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Selection of Sewage Treatment Technologies Using Multicriteria Analysis(*)

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ABSTRACT
One of the main causes of water body pollution is the discharge of untreated sewage. To reduce this type of pollution, the implementation of sewage treatment systems, especially the unit responsible for managing treatment, is necessary. The selection of sewage treatment technologies is a complex process, as it involves both quantitative and qualitative variables. To achieve the goal defined in this work, which is the selection of sewage treatment technologies applicable to municipalities in the state of Goiás that do not have a sanitary sewage system, the Electre I method was adopted. Multicriteria analysis was used to select the 37 most commonly used sewage treatment technologies in Brazil and define a set composed of the best technology options. For this, three scenarios were defined, in which 16 criteria with technical, economic, social, and environmental characteristics were selected for scenario 1, 10 criteria for scenario 2, and eight criteria for scenario 3. The method was suitable for selecting sewage treatment technologies, with selection for scenario 1 comprising a set of two alternatives (anaerobic pond + facultative pond + maturation pond and slow infiltration); scenario 2 comprising a set of five alternatives (septic tanks, facultative pond, facultative aerated pond, slow infiltration, and UASB reactor), and scenario 3 comprising three alternatives (septic tanks, facultative aerated pond, and UASB reactor).

KEYWORDS: Multicriteria decision-making method. Sewage Treatment Technologies. Electre I.

1. INTRODUCTION

Law nº 11,445/2007, which establishes national guidelines for basic sanitation in the country, in its art. 19, states that public service provision should include short, medium, and long-term objectives for the universalization of basic sanitation services, including sanitary sewage.

According to data released by the National Information System on Sanitation (SNIS), based on the diagnosis conducted in 2017, this goal is far from being achieved. In Brazil, 46% of generated sewage is treated, and 73.7% of collected sewage receives treatment, highlighting the lack of sewage treatment systems in most Brazilian cities.

In the state of Goiás, according to data from 2019 provided by SNIS, referring to the diagnosis conducted in 2017, 48% of generated sewage and 87% of collected sewage in the state receive treatment. Furthermore, approximately 67% of municipalities do not have a sanitary sewage system in place (SNIS, 2019).

Population growth and urbanization of cities are directly related to the availability of water in sufficient quantity and quality for use. Anthropogenic actions cause changes in the environment, mainly leading to water body pollution. The discharge of untreated sewage alters the physical, chemical, and biological parameters of water bodies and compromises their multiple uses, also promoting the emergence of waterborne diseases, making it one of the main causes of water contamination.

The deficit in sewage collection and treatment in Brazilian cities has generated a significant portion of pollutant load reaching water bodies, negatively affecting multiple uses of water resources (Brazil, 2017). To treat these liquid discharges, there is a wide variety of technologies available in the literature that, if implemented, can reduce the impacts caused by the discharge of raw sewage into water bodies.

The treatment of this sewage is classified into preliminary, primary, secondary, and tertiary levels, which, when used separately or in combination, result in different sewage

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treatment process configurations (Von Sperling, 2014). After treatment, the final disposal can be done in bodies of water, in the soil, or sent for reuse, provided it meets legal regulations. Similarly, the proper disposal of the generated sludge is necessary.

Deciding which sewage treatment process to adopt can be a complex task. The choice of a sewage treatment process is not limited to environmental, public health, and/or legal requirements but also considers economic, social, operational, political, and community aspirations (Brazil, 2017; Castro, 2007). According to Von Sperling (2014), selecting the most suitable alternative for the analyzed reality should be done by assigning criteria and/or weights.

In recent decades, various decision support methods have been developed. With the variety and quantity of methods available, the choice of the method depends on the particular problem considered and the preferences of decision-makers. Given the criteria to be considered in the selection of sewage treatment technologies and their subjectivity, this work will use the multicriteria analysis methodology, which aims to deal with multiple quantitative and qualitative criteria simultaneously.

2. MATERIALS AND METHODS

2.1. Data collection and scenario definition

The urban population was estimated for each of the 165 municipalities in the state of Goiás that do not have a sanitary sewage system. The geometric method was used, considering population growth as a function of the existing population at each moment (VON SPERLING, 2014), for a 20-year project horizon (2020 - 2040). This method considers time as an exponential for annual growth based on the rate:

$$Pn = rg^{(n-0)} * Po \quad \text{(Eq. 1)},$$

where:

$$rg = \left(\frac{Pn}{Po}\right)^{\left(\frac{1}{n-0}\right)} \quad \text{(Eq. 2)}$$

$$Tg\% = (rg - 1) * 100 \quad \text{(Eq. 3)}$$

Pn = population projection for the desired year
rg = population growth rate
n = year for which the population projection is desired
0 = reference year for the calculation of the projection
Po = population of the reference year used for the projection
Tg = Population growth rate in percentage

Once the project's population was defined, the municipalities were ranked based on the calculated population in ascending order, making it possible to identify the municipalities in

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three population categories: above 50,000 (2%), between 10,000 and 50,000 inhabitants (22%), and below 10,000 inhabitants (76%).

2.2. Scenario Definition

To choose technologies that best represent the needs of each municipality, three scenarios were defined with criteria that best suited these population categories:

- Scenario 1: Population above 50,000 inhabitants.
- Scenario 2: Population between 10,000 and 50,000 inhabitants.
- Scenario 3: Population below 10,000 inhabitants.

2.3. Application of Questionnaires

Questionnaires were administered to experts working in the field of sanitary sewage. In each scenario, importance weights were assigned to each criterion listed based on their preferences, using simple ranking. Once the necessary data for the research were obtained, the data were tabulated and processed using Microsoft Excel®.

2.4. Definition of Alternatives and Criteria

The selection of alternatives for this study was based on a systematic literature review and comprised 37 combinations of sewage treatment technologies most commonly used in Brazil, as highlighted by Von Sperling (2014).

In a multicriteria decision-making process, the defined criteria must allow the evaluation of each proposed alternative. In the systematic literature review, no significant number of studies were found that simultaneously address the selection of sewage treatment technologies employing economic, technical, social, and environmental characteristics for criterion definition. Therefore, considering this observation and based on the available data for quantitative and qualitative comparison presented by Von Sperling (2014) and following the recommendations proposed by Campos (2011) not to use more than 20 attributes simultaneously at the same level of equality, initially, 16 criteria with economic, technical, social, and environmental characteristics were selected.

Then, according to the method's peculiarity pointed out by Costa (2016), once the Kernel (K) of the set of studied alternatives was found, it does not change, as alternatives belonging to the dominant set complement each other, achieving the best performance. Thus, out of the 16 selected criteria, 16 were considered for scenario 1, 10 for scenario 2, and eight for scenario 3.

2.5. Definition of Weights and Thresholds

Weights play an important role in resolving conflicts between criteria, decisively influencing the results obtained, as the weights should as faithfully as possible reflect the decision maker's preferences. To define the weights of the selected criteria, a consultation was made with specialists in the field of sanitary sewage, working in education and at the Goiás Sanitation Company (SANEAGO), and designers, as five specialists answered the questionnaires.

Three questionnaires were sent to the specialists consulted, in which the technique used for weight assignment was simple ranking. In this technique, the specialist prioritizes the criteria in order of preference, associating:

- Scenario 1 (population above 50,000 hab.): value 1 for the least important criterion and value 16 for the most important.
- Scenario 2 (population between 10,000 and 50,000 hab.): value 1 for the least important criterion and value 10 for the most important.
- Scenario 3 (population below 10,000 hab.): value 1 for the least important criterion and value 8 for the most important.

As a result of the research, the importance weights associated with the criteria for selecting sewage treatment technologies for the municipalities of the state of Goiás were obtained through arithmetic mean and normalization of the obtained weights for each criterion, respectively.

Concordance and Discordance Thresholds were defined based on the literature review conducted.

2.6. Application of Electre I Method

With the input data defined, the maximum difference between criteria was established, and normalization of all values was performed. Then, pairwise overclassification relationships occurred, considering the concepts of concordance (Equation 4) and discordance (Equation 5 and Equation 6). Concordance occurs when one alternative weakly dominates another, and discordance occurs when there are no criteria where the preference intensity between alternatives exceeds an acceptable limit.

$$C(a,b) = \frac{1}{P} \sum_{j:q_j(a) \geq g_j(b)} p_j \qquad onde \quad P = \sum_{j=1}^{n} p_j \qquad \text{(Eq. 4),}$$

where:

gj(a) = performance of alternative *a* on criterion *j*

gj(b) = performance of alternative *b* on criterion *j*

pj = normalized weight of criterion j (the sum of weights equals 1)

C(a, b) = concordance index representing how much "a" overclassifies "b."

The discordance index corresponds to how much alternative "a" is inferior to alternative "b." The index has values between 0 and 1, and δ corresponds to the maximum difference for any criterion.

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$$D(a,b) = \begin{cases} 0 & se\ g_j\ (a) \geq\ g_j\ (b), \quad \forall j \\ \frac{1}{\delta} \max_j\ [g_j(b) -\ g_j(a)] \end{cases} \quad \text{(Eq. 5)}$$

For:

$$\delta = \max_{c,d,j}[g_j(c) -\ g_j(d)] \quad \text{(Eq. 6)}$$

Next, the threshold between concordance and discordance is defined for dominance testing. In this work, it was defined based on the literature review, and two conditions established in Equation 5 must be met:

S = overclassification
c = concordance threshold, relatively large
d = discordance threshold, relatively small
D (a, b) = discordance index corresponding to how much alternative "a" is inferior to alternative "b."
δ = criteria scale.

Once the dominance matrix is defined, the "K" matrix is assembled, which defines the selection of the best set of alternatives.

3. RESULTS

3.1. Alternatives

The 37 combinations of sewage treatment technologies most commonly used in Brazil, as highlighted by Von Sperling (2014), are: A1 - Primary treatment (septic tanks); A2 - Conventional primary treatment; A3 - Advanced primary treatment; A4 - Facultative pond; A5 - Anaerobic pond-facultative pond; A6 - Facultative aerated pond; A7 - Complete mixing aerated pond - sedimentation pond; A8 - Anaerobic pond + facultative pond + maturation ponds; A9 - Anaerobic pond + facultative pond + high-rate pond; A10 - Anaerobic pond + facultative pond + algae removal; A11 - Slow infiltration; A12 - Rapid infiltration; A13 - Surface runoff; A14 - Constructed wetland systems; A15 - Septic tank + anaerobic filter; A16 - Septic tank + infiltration; A17 - UASB reactor; A18 - UASB + activated sludge; A19 - UASB + submerged aerated biofilter; A20 - UASB + anaerobic filter; A21 - UASB + high-rate trickling filter; A22 - UASB + dissolved air flotation; A23 - UASB + polishing ponds/maturation ponds; A24 - UASB + facultative aerated pond; A25 - UASB + complete mixing aerated pond + settling pond; A26 - UASB + surface runoff; A27 - Conventional activated sludge; A28 - Extended aeration activated sludge; A29 - Batch activated sludge (extended aeration); A30 - Conventional activated sludge with biological nitrogen removal; A31 - Conventional activated sludge with biological nitrogen/phosphorus removal; A32 - Conventional activated sludge + tertiary filtration; A33 - Low-rate percolating biological filter; A34 - High-rate percolating biological filter; A35 - Submerged aerated biological

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filter with nitrification; A36 - Submerged aerated biological filter with biological nitrogen removal; A37 - Septic tank + rotating biological contactor.

The 37 alternatives presented were used in the application of the Electre I method for the selection of sewage treatment technologies for the three proposed scenarios.

3.2. Criteria, Weights, and Thresholds

Chart 1 presents the criteria defined for the study, including economic, technical, social, and environmental characteristics, based on a systematic literature review. It also shows the normalized weights assigned by experts and the vector direction for each criterion in the three scenarios.

Chart 1 - Normalized criteria weights - Scenario 1, Scenario 2, and Scenario 3

Characteristic	Criterion	Weight for scenario 1	Weight for scenario 2	Weight for scenario 3	Vector Direction
Economic	Operation and maintenance	0,0955	0,1345	0,1722	Minimization
	Consumed power	0,0746	0,1164	0,1389	Minimization
	Demand per area	0,0418	0,1309	-	Minimization
	Investment	0,0701	0,0727	0,15	Minimization
Environmental	Liquid sludge to be treated	0,0791	0,1018	0,1167	Minimization
	Dehydrated sludge to be disposed of	0,0896	-	-	Minimization
Social	Odor	0,0567	0,0727	-	Minimization
	Noise	0,0328	-	-	Minimization
	Aerosols	0,0224	-	-	Minimization
	Insect attraction	0,0448	0,0473	0,0444	Minimization
Technical	Reliability	0,097	-		Minimization
	Complexity	0,0791	0,1527	0,1556	Minimization
	Flow rate variability resistance	0,0418	-	-	Minimization
	Coliforms	0,0522	0,0727	0,1	Minimization
	Nutrients	0,0567			Minimization
	Biochemical Oxygen Demand (BOD)	0,0657	0,0982	0,1222	Minimization

Source: Prepared by the authors.

Based on the literature review, the concordance threshold (c) was set at 0.6, and the discordance threshold (d) was set at 0.4, as adopted by Andrade (2014) and Araújo (2014).

3.3. Scenario 1: Population above 50,000 Inhabitants

After collecting the necessary data for the Electre I method, the data for Scenario 1 was entered into an Excel spreadsheet, as shown in Table 1.

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Table 1 - Input data for Electre I method in Scenario 1

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
A1	8	0	0	150	360	35	2	4	5	4	4	3	4	1	1	1
A2	8	0	0	150	730	40	2	4	5	3	4	3	4	2	3	2
A3	35	0	0	200	2.500	110	3	4	5	3	4	3	4	2	3	2
A4	8	0	4	160	90	30	4	5	5	2	4	1	4	3	2	3
0A5	8	0	3	140	160	60	1	5	5	2	4	1	4	3	2	3
A6	20	18	1	200	220	30	4	1	1	3	4	2	4	3	2	3
A7	20	22	0	200	360	35	3	1	1	2	3	3	3	3	2	3
A8	10	0	5	370	160	60	3	5	5	2	4	1	4	5	3	3
A9	14	2	4	200	160	60	3	2	2	2	4	3	4	5	4	3
A10	14	0	3	200	190	70	3	5	5	2	4	3	4	3	2	4
A11	6	0	50	200	0	0	2	5	6	2	4	2	4	4	4	5
A12	8	0	6	200	0	0	2	5	5	2	4	2	4	4	4	5
A13	10	0	4	200	0	0	2	5	6	2	4	1	4	2	3	4
A14	10	0	5	200	0	0	2	5	5	2	4	1	4	2	2	4
A15	20	0	0	300	1.000	50	2	4	5	4	3	2	3	2	1	3
A16	12	0	2	150	360	35	2	5	5	2	3	2	4	4	4	5
A17	10	0	0	120	220	35	2	4	5	4	3	2	2	2	1	3
A18	30	20	2	250	400	60	2	5	5	2	4	1	2	5	3	3
A19	30	20	0	250	400	55	2	5	5	2	4	1	2	5	3	3
A20	15	0	0	220	300	50	2	5	5	2	4	1	2	5	3	3
A21	18	0	0	250	400	55	2	5	5	2	4	1	2	5	3	3
A22	22	12	0	250	470	75	2	5	5	2	4	1	2	5	3	3
A23	14	0	3	450	250	35	2	5	5	2	4	1	2	5	3	3
A24	20	5	0	250	300	50	2	5	5	2	4	1	2	5	3	3
A25	20	8	0	250	300	50	2	5	5	2	4	1	2	5	3	3
A26	18	0	3	250	220	35	2	5	5	2	4	1	2	5	3	3
A27	40	26	0	300	3.000	90	4	1	6	4	4	5	3	2	3	4
A28	40	35	0	270	2.000	105	5	1	6	4	4	4	4	2	3	5
A29	40	35	0	270	2.000	105	5	1	6	4	4	5	3	2	3	4
A30	50	22	0	400	3.000	90	4	1	6	4	4	5	3	2	3	4
A31	55	22	0	450	3.000	90	4	1	6	4	4	5	3	2	3	4
A32	55	26	0	450	3.100	100	4	1	6	4	4	5	3	2	3	4
A33	30	0	0	300	1.100	80	4	4	4	2	4	3	3	2	3	4
A34	30	0	0	300	1.900	80	4	4	4	3	4	3	4	2	2	4
A35	35	26	0	250	3.000	90	5	2	5	4	4	4	3	2	2	5
A36	35	22	0	300	3.000	90	5	2	5	4	4	4	3	2	2	5
A37	30	0	0	300	1.500	75	4	4	5	3	3	3	3	2	2	4

Source: Von Sperling (2014).

The normalization of input data was carried out by dividing the value of each criterion by the total sum of the indicated criterion. Subsequently, the scale value (δ) of each criterion was determined for the construction of concordance and discordance matrices. In this process, concordance indices were calculated for matrix construction. These indices involve the summation of criterion weights, where one alternative surpasses another, and discordance indices, determined by the maximum difference between individual assessments, divided by the scale value (δ).

Before constructing the dominance matrix, concordance and discordance thresholds were defined in this study as c = 0.6 and d = 0.4, respectively. The next step was to verify the conditions established in Equation 6.

Once the dominance matrix was defined, the final step of the method involved representing the relationships of over-classification using graphs. Figure 1 presents the over-

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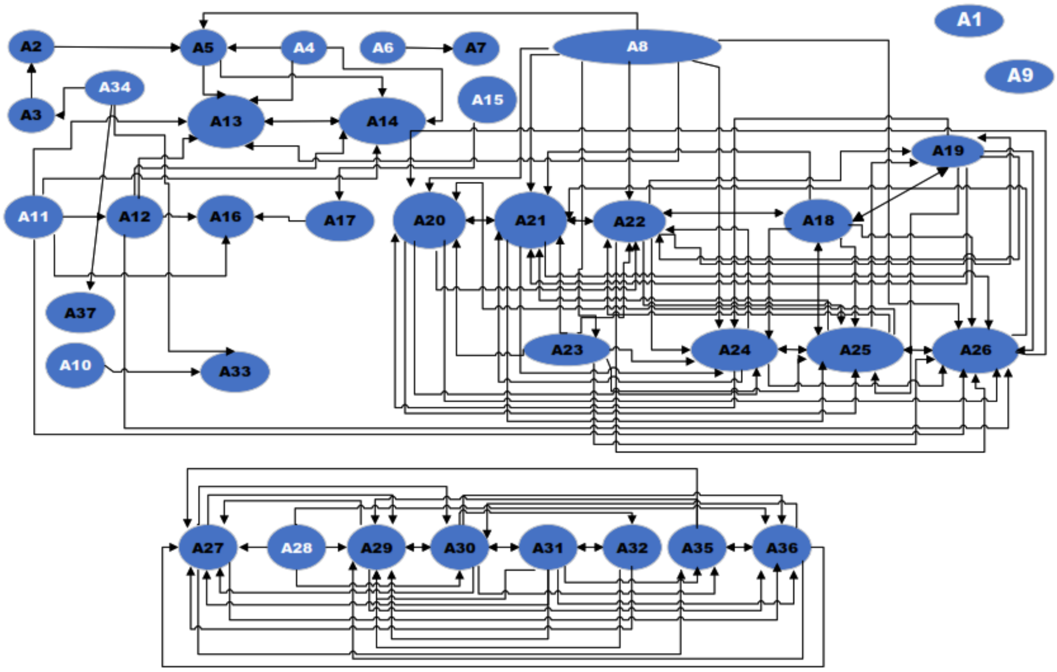
classification relationship, where it can be observed that alternatives A1, A4, A6, A8, A9, A10, A11, A15, A28, and A34 (highlighted in white in Figure 2) were not surpassed by any other alternative.

Figure 1 - Overclassification ratio of the alternatives, using a graph with c = 0.6 and d = 0.4, scenario 1



Source: Prepared by the authors.

For Scenario 1, using the Electre I method, a set of 10 alternatives was selected as the most suitable for the population with over 50,000 inhabitants: primary treatment - septic tanks, facultative pond, facultative aerated pond, anaerobic pond + facultative pond + maturation pond, anaerobic pond + facultative pond + high-rate pond, anaerobic pond + facultative pond + algae removal, slow infiltration, septic tank + anaerobic filter, extended aeration activated sludge, and high-rate percolating biological filter.

Regarding the selected technologies, two of them require special consideration:

- Considering the specificity of service due to population and pollutant removal efficiency of septic tanks, their use is proposed along with the implementation of additional systems such as anaerobic filters, submerged aerated filters, batch activated sludge, etc., for areas with low population density or where sewer network installation is not feasible due to cost or topography.
- Although the area demand criterion is not a major preference among the majority of consulted experts, considering the population considered for Scenario 1 and the extremely high area requirement of the slow infiltration technology, it is advisable to consider this technology for the final disposal of treated sewage.

All selected treatment technologies in Scenario 1 require preliminary treatment units and solutions for the treatment and final disposal of generated sludge.

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3.4. Scenario 2: Population between 10,000 and 50,000 Inhabitants

After defining the necessary data for the method application, the data for Scenario 2 were entered for each alternative concerning each criterion in an Excel spreadsheet, as shown in Table 2.

Table 2 - Input data for the Electre I method for scenario 2

	CC1	CC2	CC3	CC4	CC5	CC6	CC7	CC8	CC9	CC10
A1	8	0	150	0,05	360	2	4	3	1	1
A2	8	0	150	0,04	730	2	3	3	2	2
A3	35	0	200	0,06	2.500	3	3	3	2	2
A4	8	0	160	4,00	90	4	2	1	3	3
A5	8	0	140	3,00	160	1	2	1	3	3
A6	20	18	200	0,50	220	4	3	2	3	3
A7	20	22	200	0,40	360	3	2	3	3	3
A8	10	0	370	5,00	160	3	2	1	5	3
A9	14	2	200	3,50	160	3	2	3	5	3
A10	14	0	200	3,20	190	3	2	3	3	4
A11	6	0	200	50,00	0	2	2	2	4	5
A12	8	0	200	6,00	0	2	2	2	4	5
A13	10	0	200	3,50	0	2	2	1	2	4
A14	10	0	200	5,00	0	2	2	1	2	4
A15	20	0	300	0,35	1.000	2	4	2	2	3
A16	12	0	150	1,50	360	2	2	2	4	5
A17	10	0	120	0,10	220	2	4	2	2	3
A18	30	20	250	2,00	400	2	2	1	5	3
A19	30	20	250	0,15	400	2	2	1	5	3
A20	15	0	220	0,15	300	2	2	1	5	3
A21	18	0	250	0,20	400	2	2	1	5	3
A22	22	12	250	0,15	470	2	2	1	5	3
A23	14	0	450	2,50	250	2	2	1	5	3
A24	20	5	250	0,30	300	2	2	1	5	3
A25	20	8	250	0,30	300	2	2	1	5	3
A26	18	0	250	3,00	220	2	2	1	5	3
A27	40	26	300	0,25	3.000	4	4	5	2	4
A28	40	35	270	0,25	2.000	5	4	4	2	5
A29	40	35	270	0,25	2.000	5	4	5	2	4
A30	50	22	400	0,25	3.000	4	4	5	2	4
A31	55	22	450	0,25	3.000	4	4	5	2	4
A32	55	26	450	0,30	3.100	4	4	5	2	4
A33	30	0	300	0,30	1.100	4	2	3	2	4
A34	30	0	300	0,25	1.900	4	3	3	2	4
A35	35	26	250	0,15	3.000	5	4	4	2	5
A36	35	22	300	0,15	3.000	5	4	4	2	5
A37	30	0	300	0,20	1.500	4	3	3	2	4

Source: Von Sperling (2014).

The same normalization procedure used in Scenarios 1 and 2 was applied to the input data for Scenario 2. The last step of the method involved representing the over-classification relationships using graphs. Figure 2 presents the over-classification relationship, where alternatives A1, A4, A6, A11, and A17 (highlighted in white) were not surpassed by any other alternative.

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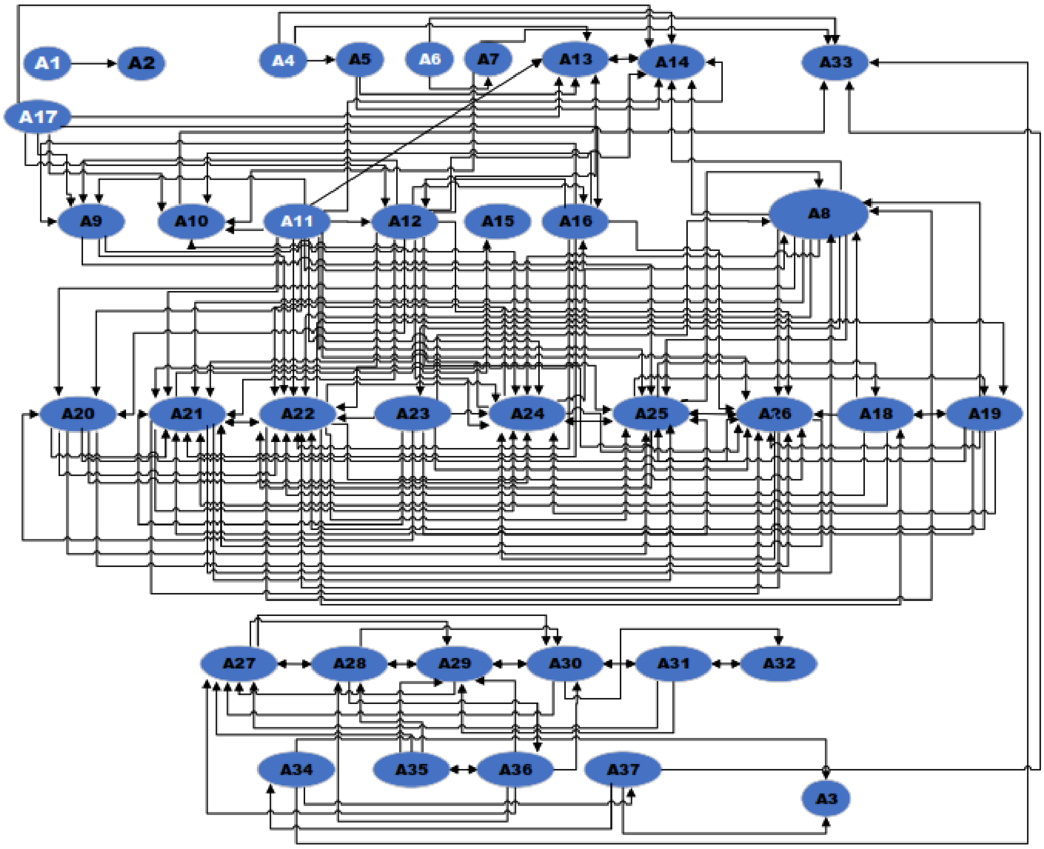
Figure 1 - Overclassification ratio of the alternatives, using a graph with c = 0.6 and d = 0.4, scenario 2



Source: Prepared by the authors.

In this scenario, the set of most suitable technologies for the population of 10,000 to 50,000 inhabitants, determined using the Electre I method, comprises five alternatives: primary treatment (septic tanks), facultative pond, facultative aerated pond, slow infiltration, and UASB reactor.

The UASB technology can be used as a single treatment unit or combined with post-treatment. During the evaluation for the choice of the treatment system, considering the difficulty in meeting discharge standards, it is prudent to assess the inclusion of post-treatment to the UASB reactor, such as series polishing ponds, aerobic reactor + secondary settler, biological filter + secondary settler, aerated biofilter, surface flow, anaerobic filter, etc.

For the selected alternatives, primary treatment, and slow infiltration, the same considerations as those in Section 3.3 apply. All selected treatment technologies in Scenario 2 require preliminary treatment units and solutions for the treatment and final disposal of generated sludge.

3.5. Scenario 3: Population Below 10,000 Inhabitants

After defining the necessary data for the method application, the data for Scenario 3 were entered for each alternative concerning each criterion in an Excel spreadsheet, as shown in Table 3.

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Table 3 - Input data for the Electre I method for scenario 3

	CCC1	CCC2	CCC3	CCC4	CCC5	CCC6	CCC7	CCC8
A1	8	0	150	360	4	3	1	1
A2	8	0	150	730	3	3	2	2
A3	35	0	200	2.500	3	3	2	2
A4	8	0	160	90	2	1	3	3
A5	8	0	140	160	2	1	3	3
A6	20	18	200	220	3	2	3	3
A7	20	22	200	360	2	3	3	3
A8	10	0	370	160	2	1	5	3
A9	14	2	200	160	2	3	5	3
A10	14	0	200	190	2	3	3	4
A11	6	0	200	0	2	2	4	5
A12	8	0	200	0	2	2	4	5
A13	10	0	200	0	2	1	2	4
A14	10	0	200	0	2	1	2	4
A15	20	0	300	1.000	4	2	2	3
A16	12	0	150	360	2	2	4	5
A17	10	0	120	220	4	2	2	3
A18	30	20	250	400	2	1	5	3
A19	30	20	250	400	2	1	5	3
A20	15	0	220	300	2	1	5	3
A21	18	0	250	400	2	1	5	3
A22	22	12	250	470	2	1	5	3
A23	14	0	450	250	2	1	5	3
A24	20	5	250	300	2	1	5	3
A25	20	8	250	300	2	1	5	3
A26	18	0	250	220	2	1	5	3
A27	40	26	300	3.000	4	5	2	4
A28	40	35	270	2.000	4	4	2	5
A29	40	35	270	2.000	4	5	2	4
A30	50	22	400	3.000	4	5	2	4
A31	55	22	450	3.000	4	5	2	4
A32	55	26	450	3.100	4	5	2	4
A33	30	0	300	1.100	2	3	2	4
A34	30	0	300	1.900	3	3	2	4
A35	35	26	250	3.000	4	4	2	5
A36	35	22	300	3.000	4	4	2	5
A37	30	0	300	1.500	3	3	2	4

Source: Von Sperling (2014).

The input data for Scenario 3 underwent the same normalization process as in Scenarios 1 and 2. The last step of the method involved representing the over-classification relationships using graphs. Figure 3 presents the over-classification relationship, where alternatives A1, A6, and A17 were not surpassed by other alternatives.

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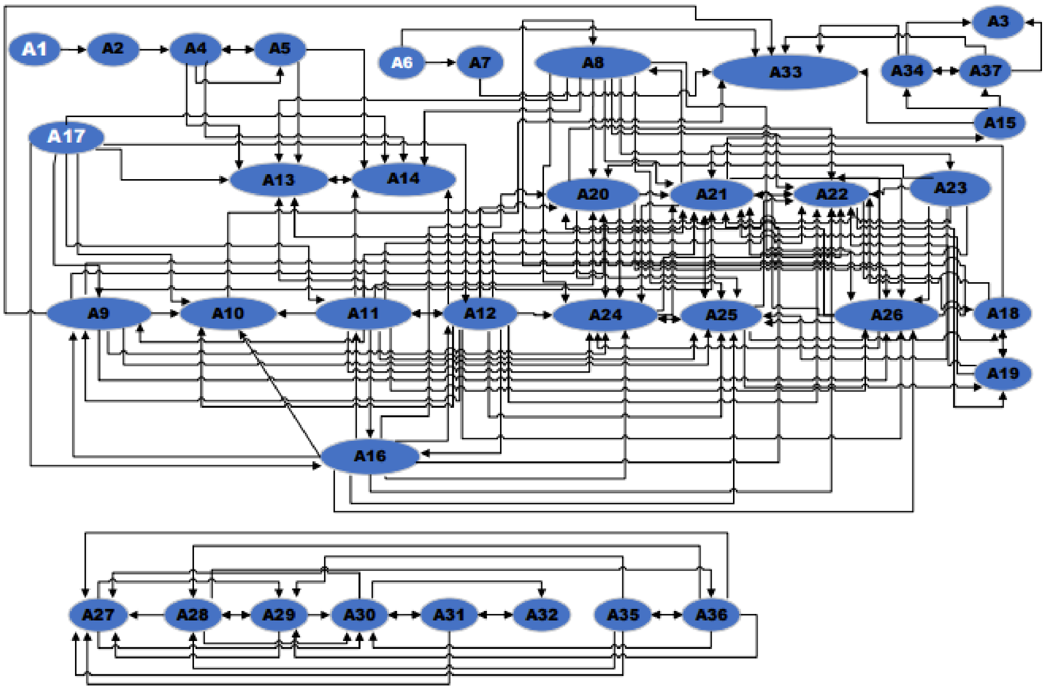
Figure 2 - Overclassification ratio of the alternatives, using a graph with c = 0.6 and d = 0.4, scenario 3



Source: Prepared by the authors.

For Scenario 3, the set of most suitable technologies for the population below 10,000 inhabitants, determined using the Electre I method, comprises three alternatives: primary treatment (septic tanks), facultative aerated pond, and UASB reactor.

The UASB technology can be used as a single treatment unit or combined with post-treatment. During the evaluation for the choice of the treatment system, considering the difficulty in meeting discharge standards, it is advisable to evaluate the inclusion of post-treatment to the UASB reactor with series polishing ponds. The recommendation of ponds is based on ease of operation, considering that most municipalities with fewer than 10,000 inhabitants in the state of Goiás are far from major urban centers, making maintenance challenging. All selected treatment technologies in Scenario 3 require preliminary treatment units and solutions for the treatment and final disposal of generated sludge.

3.6. Sensitivity Analysis

Initially, new weights for the adopted criteria were randomly assigned. Subsequently, new threshold values were linearly assigned for scenarios 1, 2, and 3, which did not significantly affect the obtained results. New thresholds were defined, and new simulations were carried out for the three scenarios, with c = 0.7 and d = 0.3, and then for c = 0.5 and d = 0.5.

3.6.1. Scenario 1: Population above 50,000 Inhabitants

The thresholds defined for scenario 1, c = 0.6 and d = 0.4, although widely used in this study, were not the most efficient for solving this type of problem. After sensitivity analysis,

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concordance and discordance thresholds c = 0.5 and d = 0.5 were found to be more suitable for resolving this issue. These thresholds eliminated a significant number of options and selected the set with the best alternatives (A8 and A11).

Considering the preferences of experts regarding the assigned weights, the Electre I method was deemed suitable for selecting sewage treatment technologies. This decision was made because the selected technologies align with those currently used in the state, and the cosulted experts work in the field of sanitation in the state of Goiás.

For septic tank technologies, it is advisable to consider them for areas with low population density or where the implementation of a sewage network is not possible due to cost or topographical reasons. Additionally, slow infiltration technology should be considered as an option for the final disposal of treated sewage, especially in areas with limited or few alternatives for a receiving body.

When choosing the treatment type for each municipality based on the specific characteristics of each location and the available analysis time, the decision-maker can adopt either the smallest or the largest presented set.

3.6.2. Scenario 2: Population between 10,000 and 50,000 Inhabitants

For scenario 2, thresholds c = 0.5 and d = 0.5 eliminated a significant number of options and selected a set with one alternative (A11). However, the selected slow infiltration alternative alone is not suitable as the sole treatment technology for this population range.

Considering the problem to be solved, it is more appropriate for this study to select the set composed of the five alternatives chosen for thresholds c = 0.6 and d = 0.4: primary treatment (septic tanks), facultative pond, facultative aerated pond, slow infiltration, and UASB reactor.

3.6.3. Scenario 3: Population below 10,000 Inhabitants

For scenario 3, the defined thresholds (c = 0.6 and d = 0.4) proved suitable for resolving this type of problem, as they eliminated a significant number of options and selected the set with the best alternatives: primary treatment (septic tanks), facultative aerated pond, and UASB reactor.

The selected technologies were appropriate for the population below 10,000 inhabitants. When choosing the treatment type for each municipality based on the specific characteristics of each location and the available analysis time, the decision-maker can adopt either the smallest or the largest presented set.

4. CONCLUSIONS

The Electre I method was used for selecting domestic wastewater treatment technologies, proving suitable for the problem at hand, where the expected result is the selection of the best alternatives. The objective is to eliminate as many possible actions as

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possible and incorporate criteria related to social, economic, technical, and environmental aspects.

For scenario 1, with the adoption of 16 evaluation criteria using thresholds c = 0.6 and d = 0.4, a set of 10 alternatives was selected as the most suitable for the population of over 50,000 inhabitants: primary treatment - septic tanks, facultative pond, facultative aerated pond, anaerobic pond + facultative pond + maturation pond, anaerobic pond + facultative pond + high-rate pond, anaerobic pond + facultative pond + algae removal, slow infiltration, septic tank + anaerobic filter, extended aeration activated sludge, and high-rate biological trickling filter.

For scenario 2, with the adoption of 10 evaluation criteria using thresholds c = 0.6 and d = 0.4, a set of five alternatives was formed as the most suitable for the population between 10,000 and 50,000 inhabitants: primary treatment (septic tanks), facultative pond, facultative aerated pond, slow infiltration, and UASB reactor.

For scenario 3, with a population of up to 10,000 inhabitants and the adoption of eight evaluation criteria using thresholds c = 0.6 and d = 0.4, a set of three alternatives was formed: primary treatment (septic tanks), facultative aerated pond, and UASB reactor.

As observed in the presentation of the method application results, the larger the number of criteria, the larger the selected set. The selected technologies, according to expert preferences, are less complex, cost-effective, and operationally simple. Generally, there was no concern about the availability of space since most selected processes require a larger area for implementation.

To assess the stability of the method, considering the subjective nature of weight assignment, a sensitivity analysis was conducted. Consistency of results was observed after altering the assigned weights for the three scenarios. As the method is also sensitive to defined thresholds, new thresholds were assigned for the three scenarios. Increasing the restriction led to a larger set of selected alternatives, contrary to one of the method's objectives, which is to eliminate as many actions as possible.

After sensitivity analysis, a set composed of two alternatives (anaerobic pond + facultative pond + maturation pond and slow infiltration) was selected for the population of over 50,000 inhabitants. For the population between 10,000 and 50,000 inhabitants, the smallest selected set consisted of one alternative, slow infiltration, after sensitivity analysis. However, this single alternative of slow infiltration is not the only treatment technology suitable for this population range. Therefore, it is considered more appropriate for this study, considering the problem to be solved, to select the set composed of the five alternatives chosen before sensitivity analysis: primary treatment (septic tanks), facultative pond, facultative aerated pond, slow infiltration, and UASB reactor. For the population of up to 10,000 inhabitants, the set was composed of three alternatives (septic tanks, facultative aerated pond, and UASB reactor).

It is recommended to use septic tank technology, selected in scenarios 2 and 3, for areas with low population density or where the implementation of a sewage network is not possible due to cost or topographical constraints. Also, due to its pollutant removal efficiency, it is suggested to implement this technology along with post-treatments such as anaerobic filter, submerged aerated filter, batch activated sludge, etc.

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Considering the highly elevated area requirement for slow infiltration technology, it is important to note that this technology can be used for the final disposal of treated sewage for scenarios 1 and 2, considering the population to be served, as well as for municipalities with limited or no options for receiving bodies.

The application of the method proved suitable for solving the presented problem, optimizing decision-makers' time during the process of choosing wastewater treatment technologies.

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