Ambiente & Água - An Interdisciplinary Journal of Applied Science
ISSN 1980-993X – doi:10.4136/1980-993X
www.ambi-agua.net
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Technical-financial analysis of conventional and alternative technologies for the treatment of sewage in small to large cities

ARTICLES doi:10.4136/ambi-agua.2906

Received: 07 Dec. 2022; Accepted: 22 May 2023

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ABSTRACT

In Brazil, there is low coverage of sewage collection and treatment, a condition that is even more critical in smaller cities. One reason for this is the lack of resources for investment in conventional reactors. The present study therefore compared the costs of different treatment alternatives based on the average values of construction and operation present in the literature, the values of the price per square meter for land acquisition, electricity tariffs, and final sludge disposal by considering different operating times of wastewater treatment plants (WWTPs). This allowed inferences about the costs associated with the choice of the configuration of a municipal WWTP. Based on the scenarios studied, it was observed that the conventional systems evaluated are, in general, more costly, especially after several years of operation. However, the choice of these treatment units may be more interesting in scenarios with high cost per square metre and lower electricity rates or where there is no area availability. For smaller cities and with lower real estate pressure, the natural systems evaluated are more indicated due to the low total costs (construction and operation) and adequate pollutant-removal efficiencies.

Keywords: choice of wwtp, methodology of choice sewage treatment, natural systems, treatment costs.

Análise técnico-financeira de tecnologias convencionais e alternativas para o tratamento de esgoto sanitário em cidades de pequeno a grande porte

RESUMO

No Brasil, verifica-se baixa cobertura de coleta e tratamento de esgotos, condição que é ainda mais crítica em cidades de menor porte. Um dos motivos apontados é a falta de recursos para investimento em reatores convencionais. Assim, o presente trabalho objetivou comparar custos de diferentes alternativas de tratamento, tendo como base, valores médios de construção e operação, presentes na literatura, valores do preço do metro quadrado para aquisição de terra, de tarifas de energia elétrica e da disposição final do lodo, considerando diferentes tempos de funcionamento das Estações de Tratamentos de Esgotos (ETE), permitindo fazer inferências sobre os custos associados na escolha da configuração de uma ETE municipal. Com base nos cenários estudados, observou-se que os sistemas convencionais avaliados são, em geral, mais onerosos, sobretudo após vários anos de operação. A escolha dessas unidades de tratamento, no entanto, pode ser mais interessante em cenários com alto custo do metro quadrado e tarifas de energia elétrica mais baratas, ou onde não haja disponibilidade de área. Para cidades de menor porte, com menor pressão imobiliária, os sistemas naturais avaliados são mais indicados, pelos baixos custos totais (construção e operação) e adequadas eficiências de remoção de poluentes.

Palavras-chave: custos de tratamento, escolha de ETE, metodologia de escolha, sistemas naturais, tratamento de esgoto.

1. INTRODUCTION

The proper management of wastewater, mainly of sanitary origin, has become a great challenge in recent years for developing countries (Ferreira *et al.*, 2021; Ashouri and Rafei, 2018). According to estimates presented in the Sanitation ATLAS (ANA, 2017), which has data for the year 2013, 43% of the Brazilian population is served with sewage collection and treatment, 18% have sewage collected but not treated, 12% have individual solutions, while the rest have no collection or treatment. As a result of this lack of sanitation infrastructure, the quality of the receiving water bodies deteriorates, which has adverse consequences for biodiversity and society (Pujol-Vila *et al.*, 2016; Kaufman *et al.*, 2021).

The consequences of the discharge of sewage into the environment without proper treatment include the depletion of dissolved oxygen (DO) levels, the eutrophication of water bodies, the salinization of the soil, increases in water treatment cost, reductions in the water infiltration capacity in the soil, and the proliferation of disease vectors (Liang and Yang, 2019; Matos, 2010; von Sperling, 2014). Therefore, to achieve better environmental and social conditions, it is necessary to adopt measures to reduce the load of pollutants released into the environment, including increasing the efficiency of existing systems and improving the coverage of sewage collection and treatment systems (Lima *et al.*, 2018).

The lack of effluent treatment is more prominent in smaller cities due to financial difficulties and the lack of professional qualifications and technical capacity in terms of the managers involved (Ferreira *et al.*, 2021).

In this scenario, alternative treatment systems (constructed wetland system (CWs); overland flow systems (OFs), anaerobic ponds (ANPs) + facultative ponds (FPs); facultative ponds (FPs) and fertigation (FERT)) are usually adopted as solutions in small cities to replace conventional reactors (upflow anaerobic sludge blankets (UASBs); UASBs + activated sludge (AS); UASBs + submerged aerated biofilters (SABs); and UASBs + trickling filters (TFs)) due to lower installation costs (provided there are favourable topographic conditions) and greater operational simplicity. However, few studies have performed financial comparisons of the alternatives for different scenarios by considering factors such as the size of the population served by sewage, the station operating time, and installation and operating costs.

To support the comparison between the treatment options evaluated in this study, it is necessary to analyse the data of the involved costs from the implementation to continuous operation for some years. Authors such as Xian-Wen (1995), Tsagarakis *et al.* (2003), von Sperling and Salazar (2013) and von Sperling (2014) have typical ranges of demand for built-up areas and construction, operating and maintenance per inhabitant costs or costs per flow-rate of treated sewage. However, this approach is simplified because it does not consider regional kilowatt-hour prices, which are embedded in the price of operation, labour, square metre of the area, and construction materials, important in terms of the magnitude of construction and implementation costs (Gavasci *et al.*, 2010). In addition, according to Goffi *et al.* (2018) and

Niu *et al.* (2016), some factors that make up the total amount may be independent of the treatment capacity of the wastewater treatment plant (WWTP) and may be intrinsic to the particularities of each location. Thus, there are several aspects to be considered when choosing the design of a WWTP unit.

The present study therefore compared the costs of construction, operation, and maintenance of WWTPs with the conventional and natural treatment configurations mentioned above by simulating the values associated with different population sizes, associated cost ranges (construction, operation, and maintenance), and periods of operation of the WWTP. The influence of electricity prices, land square metres, and sludge disposal was also evaluated.

2. RESEARCH METHODS

The study was divided into parts according to the type of approach given and is organized as following:

2.1. Comparison of costs for different population sizes

Graphs of the total costs were constructed by using the values proposed by von Sperling (2014) (Table 1) considering the per inhabitant costs of construction, operation, and maintenance.

In the analyses, the following reactors were compared: UASBs, UASBs followed by post treatment with AS, SABs and TFs, which are the conventional systems; CWs, OFs, ANPs + FPs, and FPs, in addition to disposal in the soil to provide nutrients, a technique called FERT, which constitute the natural treatment units. In von Sperling (2014), the latter is introduced as slow infiltration. These configurations are widely used in Brazil, as pointed out by Ferreira *et al.* (2021), ANA (2017) and Marques *et al.* (2017).

Scenarios of populations of one thousand to ten million inhabitants were constructed to cover the common ranges found in Brazilian cities.

2.2. Comparison of costs for different population sizes according to operating time

There is no variation in costs as a function of the number of inhabitants, as the costs presented by von Sperling (2014) are per inhabitant values regardless of the size of the city, and one reactor is the most expensive, and the other is the most economically feasible in all population ranges. However, while the construction costs are present only in the first year, the values associated with the operation and maintenance of the reactors are continuous, year after year. Thus, there may be changes over time, and a system may become more interesting than another from an economic point of view. For this comparison, scenarios were analysed with 1, 2, 5, 10, 20 and 50 years of operation by multiplying the number of years of operation by the operation and maintenance cost of Table 1. Scenarios of up to 20 years are usually used; however, in the present study, we chose to also consider the 50-year scenario, as it presents interesting results, especially for fertigation.

Table 1. Area demand, power consumption and construction and operating costs per inhabitant typical of treatment systems.

Systems		Area demand (m^2 hab^{-1})	power consumed (kWh hab^{-1} $year^{-1}$)	dehydrated sludge (L hab^{-1} $year^{-1}$)	construction (BRL hab^{-1})	Operation and maintenance (BRL hab^{-1} $year^{-1}$)
Conventional	UASB	0,10	0	35	120	10
	UASB + AS	0,2	20	60	250	30
	UASB + SAB	0,15	20	55	250	30
	UASB + TF	0,2	0	55	250	18
Natural	CWs	5,0	0	0	200	10
	OFs	3,5	0	0	200	10
	ANP + FP	3,0	0	60	140	8
	FP	4,0	0	30	160	8
	FERT	50	0	0	200	6

Where, UASB refers to Upflow Anaerobic Sludge Blanket, AS, to Activated Sludge, SAB, to submerged aerated biofilter, TF, to Trickling Filters, CWs, to Constructed Wetland Systems, OFs, to overland flow systems, ANP, to Anaerobic Pond, FP, to Facultative Pond, FERT, to Fertigation. The upper limits of the ranges presented in the referenced source were considered.
Source: Von Sperling (2014).

2.3. Comparison of costs using different values of prices per square metre of land, electricity, and final sludge disposal

The third step consisted of collecting information from various sources regarding the costs per square metre of land, the price of electricity, and the cost of disposing of the solid waste generated in the treatment process, which is the sludge from the WWTP. The costs of the area were surveyed through public agencies that have bare land values, such as the Institute of Colonization and Agrarian Reform (Incra, 2018) and the Company of Technical Assistance and Rural Extension of the State of Minas Gerais (Emater, 2018), in addition to sites of real estate agencies of cities with different population sizes. According to Xian-Wen (1995), the cost of land can vary considerably depending on its use, productivity, availability, and owner, so a wide range of area costs can be found within the same municipality. In addition, in larger cities, demand, speculation, and real estate pressure are higher, which can increase the price per square metre.

Table 1 shows the costs associated with construction; however, as previously discussed, these can be variable depending on the characteristics of the cities and the region where the WWTP is installed. Thus, a new analysis was performed with calculation of the construction based only on the land acquisition costs by adopting a range of BRL 0.10 to BRL 5.00 per square metre, which is a price range compatible with that was found in the sources of national data, in real estate agencies, and in the references Emater (2018) and Incra (2018). In this regard, natural systems tend to have higher costs given the greater area demand. However, they have fewer problems with sludge management and energy expenditure, which makes their adoption interesting for smaller cities. Additionally, to evaluate the influence of energy costs and sludge management, these data were jointly analysed and were included in the calculation of financial costs.

The state tariffs for 2018 are shown on the website of the National Electric Energy Agency (ANEEL, 2018). For comparison, the scenarios were set with the minimum values (BRL 0.31 kWh^{-1}), means (BRL 0.51 kWh^{-1}), and maximum values (BRL 0.77 kWh^{-1}).

To evaluate the final sludge disposal costs, the values presented in Andreoli *et al.* (2014) for final disposal in landfills were used – the most common destination in Brazil –, which are US $20 to 60 per ton of dewatered sludge. In this study, the cost of BRL 220.00 per ton of sludge was considered, which corresponds to the upper limit of the range reported by Andreoli *et al.* (2014) converted using the ratio of US $1.00 = BRL 3.67. To convert the values presented in Table 1 to tons, the density of the dewatered sludge was considered to be 1100 kg m^{-3} (Andreoli *et al.*, 2014).

It should be noted that the costs presented here may be out of date. For the application of the proposed methodology, aiming at a more careful analysis, for decision making, current and regionalized data should be used.

2.4. Comparison of efficiencies

Table 2 is used to guide the discussions. It shows the typical efficiencies of the reactors evaluated to remove pollutants from sewage, also present in von Sperling (2014). The reason for this is that in addition to choosing the most economical system, the system must have adequate efficiency for the final disposal of the treated effluent.

However, a separate discussion of the financial aspects and removal efficiency does not allow us to choose one alternative over another, as the decision ends up being restricted to financial availability or to a subjective field. To make comparisons with a joint approach of the relevant aspects when adopting a treatment configuration, von Sperling (2014) presents a qualitative comparative analysis, which is used as a quantitative analysis in this study. In the aforementioned reference, four criteria are presented (removal efficiency, economy, operational aspects, and environmental problems), and their respective most relevant characteristics are explained in the legend of Table 3. In this study, each characteristic received a score from zero to five; the score of each characteristic was summed, and a total score was obtained for each of the four evaluation criteria. The sum of scores for each treatment was obtained by summing the total of the four criteria. Thus, the higher the sum, the more appropriate the treatment is. This analysis is shown in Table 3.

Table 2. Average efficiencies of removal of BOD, Total Nitrogen (N), Total Phosphorus (P) and coliforms.

Systems		Average efficiencies of removal			
		BOD (%)	**N (%)**	**P (%)**	**coliforms (units log)**
Conventional	UASB	60-75	<60	< 35	≈ 1
	UASB + AS	83-93	< 60	< 35	1-2
	UASB + SAB	83-93	< 60	< 35	1-2
	UASB + TF	83-93	< 60	< 35	1-2
Natural	CWs	80-90	< 60	< 35	3-4
	OFs	80-90	< 60	< 35	2-3
	ANP + FP	75-85	< 60	< 35	1-2
	FP	75-85	< 60	< 35	1-2
	FERT	90-99	>75	>85	3-5

Source: Von Sperling (2014).

Table 3. Relative assessment of the main treatment systems.

Systems		Removal efficiency *	Economy **	Operational aspects ***	Environmental problems ****	Summation
Conventional	UASB	6	22	20	15	63
	UASB + AS	8	10	21	10	49
	UASB + SAB	9	14	23	16	62
	UASB + TF	8	13	24	15	60
Natural	CWs	9	18	24	14	65
	OFs	9	18	25	10	62
	ANP + FP	7	21	25	13	66
	FP	7	19	25	15	66
	FERT	13	19	23	14	69

* Sum of the gradations presented for the removal of BOD, nutrients and coliforms;
** It encompasses area and energy requirements, and costs of implantation, operation and treatment of generated by-products;
*** Ability to withstand variations in sewage characteristics, reliability, operational simplicity and independence from environmental factors;
**** Bad odors, noise, aerosols and insects and worms.
Source: modified from Von Sperling (2014).

3. RESULTS AND DISCUSSION

The results are presented and discussed below; they are divided by population sizes, operating time, price per square metre of land, electricity and final sludge disposal.

3.1. Comparison of costs for different population sizes

Figure 1 shows the costs for each treatment system. There is no change in the trend with the growth of the size of the treatment plant. This is because the costs embedded in the construction, operation, and maintenance values are fixed per inhabitant and there are nine adjusted equations of type Y = (a+b) x, where a and b are the costs of construction, and operation and maintenance, respectively, x is the number of inhabitants, and Y is the total cost. Except for UASBs, there is therefore no condition in which conventional systems are more economically feasible than natural systems, even though these systems require larger areas. The exception of UASBs occurs because it has construction costs much lower than those of the other treatments.

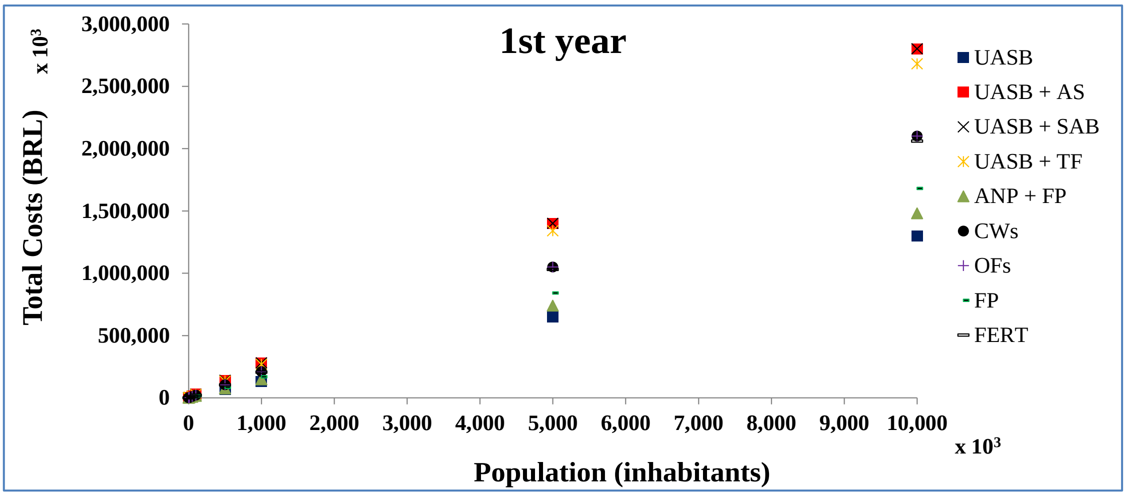

Figure 1. Total costs in the 1st year of operation depending on the number of inhabitants (from the author).

Thus, according to the first analysis, the use of UASB reactors is the most interesting for cost reduction, followed by ANPs + FPs, FPs, and FERT. However, it is also necessary to verify whether the treatment complies with the legal requirements for effluent discharge presented in state (COPAM, 2008) and federal (CONAMA, 2011) laws, which require minimum removal of 70% (annual mean) and 60%, respectively, or effluent concentrations of a maximum of 60 mg L^{-1} and 120 mg L^{-1}, respectively.

The use of the UASB reactor followed by the AS and the SABs is the most costly due to the operating costs, which include the energy expenditure for artificial oxygen supply through aerators.

The Sanitation ATLAS (ANA, 2017) provides the number of inhabitants served by each technology, and the conventional AS covers 24% of the population (16.5 million), followed by the primary treatment (7.9 million), the ANPs + FPs (5.5 million), the UASBs + SAB (4.5 million), and AS with prolonged aeration (4.4 million). The results indicate that, despite being present in fewer stations, due to the costs of aeration and skilled labour, AS serves a larger population. This condition shows that this technology is characterized by economies of scale, i.e., it treats large volumes of sewage in a few treatment units, as discussed by Ferreira *et al.* (2021). This attribute made AS the most viable treatment option for large centres for several years, especially when considering the centralized management of sewage.

3.2. Comparison of costs for different population sizes according to operating time

By using the typical and mean cost values of the treatment units, the conventional systems prove to be even more costly with increasing operating time, and the difference has a tendency to increase over time compared to the natural systems. Figure 2 shows the overview of the costs of the alternatives after 2 years of operation.

The differences between the costs of the least expensive and most expensive systems in the first year range from BRL 1.5×10^5 to BRL 1.5×10^9 with the population ranging from 1,000 to 10,000,000 inhabitants. The lowest costs are found with the UASB reactor operating alone (without posttreatment), and the highest costs are found for AS and SABs. After 2 years of operation, the difference between the options increases, ranging from BRL 1.7×10^5 to BRL 1.7×10^9. After 5 years, the trend is maintained, and the anaerobic reactor remains the most economical. Figure 3 shows that the cost of ANPs + FPs is similar to that of UASB reactor installation in a WWTP only when the simulation of WWTP operation is performed for 10 years. This is because the operating costs of ANPs followed by FPs are lower than those of UASBs; thus, the costs of the Australian system over the years compensates for the difference between the construction costs of the reactors, which is lower for the anaerobic reactor. In this scenario, the cumulative costs of the lower cost alternatives total BRL 3.3×10^5 and the cumulative costs of the most expensive alternatives total BRL 3.3×10^9.

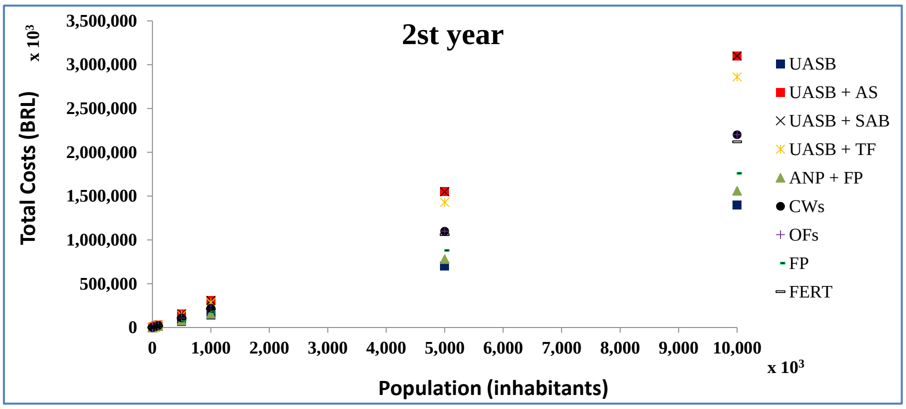

Figure 2. Total costs in the second year of operation depending on the number of inhabitants (from the author).

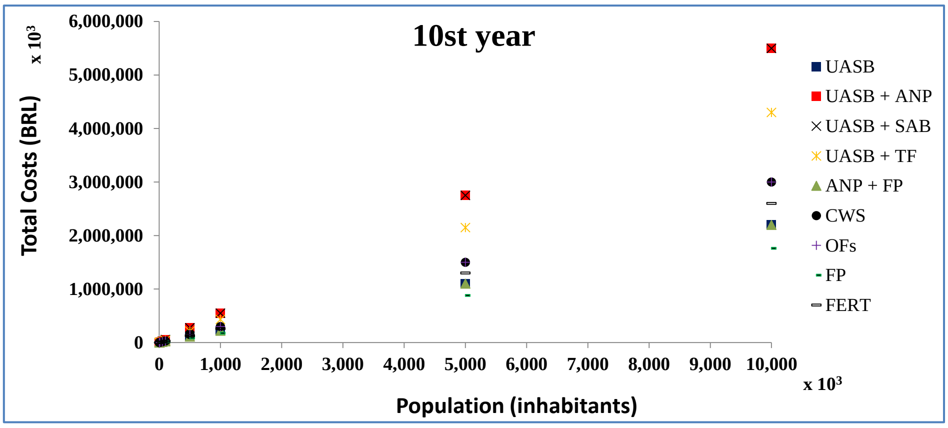

Figure 3. Total costs in the tenth year of operation depending on the number of inhabitants (from the author).

Figure 4 shows that the ANP + FP system becomes the most interesting option twenty years after the WWTP installation, followed by FPs, UASBs, and FERT.

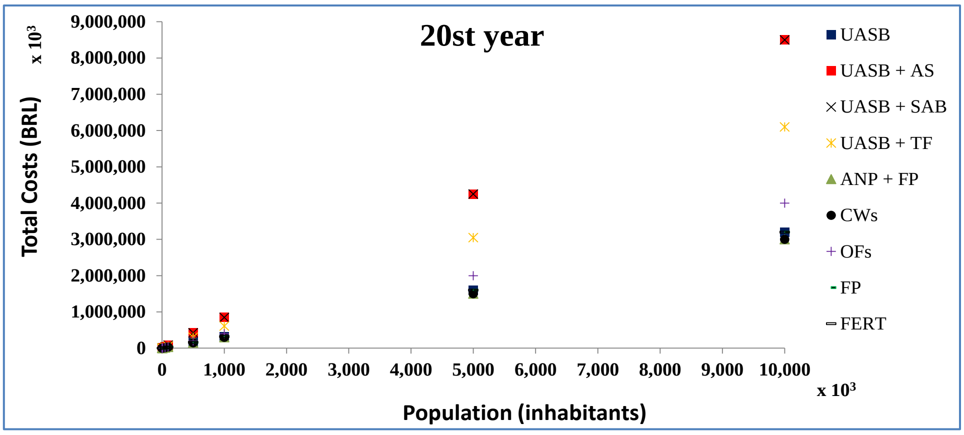

Figure 4. Total costs in the twentieth year of operation depending on the number of inhabitants (from the author).

Figure 5 shows the costs after 50 years of operation. Under this condition, disposal in the soil is the best alternative because of the lower operating costs, which are approximately BRL 6.00 inhab^{-1} year^{-1} (von Sperling, 2014). For the scenario with a population of 10 million inhabitants, FERT becomes BRL 1.25 x 10^{13} less expensive than the UASB reactor, followed by AS or SABs.

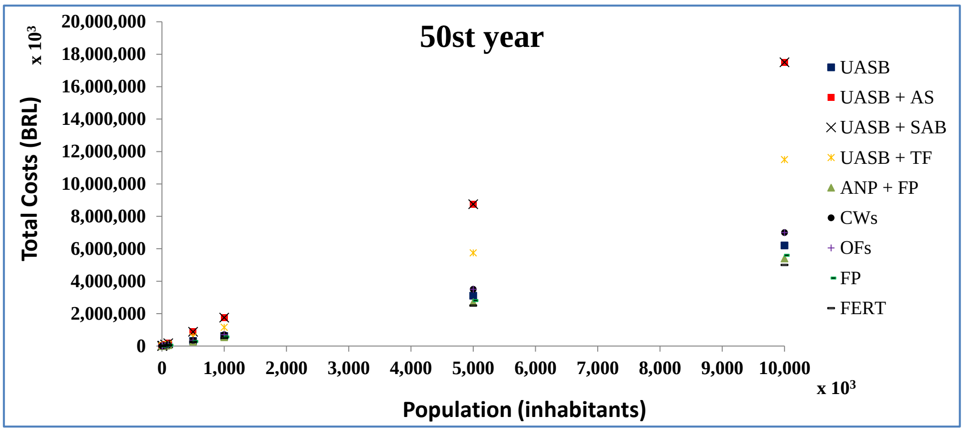

Figure 5. Total costs in the fiftieth year of operation depending on the number of inhabitants (from the author).

The results show that FERT is a viable alternative to be adopted in WWTPs in the long term because its financial costs are lower. In addition, the use of sewage as a source of nutrients is more sustainable and integrated with society and reduces agricultural production costs as it reduces or eliminates the need of artificial fertilizers and reduces the costs of effluent treatment because no advanced treatments are necessary, as discussed by Muga and Mihelcic (2008).

To convert the values of gain per area to per inhabitant gain, it is necessary to adopt the contribution of sewage per inhabitant as 150 L hab^{-1} d^{-1} by estimating the flow rate produced annually. With the dose applied per area (3750 m^3 ha^{-1} year $^{-1}$) and the gain per area, we find that the value was BRL 7.33 per inhabitant. Thus, for example, after 50 years of operation and a population of 10,000 inhabitants, FERT costs BRL 5,000,000.00 and BRL 3,665,000.00 of income is generated, which results in a net expenditure of BRL 1,335,000.00. Another advantage of FERT is that this treatment concept is also the final destination of the wastewater (Matos and Matos, 2017).

Biomass is also generated in CWs, which can be used for biogas production (60% methane) and electricity generation, in addition to being composted for horticultural fertilization and used for animal nutrition. However, for these applications, infrastructure, equipment and area would be needed, whose costs were not considered in this study. Matos *et al.* (2011) cultivated elephant grass in CWs with horizontal subsurface runoff (CWs-HSSR) to treat dairy wastewater (DWW) and estimated that the annual productivity of elephant grass would be 45.9 t ha^{-1} year $^{-1}$ according to evaluation after cuts every 60 days. Thus, there is great potential for using CWs to generate productive areas in smaller spaces.

With regard to the health safety of using vegetation irrigated with wastewater in animal feed, there are several studies that show that the risk is low, especially if the application is interrupted for 2 weeks (Alves *et al.*, 2017; Silva *et al.*, 2016; Santos *et al.*, 2016; 2017). One of the studies shows that the health of animals fed with fertirrigated products was not affected and that most of the heavy metals remain in the roots (Lopes *et al.*, 2020).

What makes CWs noncompetitive in relation to the disposal of wastewater in the soil as a source of nutrients is the higher operating cost, which is mainly associated with the need to change the support medium for filling the units. According to Kadlec and Wallace (2009), the replacement of the substrate is approximately 10 to 19% of the initial cost of the work, in addition to the costs of its final disposal. Even so, the technology has great potential as an alternative or complementary system for the treatment of sewage in developing countries or for the decentralized treatment of several locations (Ferreira *et al.*, 2021; Alufasi *et al.*, 2017; Jung *et al.*, 2018).

3.3. Comparison of costs using different values of the price per square metre, electricity, and final sludge disposal

In this analysis, the costs are evaluated according to different variables by fixing the population at 100,000 inhabitants and varying the costs of area (price per square metre), electricity, and final sludge disposal. Table 4 shows the projections of costs associated with the price of the square metre, energy demand, and sludge disposal in landfills.

The cost assessment shows that the use of runoff ramps and CWs are more indicated in scenarios with the lowest square metre value. FERT is not the most expensive of the natural systems under these conditions, especially due to the absence of sludge generated for disposal. However, this form of treatment becomes the most expensive as the price per square metre increases because of the large space requirement for sewage application as a source of nutrients according to crop requirements (Matos and Matos, 2017)). Thus, this technique may not be an option for large centres. In turn, it may be interesting in places with availability and lower area costs, in addition to generating dividends through crop production. It should also be noted that fertigation is liquid fertilization, being done before, as soil preparation, to receive planting before the rainy season.

Table 4. Total cost projections for area acquisition, cost of energy demand and disposal of dry sludge in landfills, in different scenarios, considering a population of 100,000 inhabitants (for area cost of BRL 0.20 and BRL 5.00 per m^2).

Unit		Total cost (BRL) x 10^5			
		Area cost (BRL m^{-2})			
		0,20		**5,00**	
		Energy cost (BRL kWh^{-1})			
		0,31	**0,77**	**0,31**	**0,77**
Conventional	UASB	8,5	8,5	9,0	9,0
	UASB + AS	20,8	30,0	21,7	30,9
	UASB + SAB	19,5	28,7	20,3	29,5
	UASB + TF	13,4	13,4	14,3	14,3
Natural	CWs	1,0	1,0	25,0	25,0
	OFs	0,7	0,7	17,5	17,5
	ANP + FP	15,1	15,1	29,5	29,5
	FP	8,1	8,1	27,3	27,3
	FERT	10,0	10,0	250,0	250,0

Source: from the author.

The removal and final disposal of sludge from the stabilization ponds was considered over a 10-year horizon.

However, the centralization of treatment in robust and compact units has other costs that may lead to the choice of natural and decentralized alternatives, as observed by Wilderer and Schreff (2000), Gavasci *et al.* (2010) and Ferreira *et al.* (2021). The authors cite, for example, the additional costs when there is the need to install a complex collection network with larger extension and pumping and storage units (Wilderer and Schreff, 2000). According to von Sperling and Salazar (2013), sewage collection costs can correspond to up to 60% of the total costs of implementing a treatment plant.

The joint analysis of the tables and graphs presented shows that the price of the square metre of the land influences the choice of the treatment system more than the size of the population; however, these variables end up indirectly relating to each other. The larger the population size, the greater the demand and the smaller the available area, and thus the higher the costs per square metre.

Thus, we can choose one treatment composition over another depending on the value of the square metre and the prices of sludge disposal and electricity. According to von Sperling and Salazar (2013), the analysis of economic feasibility, however, must be accompanied by the evaluation of the station's objective, in addition to the main characteristics and efficiencies provided by the treatment units.

Table 2 shows that the natural systems are efficient in the removal of organic matter, as are the conventional systems, However, they can generate effluents with lower nutrient concentrations and counts of thermotolerant coliforms, especially FERT (which does not generate an effluent to be discarded). The presence of algae and plants in FERT techniques and when using CWs is an important part of the N and P removal process, while inhospitable conditions are found in these systems for the survival of pathogenic organisms (Matos and Matos, 2017).

In addition to these contaminants, several studies have demonstrated the great potential of these natural systems to remove heavy metals and organic compounds emerging from different wastewaters (Wu *et al.*, 2015; Zhang *et al.*, 2015). Given the high efficiencies, operational and maintenance simplicity, low operating costs, ponds, CWs and FERT are well evaluated (Table

3) as treatment units and are therefore recommended for locations with large area availability. It is important to realize that although they require large areas, natural systems can be integrated into the urban landscape as green areas, unlike large conventional WWTPs, which usually have significant visual impacts (Starkl *et al.*, 2013).

The three economic analysis methodologies presented in this study reveal different results for the most economically attractive treatment configuration. This shows that the usual perception, which considers only the per inhabitant cost involved in the construction and operation of WWTPs, is very simplistic and omits other important factors. By considering only the per inhabitant costs, the data analysis shows that the UASB reactor is the least expensive technology, followed by the ANPs + FPs, FPs and FERT. This ranking comes from modifications that consider the operating time of the WWTP, where the costs of the UASB reactor are equal in the tenth year using the ANPs + FPs (Australian system). In the twentieth year, the Australian system and the FP are the configurations with the lowest cost, while in the fiftieth year, FERT is the configuration with the lowest cost. In general, when considering the variables cost per square metre of land, energy, and final sludge disposal, natural systems (CWs, OFs, ANPs + FPs, FPs and FERT) are more interesting than the conventional systems (UASBs, UASBs + AS, UASBs + SABs, UASBs + TFs) in scenarios with low square metre cost. This relationship tends to reverse with increasing cost per square metre.

However, we cannot fail to consider that the area requirements for natural systems can often make them prohibitive in certain locations.

4. FINAL CONSIDERATIONS

This study showed that the economic analysis of treatment configurations considering only per inhabitant costs is incomplete and not compatible with the results of more comprehensive analyses. However, although there is no universal tool to predict costs, and each location has particularities that should be considered, so the inclusion of variables tends to generate more assertive results.

Based on the evaluated scenarios, it was possible to conclude the following:

- In general, conventional systems (UASBs followed by AS, SABs, and TFs) are more expensive, especially after several years of operation;
- The choice of conventional systems becomes more interesting in scenarios with high cost per square metre of land, especially with lower electricity rates;
- For smaller cities, natural systems (CWs, OFs, ANPs + FPs, FPs and FERT) are more indicated due to their low costs, operational simplicity, and adequate removal efficiencies;
- Future studies should include variables to analyse the influence of demographic density on the construction costs of WWTPs and test the adherence of the results with data from actual works.

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