

ЗБАЛАНСОВАНЕ ПРИРОДОКОРИСТУВАННЯ

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MULTI-CRITERION ASSESSMENT OF THE PRIORITY OF ENVIRONMENTAL PROTECTION MEASURES BASED ON OPEN ONLINE DATA

Purpose. To develop and test a methodology for multi-criteria assessment of environmental protection priorities using open online data under conditions of incomplete information and interval uncertainty.

Methods. Systems analysis, multi-criteria assessment, an additive utility function, expert weighting of criteria, normalization of heterogeneous indicators, interval analysis, and scenario analysis. Open online sources selected as the information basis: NASA FIRMS for active fires, JRC Global Surface Water for water dynamics, ESA WorldCover and Sentinel-2/Copernicus Data Space for land cover and vegetation indicators, OpenAQ for air quality, HDX for administrative boundaries, Global Forest Watch for tree cover loss, and EkoZagroza as an auxiliary source of environmental threat reports.

Results. The study addresses a practical problem in environmental management: how to justify priority actions when several measures are relevant simultaneously, and the available data have different spatial resolutions, reliability, and completeness. A pilot computational experiment conducted for a conditional urbanized area in the Kharkiv region. Six environmental alternatives assessed: greening, cleaning water bodies, reclamation of disturbed lands, strengthening air monitoring, improving waste management, and fire-prevention measures. Six criteria used: environmental effect, implementation cost, implementation time, social significance, risk of inaction, and availability of online data. The highest baseline utility scores obtained for waste management improvement, and fire-prevention measures. The following priorities water body cleaning, greening, strengthening of air monitoring, and reclamation of disturbed lands. Scenario analysis showed that the first two alternatives remain the highest-priority group under different weighting assumptions.

Conclusions. The proposed methodology enables formalizing preliminary environmental decision-making even when online data are incomplete. Interval representation does not eliminate uncertainty but makes it explicit and useful for assessing the reliability of ranking results. The method can support the preliminary justification of local environmental protection programs and should be further tested using actual datasets for specific territorial communities.

KEYWORDS: *environmental protection measures, multi-criteria assessment, environmental management, online data, interval uncertainty, utility function*

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Introduction

Environmental management at the local community and urban levels is increasingly carried out under conditions marked by a combination of constraints: insufficient financial resources, incomplete environmental monitoring,

inconsistent open data, and uncertainty about the consequences of delaying management actions. For a single area, the following measures may all be relevant at the same time: landscaping, water-body cleanup, reclamation of disturbed land,

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enhanced air-quality monitoring, improved waste management, and fire prevention measures. Under these conditions, the key scientific and practical task is not only to describe environmental problems but also to make an informed selection of priority environmental protection measures.

The complexity of such a choice stems from the multiple criteria involved. One environmental protection measure may have a significant ecological impact but require substantial costs and a long time to implement; another measure may be cheaper and faster but have only a local or indirect effect. Furthermore, the decision must consider social significance, the risk of inaction, and the reliability of the information base. Therefore, prioritizing measures falls into the category of multi-criteria decision-making under conditions of uncertainty.

The methodological foundation of this study is a systematic approach to decision-making, developed in works on multi-criteria optimization, utility theory, and uncertainty analysis [1–8]. In her dissertation, N. O. Brynza demonstrates the need to account for the complexity, multi-criteria nature, and interval uncertainty of the input data when selecting effective solutions [1]. This point is particularly important for environmental issues, since natural, social, and economic indicators differ in nature, units of measurement, and reliability.

Modern open online data creates new opportunities for preliminary environmental assessments. NASA FIRMS provides access to

near-real-time MODIS and VIIRS data on active fires [19; 20]. RC Global Surface Water contains data on the spatiotemporal distribution of surface water for the period 1984–2021. [21; 22]. ESA WorldCover provides global land cover maps with a spatial resolution of 10 meters [23], a Copernicus Data Space provides open access to Sentinel data and data processing services [24]. OpenAQ provides open data on air quality and an API for accessing it [25]. HDX contains administrative boundaries of Ukraine [26], Global Forest Watch publishes data on deforestation [27], and EcoZagroza is the official resource for recording environmental threats, although its historical data and full functionality were in the process of being restored at the time of this study's preparation [28].

An analysis of recent studies confirms the widespread use of multi-criteria analysis in environmental management, water resource management, nature-based decision-making, and the assessment of ecosystem services [9–15]. At the same time, the issue of combining open online data, expert assessments, and interval uncertainty into a single applied procedure for ranking environmental protection measures remains underdeveloped. This article addresses this unresolved issue.

The aim of this study is to develop and test a methodology for the multi-criteria prioritization of environmental protection measures based on open online data, considering the interval uncertainty of the source information.

Methods

The object of this study is the process of preselecting priority environmental protection measures for an urbanized area under conditions of incomplete online information. The subject of this study is a methodology for multi-criteria ranking of environmental protection alternatives using a utility function, expert weighting coefficients, and interval data representation.

The pilot test was conducted as a computational experiment for a hypothetical urbanized area in the Kharkiv region. This format was chosen because the article's purpose is to verify the methodological suitability of the systematic procedure rather than to replace comprehensive field monitoring. The actual application of the methodology to a specific community requires loading spatial data into a GIS environment and

aggregating indicators within administrative polygons.

The experimental conditions are as follows: six alternative environmental protection measures, six evaluation criteria, a scale of initial ratings [0; 10], interval representation of initial ratings, and four scenarios for weighting coefficients are considered. Laboratory equipment and reagents were not used, as the study is a digital computational experiment based on open-source data and expert-interval formalization.

The research logic is presented in Fig. 1. The main stages are: selection of online sources, development of indicators, conversion of indicators into an expert interval scale, normalization of criteria, calculation of the integral utility function, ranking of alternatives, and scenario analysis of the stability of results.

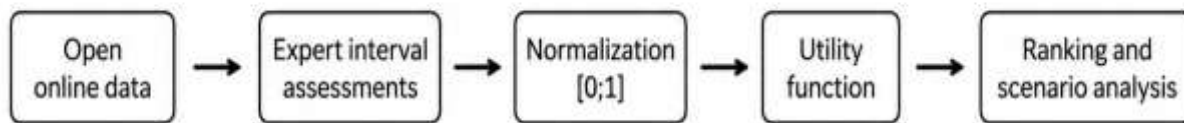


Fig. 1 – Logical scheme of the multi-criteria online research methodology

Table 1

Open online sources suitable for generating input data

Data block	Source	Specifications for the model
Administrative boundaries	HDX Ukraine Subnational Administrative Boundaries	Boundaries of communities/districts, area, spatial aggregation
Fire activity	NASA FIRMS MODIS/VIIRS	Number of fire points, FRP, fire density
Surface water	JRC Global Surface Water	Availability, seasonality, and changes in the water surface
Land cover	ESA WorldCover, Sentinel-2, Copernicus Data Space	Green areas, built-up areas, bare soil, NDVI
Air	OpenAQ API and local networks	Number of stations, PM2.5, PM10, days with data
Loss of forest cover	Global Forest Watch / GLAD	Loss of forest cover by year
Environmental threats	ЕкоЗагроза	Auxiliary layer of threat notifications

For the purposes of this study, six alternative environmental protection measures were identified (Table 2). These reflect typical areas of environmental protection in urbanized areas and can be tailored to address the community's specific environmental challenges.

The alternatives were evaluated based on six criteria (Table 3). Criteria C1, C4, C5, and C6 are positive factors; that is, increases in these criteria raise the measure's priority. Criteria C2 and C3 are negative factors, as higher costs and longer implementation periods lower the priority, all other things being equal.

Table 2

Environmental protection alternatives and online indicators

Code	Alternative	Online indicators
A1	Landscaping	NDVI, proportion of green spaces, loss of tree cover, population
A2	Water body cleanup	Water area, seasonality, loss/change in water surface area
A3	Remediation of Disturbed Lands	Proportion of bare soil, development, loss of tree cover
A4	Enhanced Air Quality Monitoring	Number of stations, days with data, PM2.5, PM10
A5	Improved Waste Management	Threat alerts, urbanization, population, local programs
A6	Fire Prevention Measures	Number of fires, FRP, fire density, green areas

Table 3

Evaluation criteria and baseline weights

Code	Criterion	Optimization objective	Weight
C1	Environmental impact	max	0.25
C2	Implementation cost	min	0.15
C3	Implementation timeline	min	0.1
C4	Social significance	max	0.2
C5	Risk of inaction	max	0.2
C6	Availability of online data	max	0.1

For incentive criteria, the normalized value was calculated using the formula:

$$x_{ij} = \frac{a_{ij} - a_i^{min}}{a_i^{max} - a_i^{min}}$$

Reverse normalisation was used for the disincentive criteria:

$$x_{ij} = \frac{a_i^{max} - a_{ij}}{a_i^{max} - a_i^{min}}$$

The overall priority rating of the jth measure was determined using an additive utility function:

$$U_j = \sum_{i=1}^n w_i \cdot x_{ij}$$

where w_i – the weighting coefficient of the i-th criterion,

x_{ij} – the normalized value of the i-th criterion for the j-th alternative.

Under conditions of interval uncertainty, the following representation was used

$$\bar{U}_j = [U_j^-; U_j^+]$$

and for the basic ranking, the midpoint of the interval was calculated

$$U_{jc} = \frac{(U_j^- + U_j^+)}{2}$$

Interval length $\Delta U = U_j^+ - U_j^-$ was interpreted as an indicator of the uncertainty of the assessment.

Results

In the first stage, an initial expert-based interval matrix was developed for evaluating alternatives on a scale of [0; 10] (Table 4). The intervals reflect the incompleteness of online information, the varying levels of detail in open data, and the need for expert interpretation of

spatial indicators. For example, NASA FIRMS data is given greater weight for fire prevention measures, JRC Global Surface Water for the clean-up of water bodies, and ESA WorldCover, Sentinel-2 and Global Forest Watch for greening and land restoration.

Table 4

Initial expert-interval assessment matrix [0; 10]

Code	Event	C1	C2	C3	C4	C5	C6
A1	Landscaping	[6; 8]	[4; 6]	[3; 5]	[7; 9]	[5; 7]	[7; 9]
A2	Water body treatment	[7; 9]	[6; 8]	[5; 7]	[6; 8]	[7; 9]	[6; 8]
A3	Rehabilitation of disturbed land	[6; 9]	[7; 9]	[6; 9]	[5; 7]	[6; 9]	[4; 6]
A4	Enhanced air quality monitoring	[5; 7]	[3; 5]	[2; 4]	[6; 8]	[5; 8]	[8; 10]
A5	Improved waste management	[7; 9]	[5; 7]	[4; 6]	[8; 10]	[7; 9]	[6; 8]
A6	Fire prevention measures	[6; 8]	[3; 5]	[2; 4]	[6; 8]	[8; 10]	[7; 9]

After normalization, all criteria were converted to a dimensionless scale [0; 1] (табл. 5). The normalized matrix allows for the comparison of indicators of different types: environmental, economic, social, and informational.

Calculation of the integrated utility function based on the weightings revealed that improving waste management and fire prevention measures are the highest priorities (Table 6). These alternatives combine a high risk of inaction, significant social importance, and relatively acceptable cost and implementation timeframe parameters.

The graphical representation of the utility intervals (Fig. 2) shows that the first two alternatives' intervals overlap slightly. This means that the difference between A5 and A6 is small, and the final decision may depend on the clarification of local data, financial conditions and the positions of the stakeholders.

To verify the robustness of the results, a scenario analysis was carried out using four sets of weighting coefficients: baseline, environmental, budgetary-temporal, and informational. The environmental scenario emphasizes the magnitude of environmental impact and the risk

Table 5

Normalized interval assessment matrix [0; 1]

Code	Event	C1	C2	C3	C4	C5	C6
A1	Landscaping	[0.250; 0.750]	[0.500; 0.833]	[0.571; 0.857]	[0.400; 0.800]	[0.000; 0.400]	[0.500; 0.833]
A2	Water body treatment	[0.500; 1.000]	[0.167; 0.500]	[0.286; 0.571]	[0.200; 0.600]	[0.400; 0.800]	[0.333; 0.667]
A3	Rehabilitation of disturbed land	[0.250; 1.000]	[0.000; 0.333]	[0.000; 0.429]	[0.000; 0.400]	[0.200; 0.800]	[0.000; 0.333]
A4	Enhanced air quality monitoring	[0.000; 0.500]	[0.667; 1.000]	[0.714; 1.000]	[0.200; 0.600]	[0.000; 0.600]	[0.667; 1.000]
A5	Improved waste management	[0.500; 1.000]	[0.333; 0.667]	[0.429; 0.714]	[0.600; 1.000]	[0.400; 0.800]	[0.333; 0.667]
A6	Fire prevention measures	[0.250; 0.750]	[0.667; 1.000]	[0.714; 1.000]	[0.200; 0.600]	[0.600; 1.000]	[0.500; 0.833]

Table 6

Integral priority scores of environmental protection measures

Code	Event	U_{min}	U_{max}	U_c	ΔU	Rank
A5	Improved waste management	0.451	0.848	0.650	0.397	1
A6	Fire prevention measures	0.444	0.841	0.642	0.397	2
A2	Water body treatment	0.332	0.729	0.530	0.397	3
A1	Landscaping	0.325	0.722	0.523	0.397	4
A4	Enhanced air quality monitoring	0.278	0.715	0.497	0.437	5
A3	Rehabilitation of disturbed land	0.102	0.616	0.359	0.514	6

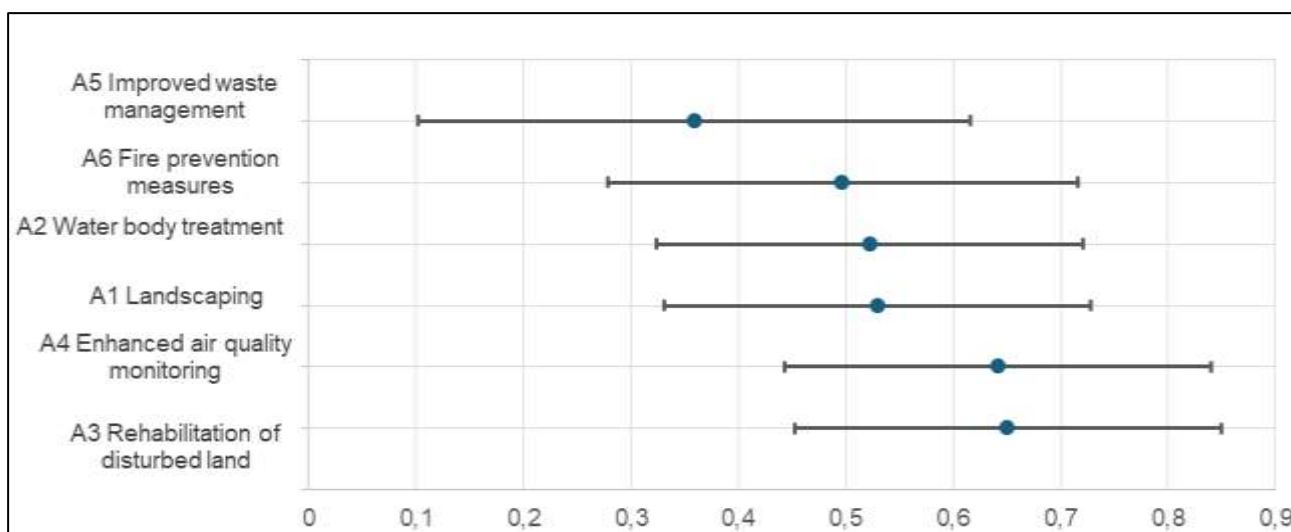


Fig. 2 – Interval priority scores of environmental protection measures

of inaction; the budgetary-temporal scenario emphasizes costs and the implementation time-frame; and the informational scenario emphasizes the availability of online data. The resulting rankings are shown in Table 7.

Under the baseline scenario (Fig/ 3), alternative A5 – improving waste management – came first ($U_c = 0.650$). Fire safety measures A6 came second ($U_c = 0.642$). The difference between them is only 0.007, indicating that both measures belong to the same highest-priority group.

The purification of water bodies (A2) was assigned a third rank ($U_c = 0.530$). Its high environmental significance is partly offset by

higher costs and a longer implementation time-frame. Landscaping of the A1 area has a fourth rank ($U_c = 0.523$) due to its positive social impact, but a lower risk of inaction than A5 and A6.

Enhanced atmospheric air monitoring (A4) ranks fifth under the baseline scenario, although it rises to third place under the budget-time scenario. This reflects the nature of monitoring measures: they are relatively quick and inexpensive, but their direct environmental benefits are indirect. The rehabilitation of disturbed land (A3) has the lowest ranking in all scenarios, which is explained by its high cost, duration, and the widest range of uncertainty.

Table 7

Ranks of alternatives under weighting scenarios

Code	Event	Basic	Environmental	Budget and time	Information
A1	Landscaping	4	4	4	3
A2	Water body treatment	3	3	5	4
A3	Land restoration	6	6	6	6
A4	Enhanced air quality monitoring	5	5	3	5
A5	Improved waste management	1	1	2	1
A6	Fire prevention measures	2	2	1	2

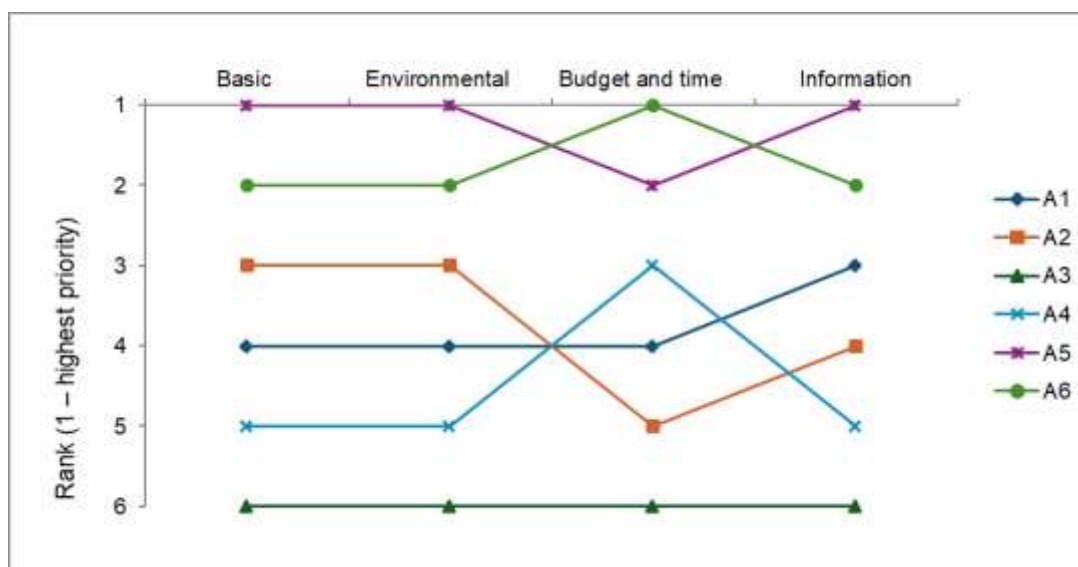


Fig. 3 – Change in alternative ranks under weighting scenarios

Thus, the computational experiment revealed three patterns: firstly, measures combining a high environmental impact with a

high risk of inaction occupy the top of the ranking; secondly, low cost and short duration can significantly alter an alternative's position

in a budget-time scenario; thirdly, the width of the interval of the integrated assessment is an

important indicator of the need for additional data.

Discussion

The results obtained are consistent with the current approach to multi-criteria environmental assessment, which holds that a management decision should take into account not just a single dominant indicator, but a system of environmental, economic, social, and informational criteria [9–15]. Works on MCDA emphasize that environmental problems are multidimensional, conflicting, and sensitive to weighting assumptions, and therefore require stability analysis and transparent justification of criteria [11, 12]. The scenario analysis conducted confirmed this thesis: when weighting coefficients are changed, the first two alternatives remain in the leading group, whilst the positions of A1, A2, and A4 are more sensitive.

A comparison with the literature on nature-based solutions shows that greening and the restoration of ecosystem functions generally have significant socio-environmental impacts, but their priority depends on local demand for ecosystem services, available land, costs, and expected co-benefits [13–18]. In this study, greening received a medium ranking, which does not negate its importance but reflects a methodological distinction between its strategic value and its priority under conditions of limited resources.

Waste management ranked first because it offers environmental, public health, and social benefits. In practice, its assessment requires further clarification based on local programs, open budgets, public procurement data, and reports of unauthorized waste dumps. At the same time, this

area is often well understood by the local population, which enhances its social significance.

Fire prevention measures ranked second and remained in the highest-priority group across all scenarios. This is because fires can rapidly lead to a deterioration in air quality, loss of vegetation cover, soil degradation, and secondary environmental risks. The availability of NASA FIRMS open data makes this area particularly suitable for online research and operational environmental management [19; 20].

The scientific novelty of this work lies in adapting a multi-criteria decision-making methodology under interval uncertainty to the task of selecting environmental protection measures based on open online data. Unlike conventional expert ranking, the proposed approach provides a formal structure of criteria, transparent weighting assumptions, the calculation of interval utility values, and verification of the robustness of the results.

The practical value of the methodology lies in its use as a preliminary tool for developing community environmental protection programs. The results do not replace field monitoring, but they do help us determine which alternatives should have priority for additional data collection. The widest range of uncertainty was found for the reclamation of disturbed land, indicating the need for a spatial inventory of degraded sites, an assessment of soil contamination, and a technical and economic justification..

Conclusions

A methodology is proposed for the multi-criteria prioritization of environmental protection measures based on open online data. The methodology combines systematic analysis, expert-based interval formalization, criterion normalization, an additive utility function, and scenario analysis of weighting coefficients.

The study's information base has been established, comprising NASA FIRMS, JRC Global Surface Water, ESA WorldCover, Copernicus Data Space, OpenAQ, HDX, Global Forest Watch and EcoZagroza. These sources enable the development of indicators to assess fire activity, the state of surface waters, green areas,

land cover, atmospheric air quality, administrative boundaries, and environmental threats.

According to the results of the pilot computational experiment, waste management improvements and fire safety measures were given the highest priority. Their integral scores, based on the midpoint of the interval, were 0.650 and 0.642, respectively, indicating that these alternatives are closely matched and that further local data refinement is required before a final management decision can be made.

It has been established that the clean-up of water bodies and the greening of the area form the middle priority group, whilst enhanced air

monitoring is particularly sensitive to the budget and time constraints. The restoration of disturbed land has the lowest short-term priority and the greatest uncertainty, explained by its high cost, long duration, and the lack of detailed online data.

A cause-and-effect analysis shows that the priority of an environmental protection measure is determined not only by its environmental impact, but by a combination of environmental effectiveness, the risk of inaction, social significance, cost, implementation timeframe, and the availability of information. The answer to the

question posed in the introduction is affirmative: even with incomplete online information, it is possible to obtain a well-founded preliminary ranking of environmental protection measures by using a multi-criteria model with interval data representation.

Further research should focus on testing the methodology within specific local communities in the Kharkiv region, involving the automated aggregation of indicators within a GIS and the comparison of online assessment results with field environmental monitoring data.

Conflict of Interest

The author declares no conflict of interest regarding the publication of this manuscript. Furthermore, the author has fully adhered to ethical norms, including avoiding plagiarism, data falsification, and duplicate publication.

AI Statement

During the preparation of this manuscript, artificial intelligence ChatGPT-5.5 (OpenAI, 2026) used for organizational support, text structuring, language editing, and performing auxiliary calculations. No synthetic field data were used. The author bears full responsibility for the content, the accuracy of the data, the interpretation of the results, and the conclusions.

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БАГАТОКРИТЕРІАЛЬНА ОЦІНКА ПРІОРИТЕТНОСТІ ПРИРОДООХОРОННИХ ЗАХОДІВ НА ОСНОВІ ВІДКРИТИХ ОНЛАЙН-ДАНИХ

Мета. Розробити й апробувати методику багатокритеріальної оцінки пріоритетності природоохоронних заходів на основі відкритих онлайн-даних за умов неповноти та інтервальної невизначеності вихідної інформації.

Методи. Системний аналіз, багатокритеріальне оцінювання, адитивну функцію корисності, експертне зважування критеріїв, нормалізацію показників і сценарний аналіз. Як інформаційну базу обґрунтовано використання відкритих джерел: NASA FIRMS для пожежної активності, JRC Global Surface Water для поверхневих вод, ESA WorldCover і Sentinel-2/Copernicus Data Space для земного та рослинного

покриву, OpenAQ для якості повітря, HDX для адміністративних меж, Global Forest Watch для втрат деревного покриву та ЕкоЗагрози як допоміжного джерела повідомлень про екологічні загрози.

Результати. Дослідження спрямоване на підтримку попереднього вибору першочергових дій у сфері екологічного менеджменту для урбанізованих територій, де одночасно актуальні проблеми зелених насаджень, водних об'єктів, порушених земель, атмосферного повітря, відходів і пожежної небезпеки. Проведено пілотний обчислювальний експеримент для умовної урбанізованої території Харківського регіону з шістьма альтернативами та шістьма критеріями. Сформовано експертно-інтервальну матрицю оцінювання природоохоронних заходів за критеріями екологічного ефекту, вартості, терміну реалізації, соціальної значущості, ризику бездіяльності та доступності онлайн-даних. Найвищі інтегральні оцінки за базовими вагами отримали удосконалення управління відходами та протипожежні заходи. Далі розташувалися очищення водних об'єктів, озеленення території, посилення моніторингу атмосферного повітря та рекультивация порушених земель. Сценарний аналіз показав, що перші дві альтернативи залишаються групою найвищої пріоритетності за різних схем вагових коефіцієнтів.

Висновки. Запропонована методика дає змогу формалізувати вибір природоохоронних пріоритетів навіть за умов неповної онлайн-інформації. Інтервальне представлення даних дозволяє не приховувати невизначеність, а використовувати її як окрему характеристику надійності управлінського рішення. Методика може бути застосована для попереднього обґрунтування програм охорони довкілля територіальних громад і потребує подальшої апробації на фактичних локальних наборах даних.

КЛЮЧОВІ СЛОВА: *природоохоронні заходи, багатокритеріальне оцінювання, екологічний менеджмент, онлайн-дані, інтервальна невизначеність, функція корисності*

Конфлікт інтересів

Автор заявляє, що конфлікту інтересів щодо публікації цього рукопису немає. Крім того, автор повністю дотримувався етичних норм, включаючи плагіат, фальсифікацію даних та подвійну публікацію.

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