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Integral assessment of the effectiveness of water resource management in communities for sustainable development

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Abstract. The relevance of this study stems from the need to develop comprehensive monitoring systems for evaluating the effectiveness of water resource management that take into account environmental, social and economic dimensions. This study aimed to analyse and assess existing approaches to the development of an integrated monitoring system for evaluating the effectiveness of water resource management at the level of territorial communities, with the goal of ensuring environmental safety and sustainable development. The research was based on a systems approach and employed SWOT analysis, comparative analysis and modelling. Based on a review of the scientific literature, a multi-level system of indicators was developed, comprising nine key indicators grouped into environmental, social and economic components. The calculated integral indicator of water resource management effectiveness was 0.382, indicating a below-average level of effectiveness. The component analysis revealed a critical imbalance: the environmental component scored extremely low (0.03), due to the absence of designated water protection zones (0%) and the poor condition of water bodies (0% classified as in "good" condition). The social component demonstrated a relatively high result (0.6174), attributed to a high level of access to centralised water supply (89.8%) and wastewater services (87%). The economic component (0.518) reflected a moderate level of effectiveness; however, it was negatively affected by high water losses in the distribution networks (44%) and a low rate of water reuse (1%). Forecast modelling for the period up to 2050 indicated the potential to achieve a high level of effectiveness (0.963), provided that integrated measures are implemented across all key areas, with the

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most dynamic improvements expected between 2023 and 2030. The practical value of the study lies in the development of a scientifically grounded basis for assessing the effectiveness of water resource management at the level of territorial communities. This enables the identification of priority areas for improving the system and supports the adoption of evidence-based management decisions in the field of water governance

Keywords: assessment; environmental safety; monitoring; territorial communities; quality indicators; basin-based approach

Introduction

Effective water management is a key factor in ensuring environmental safety, promoting sustainable community development, and preserving water potential for future generations. In the context of increasing anthropogenic pressure, climate change and water scarcity, the development of integrated monitoring systems becomes particularly crucial. Such systems enable the assessment of water management performance at the community level. For Ukraine, which is striving to align its environmental policy with the requirements of the European Union and the United Nations (UN) Sustainable Development Goals (SDGs), the implementation of integrated approaches to water resource management represents an important strategic objective. Despite numerous studies in the field of water governance, the development of integral indicators for assessing management effectiveness at the level of territorial communities remains underexplored.

Integrated water management has emerged as a leading focus of ecosystem research between 2020 and 2024, driven by global challenges in securing water access, conserving resources and promoting rational use. The issue of comprehensive monitoring of aquatic ecosystems has been explored in detail by M.A.E. Forio & P.L.M. Goethals (2020), who developed an integrated methodology for the analysis of aquatic ecosystems based on a synthesis of hydromorphological characteristics, physicochemical properties, and biological parameters. The researchers highlight the importance of multi-tiered monitoring in ensuring sustainable water management and fulfilling the SDGs related to clean water and terrestrial ecosystems.

Current monitoring systems predominantly focus on isolated aspects of water use, often overlooking the complex interplay between ecological, social and economic factors. In contrast, European concepts of integrated water management emphasise the need to consider the full range of interconnections within water-ecological systems, aligning human needs with environmental requirements. Research conducted between 2020 and 2024 has placed increasing importance on the application of advanced monitoring technologies, particularly the use of the Internet of Things, wireless sensor networks, and real-time data collection systems. R. Martínez *et al.* (2020) developed an integrated water quality control system based on IoT technologies, enabling real-time data collection and processing. These innovations significantly enhance the responsiveness and quality of decision-making related to water use. Studies aimed at developing comprehensive performance indicators for water management, which integrate economic, social and environmental dimensions, deserve particular attention. For instance, S. Bilalova *et al.* (2023) demonstrated in their research that such indicators allow not only for an assessment of the current state of water use but also for trend forecasting, the identification of critical influencing factors, and the formulation of evidence-based directions for improving local water policy.

Research dedicated to developing integrated groundwater-monitoring systems is particularly pertinent for Ukraine. A. Hienova *et al.* (2023) proposed a comprehensive approach to monitoring groundwater in the country's industrial regions that enables efficient identification of pollution sources and assessment of their impact on the environmental safety of water resources. Valuable insights into regional aspects of water-resource management were provided by H. Kireitseva *et al.* (2024), who examined the internal and external factors governing the use and conservation of water resources in the Zhytomyr Region. The study identified key determinants of water-use efficiency in the region, including institutional, economic and environmental factors. Findings indicated that obsolete water-supply technologies and insufficient coordination between different levels of governance exert the greatest influence on the condition of water resources. However, no specific mechanisms were suggested for integrating the identified factors into a comprehensive community-level monitoring system for management effectiveness. A promising avenue for further improvement is the integration of watermanagement strategies into land-use planning, as proposed by S. Kalogiannidis *et al.* (2023). This approach would facilitate more effective delineation and enforcement of water-protection zones – a critical element of the environmental dimension of the integral indicator. In Zhytomyr, the issue is particularly pressing, given the documented absence of designated water-protection zones for local water bodies.

An analysis of scientific literature indicates a growing interest in the development of integral indicators for assessing the effectiveness of water resource management, which combine environmental, social and economic dimensions. However, the formation of such indicators at the level of territorial communities – particularly in the context of decentralised governance in Ukraine – remains insufficiently explored. This study aimed to conduct a systematic analysis and comprehensive assessment of current approaches used to develop integrated monitoring systems for evaluating the effectiveness of water resource management at the territorial communities level, with a focus on ensuring environmental safety and sustainable resource use.

Materials and Methods

The methodological basis of the study was a systems approach to evaluating the performance of water management activities at the level of a territorial community. The research was conducted using data from the Zhytomyr urban territorial community, selected as a representative example of mid-sized Ukrainian communities that face typical challenges related to water resources. The study drew on a wide range of sources, including: official documents from Zhytomyr City Council (2023a; 2023b), such as the General Plan of the Zhytomyr Urban Territorial Community, the Sustainable Urban Mobility Plan of Zhytomyr, and the Integrated Urban Development Concept of Zhytomyr until 2030 (Ministry of Regional Development, Construction, Housing and Communal Services of Ukraine, 2019); statistical data from the Zhytomyrvodokanal municipal enterprise for 2020-2023 (Zhytomyr Vodokanal…, 2022); state statistical reporting forms 2-TP (water management), 1-housing stock, 11-NKREKP (State Statistics of Ukraine, n.d.); monitoring data from the Pripyat River Basin Water Resources Management (2023); and data from the State Water Cadastre of Ukraine (2023), the State Land Cadastre of Ukraine (2023), as well as the authors' research findings.

A range of scientific methods was applied to achieve the stated aim and address the objectives of the study. Systems analysis was used to explore water resource management comprehensively, incorporating environmental, social and economic dimensions. This made it possible to consider the water management system as a set of interrelated elements. SWOT analysis was employed to identify the strengths, weaknesses, opportunities and threats in the field of water resource management within the Zhytomyr urban territorial community. Based on the SMART methodology, the following key strategic goals and objectives were defined: ensuring effective and sustainable water resource management through the development of an integrated monitoring system and the adoption of modern water supply technologies; protecting and restoring aquatic ecosystems by delineating water protection zones and implementing ecological rehabilitation programmes; improving access to safe drinking water and sanitation by modernising infrastructure and expanding the centralised water supply network; enhancing climate resilience and preventing flooding through the development of stormwater management systems and early warning mechanisms; promoting sustainable and efficient water use by reducing water losses in distribution networks and introducing water reuse technologies.

This structuring ensured that each identified area met the criteria of specificity, measurability, attainability, relevance, and time-boundedness. To bring heterogeneous indicators (shares, percentages, absolute values) onto a unified measurement scale ranging from 0 to 1, data standardisation methods were applied – an essential requirement for calculating a composite indicator. Two standardisation algorithms were used in the study: one for increasing-type indicators (1) and one for decreasing-type indicators (2):

$$K_1 = (X - X_{(min)}) / (X_{(max)} - X_{(min)}); \quad (1)$$

$$K_1 = (X_{(max)} - X) / (X_{(max)} - X_{(min)}), \quad (2)$$

where X – the actual value of the indicator; $X_{(min)}$ and $X_{(max)}$ – the minimum and maximum possible values; K_1 – the standardised value for increasing-type indicators; K_2 – the standardised value for decreasingtype indicators.

A key element of the research methodology was the composite assessment method, which was used to calculate the overall water management performance indicator. This indicator is derived from the standardised values of the environmental, social, and economic components, weighted according to the following algorithm:

$$I = \alpha_1 E + \alpha_2 C + \alpha_3 K, \quad (3)$$

where I – the integral effectiveness indicator; α_1, α_2, α_3 – the weighting coefficients (their sum equals 1); E – the environmental component; C – the social component; K – the economic component.

Each component value was calculated as the arithmetic mean of the standardised values of the corresponding indicators:

$$E = \frac{K_{1E} + K_{2E} + K_{3E} + K_{4E}}{4}; \quad (4)$$

$$C = \frac{K_{1C} + K_{2C} + K_{3C}}{3}; \quad (5)$$

$$K = \frac{N_{1K} + N_{2K}}{2}, \quad (6)$$

where K_{1E}, K_{2E}, K_{3E}, K_{4E} – the standardised values of environmental indicators; K_{1C}, K_{2C}, K_{3C} – the standardised values of social indicators; N_{1K}, N_{2K} – the standardised values of economic indicators.

This approach enables the aggregation of heterogeneous indicators into a single assessment, the consideration of the relative importance of different management aspects, the tracking of overall trends, the comparison of management effectiveness across communities, and the justification of intervention priorities. The weighting coefficients α_1, α_2, and α_3 were determined through expert evaluation based on a survey of professionals in the field of water management. The expert survey was conducted in February-March 2023 at Zhytomyr Polytechnic State University. Twelve experts participated in the study: five academics from universities and research institutions, five representatives of local government and state agencies in the water sector, and two specialists from regional water supply companies. The survey was conducted individually in a mixed format: eight in-person interviews and four remote questionnaires completed via Google Forms, with anonymity settings enabled. Experts were asked to assess the importance of each indicator and component using a ten-point scale. The results were normalised to ensure that the sum of the weighting coefficients equalled one. The study was conducted in accordance with ethical standards, following the principles of The Declaration of Helsinki (2013). All participants gave informed consent, were briefed on the purpose of the study and the intended use of the results, and were guaranteed confidentiality of personal data and the right to withdraw from the study at any stage. The selection of environmental indicators aligns with the recommendations of M.A.E. Forio & P.L.M. Goethals (2020) regarding integrated monitoring of aquatic ecosystems. The economic indicators – particularly the water loss metric – correspond to the approaches outlined in the research of F.L.R. Tambo *et al*. (2022).

Based on the target indicators for 2030, 2040 and 2050, a simulation of the integral performance indicator was carried out. The targets include: achieving 100% coverage with centralised water supply and wastewater services by 2050, with interim targets of 93% by 2030 and 97% by 2040; reducing water losses in distribution networks from the current 44% to 30% by 2030, 20% by 2040, and 12% by 2050; increasing the share of reused water in industry from 1% to 25%, 45% and 65% for the respective periods; achieving 100% delineation of water protection zones by 2030; and improving the ecological status of water bodies, with 30%, 60% and 80% classified as in "good" condition by 2030, 2040 and 2050 respectively. The "good" condition of water bodies is defined as a condition that meets the criteria of the Directive of the European Parliament and of the Council No. 2000/60/EC (2000), in which water quality indicators ensure the proper functioning of aquatic ecosystems and their suitability for water use. These targets were developed in accordance with the strategic development documents of the Zhytomyr community (Ministry of Regional Development, Construction, Housing and Communal Services of Ukraine, 2019), the provisions of the Directive of the European Parliament and of the Council No. 2000/60/EC (2000), which has been incorporated into Ukrainian legislation, as well as the UN SDGs, in particular Goal 6 "Clean Water and Sanitation" and Goal 11 "Sustainable Cities and Communities".

The research was carried out in four consecutive stages. During the first stage (SeptemberDecember 2022), data on the condition of water resources and their management system within the Zhytomyr urban territorial community were collected and systematised, and strategic documents, statistical records and monitoring results were analysed. The second stage (January-March 2023) focused on developing an indicator system for evaluating the effectiveness of water-resource management. The third stage (April-May 2023) involved calculating the integral watermanagement effectiveness indicator using the methodology developed. The final stage (June-August 2023) comprised an analysis of the results obtained and the formulation of recommendations for enhancing the community's water-management system.

Results and Discussion

Effective water-resource management in territorial communities necessitates a systems approach rooted in an objective analysis of the current situation and in the establishment of strategic directions for improvement. Assessment of water-sector performance in the Zhytomyr urban territorial community began with an examination of the links between strategic water-use objectives and the community's principal planning documents. Alignment with the General Plan of the Zhytomyr Urban Territorial Community is crucial, as water-protection objectives must be integrated into spatial planning (Zhytomyr City Council, 2023a). The Integrated Urban Development Concept of Zhytomyr until 2030 is likewise pivotal, because the strategic goals of sustainable water management should correspond to the city's overall vision and development priorities (Ministry of Regional Development, Construction, Housing and Communal Services of Ukraine, 2019). The Sustainable Urban Mobility Plan of Zhytomyr outlines measures to reduce the environmental impact of transport on water resources and to support the development of infrastructure along water bodies (Zhytomyr City Council, 2023b). The Development Strategy of the Zhytomyrvodokanal municipal enterprise to 2030 also plays an important role in setting objectives for infrastructure modernisation and reducing water losses. It is worth noting that all targets are aligned with the national SDG Ukraine Monitoring Report (2020). Based on an analysis of the current state of water resource management in the Zhytomyr urban territorial community, a SWOT analysis was conducted. The results are presented in Table 1.

Table 1. SWOT analysis of the water resource management system in the Zhytomyr urban territorial community

Strengths (S)	Weaknesses (W)
S1 – Availability of numerous lakes and reservoirs	W1 – Pollution of water bodies
S2 – Development of water supply and wastewater infrastructure	W2 – Littering with household waste
S3 – Introduction of modern water treatment technologies	W3 – Lack of comprehensive, integrated water resource management
S4 – Presence of recreational and ecological zones	W4 – Shortage of drinking water in certain areas and generally poor water quality
S5 – Public engagement in water resource protection	W5 – Underdeveloped water supply and wastewater infrastructure in some settlements; absence of sewerage systems
S6 – Water-related activities such as open-water competitions	W6 – Uncontrolled use of water resources and water protection zones
S7 – Availability of reservoirs suitable for renewable energy production	W7 – Non-compliance with regulations on riparian buffer zones and protected water areas
S8 – Availability of qualified personnel in the field of water resource protection	W8 – Inefficient water use in both industry and households
S9 – Gradual greening of industry	W9 – Outdated infrastructure and technologies
S10 – International cooperation	W10 – Insufficient cooperation between local authorities, businesses and the public
	W11 – Low public awareness
	W12 – Inadequate financial resources
	W13 – Loss of local biodiversity and increasing biological invasions
	W14 – Lack of alternative sources of drinking water

Table 1. Continued

Opportunities (O)	Threats (T)
O1 – Development of water-based tourism and recreation O2 – Introduction of new water treatment and supply technologies O3 – Infrastructure improvements: modernisation of dams and reservoirs, and flexible reservoir management O4 – Promotion and support for water-saving technologies and the installation of local treatment facilities by businesses O5 – Creation of favourable conditions for attracting investment in infrastructure development O6 – Raising public awareness of the importance of preserving water resources O7 – Development of a water resource monitoring system O8 – Strengthening cooperation between authorities, businesses, NGOs and citizens O9 – Design and implementation of revitalisation and decontamination programmes for small rivers O10 – Development of integrated stormwater drainage and treatment systems O11 – Support for academic collaboration and scientific research	T1 – Climate change (including floods and droughts) T2 – Hydromorphological changes T3 – War and the impact of military activity on water resources T4 – Increasing pollution from industrial, agricultural and domestic sources T5 – Unregulated well drilling and over-extraction of groundwater T6 – Soil erosion and clogging of watercourses T7 – Loss of biodiversity in aquatic ecosystems T8 – Lack of effective water resource management T9 – Non-compliance with riparian buffer zones and protected water areas T10 – Conflicts over water resources T11 – Risks to public health T12 – Negative impacts on economic development

Source: developed by the authors

Applying the principles of SMART planning, five core strategic directions were identified: ensuring effective and sustainable water-resource management; protecting and restoring aquatic ecosystems; providing access to safe drinking water and adequate sanitation; enhancing climate resilience and preventing local flooding; promoting the sustainable and efficient use of water resources. On the basis of these goals, an indicator system was devised to monitor the effectiveness of waterresource management in the Zhytomyr urban amalgamated territorial community. The system comprises nine key indicators with target values for 2030, 2040 and 2050, covering water protection, attainment of good ecological status, water-use management and infrastructure development (Table 2).

Table 2. Indicators for calculating the integral effectiveness indicator of water-resource management

No.	Indicator	Unit	Baseline (2023)	Target	Calculation formula
			Environmental (*E*)		
1	Proportion of wastewater treated	%	97%	2030: 99% 2040: 99.5% 2050: 100%	(Volume of treated wastewater / Total volume of wastewater) × 100%
2	Proportion of water bodies with delineated water-protection zones	%	0%	2030: 100% 2040: 100% 2050: 100%	(Number of water bodies with delineated zones / Total number of water bodies) × 100%
3	Proportion of stormwater treated	%	10%	2030: 30% 2040: 60% 2050: 90%	(Volume of treated stormwater / Total volume of stormwater runoff) × 100%
4	Proportion of surface-water bodies with "good" ecological and chemical status	%	0%	2030: 30% 2040: 60% 2050: 80%	(Number of water bodies in "good" status / Total number of water bodies) × 100%
			Social component (*C*)		
5	Level of access to centralised wastewater services	%	87%	2030: 92% 2040: 96% 2050: 100%	(Population connected to centralised wastewater services / Total population) × 100%
6	Proportion of the population with access to a centralised water supply	%	89.8%	2030: 93% 2040: 97% 2050: 100%	(Population with access to centralised water supply / Total population) × 100%
7	Level of implementation of the River Basin Management Plan measures within the community's territory	%	0%	2030: 50% 2040: 75% 2050: 100%	(Number of measures implemented / Total number of planned measures within the community) × 100%

Table 2. Continued

No.	Indicator	Unit	Baseline (2023)	Target	Calculation formula
Economic component (K)					
8	Water losses in supply networks	%	44%	2030: 30% 2040: 20% 2050: 12%	(Volume of water lost / Total volume of water supplied to the network) × 100%
9	Proportion of reused and recycled water in industry	%	1%	2030: 25% 2040: 45% 2050: 65%	(Volume of reused water / Total volume of water used in industry) × 100%

Source: developed by the authors

The baseline indicators for 2023 highlight several critical issues, including a high level of water losses (44%) and a low rate of stormwater treatment (10%). At the same time, there are positive parameters, such as a wastewater treatment rate of 97% and access to a centralised water supply at 76.85%. The target indicators for 2050 aim to increase stormwater treatment to 90%, reduce water losses to 12%, and raise the share of reused water to 65%, aligning with EU standards and the UN SDGs. To enable a comprehensive assessment of the effectiveness of water resource management at the territorial community level and support evidence-based decision-making, a multi-level system of indicators has been developed (Fig. 1). The integral indicator of water resource management effectiveness brings together all levels and categories of assessment into a single system, providing a general evaluation of water resource governance within the territorial community.

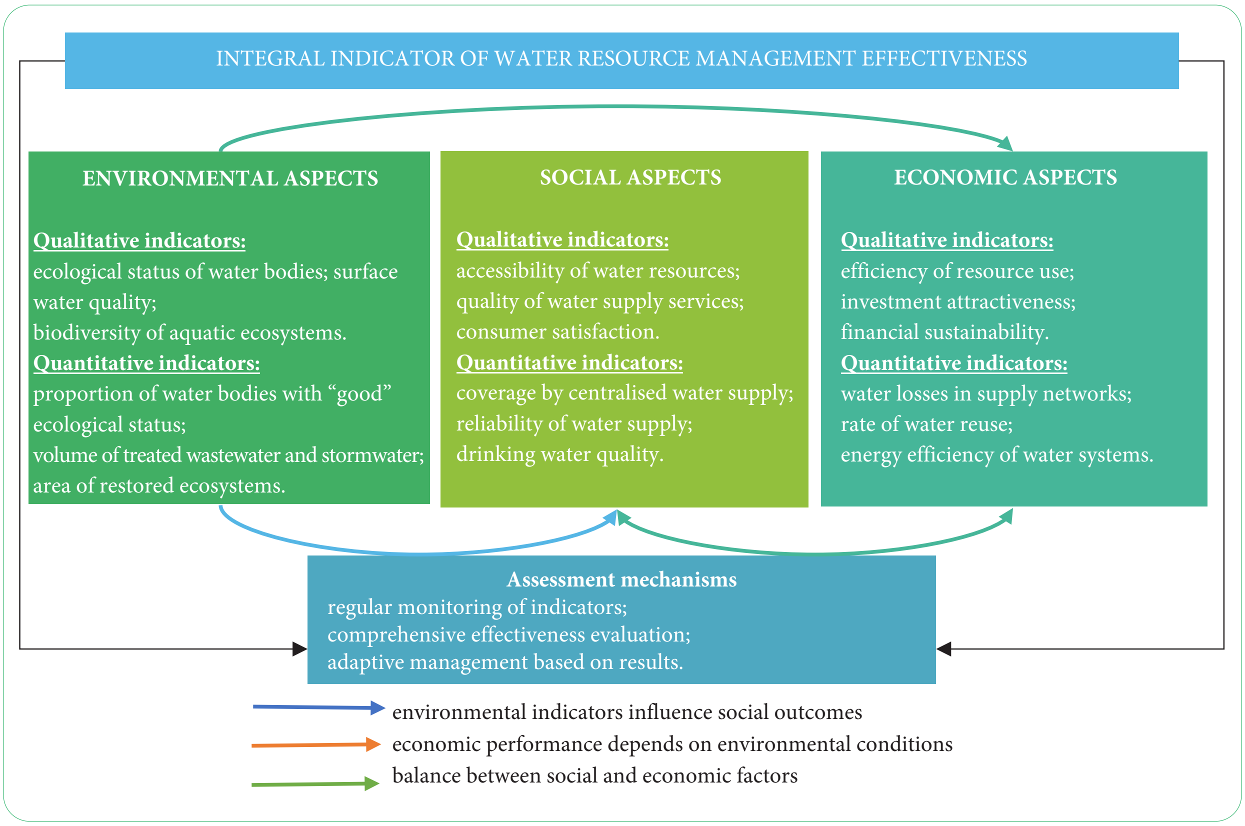

Figure 1. Multi-level indicator system for assessing the effectiveness of water resource management in the Zhytomyr urban territorial community

Source: developed by the authors

Figure 1 illustrates the structure of the multi-level indicator system for assessing the effectiveness of water resource management in the Zhytomyr urban territorial community. The system comprises three main components – environmental, social and economic – each of which is constructed from a set of relevant indicators. Each component includes both qualitative and quantitative indicators. Environmental qualitative indicators include the ecological status of water bodies, surface water quality, and biodiversity of aquatic ecosystems, while the quantitative ones comprise the proportion of water bodies with "good" ecological status, volume of treated wastewater, and area of restored ecosystems. Social qualitative indicators address accessibility of water resources, quality of water supply services, and consumer satisfaction, whereas the quantitative ones cover coverage by centralised water supply, reliability of water supply, and drinking water quality. Economic qualitative indicators relate to efficiency of resource use, investment attractiveness, and financial sustainability, while the quantitative ones include water losses in supply networks, rate of water reuse, and energy efficiency of the systems. Additionally, the interrelations between indicators are presented – the influence of environmental indicators on social factors, the dependency of economic aspects on environmental conditions, and the balance between social and economic dimensions – as well as evaluation mechanisms, including regular indicator monitoring, comprehensive performance assessment, and adaptive management based on outcomes. This indicator system reflects an integrated approach to assessing the effectiveness of water resource management at the level of the territorial community. To calculate the integrated performance indicator, all individual indicators were first normalised using formulas (1) and (2). The results of this normalisation are presented in Table 3.

Table 3. Results of indicator normalisation for the assessment of water resource management effectiveness

Component	Indicator	Actual value, %	Normalised value
Environmental	Proportion of wastewater treated	97	0.97
Environmental	Proportion of water bodies with delineated water-protection zones	0	0
Environmental	Proportion of stormwater treated	10	0.1
Environmental	Proportion of surface-water bodies with "good" ecological and chemical status	0	0
Social	Level of access to centralised wastewater services	87	0.87
Social	Proportion of the population with access to a centralised water supply	89.8	0.898
Social	Level of implementation of the River Basin Management Plan (RBMP) measures within the community's territory	0	0
Economic	Water losses in supply networks	44	0.56 (inversion: 1-0.44)
Economic	Proportion of reused and recycled water in industry	1	0.01

Source: developed by the authors

The weighting coefficients for the main components of the integrated indicator – environmental, social, and economic – are 0.35, 0.35, and 0.30, respectively. The equal weighting of the environmental and social components reflects their equal importance, aligning with the concept of sustainable development, which emphasises the need to balance environmental, social, and economic dimensions. The methodology for determining these weights through expert consultation is consistent with the approach used by S. Bilalova *et al.* (2023) in assessing the effectiveness of integrated water resources management implementation. This approach allows for the consideration of the priorities of various stakeholders and ensures a balanced assessment. The environmental component was calculated using formula (4) as the sum of the weighted normalised values of the indicators:

$$E = 0 \times 0.35 + 0 \times 0.35 + 0.1 \times 0.3 = 0.03, \qquad (7)$$

where 1st 0 – the normalised value of the indicator "Proportion of water bodies with delineated waterprotection zones"; 2nd 0 – the normalised value of the indicator "Proportion of surface-water bodies with "good" ecological and chemical status"; 0.1 – the normalised value of the indicator "Proportion of stormwater treated"; 0.35, 0.35, and 0.3 – the weighting coefficients for the respective indicators. The social component was determined using formula (5):

$$S = 0.87 \times 0.4 + 0.898 \times 0.3 + 0 \times 0.3 = 0.6174, \qquad (8)$$

where 0.87 – the normalised value of the indicator "Level of access to centralised wastewater services" 0.898 – the normalised value of the indicator "Proportion of the population with access to centralised water supply"; 0 – the normalised value of the indicator "Level of implementation of the RBMP measures" 0.4 and 0.3 – the weighting coefficients for the respective indicators. The economic component was calculated using formula (6), taking into account the specific method of normalising the indicator for water loss:

$$K = 0.56 \times 0.4 + 0.01 \times 0.3 + 0.97 \times 0.3 = 0.518, \qquad (9)$$

where 0.56 – the normalised value of the indicator "Water losses in supply networks" (inversion: 10.44); 0.01 – the normalised value of the indicator "Proportion of reused and recycled water in industry"; 0.97 – the normalised value of the indicator "Proportion of wastewater treated"; 0.4 and 0.3 – the weighting coefficients assigned to the respective indicators. The results of the calculation of the components of the integrated indicator of water resources management efficiency in the Zhytomyr urban territorial community are visualised in Figure 2.

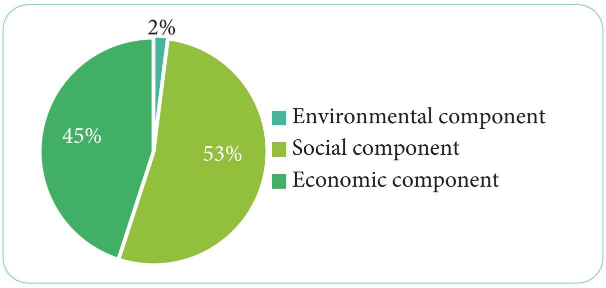

Figure 2. Proportions of the components of the integrated indicator of water resources management efficiency in the Zhytomyr urban territorial community, 2023

Source: developed by the authors

A detailed analysis of the structural elements revealed a critical imbalance in the development of different aspects of the water resource management system. The environmental dimension demonstrated critically low results (0.03), primarily due to the complete absence of legally defined protective water zones – none of the water bodies have formally established boundaries for protection. Additionally, the ecological condition of water bodies is unsatisfactory, with no surface water masses classified as having a "good" ecological status, and surface runoff treatment is inadequate, covering only 10% of the total stormwater volume. The social component showed relatively satisfactory results (0.6174), attributed to the high level of access to centralised water supply systems, providing quality drinking water to 89.8% of the community's population, and the significant coverage of wastewater services, which are available to 87% of residents. However, the overall score of the social component is negatively affected by the complete lack of implementation of the measures outlined in the River Basin Management Plan, with a current execution rate of 0%. The economic component (0.518) reflects a moderate level of performance. Nevertheless, it is adversely influenced by significant water losses in distribution networks, amounting to 44% of the total volume supplied, and by the minimal level of water reuse in industry, which stands at just 1% of overall industrial water consumption. In contrast, the high level of wastewater treatment – 97% of total wastewater entering treatment facilities – positively contributes to the economic component score.

The critically low result for the environmental component (0.03) aligns with the findings of H. Kireitseva *et al.* (2024), who identified similar issues in other communities within the Zhytomyr Region. The high rate of water loss (44%) exceeds the average levels reported for cities in Eastern Europe and requires urgent attention – an issue also confirmed by the research of I. Kapelista *et al.* (2024). In the final stage, the integrated indicator was calculated using formula (3), applying the respective weighting coefficients for each component:

$$I = 0.03 \times 0.35 + 0.6174 \times 0.35 + 0.518 \times 0.3 = 0.382. \quad (10)$$

The calculations carried out indicate that the composite indicator of water resource management performance stands at 0.382, which reflects a level of efficiency below the average benchmark. This result highlights the existence of significant potential for improving the system of integrated water resource management within the studied territorial community. Based on the target values of indicators for 2030, 2040 and 2050, a model of the projected dynamics of the integrated efficiency indicator was developed using formulas (1-6). The results of this modelling are presented in Table 4.

Table 4. Projected dynamics of the integrated indicator of water resource management efficiency

Year	Environmental component	Social component	Economic component	Integrated indicator
2023	0.03	0.6174	0.518	0.382
2030	0.648	0.883	0.725	0.749
2040	0.799	0.927	0.875	0.867
2050	0.925	1.000	0.965	0.963

Source: developed by the authors

Scenario planning for the period up to 2050 demonstrates the potential to achieve a high level of efficiency (0.963) provided that all planned measures are comprehensively implemented. The stepwise improvement of indicators involves three main stages of system development. The period 2023-2030 is characterised by the most intensive growth, with the integrated indicator projected to reach 0.749, driven primarily by significant progress in the environmental component, which is expected to increase to 0.648. This growth will result from the planned demarcation of protective buffer zones for all water bodies in the community. The subsequent 2030-2040 phase may be regarded as a period of system stabilisation, during which the integrated indicator is projected to reach 0.867, with steady improvements expected across all components of water resource management. The final optimisation phase (2040-2050) anticipates achieving a level of 0.963, aligning with best international practices in water management. This includes reaching the maximum value (1.000) for the social component.

To improve the effectiveness of integrated water resource management in the Zhytomyr urban territorial community, priority attention should be given to three key areas: environmental aspects of water use, including the delineation of water protection zones and the modernisation of stormwater treatment systems to enhance the quality of water bodies; economic optimisation of the system through the reduction of water losses in distribution networks and the implementation of water recycling technologies in industrial processes; and enhancement of the social component by increasing the level of implementation of basin management measures and ensuring universal access to quality water supply and sanitation services. The results obtained are consistent with research findings that underscore the need for a comprehensive approach to urban water management and the integration of various aspects of water resource governance.

An in-depth analysis of water resource management effectiveness indicates that the proposed multilevel indicator system aligns with approaches developed in the research by M. AbdiDehkordi *et al.* (2021), who proposed a composite water resource resilience index that accounts for various components, including reservoir conditions and inter-basin water transfers. This approach enables the assessment of not only the current state but also the dev elopment potential of water resource management systems. The environmental component, which proved to be the most critical issue for the Zhytomyr community (0.03), can be significantly improved through the adoption of strategies proposed by J.C. Ferreira *et al.* (2024), who examined the effectiveness of integrating blue-green infrastructure into water management systems. This approach is particularly relevant for urban areas with high population density and limited opportunities for the expansion of traditional "grey" infrastructure. Notably, the findings of B. Essex *et al.* (2020) on global solutions for integrated water resource management in cities around the world highlight the importance of accounting for local specificities when implementing universal approaches. This is particularly relevant for the Zhytomyr community, which faces specific challenges such as a high level of water loss (44%) and a low level of stormwater treatment (10%). The evaluation of the economic efficiency of water use, especially in the context of significant distribution losses and low levels of water reuse, aligns with the approaches developed by X. Cao *et al.* (2021), who proposed a methodology for assessing water use efficiency in agricultural production from a water footprint perspective. This methodology could be adapted for the industrial sector of the Zhytomyr community to improve water use efficiency and achieve targeted reuse indicators.

The results of the evaluation of water resource management effectiveness in the Zhytomyr community underscore the importance of a comprehensive approach, as supported by international experience. R. Calipha & S. Katav-Herz *et al.* (2025) demonstrated that the implementation of the EU Water Framework Directive led to a 40% improvement in surface water quality and a 25% reduction in groundwater pollution over a 15-year period – outcomes that may serve as valuable benchmarks for Ukrainian communities in the context of European integration. P. Hellegers & G. Van Halsema (2021) identified methodological shortcomings in SDG indicator 6.4.1, "Change in water-use efficiency over time", and proposed improvements for further development of indicator systems. Yu. Huseynov *et al.* (2024) analysed 170 water resource management indicators according to four sustainability criteria, using the DPSIR framework (Drivers, Pressures, States, Impacts, and Responses). This approach is particularly relevant to the Zhytomyr community, where the ecological component is critically low (0.03). The study also highlights the potential for improving assessment schemes through strategic planning of monitoring networks and the use of innovative diagnostic tools – an essential step towards optimising the utilisation of available data within the developed monitoring system. B. Essex *et al.* (2020) proposed a national monitoring framework for water-related SDGs in Europe based on a participatory approach and stakeholder consensus evaluation, which aligns with the expert survey methodology employed in the Zhytomyr community. A common thread across all studies is the recognition of the need for an integrated approach that combines technical solutions with institutional innovation. The effectiveness of water governance is shown to depend heavily on the quality of monitoring and evaluation systems, thereby reinforcing the relevance of the multi-level indicator framework that has been developed.

Also noteworthy is the study by J.Y. Al-Jawad *et al.* (2019), which outlines an optimal integrated approach to water resource management aimed at addressing multidisciplinary challenges. This approach – incorporating social, environmental, and economic dimensions – corresponds to the structure of the proposed multi-tiered indicator system. The study employed mathematical optimisation models to balance the competing demands of different water users, resulting in a 25% improvement in resource allocation efficiency and a 30% reduction in conflicts between water-use sectors. The methodological approach of the study is particularly valuable in that it takes into account the uncertainty associated with forecasting water resources and incorporates adaptive management mechanisms – an aspect that is critically important in the context of climate change and increasing anthropogenic pressure on aquatic ecosystems. A similar approach to the comprehensive analysis of urban water management was demonstrated by B. Essex *et al.* (2022) in their study of global challenges in integrated water resources management in cities worldwide. The authors analysed 200 cities representing over 95% of the world's urban population, applying the City Blueprint Approach for an empirical assessment of 125 cities and a statistical model to evaluate water governance performance in a further 75. The study revealed significant gaps in achieving water-related SDGs, particularly Goals 6 and 11. It emphasised that addressing water challenges can serve as a gateway to meeting other SDG targets, given that water is directly or indirectly linked to nearly all of them. A regional approach to indicator development is presented in the study by M. Ben-Daoud *et al.* (2021), which proposed an indicator framework for integrated water resources management to assess governance systems in the R'dom sub-basin in Morocco. A comprehensive methodology was developed encompassing ecological, social, economic, and institutional dimensions, validated through an international expert panel. The study utilised the DPSIR framework to classify all indicators, enabling a holistic analysis of causal relationships within the water management system.

It is worth noting that the greatest progress in improving the effectiveness of water resources management is expected in the ecological dimension, where the indicator is projected to rise from 0.03 in 2023 to 0.925 by 2050. Such growth is achievable, provided that a comprehensive set of measures is implemented, aimed at improving the ecological condition of water bodies, establishing water protection zones, and increasing the level of stormwater treatment. To assess the effectiveness of these measures, the approaches proposed by J. Katusiime and B. Schütt (2020) may be applied, highlighting the importance of institutional mechanisms and strategic frameworks for the successful implementation of integrated water resource management. The analysis also shows that the social dimension of water management effectiveness currently records the highest score (0.798) among the three components. This is attributed to the high level of access to centralised water supply and sanitation services in the Zhytomyr community. However, in order to achieve the maximum level of effectiveness (1.000) by 2050, it is necessary to ensure 100% population access to quality water supply and wastewater services, as well as the full implementation of the measures outlined in the River Basin Management Plan (Pripyat River Basin Water Resources Management, 2023).

The economic component of water management effectiveness in the Zhytomyr community (0.518) requires substantial improvement, particularly in reducing water losses in distribution networks and increasing the rate of water reuse in industry. Meeting the target indicators – reducing water losses to 12% and increasing the share of reused water to 65% – will require significant investment in infrastructure modernisation and the adoption of water-saving technologies. The importance of economic efficiency in water resource use was also emphasised in the study by N.R. Gayathri *et al*. (2024), who developed an intelligent system for monitoring and managing water quality, enabling the optimisation of water use and the reduction of operational costs.

Thus, the proposed integrated system for assessing the effectiveness of water resource management in communities allows for a comprehensive evaluation of the current state of the management system, identification of critical areas requiring priority attention, and forecasting of the system's development dynamics, provided the necessary measures are implemented. This system can be adapted for use in other territorial communities in Ukraine, taking into account their specific features and challenges in water resource management. The developed system of indicators and the integrated approach to evaluating water management effectiveness provide a methodological foundation for monitoring and assessing progress in achieving the SDGs at the territorial communities level. They also offer tools for informed decision-making and the development of water management strategies that consider the economic, social, and environmental dimensions of water use. Furthermore, the proposed approach enables comparative analysis of water management effectiveness across different territorial communities, laying the groundwork for knowledge exchange and the adoption of best practices.

Conclusions

The conducted study on the integrated monitoring system for assessing the performance of water management activities at the level of territorial communities allows for the following general conclusions. The developed methodological framework for analysing the effectiveness of community water management integrates environmental, social, and economic dimensions into a comprehensive indicator, providing a tool for diagnosing problem areas and supporting evidence-based decision-making. The monitoring system comprises nine interrelated indicators across the three pillars of sustainable development, ensuring a comprehensive assessment of water management performance. The use of the expert method to determine weighting coefficients ensured that the priorities of various management vectors were taken into account.

Empirical testing of the methodological tools using data from the Zhytomyr community revealed significant imbalances in the functioning of different components of the management system. The environmental dimension requires the most urgent attention, with its indicator value at just 0.03, reflecting the absence of legally defined water protection zones and the poor condition of surface water bodies. The social dimension, with an indicator value of 0.6174, demonstrated comparatively better outcomes due to the high level of population coverage by centralised water supply and sanitation services. The economic dimension (0.518) was characterised by moderate performance.

Forward-looking modelling to 2050 indicates the potential for a substantial improvement in management effectiveness, reaching a level of 0.963, provided that the established target values for all indicators are achieved. The most rapid progress is expected between 2023 and 2030, particularly in the environmental dimension, following the designation of water protection zones for all water bodies in the community and an increase in the treatment rate of stormwater to 30%. The developed indicator system and the comprehensive approach to evaluating water management performance form a methodological basis for monitoring and analysing progress towards the SDGs at the level of territorial communities. The proposed approach also enables comparative analysis of water management efficiency across different territorial communities, providing a foundation for knowledge exchange and the implementation of best practices. Areas for further research include expanding the proposed methodology to other territorial communities in Ukraine to validate the universality of the indicator system, as well as developing an automated monitoring system using IoT technologies to ensure real-time data collection.

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Інтегральна оцінка ефективності управління водними ресурсами громад для сталого розвитку

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Анотація. Актуальність дослідження зумовлена необхідністю розробки комплексних систем моніторингу для оцінки ефективності управління водними ресурсами, що враховують екологічні, соціальні та економічні аспекти. Метою дослідження було проаналізувати та оцінити існуючі підходи до формування інтегральної системи моніторингу ефективності управління водними ресурсами на рівні територіальних громад для забезпечення екологічної безпеки та сталого розвитку. Дослідження ґрунтувалося на системному підході з використанням SWOT-аналізу, порівняльного аналізу та моделювання. На основі аналізу наукової літератури було розроблено багаторівневу систему показників, що включає 9 ключових індикаторів, згрупованих за екологічною, соціальною та економічною складовими. Розрахований інтегральний показник ефективності управління водними ресурсами становить 0,382, що відповідає нижчому за середній рівню ефективності. Аналіз складових виявив критичний дисбаланс: екологічна складова має критично низький рівень (0,03), що зумовлено відсутністю визначених водоохоронних зон (0 %) та незадовільним станом водних об’єктів (0 % об’єктів з «добрим» станом). Соціальна складова показала відносно високий результат (0,6174) завдяки високому рівню забезпеченості централізованим водопостачанням (89,8 %) та водовідведенням (87 %). Економічна складова (0,518) характеризується середнім рівнем ефективності, але негативно впливають високі втрати води в мережах (44 %) та низький рівень повторного використання води (1 %). Прогностичне моделювання на період до 2050 року показало можливість досягнення високого рівня ефективності (0,963) за умови комплексної реалізації заходів за всіма напрямами, з найбільш динамічним зростанням у 2023-2030 роках. Практична цінність дослідження полягає у формуванні науково обґрунтованої основи для оцінки ефективності управління водними ресурсами на рівні територіальних громад, що дозволяє визначати пріоритетні напрями вдосконалення системи для прийняття обґрунтованих управлінських рішень у сфері водного господарства

Ключові слова: оцінювання; екологічна безпека; моніторинг; територіальні громади; індикатори якості; басейновий підхід