

Indicators for prioritizing rural communities eligible for the implementation of sewerage systems in Ceará's semi-arid region: an application of the Delphi method

Indicadores para a priorização de comunidades rurais aptas à implantação de esgotamento sanitário no semiárido cearense: uma aplicação da metodologia Delphi

George Émerson Pereira Farias¹ , Francisco Casimiro Filho² , Patrícia Verônica Pinheiro Sales Lima² 

¹Departamento de Construção Civil, Instituto Federal de Educação, Ciência e Tecnologia do Ceará (IFCE), Fortaleza (CE), Brasil. E-mail: geempefa@hotmail.com

²Universidade Federal do Ceará, Centro de Ciências Agrárias (UFC), Fortaleza (CE), Brasil. E-mails: casimiro@ufc.br; ppvpslima@gmail.com

How to cite: Farias, G., Filho, F., Lima, P. (2026). Indicators for prioritizing rural communities eligible for the implementation of sewerage systems in Ceará's semi-arid region: an application of the delphi method. *Revista de Economia e Sociologia Rural*, 64, e301639. <https://doi.org/10.1590/1806-9479.2026.301639>

Abstract: Basic sanitation is fundamental to promoting quality of life. However, a significant portion of the population living in rural communities faces difficulties in accessing this service. In these localities, socio-environmental characteristics hinder the implementation of conventional sewerage systems. This study employed the Delphi methodology to identify indicators capable of informing decision-making in selecting rural communities most suitable to receive sewerage systems. Experts who participated in the study evaluated 27 indicators, of which 20 were deemed relevant and 7 deemed irrelevant. The results establish a robust framework for prioritizing investments in sewerage, providing a technical basis for the development of territorially targeted monitoring systems. The study contributes to public policy formulation by offering a decision-support model that ensures the selection of communities with potential for sustainable sewerage services in the semi-arid region.

Keywords: basic sanitation, effluent, rural community, technology, sewage treatment.

Resumo: O saneamento básico é fundamental para promover qualidade de vida. Contudo, parcela significativa da população que vive em comunidades rurais enfrenta dificuldades de acesso a esse serviço. Nessas localidades, particularidades socioambientais dificultam a implementação de sistemas convencionais de tratamento de esgoto. Este estudo utilizou a metodologia Delphi para identificar indicadores capazes de subsidiar a tomada de decisão na seleção de comunidades rurais mais aptas a receberem sistemas de esgotamento sanitário. Especialistas que participaram da pesquisa avaliaram de 27 indicadores, dos quais 20 foram classificados como relevantes e 7 como irrelevantes. Os resultados estabelecem um framework robusto para a priorização de investimentos em esgotamento, fornecendo base técnica para a estruturação de sistemas de monitoramento territorializados. O estudo contribui para a formulação de políticas públicas, ao oferecer um modelo de suporte à decisão que assegura a escolha de comunidades com potencial de sustentabilidade para o esgotamento sanitário no semiárido.

Palavras-chave: saneamento básico, efluente, comunidade rural, tecnologia, tratamento de esgoto.

1 Introduction

Achieving Sustainable Development Goal 6 (SDG 6) by 2030 depends on advances in territories historically underserved, such as semiarid areas of Brazil (Instituto de Pesquisa Econômica Aplicada, 2024). In Ceará, it is estimated that a very high share of the rural population remains without adequate wastewater sanitation coverage, with direct impacts on public health and water resources (Ceará, 2021). Despite recent regulatory milestones, the challenge of selecting technologies suited to local socioenvironmental and operational conditions persists.



In semiarid regions such as the interior of Ceará, the socioeconomic context and environmental and territorial characteristics impose specific challenges for the selection and operation of wastewater sanitation systems. There is a need for a consensual and validated set of indicators integrating environmental, economic, social, and technical dimensions to guide the selection of technologies in rural communities of the semiarid. In practice, decisions are often made with fragmented evidence, heightening the risk of poorly fitting solutions with low operational sustainability (Sousa & Gomes, 2019).

Various studies have sought to indicate appropriate technologies for small communities. Researchers have employed sets of indicators organized into four dimensions, environmental, economic, social, and technical, as a basis for evaluating and selecting technologies (Huang et al., 2021; Lu et al., 2023; Wang et al., 2022). However, studies that simultaneously encompass all four dimensions remain scarce. Among key indicators, those in the environmental dimension commonly include sludge generation, sludge reuse, risk of pollution to water sources, precipitation, temperature, and topography. In the economic dimension, ability and willingness to pay for capital costs, capacity to pay for improvements, operation and maintenance costs, and regional GDP stand out. In the social dimension, identified indicators include community area, population size, acceptability, community participation, frequency of sanitation-related diseases, and attraction of insects. In the technical dimension, examples include disinfection process, BOD5 removal efficiency, system complexity, prior access to water supply systems, technological compatibility, and nutrient removal (Freitas, 2020; Gontijo et al., 2024; Huang et al., 2021; Lu et al., 2023; Seleman & Bhat, 2016; Wang et al., 2022; Wu et al., 2020).

To address this gap, we adopted the Delphi method, recognized for structuring the convergence of expert opinion in domains that are emergent and context-dependent (Hasson et al., 2025). The originality of this study lies in applying the Delphi method to identify the indicators most closely aligned with priority suitability. This approach avoids waste of public resources by preventing the deployment of sewerage systems in locations lacking operational or social sustainability, ensuring that investment is directed to communities where policy outcomes will be enhanced. Moreover, by defining these criteria at the selection stage, we establish a technical baseline that will guide future monitoring, avoiding the collection of irrelevant and ineffective data after project completion.

We aim to identify and prioritize indicators that reflect the potential of rural communities in Ceará's semi-arid region to inform decision-making in selecting locations most suitable to receive sewerage systems. The proposal seeks to provide criteria that maximize operational sustainability and the outcomes of implementing these policies.

2 Theoretical Foundation

Brazil has a significant portion of the population living in poverty and social vulnerability, a condition that manifests more acutely in rural areas and in the Northeast region of the country. The precariousness of basic sanitation services is among the main factors contributing to the poverty indices of these populations (Marcelino & Cunha, 2024). However, promoting access to adequate sanitation systems for this population requires recognizing and understanding their territorial, social, and economic particularities.

Prioritizing areas for the deployment of sewerage systems in rural zones requires recognizing communities that exhibit greater socio-environmental and operational suitability. The heterogeneity of these areas renders standardized models unviable, making the selection of priority localities a complex process that demands rigorous multicriteria analysis. In Ceará, for example, the diversity of the rural territory justifies an assessment based on four interdependent dimensions: environmental, economic, social, and technical (Huang et al., 2021; Lu et al., 2023; Wang et al., 2022; Wu et al., 2020).

The environmental dimension encompasses crucial indicators such as climate, availability of water resources, pollution levels, and geomorphological characteristics. Climatic factors, such as high temperatures, directly influence the concentration of effluents due to evaporation. Water availability, in turn, determines the degree of wastewater dilution. The perception of negative environmental impacts, such as the pollution of water bodies, can act as a catalyst for community adherence to sanitation solutions. Additionally, topography and relief may impose restrictions on centralized systems, favoring the adoption of individual solutions (Huang et al., 2021; Wang et al., 2022; Wu et al., 2020).

In the economic dimension, the analysis focuses on the financial sustainability of the system. The viability of a project is intrinsically linked to the costs of implementation, operation, and maintenance (O&M), as well as the source of funds for initial investment. It is imperative to define a clear management model—be it community-based, through NGOs, or another entity—since the absence of adequate O&M results in rapid deterioration of infrastructure. The regional Gross Domestic Product (GDP) serves as an indicator of investment capacity and financial sustainability of the system, also reflecting the level of available supporting infrastructure, such as access to water and electricity (Freitas, 2020; Huang et al., 2021; Lisboa et al., 2020; Seleman & Bhat, 2016; Wang et al., 2022).

The social dimension assesses indicators associated with well-being and community acceptance of the technology. The prevalence of waterborne diseases constitutes a critical social indicator, and the perception of health benefits is a strong motivator for adherence to and funding of the system. The acceptability of the technology is a determining factor for the project's success; systems perceived as complex or that generate low-acceptance byproducts, such as sludge for agricultural use, may face resistance. Factors such as noise, odor, and attraction of vectors are also relevant aspects that influence perception and must be considered (Freitas, 2020; Huang et al., 2021; Lisboa et al., 2020; Lu et al., 2023; Seleman & Bhat, 2016; Wu et al., 2020).

Finally, the technical dimension focuses on treatment efficiency and the compatibility of the technology with local capacities. Efficiency parameters, such as the removal of Biochemical Oxygen Demand (BOD), coliforms, and nutrients, are fundamental. However, the effectiveness of a system can be neutralized by the lack of qualified labor for its operation. Technical sustainability also depends on the availability of local materials for construction and maintenance, avoiding reliance on rare or hard-to-access inputs. Access to the piped water network is another relevant technical indicator, as it directly impacts the volume and concentration of wastewater generated, conditioning the choice of treatment (Freitas, 2020; Lisboa et al., 2020; Lu et al., 2023; Seleman & Bhat, 2016; Wang et al., 2022).

It is essential to recognize the interdependence among the analyzed dimensions, as a single indicator may have cross-cutting implications. For this reason, the selection and weighting of the criteria must be submitted to validation by experts, ensuring that the evaluation model is robust and truly adapted to the particularities of the region under study (Freitas, 2020; Lisboa et al., 2020; Lu et al., 2023; Seleman & Bhat, 2016; Wang et al., 2022; Wu et al., 2020). Thus, the indicators cease to be mere metrics of technical performance and become decision-support tools, enabling the identification of where public investment will have the greatest likelihood of success and long-term sustainability.

3 Methodology

3.1 The Delphi method

The Delphi method is a research tool that seeks the convergence of expert opinion to identify the most relevant factors in complex topics or areas with an incipient knowledge base.

Developed in the 1950s for military purposes, the method has become widely used due to its flexibility and adaptability (Hasson et al., 2025).

Among the main characteristics are: the anonymity of the consulted experts, the iterative process that enables the progressive refinement of responses, controlled feedback provided individually or in groups, the ease of building convergence of opinions, broad applicability across different fields of knowledge, and the possibility of remote participation enabled by digital technologies. These elements make Delphi one of the most effective methodologies for achieving consensus on complex issues (Abreu & Mesias, 2020; Hasson et al., 2025).

Traditionally, application of the method begins with open-ended questions to experts in order to identify relevant topics that will form the basis for subsequent rounds. In one of its variations, however, the initial questionnaire can be developed from a prior literature review. After each round, participants receive feedback consolidating the results and are invited to re-evaluate their responses until consensus is reached. In general, convergence of opinions occurs in the second or third round (Abreu & Mesias, 2020; Hasson et al., 2025).

Given the complexity and scarcity of research focused on basic sanitation in rural areas, the Delphi method is particularly suitable for identifying the most relevant indicators for rural wastewater sanitation. This technique has already been applied in different research fields, including sanitation studies (Mattos Pereira et al., 2021; Diamond et al., 2014; Souza & Nunes, 2023). Its application enables the construction of consensus among experts while accounting for the socioeconomic, environmental, and cultural specificities of rural communities in the Ceará semiarid (Freitas, 2020; Lisbôa et al., 2020; Souza & Nunes, 2023).

3.2 Study development

The appropriate selection of experts is fundamental to the application of the Delphi method, as their preferences are directly reflected in the final results (Freitas, 2020; Souza & Nunes, 2023). For this research, we selected experts with advanced knowledge of rural sanitation in the state of Ceará (Abreu & Mesias, 2020; Scott et al., 2025), including technicians from the Integrated Rural Sanitation System (SISAR), the Rural Sanitation Management Office of the Ceará Water and Sewerage Company (Cagece), the National Health Foundation (Funasa), the Regulatory Agency of the State of Ceará (Arce), academic researchers from the Federal University of Ceará (UFC) and the Ceará Institute of Science and Technology (IFCE), as well as consultants and designers specializing in rural infrastructure.

In total, 82 experts were invited to participate after providing informed consent regarding the study's objectives. The questionnaire was administered electronically via the Google Forms platform (Pereira et al., 2022; Souza & Nunes, 2023). The first data-collection round occurred between 20 May 2025 and 7 June 2025, and the second round, which included feedback on the results from the previous stage, was conducted between 23 June 2025 and 21 July 2025, at which point it was possible to assess whether consensus had been reached.

Prior to defining the questionnaire, we conducted an in-depth literature review on basic sanitation and rural wastewater sanitation. This stage resulted in the selection of 27 indicators, grouped into four dimensions, environmental, economic, social, and technical, and presented in Table 1 (Lisbôa et al., 2020; Seleman & Bhat, 2016). These indicators comprised the first-round instrument, while the second-round questionnaire was built from the first, incorporating the mode of the responses obtained. These indicators were selected specifically for their ability to characterize the potential for success and the suitability of rural communities, functioning as screening criteria for planning public investments.

Table 1. Dimensions and indicators for receiving investment in rural wastewater sanitation.

Dimension	Criterion	Description	Bibliographic reference
Social	Odor	Odor generation during the treatment process	Freitas (2020)
	Community area	Depending on the number of dwellings, may indicate distances between houses	Lu et al. (2023), Huang et al. (2021)
	Number of inhabitants	Number of people living in the community.	Lu et al. (2023), Wang et al. (2022)
	Noise	Noise generation during the treatment process	Freitas (2020)
	Insect attraction	Possibility of insect attraction during the treatment process	Freitas (2020)
	Acceptability	Overall acceptance of the technology	Seleman and Bhat (2016), Lisbôa et al. (2020)
	Community participation	Resident participation in deciding the type of sanitation system	Wu et al. (2020)
	Incidence of diseases	Amount and frequency of diseases related to lack of sanitation	Wu et al. (2020)
Technical	Coliforms	Sewage disinfection process to inactivate microorganisms that threaten human health	Freitas (2020), Lisbôa et al. (2020)
	Nutrients	Efficiency of nutrient removal	Freitas (2020), Lisbôa et al. (2020)
	Biochemical Oxygen Demand (BOD)	Wastewater quality defined directly by the percentage of BOD removal	Freitas (2020), Lisbôa et al. (2020)
	Complexity/Local skills	Skill and training level required of the operator; operational ease/difficulty in routine and emergency situations; capacity of local workers to perform associated technical tasks	Freitas (2020); Seleman and Bhat (2016)
	Access to piped water supply	Whether the community has access to piped water	Lu et al. (2023), Wang et al. (2022)
	Compatibility	Compatibility with materials available for construction and operation of the technology	Seleman and Bhat (2016)
	Environmental	Dewatered sludge for disposal	Volume of dewatered sludge to be disposed
Risk of pollution of water sources		Risk of discharging effluents into the environment	Seleman and Bhat (2016)
Nutrient recovery		Potential for nutrient recovery from the proposed technology for agricultural use	Seleman and Bhat (2016)
Precipitation		Amount of rainfall in the region	Lu et al. (2023), Wang et al. (2022)
Temperature		Regional temperature	Lu et al. (2023), Wang et al. (2022)
Terrain/topography		Characteristics of the terrain and topography where the community is located	Wang et al. (2022), Huang et al. (2021)
Water resource pollution		Nearby water sources show signs of pollution	Wu et al. (2020)
Economic	Willingness to pay	Willingness to pay the total investment cost	Seleman and Bhat (2016)
	Ability to pay for improvements	Ability of households to pay for investment and operating costs	Seleman and Bhat (2016)
	Operation and maintenance	Costs related to operation and maintenance associated with treatment plant management	Freitas (2020), Lisbôa et al. (2020), (Gontijo et al., 2024)
	Investment	Capital costs required to construct the wastewater treatment plant	Freitas (2020), Huang et al. (2021), Lisbôa et al. (2020)
	Regional GDP	Economic situation of the region where the community is located	Wang et al. (2022)

Source: prepared by the authors.

The first-round questionnaire was structured with a title, an introduction, general information about the participants, and an evaluation of each indicator and dimension. Data collection was anonymous, and no identifying information such as name, phone number, or email address was requested. To evaluate the indicators, a five-point Likert scale was used, ranging from 1 (not important) to 5 (extremely important) (Abreu & Mesias, 2020; Sörelis et al., 2023).

In addition, at the end of each closed-ended question, an open field was provided for qualitative suggestions and comments (Abreu et al., 2022; Scott et al., 2025).

3.3 Consensus

The convergence of experts' responses is one of the main criteria for concluding the Delphi process. To assess consensus in each survey round, we used the percentage of agreement among participants, as this is one of the most commonly employed metrics in this method. Convergence of opinion was considered to have been reached when 75% or more of panelists rated the indicator in the 1.0–2.0 or 4.0–5.0 ranges, with the final score of the indicator assigned as the prevailing evaluation within each pair (Diamond et al., 2014; Scott et al., 2025; Söreljus et al., 2023).

4 Results and Discussion

4.1 Expert participation

The online questionnaire was sent to a total of 82 experts selected to take part in the study. In the first round, 38 responses were received, corresponding to a response rate of approximately 46.3% of the initial group. In the second round, although the form was resent to all participants from the previous round, the number of responses fell to 25, representing about 30.5% of those initially invited. This reduction in participation across rounds is common in Delphi studies, as engagement tends to decrease as the process advances (Abreu & Mesias, 2020).

The decline in participation can be explained by the technical profile of the experts as well as the demands of their professional routines, which make it difficult to maintain engagement over time. Despite this drop, the number of responses obtained was sufficient to ensure the reliability of the results, as it remained within the range considered adequate in the literature, which varies between 10 and 80 participants (Hasson et al., 2025). Moreover, there is no strict consensus on the minimum number of panelists or the required retention rate to validate the Delphi method; the key point is that validity and reliability criteria are adequately met (Diamond et al., 2014).

Thus, even with the reduction in the number of participants in the second round, the volume of responses was sufficient to ensure the representativeness and consistency of the results, contributing to the credibility of the consensus process carried out in this research.

4.2 Environmental, economic, social, and technical dimensions

The first section of the questionnaire asked experts to assess the importance of the four dimensions, environmental, economic, social, and technical. From the first round, consensus was observed among participants, which was consolidated and confirmed in the subsequent round. Table 2 presents the most frequently chosen ratings in each round, as well as the final consensus outcome.

The four analyzed dimensions encompass a diverse set of indicators used to select rural sewage collection and treatment systems (Huang et al., 2021; Lu et al., 2023; Wang et al., 2022), constituting a comprehensive proposal for assessing this type of infrastructure. In the first round, all dimensions received ratings predominantly between 4.0 and 5.0, demonstrating

their relevance to the study context. In the following round, the level of consensus increased, especially in the environmental, social, and technical dimensions, which achieved a final rating of 5.0 and were classified as extremely important. The economic dimension, in turn, reached a rating of 4.0, being considered very important.

Table 2. Most frequently chosen ratings by round and consensus.

Dimension	Rating	Count/Percentage of votes		Consensus
		Round 1	Round 2	
Environmental	5,0	26/68,4	22/88,0	5,0
	4,0	9/23,7	3/12,0	
	3,0	2/5,3	0/0	
Economic	5,0	14/36,8	6/24,0	4,0
	4,0	18/47,4	16/64,0	
	3,0	4/10,5	2/8,0	
Social	5,0	23/60,5	22/88,0	5,0
	4,0	11/28,9	1/4,0	
	3,0	3/7,9	2/8,0	
Technical	5,0	18/47,4	20/80,0	5,0
	4,0	14/36,8	4/16,0	
	3,0	5/13,2	1/4,0	

Source: prepared by the authors.

Although the economic dimension received a slightly lower evaluation than the others, it remains a relevant factor in the choice of wastewater treatment technologies (Lu et al., 2023). In fact, the implementation, maintenance, and operation of sanitation systems require substantial financial investments (Castro et al., 2021). However, the lower score attributed to this dimension may be related to the fact that, in many cases, resources come from public funds or government subsidies. Moreover, the social and environmental benefits resulting from the implementation of these systems are difficult to quantify monetarily, which may downplay the weight of the economic aspect relative to the environmental, social, and technical dimensions (Cunha & Borja, 2018).

Thus, the experts' assessment reinforces the understanding that, while the economic aspect is relevant, the environmental, social, and technical dimensions carry greater weight when prioritizing indicators for rural sanitation. This perception aligns with the literature, which highlights the importance of a multidimensional approach to decision-making in sanitation infrastructure contexts (Lu et al., 2023; Zhang et al., 2025).

4.3 Environmental dimension indicators

Five indicators were selected to compose the environmental dimension, whose relevance was assessed by the experts. The indicator labels, the distribution of ratings in each round, and the consensus achieved are presented in Table 3.

The indicators considered most relevant by the experts were "proximity of the rural community to protected areas" and "proximity of the community to water sources," both reaching consensus at a rating of 5.0. In addition, "precipitation in the region" reached consensus at 4.0. These results reinforce the pertinence of these indicators for the environmental dimension, consistent with findings by Lu et al. (2023), Wang et al. (2022) and Wu et al. (2020).

Table 3. Most frequently chosen ratings by round and consensus for the environmental indicators.

Environmental indicator	Rating	Count/Percentage of votes		Consensus
		Round 1	Round 2	
Proximity of the community to protected areas	5,0	19/50	21/84,0	5,0
	4,0	10/26,3	4/16,0	
	3,0	7/18,4	0/0	
Proximity of the community to water sources	5,0	29/76,3	23/92,0	5,0
	4,0	6/15,8	2/8,0	
	3,0	2/5,3	0/0	
Nutrient recovery/utilization	5,0	8/21,1	2/8,0	3,0
	4,0	10/26,3	8/32,0	
	3,0	14/36,8	12/48	
Precipitation in the region	5,0	7/18,4	1/4,0	4,0
	4,0	14/36,8	20/80,0	
	3,0	10/26,3	3/12,0	
Average regional temperature	5,0	10/26,2	2/8,0	3,0
	4,0	9/23,7	5/20,0	
	3,0	10/26,3	15/60,0	

Source: prepared by the authors.

The importance of the first two indicators is justified by the fact that communities located near protected areas and water sources, when lacking wastewater sanitation infrastructure, tend to cause significant environmental impacts, especially on local water resources. These impacts may arise from the use of precarious solutions or the direct discharge of raw sewage into the environment (Rocha & Oliveira, 2023; Seleman & Bhat, 2016). Wu et al. (2020) emphasizes that pollution generated by rural communities is, to a large extent, unintentional. When residents perceive that a water source is polluted, they tend to show greater interest in implementing adequate sanitation systems.

“Precipitation in the region” was also considered a crucial indicator, as it directly influences the volume of water available for domestic use and, consequently, the characteristics of the wastewater produced. In many rural communities, rainwater often constitutes the main supply source or complements existing supplies, increasing water consumption and altering effluent composition (Lu et al., 2023; Wang et al., 2022). In water-scarce regions, wastewater tends to present higher pollutant concentrations, making treatment more difficult. Conversely, in areas with greater water availability, effluents are more diluted and therefore easier to treat (Lu et al., 2023; Wang et al., 2022).

By contrast, the indicators “nutrient recovery from treated wastewater” and “average regional temperature” reached consensus at 3.0 and were considered lower priority by the experts. Nutrient recovery, such as using sewage sludge as agricultural fertilizer, is a recognized strategy for mitigating environmental impacts and promoting sustainability (Makisha & Semenova, 2018). However, studies indicate that rural populations often resist its use due to complex handling, perceived lack of necessity in agricultural practice, or prejudice against consuming foods grown with this type of amendment (Kiselev et al., 2019; Seleman & Bhat, 2016). Thus, the experts’ stance aligns with the literature.

Regarding “temperature,” its impact on wastewater quantity and quality is acknowledged, albeit indirectly. Higher temperatures can increase water consumption, generating greater wastewater volumes, whereas high temperatures associated with water scarcity tend to produce more concentrated effluents that are harder to treat (Lu et al., 2023; Wang et al., 2022). In this sense, analyzing temperature in isolation limits its relevance as an environmental indicator, since it is linked to other factors such as precipitation and water availability.

4.4 Economic dimension indicators

Six indicators were selected to compose the economic dimension, whose importance was assessed by the experts. The label of each indicator, the distribution of ratings in each round, and the final consensus are presented in Table 4.

Table 4. Most frequently chosen ratings by round and consensus for the economic indicators.

Economic indicator	Rating	Count/Percentage of votes		Consensus
		Round 1	Round 2	
Willingness to pay for the investment	5,0	16/42,1	18/72,0	5,0
	4,0	5/13,2	4/16,0	
	3,0	11/28,9	0/0	
Ability to pay for improvements	5,0	12/31,6	18/72,0	5,0
	4,0	10/26,3	5/20,0	
	3,0	10/26,3	1/4	
Operation and maintenance costs	5,0	15/39,5	21/84,0	5,0
	4,0	14/36,8	3/12,0	
	3,0	8/21,1	1/4,0	
Capital investment in the sanitation system	5,0	16/42,1	20/80,0	5,0
	4,0	12/31,6	5/20,0	
	3,0	9/23,7	0/0	
Municipal GDP	5,0	5/13,2	2/8,0	4,0
	4,0	17/44,7	17/68,0	
	3,0	11/28,9	4/16,0	
Community access to social programs	5,0	17/44,7	22/88,0	5,0
	4,0	10/26,3	2/8,0	
	3,0	10/26,3	0/0	

Source: prepared by the authors.

All indicators proposed for the economic dimension received ratings of 4.0 or 5.0, being considered relevant for investment analysis in rural wastewater sanitation. These indicators cover aspects related to capital, operation, and maintenance costs, the region's economic conditions, and the community's ability to pay.

The first indicator, willingness to pay for the investment, seeks to assess whether the community is financially willing to bear the initial costs of the sanitation system. When willingness to pay exists, it is assumed that residents recognize the importance of sanitation and show interest in receiving the system (Seleman & Bhat, 2016). The second, ability to pay for improvements, evaluates whether the community has the means and interest to finance upgrades to existing systems, indicating awareness of the benefits of interventions and interest in additional investments (Seleman & Bhat, 2016).

The third indicator, operation and maintenance costs, refers to the amounts required to keep the sanitation system functioning properly, understood as the monthly bill users would need to pay. These costs are essential to ensure the sustainability of sewage collection and treatment systems (Freitas, 2020; Gontijo et al., 2024; Lisbôa et al., 2020). The fourth, capital investment in the sanitation system, relates to implementation expenses, including the monetary resources required to build the treatment plant. Smaller communities with lower financial capacity tend to opt for simpler and more economical systems (Huang et al., 2021).

The fifth indicator, municipal GDP, reflects the region's economic level, influencing the community's capacity to support more complex systems. Regions with higher GDP generally have better infrastructure, greater purchasing power, and more favorable conditions for implementing advanced technologies (Lu et al., 2023; Wang et al., 2022). Finally, community access to social programs measures the socioeconomic vulnerability of the rural population and is an important indicator for understanding the degree of social exclusion and the potential financial support for sanitation systems (Cunha & Borja, 2018; Sousa, 2021).

Taken together, these indicators provide a comprehensive view of the economic conditions that influence the implementation and sustainability of rural wastewater sanitation systems in semiarid areas. The experts' assessment reinforces the relevance of economic aspects, although their relative importance may vary according to regional context and the availability of public and private resources.

4.5 Social dimension indicators

Nine indicators were selected to compose the social dimension, whose importance was assessed by the experts. The label of each indicator, the distribution of ratings in each round, and the final consensus are presented in Table 5.

Table 5. Most frequently chosen ratings by round and consensus for the social indicators.

Social indicator	Rating	Count/Percentage of votes		Consensus
		Round 1	Round 2	
Average educational level of the community	5,0	9/23,7	0/0	3,0
	4,0	10/26,3	8/32,0	
	3,0	13/34,2	14/56,0	
Presence of public health and education facilities	5,0	9/23,7	7/28,0	4,0
	4,0	18/47,4	17/68,0	
	3,0	10/26,3	1/4,0	
Community engagement and participation	5,0	22/57,9	23/92,0	5,0
	4,0	11/28,9	2/8,0	
	3,0	3/7,9	0/0	
Employment and income for the community	5,0	13/34,2	4/16,0	4,0
	4,0	13/34,2	17/68,0	
	3,0	10/26,3	2/8,0	
Community acceptance of the proposed technology	5,0	19/50,0	21/84,0	5,0
	4,0	10/26,3	3/12,0	
	3,0	4/10,5	0/0	
Area size of the community	5,0	10/26,3	1/4,0	4,0
	4,0	14/36,8	20/80,0	
	3,0	12/31,6	4/16,0	
Number of inhabitants residing in the community	5,0	9/23,7	2/8,0	3,0
	4,0	12/31,6	6/24,0	
	3,0	16/42,1	16/64,0	
Number of dwellings belonging to the community	5,0	9/23,7	1/4,0	3,0
	4,0	9/23,7	6/24,0	
	3,0	18/47,4	17/68,0	
Diseases related to lack of sanitation	5,0	25/65,8	25/100,0	5,0
	4,0	9/23,7	0/0	
	3,0	4/10,5	0/0	

Source: prepared by the authors.

The results indicate that, among the nine indicators, six received ratings of 4.0 or 5.0 and were therefore considered priorities for the study. The remaining three received ratings of 3.0 and may be considered secondary in the analysis of rural sanitation. The indicator "average educational level of the community" may influence acceptance of the sanitation system, since communities with higher education levels tend to be more aware of the importance of sanitation, have better access to services, and greater financial capacity to cover costs (Seleman & Bhat, 2016; Wu et al., 2020). Nevertheless, panelists judged that this indicator does not directly affect the need to implement the system, assigning it a rating of 3.0.

The indicator "presence of public health and education facilities" reflects a community's level of development. Better-structured localities generally have consolidated infrastructure, including water supply, electricity, and road access, conditions essential for sanitation system implementation (Huang et al., 2021; Lu et al., 2023; Wang et al., 2022). Thus, the consensus at 4.0 reinforces this indicator's importance in assessing rural communities.

"Community engagement and participation" also showed high relevance, reaching consensus at 5.0. Studies indicate that communities engaged in decision-making and planning of the sanitation system tend to exhibit lower abandonment rates, greater autonomy in management, and better infrastructure maintenance (Castro et al., 2021; Wu et al., 2020). Therefore, social participation is considered a crucial factor for the success of interventions.

Other important aspect is "employment and income generated for the community," which should be considered when selecting the sanitation system. The possibility of using local labor favors sustainability and strengthens the community's economy, while also promoting greater project acceptance. The experts' assessment confirmed this indicator's relevance, as it reflects the economic and social conditions that influence the feasibility of the adopted solutions (Freitas, 2020; Seleman & Bhat, 2016).

"Community acceptance of the proposed technology" was also deemed essential, since systems rejected by the population tend to fall into disuse, be abandoned, or become scrapped, undermining project sustainability (Freitas, 2020; Seleman & Bhat, 2016). Thus, the 5.0 rating underscores the importance of considering local preferences when selecting sanitation technologies.

Another relevant indicator is the "area size of the community," which conveys the degree of dwelling dispersion. Communities with houses in close proximity on flat terrain tend to receive centralized systems, whereas dispersed residences hinder this choice and favor decentralized solutions (Huang et al., 2021). Experts assigned this indicator a rating of 4.0, reflecting its importance for regional analysis.

By contrast, the indicators "number of inhabitants residing in the community" and "number of dwellings belonging to the community" received ratings of 3.0 and were considered of lower relevance. These factors are important for estimating the amount of effluent produced and defining infrastructure parameters such as pipeline length and per capita costs (Huang et al., 2021; Lu et al., 2023; Wang et al., 2022). However, possible overlap with the indicator "area size of the community" may explain the lower scores attributed.

Finally, the indicator "diseases related to lack of sanitation" aimed to assess the incidence and frequency of illnesses stemming from the absence of adequate sanitation infrastructure. Typically, health problems associated with poor sanitation encourage adherence to wastewater sanitation systems (Wu et al., 2020). Thus, the reduction of diseases brought about by implementing sanitation systems contributes to improved quality of life, lower medical expenditures, and increased productivity (Castro et al., 2021). The experts considered this indicator relevant, reinforcing its importance in prioritizing interventions.

4.6 Technical dimension indicators

Seven indicators were selected to compose the technical dimension, whose importance was assessed by the experts. The label of each indicator, the distribution of ratings in each round, and the final consensus are presented in Table 6.

Table 6. Most frequently chosen ratings by round and consensus for the technical indicators.

Technical indicator	Rating	Count/Percentage of votes		Consensus
		Round 1	Round 2	
Treatment efficiency	5,0	17/44,7	24/96,0	5,0
	4,0	13/34,2	1/4,0	
	3,0	5/13,2	0/0	
Local labor	5,0	13/34,2	3/12,0	4,0
	4,0	15/39,5	17/68,0	
	3,0	9/23,7	4/16,0	
Access to a water supply system	5,0	19/50,0	21/84,0	5,0
	4,0	13/34,2	1/4,0	
	3,0	5/13,2	1/4,0	
Access to electricity	5,0	18/47,4	20/80,0	5,0
	4,0	14/36,8	2/8,0	
	3,0	4/10,5	1/4,0	
Relief and topography	5,0	14/36,8	20/80,0	5,0
	4,0	13/34,2	4/16,0	
	3,0	9/23,7	0/0	
Road access to the community	5,0	8/21,1	0/0	3,0
	4,0	9/23,7	6/24,0	
	3,0	14/36,8	16/64,0	
Technological compatibility	5,0	12/31,6	1/4,0	3,0
	4,0	9/23,7	3/12,0	
	3,0	13/34,2	17/68,0	

Source: prepared by the authors.

The results indicate that, among the seven indicators, five received ratings of 4.0 or 5.0 and were considered relevant for evaluating rural sanitation systems. The remaining two received ratings of 3.0 and were considered of lower relevance when prioritizing technical actions.

The first indicator, treatment efficiency, assesses experts' perception of the importance of pollutant removal capacity, especially Biochemical Oxygen Demand (BOD). Treatment technologies that remove greater amounts of contaminants produce effluents that are less harmful to the environment (Seleman & Bhat, 2016). Experts reached consensus at 5.0 in the first round, reinforcing the relevance of this aspect.

Another important indicator is local labor, which seeks to identify the availability of qualified personnel to operate the system. The absence of professionals with adequate education levels may render certain technologies unfeasible. The literature confirms that the difficulty of finding trained operators within the community undermines system sustainability (Seleman & Bhat, 2016). Thus, experts assigned this indicator a rating of 4.0, recognizing its relevance.

The third indicator, access to a water supply system, assesses the importance of the community already having piped water prior to installing the wastewater system. Technologies that demand greater water use depend on this infrastructure. Moreover, communities with piped water generally have better infrastructure and social organization, facilitating the implementation of more complex systems (Lu et al., 2023; Wang et al., 2022). This indicator received a rating of 5.0, reflecting its high relevance.

“Access to electricity” is another crucial factor, as centralized wastewater systems require electrical power to operate electromechanical equipment. Thus, the presence of electricity in the community indicates a higher level of infrastructure, which favors the adoption of more effective technologies (Lu et al., 2023). Experts assigned this indicator a rating of 5.0, underscoring its importance.

The indicator “relief and topography” identifies characteristics of the terrain where the community is located. Rugged terrain, presence of rivers and streams, shallow soils, or slopes influence the choice of sewage collection and treatment type. This is because soil morphology and relief affect wastewater generation, the spatial distribution of dwellings, and implementation costs (Huang et al., 2021; Wang et al., 2022; Zhang et al., 2025). Experts assigned this indicator a rating of 5.0, confirming its relevance.

By contrast, “road access to the community” was rated 3.0 by experts. Although access is important for the delivery of materials and equipment, its relevance to selecting the sanitation system was considered moderate, as it is not a determining factor in most rural contexts (Huang et al., 2021; Lu et al., 2023).

Finally, the indicator technological compatibility assesses whether the proposed technology is compatible with materials available in the region for construction, operation, and maintenance. Communities with difficulties accessing specific materials should prioritize simpler, easier to implement technologies. Although studies indicate the importance of this aspect, experts assigned it a rating of 3.0, considering it of lower relevance in the overall assessment (Lu et al., 2023; Wang et al., 2022; Wu et al., 2020).

4.7 Dimension and indicators for the Ceará semiarid

The indicators considered by the experts that showed the highest consensus in the assessment are consolidated in Table 7. This table brings together the dimensions and the main indicators classified as priorities for the Ceará semiarid region, based on participants' opinions.

Table 7. Most relevant indicators by dimension and expert-consensus for the Ceará semiarid.

Dimension	Indicator
Environmental	Proximity of the community to protected areas
	Proximity of the community to water sources
	Precipitation in the region
Economic	Willingness to pay for the investment
	Ability to pay for improvements
	Operation and maintenance costs
	Capital investment in the sanitation system
	Municipal GDP
Social	Community access to social programs
	Presence of public health and education facilities
	Community engagement and participation
	Employment and income for the community
	Community acceptance of the proposed technology
Technical	Area size of the community
	Diseases related to lack of sanitation
	Treatment efficiency
	Local labor
	Access to a water supply system
	Access to electricity
	Relief and topography

Source: prepared by the authors.

After the assessment, it was verified that all four dimensions, environmental, economic, social, and technical, were considered relevant by the experts for the context of rural sanitation in the semi-arid. No comments were recorded in the questionnaire's open field suggesting changes or the inclusion of new dimensions.

Of the 27 indicators initially submitted for evaluation, 7 were deemed irrelevant and therefore excluded. Among these, 2 belonged to the environmental dimension, none to the economic dimension, 3 to the social dimension, and 2 to the technical dimension. The remaining 20 indicators were considered relevant and retained for the final analysis. It is important to note that no participant suggested adding new indicators or made comments that would justify changes to the list.

With the removal of indicators considered irrelevant, the environmental dimension now comprises only 3 indicators, whereas the economic and social dimensions each comprise 7 indicators, and the technical dimension 5 indicators. It should be emphasized that the number of indicators in each dimension should not be interpreted as reflecting greater or lesser importance of one dimension relative to the others. All remain essential for a comprehensive assessment of rural sanitation in the semi-arid region.

5 Conclusions

This study showed that the Ceará semi-arid has a significant share of its population living in rural communities, characterized by environmental, economic, social, and technical specificities that require an appropriate assessment approach. The application of the Delphi methodology fulfilled its objective of identifying and prioritizing indicators for selecting rural communities suitable for the deployment of sewerage systems in Ceará's semi-arid region.

Although this study concentrates on the planning stage and the structuring of criteria within the PDCA cycle, it establishes the technical foundation necessary for the subsequent phases of execution, monitoring, and impact assessment to be conducted with rigor. The identification of these priority indicators fills a gap in public administration, offering a tool that replaces decisions based on fragmented evidence with a multidimensional and territorialized protocol. From an institutional perspective, these findings illuminate the need to reform the mechanisms for selecting investments, given that the persistence of arrangements that ignore technical and social variables validated in this study contributes to the historical inefficiency of rural sanitation policies.

The analysis revealed that, of the 27 indicators initially proposed, 20 were considered relevant and 7 were discarded, with no need to include new items. Notably, most relevant indicators belong to the environmental, social, and technical dimensions, reinforcing the importance of a multidimensional approach to assessing rural sanitation. The economic dimension, although also considered relevant, carried less weight in prioritization, reflecting the perception that environmental, social, and technical factors have a greater impact on the effectiveness and sustainability of interventions. This hierarchical prioritization suggests that current governance models should transition from a purely economic perspective to an arrangement that prioritizes operational sustainability and social acceptability, ensuring a more equitable distribution of services.

The identification of indicators for rural sewerage systems represents the starting point for optimizing resource allocation and for designing more effective public policies. Based on these indicators, it is possible to structure a prioritization index that categorizes communities according to their investment needs, supporting the decision-making process and the strategic allocation of resources, and avoiding the abandonment of systems due to a lack of local suitability.

Finally, the study underscores the relevance of an integrated and participatory approach that considers local particularities and expert perspectives to promote the universalization of basic sanitation in rural semiarid areas, contributing to the achievement of the Sustainable Development Goals and to improving the quality of life in these communities.

As limitations, the temporal horizon of the study and the geographic restriction to Ceará's territory are recognized, which impede automatic generalizations to other Brazilian biomes without the necessary adjustments. Furthermore, the proposed indicators lack application in a real case study to validate their field sensitivity. Therefore, there is room for future lines of inquiry that apply this system in pilot communities and explore its integration with digital management tools, thus completing the monitoring and evaluation (Check) cycle to verify the tool's effectiveness in improving public health indices and environmental preservation.

During the preparation of this work, the author(s) used AI Acadêmico 24h to improve the writing and translate the article into English. After using this tool/service, the author(s) reviewed and edited the content as needed and assume full responsibility for the content of the published article.

Authors' contributions:

GEPF: conceptualization, data collection, formal analysis, investigation, methodology, validation, visualization, writing. FCF: formal analysis, supervision, visualization. PVPSL: formal analysis, methodology, software, validation, visualization, writing.

Financial support:

Fundação Cearense de Apoio ao Desenvolvimento Científico e Tecnológico (FUNCAP).

Conflicts of interest:

Nothing to declare.

Ethics approval:

Not applicable.

Data availability:

The research data are available on request.

Acknowledgements

We acknowledge Fundação Cearense de Apoio ao Desenvolvimento Científico e Tecnológico (FUNCAP) for their support through a research fellowship.

***Corresponding author:**

George Émerson Pereira Farias. geempefa@hotmail.com

6 References

- Abreu, I., & Mesias, F. J. (2020). The assessment of rural development: Identification of an applicable set of indicators through a Delphi approach. *Journal of Rural Studies*, 80(June), 578-585. <https://doi.org/10.1016/j.jrurstud.2020.10.045>
- Abreu, I., Mesías, F. J., & Ramajo, J. (2022). Design and validation of an index to measure development in rural areas through stakeholder participation. *Journal of Rural Studies*, 95(August), 232-240. <https://doi.org/10.1016/j.jrurstud.2022.09.022>
- Castro, L. A., Taleires, F. C. S. S., & Silveira, S. S. (2021). Índice de desenvolvimento humano em municípios que possuem sistema integrado de saneamento rural: uma análise comparativa. *Ciência & Saúde Coletiva*, 26(1), 351-357. <https://doi.org/10.1590/1413-81232020261.24452018>
- Ceará. Assembléia Legislativa do Estado do Ceará. Conselho de Altos Estudos e Assuntos Estratégicos. (2021). *Cenário atual do saneamento básico no Ceará*. Fortaleza: Assembleia Legislativa do Estado do Ceará, INESP.
- Cunha, M. A., & Borja, P. C. (2018). Growth acceleration program in the state of Bahia and its contribution to face the basic sanitation universalization challenges. *Urbe*, 10, 173-185. <https://doi.org/10.1590/2175-3369.010.supl1.a009>
- Diamond, I. R., Grant, R. C., Feldman, B. M., Pencharz, P. B., Ling, S. C., Moore, A. M., & Wales, P. W. (2014). Defining consensus: a systematic review recommends methodologic criteria for reporting of Delphi studies. *Journal of Clinical Epidemiology*, 67(4), 401-409. <https://doi.org/10.1016/j.jclinepi.2013.12.002>
- Freitas, E. C. B. (2020). *Seleção de tecnologias de tratamento de esgoto utilizando análise multicritério*. Goiânia: Universidade Federal de Goiânia.
- Gontijo, H. M., Ribeiro, S. S., & Lima, S. C. R. B. (2024). Gestão da água e do esgotamento sanitário em Divinópolis/MG: o discurso vigente acerca da fragmentação urbano/rural. *Revista de Economia e Sociologia Rural*, 62(3), 1-22. <https://doi.org/10.1590/1806-9479.2023.265399pt>
- Hasson, F., Keeney, S., & McKenna, H. (2025). Revisiting the Delphi technique: research thinking and practice: A discussion paper. *International Journal of Nursing Studies*, 168(May), 105119. <https://doi.org/10.1016/j.ijnurstu.2025.105119>
- Huang, Y., Li, P., Li, H., Zhang, B., & He, Y. (2021). To centralize or to decentralize? A systematic framework for optimizing rural wastewater treatment planning. *Journal of Environmental Management*, 300(September), 113673. <https://doi.org/10.1016/j.jenvman.2021.113673>
- Instituto de Pesquisa Econômica Aplicada – IPEA. *Agenda 2030: objetivos de desenvolvimento sustentável: avaliação do progresso das principais metas globais para o Brasil: ODS 6: assegurar a disponibilidade e a gestão sustentável da água e do saneamento para todas e todos* (Cadernos ODS, No. 6, 19 p.). Brasília: IPEA, 2024. <https://doi.org/10.38116/ri2024ODS6>.
- Kiselev, A. V., Magaril, E. R., & Rada, E. C. (2019). Energy and Sustainability Assessment of Municipal Wastewater Treatment Under Circular Economy Paradigm. *WIT Transactions on Ecology and the Environment*, 237, 109-120. <https://doi.org/10.2495/ESUS190101>
- Lisbôa, E. G., Lisbô, É. G., Lobo, M. A. A., Tourinho, H. L. Z., Bello, L. A. L., & Borges, F. Q. (2020). Aplicação de um modelo Multicriterial para auxiliar a seleção de tecnologias de tratamento de águas residuais em zonas urbanas. *Brazilian Journal of Development*, 6(4), 20739-20768. <https://doi.org/10.34117/bjdv6n4-303>

- Lu, M. Y., Yang, S. S., Yu, X. L., Sun, H. J., Pang, J. W., Ren, N. Q., & Ding, J. (2023). Decision support framework adapted to local conditions to select technologies for rural domestic sewage treatment in the Yangtze River Economic Belt. *Journal of Cleaner Production*, 426(August), 139067. <https://doi.org/10.1016/j.jclepro.2023.139067>
- Makisha, N., & Semenova, D. (2018). Production of biogas at wastewater treatment plants and its further application. In *International Conference on Research in Mechanical Engineering Sciences* (pp. 04016). Les Ulis, France: MATEC Web of Conferences. <https://doi.org/10.1051/mateconf/201714404016>
- Marcelino, G. C., & Cunha, M. S. (2024). Pobreza multidimensional no Brasil: evidências para as áreas rurais e urbanas. *Revista de Economia e Sociologia Rural*, 62(1), 1-20. <https://doi.org/10.1590/1806-9479.2022.266430en>
- Mattos Pereira, R. G., Passos Rezende, A. A., Bastos Braga, G., Castro Galvão Júnior, A., & Teixeira, J. C. (2021). Proposta metodológica para avaliação da gestão municipal de saneamento básico. *Revista DAE*, 69(232), 146-162. <https://doi.org/10.36659/dae.2021.067>
- Pereira, A. C., Rezende, B. A., Alves, F. H. S., Marques, A. L. P., Silva, L. F., Feitoza, V. S., & Rocha, H. F. (2022). Uso da análise multicritério baseada no método híbrido AHP/TOPSIS para implantação de intervenções de programas hidroambientais: Estudo de caso na bacia hidrográfica do rio Doce. *Revista Mineira de Recursos Hídricos*, 3(1), e022009. <https://doi.org/10.59824/rmrh.v3i.228>
- Rocha, A. S., & Oliveira, L. D. (2023). Political ecology and basic sanitation: Analysis from the metropolitan periphery of the Rio de Janeiro. *Atelie Geografico*, 17(1), 112-133. <https://doi.org/10.5216/ag.v17i1.74784>
- Scott, M., Ghazanfar, M., Windsor, J., Ramsay, G., Bekheit, M., Ke, L., Smith, M., Giovinazzo, F., Mohamed, M., Pandanaboyana, S., Huang, W., Ahmed, I., & Siriwardena, A. K. (2025). The management of splanchnic vein thrombosis in acute pancreatitis: a global DELPHI consensus study. *HPB: The Official Journal of the International Hepato Pancreato Biliary Association*, 27(3), 343-351. <https://doi.org/10.1016/j.hpb.2024.12.002>
- Seleman, A., & Bhat, M. G. (2016). Multi-criteria assessment of sanitation technologies in rural Tanzania: Implications for program implementation, health and socio-economic improvements. *Technology in Society*, 46, 70-79. <https://doi.org/10.1016/j.techsoc.2016.04.003>
- Sörelíus, K., Verhoek, R., Berard, X., Lyons, O. T. A., Puges, M., & Wyss, T. R. (2023). Vascular graft and endograft infections: a delphi consensus document on terminology, definitions, treatment, outcomes, follow up, and reporting standards. *International Journal of Biological Macromolecules*, 71(3), 497-507. <https://doi.org/10.1016/j.ijvs.2025.07.044>
- Sousa, A. C. A. (2021). What to expect from the new sanitation framework? *Cadernos de Saúde Pública*, 36(12), <https://doi.org/10.1590/0102-311x00224020>
- Sousa, A. C. A., & Gomes, J. P. (2019). Desafios para o investimento público em saneamento no Brasil. *Saúde em Debate*, 43(spe7), 36-49. <https://doi.org/10.1590/0103-11042019s703>
- Souza, S. O., & Nunes, A. B. A. (2023). Indicadores de desempenho para avaliação de estações de tratamento de esgoto de uma bacia de esgotamento em Fortaleza, Ceará, Brasil. *Revista AIDIS de ingeniería y ciencias ambientales: Investigación, desarrollo y práctica*, 16(1), 257-284. <https://doi.org/10.22201/iingen.0718378xe.2023.16.1.82448>
- Wang, C., Feng, B., Wang, P., Guo, W., Li, X., Gao, H., Zhang, B., & Chen, J. (2022). Revealing factors influencing spatial variation in the quantity and quality of rural domestic sewage discharge across China. *Process Safety and Environmental Protection*, 162, 200-210. <https://doi.org/10.1016/j.psep.2022.03.071>

Wu, S., Fu, H., Li, H., Ding, C., & Wang, M. (2020). Residents' willingness to invest in sanitation: Evidence from rural china. *Desalination and Water Treatment*, 182, 405-413. <https://doi.org/10.5004/dwt.2020.25317>

Zhang, R., Wang, Z., Cao, Z., Rousseau, D. P. L., & Van Hulle, S. (2025). Addressing the rural wastewater treatment dilemma: A techno-environmental-economic analysis. *Chemical Engineering Journal*, 504, 158905. <https://doi.org/10.1016/j.cej.2024.158905>

Submitted on: October 10, 2025.

Accepted on: February 12, 2026.

JEL Classification: Y900.

Associate Editor: Erlaine Binotto