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MULTIDIMENSIONAL ANALYSIS OF REGIONAL WATER MANAGEMENT: A COMPREHENSIVE APPROACH

Introduction. *Water resources are of critical importance for the sustainable development of the Zhytomyr region. The region possesses considerable hydrological potential, including 53 reservoirs (76,000 ha) and 2,075 ponds (123,000 ha). Surface water accounts for 77% of the total supply, while groundwater comprises the remaining 23%.*

Problem Statement. *Effective water resource management in the region has been increasingly challenged by rising demand, environmental pollution, unregulated exploitation, and climate change. Conventional planning approaches often fail to account for the complex interdependencies among various influencing factors. Therefore, the development of a comprehensive methodology capable of revealing hidden correlations and supporting strategic decision-making is both timely and necessary.*

Purpose. *This study aims to develop an integrated framework for analyzing water use in the Zhytomyr region by combining SWOT analysis with correlation and cluster analysis, thereby enhancing the effectiveness of strategic planning processes.*

Materials and Methods. *A multidimensional methodology has been employed, incorporating SWOT analysis, Pearson correlation analysis, and cluster analysis using the k-means algorithm. Data processing and visualization have been conducted using the Orange data mining platform.*

Results. *The SWOT analysis has identified key influencing factors. The correlation analysis has revealed statistically significant interrelationships among variables, highlighting the systemic nature of regional water challenges. The analysis has classified the variables into the five key groups: (1) infrastructure and technology, (2) environmental factors, (3) management and cooperation, (4) pollution-related issues, and (5) water quality and financing.*

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Conclusions. *The integrated analytical approach has provided a holistic understanding of regional water use and uncovered complex interactions among system components. The results emphasize the necessity of adopting a systems-oriented strategy for water resource management. Based on the findings, the study offers targeted recommendations for priority investment, including infrastructure modernization, enhancement of monitoring systems, and deployment of innovation technologies.*

Keywords: water resources, innovative approaches, integrated water resource management, sustainable development, ecological safety.

The Zhytomyr region's water resources are critically important for its sustainable development. Public health, economic growth, and environmental quality all depend on them. The region has significant hydrological potential, including 53 reservoirs with a total area of 76,000 ha and 2,075 ponds covering 123,000 ha [2]. These water bodies are primarily used for energy production (hydroelectric power stations), water supply, recreation, and other purposes. Surface waters account for approximately 77%, while groundwater makes up about 23% [1].

Rising water demand, pollution of water bodies, and climate change are the main challenges to effective regional water resource management. In 2022, approximately 5,261 million m^3 of water were discharged into surface waters; of that amount, only a little more than 1,105 million m^3 met sanitary standards, while 184 million m^3 were discharged without any treatment [2]. Furthermore, uncontrolled usage and violations of protection regulations continue to exacerbate the situation. Pollution from organic substances, including biogenic and toxic elements, along with increasing plastic contamination, has elevated the region's ecological risks [2, 3].

Climate change also poses a significant threat to Zhytomyr's water resource system. Floods and droughts caused by global warming may seriously affect both the quality and quantity of water. It is worth noting that traditional approaches to strategic planning often overlook the complex relationships among the various factors influencing water use. For instance, insufficient integration of infrastructure, environmental, and social dimensions of water management leads to inefficiencies and an inability to effectively address existing challenges [4].

Moreover, the implementation of innovative strategies in development policy serves as a foundation for ensuring sustainable economic growth and enhancing national competitiveness [5]. The adoption of innovation in the field of water resource management can improve resource use efficiency, reduce pollution, and strengthen resilience to climate change.

A review of earlier studies suggests that the strategic planning of water resources can be improved by combining multiple analytical approaches. For example, Raju and Duckstein [6] demonstrated how integrated cluster analysis and multi-criteria decision-making (MCDM) can effectively rank alternative water management strategies. Pereira [7] employed various methods — including correlation matrix analysis, principal component analysis (PCA), and cluster analysis — to integrate key elements of water resource management, such as land use, seasonality, and water quality.

Conventional strategic planning methods often fail to account for the complex interrelationships among different factors affecting water use. This lack of integration across infrastructural, environmental, and social aspects frequently results in inefficiencies and hinders effective problem-solving [4].

At the same time, the implementation of innovative approaches in development strategies is a key factor in ensuring economic growth and enhancing national competitiveness [5]. Innovative development, particularly in the field of water resource management, can contribute to more efficient resource use, pollution reduction, and increased resilience to climate change.

An analysis of recent studies and publications demonstrates the effectiveness of combining various analytical methods to improve strategic water resource planning. Specifically, the work of Raju and Duckstein [6] showed that integrating cluster analysis with multi-criteria decision-making (MCDM) effectively ranks alternative water management strategies. Pereira [7] applied a comprehensive approach that includes a correlation matrix, principal component analysis (PCA), and cluster analysis to integrate multiple aspects of water resource management, including land use, seasonality, and water quality.

According to the authors' experience discussed in Fabbrocino [8], the pre-operational use of both cluster and correlation analysis has proven beneficial for identifying the primary indicators influencing water quality in multilayer aquifer systems. In the study by Gu [9], the authors described various clustering techniques — including self-organizing maps, k-means clustering, and hierarchical agglomerative clustering — and their practical applications in identifying residential water consumption patterns. These techniques support the accurate evaluation of water demand and, consequently, enhance water resource management strategies.

Maruyama [10] developed an entropy-based clustering method for assessing Potential Water Resource Availability (PWRA), aimed at classifying and evaluating regional water resource attributes.

However, the combination of SWOT analysis with correlation and cluster analysis remains an underexplored direction. There is a growing trend toward integrating analytical methods to achieve a more comprehensive understanding of water resources and their management. Clustering algorithms, in particular, are increasingly applied in hydrology and water resource studies. Multidimensional statistical approaches allow researchers and planners to account for complex interrelationships among the many variables influencing water systems [11].

There is significant potential for further research into the integration of SWOT analysis with correlation and clustering techniques. This combined approach could be particularly beneficial for regional water resource management in areas such as the Zhytomyr region.

The aim of this study is to perform a correlation analysis of SWOT indicators and to develop a sensitivity map to enhance water resource management strategies in the Zhytomyr region. The primary objectives include: conducting a correlation analysis among SWOT indicators to identify key interrelationships; applying k-means cluster analysis to group similar indicators and develop a sensitivity map; identifying priority areas for investment and management; and formulating recommendations to improve water resource management based on the analysis results. The proposed approach is intended to support more effective water resource utilization, enhance ecological safety, and promote the sustainable development of the Zhytomyr region.

A step-by-step methodology has been developed to guide the comprehensive analysis, enabling a systematic examination of various aspects of regional water use. The first and foundational step involved performing a SWOT analysis. This method was selected as the initial stage due to its capacity to provide a structured overview of the current situation and future development potential. To ensure the objectivity and comprehensiveness of the SWOT analysis, a panel of experts from diverse fields relevant to the region's water management was assembled [12].

Based on expert assessments and analysis of available data, 10 strengths, 14 weaknesses, 11 opportunities, and 12 threats related to the use and conservation of the region's water resources have been identified. The results of this stage are summarized in Table 1 that provides a clear visual representation of the key factors influencing water use in the Zhytomyr region.

Following the completion of the SWOT analysis and the identification of key factors influencing water use in the region, it became necessary to gain a deeper understanding of the interrelationships among these factors. To achieve this, a quantitative method — correlation analysis — was employed. This approach enables the transition from a qualitative assessment of factors to their quantitative characterization, facilitating the identification of statistically significant relationships.

For the correlation analysis, the Orange data mining tool was used, specifically its Correlation widget. This tool was selected for its ability to efficiently process large datasets and visually present the results. Pearson correlation coefficients were calculated for all possible pairs of SWOT

Table 1. **SWOT Analysis of Water Resource Use and Conservation in the Zhytomyr Region**

Strengths (S)	Weaknesses (W)
S1 — Availability of numerous water bodies and reservoirs S2 — Development of water supply and sewage infrastructure S3 — Implementation of modern water purification technologies S4 — Availability of recreational and ecological zones S5 — Public involvement in water resource protection S6 — Water activities: open water competitions S7 — Availability of reservoirs that can be used for renewable energy production S8 — Availability of qualified personnel for water resource protection S9 — Gradual industrial greening S10 — International cooperation	W1 — Pollution of water bodies W2 — Littering with household waste W3 — Lack of integrated water resource management W4 — Lack of drinking water in certain areas and overall poor quality of drinking water W5 — Insufficient development of water supply and sewage systems in some localities, absence of sewage systems W6 — Uncontrolled use of water resources and water protection zones W7 — Non-compliance with the regime of coastal protective strips and water protection zones W8 — Wasteful use of water in both industry and households W9 — Outdated infrastructure and technologies W10 — Insufficient cooperation between local authorities, businesses, and the public W11 — Insufficient public awareness W12 — Lack of financial resources W13 — Loss of local biodiversity and increase in biological invasions W14 — Absence of alternative drinking water sources
Opportunities (O)	Threats (T)
O1 — Development of water tourism and recreation O2 — Introduction of new water purification and supply technologies O3 — Improvement of infrastructure: modernization of dams and reservoirs and flexible management of reservoirs O4 — Promotion and encouragement of water-saving technologies and installation of local treatment facilities by businesses O5 — Creating favorable conditions for attracting investments in infrastructure development O6 — Raising public awareness about the importance of water resource conservation O7 — Development of a water resource monitoring system O8 — Development of cooperation between authorities, enterprises, public organizations, and citizens O9 — Development and implementation of programs for the revitalization and decontamination of small rivers O10 — Development of integrated stormwater drainage and treatment systems O11 — Promotion of cooperation with researchers and conducting scholarly research	T1 — Climate change (including floods and droughts) T2 — Hydromorphological changes T3 — War and the impact of military actions on water resources T4 — Increased pollution of water resources by industrial, agricultural, and household waste T5 — Uncontrolled drilling of wells and excessive extraction of groundwater T6 — Soil erosion and clogging of waterways T7 — Loss of biodiversity in aquatic ecosystems T8 — Lack of effective water resource management T9 — Non-compliance with the regime of coastal protective strips and water protection zones T10 — Conflicts over water resources T11 — Threat to public health T12 — Impact on economic development

Source: prepared by the authors.

indicators, yielding a total of 460 combinations within the selected dataset. This analysis not only confirmed several intuitively understood relationships between factors but also revealed previously unrecognized interdependencies that may significantly influence strategic water resource planning in the region.

While correlation analysis provided valuable insights into pairwise relationships among SWOT factors, a more comprehensive understanding of the data required an additional layer of analysis. Consequently, cluster analysis was employed to identify more complex, multidimensional patterns.

The k-means clustering algorithm was chosen for this task due to its proven effectiveness in processing multidimensional datasets. This algorithm facilitates the automatic identification of groups (clusters) of factors that share similar characteristics or patterns of interaction. By applying k-means to the SWOT indicators, the study not only validated the findings of the correlation analysis but also uncovered higher-order relationships that may not be evident through pairwise analysis alone.

The application of this integrated methodology — comprising SWOT analysis, correlation analysis, and cluster analysis — has provided a comprehensive understanding of water use in the Zhytomyr region. This multifaceted approach has enhanced the analytical framework for strategic planning and informed the development of more effective water resource management strategies.

More specifically, according to the research conducted by Kireitseva [12], the data analysis highlights key factors that should be addressed to enhance water resource management in the Zhytomyr region. Strengths such as the development of water supply and sewage infrastructure (S2), the availability of qualified personnel (S8), international cooperation (S10), the abundance of water bodies and reservoirs (S1), and the implementation of modern water purification technologies (S3) can significantly contribute to more sustainable and efficient water management if further developed and strategically prioritized.

At the same time, it is essential to address critical weaknesses, including the inefficient use of water resources (W8), the absence of integrated management systems (W3), and the uncontrolled exploitation of water bodies (W6). These issues require urgent attention to prevent further degradation of the region's water resource conditions.

Priority areas for investment and development have also been identified, such as the revitalization of small rivers (O9), the development of integrated sewage systems (O10), the advancement of monitoring systems (O7), and the adoption of innovative water purification and supply technologies (O2). Investments in these domains can contribute to solving existing challenges while reinforcing the sustainability and resilience of community water resources.

Indicators of potential threats, such as increased water pollution (T4), biodiversity loss (T7), and the absence of effective management frameworks (T8), should be incorporated into ongoing risk assessments. Recognizing and understanding these threats is critical for developing strategies aimed at minimizing or eliminating their impact.

Following the SWOT analysis, the next phase of the research involved correlation analysis, which enabled the identification and quantitative evaluation of interrelationships among the various factors influencing water use in the Zhytomyr region. The results of this analysis are presented in Tables 2—5, which illustrate: (1) the impact of strengths on realizing opportunities (SO); (2) the impact of strengths on mitigating threats (ST); (3) the impact of weaknesses on realizing opportunities (WO); and (4) the impact of weaknesses on exacerbating threats (WT).

The analysis of the correlation results presented in Table 2 illustrating the impact of strengths on the realization of opportunities, reveals several significant interrelationships:

- **Highest positive correlations**: The strongest positive correlation (1.000) is observed between S8 (availability of qualified personnel) and O1 (development of water tourism and recreation). This underscores the critical role of human capital in advancing the water tourism sector in the region. A strong positive correlation (0.955) between S7 (availability of reservoirs for renewable energy production) and O6 (increasing public awareness) suggests that the presence of reservoirs creates opportunities for public education initiatives related to water resource conservation. Additionally, a moderate positive correlation (0.577) between S5 (public involvement in water resource protection) and O1 (development of water tourism and recreation) highlights the role of civic engagement in promoting sustainable tourism.

- **Significant negative correlations**: A strong negative correlation (–0.571) between S8 (availability of qualified personnel) and both O3 (infrastructure improvement) and O11 (promotion of scientific research) may reflect a potential mismatch between current human resource capacity and the requirements for infrastructure modernization and research development. A moderate negative correlation (–0.578) between S6 (water activities) and O1 (development of water tourism and recreation) suggests possible competition or conflicts between different types of water use.
- **Unexpected interrelationships**: A weak negative correlation between S2 (development of water supply and sewage infrastructure) and most opportunities may indicate that the current state or rigidity of existing infrastructure could hinder the realization of emerging opportunities. The absence of strong correlations for S1 (availability of numerous water bodies and reservoirs) with most opportunities is unexpected, considering the fundamental importance of these resources for regional development.

In summary, the strong positive correlation between qualified personnel and tourism development highlights the importance of investing in education and training in the fields of water management and tourism. The strong association between reservoir availability and public awareness suggests the potential to use these facilities as educational platforms to promote sustainable water use. The negative correlation between water activities and tourism points to the need for strategies that balance competing water uses. The negative correlations between human capital and infrastructure development may indicate a need for retraining existing personnel or recruiting new specialists to support modernization efforts. Finally, the weak correlations observed between some strengths and opportunities reinforce the need for a comprehensive, integrated approach to water resource

Table 2. **Impact of Strengths on Realizing Opportunities (SO)**

SO	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11
S1	–0.256	–0.004	+0.115	+0.053	+0.029	–0.014	–0.029	–0.029	–0.004	–0.029	+0.115
S2	–0.020	–0.093	+0.097	+0.104	+0.101	–0.202	–0.101	–0.101	–0.093	–0.101	+0.097
S3	+0.085	–0.126	–0.027	+0.065	+0.098	+0.171	–0.098	–0.098	–0.126	–0.098	–0.027
S4	+0.078	+0.000	–0.012	–0.059	–0.030	–0.436	+0.030	+0.030	+0.000	+0.030	–0.012
S5	+0.577	+0.024	–0.337	–0.024	–0.025	+0.012	+0.025	+0.025	+0.024	+0.025	–0.337
S6	–0.578	–0.012	+0.317	+0.013	+0.012	–0.025	–0.012	–0.012	–0.012	–0.012	+0.317
S7	–0.014	+0.424	+0.000	–0.466	–0.455	+0.955	+0.455	+0.455	+0.424	+0.455	+0.000
S8	+1.000	–0.007	–0.571	–0.035	–0.014	+0.029	+0.014	+0.014	–0.007	+0.014	–0.571
S9	+0.078	+0.000	–0.012	–0.059	–0.030	–0.436	+0.030	+0.030	+0.000	+0.030	–0.012
S10	–0.032	–0.282	+0.032	+0.252	+0.273	–0.115	–0.273	–0.273	–0.282	–0.273	+0.032

management that accounts for the full spectrum of interrelated factors.

The analysis of the correlation results presented in Table 3 demonstrating the impact of strengths on mitigating threats (ST), reveals the following key interrelationships:

- **Highest positive correlations**: The strongest positive correlation (1.000) is observed between S8 (availability of qualified personnel) and T2 (hydromorphological changes), highlighting the critical role of expertise in addressing challenges related to alterations in aquatic ecosystems. A strong positive correlation (0.955) exists between S7 (availability of reservoirs for renewable energy production) and both T6 (soil erosion and clogging of waterways) and T8 (lack of ef-

Table 3. **Impact of Strengths on Mitigating Threats (ST)**

ST	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
S1	–0.233	–0.256	+0.010	–0.037	+0.037	–0.014	–0.037	–0.004	–0.014	–0.001	–0.233	–0.015
S2	–0.016	–0.020	–0.196	–0.103	+0.103	–0.202	–0.199	–0.093	–0.202	–0.210	–0.016	–0.128
S3	+0.054	+0.085	+0.138	–0.087	+0.087	+0.171	+0.197	–0.126	+0.171	+0.156	+0.054	–0.099
S4	+0.050	+0.078	–0.462	+0.040	–0.040	–0.436	–0.392	+0.0	–0.436	–0.429	+0.050	+0.015
S5	+0.578	+0.577	+0.013	+0.025	–0.025	+0.012	+0.012	+0.024	+0.012	–0.025	+0.578	–0.000
S6	–0.577	–0.578	–0.024	–0.013	+0.013	–0.025	–0.024	–0.012	–0.025	+0.011	–0.577	–0.000
S7	–0.029	–0.014	+0.933	+0.461	–0.461	+0.955	+0.935	+0.424	+0.955	+0.935	–0.029	+0.486
S8	+0.980	+1.000	+0.007	+0.021	–0.021	+0.029	+0.048	–0.007	+0.029	+0.006	+0.980	–0.000
S9	+0.050	+0.078	–0.462	+0.040	–0.040	–0.436	–0.392	+0.00	–0.436	–0.429	+0.050	+0.015
S10	–0.050	–0.032	–0.133	–0.267	+0.267	–0.115	–0.092	–0.282	–0.115	–0.099	–0.050	–0.254

Table 4. **Impact of Weaknesses on Realizing Opportunities (WO)**

WO	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11
W1	+0.940	+0.007	–0.560	+0.035	+0.014	–0.029	–0.014	–0.014	+0.007	–0.014	–0.560
W2	+0.029	–0.935	+0.00	+0.933	+0.955	–0.455	–0.955	–0.955	–0.935	–0.955	+0.00
W3	–0.014	+0.511	+0.00	–0.466	–0.500	+0.955	+0.500	+0.500	+0.511	+0.500	+0.00
W4	–0.029	+0.935	–0.00	–0.933	–0.955	+0.455	+0.955	+0.955	+0.935	+0.955	–0.00
W5	+0.029	–0.935	+0.00	+0.933	+0.955	–0.455	–0.955	–0.955	–0.935	–0.955	+0.00
W6	+0.029	–0.935	+0.00	+0.933	+0.955	–0.455	–0.955	–0.955	–0.935	–0.955	+0.00
W7	–0.029	+0.935	–0.00	–0.933	–0.955	+0.455	+0.955	+0.955	+0.935	+0.955	–0.00
W8	–0.029	+0.935	–0.00	–0.933	–0.955	+0.455	+0.955	+0.955	+0.935	+0.955	–0.00
W9	–0.014	+0.511	+0.00	–0.466	–0.500	+0.955	+0.500	+0.500	+0.511	+0.500	+0.00
W10	–0.541	+0.044	+0.973	–0.020	–0.033	+0.016	+0.033	+0.033	+0.044	+0.033	+0.973
W11	–0.029	+0.935	–0.00	–0.933	–0.955	+0.455	+0.955	+0.955	+0.935	+0.955	–0.00
W12	–0.029	+0.935	–0.00	–0.933	–0.955	+0.455	+0.955	+0.955	+0.935	+0.955	–0.00
W13	+0.029	–0.935	+0.00	+0.933	+0.955	–0.455	–0.955	–0.955	–0.935	–0.955	+0.00
W14	–0.029	+0.935	–0.00	–0.933	–0.955	+0.455	+0.955	+0.955	+0.935	+0.955	–0.00

fective water resource management). This suggests that reservoirs play a significant role in mitigating erosion and enhancing water management. Another high positive correlation (0.980) between S8 and both T1 (climate change) and T11 (threat to public health) underscores the value of professional expertise in adapting to climate change and mitigating health risks related to water resources.

- **Significant negative correlations**: A moderate negative correlation (–0.578) between S6 (water activities) and T2 (hydromorphological changes) may indicate potential conflicts between recreational water use and the need to preserve natural aquatic ecosystems. Additionally, a negative correlation (–0.462) between S4 (availability of recreational and ecological zones) and T3 (war and the impact of military actions on water resources) suggests the vulnerability of these zones during military conflicts.
- **Unexpected interrelationships**: The weak correlation between S1 (availability of numerous water bodies and reservoirs) and most threats is unexpected, given the potential of these resources to mitigate a wide range of hazards. The positive correlation (0.933) between S7 (availability of reservoirs for renewable energy production) and T3 (war and the impact of military actions on water resources) may reflect the dual role of reservoirs as both strategic assets and potential targets in conflict scenarios.

In summary, the strong positive correlations between the availability of qualified personnel and several key threats highlight the importance of investing in human capital to address ecological, environmental, and social challenges. High correlations between reservoir availability and various threats confirm the multifunctional utility of these structures in solving critical water-related issues. Negative correlations between ecological zones and specific threats call for the development of protective strategies to safeguard vulnerable areas. The moderate negative correlation between water activities and hydromorphological changes points to the need for harmonizing recreational use with ecological preservation. Furthermore, the correlation between reservoirs and military threats underscores the necessity of con-

Table 5. **Impact of Weaknesses on Exacerbating Threats (WT)**

WT	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
W1	+0.960	+0.940	–0.07	–0.014	+0.014	–0.029	–0.048	+0.007	–0.029	–0.048	+0.960	+0.007
W2	+0.014	+0.029	–0.466	–0.955	+0.955	–0.455	–0.424	–0.935	–0.455	–0.455	+0.014	–0.987
W3	+0.014	–0.014	+0.978	+0.955	–0.500	+0.955	+0.891	+0.511	+0.955	+0.891	+0.014	+0.501
W4	–0.014	–0.029	+0.466	+0.500	–0.955	+0.455	+0.424	+0.935	+0.455	+0.455	–0.014	+0.987
W5	+0.014	+0.029	–0.466	–0.955	+0.955	–0.455	–0.424	–0.935	–0.455	–0.455	+0.014	–0.987
W6	+0.014	+0.029	–0.466	–0.955	+0.955	–0.455	–0.424	–0.935	–0.455	–0.455	+0.014	–0.987
W7	–0.014	–0.029	+0.466	+0.955	–0.955	+0.455	+0.424	+0.935	+0.455	+0.455	–0.014	+0.987
W8	–0.014	–0.029	+0.466	+0.955	–0.955	+0.455	+0.424	+0.935	+0.455	+0.455	–0.014	+0.987
W9	+0.014	–0.014	+0.978	+0.500	–0.500	+0.955	+0.891	+0.511	+0.955	+0.891	+0.014	+0.501
W10	–0.529	–0.541	+0.029	+0.033	–0.033	+0.016	+0.004	+0.044	+0.016	–0.021	–0.529	+0.004
W11	–0.014	–0.029	+0.466	+0.955	–0.955	+0.455	+0.424	+0.935	+0.455	+0.455	–0.014	+0.987
W12	–0.014	–0.029	+0.466	+0.955	–0.955	+0.455	+0.424	+0.935	+0.455	+0.455	–0.014	+0.987
W13	+0.014	+0.029	–0.466	–0.955	+0.955	–0.455	–0.424	–0.935	–0.455	–0.455	+0.014	–0.987
W14	–0.014	–0.029	+0.466	+0.955	–0.955	+0.455	+0.424	+0.935	+0.455	+0.455	–0.014	+0.987

sidering water infrastructure in national security planning. Finally, the weak correlations observed between certain strengths and threats indicate an opportunity to develop more targeted and effective strategies to leverage existing assets for mitigating potential risks.

The analysis of the correlation results presented in Table 4 demonstrating the impact of weaknesses on realizing opportunities (WO), reveals the following key interrelationships:

- **Highest positive correlations**: A high positive correlation (0.973) between W10 (insufficient cooperation among stakeholders) and both O3 (infrastructure improvement) and O11 (promotion of scientific research) suggests that strengthening stakeholder collaboration can significantly enhance infrastructure development and scientific advancement. Strong positive correlations (0.955) between several weaknesses (W2 — outdated infrastructure, W5 — insufficient public awareness, W6 — uncontrolled water use) and O5 (creating favorable conditions for investment) indicate that addressing these issues could unlock substantial investment opportunities. Additionally, a high positive correlation (0.940) between W1 (pollution of water bodies) and O1 (development of water tourism and recreation) is an unexpected but intriguing result, potentially pointing to opportunities for developing ecotourism initiatives centered on the restoration of aquatic ecosystems.
- **Significant negative correlations**: A strong negative correlation (–0.955) between several weaknesses (W2, W5, W6, W13 — inefficient legal and institutional frameworks) and O7 (development of a monitoring system), O8 (enhancement of cooperation), and O10 (development of integrated systems) indicates that these weaknesses could significantly hinder the realization of the mentioned opportunities. A notable negative correlation (–0.560) between W1 (pollution of water bodies) and both O3 (infrastructure improvement) and O11 (promotion of scientific research) suggests that environmental degradation complicates efforts toward modernization and innovation.
- **Unexpected interrelationships**: A strong positive correlation (0.955) between W3 (lack of integrated management) and O6 (increasing public awareness) implies that recognition of poor management practices may trigger educational and advocacy efforts. Surprisingly, W12 (insufficient financial resources) does not show strong correlations with most opportunities, despite the well-established importance of funding in supporting strategic initiatives.

In summary, the strong positive correlations between insufficient cooperation and opportunities for infrastructure improvement and research underscore the importance of enhancing stakeholder engagement to realize these potentials. The correlations between certain weaknesses and investment-fostering opportunities highlight the role of problem-solving in attracting capital to the water sector. The unexpected positive relationship between water pollution and tourism development suggests the potential for targeted ecotourism focused on aquatic ecosystem rehabilitation. Strong negative correlations between several weaknesses and opportunities related to monitoring, collaboration, and systemic integration emphasize the urgency of adopting a holistic, systems-based approach to overcome structural and institutional barriers. The positive link between lack of integrated management and increased public awareness suggests that educational and outreach strategies could play a transformative role in advancing sustainable water governance.

The analysis of the correlation results presented in Table 5 illustrating the impact of weaknesses on exacerbating threats (WT), reveals the following key interrelationships:

- **Highest positive correlations**: The strongest positive correlation (0.987) is observed between W4 (inefficient water supply systems), W8 (low public awareness), W11 (lack of alternative water sources), W12 (insufficient financial resources), W14 (ineffective planning), and T12 (impact on economic development). This suggests that these systemic weaknesses significantly contribute to undermining regional economic growth. A high positive correlation (0.978) between W3 (lack of integrated management) and T3 (war and the impact of military actions) highlights the importance of cohesive water governance frameworks in ensuring resilience under conflict conditions. Additionally, a strong correlation (0.960) between W1 (pollution of water bodies) and both T1 (climate change) and T11 (threats to public health) indicates that water pollution may significantly amplify environmental and health-related risks.

- **Significant negative correlations**: A strong negative correlation (–0.987) between W2 (littering), W5 (outdated infrastructure), W6 (uncontrolled use of water resources), W13 (loss of biodiversity), and T12 (impact on economic development) suggests that targeted interventions in infrastructure, conservation, and resource control can effectively mitigate economic threats. A similarly significant negative correlation (–0.955) between many weaknesses and T5 (uncontrolled well drilling) points to the potential of broader water management improvements in curbing unsustainable groundwater extraction.
- **Unexpected interrelationships**: The weak correlation between W12 (insufficient financial resources) and most threats is unexpected, given the commonly recognized role of funding in environmental mitigation. Interestingly, a strong positive correlation (0.955) between W3 (lack of integrated management) and both T6 (soil erosion and clogging of waterways) and T9 (non-compliance with water protection zones) suggests that strengthening integrated management systems may have a direct and significant effect on these issues.

In conclusion, the strong positive correlations between several weaknesses and their influence on economic development highlight the essential role of effective water resource management in ensuring regional economic sustainability. The interrelationship between water pollution, climate change, and public health threats underscores the urgency of adopting integrated strategies that address environmental and social challenges simultaneously. The high correlation between the absence of integrated management and various threats points to the need for a coherent, systemic water governance model. Negative correlations with threats such as uncontrolled well drilling demonstrate that mitigating specific weaknesses can substantially reduce environmental vulnerability. The dual presence of both positive and negative correlations for certain factors (e.g., W3) illustrates the complexity of interdependencies within the water system and underscores the importance of multidimensional strategy development. Ultimately, addressing core weaknesses can significantly reduce exposure to a range of water-related threats.

Thus, a comprehensive analysis of the interrelationships among strengths, weaknesses, opportunities, and threats (SWOT) in the water use sector of the Zhytomyr region provides critically important insights for developing effective water resource management strategies. The findings highlight the necessity of an integrated approach that considers the complex interactions among various factors and underscores the importance of investments in human capital and infrastructure to enhance the resilience and sustainability of water management systems in the face of future challenges.

In addition, the development of risk management strategies is essential — strategies that address existing issues while anticipating potential threats related to climate change, environmental degradation, and economic pressures. Priority areas requiring targeted investments include the modernization of water infrastructure, the development of comprehensive monitoring systems, and the implementation of advanced water purification technologies. These efforts should account for potential synergies and conflicts among different aspects of water use.

The analysis also emphasizes the critical importance of cooperation among stakeholders — including government authorities, businesses, scientific

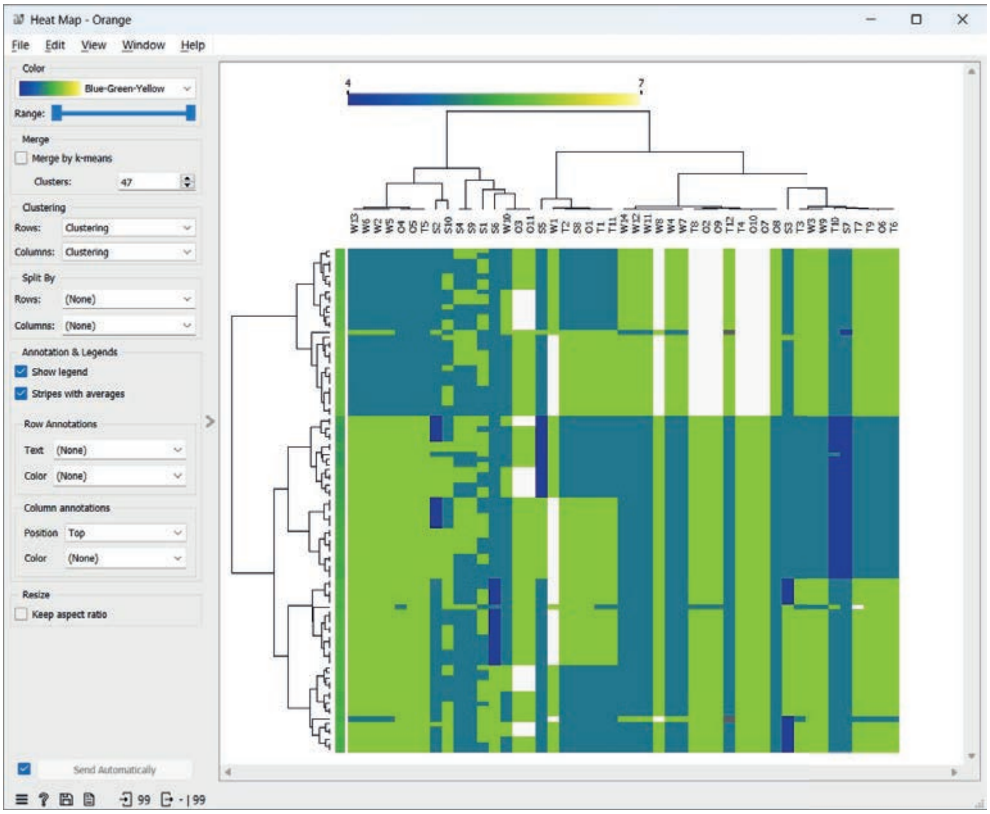


Fig. 1. Heat map with grouping to display the intensity of connections between indicators
Source: prepared by the authors.

institutions, and the public — for successful and sustainable water resource management. Furthermore, educational and informational campaigns aimed at raising public awareness about the importance of sustainable water use are vital components of a holistic strategy.

To deepen the understanding of interrelationships among various factors and uncover hidden patterns in the data, the next stage of the research involved applying cluster analysis. This method enables the grouping of factors based on their similarities and interconnections, offering additional insights for strategic water use planning in the region. Given that the analysis was conducted on multicriteria data, it was necessary to aggregate rows for subsequent processing. This aggregation was performed using the k-means algorithm, which classified the data into 47 selected clusters.

Figs. 1 and 2 present the results of the cluster analysis, which assess both internal and external factors influencing water resource use and conservation in the Zhytomyr region. Fig. 1 displays a dendrogram and a heat map, illustrating the clustering based on the similarity among indicators. Green and blue color gradients represent varying degrees of similarity, where dark blue squares indicate a low level of connection, and light green squares indicate a high level of similarity between the indicators.

Fig. 2 presents an alternative view of the heat map using different colour scales to display the intensity of connections between indicators. Yellow and purple colours indicate variations in values, where yellow denotes high intensity and purple indicates low intensity.

Based on the heat maps presented in Figs. 1 and 2 from the cluster analysis, several key results can be identified. The analysis revealed distinct groupings of factors, each reflecting core thematic areas within the water resource management system of the Zhytomyr region. The primary clusters are described as follows:

a) **Infrastructure and Technology Cluster:** Comprising factors S1, S2, S3, O2, O3, and O10, this cluster includes strengths related to the state of water infrastructure and opportunities for its further development and technological modernization.

b) **Environmental Factors Cluster:** Including S4, S9, T6, and T7, this group combines strengths and threats associated with ecological zones and risks to ecosystems, reflecting the ecological dimension of water resource sustainability.

c) **Management and Cooperation Cluster:** This cluster — encompassing S5, S10, O7, O8, W3, and W10 — relates to the governance of water resources, stakeholder coordination, and institutional capacity, highlighting the systemic importance of management and collaboration.

d) **Pollution and Usage Issues Cluster:** Formed by W2, W5, W6, and W13, this group reflects weaknesses connected to pollution, waste, and inefficient use of water resources, which present persistent operational challenges.

e) **Water Quality and Financing Cluster:** This includes W4, W7, W8, W11, W12, and W14, encompassing issues of water quality, its usage, and the availability of financial resources to address these concerns effectively.

An analysis of both intra-cluster and inter-cluster correlations reveals further insights into the structure of interrelationships:

- **Infrastructure and Technology Cluster:** Exhibits the highest internal positive correlation, indicating a strong linkage between infrastructure-related strengths and opportunities for technological development.
- **Environmental Factors Cluster:** Shows moderate internal correlations, reflecting the connectedness of ecological features and environmental threats.
- **Management and Cooperation Cluster:** Demonstrates varied internal relationships, underscoring the multidimensional and interconnected nature of governance, stakeholder engagement, and institutional effectiveness.
- **Pollution and Usage Issues Cluster:** Displays strong internal correlations, reinforcing the closely linked nature of these weaknesses in water use practices.
- **Water Quality and Financing Cluster:** Shows high internal consistency, indicating the interdependence between water quality challenges, usage patterns, and financial limitations.

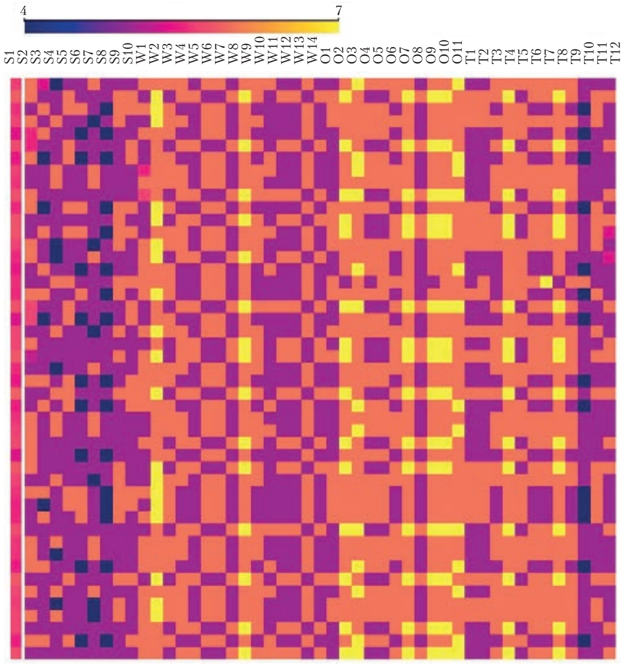
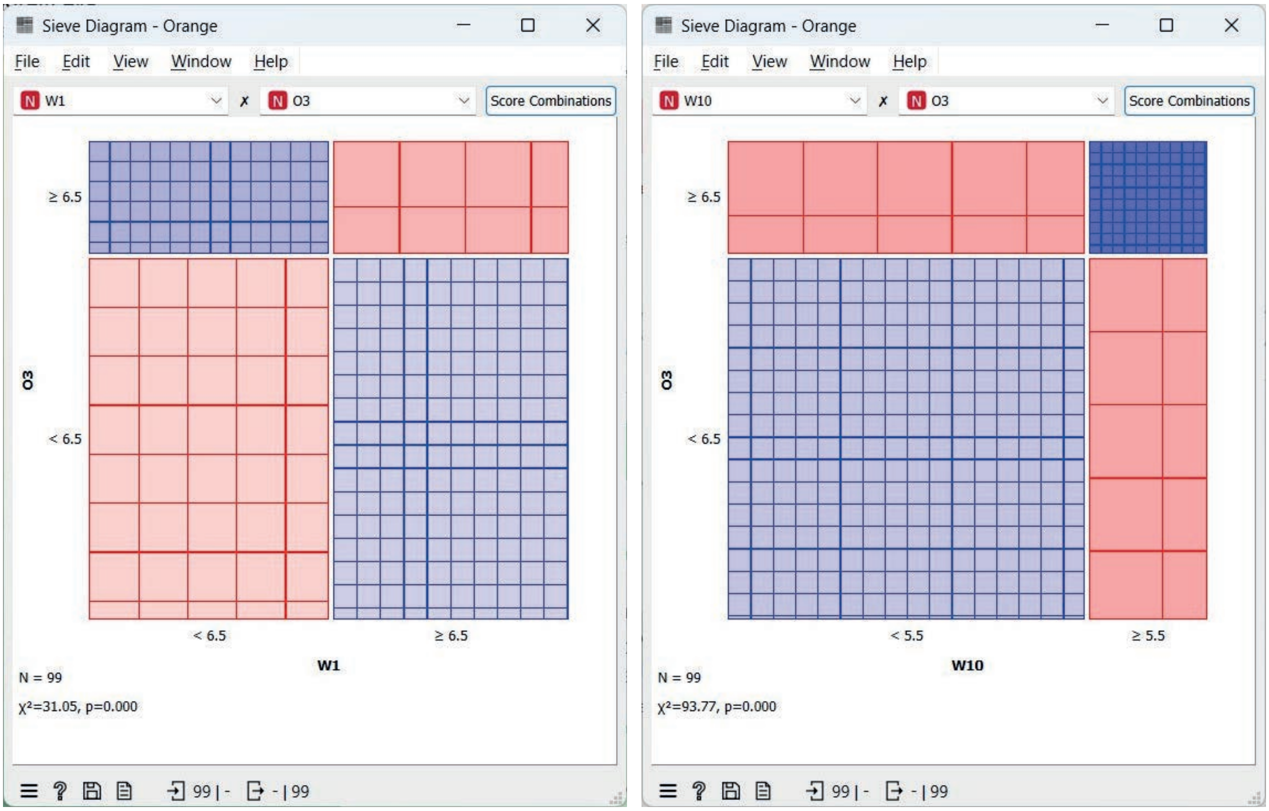


Fig. 2. Density distribution of indicators
Source: prepared by the authors.

Regarding **inter-cluster relationships**, several notable correlations were observed:

- A **moderate positive correlation** between the infrastructure and management clusters suggests that improved infrastructure could support enhanced governance and coordination efforts.
- The **environmental factors cluster** exhibits **weak correlations** with other clusters, signaling the need for specialized attention to environmental considerations when formulating strategic responses.



a *b*

Fig. 3. Mosaic plot of the interrelationship between factors (example for two pairs: W10-O3 and W1-O3): *a* — Plot of the high positive correlation (0.973) between W10 (Insufficient cooperation among stakeholders) and O3 (Infrastructure improvement); *b* — Plot of the significant negative correlation (–0.560) between W1 (Pollution of water bodies) and O3 (Infrastructure improvement)

- The **pollution and water quality clusters** show **negative correlations** with the infrastructure cluster, indicating the potential to mitigate these issues through targeted infrastructure investment.
- The overall **complexity of the inter-cluster structure** highlights the necessity for an integrated and systems-based approach to water resource management.

To further investigate factor interrelationships, the **mosaic plot method** was applied. In this visualization, the area of each rectangle represents the expected frequency, while the observed frequency is indicated by the number of squares within each rectangle. Two specific factor pairs were selected to demonstrate the utility of this method:

- **W10 (Insufficient cooperation among stakeholders)** and **O3 (Infrastructure improvement).**
- **W1 (Pollution of water bodies)** and **O3 (Infrastructure improvement).**

These factor pairs were selected based on their statistically significant correlations identified in earlier stages of analysis and their strategic relevance within the regional water resource management framework. Mosaic plots provide an intuitive visual tool for assessing these relationships, helping to interpret the interaction patterns between weaknesses and opportunities.

As illustrated in Fig. 3, mosaic plots enable a visual evaluation of deviations between observed and expected frequencies. These deviations — proportional to Pearson's standardized residuals — are represented by both shading density and color, where blue denotes positive deviations and red indicates negative deviations from statistical independence.

The W10-O3 pair (*Insufficient cooperation among stakeholders* and *Infrastructure improvement*) is shown in Fig. 3a. This pair exhibits a high positive correlation ($r = 0.973$), reflecting a strong association between the lack of stakeholder coordination and the recognized need for infrastructure development. This finding highlights the crucial role of stakeholder engagement and coordinated action in ensuring the success of water infrastructure modernization initiatives.

In contrast, the W1-O3 pair (*Pollution of water bodies* and *Infrastructure improvement*), shown in Fig. 3b, displays a significant negative correlation ($r = -0.560$). This indicates a potential conflict between high levels of water pollution and the feasibility or pace of infrastructure improvements. In such contexts, environmental degradation may act as a limiting factor, complicating modernization efforts and requiring additional mitigation strategies.

In summary, the mosaic plot analysis of interrelationships among SWOT factors offers a comprehensive and visually accessible representation of the water use system in the Zhytomyr region. It supports and validates the findings of the previous correlation and cluster analyses, revealing both strong positive and negative interdependencies among key factors. By examining these contrasting relationships, the analysis contributes to a deeper understanding of the complex dynamics affecting water infrastructure development. It also reinforces the need for an integrated water management strategy that simultaneously addresses social factors (e.g., stakeholder cooperation) and environmental constraints (e.g., pollution levels).

The study has identified key directions for strategic intervention, including investment in human capital, modernization of infrastructure, strengthening of stakeholder cooperation, and the implementation of innovative water purification technologies. The comprehensive approach — combining SWOT analysis, correlation analysis, cluster analysis, and the mosaic plot method — has provided an in-depth understanding of the state of water resource management in the Zhytomyr region.

While SWOT analysis alone has offered a general overview of strengths, weaknesses, opportunities, and threats, it has not enabled a quantitative assessment of interrelationships between factors, has not revealed hidden patterns or groupings, and has led to a simplified interpretation of the complex water use system. In contrast, correlation analysis has allowed for the quantitative evaluation of the strength and direction of relationships between factors. It has revealed previously unnoticed dependencies and has made it possible to prioritize key factors based on their influence on other system components.

Cluster analysis has complemented the research by identifying five main groups of interrelated factors — infrastructure and technology, environmental factors, management and cooperation, pollution and usage issues, and water quality and financing. These groupings have formed a structured basis for the development of targeted water resource management strategies.

The mosaic plot method has added a valuable visual dimension by integrating the results of earlier analyses into a unified format. It has visually illustrated complex interrelationships between factors and has highlighted deviations from expected interaction frequencies, thereby supporting deeper insight into factor dynamics.

The proposed methodological framework has demonstrated its potential for broader application in analyzing water use systems in other regions and has laid the foundation for the development of effective and data-driven water resource management strategies.

Overall, the findings have underscored the importance of an integrated approach to water resource management — one that considers the intricate interdependencies between environmental, social, and economic factors to support the sustainable development of regional water systems.

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БАГАТОВИМІРНИЙ АНАЛІЗ РЕГІОНАЛЬНОГО УПРАВЛІННЯ ВОДНИМИ РЕСУРСАМИ: КОМПЛЕКС-НИЙ ПІДХІД

Вступ. Водні ресурси є критично важливими для сталого розвитку Житомирської області. Регіон має значний гідрологічний потенціал: 53 водосховища (76 тис. га) та 2075 ставків (123 тис. га). Поверхневі води становлять 77 %, підземні — 23 %.

Проблематика. Ефективне управління водними ресурсами ускладнюють зростаючий попит, забруднення, неконтрольоване використання та кліматичні зміни. Традиційні методи планування ігнорують складні взаємозв'язки між факторами, тому актуальним є розроблення комплексного підходу для виявлення прихованих залежностей та ефективного стратегічного планування.

Мета. Розробити інтегрований підхід до аналізу водокористування в Житомирській області, що поєднує *SWOT*-аналіз з кореляційним та кластерним аналізом для покращення стратегічного планування.

Матеріали й методи. Використано комплексну методологію: *SWOT*-аналіз, кореляційний аналіз за коефіцієнтом Пірсона та кластерний аналіз методом *k-means*. Обробку даних виконували за допомогою інструменту *Orange*.

Результати. Ідентифіковано ключові фактори через *SWOT*-аналіз: доступність водних об'єктів (S1), розвиток інфраструктури (S2), забруднення (W1), неконтрольоване використання (W6), кліматичні зміни (T1) та військові впливи (T3). Кореляційний аналіз виявив значущі взаємозв'язки. Кластерний аналіз визначив п'ять груп: інфраструктура та технології, екологічні фактори, управління та співпраця, проблеми забруднення, якість води та фінансування.

Висновки. Інтегрований підхід забезпечив цілісне розуміння водокористування в регіоні та показав складні взаємозв'язки між змінними. Результати вказують на необхідність комплексного підходу до управління водними ресурсами з урахуванням зв'язків між компонентами системи. Дослідження надає рекомендації щодо пріоритетних напрямів інвестування: модернізація інфраструктури, розвиток моніторингу та впровадження інноваційних технологій.

Ключові слова: водні ресурси, інноваційні підходи, інтегроване управління водними ресурсами, сталий розвиток, екологічна безпека.