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INTEGRATING BEHAVIORAL ANALYSIS FOR SUSTAINABLE DRINKING WATER MANAGEMENT IN RURAL ROMANIA

Access to safe drinking water and the sustainable management of water resources are fundamental priorities for global sustainable development policies, as explicitly reflected in Goal 6 of the United Nations 2030 Agenda. In rural communities across Central and Eastern Europe, these objectives face numerous challenges arising from both natural factors and local infrastructural and behavioral limitations. This study provides a detailed investigation of behaviors, perceptions, and practices related to drinking water resources in the commune of Ceanu Mare, Romania, based on 741 questionnaires administered in nine representative villages (September–December 2024), supplemented by hydrogeological and geotechnical analyses of local water sources. The data were processed statistically and geospatially using modern tools and validated methodologies. Perceptions of water quality differ significantly between villages with access to public water supply infrastructure and those without, while the willingness to adopt alternative solutions (filters, network expansion) is high. The analysis of socio-demographic correlations highlights the heightened vulnerability of elderly and large households. This study offers an integrated and up-to-date perspective on the management of drinking water resources in rural settings, underscoring the need for proactive, evidence-based local policies that are essential for achieving sustainable development objectives in the region.

1. INTRODUCTION

In the current global context, access to safe drinking water remains a major concern, being directly correlated with public health, sustainable economic development, social equity, and the well-being of both rural and urban communities. According to the latest

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reports of the United Nations (UN), more than two billion people worldwide still face limited or unsafe access to potable water, a situation that generates severe effects on the health and quality of life of vulnerable populations, especially those in rural areas [1]. In this context, the Sustainable Development Goals (SDGs), adopted in 2015 by UN member states, provide an integrated and ambitious framework that explicitly places access to safe drinking water and the sustainable management of water resources at the center of global development, as reflected in Goal 6 – *Clean Water and Sanitation* [2, 3].

The issue of water resources is even more complex in rural areas, where infrastructure is limited and integrated water resource management frequently faces multiple challenges, ranging from the contamination of groundwater and surface water sources to the limited access of the local population to modern and efficient drinking water supply systems [4]. In numerous rural regions worldwide, including many areas of Central and Eastern Europe, such as Romania, local populations often depend on their own water sources, which are frequently vulnerable to environmental factors and anthropogenic contamination. This inevitably leads to increased public health risks and difficulties in achieving the targets set by SDG 6 [5].

In Romania, approximately 46% of the population resides in rural areas, according to the National Institute of Statistics (2023), and access to potable water supply services continues to be problematic in many regions, especially in isolated rural areas or communities with deficient infrastructure. Recent studies have emphasized that the critical situation regarding access to drinking water is not determined solely by the physical lack of resources, but also by the behaviors of rural populations toward these resources and their management at local and community levels [6]. Thus, an integrated and multidimensional approach – including the analysis of population behavior, perceptions, practices, and attitudes toward available water resources – becomes essential for the formulation of effective and sustainable public policies.

A representative case for such challenges is Ceanu Mare commune, located in Cluj County, Romania, which comprises several villages characterized by socio-economic and geological diversity, yet commonly facing difficulties related to access, management, and the local population's perceptions of potable water resources. Ceanu Mare commune provides a relevant framework for analysis, as it illustrates the specific rural variability of Central and Eastern Europe regarding infrastructure, community behaviors, and the diversity of ecological, sanitary, and economic challenges associated with water management [7].

Although there is extensive research on water resource management, recent scientific literature reveals a significant gap regarding detailed and comprehensive analysis of rural populations' behavior toward drinking water resources, especially in the context of the specific SDG targets. Existing studies tend to address the subject superficially or predominantly from a technical and hydrological perspective, neglecting the behavioral, perceptual, and community dimensions that are essential for ensuring long-term sustainability [2, 8]. This article aims to fill precisely this gap identified in the literature by

providing an integrated, methodologically complex, and in-depth approach that combines technical and hydrogeological analysis with detailed sociological research on the behavior, perceptions, and practices of the rural population in Ceanu Mare regarding drinking water resources.

Sustainable and integrated management of water resources in rural communities has become a major concern in recent scientific literature, as these communities are often exposed to complex and multiple vulnerabilities such as limited access to drinking water, the risk of source contamination, and the lack of efficient monitoring and distribution systems [9]. In this context, several recent studies published in prestigious international journals underline the importance of an integrated, interdisciplinary, and contextual approach in the analysis of water resources, explicitly incorporating social, economic, and behavioral factors [10–12].

The modern concept of sustainable water resource management is closely linked to the SDG paradigm, adopted by the United Nations in 2015 [21]. In particular, Goal 6 – *Clean Water and Sanitation* – emphasizes the need for universal and equitable access to safe and affordable drinking water for all by 2030. However, recent specialty literature highlights that, when confronted with the realities of rural communities in various regions of the world, these objectives frequently encounter complex obstacles arising from local socio-economic, infrastructural, and behavioral conditions [13, 14].

For example, recent research conducted in rural communities in Bangladesh and Nigeria clearly highlights that technical and hydrological infrastructure alone is not sufficient to ensure the sustainability and quality of drinking water. Behavioral and cultural factors play a decisive role in the success or failure of water management interventions, while the perceptions and attitudes of the local population often prove decisive in the adoption of sustainable and efficient practices [15, 16]. Studies reveal that risk perception related to water quality and the preventive behavior of the population are essential for the implementation of effective and durable public policies in rural areas [17, 18].

Moreover, recent research shows that, in many cases, local conditions are insufficiently understood or even ignored, leading to inadequate investments in water infrastructure and a limited understanding of the real vulnerabilities of rural communities in the face of contamination risks [19, 20]. Therefore, a holistic, interdisciplinary approach is required, one that explicitly and comprehensively includes the analysis of local soil characteristics, hydrogeology, and water quality, in correlation with the behavior of the rural population.

Recent approaches in the international academic literature also emphasize the need to integrate advanced research technologies and methodologies in the assessment of water resources. Modern technologies such as Geographic Information Systems (GIS), advanced statistical analyses (Pearson correlations, multiple logistic regressions, etc.), and detailed hydrogeological analysis have become fundamental tools for a complete and profound understanding of the local context and for developing policies tailored to the specific realities of each community [21, 22].

Furthermore, the concept of the circular economy and technologies associated with the Fourth Industrial Revolution (4IR) have recently been proposed in literature as innovative tools that can directly support the integrated management of water resources and significantly contribute to achieving the Sustainable Development Goals (SDGs) [23, 24]. The application of these innovative models in rural communities can contribute significantly to reducing unnecessary water consumption, optimizing resource management, and improving the quality of life for the population, in line with the global objectives of sustainable development.

Nevertheless, despite significant progress in recent academic research, the literature still reveals numerous gaps in the approach to rural populations' behavior regarding water resources. Very few studies explicitly focus on the detailed perceptions of the population, everyday behaviors, local socio-cultural factors, and the practical implications of these behaviors for public policy. This dimension is often mentioned only superficially or incompletely, which generates difficulties in the implementation and long-term sustainability of local policies [25, 26].

Thus, the present article aims to fill precisely this scientific gap by providing a rigorous and detailed analysis of the behavior of rural residents in Ceanu Mare commune, Romania, explicitly integrating socio-economic, geological, hydrogeological, and behavioral analysis to provide relevant data to policy makers, the academic community, and sustainable local practices. Essentially, this research seeks to contribute to the effective implementation of the SDGs, especially Goal 6, in specific rural communities, providing a replicable and adaptable model at the global level.

The general aim of this research is therefore to thoroughly evaluate and analyze the behavior and attitudes of rural inhabitants regarding the available drinking water, in direct relation to the integrated and sustainable management of these resources, in explicit accordance with the Sustainable Development Goals. Specifically, the study objectives are as follows: i) to evaluate and provide a detailed description of the available resources and local water infrastructure in Ceanu Mare commune, ii) to identify and analyze the behaviors, perceptions, and practices of the local population in relation to drinking water, iii) to analyze correlations between socio-demographic variables and the identified behaviors, iv) to assess the influence of the local geological and hydrogeological context on access to and perceptions of water among the population, and v) to formulate recommendations based on results, for improving local and national policies in the field of sustainable water resource management.

2. MATERIALS AND METHODS

Study area. The research was conducted in Ceanu Mare commune, located in the southeastern part of Cluj County, Romania. According to technical data provided by the Ceanu Mare Town Hall, the commune consists of 13 villages, with a partially developed

drinking water supply infrastructure and significant disparities between villages regarding access to the network. Out of the 13 villages, 9 were selected for detailed analysis due to their socio-economic and demographic relevance in the context of the study. The analyzed villages are: Ceanu Mare (the commune's administrative center), Boian, Hodăi-Boian, Iacobeni, Bolduț, Fânațe, Ștrucut, Dosu Napului, and Ciurgău.

Sociological study and behavioral analysis. The main method for collecting data on residents' behavior toward water resources was the administration of a structured questionnaire during the period September–December 2024. In total, 741 valid questionnaires were administered, distributed proportionally according to the population of each analyzed village: Ceanu Mare (260), Boian (144), Hodăi-Boian (111), Iacobeni (97), Bolduț (76), Fânațe (21), Ștrucut (14), Dosu Napului (14), and Ciurgău (4).

The questionnaires were designed to evaluate:

- the type of water source used (well, public water supply network, bottled sources),
- behaviors and perceptions regarding water quality,
- risk perception related to public health associated with the sources used,
- the willingness of the population to adopt alternative and sustainable solutions.

The questionnaires were administered by the first author and verified by all other authors, thus ensuring the validation and accuracy of the collected information.

Statistical analysis. The data obtained from the questionnaires were centralized, processed, and statistically analyzed using Microsoft Excel (Office 365). For descriptive calculations (minimum, maximum, mean values, frequencies) and chart generation, the standard formulas of Excel were used. Correlation analyses between variables, including Pearson's coefficients, were performed using Excel functions, validating the hypotheses regarding the relationships between relevant variables.

Ethical considerations. The research fully complied with ethical standards regarding confidentiality, anonymity, and the protection of respondents' personal data. Informed consent was obtained for each administered questionnaire, with clear explanations provided regarding the purpose and use of the collected data. Individual data were not disclosed to any third party and were used exclusively for scientific analysis purposes. All data used is genuine, collected directly by the author, without the use of artificial intelligence tools for their generation or interpretation.

3. RESULTS AND DISCUSSION

3.1. STRUCTURE OF WATER SOURCE USE IN HOUSEHOLDS IN CEANU MARE COMMUNE

Water source usage behavior at the household level in Ceanu Mare commune reveals significant differences between villages, reflecting both infrastructure access and local practices and perceptions.

The 741 questionnaires administered in the field represent an extensive data collection effort that covers all investigated villages and reflects a response rate of approximately 22.23% of the total commune population. The sample is gender-balanced: among respondents, 388 are female (52.37%), and 353 are male (47.63%). This balanced gender distribution enables careful analysis of behavioral differences by sex, as well as the exploration of correlations between demographic profile and water consumption. The age range of participants spans from 14 to 98 years, enabling comprehensive analysis across intergenerational dimensions. Regarding household composition, most respondents live in family units of 2–4 persons, although there are also single-person households and units with more than 5 persons, up to a maximum of 10. This diversity provides the premises for relevant correlations between household size and water use volume. A good spatial dispersion of the sample is also noted, enabling differentiated investigation of localities with and without public water supply, as well as those where households rely almost exclusively on wells or bottled water. Thus, the sample not only reflects the demographic dimension of the commune but also provides a solid basis for a cross-sectional analysis from both a social and functional perspective.

Questionnaire data analysis highlights a high dependence on private wells in villages not connected to the public water supply, whereas the public network is predominantly used for drinking and cooking in villages fully or partially connected. The use of bottled water for household consumption is marginal, indicating both economic barriers and a high degree of trust in local sources or a lack of alternatives.

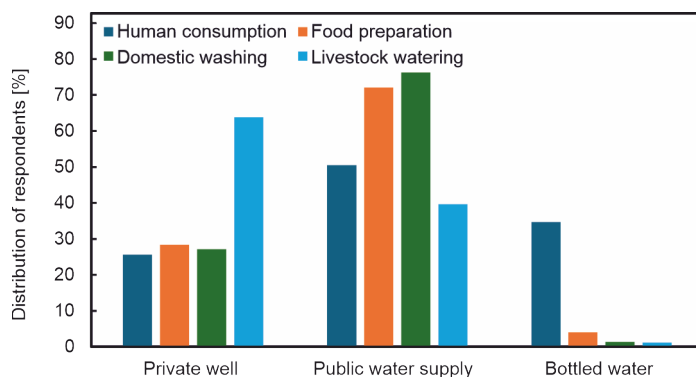


Fig. 1. Percentage distribution of respondents by water source and activity in households from Ceanu Mare commune

Data analysis (Fig. 1) further highlights notable differences in household water source usage in Ceanu Mare commune, depending on the type of activity. The public water supply network represents the main source for drinking (50.47%), as well as for cooking (72.06%) and washing (76.25%), indicating a clear preference for this source where available. Conversely, private wells are predominantly used for watering animals

(63.83%), reflecting both rural tradition and the accessibility of this source in the agricultural environment. The use of bottled water is especially relevant for personal consumption (drinking – 34.68%), but remains marginal for other household or agricultural activities. These results underscore the ongoing reliance on individual sources in the rural context and highlight the need for policies aimed at expanding and modernizing the public water supply network to ensure safe and sustainable consumption.

Table 1

Minimum, maximum, and average daily water volumes used from main sources by activity in households from Ceanu Mare commune [dm³/household]

Water source	Utilization purpose	Daily use		
		Minimum	Maximum	Mean
Private well	human consumption	1	20	3.94
	food preparation	1	70	8.44
	domestic washing	2	200	42.55
	livestock watering	0	3000	62.11
Public water supply	human consumption	0.5	20	2.71
	food preparation	1	80	8.98
	domestic washing	2	250	38.31
	livestock watering	1	500	35.13
Bottled water	human consumption	0.5	10	2.64
	food preparation	1	20	5.02
	domestic washing	1	25	5.9
	livestock watering ^a	1	10	3.33

^aIn rare cases, this category may also include water use for companion animals kept within the household.

The data summarized in Table 1 reveal considerable variability in household water consumption, depending both on the source used and the specific activity. For domestic consumption (drinking, cooking, washing), the average daily volumes of water drawn from private wells and the public supply network are similar, with a slightly higher mean for wells in the case of washing (42.55 dm³ compared to 38.31 dm³), but with significantly higher maximum values for this activity, indicating the presence of households with increased needs (Fig. 2). Concerning watering animals, the differences become even more pronounced: the daily average volume of water used from private wells is almost double that from the network (62.11 dm³ compared to 35.13 dm³), and the maximum values reach very high levels (up to 3000 dm³/household), reflecting both the size of individual farms and the degree of reliance on local resources. The use of bottled water remains limited, with low average values regardless of activity, confirming its marginal role in meeting daily needs. These data highlight both the diversity of consumption practices and the pressure on individual sources, with direct implications for resource sustainability and local management policies.

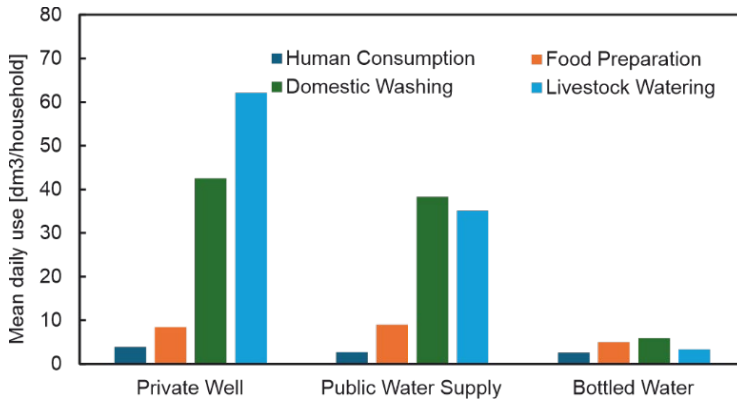


Fig. 2. The volume of water used depending on activity sources in households in Ceanu Mare commune

Figure 3 illustrates the specific structure of water source use at the rural household level, measured by the number of respondents who reported actual consumption (values > 0) for each source–activity combination. It can be observed that the public water supply network is used by the largest number of respondents for basic activities (drinking – 374, cooking – 534, washing – 565), confirming its essential role where it is accessible. For watering animals, private wells predominate (473 respondents), highlighting the agricultural sector’s dependence on traditional resources. The use of bottled water is widespread only for drinking (257 respondents) but remains marginal for other activities. This numerical distribution highlights the preferences and constraints present in water management at the rural household level and can guide future interventions to improve access to and the quality of water supply services.

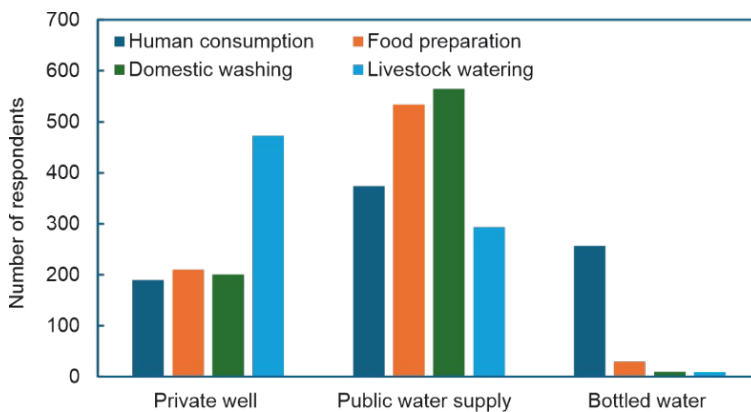


Fig. 3. Number of respondents reporting actual use ($\neq 0$) of each water source for various activities in households from Ceanu Mare commune

3.2. PERCEPTION OF WATER QUALITY AND ASSOCIATED RISKS

The interpretation of the questionnaires reveals significant differences between the perceptions of Ceanu Mare commune residents regarding the quality of water from private wells compared to that supplied by the public network. In most of the analyzed villages, the public water supply network enjoys a high level of trust, being rated as “good” or “very good” by 65–90% of respondents, depending on the village (Fig. 4).

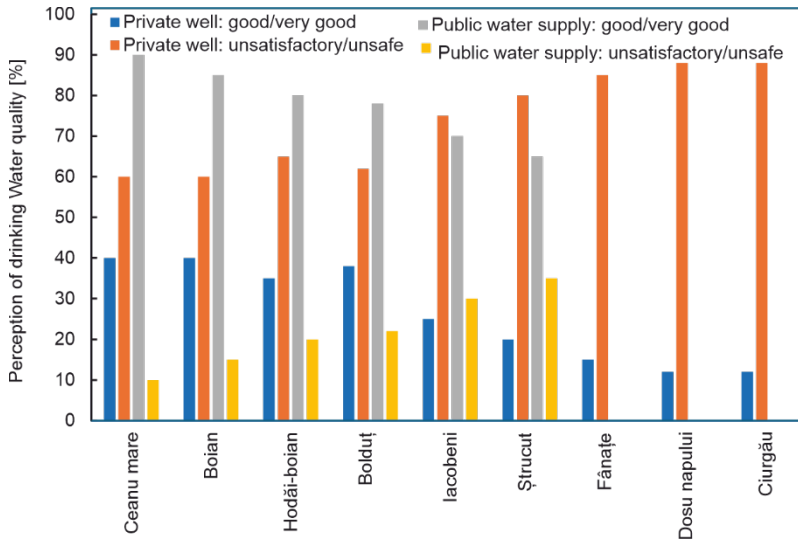


Fig. 4. Percentage distribution of perceptions regarding drinking water quality by source (private well and public water supply network) and village

At the same time, the negative perception of water from individual wells remains pronounced, with over 60% of residents considering it “unsatisfactory” or “unsafe,” especially in villages where a higher incidence of previously identified quality issues exists. In the villages of Fânafe, Dosu Napului, and Ciurgău, there is no public water supply available. These results highlight the need to maintain a sustained effort to modernize the public water infrastructure and to properly inform the population about the risks associated with consuming water from traditional sources, in the context of strengthening the sustainability and safety of drinking water resources in rural areas.

3.3. STATISTICAL CORRELATIONS BETWEEN RELEVANT VARIABLES

3.3.1. RELATIONSHIPS BETWEEN DEMOGRAPHIC/GEOGRAPHIC FACTORS AND WATER CONSUMPTION

To investigate the influence of certain demographic and geographic factors on the volume of water consumed in rural households, Pearson correlation coefficients were

calculated for the relevant variables. The statistical relationships, coefficient values, and corresponding significance levels are summarized in Table 2.

Table 2

Relevant relationships between variables. Inferential approach

Tested relationship	Pearson's coefficient r	Statistical significance p -value	Interpretation	No. of valid cases
Age × bottled water (drinking)	-0.166	0.0076	weak negative correlation: younger respondents prefer bottled	257
No. of persons × water for animals	0.101	0.0278	weak positive correlation: larger households → higher consumption	473
Well–animal distance × water for animals	0.127	0.0056	positive correlation: greater distance → higher volume	473

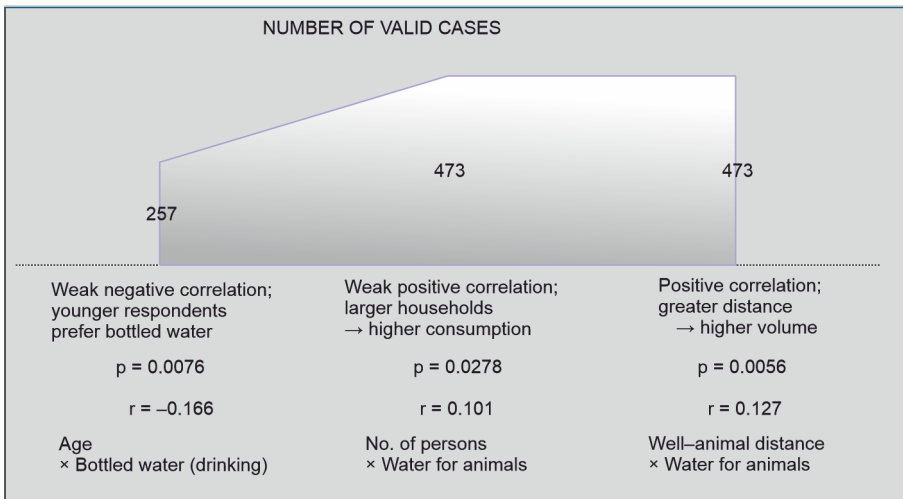


Fig. 5. Relevant relationships between variables – inferential approach

The data indicates (Fig. 5) that younger respondents prefer bottled water, larger households consume more water, also highlights the fact that there is an influence between the distance from the water source and the volume consumed. All identified relationships are statistically significant ($p < 0.05$), although the coefficients indicate a low intensity of the associations ($r < 0.2$). These results suggest that factors such as age, household size, or distance to the water source may have a measurable influence on consumption, even if infrastructure does not differ substantially between households.

3.3.2. PEARSON'S CORRELATIONS BETWEEN VARIABLES OF INTEREST

To further explore possible connections between demographic, geographic, and water consumption behavior variables at the household level in Ceanu Mare, Pearson correlation coefficients were analyzed (Fig. 6). This method enabled the statistical testing of links between age, household size, distance to the water source, and the volumes of water used for various domestic and agricultural purposes.

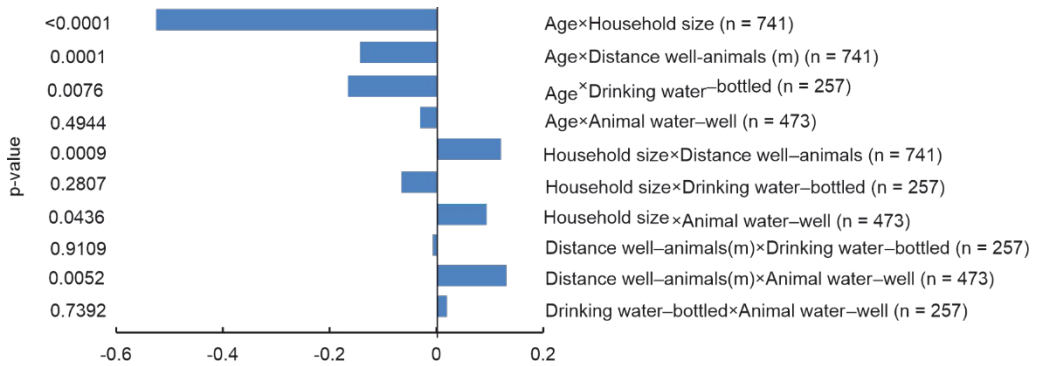


Fig. 6. Relevant Pearson correlation coefficients (r) between demographic, geographic, and consumption variables, with p -values and number of valid cases (n) indicated

Table 3 summarizes Pearson's coefficients, statistical significance values, and the number of valid observations for each tested relationship.

Table 3

Relevant Pearson's correlation coefficients, statistical significance, and number of valid cases between demographic, geographic, and consumption variables

Variable 1	Variable 2	Pearson's coefficient r	Statistical significance p -value	No. of valid cases
Age	household size	-0.525	< 0.0001	741
Age	distance well-animals, m	-0.143	0.0001	741
Age	drinking water bottled	-0.166	0.0076	257
Age	animal water – well	-0.031	0.4944	473
Household size	distance well-animals, m	0.121	0.0009	741
Household size	drinking water – bottled	-0.066	0.2807	257
Household size	animal water – well	0.094	0.0436	473
Distance well-animals, m	drinking water bottled	-0.007	0.9109	257
Distance well-animals, m	animal water – well	0.131	0.0052	473
Drinking water-bottled	animal water – well	0.020	0.7392	257

There is a strong negative correlation between age and household size ($r = -0.525$, $p < 0.0001$), indicating that elderly respondents often live in households with fewer

members. Additionally, age is weakly negatively correlated both with the distance to the well ($r = -0.143$) and the use of bottled water for drinking ($r = -0.166$), suggesting that younger individuals tend to live farther from the traditional source and prefer bottled water. Household size shows a positive correlation with water consumption for animals ($r = 0.094$) and with the distance to the well ($r = 0.121$), suggesting that larger families use more water for agricultural purposes and are located more on the periphery. The other correlations are not statistically significant ($p > 0.05$), indicating a lack of consistent associations between those variables in the analyzed rural context.

The current research results indicate a complex situation regarding the behavior and perceptions of the population in Ceanu Mare commune towards the available drinking water resources. These findings support the importance of an integrated approach to water resource management, with a focus on local perceptions and behaviors, as also highlighted in recent international studies. Notable differences in water quality perception between villages fully connected to the public network and those with limited or no access underscore the importance of expanding public infrastructure. This situation reflects the conclusions of similar studies conducted in rural areas of other regions, which emphasize that modern infrastructure significantly influences population perceptions regarding the safety and quality of water used.

The increased willingness of the population to adopt alternative solutions, such as installing individual filters and expanding the public network, represents an important opportunity for local authorities and decision-makers. These alternative solutions are promoted and supported internationally as effective measures for improving the quality of life in rural areas and for achieving sustainable development goals, especially SDG 6 – *Clean Water and Sanitation*.

The identified correlations between socio-demographic variables and behaviors regarding drinking water indicate the need for awareness and information campaigns tailored to specific groups, especially the elderly and larger households, as these are the groups at higher risk and would benefit most from the proposed sustainable solutions.

Therefore, the present study makes a significant contribution to literature through an integrated and comprehensive approach to water resource issues in rural areas, providing concrete data and valuable interpretations for the development of effective and sustainable public policies at the local and regional levels.

4. PUBLIC POLICY RECOMMENDATIONS FOR SUSTAINABLE DRINKING WATER MANAGEMENT IN RURAL AREAS

- *Expansion and modernization of the public water supply network.* The results indicate that households in villages without access to the public network remain dependent on wells, which are associated with significant health risks (nitrate/nitrite levels above permissible limits). The primary recommendation is to extend the public water

supply network to all villages in the commune, prioritizing the most vulnerable ones (e.g., Fânațe, Dosu Napului, Ciurgău).

- *Continuous and transparent monitoring of water quality.* It is recommended to establish a local program for the periodic monitoring of water quality (for both the network and wells), with transparent publication of results. This will increase the population's awareness and trust, and allow for rapid intervention in case of contamination.

- *Education and awareness programs adapted to vulnerable groups.* Given the correlations identified between age, household structure, and consumption behavior, it is necessary to implement targeted information campaigns for the elderly and large families in order to prevent risks associated with unsafe sources and to promote sustainable solutions (e.g., use of filters, regular water testing, and well sanitation).

- *Subsidies and financial support for filter acquisition and well rehabilitation.* Until the extension of the public network is completed, authorities may offer subsidies or financial facilities for the installation of certified water filters and for the rehabilitation of existing wells, reducing exposure to pollutants and supporting public health.

- *Integration of modern technologies in local water management.* The use of GIS systems for source mapping, data digitization, and the development of a water quality registry will enable local authorities to manage resources more efficiently and to quickly identify high-risk areas.

- *Creating partnerships between local authorities, the population, and academia.* Continuous involvement of universities, civil society, and regional water operators in monitoring, analysis, and interventions will strengthen the community's capacity to respond effectively to drinking water challenges.

- *Development of climate change adaptation strategies.* Given the potential variations in water resources caused by climate change, it is recommended to include local adaptation strategies (drought management, source protection, resource diversification) in local development plans.

- *Encouraging community participation in water management decisions.* Promoting the direct involvement of the population in decision-making (public consultations, local water committees) can increase policy acceptance and the sustainability of the implemented solution.

5. CONCLUSIONS

The research conducted in Ceanu Mare commune provided a broad and integrated perspective on local population behavior regarding drinking water resources, explicitly in the context of the Sustainable Development Goals. The study clearly identified significant differences in residents' perceptions and behaviors depending on access to the public water supply infrastructure, highlighting the strategic importance of its expansion and modernization.

The main findings of the research include the prevalence of private wells as the primary source of drinking water, which is associated with the perception of considerable public health risks. The community's high willingness to adopt sustainable solutions, such as expanding public networks and using water filters, offers concrete opportunities for local and regional authorities. Thus, the implementation of effective public policies, based on the data and conclusions of the present study, can substantially contribute to improving the quality of life in rural areas, in accordance with the global objectives of sustainable development

ACKNOWLEDGMENTS

The authors thank the Ceanu Mare Town Hall for providing certain technical data and for the support offered during the conduct of this research.

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