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Application of the Analytic Hierarchy Process for selection of alternative solutions for domestic wastewater treatment

Aplicação do Método de Análise Hierárquica para a seleção de soluções alternativas de tratamento de esgoto doméstico

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ABSTRACT

Choosing the best form of domestic sewage treatment requires analyses that allow decision-making on the ideal solutions for implementation, according to the particularities of each regionality, especially when it comes to rural and isolated areas dependent on decentralized solutions. Thus, through this study, the Analytic Hierarchy Process (AHP) was used from a data collection on simplified treatment systems existing in temperate municipalities without a dry season, to evaluate priority systems in different scenarios considering environmental, social, and technical-economic indicators. Among the results for the scenarios performed, the compact upflow anaerobic reactor, the septic tank and anaerobic filter, and the septic tank and built-in flooded system of vertical subsurface flow were the solutions that proved to be the most indicated following the indicators used and the existing information. It is noteworthy that the results refer to the study area in question, and new applications of the method are needed in different climatic regions. From the application of the methodology, the AHP tool indicated that it is a viable method to assist in decision-making regarding the selection of sewage treatment systems in rural areas, which, being tied to municipal planning in basic sanitation, assists in the optimization of existing resources. The sensitivity of the method showed the importance of its application with data collected on site, in addition to the incorporation of public and experts opinions in the contribution of the degree of importance of the criteria and indicators used.

Keywords: analytic hierarchy method; rural sanitation; wastewater treatment.

RESUMO

Escolher a melhor forma de tratamento de esgoto doméstico requer análises que permitem a tomada de decisão sobre as soluções ideais de implantação, conforme as particularidades de cada regionalidade, principalmente quando se trata de áreas rurais e isoladas dependentes de soluções descentralizadas. Assim, por meio deste estudo, o método de análise hierárquica — *Analytic Hierarchy Process* (AHP) — foi utilizado com base em um levantamento de dados sobre sistemas de tratamento simplificados existentes em municípios de clima temperado sem estação de seca, para avaliar os sistemas prioritários em diferentes cenários considerando-se indicadores ambientais, sociais e técnico-econômicos. Entre os resultados para os cenários realizados, o reator anaeróbio de fluxo ascendente compacto, o tanque séptico e filtro anaeróbio, bem como o tanque séptico e sistema alagado construído de fluxo subsuperficial vertical foram as soluções que se mostraram as mais indicadas seguindo os indicadores utilizados e as informações existentes. Destaca-se que os resultados se referem à área de estudo em questão, sendo necessárias novas aplicações do método em diferentes regiões climáticas. Com a aplicação da metodologia, a ferramenta AHP mostrou ser um método viável para auxiliar na tomada de decisão quanto à seleção de sistemas de tratamento de esgoto em áreas rurais, o qual, atrelado ao planejamento municipal em saneamento básico, auxilia na otimização dos recursos existentes. A sensibilidade do método revelou a importância de sua aplicação com dados coletados *in loco*, além da incorporação de opiniões públicas e de especialistas na contribuição do grau de importância dos critérios e indicadores utilizados.

Palavras-chave: método de análise hierárquica; saneamento rural; tratamento de esgoto.

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Introduction

The search for universal access is a major challenge, especially when it comes to rural sanitation — access to sanitation in rural lands (individually or collectively), namely rural producers, traditional communities, and indigenous peoples (Funasa, 2019). Regarding domestic sewage treatment, according to the National Rural Sanitation Program (*Programa Nacional de Saneamento Rural* — PNSR), the current scenario presents a deficit of 79.4% for the population residing in rural areas (Funasa, 2019). Among the forms of disposal of domestic sewage used, there is great persistence in the use of rudimentary septic tanks, removal of untreated gray water sewage, and final disposal by infiltration. In this scenario of investment needed for the implementation of domestic sewage treatment solutions, several alternative technologies have been implemented according to local conditions. Therefore, the purpose of this study was to classify domestic sewage treatment solutions for Brazilian rural households, based on a multi-criteria analysis, in order to hierarchically judge the technical-economic, social, and environmental feasibility of the solutions evaluated.

In the context elaborated by the PNSR, the Program addresses technological solutions as one of its strategies, in order to guide the implementation of individual or collective solutions, according to the treatment divided into dark water (from the toilet) and gray water, or domestic sewage in its entirety (no separation). These matrices were prepared by the PNSR based on typical situations found in Brazilian rural areas (Funasa, 2019), and Figure 1 presents alternative solutions for treating domestic sewage without separation.

Following the above, several options can be chosen by the user when implementing a sewage treatment solution. Among so many possibilities, how to choose the best treatment configuration? Each system has its qualitative and quantitative characteristics (area, cost, pollutant removal efficiency, among others), and it is necessary to associate its implementation with studies that support the application of the indicated solution (according to environmental, social, and technical-economic aspects) among those available.

Thus, multi-criteria analyses are presented as tools capable of aligning indicators, for the integration of relevant factors in the evaluation and decision-making process (Francisco et al., 2007; Borza and Petrescu, 2016; Campolina et al., 2017).

The Analytic Hierarchy Process (AHP), a hierarchical analysis method, is a multi-criteria assessment method, based on comparing information through judgments according to their degree of importance (Saaty, 1977; Velasquez and Hester, 2013). Its methodology has already been used to analyze various environmental issues, including domestic sewage collection and treatment (Kellner et al., 2009; Sanches, 2009; Molinos-Senante et al., 2014; Ouyang et al., 2015; Pereira et al., 2019; Sun et al., 2020; Lima et al., 2020). In this study, the hierarchy of several alternative solutions for the treatment of domestic sewage (decentralized systems, for small communities or residences) was elaborated using the AHP methodology, with technical-economic, social, and environmental indicators, providing the opportunity to define the most suitable solutions for implementation and contribution to the universalization of rural sanitation.

Methodological procedures

The methodological process was developed in several stages, given the need for data collection, elaboration of calculation matrices, and scenarios for discussion of the results.

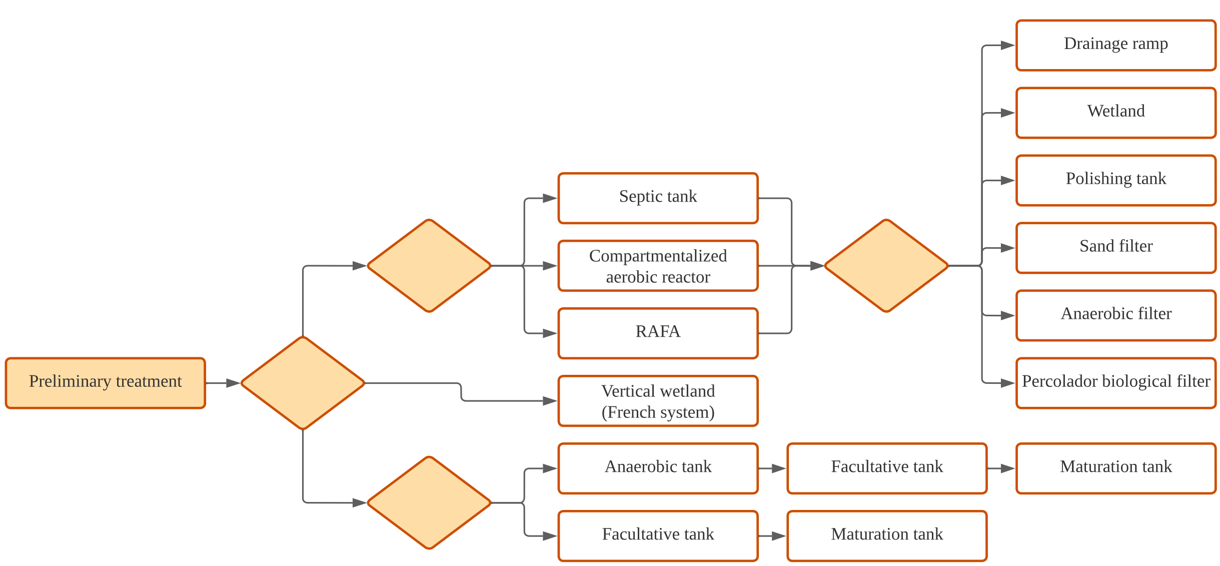

Figure 1 – Technological matrix of sewage collection and treatment solutions, according to PNSR.
RAFA: Upflow Anaerobic Reactor.
Source: based on Funasa (2019).

Step 1: Gathering data and information

According to Metcalf and Eddy et al. (2003), among the climatic aspects, the temperature interferes in the reaction rates of the microbiological growth process. Therefore, it was decided to regionalize the collection of information on existing solutions in municipalities belonging to the humid subtropical climate zone where there is no dry season (with rains throughout the year). It is represented by the acronym Cf in the Köppen climate classification, and its subdivisions are: Cfa: the hot summer zone; and Cfb: the temperate summer zone (Alvarez et al., 2013; Soares et al., 2015).

Keywords such as rural sanitation, treatment efficiency, rural area, domestic sewage treatment, sanitation — both in English and Portuguese —, were searched on the platform of Periodicals of the Coordination for the Improvement of Higher Education Personnel (*Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* — CAPES), in addition to Google Scholar, Science Direct, Web of Science, Scientific Electronic Library Online (SciELO), and Congress Proceedings of the Brazilian Association of Environmental and Health Engineering (*Associação Brasileira de Engenharia Ambiental e Sanitária* — ABES). Both studies and pilot projects (existing in the municipalities of the chosen region) were selected.

The solutions indicated by Funasa (2019) were the basis for the search, contemplated in a single or several stages: built flooded systems (BFS), compact upflow anaerobic reactor (*reator anaeróbio de fluxo ascendente* — RAFA), septic tank (ST), anaerobic filter (AF), and sand filter (SF). According to the available data, the systems were categorized as alternatives (ALTs) for the hierarchical analysis, and indicators were established for the criteria evaluated based on the list of Technical-Economic Indicators (TEIs), Environmental Indicators (EIs), and Social Indicators (SIs) proposed by Molinos-Senante et al. (2014) and presented in Chart 1.

For each indicator used, data were assigned as follows:

- In the EIs, data published in studies implemented in municipalities in the study area were used (when more than one study was found for the same solution and municipality, the average of the efficiencies was calculated), together with data from Von Sperling (2014) (in the absence of information on any step), for the calculation of global efficiency and standard deviation;
- For the TEIs, the data presented by Dotro et al. (2017) and Tonetti et al. (2018) were used, in addition to data for cost and area indicators in systems with several stages (both calculating minimum and maximum values), and establishing a maintenance frequency scale with qualitative information (considering, for each stage, the average number of times to perform maintenance on the system, and the maintenance frequency scale was established as: very low, low, moderate, high; and very high);
- As for SIs, information from Von Sperling (2014) was used, estimating a qualitative scale for the systems, according to similarity in the treatment process. For systems with more than one stage, the data set was considered, adapting the scale on a case-by-case basis, and then being elaborated in a qualitative way: very low, low, moderate, high, very high.

Chart 1 – List of criteria and indicators used in the feasibility assessment.

Criteria	Code	Indicator	Unit
Technical-economic (TEC)	ITE01	Required area	m^2/hab.
	ITE02	Implementation cost	R$/hab.
	ITE03	Maintenance frequency	Qualitative
Environmental (EC)	IAM01	BOD removal efficiency	%
	IAM02	COD removal efficiency	%
	IAM03	TC removal efficiency	unit log
	IAM04	TSS removal efficiency	%
	IAM05	N_{am} removal efficiency	%
	IAM06	N_{total} removal efficiency	%
	IAM07	P_{total} removal efficiency	%
Social (SC)	ISO01	Simplicity of operation	Qualitative
	ISO02	Unpleasant odor	Qualitative
	ISO03	Proliferation of insects and worms	Qualitative

BOD: Biochemical oxygen demand; COD: Chemical oxygen demand; TC: total coliforms; TSS: Total suspended solids; N_{am}: Ammonia Nitrogen; N_{total}: total Nitrogen; P_{total}: total Phosphorus.
Source: Tres (2021).

Step 2: Application of the hierarchical analysis method

In general, the AHP is structured according to Figure 2. The analysis is carried out level by level, comparing and establishing weight values for each piece of information: criteria; indicators; and alternatives in relation to the data for each indicator. The matrix product of the resulting weight values in the comparison of each level allows the formation of a hierarchy of alternatives that solve the problem (Saaty, 1977) — with the one with the highest score being the best solution.

The method approach is algebraic calculus, where comparisons are made in pairs, and must contain the following properties:

- reciprocity: for each input m_{ij} there is an input $1/m_{ij}$;
- identity: the input m_{ij}, where $i = j$, results in 1;
- consistency: for the consistency of the comparison matrix, the relation $m_{ij} \times m_{jk} = m_{ik}$ is valid (Saaty, 1977).

Then, the application of the method starts with the construction of a matrix $M = (m_{ij})_{n \times n}$ (pair comparison matrix) where each item to be evaluated belongs to a row and a column, where n is the number of items evaluated. The pairwise comparison is constructed using the scale assigned by Saaty (1977), in which values are assigned to items on a linear scale from 1 to 9, based on their intensity of importance (Chart 2), always with the definition of the value as an answer to the question "*how important is the i^{th} item, in relation to the j^{th} item*?".

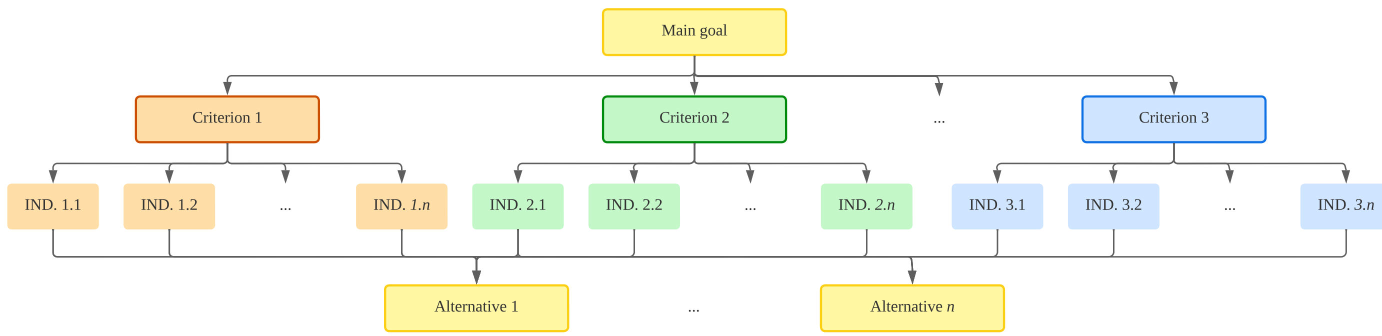

Figure 2 – Representative flowchart of the hierarchical analysis method.
IND: Indicator.
Source: Tres (2021).

Chart 2 – Linear scale of comparisons of the AHP method.

Intensity of importance	Definition	Explanation
1	Equal importance.	Two activities contribute equally to the objective.
3	Weak importance of one over the other.	Experience and judgment slightly favor one activity over the other.
5	Strong or essential importance of one over the other.	Experience and judgment strongly favor one activity over the other.
7	Demonstrated importance of one over the other.	One activity is strongly favored, and its dominance is demonstrated in practice.
9	Absolute importance of one over the other.	The evidence favoring one activity over the other is of the highest possible order of affirmation.
2, 4, 6, and 8	Intermediate values between two adjacent assessments.	

Source: Saaty (1977).

After peer comparison, it is possible to calculate the eigenvector W in an approximate way, with the following steps presented by Saaty (1977):

- sum the assessments of each column of the matrix M (Equation 1);
- divide each entry (m_{nn}) by the sum of its respective column (Equation 2);
- obtain the eigenvector W through the arithmetic mean of each row (Equation 3).

The result of the eigenvector is the weight calculated for each compared item (of the respective row).

$$M = \begin{array}{c|cccc} & \boldsymbol{M_1} & \boldsymbol{M_2} & \boldsymbol{\dots} & \boldsymbol{M_n} \\ M_1 & m_{11} & m_{12} & \dots & m_{1n} \\ M_2 & m_{21} & m_{22} & \dots & m_{2n} \\ \dots & \dots & \dots & \dots & \dots \\ M_n & m_{n1} & m_{n2} & \dots & m_{nn} \end{array} \quad (1)$$

$$\sum = \quad \sum_{i=1}^{n} m_{i1} \quad \sum_{i=1}^{n} m_{i2} \quad \dots \quad \sum_{i=1}^{n} m_{in}$$

$$M = \begin{array}{c|cccc} & \boldsymbol{M_1} & \boldsymbol{M_2} & \boldsymbol{\dots} & \boldsymbol{M_n} \\ M_1 & \frac{m_{11}}{\sum_{i=1}^{n} m_{i1}} & \frac{m_{12}}{\sum_{i=1}^{n} m_{i2}} & \dots & \frac{m_{1n}}{\sum_{i=1}^{n} m_{in}} \\ M_2 & \frac{m_{21}}{\sum_{i=1}^{n} m_{i1}} & \frac{m_{22}}{\sum_{i=1}^{n} m_{i2}} & \dots & \frac{m_{2n}}{\sum_{i=1}^{n} m_{in}} \\ \dots & \dots & \dots & \dots & \dots \\ M_n & \frac{m_{n1}}{\sum_{i=1}^{n} m_{in}} & \frac{m_{n2}}{\sum_{i=1}^{n} m_{in}} & \dots & \frac{m_{nn}}{\sum_{i=1}^{n} m_{in}} \end{array} \quad (2)$$

$$W = \begin{array}{c} \dfrac{\frac{\boldsymbol{m_{11}}}{\sum_{i=1}^{n} \boldsymbol{m_{i1}}} + \frac{\boldsymbol{m_{12}}}{\sum_{i=1}^{n} \boldsymbol{m_{i2}}} + \frac{\boldsymbol{m_{1n}}}{\sum_{i=1}^{n} \boldsymbol{m_{in}}}}{\boldsymbol{n}} \\ \dots \\ \dfrac{\frac{m_{n1}}{\sum_{i=1}^{n} m_{i1}} + \frac{m_{n2}}{\sum_{i=1}^{n} m_{in}} + \frac{m_{1n}}{\sum_{i=1}^{n} m_{in}}}{n} \end{array} = \begin{bmatrix} \boldsymbol{w_1} \\ \boldsymbol{w_2} \\ \boldsymbol{w_3} \\ \vdots \\ \boldsymbol{w_n} \end{bmatrix} \quad (3)$$

Each criterion is compared with each other, in the level 1 assessment, resulting in the eigenvector W_c, where w_{c1}, w_{c2}, w_{c3} are the weight values calculated for each criterion. For the level 2 assessment, each indicator is compared with the group of indicators of its respective criterion, resulting in the eigenvectors W_{TEIn}, W_{EIn}, W_{SIn}, where w_{i1}, w_{i2}, ..., w_{in} are the weight values of each indicator. Then, each alternative is compared in relation to the information of each indicator (level 3), resulting in the eigenvectors W_{ALTn}, where w_{a1}, w_{a2}, ..., w_{an} are the weight values of each alternative in relation to each indicator.

For the level 3 assessment, Saaty (2008) presented an alternative way to establish the weight values at this stage of the method, the rating mode, in which ranges of values are established and compared with each other, as a way of reducing the number of interactions performed. For example, when comparing the BOD removal efficiency (where the data are numbers between 0 and 100%) a classification mode is created by assigning the data in ranges from 0 to 20%, 21 to 30%, and so on. With the weight values calculated for the ranges of values, the data are normalized (divided by the largest among them), and assigned as the weight of each alternative, according to the data of each one and the correspondence of the value range (Saaty, 2008). The scales assigned for this calculation are shown in the Table 1.

Step 3: Analysis of the consistency of the weight values obtained in the pairwise comparison matrices

The assessments made need to be consistent for the AHP method to be valid, considering that, for the method $\lambda_{máx} = n$, $\lambda_{máx}$ was calculated by Equation 4 (Saaty, 1977). The W eigenvector is the ratio of the weight values for each i^{th} item evaluated by the pairwise comparison matrix, and the X vector is obtained by multiplying $M \times W$.

$$\lambda_{max} = \frac{1}{n} \times \sum_{i=1}^{n} \frac{x_i}{w_i} \quad (4)$$

The Consistency Index (CI) is also calculated from Equation 5. When close to zero, the CI shows that the judgments made are consistent and useful (Saaty, 1977).

$$\text{CI} = \frac{\lambda_{max} - n}{n - 1} \sim 0.00 \quad (5)$$

In addition to the CI, the consistency of the matrix is evaluated by the Consistency Ratio (CR), according to Equation 6. For the calculation, the CI and the Random Index (RI) are used, as shown in the Table 2. The CR consistency test should result in 0.10 or less (Saaty, 1987).

$$CR = \frac{CI}{RI} \leq 0.10 \quad (6)$$

Step 4: Calculation of partial and global priorities

Finally, the calculation of partial priority (each criterion) and global priority for each alternative was carried out to prepare the ranking of alternatives. Where $x = 1, 2, ..., X$ is the number of the alternative, $y = 1, 2, ..., Y$ is the number of technical-economic indicators, $b = 1, 2, ..., B$ is the number of environmental indicators, and $z = 1, 2, ..., Z$ is the number of social indicators, the partial score of each alternative is calculated by Equations 7, 8, and 9. The calculation was performed by the sum of the matrix product between the weight of each indicator (P_i) with the normalized weight of each alternative (TEI_x, EI_x, SI_x), being divided by the sum for each criterion (sum of TEC_x, EC_x and SC_x of all alternatives for each partial priority).

$$P_{TECx} = \frac{TEC_x}{\sum_{x=1}^{X} TEC_x}, where\ TEC_x = \sum_{y=1}^{Y} P_{iy} \times TEI_{xy}\ and\ P_{TECx} = partial\ priority\ of\ TEC \quad (7)$$

$$P_{ECx} = \frac{EC_x}{\sum_{x=1}^{X} EC_x}, where\ EC_x = \sum_{b=1}^{B} P_{ib} \times EI_{xb}\ and\ P_{ECx} = artial\ priority\ of\ EC \quad (8)$$

$$P_{SCx} = \frac{SC_x}{\sum_{x=1}^{X} SC_x}, where\ SC_x = \sum_{z=1}^{Z} P_{iz} \times SI_{xz}\ and\ P_{SCx} = partial\ priority\ of\ SC \quad (9)$$

Table 1 – Normalization scales of the weight values attributed to the alternatives, in relation to each indicator.

Indicator	Scale				
TEI01	0 – 3.20	3.21 – 6.40	6.41 – 9.60	9.61 – 12.80	12.81 – 16.00
TEI02	100 – 350	351 – 700	701 – 1,050	1,051 – 1,400	1,400 – 1,750
TEI03, SI02 and SI03	Very Low	Low	Moderate	High	Very High
EI01 to EI07	100.0 – 81.0	80.0 – 61.0	60.0 – 41.0	40.0 – 21.0	20.0 – 0.0
EI03	4.0 – 3.1	3.0 – 2.1	2.0 – 1.1	1.0 – 0.0	-
SI01	Very High	High	Moderate	Low	Very Low

Source: Tres (2021).

Table 2 – Random Index, according to the order of the pairwise comparison matrix.

Order	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty (1987).

Finally, the global priority of each alternative (GP_x) is calculated by adding the partial priority of each criterion multiplied by its respective weight, according to Equation 10.

$$GP_x = (P_{TEC} \times TEC_x) + (P_{EC} \times EC_x) + (P_{SI} \times SI_x) \quad (10)$$

Step 5: Sensitivity analysis of the method to the objective established by preparing different scenarios

To ensure that the priority analysis is adequate, a sensitivity analysis of the results obtained was also carried out. In this step, scenarios are created by alternating the weight values and data used to assess how sensitive the priorities are to changes imposed in the calculations. The elaboration of two scenarios was defined, in addition to the base scenario:

- Base Scenario: hierarchical analysis with the mean values of each indicator for each alternative;
- Data Sensitivity Scenario: hierarchical analysis with the maximum and minimum values of each indicator for each alternative, maintaining the weight values calculated for the criteria and indicators of the base scenario;
- Sensitivity Scenario of Assessments and Weight Values: hierarchical analysis with the mean values of each indicator for each alternative, changing the weight values calculated for the criteria and indicators of the base scenario.

Results and Discussion

In all of them, 37 references were selected, with a total of 63 sewage treatment arrangements (Figure 3), which were grouped into 11 types of domestic sewage treatment systems, according to the availability of information from the indicators selected for the hierarchical analysis (Chart 3).

As case studies and pilot projects were being researched, the information from each report was used to complement the data necessary for the hierarchical evaluation, mainly information from the environmental indicators. Table 3 presents information for each indicator for each setting.

Alternative effluent treatment solutions evaluated

In the ST and RAFA, in a simplified way, the effluent is treated via solid sedimentation, anaerobic digestion, and oil and grease flotation.

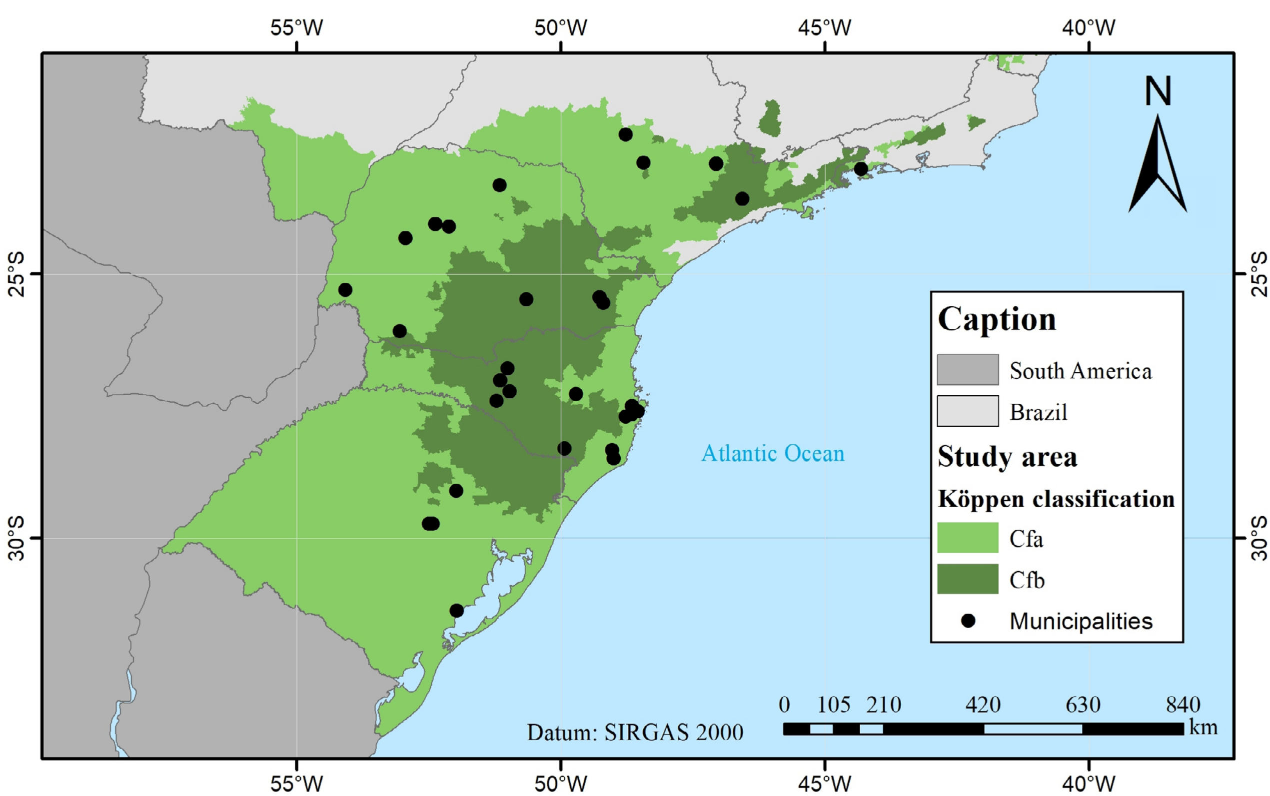

Figure 3 – Municipalities with sewage treatment arrangements in published studies for the delimited region.
Source: based on Alvarez et al. (2013).

Chart 3 – Domestic sewage treatment systems found in the data survey*.

Alternative	Acronym	Domestic sewage treatment system
ALT01	RAFA	Upflow anaerobic reactor
ALT02	RAFA + AF + BFSh	Upflow anaerobic reactor + anaerobic filter + built-in horizontal flow flooded system
ALT03	RAFA + BFSv	Upflow anaerobic reactor + built-in vertical flow flooded system
ALT04	ST + AF	Septic tank + anaerobic filter
ALT05	ST + AF + SF	Septic tank + anaerobic filter + sand filter
ALT06	ST + AF + BFSh	Septic tank + anaerobic filter + built-in horizontal flow flooded system
ALT07	ST + AF + BFSv	Septic tank + anaerobic filter + built-in vertical flow flooded system
ALT08	ST + AF + BFSv + BFSh	Septic tank + anaerobic filter + built-in hybrid flooded system (vertical flow + horizontal flow)
ALT09	ST + BFSh	Septic tank + built-in horizontal flow flooded system
ALT10	ST + BFSv	Septic tank + built-in vertical flow flooded system
ALT11	ST + BFSv + BFSh	Septic tank + built-in hybrid flooded system (vertical flow + horizontal flow)

*For each treatment system, a reference acronym was adopted to facilitate and expedite the discussion.
Source: Tres (2021).

Table 3 – Information on technical-economic, environmental, and social indicators of domestic sewage treatment systems.

Solutions	TEI01 (m^2/ inhab)	TEI02[3] (R$/ inhab)	TEI03[3]	EI01[4] (%)	EI02[4] (%)	EI03[4] (unit log)	EI04[4] (%)	EI05[4] (%)	EI06[4] (%)	EI07[4] (%)	SI01[5]	SI02[5]	SI03[5]
ALT01	0.3 – 0.8[1]	300.00 – 500.00	Low	60.00 – 75.00	48.02 ± 5.35	1.00	80.72 ± 11.62	23.23 ± 2.51	32.52 ± 3.56	11.20 ± 8.91	High	Low	Very Low
ALT02	5.6 – 11.6[1.2]	700.00 – 1,300.00	High	83.05 ± 21.31	82.77 ± 15.71	2	97.40 – 99.30	0.00 – 75.00	0.00 – 84.00	79.59 ± 9.05	Low	Moderate	High
ALT03	3.3 – 4.8[1.2]	600.00 – 1,000.00	Moderate	92.00 – 97.50	61.40	2 a 4	94.80 – 98.60	92.12	98.39	99.60	Moderate	Low	Moderate
ALT04	0.6 – 1.6[1]	200.00– 600.00	Low	71.17 ± 9.17	71.37 ± 6.67	1.24 ± 0.41	86.78 ± 3.18	19.43 ± 5.31	36.23 ± 22.81	18.37 ± 1.23	Very High	Moderate	Low
ALT05	1.0 – 2.6[1]	300.00 – 900.00	High	95.42 ± 3.98	92.64 ± 5.55	2.17 ± 1.05	94.61 ± 0.86	61.44 ± 28.40	0.00 – 27.60	32.73 – 56.27	Low	Moderate	Moderate
ALT06	5.6 – 11.6[1.2]	500.00 – 1,100.00	Moderate	91.72 ± 4.33	92.43 ± 4.73	1.93 ± 1.06	97.40 – 99.30	47.73 ± 26.56	0.00 – 84.00	36.27 ± 6.12	Moderate	High	Moderate
ALT07	3.6 – 5.6[1.2]	500.00 – 1,100.00	Moderate	86.93 – 90.20	87.86 – 91.91	1.44	95.44 – 97.72	0.00 – 43.64	0.00 – 84.00	13.72 – 43.92	Moderate	High	Moderate
ALT08	8.6 – 15.6[1.2]	700.00 – 1,300.00	Very High	94.19 – 95.64	91.53 – 94.35	1.88	84.56 – 92.28	23.79 – 58.08	0.00 – 93.60	18.52 – 47.04	Very Low	Very High	Very High
ALT09	5.3 – 10.8[1.2]	400.00 – 800.00	Moderate	89.54 ± 4.37	87.81 ± 5.92	1.92 ± 0.25	91.78 ± 6.18	50.70 ± 14.58	39.84 ± 17.69	35.27 ± 9.99	High	Moderate	Low
ALT10	3.3 – 4.8[1.2]	400.00 – 800.00	Moderate	86.98 ± 3.56	87.98 ± 3.35	2 to 4	93.60 ± 6.36	40.33 ± 10.79	40.67 ± 0.46	78.56 ± 4.26	High	Moderate	Low
ALT11	8.3 – 14.8[1.2]	700.00 – 1,300.00	High	97.20 – 99.35	94.83 – 95.52	2 to 4	85.23 – 88.51	81.11 – 86.78	0.00 – 88.80	0.00 – 72.54	Moderate	High	High

TEI01: Required area; TEI02: Cost of implementation; TEI03: Frequency of maintenance; EI01: Efficiency in removing BOD; EI02: Efficiency in removing COD; EI03: Efficiency in removing TC; EI04: Efficiency in removing TSS; EI05: Efficiency in removing Nam; EI06: Efficiency in removing Ntotal; EI07: Efficiency in removing Ptotal; SI01: Simplicity; SI02: Unpleasant odor; SI03: Proliferation of insects and worms.
Source: [1]Tonetti et al. (2018). [2]Dotro et al. (2017); [3]Adapted from Tonetti et al. (2018); [4]Tres (2021); [5]Adapted from Von Sperling (2014).

Regarding operation and maintenance, the removal and treatment of sludge is necessary over time (Tonetti et al., 2018; Funasa, 2019).

The use of these techniques (as a single step) needs to be evaluated for moderate efficiency. In addition, due to the need to remove the sludge, they are appropriate for places where they can be transported and treated (Tilley et al., 2014).

BFSs consist of impermeable ponds with aquatic plants, with a permeable layer (gravel or sand). In this system, the treatment takes place (by physical, chemical, and biological processes) during the contact of domestic sewage with microorganisms adhered to the support medium, substrate, voids, and roots, as well as rhizomes of aquatic plants in a soil-plant-water system. In the BFSh, the sewage flows horizontally through the support medium (enters at one end of the system and leaves at the opposite end), with a majority of anaerobic processes (Dotro et al., 2017). BFSv, in turn, is operated intermittently, where domestic sewage is directed to the surface and infiltrates through the support medium (from surface to bottom), as a kind of filter, and is collected at the bottom for final disposal (Dotro et al., 2017). By operating intermittently, the air enters the voids of the support medium allowing the occurrence of an aerobic process (Tilley et al., 2014; Von Sperling, 2014; Dotro et al., 2017). The most critical situation of maintenance and operation of a BFS is the clogging of the existing voids in the support medium, due to bad sizing of the BFSs or high system loads. In relation to macrophytic plants, pruning and weed control should also be performed frequently (Von Sperling, 2014; Dotro et al., 2017).

Finally, the AF consists of chambers divided into two parts, the lower being a false bottom and the upper a chamber filled with a support medium (gravel, gravel, plastic parts, for example) for the adhesion of anaerobic microorganisms of organic matter degradation (Tilley et al., 2014). The treatment flow is ascending (from bottom to surface), percolates through the support medium and is collected in the false bottom for final disposal. Regarding its operation and maintenance, the AF is at risk of clogging due to the presence of solids and bacterial growth. In these cases, its cleaning can be done by backwashing (reverse flow) or removing the support medium for cleaning (Tilley et al., 2014).

The SF, on the other hand, is composed of layers of filtering material, the upper (and deeper) layer being sand, followed by materials of greater granulometry (gravel or pebble). Thus, the treatment takes place (via upward flow) during its filtration of solids and degradation of organic matter by microorganisms. Unlike the AF, the SF is operated intermittently to allow oxygen to enter the voids of the filter layers (performing aerated processes). To avoid the clogging of the filter, maintenance is carried out by scraping the surface sand of the layer (the one that receives the greatest load of raw sewage) and replacing it with clean sand (ABNT, 1997; Tonetti et al., 2018), requiring the proper disposal of contaminated sand.

Considering the highlighted information, Chart 4 presents the positive and negative points of domestic sewage treatment by the evaluated solutions.

Chart 4 – Positive and negative aspects of sewage treatment, by type of solution.

Positive and negative aspects of sewage treatment by ST and RAFA	
+ Simple technology	- Low pathogen removal
+ No electricity required	- Low removal of organic matter
+ Low operating cost	- Low nutrient removal
+ Long service life	- Low solids removal
+ Low amount of area required	- Odors
+ Can be built underground	- Regular sludge removal, and need for treatment
Positive and negative aspects of sewage treatment by BFSh	
+ Moderate removal of organic matter and solids	- Requires pre-treatment (load reduction)
+ High nutrient removal	- Requires large areas for implementation
+ No electricity required	- Risk of clogging (filling voids)
+ Moderate pathogen removal	- Requires knowledge for construction and operation
+ Support mean can be from building materials	- More complex maintenance
+ Low operating cost	- Long startup time to full capacity
Positive and negative aspects of sewage treatment by BFSv	
+ Moderate treatment efficiency	- Requires pre-treatment (load reduction)
+ Low operating cost	- Risk of clogging (filling voids)
+ Occurrence of nitrification (due to bed aeration)	- Control of system dosage (flow)
+ Reduced implementation area	- Requires knowledge for construction and operation
+ No electricity required	- More complex and more frequent maintenance
+ Support mean can be from building materials	
Positive and negative aspects of sewage treatment by AF	
+ No electricity required	- Requires knowledge for construction and operation
+ Low operating cost	- Low removal of pathogens and nutrients
+ Long service life, low sludge production	- Risk of clogging
+ High removal of organic matter and solids	- Generated sludge must be disposed of properly
+ Moderate amount of area required	- More complex maintenance
Positive and negative aspects of sewage treatment by SF	
+ Moderate amount of area required	- Requires knowledge for construction and operation
+ Can be built underground	- Risk of clogging
+ Moderate removal of organic matter and solids	- More complex maintenance
+ Can be built by reusing civil construction materials	- The use of electricity is necessary if using pumps for intermittent flow operation.
+ Moderate pathogen removal	- Evaluate the destination of the area removed during maintenance

Source: based on Tilley et al. (2014).

Multi-criteria analysis of the evaluated solutions

The hierarchy process started by calculating the weight values of each criterion, indicating the TEC as a priority among the three criteria, with cost being one of the most critical factors in choosing the solution. Also, considering the efficiency in removing contaminants from domestic sewage, EC was the second priority criterion in the analysis. In this way, Table 4 presents the judgments made, the calculated weight values, and the data from the consistency analysis.

Regarding the indicators, for the TEIs, the cost prevailed over the others, and the frequency of maintenance was also important. For the SIs, the simplicity (ease of understanding the process) of the system prevailed, and the unpleasant odor was also important. Regarding the EIs, the removal of organic matter (BOD and COD) was defined as essential in relation to the removal of nutrients (N_{am}, N_{total}, and P_{total}), following the statements of Molinos-Senante et al. (2014). The removal of TC was also considered an indicator as important as the removal of organic matter, due to the transmission of diseases from the contamination of water courses by domestic sewage. Regarding the removal of nutrients, it was established that the removal of N_{am} is more important than the removal of N_{total} and P_{total}. Finally, the removal of TSS was defined as less important than the other indicators, as it was perceived from the TSS removal data for each alternative that the variation between them is small. Therefore, Table 5 presents the comparison matrices for the indicators of each criterion, and their respective eigenvalues, CIs and CRs.

To assign the value to each alternative in relation to the indicators, the weight values referring to the ranges of values (W_{rv}) were calculated. Based on the scale presented for each indicator in Table 1, the matrices presented in Table 6 calculate the normalized weight values for each scale value range (W_{ni}), for the indicators in question.

Table 4 – Pairwise comparison matrix of the criteria and their respective calculated weight values.

Criteria	Technical-Economic	Social	Environ-mental	Weight of each criterion
Technical-Economic	1	7	3	0.64
Social	1/7	1	1/5	0.07
Environmental	1/3	5	1	0.28
			Eigenvalue ($\lambda_{max} \sim n$)	3.07
			CI ($CI \sim 0.00$)	0.03
			CR ($CR \leq 0.10$)	0.06

Source: Tres (2021).

Table 5 – Pairwise comparison matrix of indicators and their calculated weight values.

TEI	Required area	Implementation cost	Maintenance frequency	W_i
Required area	1	1/7	1/5	0.07
Implementation cost	7	1	3	0.64
Maintenance frequency	5	1/3	1	0.28
			Eigenvalue ($\lambda_{max} \sim n$)	3.07
			CI ($CI \sim 0.00$)	0.03
			CR ($CR \leq 0.10$)	0.06
SI	**Simplicity**	**Unpleasant odor**	**Proliferation of insects and worms**	W_i
Simplicity	1	3	5	0.65
Unpleasant odor	1/3	1	2	0.23
Proliferation of insects and worms	1/5	1/2	1	0.12
			Eigenvalue ($\lambda_{max} \sim n$)	3.00
			CI ($CI \sim 0.00$)	0.00
			CR ($CR \leq 0.10$)	0.00

EI	Removal of BOD	Removal of COD	Removal of TC	Removal of TSS	Removal of N_{am}	Removal of N_{total}	Removal of P_{total}	W_i
Removal of BOD	1	2	2	7	5	3	3	0.31
Removal of COD	1/2	1	1	5	4	2	2	0.19
Removal of TC	1/2	1	1	5	2	2	2	0.17
Removal of TSS	1/7	1/5	1/5	1	1/5	1/3	1/3	0.03
Removal of Nam	1/5	1/4	1/2	5	1	3	3	0.13
Removal of Ntotal	1/3	1/2	1/2	3	1/3	1	1	0.08
Removal of Ptotal	1/3	1/2	1/2	3	1/3	1	1	0.08
							Eigenvalue ($\lambda_{max} \sim n$)	7.46
							CI ($CI \sim 0.00$)	0.08
							CR ($CR \leq 0.10$)	0.06

W_i: Weight of each indicator.
Source: Tres (2021).

Table 6 – Pairwise comparison matrix of the scale of indicators, and calculation of normalized weight.

TEI01	0 – 3.20	3.21 – 6.40	6.41 – 9.60	9.61 – 12.80	12.80 – 16	W_{rv}	W_{ni}
0 – 3.20	1	3	5	7	9	0.50	1.00
3.21 – 6.40	1/3	1	3	5	7	0.26	0.52
6.41 – 9.60	1/5	1/3	1	3	5	0.13	0.27
9.61 – 12.80	1/7	1/5	1/3	1	3	0.07	0.13
12.80 – 16.00	1/9	1/7	1/5	1/3	1	0.03	0.07
					Maximum weight	0.50	
					Eigenvalue ($\lambda_{max} \sim n$)	5.24	
					CI ($CI \sim 0.00$)	0.06	
					CR ($CR \leq 0.10$)	0.05	
TEI02	**100 – 350**	**351 – 700**	**701 – 1,050**	**1,051 – 1,400**	**1,401 – 1,750**	W_{rv}	W_{ni}
100 – 350	1	3	5	7	9	0.50	1.00
351 – 700	1/3	1	3	5	7	0.26	0.52
701 – 1,050	1/5	1/3	1	3	5	0.13	0.27
1,051 – 1,400	1/7	1/5	1/3	1	3	0.07	0.13
1,401 – 1,750	1/9	1/7	1/5	1/3	1	0.03	0.07
					Maximum weight	0.50	
					Eigenvalue ($\lambda_{max} \sim n$)	5.24	
					CI ($CI \sim 0.00$)	0.06	
					CR ($CR \leq 0.10$)	0.05	
TEI03, SI02 and SI03	**Very low**	**Low**	**Moderate**	**High**	**Very high**	W_{rv}	W_{ni}
Very low	1	3	5	7	9	0.50	1.00
Low	1/3	1	3	5	7	0.26	0.52
Moderate	1/5	1/3	1	3	5	0.13	0.27
High	1/7	1/5	1/3	1	3	0.07	0.13
Very high	1/9	1/7	1/5	1/3	1	0.03	0.07
					Maximum weight	0.50	
					Eigenvalue ($\lambda_{max} \sim n$)	5.24	
					CI ($CI \sim 0.00$)	0.06	
					CR ($CR \leq 0.10$)	0.05	
EI01 to EI07	**100.0 – 81.0**	**80.0 – 61.0**	**60.0 – 41.0**	**40.0 – 21.0**	**20.0 – 0.0**	W_{rv}	W_{ni}
100.0 – 81.0	1	3	5	7	9	0.50	1.00
80.0 – 61.0	1/3	1	3	5	7	0.26	0.52
60.0 – 41.0	1/5	1/3	1	3	5	0.13	0.27
40.0 – 21.0	1/7	1/5	1/3	1	3	0.07	0.13
20.0 – 0.0	1/9	1/7	1/5	1/3	1	0.03	0.07
					Maximum weight	0.50	
					Eigenvalue ($\lambda_{max} \sim n$)	5.24	
					CI ($CI \sim 0.00$)	0.06	
					CR ($CR \leq 0.10$)	0.05	

Continue...

Table 6 – Continuation.

EI03	4.0 – 3.1	3.0 – 2.1	2.0 – 1.1	1.0 – 0.0	W_{rv}	W_{ni}
4.0 – 3.1	1	3	5	7	0.56	1.00
3.0 – 2.1	1/3	1	3	5	0.26	0.47
2.0 – 1.1	1/5	1/3	1	3	0.12	0.22
1.0 – 0.0	1/7	1/5	1/3	1	0.06	0.10
				Maximum weight	0.56	
				Eigenvalue ($\lambda_{max} \sim n$)	4.12	
				CI ($CI \sim 0.00$)	0.04	
				CR ($CR \leq 0.10$)	0.04	

SI01	Very high	High	Moderate	Low	Very low	W_{rv}	W_{ni}
Very high	1	3	5	7	9	0.50	1.00
High	1/3	1	3	5	7	0.26	0.52
Moderate	1/5	1/3	1	3	5	0.13	0.27
Low	1/7	1/5	1/3	1	3	0.07	0.13
Very low	1/9	1/7	1/5	1/3	1	0.03	0.07
					Maximum weight	0.50	
					Eigenvalue ($\lambda_{max} \sim n$)	5.24	
					CI ($CI \sim 0.00$)	0.06	
					CR ($CR \leq 0.10$)	0.05	

Source: Tres (2021).

The assessments for calculating the weight values were carried out in order to prioritize solutions with a smaller area, cost, maintenance, odor, and proliferation of insects and worms, and greater efficiency in pollutant removal and simplicity.

Thus, normalized weight values were assigned according to each alternative. For example: for TEI01, the ST + BFSv + BFSh system needs 8.3 to 14.8 m^2/inhab. When calculated for the Base Scenario, the mean value was used (11.55 m^2/inhab.) corresponding to the normalized weight of 0.13. When performing the variation in the minimum and maximum data scenarios, the normalized weight varied to 0.27 and 0.07, respectively. Table 7 presents the summary of the results of the elaborated scenarios, according to the calculations of partial and global priorities.

Results of hierarchical analysis and comparison of scenarios performed

In general, the most present systems as priorities were:

- in relation to the TEC, RAFA, ST + AF and ST + BFSv;
- in relation to EC, they were RAFA + BFSv, ST + BFSv + BFSh, and ST + AF + SF;
- in relation to SC, they were ST + AF, RAFA, ST + BFSv and ST + BFSh;
- in terms of general priority, RAFA, ST + AF and ST + BFSv.

Hierarchy changed, mainly, as the data of the alternatives changed (Data Sensitivity Scenario). As for the general priority, the change occurred when the EC, TEC, and SC weight values were changed, and the general priority ranking followed according to the hierarchy of the criterion with the highest weight.

In relation to the Base Scenario, in the TEC, the RAFA system presented the best score in this criterion, due to the best configuration: smaller area, lower cost, and lower maintenance frequency. The ST + AF system was a configuration that presented low cost, low maintenance frequency, and its area differentiates this system from the RAFA system, occupying the 2nd place. In addition, the ST + BFSv system presented moderate values for cost, required area, and maintenance frequency (Tonetti et al., 2018), occupying the 3rd place. In EC, the RAFA+ BFSv system was the system with the best score among all those evaluated (followed by the ST + BFSv + BFSh system, and the ST + AF + BFS system). Both RAFA + BFSv and ST + BFSv + BFSh have higher efficiencies of pollutant removal, and RAFA + BFSv prevails in most environmental indicators: nutrient removal, BOD removal, and TSS removal being the reason for its first position. In the SC, the ST + AF system is the first in the ranking of this criterion, followed by RAFA (the 2nd place) and ST + BFSv and ST + BFSh (both in the 3rd place). Even not having the best concept in the indicators of ISO02 and ISO03, ST + AF has the best concept for simplicity (very high), and therefore prevailed over the other systems. The ST + BFSv and ST + BFSh systems have the same concepts for the SIs, and for this reason they kept the same Score. Finally, in general priority, RAFA maintained its position in the 1st place, followed by ST + AF and ST + BFSv. Since TEC is the most weighted criterion, the hierarchy in the general priority of the Base Scenario followed the TEC hierarchy.

Table 7 – Summary of the results of the prepared scenarios, referring to the technical-economic criterion, environmental criterion, social criterion, and global priority.

Solutions	Results regarding TEC						Results regarding EC						Results regarding SC					
	Base scenario	Data sensitivity scenario			Weight sensitivity scenario		Base scenario	Data sensitivity scenario			Weight sensitivity scenario		Base scenario	Data sensitivity scenario			Weight sensitivity scenario	
	Med.	Max.	Med.	Min.	EC	SC	Med.	Max.	Med.	Min.	EC	SC	Med.	Max.	Med.	Min.	EC	SC
ALT01	1.000	1.0000	1.0000	1.0000	1.0000	1.0000	0.3414	0.3073	0.3597	0.2721	0.3414	0.3414	0.7480	1.0000	0.7480	0.7517	0.7480	0.7480
ALT02	0.203	0.2454	0.2030	0.4544	0.2030	0.2030	0.7954	0.8380	0.8380	0.5422	0.7954	0.7954	0.2097	0.3275	0.2097	0.2096	0.2097	0.2097
ALT03	0.417	-	-	-	0.4173	0.4173	1.0000	-	-	-	1.0000	1.0000	0.4233	-	-	-	0.4233	0.4233
ALT04	0.804	1.0000	0.8036	0.9182	0.8036	0.8036	0.4330	0.3901	0.4562	0.4616	0.4330	0.4330	1.0000	0.8897	1.0000	1.0000	1.0000	1.0000
ALT05	0.644	0.4686	0.6440	0.8527	0.6440	0.6440	0.8648	0.9031	0.9110	0.8440	0.8648	0.8648	0.2318	0.3580	0.2318	0.2279	0.2318	0.2318
ALT06	0.391	0.3477	0.3906	0.4741	0.3906	0.3906	0.7788	0.8186	0.8204	0.8157	0.7788	0.7788	0.3074	0.4625	0.3074	0.2907	0.3074	0.3074
ALT07	0.417	0.3893	0.4173	0.4741	0.4173	0.4173	0.7559	0.7400	0.7963	0.8258	0.7559	0.7559	0.3074	0.4625	0.3074	0.2907	0.3074	0.3074
ALT08	0.164	0.1258	0.1635	0.2470	0.1635	0.1635	0.7559	0.7400	0.7963	0.8370	0.7559	0.7559	0.0905	0.1300	0.0905	0.1751	0.0905	0.0905
ALT09	0.623	0.4780	0.6234	0.4741	0.6234	0.6234	0.7646	0.7554	0.8054	0.8510	0.7646	0.7646	0.5979	0.8897	0.5979	0.5948	0.5979	0.5979
ALT10	0.650	0.5196	0.6500	0.4741	0.6500	0.6500	0.8325	0.8766	0.8771	0.8964	0.8325	0.8325	0.5979	0.8897	0.5979	0.5948	0.5979	0.5979
ALT11	0.188	0.2390	0.1881	0.4331	0.1881	0.1881	0.9493	1.0000	1.0000	1.0000	0.9493	0.9493	0.2853	0.4320	0.2853	0.2723	0.2853	0.2853

Results regarding global priority in the Base Scenario										
ALT01	ALT02	ALT03	ALT04	ALT05	ALT06	ALT07	ALT08	ALT09	ALT10	ALT11
1.0000	0.3866	0.6388	0.8860	0.7739	0.5498	0.5665	0.3309	0.7724	0.8113	0.4199

Results referring to global priority, with EC as a priority criterion										
ALT01	ALT02	ALT03	ALT04	ALT05	ALT06	ALT07	ALT08	ALT09	ALT10	ALT11
0.7122	0.7339	1.0000	0.7623	0.9343	0.7963	0.7866	0.6708	0.9057	0.9685	0.8640

Results referring to global priority, with SC as priority criterion										
ALT01	ALT02	ALT03	ALT04	ALT05	ALT06	ALT07	ALT08	ALT09	ALT10	ALT11
0.7853	0.3635	0.6047	1.0000	0.4340	0.4578	0.4551	0.2516	0.7182	0.7351	0.4587

Source: Tres (2021).

For the Data Sensitivity Scenario, since the RAFA + BFSv system does not have ranges of values or standard deviation for most of its EIs, this was removed in comparison with the other systems in this Scenario. The removal of RAFA + BFSv presented a small variation in the partial and final scores for TEC and SC, but did not result in any change in the hierarchy. In EC, the withdrawal of the RAFA + BFSv system changed the hierarchical order, having as the three main systems: ST + BFSv + BFSh, ST + AF + SF, and ST + BFSv (the systems increased one position in the rank — with ST + BFSv in the 4th place in the Base Scenario; with the removal of RAFA + BFSv from the analysis, it moved on to the 3rd place). The hierarchical order in relation to the general priority, with the mean values, remained the same as in the Base Scenario, considering only some changes in the Scores. Then, the hierarchical analysis was performed with the maximum and minimum values of each system. When evaluating the maximum values, ST + AF and RAFA were both in the 1st place in the TEC. Despite the difference in data for the two systems, both fall within the same range of values for assigning normalized weight values. In the hierarchical sequence, ST + BFSv was in the 2nd place, and ST + BFSh in the 3rd place in the TEC. In the EC for the maximum values, the hierarchy followed the same as the mean values, with ST + BFSv + BFSh in the 1st place, ST + AF + SF in the 2nd place, and ST + BFSv in the 3rd place (with only a small change in the partial Scores for the criterion). In the SC evaluated with the maximum values of each alternative, there was a change in priority where RAFA occupied the 1st place, and in the 2nd place there are the systems ST + AF, ST + BFSh and ST + BFSv, whereas in the 3rd place we have the systems ST + AF + BFSv and ST + AF + BFSh. For the evaluation of the maximum and minimum values in the SC, each information of each alternative was changed in one degree in the qualitative scale, and the systems that already had the maximum or minimum concept kept the same value. In general priority, the hierarchy changed so that the RAFA system was in the 1st place, ST + AF in the 2nd place, and ST + BFSv in the 3rd place — still following the order of the TEC (the criterion with greater weight for the attribution of the Score). When evaluating the minimum values, the results of partial and general priorities also changed.

In the TEC, RAFA maintained the 1st place position, ST + AF was in the 2nd place, and ST + AF + SF in the 3rd place. The BFS step in the systems caused the values of used area and cost to result in values greater than the minimum values of ST + AF + SF. This made ST + AF + SF have a better position compared to joint systems between ST and BFS. In the EC for minimum values, ST + BFSv + BFSh kept the 1st place, but the 2nd place changed to the ST + BFSv system (which was in the 3rd place in the round of medium and maximum values), and the 3rd place went to the ST+BFSh system. For the SC, in relation to the minimum values, the hierarchy of the SC remained similar to the Base Scenario, with the ST + AF system in the 1st place, the RAFA system in the 2nd place, and the ST + BFSh and ST + BFSv systems in the 3rd place. For the general priority in relation to the minimum values, the order changed to ST + AF in the 1st place, RAFA in the 2nd place, and ST + AF + SF in the 3rd place — since the TEC had greater weight among the criteria, the hierarchy remained according to this criterion.

One may observe the great interference of results obtained according to the values used in the calculation. Mainly in relation to EC, since each alternative has different pollutant removal data, this criterion was the one that changed the most in the different rounds of calculations. This Scenario allowed us to observe the importance of choosing the data used in the hierarchical analysis process — one piece of data can impact the entire calculated hierarchy.

For the evaluation of the sensitivity of assessments and weight values, the criteria weight values were changed to the SC as a priority, and then to the EC. When calculating the pairwise comparison matrix for weight calculation with SC as the priority criterion, the calculated weight values were 0.64 for the SC, 0.28 for the EC, and 0.07 for the TEC. For the EC, the calculated weight values were 0.72 for the EC, 0.19 for the TEC, and 0.08 for the SC. Both comparison matrices presented λ_{max} equal to 3.07, CI equal to 0.03, and CR equal to 0.06, with consistent results.

As the weight values of the indicators were not changed, the partial priority of each criterion remained the same as in the Base Scenario, with only general priorities being discussed now. For both the SC and the EC as a priority, it is notable that the influence of the weight assigned to the criterion changes the hierarchy of the evaluated systems, following the partial priority Scores. The variation that occurred in this Scenario shows the importance of assessing and calculating the weight values when the method is applied.

Conclusions

Among the 11 configurations of alternative solutions evaluated, the most present as partial and general priorities were RAFA, ST + AF, and ST + BFSv, for the study area. These systems presented, in general, low cost, low maintenance frequency, high/moderate simplicity, high efficiency in the removal of organic matter, nutrients, coliforms and solids, and moderate proliferation of insects and worms and generation of odors. It is noteworthy that the disposal of the treated effluent was not considered in the analysis, as it increases the number of interactions in the calculations. Considering the different hierarchies that occurred in the alteration of data and assigned weight values (comparison of Scenarios), there is a need for coherent data in the analysis of multi-criteria using the AHP method. In addition, the limitation of the study area for the replication of the multicriteria analysis is necessary, mainly due to the variance of efficiency of each solution according to location and climatic zone. Finally, this study demonstrates the possibility of further advances in rural planning, defining, in addition to demonstrating the technologies available for use, to help define the most suitable solution among them, according to the context in which it will be applied.

Contribution of authors:

TRES, V.: Conceptualization; Data curation; Methodology; Writing – original draft; AZEVEDO, J. C. R.: Supervision; KNAPIK, H. G.: Supervision.

References

Alvarez, C.A.; Stape, J.L.; Sentelhas, P.C.; Gonçalves, J.L.M.; Sparovek, G., 2013. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, v. 22, (6), 711-728. https://doi.org/10.1127/0941-2948/2013/0507.

Associação Brasileira de Normas Técnicas (ABNT), 1997. Norma Brasileira 13969: Tanques sépticos – Unidades de tratamento complementar e disposição final de efluentes líquidos – Projeto, construção e operação. Rio de Janeiro: ABNT.

Borza, S.; Petrescu, V., 2016. The Olt River pollution monitoring, using spacial analisys, analityc hierarchy process and technique for order preference by similarity methods. Process Safety and Environmental Protection, v. 101, 9-18. https://doi.org/10.1016/j.psep.2016.01.002.

Campolina, A.G.; Soárez, P.C.; Amaral, F.V.; Abe, J.M., 2017. Análise de decisão multicritério para alocação de recursos e avaliação de tecnologias em saúde: tão longe e tão perto? Caderno de Saúde Pública, v. 33, (10), 1-15. https://doi.org/10.1590/0102-311X00045517.

Dotro, G.; Langergraber, G.; Molle, P.; Nivala, J.; Puigagut, J.; Stain, O.; Von Sperling, M., 2017. Treatment wetlands. London, IWA, v. 7, 155 p.

Francisco, C.E.S.; Coelho, R.M.; Torres, R.B.; Adami, S.F., 2007. Espacialização de análise multicriterial em SIG: prioridades para recuperação de Áreas de Preservação Permanente. In: XIII Simpósio Brasileiro de Sensoriamento Remoto. Anais [...]. Florianópolis: INPE, pp. 2643-2650.

Fundação Nacional de Saúde (Funasa), 2019. Programa Nacional de Saneamento Rural. Brasília: Ministério da Saúde, 266 p.

Kellner, E.; Calijuri, M.C.; Pires, E.C., 2009. Aplicação de Indicadores de sustentabilidade para lagoas de estabilização. Engenharia Sanitária e Ambiental, v. 14, (4), 455-464. https://doi.org/10.1590/S1413-41522009000400005.

Lima, G.S.; Nunes, A.B.A.; Magalhães, A.M.C.; Campos, V.R., 2020. Aplicação de metodologia de análise hierárquica (AHP) para priorização de intervenção em estações de tratamento de esgotos – Estudo de caso na Bacia do Siqueira, Fortaleza/CE. Revista DAE, v. 68, (225), 34-50. https://doi.org/10.36659/dae.2020.051.

Metcalf & Eddy, Inc.; Tchobanoglous, G.; Burton, F.L.; Stensel, H.D., 2003. Wastewater Engineering – Treatment and Reuse. 4ª ed.. McGraw-Hill Companies, 1878 p.

Molinos-Senante, M.; Gomez, T.; Garrido-Besarba, M.; Caballero, R.; Sala-Garrido, R., 2014. Assessing the sustainability of small wastewater treatment systems: A composite indicator approach. Science of the Total Environment, v. 497-498, 607-617. https://doi.org/10.1016/j.scitotenv.2014.08.026.

Ouyang, X.; Guo, F.; Shan, D.; Yu, H.; Wang, J., 2015. Development of the integrated fuzzy analytical hierarchy process with multidimensional scaling in selection of natural wastewater treatment alternatives. Ecological Engineering, v. 74, 438-447. https://doi.org/10.1016/j.ecoleng.2014.11.006.

Pereira, A.C.; Maragon, B.B.; Santos, T.C.C.; Rezende, A.A.P., 2019. Definição de critérios para escolha de alternativas de sistemas individuais de esgotamento sanitário. In*:* Congresso Brasileiro de Engenharia Sanitária e Ambiental, 30., Natal, Anais [...]. Natal: ABES.

Saaty, R.W., 1987. The analytic hierarchy process – what it is and how it is used. Mathematical Modelling, v. 9, (3-5), 161-176. https://doi.org/10.1016/0270-0255(87)90473-8.

Saaty, T.L., 1977. A scaling method for priorities in hierarchical structures. Journal of Mathematical Psychology, v. 15, (3), 234-281. https://doi.org/10.1016/0022-2496(77)90033-5.

Saaty, T.L., 2008. Decision making with the analytic hierarchy process. International Journal of Services Sciences, v. 1, (1), 83-98. https://doi.org/10.1504/IJSSCI.2008.017590.

Sanches, A.B., 2009. Avaliação da sustentabilidade de sistemas de tratamento de esgotos sanitários: uma proposta metodológica. Doctoral Thesis, Universidade Federal do Rio Grande do Sul, Porto Alegre.

Soares, R.V.; Batista, A.C.; Tetto, A.F., 2015. Meteorologia e climatologia florestal. Curitiba: Universidade Federal do Paraná, 215 p.

Sun, Y.; Garrido-Baserda, M.; Molinos-Senante, M.; Donikian, N.A.; Poch, M.; Rosso, D., 2020. A composite indicator approach to assess the sustainability and resilience of wastewater management alternatives. Science of the Total Environment, v. 725, 138286. https://doi.org/10.1016/j.scitotenv.2020.138286.

Tilley, E.; Lukas, U.; Luthi, C.; Reymond, P.; Zurbrugg, C., 2014. Compendium of Sanitation Systems and Technologies. Dübendorf, Switzerland: Swiss Federal Institute of Aquatic Science and Technology (Eawag), 180 p.

Tonetti, A.L.; Brasil, A.L.; Madrid, F.J.P.L.; Figueiredo, I.C.S.; Schneider, J.; Cruz, L.M.O.; Duarte, N.C.; Fernandes, P.M.; Coasaca, R.L.; Garcia, R.S.; Magalhães, T.M., 2018. Tratamento de esgotos domésticos em comunidades isoladas: referencial para a escolha de soluções. Campinas: Universidade Estadual de Campinas, 153 p.

Tres, V., 2021. Estudo de viabilidade técnica-econômica, social e ambiental para seleção de tratamento de esgoto doméstico em áreas rurais. Dissertação de mestrado, Universidade Tecnológica Federal do Paraná, Curitiba.

Velasquez, M.; Hester, P.T., 2013. An Analysis of Multi-Criteria Decision Making Methods. International Journal of Operations Research, v. 10, (2), 56-66.

Von Sperling, M., 2014. Princípios do tratamento biológico de águas residuárias. introdução à qualidade das águas e ao tratamento de esgotos. Belo Horizonte: Editora UFMG, v. 1, 472 p.