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Using Principal Component Analysis to assess the performance of Romanian wastewater operators

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Abstract. *Objective: In the current global context, characterized by increasing pressures on the environment and the need to optimize resources, the wastewater management sector in Romania faces numerous challenges. These challenges relate in particular to operational efficiency and compliance with environmental standards imposed at national and European level. The present study aims to explore the performance of wastewater operators in Romania, using Principal Component Analysis (PCA) to identify the main operational and financial variables that influence this performance. The main purpose of the research is to evaluate the way different variables contribute to the overall efficiency and the fulfillment of the environmental standards. Method: In order to carry out this study, it was decided to apply the Principal Components Analysis (PCA), a statistical method recognized for its effectiveness in simplifying complex data sets by reducing their dimensionality. For data analysis, the following variables were used: the number of inhabitants connected to sewage services, the volume of wastewater discharged into the outfall without treatment, the volume of wastewater entering the wastewater treatment plants, the total revenues from exploitation, in terms of concerns the wastewater activity, the total investments in the wastewater system and the degree of compliance with the quality of the treated wastewater. Results: The results of the analysis indicate a strong association between the infrastructure and financial capacity of operators and the efficiency of wastewater management. The first two principal components presented distinct dimensions of performance related to operational capacity and compliance with environmental regulations. Originality: The originality of the study consists in using principal component analysis to extract and interpret latent dimensions from a complex data set, providing clear insight into the determinants of performance in the wastewater treatment sector. This method allows efficient and focused analysis, helping to identify key points for strategic interventions and improvements.*
Keywords: *principal component analysis (PCA); wastewater management; performance of water operators; compliance with environmental requirements; wastewater infrastructure*
JEL classification: *C10, Q53, R10*

1. Introduction

In the context of the continuous increase of requirements for the sustainable management of water resources and compliance with environmental standards, the analysis of the performance of regional water operators becomes essential.

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Romania, similar to other EU member states, faces significant challenges in terms of compliance with European standards for wastewater treatment.

The study's main goal is to use Principal Component Analysis (PCA) to identify the key variables that contribute to treated wastewater quality standards compliance by analyzing the impact of operational and financial factors on the performance of regional operators in Romania with regard to wastewater treatment activities.

Specifically, the study will investigate the relationships between the volume of treated wastewater, operating revenues, the level of investment in wastewater infrastructure, and compliance with treated water quality standards. Also, the impact of the number of inhabitants connected to sewage services on the volume of wastewater discharged without treatment will be evaluated.

Through this study, I aim to provide a detailed insight into the dynamics of wastewater sector indicators and to identify opportunities for improving the management and operation of wastewater treatment activity.

Specific objectives pursued in carrying out the study are:

1. Determining the correlations between the volume of treated wastewater and the quality of treated water. The hypothesis that there is a direct relationship between the volume of water entering wastewater treatment plants and the compliance of the results with quality standards will be tested.
2. Assessing the impact of operating revenues on investments in wastewater infrastructure. This analysis will explore whether incomes generated from treatment activities influence the level of investment, testing the hypothesis that higher revenues enable significant investment in infrastructure improvements.
3. Investigating the relationship between the number of inhabitants connected to sewage services and the volume of wastewater discharged without treatment. The paper will examine whether a greater volume of wastewater released untreated is associated with more residents being connected to the wastewater system.
4. Analysis of investments effect in the wastewater system on the volume of water discharged without treatment. The hypothesis that investments in wastewater infrastructure contribute to reducing the volume of wastewater discharged directly into the natural environment without prior treatment will be tested.
5. Verification of the link between financial performance and the degree of qualitative compliance of treated water. The assessment will examine whether a correlation exists between the financial health of the operators and the quality of treated wastewater, thereby validating or refuting the proposed hypothesis.

These specific objectives help to methodically structure the research, focusing on the key aspects that can influence the efficiency and effectiveness of the wastewater treatment activity in Romania.

2. Literature review

One of the major issues facing humanity in recent years is water quality. Water cannot be replaced hence it is segregated from other environmental elements. The foundation of freshwater ecosystems, food security, and sustainable development is the availability of enough clean water.

Pollution of limited freshwater resources puts additional pressure on freshwater resources. Sewage and other wastes, industrial effluents, agricultural discharges, chemical industry wastes, fossil fuel power plants, and nuclear power plants are the primary sources of water pollution, which renders water unfit for drinking, farming, and aquatic life. Wastewater treatment is not only important for our health, but also for keeping the environment clean and healthy.

In the last years, Romania has witnessed significant changes in the management of its natural resources, especially in terms of wastewater treatment and recycling. The global context, marked by economic crises and pandemics, has put additional pressure on regional operators in this sector, determining the need for a deep analysis of their performance. Economic, financial, and technical indicators can help solve the issues brought on by the various sizes of operators, allowing for a proper evaluation of their performance. For this reason, a performance measurement system is essential to improving the effectiveness and performance of wastewater services (Fülöp et al., 2023). This study will investigate the intricacy of economic, technological, and sustainability aspects that affect wastewater operators' efficiency in Romania, drawing inspiration from the writings of renowned academics and analysts.

The perspective offered by Zaman et al. (2012), shows the importance of sustainable development and innovation in the Romanian entrepreneurial sector is emphasized. This background is essential for understanding how wastewater operators can improve performance by adopting green technologies and by aligning with circular economy principles. Apostu et al. (2022) bring up the role of emerging technologies in increasing urban resilience. The implementation of these technologies in wastewater management not only increases efficiency, but also contributes to the robustness of critical infrastructures in the face of disturbances.

The constant operation of sewage systems is essential to their performance, and this can be accomplished through resource recovery, consumption reduction, and energy savings, which lowers the cost of managing various monitoring data types (Martínez et al., 2020). Monitoring and control systems like SMAC (social, mobile, analytics, and cloud) (Su et al., 2020), SCADA (Supervisory Control and Data Acquisition) (Nair et al., 2022), LabView software (Nanda et al., 2021), and biosensor monitoring (Ejeian et al., 2018) must be put into place in order to improve the efficiency of wastewater treatment plants. Also, Hao et al. (2013) analyzed, by applying the Principal Component Analysis method, the factors that influence the quality of wastewater, concluding that maximum importance should be given to monitoring and control of treated wastewater treatment activity. Financial analysis cannot be neglected; the methods presented by Bakó et al. (2021) in their paper are applied to evaluate the financial stability of water operators, a crucial indicator of their long-term performance. Increasing and improving efficiency is crucial to managing water and wastewater services. An important component of measuring the efficiency of water operators is the revenue obtained *(*Bakó & Fülöp, 2021).

Hysa et al. (2022) discusses the impact of the pandemic on foreign investment flows, which indirectly also affects the wastewater management sector by reducing the capital available for innovation and expansion. Also, the study of Vasile et al. (2024*)* explores the way different economic crises shape policy and sector responses, an important lesson for the long-term adaptability of wastewater operators.

The multidimensional analysis of the performance of wastewater operators in Romania reveals a series of challenges and opportunities. It is clear that technological innovation, sustainability, economic resilience and financial efficiency are all interconnected and essential to the long-term success of this vital sector. The cited papers provide a robust framework for understanding and continuously improving wastewater management, emphasizing the need for an integrated approach to navigate the increased complexity of the contemporary economic and ecological landscape.

In the current context of economic research, the current study aligns with a significant body of literature, emphasizing the importance of empirical and applied analyzes in various economic sectors. This approach is strengthened by the multiple contributions of Aivaz (2021), who explored over time various dimensions of financial and corporate performance, as well as the impact of public policies on economic indicators.

A number of previous studies such as *financial performance trend analysis* (Topor et al., 2022; Fülöp, K.-E., & Fülöp, Á.-Z., 2023) and stimulants for corporate responsibility in the support services of Constanta County and the exploration of asset nonconformities in financial statements (Matei & Aivaz, 2023), underlines the relevance of such analytical tools in evaluating and improving transparency and efficiency in the economic sector. These theoretical foundations are extended in the present study, which applies advanced statistical methodologies to decipher the complex links between *operational performance* and *compliance* in the wastewater treatment sector. The term *compliance* refers to compliance with applicable laws, regulations, rules and policies. In a business context, this involves ensuring that a company complies with all legal and ethical requirements, as well as internal standards of practice and behavior. *Compliance* includes activities such as continuous monitoring of operational compliance, risk assessment related to non-compliance and implementation of measures to prevent violations.

Therefore, compliance for the regional operator is not only a legal necessity, but also a responsibility towards the community and the environment, ensuring that the services offered are safe, sustainable and of high quality. Even though wastewater infrastructure design and operation have advanced over the past ten years, research on problems influencing wastewater effluent quality is still required (Zhang et al., 2021). In addition, a number of studies (Tomczak & Radosiński, 2017; Yang et al., 2010; Zheng et al., 2020; Alayande & Adekunle, 2015) highlight how discriminant models can be used to understand the impact of sanctions on financial indicators, a methodological approach that resonates with the PCA techniques used in current analysis to determine the key influencing factors of the performance of wastewater operators.

Mihai et al. (2018) highlight the links between the circular economy and resource efficiency. This insight is vital for wastewater operators, who need to manage resource consumption as sustainably as possible. Circular economy research and corporate reorganization (Herciu et al., 2023; Stroie et al., 2023) it also provides a framework for understanding how innovations in business models and strategic decisions can influence competitiveness and sustainability.

Therefore, this study not only fits into a rich academic context, but also proposes an original approach to interpreting public sector data specific to wastewater treatment, contributing to the existing literature by applying PCA to discern latent structures in the data, thus providing a solid basis for informed public policies and well-grounded strategic interventions.

3. Methodology

In order to carry out this study, it was decided to apply Principal Component Analysis (PCA), a statistical methodology recognized for its effectiveness in simplifying complex data sets by reducing their dimensionality.

Principal Component Analysis (PCA) was used to identify and quantify the main sources of variation in the collected data, thereby converting a large set of possibly intercorrelated variables into a small number of non-overlapping variables, called principal components (Mirea and Aivaz, 2016a).

PCA is particularly valuable for assessing the performance of wastewater operators for several reasons:

- Data Size Reduction. Regional wastewater operators generate large volumes of data and PCA helps reduce their complexity by extracting the principal components that capture most of the variation in the data. This simplifies the analysis without losing essential information.
- Identifying Hidden Patterns. PCA can reveal non-obvious relationships between variables that contribute to overall performance, providing deeper insight into the internal dynamics of treatment processes.
- Optimizing Monitoring and Reporting. By focusing on the main components of variation, PCA allows managers to focus on the key indicators that influence performance, thereby optimizing monitoring and reporting efforts.
- Flexibility and Applicability. PCA does not assume a functional form between variables, which makes it applicable in various contexts and adaptable to different types of data

(Gewers et al., 2021; Greenacre et al., 2023; Huang et al., 2022; Karamizadeh et al., 2013; Kherif and Latypova, 2019).

The use of PCA in combination with other research methods can provide a comprehensive and detailed assessment of the performance of wastewater operators, leading to tangible improvements in water resource management and wastewater treatment in Romania. Choosing this method adds significant value by clarifying critical aspects of performance and facilitating data-driven decision making.

4. Description of data

4.1 Data used

The data and information necessary to carry out the study were provided by the database of the Romanian Water Association, at the level of a number of 43 regional operators, for the year 2022, as part of the benchmarking exercise, for the water and sewage sector in Romania.

The indicators used in evaluating the performance of water and wastewater operators are:

- Residents connected to sewerage services (cumulative for all localities (locality no.)), representing the resident population connected to sewerage systems, managed by companies, at the end of 2022;
- The volume of wastewater discharged into the outfall without treatment, during the year 2022 (m^3/year);
- The volume of wastewater entering wastewater treatment plants in 2022 (m^3/year);
- Total revenues from exploitation, in terms of wastewater activity (RON /year);
- investments in the waste water system (RON /year): the total cost of investments in the sewage system in 2022;
- The degree of compliance with the quality of purified wastewater representing the number of physico-chemical tests of the treated water in accordance with the applicable standards or legal norms in the year 2022 / the number of physico -chemical tests of the treated water performed in the year 2022 × 100.

4.2 Data description

Table 1 provides descriptive statistics for different variables associated with wastewater services in Romania, based on a sample of 43 regional operators (treatment plants, water operators).

Table 1. Data description

	Mean	STD	N
wE-004 - Residents connected to sewerage services (cumulative for all localities (loc. no.)	184905.95	120080.139	43
wA-RO-025 – The volume of wastewater discharged into the outfall without treatment (m^3/year)	613861.56	1287896.889	43
wA-RO-027a – Volume of wastewater entering wastewater treatment plants (m^3/year)	16737839.14	15733093.808	43
wG-RO-002 – Total revenues from exploitation, regarding the waste water activity (RON /year)	44644731.84	37730928,439	43
wG-RO-030 – Total investments in the waste water system (RON /year)	32576757.86	49048078.012	43

CD-r-7 – Degree of compliance with the quality of treated wastewater	79.3063	33.26409	43

Source: own processing based on the Romanian Water Association 's database, https://h2obenchmark.org

Detailed data interpretation:

1. Residents connected to sewerage services (loc. no.) :
   - Average: 184,905.95 inhabitants are connected on average to sewerage services in the localities analyzed.
   - Standard Deviation (STD): 120,080,139, indicating significant variation between localities in the number of connected inhabitants.
   - N: 43 analyzed units.
2. The volume of wastewater discharged into the outfall without treatment (m^3/year) :
   - Average: 613,861.56 m^3/year, representing the average volume of wastewater discharged directly into the outfall without being treated.
   - STD: 1,287,896,889, suggesting a wide spread in the data, possibly due to large differences in treatment plant capacity and efficiency.
   - N: 43 units.
3. The volume of wastewater entering the treatment plants (m^3/year):
   - Average: 16,737,839.14 m^3/year, indicating the average volume of wastewater that is processed in treatment plants.
   - STD: 15,733,093,808, reflecting significant variation between stations, likely influenced by available capacity and technology.
   - N: 43 units.
4. Total revenues from exploitation, regarding the waste water activity (RON /year):
   - Average: 44,644,731.84 RON/year, showing the average revenues generated by wastewater management activities.
   - STD: 37,730,928,439, indicating large differences between water operators in terms of financial performance.
   - N: 43 units.
5. Total investments in the wastewater system (RON /year):
   - Average: 32,576,757.86 RON/year, representing the average annual investments in wastewater infrastructure.
   - STD: 49,048,078,012, reflecting a large variability in investment, possibly related to funding cycles and priorities of different regions or localities.
   - N: 43 units.
6. Degree of compliance with the quality of treated wastewater:
   - Average: 79.3063%, showing the average percentage of compliance with wastewater quality standards after treatment.
   - STD: 33.26409, indicating substantial variability in treatment effectiveness and compliance, which may signal problems at certain treatment plants.
   - N: 43 units.

These statistics provide a solid basis for further analysis of the factors that influence the performance of wastewater treatment activity by regional operators in Romania and for the development of strategies to improve wastewater management in Romania.

4.3 Results and Discussion

The correlation matrix presented in Table 2 provides an image of the relationships between different variables related to wastewater services from a sample of 43 water operators in Romania.

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Table 2. Matrix of correlations

		wE-004	wA-RO-025	wA - RO-27a	wG-RO-002	wG-RO-030	CD-R-7
	wE-004 - Residents connected to sewerage services (cumulative for all localities (loc. no .)	1,000	0.006	0.928	0.954	0.723	0.049
	wA-RO-025 - The volume of wastewater discharged into the outfall without treatment (m³/year)	0.006	1,000	-0.013	-0.064	-0.129	0.014
	wA-RO-027a - Volume of wastewater entering wastewater treatment plants (m³/year)	0.928	-0.013	1,000	0.917	0.689	-0.033
	wG-RO-002 - Total revenues from exploitation, regarding the waste water activity (RON /year)	0.954	-0.064	0.917	1,000	0.754	-0.042
	wG-RO-030 - Total investments in the waste water system (RON /year)	0.723	-0.129	0.689	0.754	1,000	0.012
	CD-r-7 – Degree of compliance with the quality of treated wastewater	0.049	0.014	-0.033	-0.042	0.012	1,000
Sig. (1-tailed)	wE-004 - Residents connected to sewerage services (cumulative for all localities (loc. no .)		0.485	<0.001	<0.001	<0.001	0.378
	wA-RO-025 - The volume of wastewater discharged into the outfall without treatment (m³/year)	0.485		0.468	0.341	0.204	0.464
	wA-RO-027a - Volume of wastewater entering wastewater treatment plants (m³/year)	0.000	0.468		0.000	0.000	0.416
	wG-RO-002 - Total revenues from exploitation, regarding the waste water activity (RON /year)	0.000	0.341	0.000		0.000	0.395
	wG-RO-030 - Total investments in the waste water system (RON /year)	0.000	0.204	0.000	0.000		0.469
	CD-r-7 – Degree of compliance with the quality of treated wastewater	0.378	0.464	0.416	0.395	0.469	

a. Determinant = 0.004

Source: own processing based on the Romanian Water Association 's database, *https://h2obenchmark.org*

This table allows the degree of association between variables to be analyzed, helping us to understand how different aspects of wastewater management interact.

1. Strong correlations between the number of inhabitants connected, the volume of wastewater entering the treatment plants, and operating income: there are very strong correlations (over 0.9) between the number of inhabitants connected to sewage services (wE-004), the volume of water waste water entering treatment plants (wA-RO-027a), and total operating income (wG-RO-002). This suggests that larger operators serving more residents tend to treat more wastewater and, consequently, generate more revenue.
2. The impact of the volume of wastewater discharged without treatment: the volume of wastewater discharged into the outfall without treatment (wA-RO-025) shows weak or negative correlations with the other variables. For example, there is a slightly negative correlation with total investment in the wastewater system (wG-RO-030), which could suggest that higher investments can help reduce the volume of untreated wastewater discharged.
3. Moderate correlations between investments and other variables: total investments in the wastewater system show moderate correlations with the volume of wastewater entering the plants (0.689) and total revenues (0.754), indicating that operators who invest more are those who process and generate more revenue.
4. The degree of compliance with the quality of treated wastewater: the compliance variable (CD-r-7) shows very weak correlations with all other variables, with values close to zero. This indicates that compliance with treated water quality standards is not directly influenced by operator size, volume of water treated, revenues or investments made.
5. Statistical significance: p-values below 0.05 (indicating a statistically significant correlation) are found between the number of connected inhabitants and the volume of treated wastewater, operating income, and investments, which confirms the strength and importance of these correlations in analyzing the performance of wastewater operators.

Thus, the correlation matrix provides us with a solid basis to understand the relationships between the operating capacity of regional operators, financial performance and investments in wastewater infrastructure, highlighting the need for efficient management of resources and investments to improve the quality of wastewater services.

Table 3. Kaiser -Meyer- Olkin (KMO) and Bartlett's Test

Kaiser -Meyer -Olkin Measure of Sampling Adequacy		0.792
Bartlett's Test of Sphericity	Approx. Chi-Square	215,496
	d.f	15
	Sig.	<0.001

Source: own processing based on the Romanian Water Association 's database, Processing own basis variables from the Association 's database Romanian Water, *https://h2obenchmark.org*

The data sample is appropriate for factor analysis and will yield pertinent results, according to the Kaiser-Meyer-Olkin (KMO) and Bartlett tests shown in Table 3. A p-value below 0.001 and a significance (Sig.) of <0.001 suggest a high degree of confidence in rejecting the null hypothesis. This finding implies that the variables have enough correlations with one another to support the use of factor analysis.

In conclusion, the data set is appropriate for factor analysis, with variables sufficiently correlated to extract common factors, as confirmed by the KMO results and Bartlett's test. This suggests that the analysis can move further with assurance that the examined data contains latent structures.

Table 4 provided as part of a Principal Component Analysis (PCA) presents information about how the variance in the data is captured by different components extracted in the analysis.

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This table is essential for understanding how much of the information in the original data set is explained by each principal component.

Table 4. Total variance explained

	Initial Eigenvalues			Extraction Sums of Squared Loading		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.497	58.280	58.280	3.497	58.280	58.280
2	1.025	17.076	75.356	1.025	17.076	75.356
3	0.996	16.592	91.948			
4	0.361	6.020	97.969			
5	0.084	1.406	99.374			
6	0.038	0.626	100,000			

Source: own processing based on the Romanian Water Association 's database, https://h2obenchmark.org ,
Extraction Method: Principal Component Analysis.

Interpretation:

1. First Component:
   - The first component accounts for 3.497 units of variation in the data set, according to the initial value (eigenvalue) of 3.497.
   - The percentage of variance described by the first component is 58.280%, which is a significant share of the data set's overall variance. This implies that the majority of the pertinent data in the dataset is captured by this component. Since it is the initial component, the cumulative percentage is 58.280%, which is the same value.
2. Second Component:
   - Initial value (eigenvalue): 1.025, explaining an additional unit of variance.
   - Percentage of explained variance: 17.076% - this percentage added to that of the first component brings the cumulative percentage to 75.356%. Together with the first component, these two explain most of the variance in the data.
3. Third Component:
   - Initial value (eigenvalue): 0.996, contributing to explaining the variance.
   - Percentage of explained variance: 16.592% - when added, the cumulative percentage increases to 91.948%. This suggests that the first three components cover most of the information in the data set.
4. Subsequent Components (4, 5, and 6):
   - These components have much lower eigenvalues and explain a much lower percentage of variance (6.020%, 1.406%, and 0.626%, respectively). They contribute to a small extent to the total explained variance, finally reaching 100% cumulatively with all components.

Nearly 75.35% of the data set's variance can be explained by the first two principal components, making them the most significant. This implies that these two elements alone can effectively represent the majority of information. Therefore, concentrating on these elements may be enough in further analysis to comprehend the primary structure and dynamics of the data. In order to simplify the model without losing important information, components with lower eigenvalues might be excluded because they only provide minor contributions (Mirea and Aivaz, 2016b).

Table 5 shows the coefficients for the component scores, which indicate how each variable contributes to each extracted principal component.

Table 5. Component Score (Component Score) Matrix of coefficients (Coefficient matrix)

	Component	
	1	2
wE-004 - Residents connected to sewerage services (cumulative for all localities (loc. no .)	0.277	0.102
wA-RO-025 - The volume of wastewater discharged into the outfall without treatment (m³/year)	-0.020	0.785
wA-RO-027a - Volume of wastewater entering wastewater treatment plants (m³/year)	0.272	0.040
wG-RO-002 - Total revenues from exploitation, regarding the waste water activity (RON /year)	0.279	-0.011
wG-RO-030 - Total investments in the waste water system (RON /year)	0.240	-0.079
CD-r-7 – Degree of compliance with the quality of treated wastewater	-0.002	0.584

Source: own processing based on the Romanian Water Association 's database, https://h2obenchmark.org

Interpretation of the coefficients for each component:

1. **Component 1:**

- wE-004 (Residents connected to sewerage services): The coefficient of 0.277 indicates a moderate positive contribution to this component, reflecting the size or operational capacity of wastewater operators.
- wA-RO-027a (Volume of wastewater entering treatment plants) and wG-RO-002 (Total operating income): These variables have similar coefficients (0.272 and 0.279), suggesting moderate positive contributions to the same component, which represents financial and operational capacity.
- wG-RO-030 (Total investments in the wastewater system): It has a coefficient of 0.240, also indicating a moderate positive contribution, related to investments in the wastewater infrastructure.
- wA-RO-025 (Volume of wastewater discharged into the outfall without treatment): Coefficient almost zero (-0.020), indicating a negligible contribution to this component.

2. **Component 2:**

- wA-RO-025 (Volume of wastewater discharged into the outfall without treatment): The coefficient of 0.785 indicates a very strong contribution to this component, suggesting that it may represent problems related to ineffective wastewater management.
- CD-r-7 (Degree of compliance with treated wastewater quality): A coefficient of 0.584 suggests a significant contribution, showing that this component is strongly associated with compliance with quality standards.
- The other variables: They have small coefficients on this component, indicating reduced or negative contributions (for example, wG-RO-030 with -0.079).

Following the results presented above, we can state the following:

- Component 1 appears to be associated with capacity and resource issues of wastewater operators, focusing on operational and financial dimensions.
- Component 2 reflects more performance and compliance aspects, with a focus on quality management and efficiency of the wastewater treatment process.

These coefficients can be used to calculate component scores for each observation in the data set, providing a way to reduce the dimensionality of the data while preserving essential information about its variation. This reduction facilitates further analysis such as clustering or classification, making the data easier to interpret and use in various analytical applications (Matei and Aivaz, 2023).

Figure 1 presents a *scatter plot that displays* the scores on two components (factors) for different cities in a regression analysis (REGR factor score). The scores for each city on two different axes represent how these cities rank in relation to two factors assessed in the main analysis. Interpretation of the Chart:

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1. X axis (REGR 1 factor score for analysis 1):

- This axis represents the cities' scores on the first component (factor). A higher value on this axis indicates a higher score on the first factor, which may reflect a particular characteristic or metric assessed by the study (e.g. economic performance, infrastructure capacity, etc.).

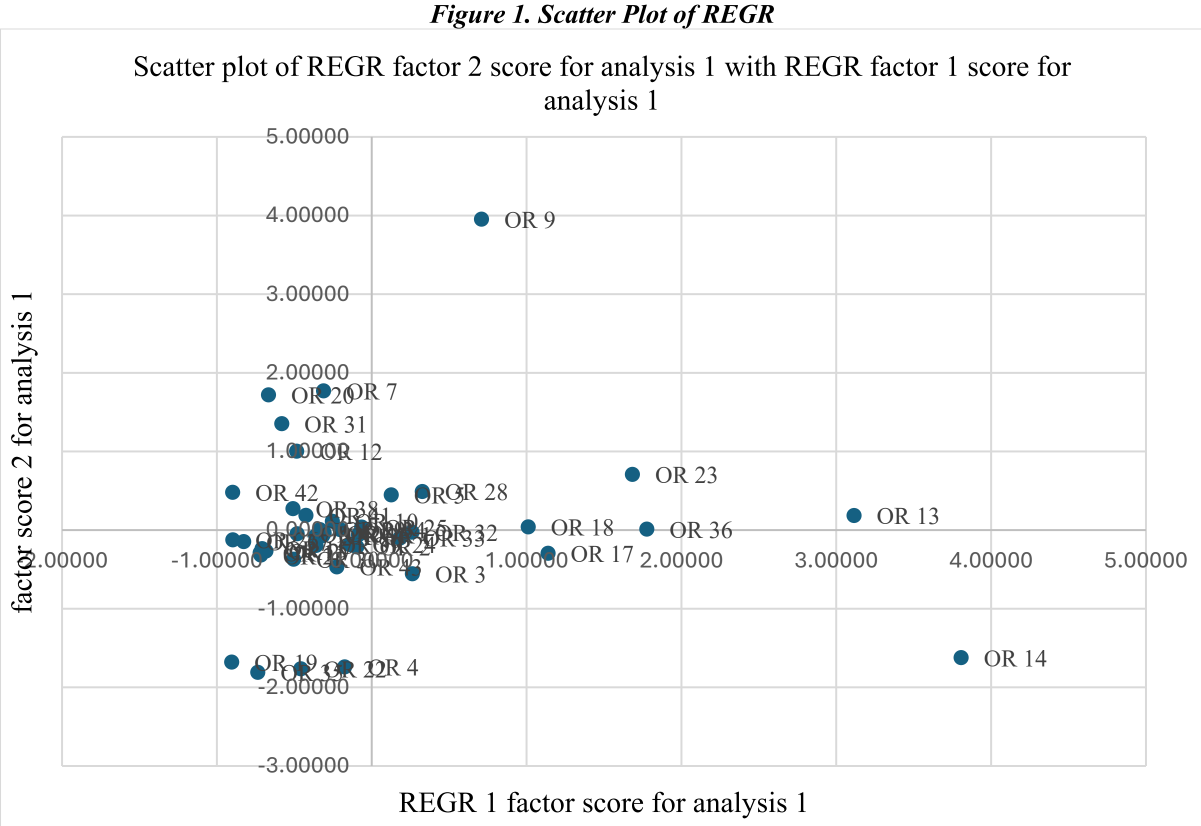
2. Y axis (REGR 2 factor score for analysis 1) :

- This axis represents the scores on the second component. Similar to the X-axis, higher values indicate higher scores, reflecting another characteristic or metric being assessed (e.g., quality of life, education level, health, etc.).

Specific Observations:

- OR 9 stands out with a high score on both components, indicating superior performance in both evaluated metrics.
- OR 14 also scores high on the first component but average on the second, suggesting good performance in the first assessed feature but less outstanding in the second.
- OR 13 and OR 23 display moderate scores on both components, placing themselves in a balanced position.
- OR 20 and OR 7 lie at the bottom of the Y-axis, indicating lower scores on the second component but varied scores on the first.

Figure 1. Scatter Plot of REGR



Source: own processing based on the Romanian Water Association 's database, *https://h2obenchmark.org* ,
Extraction Method: Principal Component Analysis.

The figure can be useful to identify and compare the relative performance of different cities according to the factors assessed in the study. The distribution of scores on the two axes can provide valuable information about areas of strength and improvement for each individual city. This analysis can help make political, investment decisions or strategic planning at the level of local or regional authorities.

The results of the study on the performance of Romanian wastewater operators, analyzed through the PCA (Principal Component Analysis) method, provide a clear picture of how operational capacity, financial strength and compliance with environmental regulations influence the efficiency of these operators.

The first component of the PCA directly highlighted the operational and financial capacity of wastewater operators. It explains a significant proportion of the total variation in the data, indicating that operator performance is closely related to a few key factors. First of all, the number of inhabitants connected to wastewater services is an important indicator of the size and operational capacity of an operator. The greater the number of inhabitants connected to the wastewater system, the greater the operator's capacity to manage a large volume of wastewater, which can lead to increased efficiency. Also, these operators manage to generate higher incomes from the wastewater treatment activity, this being another key factor of the economic performance.

Revenues from the exploitation of wastewater services are directly related to the financial capacity of the operators. The financial resources resulting from these revenues are essential to support the necessary infrastructure investments. Thus, operators with higher revenues have the ability to make significant investments in the modernization and expansion of wastewater treatment systems, thereby improving the efficiency of treatment processes and ensuring compliance with environmental standards.

Another important aspect related to this component is the volume of wastewater entering the treatment plants. Operators handling a large volume of wastewater demonstrate a strong infrastructure and high capacity to process these volumes, which contributes to their overall performance. Investments in infrastructure play a decisive role in this, as operators who allocate significant resources to the modernization and expansion of wastewater systems are able to manage wastewater flows efficiently.

The second component resulting from the PCA highlights dimensions related to compliance with environmental regulations and the efficiency of wastewater treatment processes. Specifically, this component is associated with the volume of wastewater discharged without treatment and the degree of compliance of treated waters with quality standards.

A key aspect revealed by the analysis is the close connection between the volume of wastewater discharged without treatment and the performance of operators. Operators who discharge large quantities of untreated wastewater clearly face efficiency issues in wastewater management. This can have serious economic consequences, as non-compliance with environmental regulations can attract sanctions, but also damage the reputation of operators in front of users.

Also, compliance with treated water quality standards is another important performance indicator. Operators that comply to a greater extent with these standards demonstrate a better ability to manage treatment processes and ensure adequate quality of wastewater discharged into the environment. This high level of compliance not only ensures that sanctions are avoided, but also contributes to protecting the environment and improving user confidence in the services offered.

The PCA analysis revealed two distinct dimensions of the performance of wastewater operators in Romania. The first dimension, related to operational capacity and financial strength, highlights the importance of a large number of inhabitants connected to the wastewater system, stable incomes and constant investment in infrastructure to achieve economic efficiency. The second dimension focuses on the efficiency of wastewater treatment and compliance with environmental standards, emphasizing the need for rigorous management of treatment processes.

Therefore, in order to improve the performance of the wastewater treatment sector in Romania, it is essential that operators focus their resources both on expanding operational capacity and ensuring a stable financial flow, and on optimizing water treatment processes, in order to comply with strict environmental regulations. These actions will contribute not only to operational efficiency, but also to the long-term sustainability of the sector.

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Conclusions

Based on a thorough data analysis and the identification of critical elements influencing their efficiency, the study recommends a number of strategic initiatives to enhance the performance of Romanian wastewater operators. The study's findings suggest that maintaining the sustainable performance of operators in this industry depends on both operational capability and adherence to environmental regulations.

A first element is the focus on continuing and intensifying investments in wastewater treatment infrastructure. It was clearly observed that operators investing in the modernization of wastewater treatment plants and the expansion of sewerage networks have a greater capacity to treat large volumes of wastewater and, implicitly, to meet the requirements imposed by environmental regulations. In this sense, a long-term strategy should focus on attracting European funds and initiating public-private partnerships that facilitate access to the resources needed to modernize the infrastructure. A modernized infrastructure will allow more efficient management of resources, reduction of losses and stricter compliance with environmental standards.

An important strategic direction is the adoption of green technologies and the integration of circular economy principles in wastewater management. According to the findings of the study, operators that incorporate innovative technological solutions capable of reducing emissions and improving the quality of treated water have better long-term performance. In this context, the recommendation is that the operators explore new wastewater treatment and recycling technologies, which will reduce the impact on the environment and ensure a more efficient use of resources. Adopting a circular economy approach, where treated wastewater can be reused in various industrial or agricultural processes, represents an opportunity to reduce costs and create a sustainable model of water resource management.

Compliance with treated water quality standards is another important pillar of performance. The study proved that operators with rigorous monitoring of treatment processes and strict control of wastewater quality achieve better results in terms of compliance with environmental regulations. The development of advanced monitoring and reporting systems is recommended, thus allowing real-time assessment of wastewater quality and rapid identification of problems. The implementation of such systems would reduce the risks of non-compliance and ensure greater transparency in the process of reporting to the authorities and the general public.

Another key element that emerges from the PCA analysis is the direct link between operators' revenues and their ability to invest in infrastructure and technology. To ensure a solid economic performance, wastewater operators must develop strategies that allow them to increase the revenue generated from treatment activities. This may include improving tariffs according to the volumes of water treated, diversifying sources of income by capitalizing on by-products resulting from treatment processes or offering additional services to customers.

The study carried out by applying the PCA method showed the complex dimensions of the performance of wastewater operators in Romania, providing a clear understanding of the factors that influence their efficiency and sustainability. The proposed recommendations not only address the identified issues, but also provide practical solutions that can be implemented to enhance operators' financial performance and environmental impact. Through a combination of smart investments, adopting innovative technologies and strengthening management, Romania's wastewater treatment sector can become efficient, sustainable and better prepared for the challenges of the future.

Although the current study provides a detailed and valuable analysis of the performance of wastewater operators in Romania using the Principal Component Analysis (PCA) method, there are certain limitations that must be acknowledged for a full interpretation of the results.

1. The study was based on data from 43 regional wastewater operators in Romania. Although this number is relevant for the performance analysis at the national level, there is a risk that

the results are not representative for all wastewater operators in Romania, especially for those that are small in size or that operate in more special conditions.

2. The data used for this analysis is from the year 2022, which provides a short-term perspective on operator performance. Economic factors and the legislative context may change over time, and the performance of operators may vary significantly from year to year. Longitudinal research for tracking the evolution of these indicators over time would provide a clearer picture of long-term trends.
3. Although PCA is an excellent method for reducing the size of data and extracting the most important factors from a large set of variables, there are also factors that cannot be measured directly that can influence operator performance. These factors may include issues related to local policies, community behaviors and attitudes towards wastewater consumption and treatment, or climate variables. These were partially unexplored in this research, thus limiting the depth of the conclusions.
4. The study failed to fully include the impact of global or regional economic factors, such as major economic fluctuations or external events (e.g. pandemics, economic crises), which may significantly affect the financial and operational performance of operators. A more detailed analysis should also consider these exogenous factors to provide a complete framework.

To improve the understanding of the performance of wastewater operators and contribute to the development of more effective management strategies, future research could address several directions:

1. A logical continuation of this study would be to carry out a multi-year analysis, which would follow the evolution of performance indicators over a longer period of time. This type of analysis could highlight significant changes in operator performance and the long-term impact of various investments and policies implemented.
2. Future research could include a more diverse set of variables, reflecting not only operational and financial performance, but also variables related to sustainability, technological innovation, or user satisfaction.
3. Given the effects of climate change and increasing pressures on water resources, it would be beneficial for future research to integrate factors related to climate conditions and ecological vulnerabilities into the analysis. Such a strategy might demonstrate how wastewater management is impacted by climate change and what steps can be made to guarantee the system's long-term viability.
4. Expanding the study to include a comparison with wastewater operators from other European countries would provide valuable insight into Romania's place in this sector and on international best practices that could be adopted. This type of comparative analysis could highlight the strengths and weaknesses of Romanian operators in relation to those from other EU member states.
5. Another promising area of research would be to investigate more deeply the impact of public policies and national and European regulations on operator performance. An analysis that correlates legislative changes with the evolution of operators' performance could provide valuable information for the development of more effective and better targeted policies.

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