CIÊNCIA e NATURA

ISSN 2179-460X
OPEN ACCESS

Ci. e Nat., Santa Maria, 47, spe. 2, e91595, 2025 • https://doi.org/10.5902/2179460X91595
Submitted: 03/31/2025 • Approved: 03/31/2025 • Published: 05/21/2025

Inovações e Soluções Sustentáveis em Engenharia Ambiental

Mapping the treatment units of a Wastewater Treatment plant for diagnostic purposes

Mapeamento das unidades de tratamento de uma ETE para fins de diagnóstico

Amanda Santana dos Santos[I], **Ariana de Campos**[II], **Carla Eloísa Diniz dos Santos**[II], **Julio Cesar de Souza Inácio Gonçalves**[II], **Cristiano Poleto**[III], **Mário Sérgio da Luz**[II], **Vinícius Carvalho Rocha**[II]

[I] Prefeitura Municipal de Uberaba, MG, Brasil
[II] Universidade Federal do Triângulo Mineiro, MG, Brasil
[III] Universidade Federal do Rio Grande do Sul, RS, Brasil

ABSTRACT

The aim of this work was to study the performance of a Wastewater Treatment Plant (WWTP) in the municipality of Uberaba-MG, through evaluation of the data provided by the local sanitation company. Analysis of these data, collected at the main points of the treatment stages, made it possible to assess the overall efficiency of the sewage treatment process at the plant, as well as each specific stage. The removal efficiencies of the various parameters monitored were: COD = 91.50%, Ammoniacal-N = 33.10%, Total-P = 60.87%, ST = 48.02%, TSS = 91.66%, VSS = 92.82%, and FSS = 88.80%. In addition, the pH of the final effluent was always within the limits allowed by current regulations. The analysis highlighted aspects that could be improved to add value to the process as a whole. In addition, it was observed that inadequate values for any of the parameters analyzed can lead to underuse or overload of the plant units, compromising the effectiveness of the treatment as a whole, such as the low organic load applied to the UASB reactors, such as the low HRTs resulting from the complete-mix aerated lagoons and the facultative aerated lagoons.

Keywords: Environmental pollution; Monitoring; Project verification

RESUMO

Este trabalho teve como objetivo estudar o desempenho de uma Estação de Tratamento de Esgoto (ETE) no município de Uberaba-MG, por meio da avaliação dos dados fornecidos pela companhia de saneamento local. A análise desses dados, coletados nos principais pontos das etapas do tratamento, permitiu avaliar a eficiência global do processo de tratamento de esgoto na estação, assim como de cada etapa específica. As eficiências de remoção dos diversos parâmetros monitorados foram: DQO = 91,50%, N-Amoniacal = 33,10%, P-Total = 60,87%, ST = 48,02%, SST = 91,66%, SSV = 92,82% e SSF = 88,80%. Além disso, o pH do efluente final esteve sempre dentro dos limites permitidos pelas normas vigentes. Essa análise destacou aspectos que podem ser melhorados para agregar valor ao processo como um todo. Além disso, observou-se que valores inadequados de qualquer parâmetro analisado podem levar à subutilização ou sobrecarga das unidades da estação, comprometendo a eficácia do tratamento como um todo, como a baixa COV aplicada aos reatores UASB, porém baixos TDHs resultantes das lagoas aeradas de mistura completa e as lagoas aeradas facultativas.

Palavras-chave: Poluição ambiental; Monitoramento; Verificação de projetos

1 INTRODUCTION

Historically, concern about wastewater treatment dates back to the 16th century, when several epidemics, attributed to contact with raw sewage, began to emerge. During this period, sewage management and treatment became priority issues (Barros, 2014).

When dumped into water bodies without any treatment, sewage quickly spread among the population, causing serious health problems and contaminating soil and water. This highlighted the need to treat effluent so that it could be discharged into water bodies without causing further damage (Barros, 2014).

After treatment, the efficiency of the process is a crucial measure, which is evaluated from the removal of solids, pathogens, organic matter, nitrogen, and phosphorus. To determine this efficiency, it is essential to understand the individual efficiencies of each stage of the process (Von Sperling, 2005).

In view of the above, the aim of the current study was to map the units of a municipal sewage treatment plant in order to assess the removal efficiencies at each stage and compare them with each other and with the overall efficiency. In addition, we sought to analyze how the seasonality of the flow of sewage influences the process.

Von Sperling (2005) points out that sewage production is proportional to water consumption. With population growth and an increase in industrial activities, the demand for water has grown, with a consequent increase in the amount of sewage generated. This increase, combined with the variation in flow throughout the year, affects the overall operation of the WWTP.

Tsutiya and Além Sobrinho (1999) point out the existence of coefficients of variation in the average daily and hourly flow of the highest water consumption (k_1, k_2, and k_3), which can be used to compare with the sewage coefficients. For example, multiplying k_1 and k_2 can result in underestimation of the relationship between the maximum sewage flow and the average sewage flow.

Furthermore, when considering hourly variations in sewage flows, it is important to note that these fluctuations are attenuated along the collection network. It is well known that the larger the network or population, the less likely it is that peak flows will overlap simultaneously at the entrance to the sewage treatment plant (Von Sperling, 2005).

2 METHODOLOGY

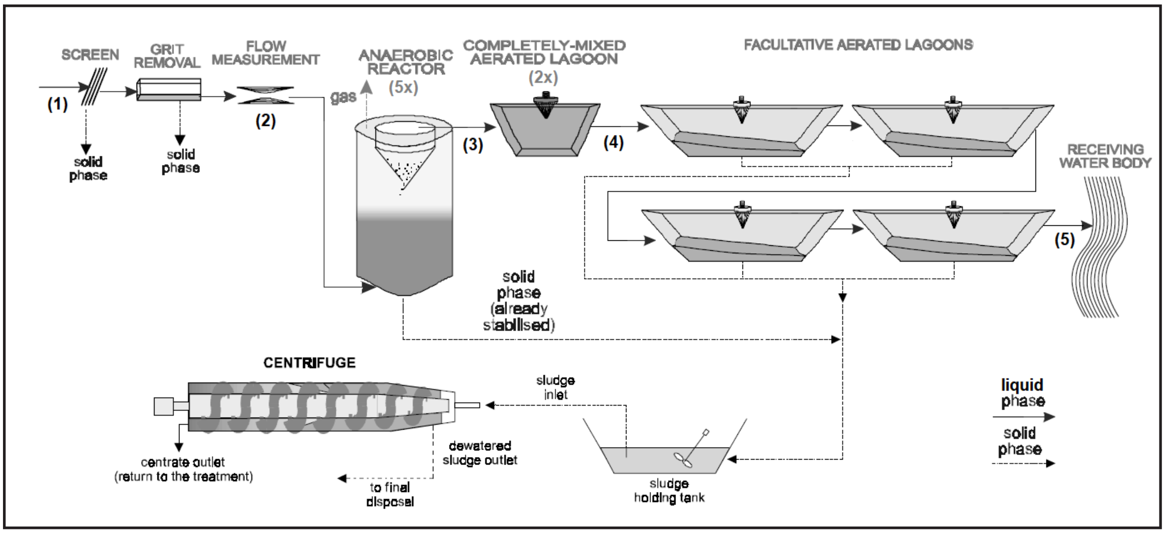
The current study focused on the Francisco Velludo Sewage Treatment Plant in Uberaba, MG, which is responsible for the sanitation of a large part of the city, treating 74% of domestic sewage. The plant, with an average treatment capacity of 465 L/s and a maximum capacity of 745 L/s, serves a population of 254,665 inhabitants and handles a daily organic load of 12,224 kg/BOD.day (MKMBR Engenharia Ambiental, 2009).

The WWTP receives sewage from the urban basin of the Uberaba River through outfalls connected to interceptors and trunk collectors. The treatment includes the preliminary stages (grids, sieves, and desanders), Upflow Anaerobic Sludge Blanket (UASB) reactors, complete-mix Aerated Lagoons (ALs), Facultative Aerated Lagoons (FALs), sludge lagoons, mechanical sludge dewatering, and support structures, such as administration, a laboratory, and workshops (Figure 3) (MKMBR Engenharia Ambiental, 2009).

At the WWTP, the sewage goes through a preliminary process to remove coarse solids and sand. This waste is then sent to landfill sites. The effluent then passes to the UASB reactors for anaerobic digestion of the organic matter, followed by the ALs, and finally the FALs, these last two units being responsible for the removal of the remaining organic matter. The treated effluent is then discharged into the Uberaba's River. The sludge generated is stabilized in other UASB reactors, mechanically dewatered, and then sent to landfills.

Between July 2017 and July 2018, daily sampling and analyses were carried out at various points in the WWTP (Figure 1). The parameters measured included flow, COD, pH, total alkalinity, total phosphorus, ammoniacal nitrogen, suspended solids (fixed, total, and volatile), and total solids, making it possible to calculate the volumetric organic load (VOL) and the hydraulic application rate (HAR). Alkalinity and VOL are essential for the operation of UASB reactors, indicating the buffer capacity of the medium and the ability to process organic matter (Von Sperling, 2005; Chernicharo, 2008).

Figure 1 – Flowchart of the Rio Uberaba Wastewater Treatment Plant



Source: Authors (2024)

Figure 1 presents the points where the daily samples were collected, which led to the data analyzed here, as follows; point 1 (raw effluent), point 2 (preliminary effluent), point 3 (effluent from the UASB reactors), point 4 (outlet of the ALs), and, finally, point 5 (treated effluent). In addition, sampling at the inlet and outlet points (points 1 and 5) was carried out using automated collectors, which take samples over a 24-hour period. At the other points, simple (manual) sampling was carried out between 10.30 am and 11 am.

The physical-chemical analyses were performed according to Standard Methods for the Examination of Water and Wastewater (APHA, 2012), ABNT standards, National Guide for Sample Collection and Preservation (ANA; CETESB, 2011) and the municipality's internal Standard Operating Procedures. The flow rate was measured using a Parshall flume, and the VOL and HAR were calculated using Equations 1 and 2, respectively. Table 1 presents the dimensions of the reactors and lagoons at the WWTP.

The average VOL is the average mass of organic matter applied daily to the UASB reactor per unit volume (Equation 1).

$$\text{VOL} = \frac{\text{Q x C}}{\text{V}} \tag{1}$$

In which: Q is the average flow rate (m^3/d); C is the average influent COD concentration ($kgCOD/m^3$); and V is the total reactor volume (m^3).

The HAR is expressed in terms of the average sewage flow per lagoon area and is based on the need for a certain area of exposure to sunlight in the lagoon. Thus:

$$\text{HAR} = \frac{\text{Q}}{\text{A}} \tag{2}$$

In which: Q is the average flow rate (m^3/d) and A is the lagoon area (ha).

The removal efficiency (E) is the percentage removal of a given pollutant (Equation 3) (Von Sperling, 2005):

$$E = \left(\frac{C_0 - C_e}{C_0}\right) x\,100 \quad (3)$$

In which C_0 is the influent concentration of a given pollutant (mg/L) and Ce is the pollutant's effluent concentration (mg/L).

The Hydraulic Retention Time (HRT) can be generalized as:

$$E = \left(\frac{C_0 - C_e}{C_0}\right) x\,100 \quad (4)$$

Table 1 – Characteristics from the Francisco Velludo WWTP

Treatment unit	Length (m)	Width (m)	Depth (m)	Total volume (m³)	Quantity
UASB	45	20	5.5	28.380	6
AL (crest)	101.5	83	5	69.239,72	2
AL (base)	85	65			
LAF (crest)	101.5	86.5	5	146.382,93	4
LAF (base)	85	70			

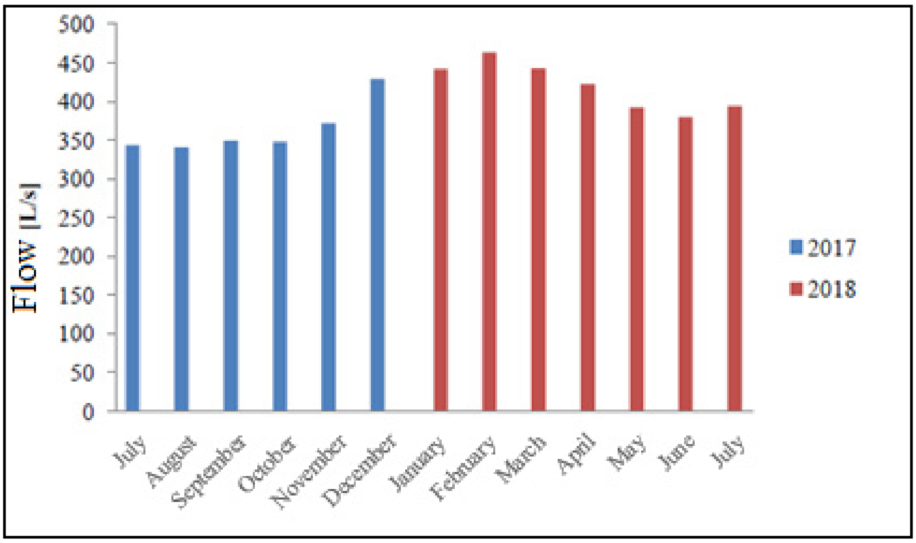
Source: Authorship (2024)

Descriptive statistical analysis of the data was carried out over an annual period (July/2017 to July/2018) for the parameters flow, COD, pH, total alkalinity, total phosphorus, ammoniacal nitrogen, SSF, SST, SSV, ST, COV, and TAH, and over a monthly period for the COD. The analysis was also performed using Excel®.

3 RESULTS AND DISCUSSION

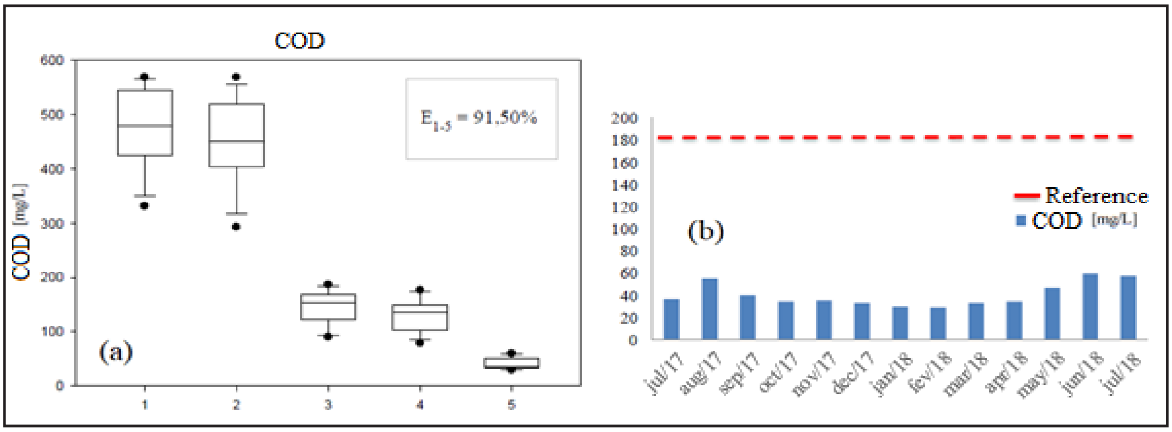
Figure 2 presents the average flow during the analysis period. It can clearly be observed that between the months of December, January, February, and March there was a considerable increase in the flow to the WWTP. This can be explained by the rainfall contributions to the municipality's sewage network. Figure 3 presents the variation in COD over the months analyzed.

Figure 2 – Average flow variation between July/2017 and July/2018



Source: Authorship (2024)

Figure 3 – (a) Annual COD removal efficiency (%), considering (1) raw sewage; (2) preliminary effluent; (3) UASB; (4) AL; and (5) treated effluent (b) Comparison between COD obtained and recommended by current legislation



Source: Authorship (2024)

Considering the difference in removal efficiencies (Figure 3a), there was a small reduction in COD concentration (5% reduction) after the preliminary treatment units (stages 1 and 2). This was to be expected, since preliminary treatment removes coarse solids, not organic matter. The comparison between stages 2 and 3, on the other hand, showed an increase in COD removal (Figure 3), since the sewage entered the UASB with an average concentration of 452.99 mgDQO/L and left with 145.35 mgDQO/L, demonstrating the ability of UASB reactors to reduce organic matter. Stages 3-4 and 4-5 showed significant differences in COD removal efficiency (Figure 3). The aerobic lagoons removed only 9.88% of the COD, while the FALs achieved almost 70% removal (Figure 3). This can be explained by the fact that aerobic lagoons keep the biomass in suspension, increasing the concentration of organic matter at the effluent outlet (VON SPERLING, 2005). In the case of the Francisco Velludo WWTP, the ALs showed low efficiency in removing total COD. Analysis of soluble COD could provide a different and perhaps more accurate picture of the efficiency of these lagoons. In addition, Figure 3b shows that the WWTP operated with COD values in the treated effluent well below the maximum recommended by current regulations (180 mg/L), demonstrating compliance with operating standards. Equation 1 was used to calculate the average VOL in the UASB reactor for the COD parameter, and the result was 0.54 kg/m³.d, as shown in Table 2.

Table 2 – VOL calculation for the UASB reactors at the Francisco Velludo WWTP

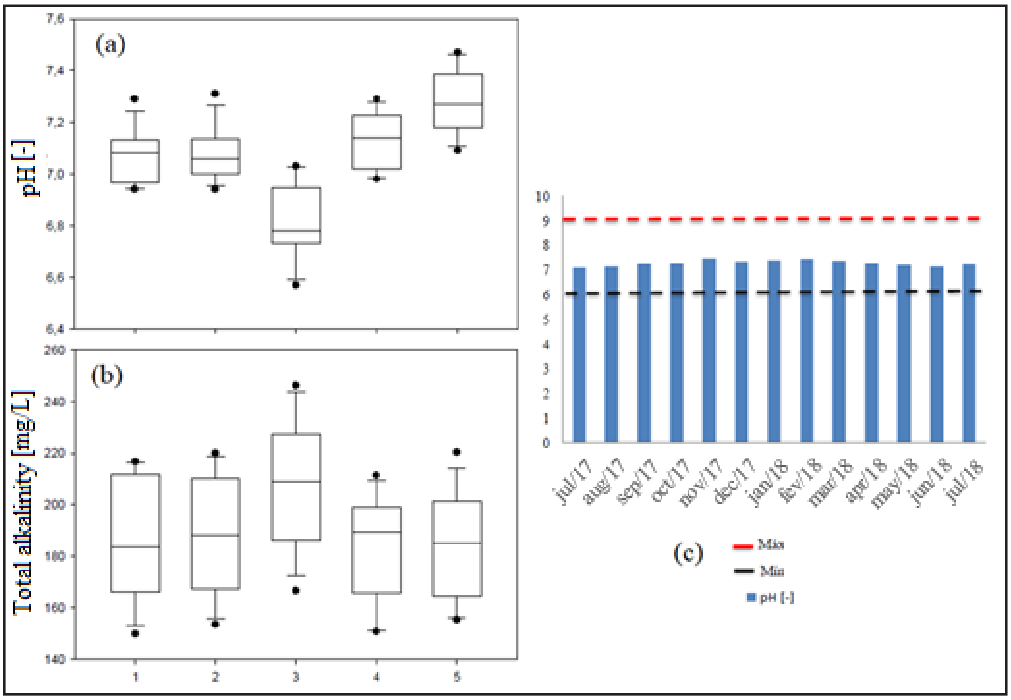
Average annual flow (L/s)	**Influent COD at UASB (mg/L)**	**UASB volume (m³)**	**VOL (kgDQO/m³.d)**
393.48 ± 42.48	452.99 ± 79.10	28.380,00	0.54

Source: Authorship (2024)

Chernicharo (2008) indicates that when treating sanitary sewage, UASB reactors should be designed to operate with a volumetric organic load of between 2.5 and 3.5 kgDQO/m³.d. Therefore, the UASB reactors at the WWTP operate with slack in terms of the VOL parameter.

The pH and alkalinity parameters are closely linked and both are extremely important for the control and proper operation of anaerobic processes. In Figures 4a and 4b, there is discrepant behavior in pH and alkalinity at treatment stage 3 (UASB): pH decreases, while alkalinity increases. According to von Sperling (2005), this is due to biological oxidation processes (methanogenesis and acidogenesis), which tend to reduce pH. This behavior can be explained by the possible presence of unconsumed volatile organic acids in the UASB reactor effluent, which reflect in the relatively low pH value.

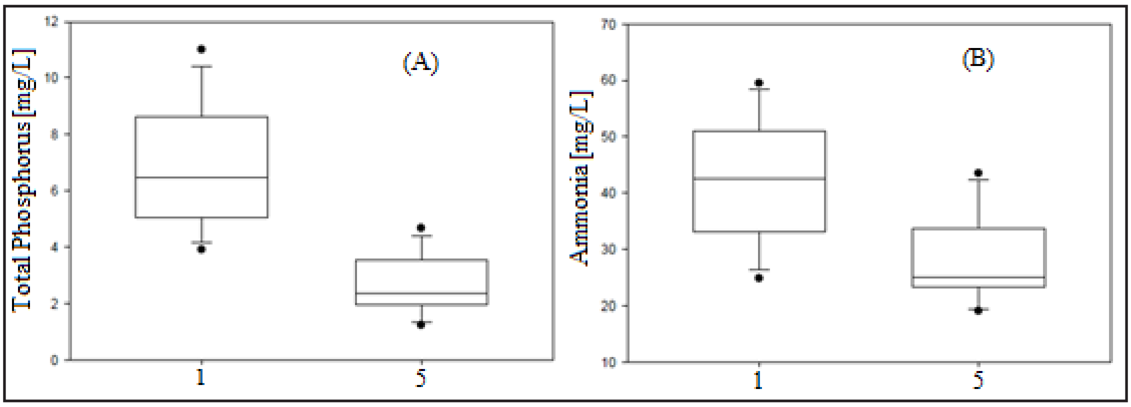
Figure 4 – (a) Annual pH boxplot 1: Raw Effluent; 2: Preliminary Effluent; 3: UASB; 4: ALs; 5: Treated Effluent. (b) Annual total alkalinity boxplot 1: Raw Sewage; 2: Preliminary Effluent; 3: UASB; 4: Aerobic Lagoons; 5: Treated Effluent. (c) Comparison between obtained and recommended pH



Source: Authorship (2024)

Alkalinity, on the other hand, is an indicator of the buffering capacity of the medium (resistance to pH variations), and its increase suggests that UASB reactors are performing well by balancing pH variations (Figure 4b). The increase in alkalinity also indicates the consumption of volatile acids generated during the anaerobic process, which occurs in both UASB reactors and FALs. This consumption of acidity results in the generation of total alkalinity (Chernicharo, 2008). The pH parameter, similar to COD, was also found to be within the limits permitted by COPAM/CERH Joint Normative Deliberation No. 8/2022 (Minas Gerais, 2022), as shown in Figure 4(c).

Figure 5 –(A) Annual total phosphorus boxplot, 1: Raw sewage; 5: Treated Effluent. (B) Annual ammoniacal-N boxplot 1: Raw sewage, 5: Treated Effluent



Source: Authorship (2024)

To analyze the variation in the parameters total phosphorus and ammoniacal nitrogen at the Francisco Velludo WWTP, weekly samples were collected at the inlet (raw effluent) and outlet (last facultative aerated lagoon). The results of monitoring the variation in ammoniacal nitrogen and phosphorus concentrations are shown in Figure 5. The WWTP demonstrating a low average annual ammoniacal nitrogen removal efficiency, reaching only 33.10%, due to the absence of tertiary treatment. According to PROSAB (1999), this limitation stems from the design of the WWTP, which was conceived to operate at a secondary treatment level, resulting in effluent with significant concentrations of nitrogen and phosphorus, which can pose risks of eutrophication to the receiving body.

Von Sperling (2005) defines that a tertiary sewage treatment system includes a maturation lagoon, which is essential for removing pathogens and nutrients, such as total phosphorus and ammoniacal nitrogen. The removal efficiency of total phosphorus was higher compared to ammoniacal nitrogen, possibly due to the shorter residence time of the phosphorus in contact with the biomass in the lagoons. On the other hand, autotrophic nitrifying bacteria, which are responsible for oxidizing ammoniacal N, found it more difficult to establish themselves in the reactors, and more difficult to compete with heterotrophic organic matter oxidizing bacteria for the use of dissolved oxygen.

Monitoring the concentrations of total solids (TS), total suspended solids (TSS), volatile suspended solids (VSS), and fixed suspended solids (FSS) showed that the four parameters behaved similarly to each other. It was possible to see that the average values of these parameters fell throughout all the treatment stages, with the only exception being in the aerobic lagoons. In the complete-mix aerated lagoons, the increase in the average concentrations of solids in the effluent is due to the increase in suspended solids (biomass), resulting from the presence of aerators in constant operation. Therefore, an increase in values of solids at the outlet of the ALs is to be expected.

In terms of overall solids removal efficiency, the TSS and VSS parameters proved to be the most effective, with average removals of 91.66% and 92.82%, respectively. On the other hand, the ST parameter showed the lowest overall removal efficiency, with only 48.02% of total solids being removed throughout the entire WWTP treatment process. The concentration of TSS in the final effluent from the Francisco Velludo WWTP remained in line with the limits established by DN COPAM/CERH No. 08/2022 (100 mg TSS)/L.

Using Equation (4), the HRTs of the UASB reactors, aerobic lagoons, and facultative lagoons were calculated, allowing comparisons with the values defined in the WWTP project, as shown in Table 3.

Table 3 – Comparison between observed and designed hydraulic detention times

Treatment Unit	Observed HRT (h)	Designed HRT (h)
UASB	20	10

AL	49	36
FAL	103	96

Source: Authorship (2024)

During the period analyzed, from July 2017 to July 2018, it was found that the Francisco Velludo WWTP operated with an average flow lower than its design capacity of 465 L/s, reaching 393.48 L/s. As a result, the overall HRT of the treatment plant was extended (Table 3). According to PROSAB (1999), for an average sewage temperature of 20°C, an HRT of approximately 8 to 10 hours is recommended for UASB reactors, while for aerobic lagoons this value varies from 48 to 96 hours, and for facultative aerobic lagoons, from 5 to 10 days. For UASB reactors, prolonged HRT can be beneficial, as it gives the biomass more time to stabilize the organic matter present in the sewage, as mentioned by Silva (2012).

Equation (2) was used to calculate the average HRT for the lagoons, giving results of 2.02 $m^3/m^2.d$ and 0.97 $m^3/m^2.d$, respectively. Little is said in the literature about recommended hydraulic application rates. However, the NTS (2009) presents a maximum reference value for the hydraulic application rate of 50 $m^3/m^2.d$. Therefore, the values obtained for this parameter are within the expected range.

4 CONCLUSIONS

The Francisco Velludo WWTP showed good overall performance, especially with regard to the COD parameter, with an annual removal efficiency of approximately 91.50%, exceeding the recommended value of 65%. In contrast, the removal efficiencies for ammoniacal nitrogen and total solids were reduced, with values of 33.10% and 48.02%, respectively, while total phosphorus removal reached 60.87%. The UASB reactor showed good control of pH and total alkalinity, with inversely proportional values, as expected in the literature. The TSS, VSS, and FSS parameters showed satisfactory solid removal efficiencies, with overall efficiencies of 91.66%, 92.82%, and 88.80%, respectively. The final average pH and TSS values were within the limits recommended by the legislation, with pH values between 6 and 9 and TSS values below 100 mg/L. The hydraulic retention times observed were consistently higher than those designed: 20 hours for the UASB reactors, 49 hours for the LAMCs, and 103 hours for the FALs. In addition, the Hydraulic Application Rate was 2.02 m³/m².d in the AL and 0.97 m³/m².d in the FALs.

ACKNOWLEDGEMENTS

This project was funded by the Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG), the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES). The data were kindly provided by the Companhia Operacional de Desenvolvimento, Saneamento e Ações Urbanas (CODAU).

REFERENCES

Agência Nacional De Água (Brasil); Companhia Ambiental Do Estado De São Paulo. (2011) Guia nacional de coleta de preservação de amostras: água, sedimento, comunidades aquáticas e efluentes líquidos. Brasília, DF: ANA; São Paulo: CETESB. 327 p.

APHA (American Public Health Association) (2012). Standard Methods for the Examination of Water and Wastewater. 22nd ed Washington. nv., il. ISBN 9780875530130

Barros, R. A história do saneamento básico na Idade Média. Disponível em: http://www.rodoinside.com.br/a-historia-do-saneamento-basico-na-idade-media/ Acesso em: 02 de setembro de 2018.

Chernicharo, C. A. L. (2008). Reatores anaeróbios. 2.ed. Belo Horizonte: Departamento de Engenharia Sanitária e Ambiental – UFMG, 2008, 380p. (Princípios do tratamento biológico de águas residuárias, 5).

Minas Gerais. Deliberação Normativa Conjunta COPAM/CERH-MG nº 08, de 21 de novembro de 2022. Dispõe sobre a classificação dos corpos de água e diretrizes ambientais para o seu enquadramento, bem como estabelece as condições e padrões de lançamento de efluentes, e dá outras providências. Disponível em: https://www.siam.mg.gov.br/sla/download.pdf?idNorma=56521. Acesso em: 12 mar. 2024.

MKMBR Engenharia AmbientaL (2009). Manual de Operação e Manutenção ETE Rio Uberaba. Brasília – DF.

Prosab (1999). Tratamento de esgotos sanitários por processos anaeróbio e disposição controlada no solo. Rio de Janeiro: ABES.

Silva, A. M. L. (2012). Estudo do Tempo de Detenção Hidráulico (TDH) em Reatores UASB e sua relação com a Eficiência de Remoção de DBO. In: II SIGA CIÊNCIA (SIMPÓSIO CIENTÍFICO DE GESTÃO AMBIENTAL) V1.2012 REALIZADO DIA 04 DE MAIO DE 2012 NA ESALQ-USP, 2., 2012, Piracicaba - Sp. Pôster. p. 1 - 5. Disponível em: http://www.esiga.org.br/sigaciencia/Trabalhos_publicados/II_SIGA_Ciencia/E.4-03%20ESTUDO%20TDH,%20Athos%20M.L.%20Silva.pdf. Acesso em: 05 dez. 2018.

Tsutiya, M. T., Alem Sobrinho, P. Coleta e transporte de esgoto sanitário. São Paulo: USP. Departamento de Sociologia, 1999. xx, 547 p. ISBN 85-900823-1-8.

Von Sperling, M. (2005). Introdução à Qualidade das Águas e ao Tratamento de Esgotos (Princípios do Tratamento Biológico de Águas Residuárias; vol. 1). Belo Horizonte: DESA-UFMG, 452p.

Authorship contributions

1 – Amanda Santana dos Santos

Mestranda em Ciência e Tecnologia Ambiental na UFTM
https://orcid.org/0009-0000-7002-2713 • amandasantanasts@gmail.com
Contribution: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Software, Supervision, Visualization

2 – Ariana de Campos:

Doutorado em Física pela Universidade Estadual de Campinas (UNICAMP)
https://orcid.org/0000-0003-3342-4777 • ariana.campos@uftm.edu.br
Contribution: Conceptualization, Formal Analysis, Investigation, Visualization

3 – Carla Eloisa Diniz dos Santos:

Doutorado em Hidráulica e Saneamento pela Universidade de São Paulo (USP)
https://orcid.org/0000-0002-5954-1026 • carla.santos@uftm.edu.br
Contribution: Conceptualization, Investigation, Visualization

4 – Julio Cesar de Souza Inácio Gonçalves:

Doutorado em Hidráulica e Saneamento pela Universidade de São Paulo (USP)
https://orcid.org/0000-0001-5584-5527 • julio.goncalves@uftm.edu.br
Contribution: Conceptualization, Formal Analysis, Investigation, Methodology, Resources, Visualization

5 – Cristiano Poleto:

Doutorado em Recursos Hídricos pela Universidade Federal do Rio Grande do Sul (UFRGS)
https://orcid.org/0000-0001-7376-1634 • cristiano.poleto@ufrgs.br
Contribution: Conceptualization, Formal Analysis, Investigation, Methodology, Visualization

6 – Mário Sérgio da Luz:

Doctorate´s degree in Materials Science Engineer at São Paulo State University (USP)
https://orcid.org/0000-0003-1226-9480 • mario.luz@uftm.edu.br
Contribution: Conceptualization, Formal Analysis, Funding acquisition, Investigation, Methodology, Resources, Visualization

7 – Vinícius Carvalho Rocha:

Doutorado em Hidráulica e Saneamento pela Universidade de São Paulo (USP)
https://orcid.org/0000-0002-4683-5738 • vinicius.rocha@uftm.edu.br
Contribution: Conceptualization, Formal Analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization

How to quote this article

Santos, A. S. dos, Campos, A. de, Santos, C. E. D. dos, Gonçalves, J. C. de S. I., Poleto, C., Luz, M. S. da, & Rocha, V. C. (2025). Mapping the treatment units of a Wastewater Treatment plant for diagnostic purposes. *Ciência e Natura*, Santa Maria, 47, spe. 2, e91595. DOI: https://doi.org/10.5902/2179460X91595.