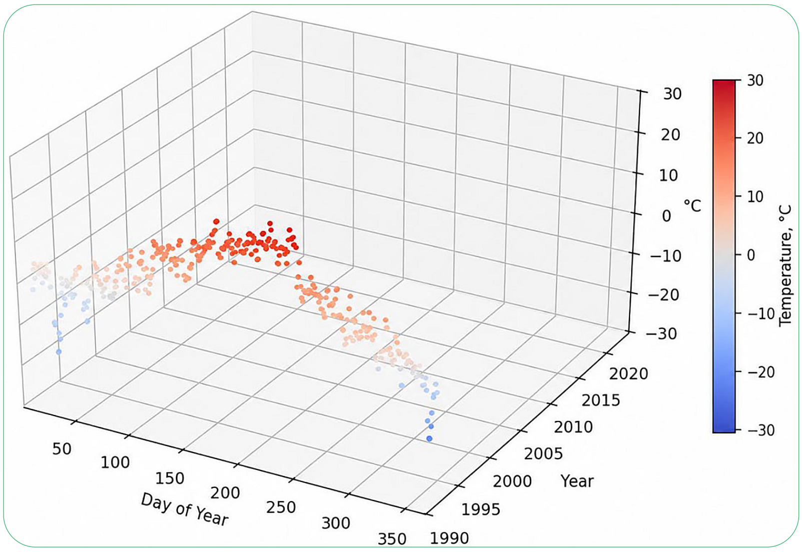

Figure 9. Temperature by years – 1992-2025
Source: compiled by the authors based on the results of the "EcoData" application

This form of data presentation makes it possible to identify anomalously warm or cold periods, analyse the duration of seasons, assess the intensity of summer maxima and winter minima, and compare the characteristics of the temperature regime across different years. The model serves as an important tool for investigating long-term climatic trends and confirming the manifestations of global warming at the local level. From a practical standpoint, the module can be utilised for climate risk analysis, assessment of thermal load on the urban environment, investigation of the impact of temperature extremes on public health, and planning of climate change adaptation measures. Three-dimensional visualisation significantly enhances the informativeness of the analysis and renders the results comprehensible to both researchers and representatives of local government authorities.

The results obtained through the three-dimensional temperature field analysis module confirm the presence of a pronounced urban heat island effect in the central part of Ivano-Frankivsk. Similar patterns were established in the study by D. Lauwaet *et al.* (2024), who demonstrated through high-resolution modelling across one hundred European cities that the greatest intensity of heat islands is characteristic of areas with high building density and a significant proportion of artificial surfaces. Similar conclusions were also presented in the work of M. Possega *et al.* (2022), which proved the intensification of thermal load in urbanised districts during extreme temperature events. The results obtained in the present study regarding the positive influence of green infrastructure on the urban temperature regime are consistent with the findings of T. Iungman *et al.* (2023), who established that increasing green space coverage represents one of the most effective nature-based approaches to reducing thermal load and improving the quality of the urban environment. Studies by C. Andrade *et al.* (2023) and N. Krupa (2025) also confirmed that the development of green infrastructure is one of the key instruments for adapting cities to climate change. Furthermore, contemporary research indicates that even a modest increase in green space coverage can provide a noticeable cooling effect in central urban districts.

The precipitation analysis and long-term temperature dynamics modules constructed in the present study confirmed the growth of climatic variability and the increasing frequency of extreme weather events. Similar trends were described in the work of C. Reis *et al.* (2022), where, based on large climatic datasets from the Copernicus service (n.d.), a substantial intensification of temperature anomalies in cities of Southern Europe was established. The study by K. Koutroumanou-Kontosi *et al.* (2022) also demonstrated the necessity of combining regional and local climate modelling for identifying the characteristics of urban microclimate formation and forecasting future climate risks.

Of particular interest are the results of applying three-dimensional visualisation within the "EcoData" system. A similar approach was described in the works of G. Lobaccaro *et al.* (2021) and S. Dimitrov *et al.* (2024), who emphasised that the application of GIS technologies, unmanned remote sensing systems, and three-dimensional modelling significantly enhances the analytical capabilities for examining the spatial structure of thermal anomalies and improves the informativeness of environmental monitoring. The results of these studies confirmed the feasibility of the approach implemented in the present work, which combines temporal and spatial analysis within a unified software environment.

The results of the analysis of spatiotemporal variability of the urban temperature regime are consistent with contemporary approaches to urban climate modelling. In particular, K. Koutroumanou-Kontosi *et al.* (2022) emphasised the necessity of combining regional and local climate models for accurate representation of the characteristics of the urban thermal environment. The methodology of integrating multi-scale climatic simulations proposed by the authors confirms the feasibility of employing long-term climatic data in combination with local spatial analysis within the developed "EcoData" application, as precisely this approach enables the identification of local temperature anomalies and assessment of potential risks for the urban environment.

The importance of applying high-resolution climatic data is confirmed by the study of G. Frustaci *et al.* (2022), in which a high-resolution air temperature dataset was created for the city of Milan. The authors demonstrated that the use of detailed spatial temperature data substantially improves the capabilities for identifying urban heat islands and analysing intra-urban temperature heterogeneity. A similar approach is implemented in the three-dimensional visualisation module of the "EcoData" application, which provides clear representation of the spatial distribution of temperature indicators and enables identification of areas with elevated thermal load. The obtained results regarding the influence of temperature anomalies on the urban environment are also consistent with the conclusions of D. Hidalgo-García & H. Rezapouraghdam (2023), who investigated the spatial variability of heat stress in the city of Seville using the UrbClim climate model and proposed measures for its mitigation. The authors demonstrated that the most effective adaptation measures include expansion of green space coverage, reduction of the proportion of artificial surfaces, and implementation of continuous temperature regime monitoring tools. This confirms the practical significance of the developed software application, which can be utilised as a decision-support tool for planning urban environment adaptation measures in response to climate change and minimising the negative consequences of urban heat islands.

Thus, the results of the study confirm global trends in the development of digital environmental monitoring systems and demonstrate the effectiveness of integrating long-term climatic data, spatial analysis, and three-dimensional visualisation for investigating climatic and ecological processes in urban areas. The developed "EcoData" application can be regarded as a promising decision-support tool in the field of urban environment management, planning of climate change adaptation measures, and implementation of sustainable urban development strategies. The conducted study confirmed that contemporary approaches to urban climate analysis are increasingly oriented toward the integration of long-term climatic data, geoinformation analysis, three-dimensional modelling, and interactive visualisation tools. Comparison of the obtained results with current international research indicates that the trends identified for Ivano-Frankivsk are consistent with pan-European processes of temperature increase, intensification of climatic variability, and formation of urban heat islands. In contrast to the majority of existing studies, which predominantly focus on individual aspects of urban environment monitoring, the developed "EcoData" software application provides a comprehensive combination of temperature regime analysis, atmospheric precipitation, water bodies, green infrastructure, and spatial thermal anomalies within a unified interactive software environment. This allows the proposed system to be regarded as a promising instrument for supporting managerial decision-making aimed at enhancing the climatic resilience of cities and implementing the principles of sustainable development of urbanised territories.

Conclusions

As a result of the conducted work, the "EcoData" software application was developed – an interactive information-analytical system designed for investigating climatic, ecological, and urban-ecological processes at the local level, particularly for the city of Ivano-Frankivsk. The system ensures the integration of long-term meteorological data, their analytical processing, and multi-level visualisation in the form of charts and three-dimensional models. The software tool combined the processing of climatic data (temperature and precipitation), analysis of ecological factors (territorial green infrastructure), spatial modelling of natural objects (water resources), and 2D and 3D visualisation of results.

Analysis of long-term climatic data for the city of Ivano-Frankivsk over the period 1990-2024 confirmed a trend toward increasing mean annual temperatures, growing frequency of extremely warm periods, and anomalous precipitation years, which is consistent with general regional and global climate change patterns. The atmospheric precipitation analysis module enabled identification of years with anomalously high and low precipitation amounts, indicating an increase in climatic variability. The three-dimensional urban heat island modelling module revealed the concentration of elevated temperatures in areas of dense urban development and transport hubs, while territories with a high proportion of green plantings are characterised by lower temperature values, confirming the role of green infrastructure in reducing thermal load. The water bodies analysis module demonstrated the positive influence of the urban lake and river network on the formation of the local microclimate. The obtained results indicate the feasibility of comprehensive consideration of climatic, hydrological, and urban-ecological factors in the development of sustainable urban development strategies. Prospects for further research lie in expanding the functionality of the system through integration of satellite data, application of artificial intelligence-based forecasting algorithms, and development of a web-oriented version of the platform for broader application in sustainable urban development management practice.

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Conflict of Interest
None.

References
[1] Andrade, C., Fonseca, A., & Santos, J.A. (2023). Climate change trends for the urban heat island intensities in two major Portuguese cities. *Sustainability*, 15(5), article number 3970. doi: 10.3390/su15053970.
[2] Arkhypova, L.M., & Pernerovska, S.V. (2015). Forecasting hydrological parameters of water bodies using singular spectrum analysis. *Scientific Bulletin of National Mining University*, 2, 45-50.
[3] Copernicus. (n.d.). Retrieved from https://cds.climate.copernicus.eu.
[4] Dimitrov, S., Iliev, M., Nedkov, S., & Borisova, B. (2024). A methodological framework for high-resolution surface urban heat island mapping: Integration of UAS remote sensing, GIS, and the local climate zone concept for surface urban heat island assessment. *Remote Sensing*, 16(21), article number 4007. doi: 10.3390/rs16214007.
[5] Frustaci, G., Onorati, G., Malatesta, L., & Bisignano, A. (2022). High-resolution gridded air temperature data for the urban environment: The Milan data set. *Forecasting*, 4(1), 238-261. doi: 10.3390/forecast4010014.
[6] Hidalgo-García, D., & Rezapouraghdam, H. (2023). Variability of heat stress using the UrbClim climate model in the city of Seville: Mitigation proposal. *Environmental Monitoring and Assessment*, 195, article number 1164. doi: 10.1007/s10661-023-11768-8.
[7] Hofierka, J., & Fedor, T. (2025). Modelling and visualisation of heat stress in urban areas using high-resolution geospatial data. *Abstracts of the ICA*, 10, article number 107. doi: 10.5194/ica-abs-10-107-2025.
[8] Hramchuk, M. (2025). Integrated "Smart City" model as a factor of digitalization and eco-balanced development: A socio-philosophical analysis. *Humanities Studies*, 23(100), 35-45. doi: 10.32782/hst-2025-23-100-04.
[9] Hutnyk, V., & Kachala, S.V. (2025). Biodiversity conservation under climate change: Challenges and prospects for Ukraine. In *Proceedings of the regional conference "Youth ecoforum – 2025"* (pp. 25-26). Ivano-Frankivsk: Ivano-Frankivsk National Technical University of Oil and Gas.
[10] IQAir. (2026). Retrieved from https://www.iqair.com.
[11] Iungman, T., *et al.* (2023). Cooling cities through urban green infrastructure: A health impact assessment of European cities. *The Lancet*, 401(10376), 577-589. doi: 10.1016/S0140-6736(22)02585-5.
[12] Koutroumanou-Kontosi, K., Cartalis, C., & Santamouris, M. (2022). A methodology for bridging the gap between regional- and city-scale climate simulations for the urban thermal environment. *Climate*, 10(7), article number 106. doi: 10.3390/cli10070106.
[13] Krupa, N. (2025). Integrated models of urban ecosystems: A systems approach to sustainable development planning. In *Current problems, ways and prospects of development of landscape architecture, horticulture, urban ecology and phytomelioration* (pp. 152-154). Bila Tserkva: Bila Tserkva National Agrarian University. doi: 10.33245/25-09-2025.
[14] Lauwaet, D., Berckmans, J., Hooyberghs, H., Wouters, H., Driesen, G., Lefebre, F., & De Ridder, K. (2024). High resolution modelling of the urban heat island of 100 European cities. *Urban Climate*, 54, article number 101850. doi: 10.1016/j.uclim.2024.101850.
[15] Lishchenko, L., & Kudryashov, O. (2021). The results of the study of spatio-temporal changes in surface temperatures of Zaporizhzhia based on satellite data. *Ukrainian Journal of Remote Sensing*, 8(3), 27-36. doi: 10.36023/ujrs.2021.8.3.198.

[16] Lobaccaro, G., Acero, J.A., Martín-García, D., Kennedy, C., & Galatioto, A. (2021). Applications of models and tools for mesoscale and microscale thermal analysis in mid-latitude climate regions: A review. *Sustainability*, 13(22), article number 12385. doi: 10.3390/su132212385.

[17] Meteostat. (n.d.). Retrieved from https://meteostat.net.

[18] Pazynych, N. (2020). Valley complexes as ecosystem assets of heat island of urban agglomerations (on the example of the right-bank part of Kyiv). *Ukrainian Journal of Remote Sensing*, 26, 38-47. doi: 10.36023/ujrs.2020.26.181.

[19] Pernerovska, S.V. (2014). Determination of the degree of hydroecological risk as the main parameter of sustainable development of a hydroecosystem. *Ecological Safety and Balanced Use of Resources*, 5(3), 23-28.

[20] Possega, M., Baklanov, A., Lhotka, O., Plavcová, E., & Belda, M. (2022). Observational evidence of intensified nocturnal urban heat island during heatwaves in European cities. *Environmental Research Letters*, 17(12), article number 124013. doi: 10.1088/1748-9326/aca3ba.

[21] Rees, G., Hebryn-Baidy, L., & Belenok, V. (2024). Temporal variations in land surface temperature within an urban ecosystem: A comprehensive assessment of land use and land cover change in Kharkiv, Ukraine. *Remote Sensing*, 16(9), article number 1637. doi: 10.3390/rs16091637.

[22] Reis, C., Lopes, A., & Nouri, A.S. (2022). Assessing urban heat island effects through local weather types in Lisbon's metropolitan area using big data from the Copernicus service. *Urban Climate*, 43, article number 101168. doi: 10.1016/j.uclim.2022.101168.

[23] Vasylieva, N., Vasylieva, O., Prylipko, S., & Shevchenko, N. (2024). Public management of recreational nature use on the principles of sustainable inclusive development under urbanization conditions. *Scientific Bulletin: Public Administration*, 2(16), 90-100. doi: 10.33269/2618-0065-2024-2(16)-90-100.

[24] Voronkova, V.H., Nikitenko, V.O., & Metelenko, N.H. (2025). "Green" digital transformation as a driver of sustainable regional development in post-war recovery. *Educational Discourse: Collection of Scientific Papers*, 52(1-2), 22-30. doi: 10.33930/ed.2019.5007.52(1-2)-4.

[25] Zatserkovnyi, V., De Donatis, M., Plichko, L., Sakhniuk, S., Odarchuk, N., & Mironchuk, T. (2024). Using remote sensing technologies for monitoring urban heat islands. *Bulletin of Taras Shevchenko National University of Kyiv: Geography*, 3(106), 99-106. doi: 10.17721/1728-2713.106.13.

Інтерактивна система для аналізу кліматичних та екологічних процесів міських територій

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Анотація. Актуальність дослідження зумовлена зростаючим впливом кліматичних змін на функціонування урбанізованих територій, що проявляється у підвищенні температури, нерівномірності атмосферних опадів, збільшенні частоти екстремальних гідрометеорологічних явищ та формуванні міських теплових островів. В умовах інтенсивної урбанізації та трансформації природного середовища особливої значущості набуває необхідність комплексного аналізу кліматичних і екологічних процесів на локальному рівні. Метою дослідження була розробка інтерактивної інформаційно-аналітичної системи для комплексного аналізу кліматичних та екологічних процесів міських територій. Методологія дослідження ґрунтувалася на використанні методів статистичного аналізу кліматичних даних, геоінформаційного аналізу, тривимірного моделювання та програмної розробки інтерактивного застосунку. У результаті дослідження розроблено програмний застосунок «EcoData», який інтегрує модулі аналізу температури, атмосферних опадів, водних об'єктів, озеленення та міських теплових островів. Реалізовано інструменти побудови інтерактивних графіків і тривимірних моделей для аналізу кліматичних показників за період 1990-2024 рр. Встановлено тенденцію до підвищення температурних показників та наявність локальних теплових аномалій у центральній частині міста. Виявлено роки з аномально високою та низькою кількістю опадів. Показано позитивний вплив зелених насаджень на зниження температурного навантаження міського середовища. Отримані результати можуть бути використані у наукових дослідженнях, освітньому процесі, під час розробки міських кліматичних стратегій, програм озеленення та заходів адаптації до змін клімату

Ключові слова: екологічний моніторинг; температурний режим; тепловий острів; 3D-моделювання; урбанізовані території