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**Environment**

# Evaluation of Australian system of water stabilization ponds in the treatment of landfill leachate – case study: Fraiburgo/SC

## Avaliação de sistema australiano de lagoas de estabilização de água no tratamento de lixiviado de aterro sanitário – estudo de caso: Fraiburgo/SC

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## ABSTRACT

The research aimed to evaluate the temporal of physical-chemical parameters on the efficiency of organic load removal in the Australian-type stabilization ponds in the landfill leachate treatment, Fraiburgo/SC. The average monthly -BOD removal efficiency ranged from 26.8% to 58.0% in September and January, and the annual average was between 28.6% and 65.0% for 2014 and 2018, respectively. The monthly average efficiency of COD was verified between the values of 25.0% and 48.3% for the months of September and May, respectively, and the annual average presented the range of 29.8% and 58.6% for the years 2020 and 2012. The COD/BOD ratio showed an average value of 2.29 (easily biologically degraded) and 2.68 (low biodegradable) for raw and treated leachate. The pH values concentrated around 7.1 to 9.0, indicating a methanogenic phase. Thus, leachate contains compounds that are not easily degraded, such as humic and fulvic acids. For effluent temperature, there was no apparent change, with the highest frequency between 17 and 26 °C. The average annual removal efficiency was between 13.5% and 58.2% for 2019 and 2018. The stabilization ponds showed low efficiency for the removal of organic load, not reaching values recommended by the Resolution from CONAMA #430/2011. In short, the low efficiency verified in this study can be related to the landfill age, presenting low biodegradability, hydraulic detention time, system overloads, and local precipitation.

**Keywords**: Biological treatment; Manure; BOD

## RESUMO

A pesquisa objetivou a avaliação temporal dos parâmetros físico-químicos na eficiência de remoção de carga orgânica do sistema de lagoas de estabilização tipo australiano no tratamento de lixiviado de aterro sanitário, Fraiburgo/SC. A eficiência de remoção média mensal de DBO variou entre 26,8% e 58,0% para setembro e janeiro, e a média anual ficou entre 28,6% e 65,0% para 2014 e 2018, respectivamente. A eficiência média mensal de DQO variou entre 25,0% e 48,3% para setembro e maio, respectivamente, e a média anual apresentou a faixa de 29,8% e 58,6% para 2020 e 2012. A relação DQO/DBO apresentou um valor médio de 2,29 (facilmente degradados biologicamente) e 2,68 (pouco biodegradável) para o lixiviado bruto e tratado. Os valores de pH concentraram-se em torno de 7,1 a 9,0, indicando uma fase metanogênica. Portanto, o lixiviado contém compostos que não são facilmente degradados, como os ácidos h*úmicos e fúlvicos. Para temperatura do efluente, não teve aparente mudança, com a maior frequência entre 17 e 26 °C. A eficiência de remoção média anual foi de 13,5% a 58,2% para 2019 e 2018. As lagoas de estabilização apresentaram, no geral, baixa eficiên*cia para remoção de carga orgânica, não atingindo valores recomendados pela resolução CONAMA n° 430/2011, que pode ser relacionada à idade do aterro, apresentando baixa biodegradabilidade, tempo de detenção hidráulica, sobrecargas dos sistemas e precipitaç*ão local*.


**Palavras-chave**: Tratamento biológico; Chorume; DBO

# 1 INTRODUCTION

Landfills are the most widely used and environmentally appropriate alternative for municipal solid waste (MSW) disposal (Brasil, 2010; Han et al., 2016; Laiju et al., 2023). In Brazil, with the creation of the National Solid Waste Law, instituted by Federal Law No. 12,305/2010, the disposal of MSWs in controlled landfills and dumps was prohibited, considering they are inappropriate places to receive this waste, mainly due to the lack of basic waterproofing, threatening the integrity of soil and surface and groundwater (Lebron et al., 2021).

Afterward, the opening of landfills has been increasing, it is estimated that 51.5% of Brazilian municipalities still have controlled landfills or dumps. Since 2021, landfills received 60% of the solid waste collected, while 40% was destined for places of inadequate final disposal (Abrelpe, 2020).

According to the Brazilian Association of Technical Standards, the landfill is defined as a technique of final disposal, aiming at the confinement of waste to the smaller possible area. However, during the decomposition of the residues occurs production of leaching, which is a liquid produced when rainwater percolates by the residues and by-products of organic matter deposited in landfills (Araújo et al., 2020).

The composition of landfill leaching depends on different factors such as landfill age, precipitation, climate, seasonal variability, type and composition of MSW, and waste compaction, among others. In addition, leaching can be characterized by a high concentration of ammoniacal nitrogen (N-$NH_3$), chloride, sulfate, and heavy metals, besides presenting a high biochemical oxygen demand (BOD) and values of 1,000 to 25,000 mg L-1 (Lebron et al., 2021) may occur. Due to the high risk to human health and the environment, the leaching generated must be collected and treated appropriately to comply with environmental legislation by the conditions and standards of Resolution of the National Council for the Environment (CONAMA) #430 (Brasil, 2011).

Currently, there are several types of technologies available for leaching treatment such as biological processes (aerobic and anaerobic stabilization ponds, biological filters, activated sludge), physicochemical processes (flocculation, coagulation, adsorption, chemical precipitation, pH adjustment, etc.), membrane filtration, advanced oxidative treatments and natural systems (wetlands) (Costa et al., 2019). The biological treatment system, such as Australian-type stabilization ponds, is the most common technology applied in landfills in Brazil, due to its economic viability and high efficiency in the removal of biodegradable organic matter (Dos Santos & Haandel, 2021; Ho & Goethals, 2020). Pond systems are an attractive alternative for their ease of operation, projection, and maintenance, little technical manpower, low costs, and simple equipment (Phuntsho et al., 2016; Edokpayi et al., 2021; Ho & Goethals, 2020; Mahapatra et al., 2022).

In general, this Australian system is an anaerobic lagoon followed by an optional lagoon, and the maturation pond (MP) can still be used to increase the removal efficiency of pathogenic organisms (Von Sperling, 2002; Melo & Lindner, 2013; Dos

Santos & Haandel, 2021). This technology consists mainly of the stabilization of carbonaceous organic matter through the action of microorganisms. Anaerobic ponds are responsible for the oxidation of organic compounds before treatment by optional ponds. At this stage, the lagoons can be built with a greater depth than the others and can vary from 2 to 5 meters, considering that it is independent of the photosynthetic action of algae (Funasa, 2019; Li et al., 2018).

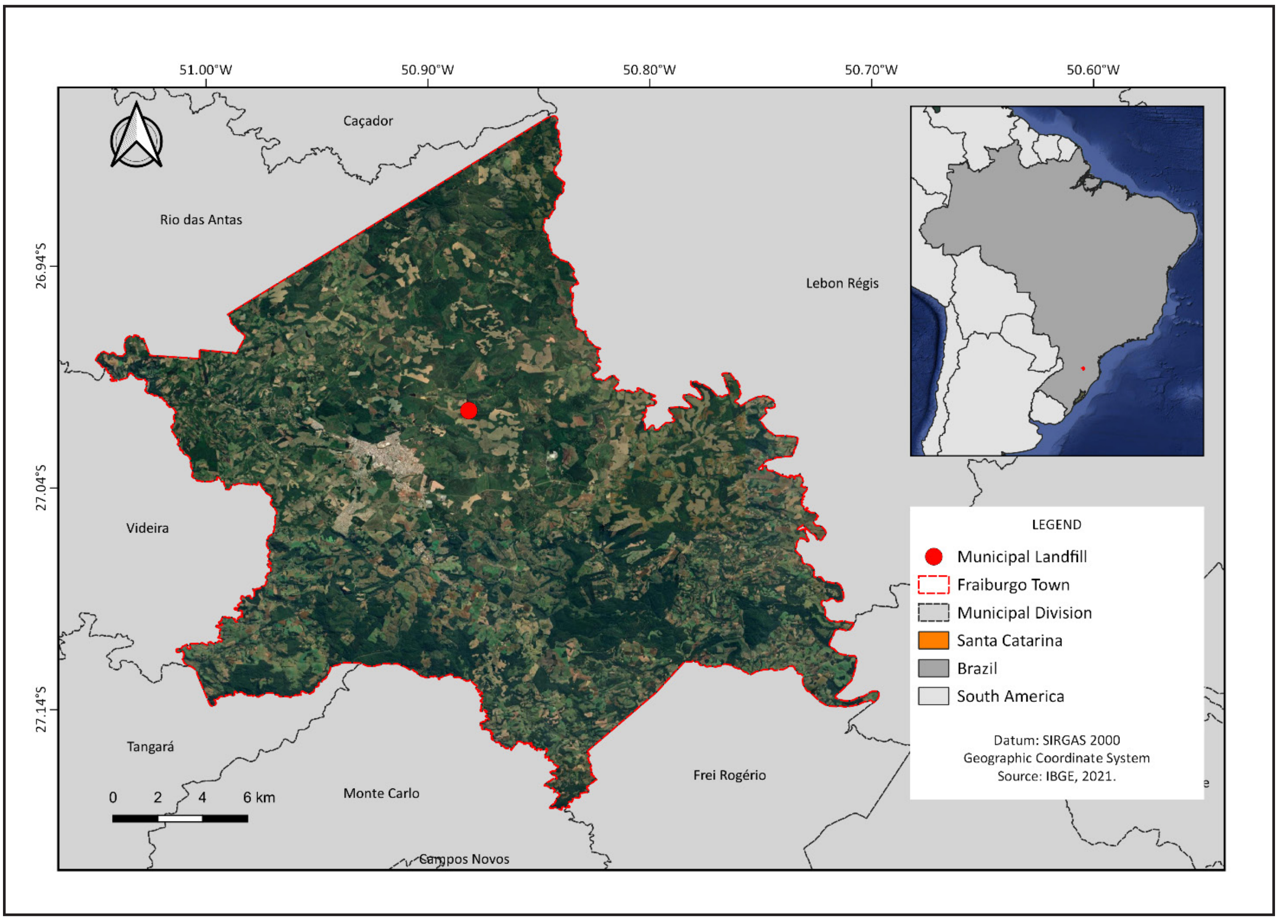
In this context, the aim of this study was to evaluate temporally the influence of physical-chemical parameters on the efficiency of removal of organic load from the Australian-type stabilization pond system in the treatment of landfill leaching located in the city of Fraiburgo, State of Santa Catarina (SC), Brazil.

## 2 MATERIAL AND METHODS

### 2.1 Study area

The municipal landfill of Fraiburgo (Figure 1) is located approximately 5.5 km away from the urban perimeter and has a total area of 242,000 square meters, with coordinates UTM 511750 (X) and 7013000 (Y). In 2012, it had its operating license renewed to operate with a useful life of 12 years. Daily, the landfill receives 20 tons of solid waste from the city of Fraiburgo and Lebon Régis, in the state of Santa Catarina. The climate of Fraiburgo/SC is defined as temperate and humid with cool summers and harsh winters, and significant rainfall throughout the year. The average annual temperature is 18.1 °C an average of the maximum and minimum of 23.3 and 12.8 °C, respectively. The average annual rainfall is 134.2 mm per month (Fraiburgo, 2012).

Figure 1 – A) Location of the Municipal Landfill of Fraiburgo/SC; and B) Cell construction for MSW receipt




Source: Fraiburgo, 2012

The environmental operating license was issued by the defunct Environmental Foundation (FATMA), replaced by the State Institute of Santa Catarina (IMA), and other environmental control mechanisms, among which are: groundwater monitoring wells, leach treatment plant, composed of biological treatment through anaerobic and optional lagoons, drainage and burning of gases and cells for disposal of waste with geomembrane waterproofing of High-Density Polyethylene (PEAD).

The landfill effluent treatment plant consists of three stabilization ponds in the Australian system type, being dimensioned an anaerobic lagoon, an aeration optional pond, and a maturation pond, these are respectively in series. After biological treatment, leaching undergoes physical-chemical treatment with aluminum sulfate - decanter and flocculate - and a stone filter, however, these mentioned treatments will not be evaluated in this article. In all, the leach generation flow rate is 0.4 L $s^{-1}$. The physical-chemical and microbiological monitoring of the sewage treatment plant is carried out monthly, in which the responsible company made the monitoring data available for scientific study purposes, the study of these parameters is mentioned below.

### 2.2 Physical-Chemical Parameters

The analyzed data were made available by the Fraiburgo Sanitation Company (Sanefrai) and from these, we sought to evaluate the efficiency of the system through some physical-chemical parameters. Thus, the parameters of Biochemical Oxygen Demand ($BOD_{5,20}$), Chemical Oxygen Demand (COD), pH, temperature, phosphorus, total nitrogen (TN), total ammoniacal nitrogen (TAN) and turbidity, at the entrance and exit of the treatment system were analyzed monthly, according to Apha methodology (2005). The monitoring period of the system was from January 2012 to March 2021. The repetitions were performed in duplicate, according to the recommendations of the APA methodology (2005).

Equation (1) was used to calculate removal efficiency for the parameters (Rosa, 2012).

$$E(\%) = \left(\frac{S_0 - S}{S_0}\right) \times 100\% \quad (1)$$

Where E is the removal efficiency of BOD and COD (%), S0 is the concentration of the affluent (mg L-1) and S is the concentration of the effluent (mg L-1).

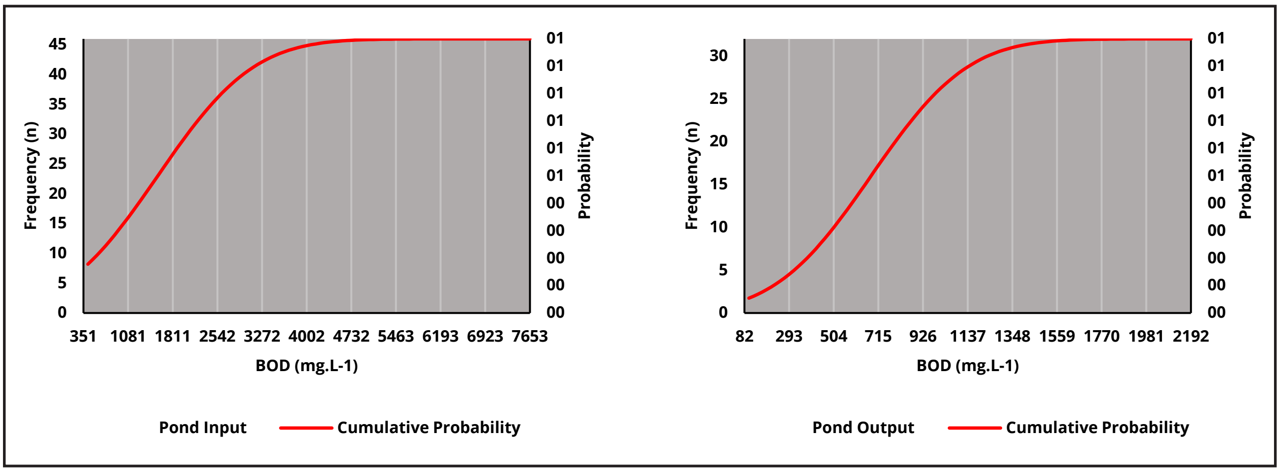
### 2.3 Statistical Analysis of Data

The data were analyzed based on classical statistics such as absolute frequency (histogram) and normal distribution, or Gauss, with cumulative probability function (CPF) of non-excellence. All these statistics were performed in the Excel software of the Microsoft Office suite, and the monthly and annual average was performed for all parameters, aiming to verify the short and long-term time differences. The outliers of the data sets were identified and excluded from the rest of the analyses since these indicate atypical values that may impair the interpretation of the data.

## 3 RESULTS AND DISCUSSION

BOD is the amount of oxygen needed to stabilize carbonaceous matter by biological processes. Thus, it is considered an influencing parameter for evaluating the feasibility of the treatment of biodegradable organic matter by microorganisms Moody & Townsend (2017). Figure 2 shows the frequency distribution of BOD concentration at the entrances and exits of the pond system, in addition to the cumulative probability of these data.

Figure 2 – BOD frequency distribution in a) the pond input system; and b) the pond output system



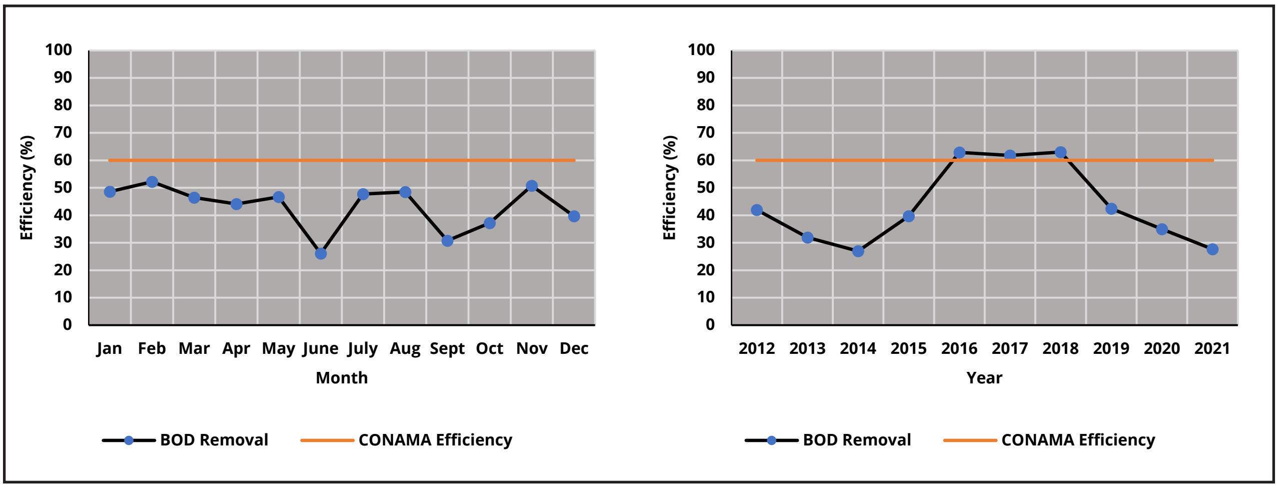

Source: Author (2023)

Through analyzing the behavior of the variables, it is noticed that the highest occurrence of BOD intake in the lagoon was around 350 to 2,500 mg $L^{-1}$, and 80% of the time presented a value within this range. Morais et al. (2020) found similar values in the leached landfill of Rio Branco/AC, however, these are characteristic of the rainy season.

Although the information indicates a median BOD, it is worth mentioning that very low BOD values for stabilization ponds can kill, interfere with or inhibit microbiological activity. At the exit of the system presented a higher frequency between 290 and 1,100 mg $L^{-1}$, this range presented a cumulative probability of 90%. Morais et al. (2020) found a value within this range with 698 m $L^{-1}$ after passing through the Australian system, it is worth mentioning that temperature influences the functioning of the lagoons, so its location affects the removal efficiency.

The temporal analysis of BOD removal efficiency was performed for the annual and monthly averages between 2012 and 2021, which are presented in Figure 3.

Figure 3 – a) Average Monthly BOD Removal Efficiency (%); and b) Average Annual BOD Removal Efficiency (%)




Source: Author (2023)

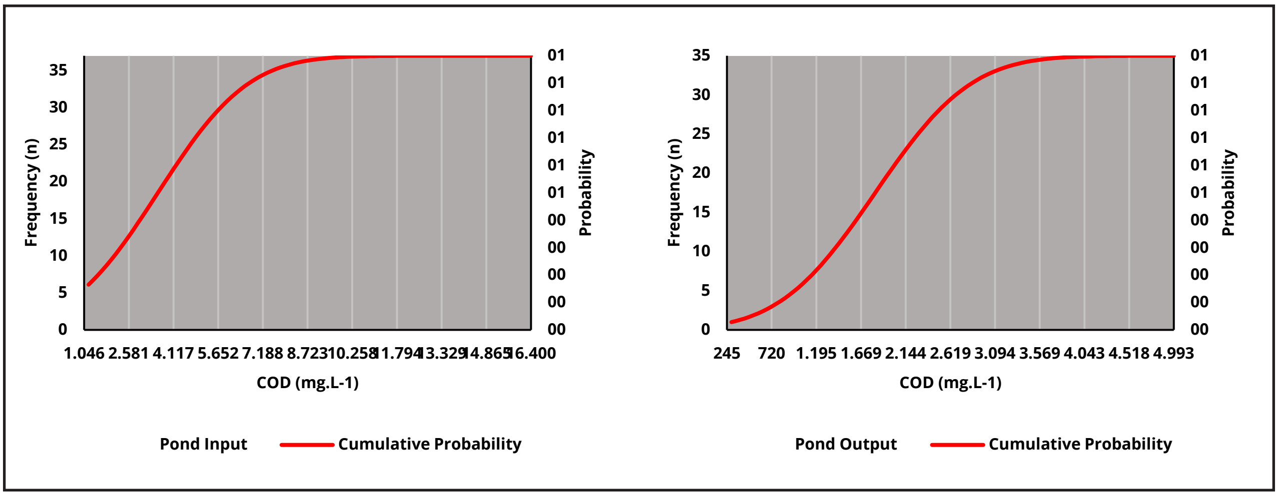
The average monthly BOD removal efficiency ranged from 26.8% to 58.0% in September and January, respectively. Meanwhile, the average annual removal was between the range of 28.6% and 65.0% for 2014 and 2018, respectively. However, Resolution from CONAMA #430/2011 conditions the minimum limit of removal BOD of 60%, if only the monthly averages are considered, the pond system does not confer credibility, since no month presented efficiency above the amount stipulated in the legislation. Nonetheless, considering the average annual efficiencies, the system was at the limit defined by the legislation only in 2016 and 2018 (Brasil, 2011). One of the main interferences is related to the hydraulic holding time, which should be sufficient to meet the development of bacteria, or it may cause system failures (Morais et al., 2020; Edokpayi et al., 2021).

It was also found that the ponds seem to oscillate their efficiency throughout the time series. These characteristics may be associated with rainfall in the Fraiburgo region, a factor that can influence the composition, concentration, and amount of effluent generated (Bassani, 2010). Fraiburgo has a temperate and humid climate, with rainfall well distributed throughout the year, although there are seasonal variations in both rainfall and temperatures. The months of January and October are the rainiest, while August is the driest. Average monthly temperatures range from 11.9 °C in July to 20.2 °C in January INMET (2025).

In an optional lagoon, temperature, and winds are the main environmental interferences and are fundamentally related to the degree of effluent mixture, reducing the possibility of stagnant areas. Moreover, it is an important factor to consider, since the point where oxygen has values equal to zero, a phase known as oxy pause, suffers variations that affect the metabolic activity of the microbiota Vale (2006).

COD is the amount of oxygen required to stabilize organic matter through chemical processes through an oxidant (Limberger et al., 2017). By measuring the biodegradable, inert organic load and inorganic materials its concentration is overestimated and should be higher than BOD. The frequency distribution for the COD values at the system input and output is shown in Figure 4.

Figure 4 – Frequency distribution of COD in a) the pond input system; and b) the pond output system




Source: Author (2023)

It is observed the high values of COD at the entrance of the lagoon, which is between 1,000 and 5,500 mg $L^{-1}$, present a probability of occurrence of 80%. According to Costa et al. (2019), this range is found for landfills between 10 and 20 years. Moreover, the concentration of 700 to 3,000 mg $L^{-1}$ of COD occurs more frequently at the exit of the lagoon, with approximately 85% cumulative probability. As mentioned earlier, the COD must be higher than the BOD, thus the data corroborate the literature evident in the frequency distributions presented. Morais et al. (2020) observed similar values of approximately 4,700 and 1,700 mg $L^{-1}$ of COD at the entrance of the anaerobic lagoon and exit of the optional lagoon, respectively.

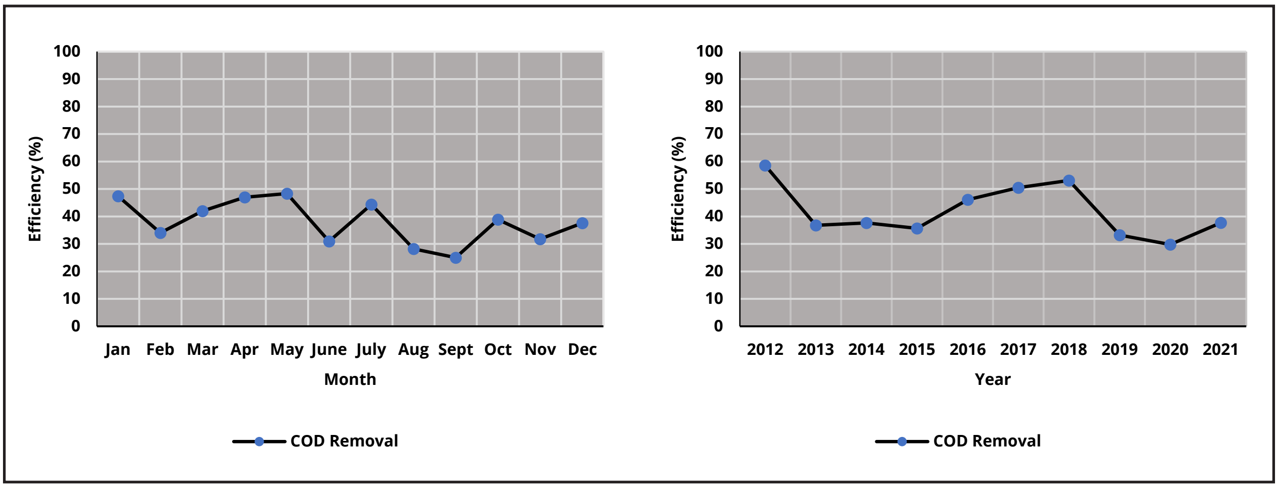
In Brazilian legislation, there are no posting patterns for the COD parameter, and the most usual for studies is the definition of the biodegradability relationship that is given by the reason of COD and BOD. In this study, the crude leach presented an average value of 2.29 and for the treated leachate of 2.68, and the crude effluent was characterized as easily degraded biologically, while the treaty was characterized as poorly biodegradable (Maus, et al., 2009). These results show that the biological treatment of stabilization ponds was not efficient or sufficient to increase the biodegradability of the treated effluent, mainly due to the difficulty of this system in recalcitrant removal compounds, which increase the rates of COD, BOD, and ammonia (Morais et al., 2020; Costa, et al., 2019).

These recalcitrant compounds are characterized by being substances with low biodegradability, which persist in the environment for long periods. These compounds include synthetic organic substances, such as pesticides, drugs, surfactants, humic and fulvic acids, and others that are resistant to microbial degradation. Although they were not analyzed in the study due to methodological limitations and the lack of specific equipment for their detection, their presence is known due to the low degradability observed in the effluent (Hu et al., 2024).

Noerfitriyani et al. (2018) found little biodegradability and the parameters of BOD and COD exceeded the standard limit in leached treated by landfill stabilization ponds located in Indonesia, demonstrating that the lagoons do not meet the design criteria and require improvements in the system.

Almeida (2020) indicates the presence of recalcitrant compounds in the concentrations of COD of landfill leaching, also observing the positive strong correlation between the COD and metals such as aluminum, lead, chromium, iron, zinc, and manganese, which make up the inorganic fraction present in the effluent. Thus, for high ammoniacal nitrogen concentrations and low effluent biodegradability, characteristic of more mature landfills, the single use of biological treatment is not indicated, and the combination of these with physical-chemical treatments is recommended (Costa et al., 2019). Figure 5 shows the average removal efficiencies monthly and annually of COD, respectively.

Figure 5 – a) Average monthly COD removal efficiency (%); and b) Average annual COD removal efficiency (%)



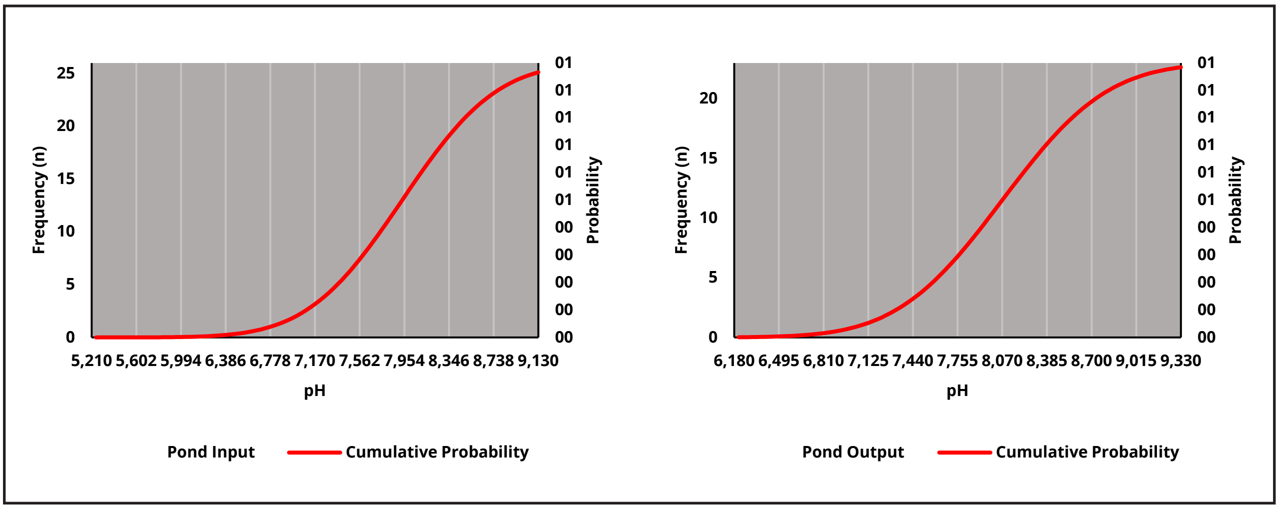

Source: Author (2023)

The average monthly efficiency of COD was verified between the values of 25.0% and 48.3% for the months of September and May, respectively. Meanwhile, the average annual removal was 29.8% and 58.6% for the years 2020 and 2012. It was found that in 2020 the average removal obtained a significant decrease to approximately 30% of COD removal, while in 2018 the efficiency reached the value of 53%. When analyzing the monthly averages, a loss of COD efficiency was identified for ponds of approximately 20% in August and September.

In this study, the relationship between the annual and monthly rainfall of the nearest landfill station (ANA - 02751022) was also evaluated with the efficiencies of COD removal. Therefore, it was observed that most of the time, rain is inversely related to the values of COD. Mendonça and Mendonça (2017) states that rain periods can reduce retention time, in addition, they can dilute effluents, directly affecting the substrate available to microorganisms in biomass. Another important factor is the age of the landfill since the application of only anaerobic and aerobic stabilization ponds are not suitable for the leaching treatment of landfills older than five years (Costa et al., 2019).

The pH indicates the condition of acidity, neutrality, or alkalinity of the sample. This parameter influences the balance of environmental reactions and microbiota conditioning (Bassani, 2010; Kayira & Wanda, 2021). Figure 6 shows the frequency distribution of the pH values for leaching at the entrance and exit of the stabilization process in ponds.

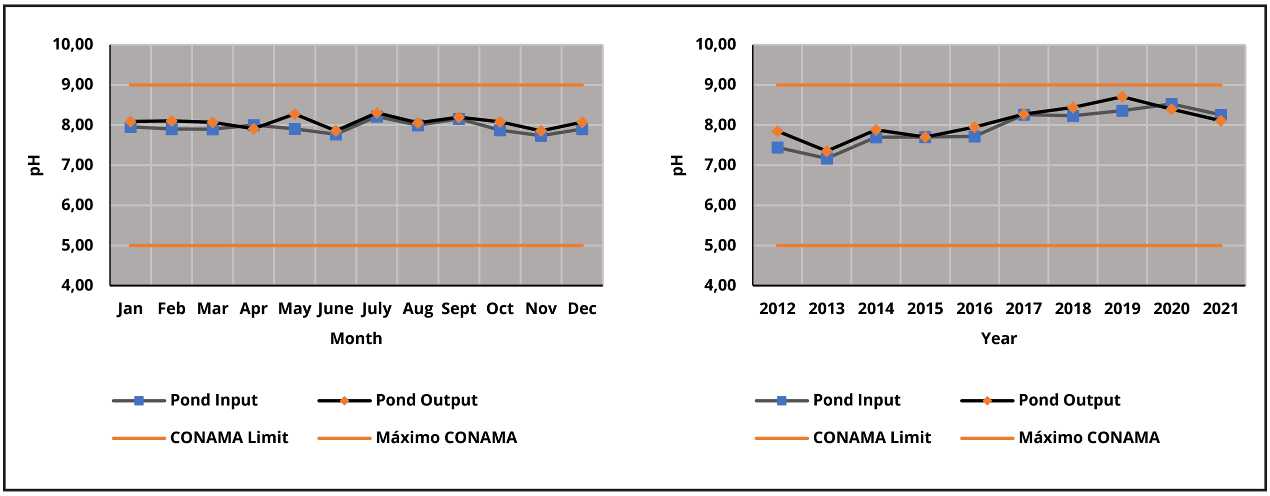
Figure 6 – The pH frequency distribution in a) the pond input system; and b) the pond output system




Source: Author (2023)

The pond system did not show major interference in the pH, according to the normal distributions, which reach an approximate peak of 8. The pH values at the system input were concentrated around 7.1 to 8.7, while the output presented values from 7.4 to 9.0. Ribeiro et al. (2021) also observed values above neutrality and with little difference between a range of 7.2 to 8.4, in which the increase in pH is caused by the consumption of volatile fatty acids through anaerobic bacteria. Other studies have also shown high alkalinity values, indicating that the landfill is in the methanogenic phase, i.e., leached contains compounds that are not easily degraded, such as humic and fulvic acids (Costa et al., 2019), also corroborating the indicators of the low efficiency of stabilization ponds found in this study. Figure 7 shows the monthly and annual pH average for leaching at the input and output of the pond system.

Figure 7 – a) Monthly average of pH; and b) Annual average of pH




Source: Author (2023)

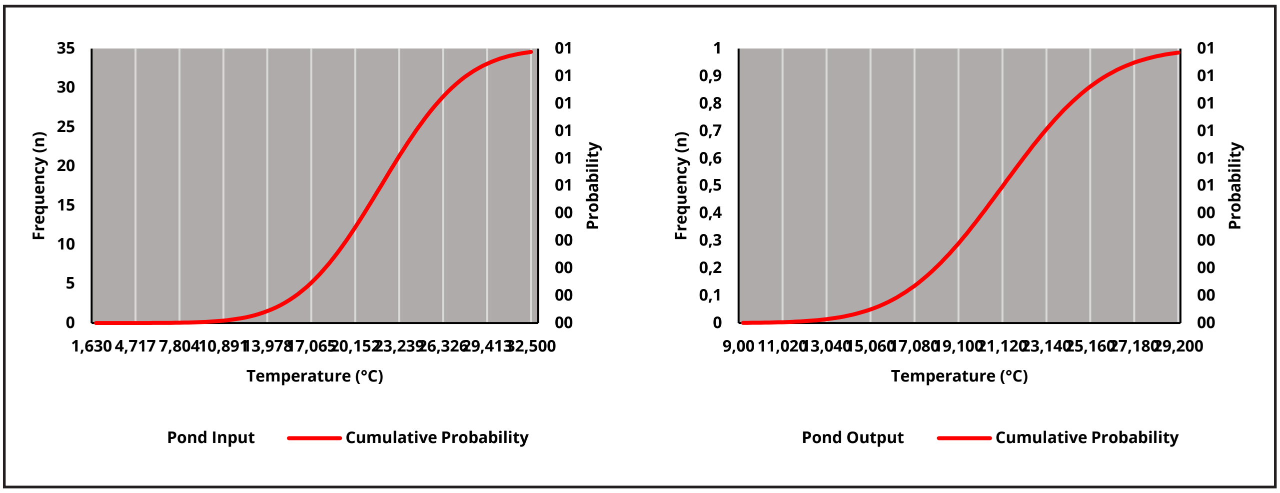
Resolution from CONAMA #430/2011, defines that for the release of effluents into water bodies, the pH must be between the values of 5 and 9 (Brasil, 2011). It is noteworthy that the mean time values obtained from monitoring do not exceed the legislation, also showing that the effluent varies between a more alkaline pH and neutrality. The monthly averages were constant and showed few changes between the entry and exit of the system, however, when observing the annual averages, there is an increase in pH for entry and exit of the lagoons that begins in 2016 and has its apex in 2019, reaching almost the maximum limit allowed by the legislation.

The lagoons are characterized by being discovered, thus causing a bad odor and promoting the proliferation of insects. Meanwhile, if operational care occurs, i.e., keeping the pH in an appropriate range for acid digestion and methanogenic fermentation, the odor can be minimized (Funasa, 2019). Therefore, the oscillation of the pH in the alkaline range in the lagoons represents a negative point, considering that a more basic pH compromises the development of the microbiota.

Photosynthesis and desorption of ammonia are processes that affect pH variation. While photosynthesis decreases acidity, ammonia desorption raises it (Santos, Dos & Haandel, Van, 2021). Thus, due to the non-variation of pH at the entrance and exit of the pond system, these two processes seem to occur in equilibrium, that is, proportionally.

Temperature is one of the essential control parameters for interpreting the operation of stabilization pond systems (Ho & Goethals, 2020), since, as well as pH, it influences the microbiological activity of the medium (Bassani, 2010). Thus, the frequency distribution of the values sampled for temperature are presented in Figure 8.

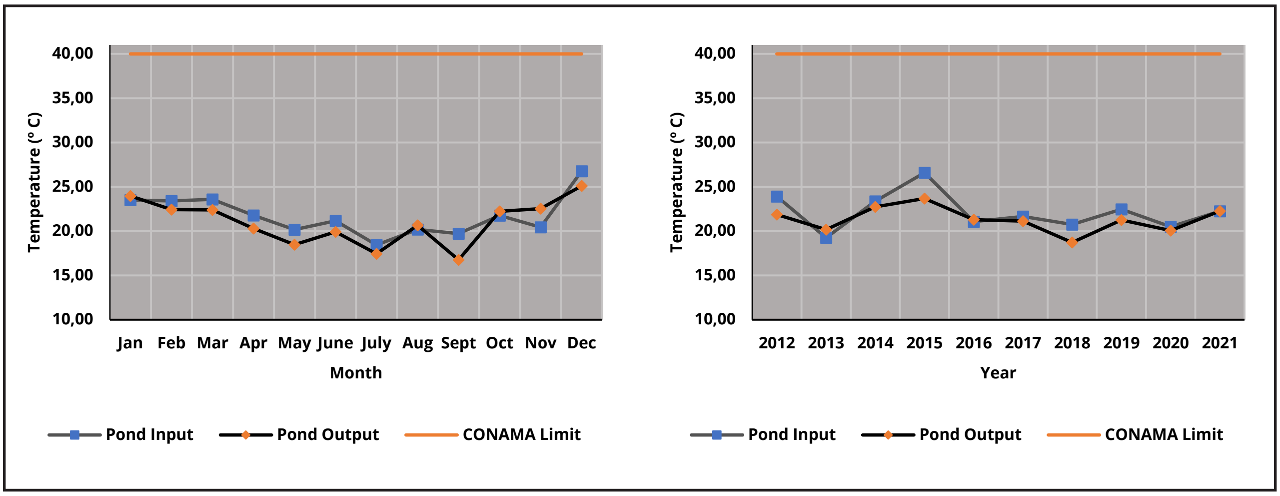
Figure 8 – Temperature frequency distribution in a) the pond input system; and b) the pond output system




Source: Author (2023)

The frequency distribution between the input and the output of the pond system had no apparent change, whereas, at the first, the temperature values had a higher frequency between 17 and 26 °C. At the exit of the lagoons, the values were approximate, and the highest frequency was found between 17 and 25 °C. Resolution from CONAMA #430/2011 establishes a maximum allowed of 40 °C for the release of effluents into water bodies. In this case, it is possible to observe through Figure 9 that the temperature is in accordance with the legislation. The analysis of this parameter is important since it directly interferes with the physical, chemical and biochemical reactions in the lagoons (Mendonça, S. & Mendonça, L., 2017).

Figure 9 – a) Average monthly temperature (°C); and b) Annual average temperature (°C)



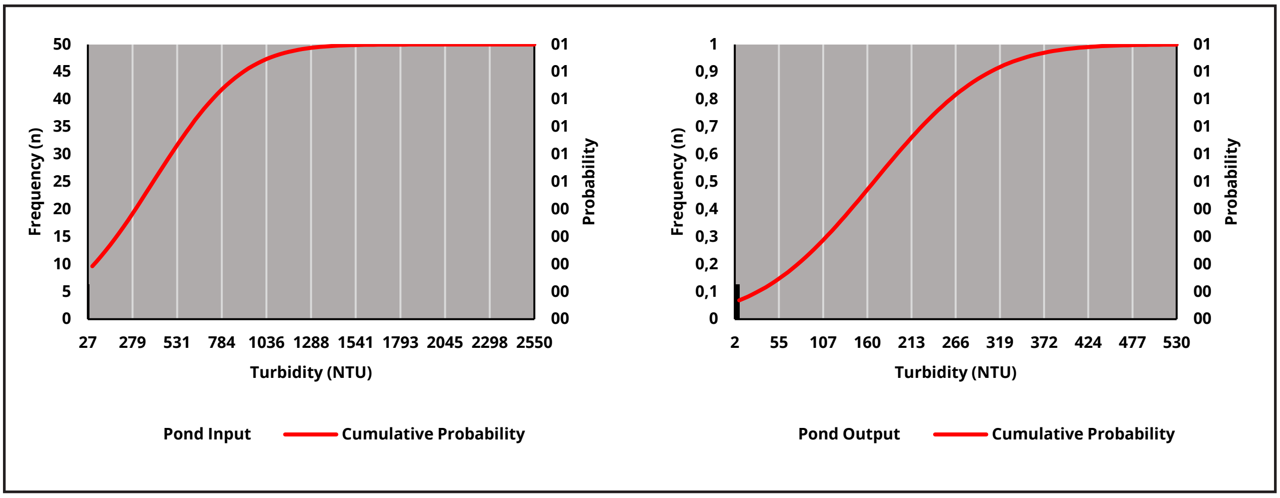

Source: Author (2023)

It is also verified that the temperature follows the characteristics of the climatic season of the year, presenting higher values in the summer months (December, January, and February). According to Vale (2006), microorganisms do not have the characteristic of altering the internal temperature of the medium, on the contrary, their metabolic activity is affected by external environmental temperature, influencing the speed of the anaerobic digestion process. Thus, for an average monthly temperature below 20 °C, it is expected in the literature that the efficiency in the removal of BOD5.20 is up to 50% and up to 70% when the temperature is greater than 25 °C (Funasa, 2019).

However, it is observed that for these periods the BOD efficiency did not reach these values, even when the temperature was maximum. Thus, there is a possibility that the composition of the leachate contains a high fraction of recalcitrant components, hindering biological action. Or even, the biological composition of this Lagoon System is not efficient in this case.

Turbidity indicates the presence of particulate solids with dispersion and light absorption (Braga et al., 2005). In other words, it represents the degree of interference with the passage of light through water, giving it a blurred appearance. The frequency distribution for the turbidity data at the system input and output is shown in Figure 10.

Figure 10 – Frequency distribution of turbidity in a) the pond input system; and b) the pond output system



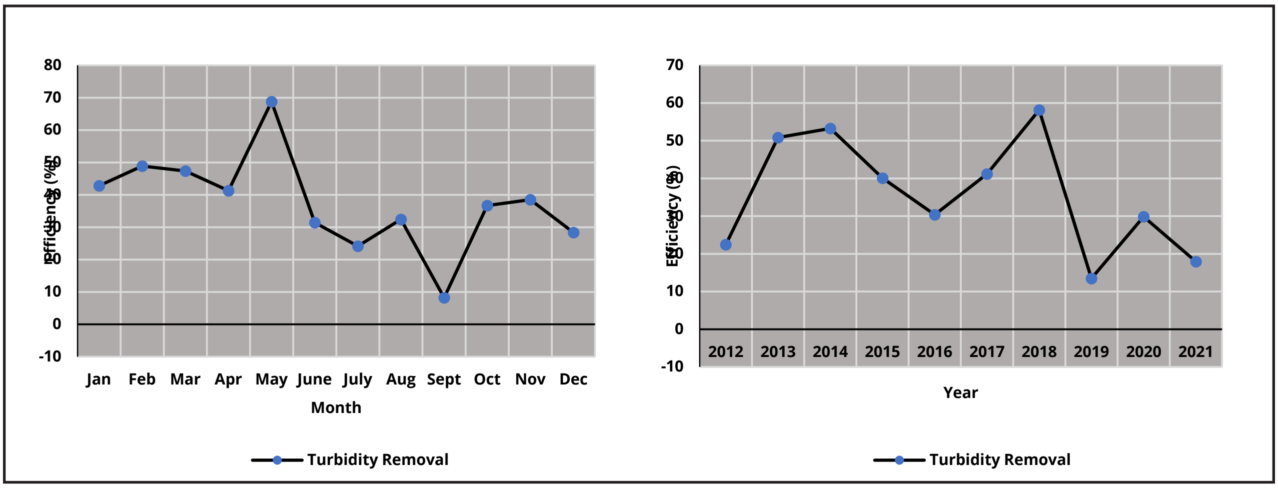

Source: Author (2023)

At the entrance of the system, the highest frequency was between the range of 27 to 1,000 NTU, while at the output of this system, the frequency was around 2 to 320 NTU. These results show that using an Australian system presents good efficiency to reduce turbidity in the treatment of landfill effluents, which corroborates the studies by Santos (2022), who carried out experiments to treat the leachate generated by observing the rainy and dry periods, where he presented a turbidity removal of approximately 75% and 84%, for the rainy and dry periods, respectively.

Figure 11 shows the average monthly and annual turbidity reduction efficiencies of the pond system.

The average monthly turbidity removal efficiency was between 8.2% and 68.8% for September and May, respectively. Meanwhile, the removal of turbidity reached annual average values of 13.5% to 58.2% for the years 2019 and 2018, respectively. Among the elements that can alter the characteristics belonging to the leached, is rainfall, which influences the supply of suspended and dissolved materials through the flow or infiltration of rainwater (Li et al., 2018). Another possible effect associated with this is the possibility of greater dilution or concentration of substance present in slurry.

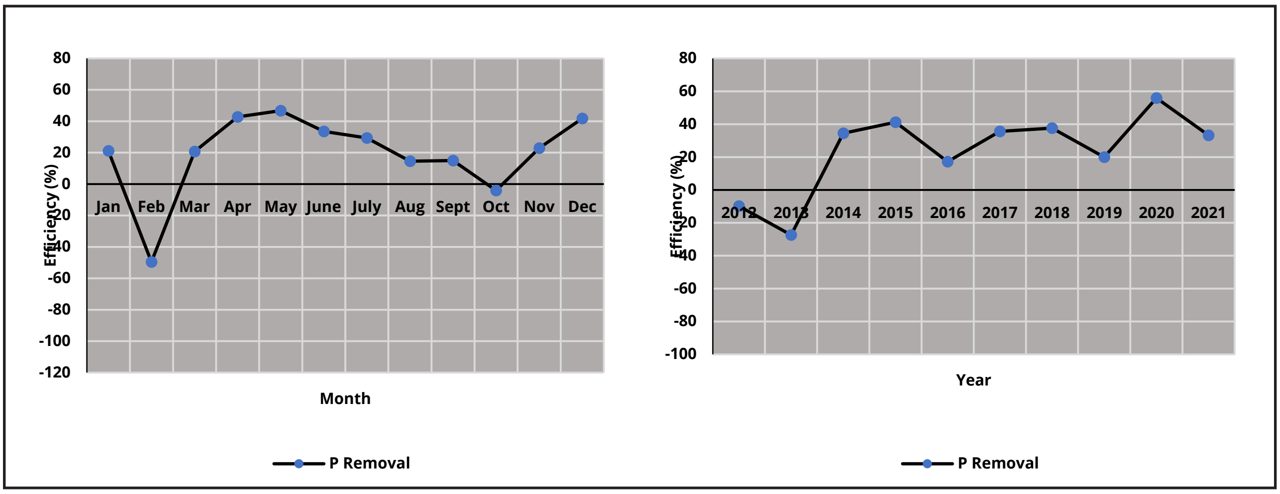
Figure 11 – a) Average monthly turbidity efficiency (%); and b) Annual average turbidity efficiency (%)




Source: Author (2023)

Figure 12 shows the average monthly and annual phosphorus reduction efficiencies of the pond system.

Figure 12 – a) Average monthly phosphorus efficiency (%); and b) Annual average phosphorus efficiency (%)




Source: Author (2023)

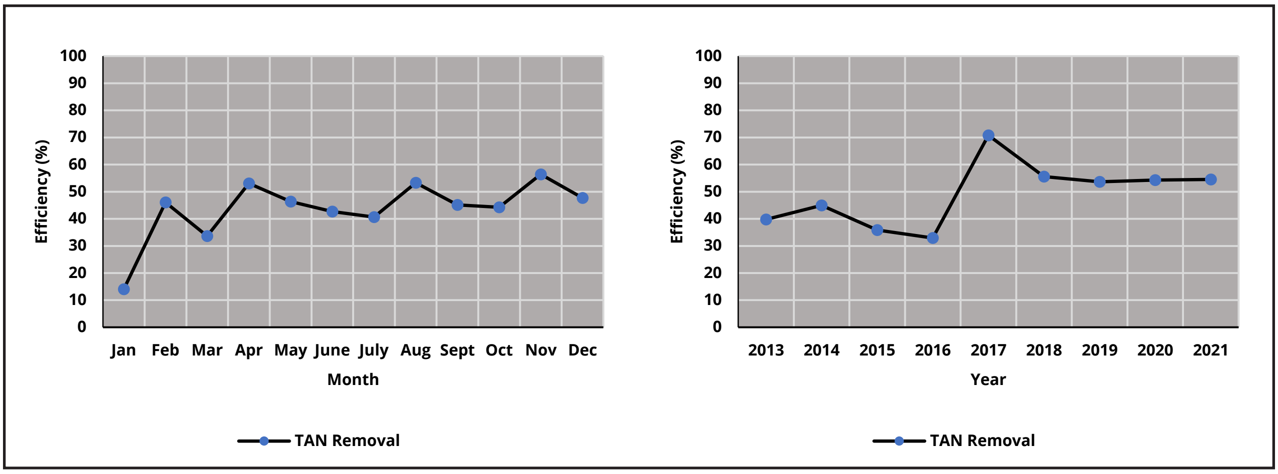
The analysis of the historical performance of the lagoon system indicated operational challenges in phosphorus removal during February and October, characterized by one episode of negative removal and another of null removal, respectively. In contrast, the system exhibited its highest efficiency in May, with mean phosphorus removal rates approaching 50%.

From 2013 onwards, the system underwent improvements, reflected in the results, in which the initial values indicated an increase in phosphorus in the final effluent. In the following years, removals ranging from 20 to 60% were observed throughout the year.

Phosphorus removal efficiency in facultative pond systems is highly influenced by pH, as the precipitation of hydroxyapatite—one of the primary physicochemical removal mechanisms—requires alkaline conditions, typically within a pH range of 9.5 to 9.7 (Santos, Dos & Van Haandel, 2021). Nevertheless, as previously discussed, the pH values observed in the final effluent ranged from 7.0 to 9.0, suggesting that phosphorus removal occurred predominantly via biological pathways, primarily through microbial uptake and assimilation.

Figure 13 shows the average monthly and annual total ammoniacal nitrogen (TAN) reduction efficiencies of the pond system.

Figure 13 – a) Average monthly total ammoniacal nitrogen (TAN) efficiency (%); and b) Annual average TAN efficiency (%)




Source: Author (2023)

In January, the lowest average of NHS removal was recorded around 15%. In the other months, however, the efficiency exceeded 30%, with all the years of the series presenting an annual average above this limit. According to the Brazilian environmental legislation, the effluents, regardless of the flow, must have a maximum of 20 mg $L^{-1}$ N (Brasil, 2011). However, within the historical series, the minimum value found for ammoniacal nitrogen was 40.2 mg $L^{-1}$, not fitting the effluent discharge standards.

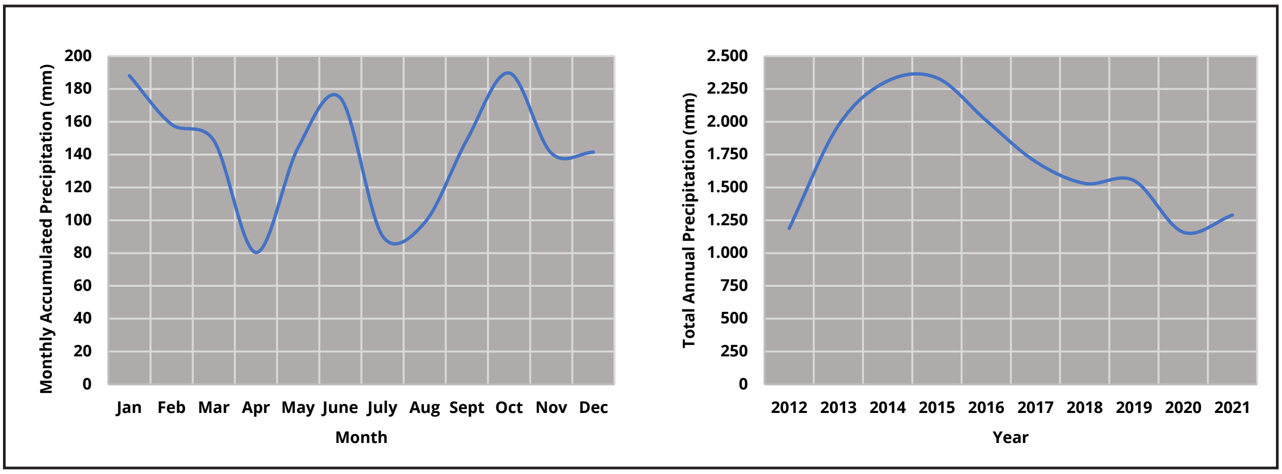
From 2017 onwards, the system exhibited consistent improvement, stabilizing the biological removal of TAN at approximately 55%. These results indicate satisfactory performance of the pond system in TAN removal, challenging the common perception that such systems are inherently inefficient for nutrient removal (Santos, Dos; Haandel, Van, 2021).

Ammonia ($NH_3$) removal in treatment ponds occurs predominantly through three mechanisms: volatilization of gaseous $NH_3$, assimilation of ammonia by algal biomass, and biological nitrification. Among these processes, nitrification generally contributes only a minor fraction to the removal of total ammoniacal nitrogen (TAN). The assimilation of ammonia by algal biomass depends on biological activity within the system and is influenced by factors such as temperature, organic loading, hydraulic retention time, and effluent characteristics (EPA, 2011).

The ammonia desorption rate is proportional to the concentration of the non-ionized fraction, whose presence is strongly dependent on pH. At pH 9.1, this fraction accounts for approximately 50% of the total ammonia. At neutral pH, this proportion decreases drastically to about 1%. Therefore, the pH range between 8 and 9 observed in the system from 2017 to 2021 may have partially favored this mechanism. However, the total ammonia concentration also influences the desorption process (Santos, Dos & Haandel, Van, 2021), and from 2016 onwards, it is possible that this parameter increased, even without a proportional rise in pH.

Figure 14 presents the precipitation data extracted from the station's historical series (code: 02751022) of the National Water Agency (ANA).

Figure 14 – a) Monthly accumulated precipitation; and b) total annual precipitation (%)




Source: Author (2023)

The months with the lowest average accumulated precipitation were April and July, both presenting approximately 80 mm per month. Conversely, the highest average monthly precipitation volumes throughout the historical series were primarily recorded in January, June, and October.

Between 2013 and 2016, the annual precipitation totals exceeded 1,900 mm, whereas the years 2012 and 2020 recorded the lowest values in the series, with totals below 1,200 mm year$^{-1}$. From 2017 onwards, a decreasing trend in annual rainfall volumes has been observed.

Precipitation showed a negative correlation only with COD removal. In periods of higher rainfall, the dilution of the effluent tends to increase, which can hinder the processes of degradation of organic matter (EPA, 2011).

Although stabilization ponds are notable for their operational simplicity, their open configuration makes them susceptible to various environmental interferences, such as fluctuations in air temperature, evaporation, precipitation, wind intensity, and even the introduction of exogenous microorganisms.

After the evaluation of the stabilization pond system, the low efficiency of BOD and COD was verified, according to the legislation and literature. There are two hypotheses about system inefficiency that should be explored: operating and/or maintenance failures; and/or inappropriate technology for the treatment of effluent. The characterization of the leached landfill is not something simple due to the presence of several contaminants (Boonorat et al., 2018), however, this step contributes to the determination of technologies.

Miao et al. (2019) state that landfill leaching treatments should combine physical-chemical and biological methods, mainly aiming at the removal of ammonia and recalcitrant compounds (Lebron et al., 2021). On the other hand, some authors point out some failures of the stabilization ponds, which can be intensified by inadequate operation and/or maintenance, and the accumulation of sludge is mentioned, reducing the depth of the lagoons, and meteorological factors such as wind, interfering in the velocity of the liquid (Gopolang & Letshwenyo, 2018).

## 4 CONCLUSIONS

Landfill effluents are characterized by high pollutant load. The treatment of anaerobic and optional stabilization ponds is widely used for the treatment of landfill leaching, indicated in the literature with high efficiency in the removal of organic load. In this work, the stabilization ponds of the Municipal Landfill of Fraiburgo - SANEFRAI did not present high efficiency for removal of organic load, only in 2016 and 2018 a bod removal above 60% achieved as recommended by environmental legislation. Meanwhile, the pH and temperature parameters were within the limit allowed by Resolution from CONAMA #430/2011. Additionally, it was found that the leached from the landfill presents low biodegradability classified with age from 5 to 10 years, corroborating the low efficiency of the ponds, characteristic of effluent with a high concentration of recalcitrant components. In this case, it is recommended the combination of physical-chemical and biological methods in the treatment of leachate from landfills, as is already common in SANEFRAI. Other factors may be affecting efficiencies such as hydraulic holding time, sludge buildup, tank system overloads, local precipitation, and wind.

As a final consideration, it is recommended that future wastewater treatment designs incorporate a UASB reactor followed by Advanced Oxidation Processes (AOPs). While the UASB reactor efficiently reduces the organic load, its limited BOD removal capacity necessitates additional treatment. The integration of AOPs—particularly Fenton and Ozone-UV processes—can effectively degrade recalcitrant compounds and significantly reduce COD, enhancing effluent quality. This combined approach improves biodegradability and supports compliance with more stringent environmental standards. Therefore, adopting these sequential treatment stages may lead to more robust and efficient wastewater management systems.

To improve efficiency, hydraulic retention time can be increased using flow baffles and equalization basins. Periodic sludge removal helps maintain the effective volume of the ponds. System overloads should be controlled through flow regulation and pre-treatment. Operational adjustments must align with the actual treatment capacity.

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## REFERENCES

APHA (American Public Health Association). (2005). *Standard methods for the examination of water and wastewater* (21st ed.). Washington, D.C.: APHA-AWWA-WEF.

Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais (ABRELPE). (2020). *Panorama dos resíduos sólidos no Brasil 2020.* Recuperado em 14 de dezembro de 2022, de https://abrelpe.org.br/panorama/

Almeida, M. V. A. (2020). *Comportamento biodegradável do aterro sanitário em Campina Grande-PB em função dos subprodutos gerados* (Tese de doutorado). Programa de Pós-Graduação em Recursos Naturais, Universidade Federal de Campina Grande, Campina Grande.

Araújo, L. G. S., Norberto, A. S., Ferreira, R. P. S., Mariano, M. O. H., & Callado, N. H. (2020). Evaluation of the efficiency of leachate treatment in a landfill. *Research, Society and Development*, 9(7), 1-35. https://doi.org/10.33448/rsd-v9i7.4466

Bassani, F. (2010). *Monitoramento do lixiviado do aterro controlado de Maringá, Paraná, e avaliação da tratabilidade com coagulantes naturais, radiação ultravioleta (UV) e ozônio* (Dissertação de mestrado). Programa de Pós-Graduação em Engenharia Urbana, Universidade Estadual de Maringá, Maringá.

Boonnorat, J., Techkarnjanaruk, S., Honda, R., Angthong, S., Boonapatcharoen, N., Muenmee, S., & Prachanurak, P. (2018). Use of aged sludge bioaugmentation in two-stage activated sludge system to enhance the biodegradation of toxic organic compounds in high strength wastewater. *Chemosphere*, 202, 208-217. https://doi.org/10.1016/j.chemosphere.2018.03.084

Braga, B., Hespanhol, I., Conejo, J. G. L., Mierzwa, J. C., Barros, M. T. L., Spencer, M., Porto, M., Nucci, N., Juliano, N., & Eiger, S. (2005). *Introdução à engenharia ambiental: o desafio do desenvolvimento sustentável.* Pearson Prentice Hall.

Brasil. (2010). Lei nº 12.305 de 2 de agosto de 2010. *Diário Oficial da União*, Brasília.

Brasil. (2011). Resolução CONAMA n° 430 de 13 de maio de 2011. *Diário Oficial da União*, Seção 92, p. 89, 2011, Brasília.

Costa, A. M., Alfaia, R. G. S. M., & Campos, J. C. (2019). Landfill leachate treatment in Brazil - An overview. *Journal of Environmental Management*, 232, 110-116. https://doi.org/10.1016/j.jenvman.2018.11.006

Dos Santos, S. L., & Haandel, A. (2021). Transformation of waste stabilization ponds: Reengineering of an obsolete sewage treatment system. *Water*, 13, 1193. https://doi.org/10.3390/w13091193

Edokpayi, J. N., Odiyo, J. O., Popoola, O. E., & Msagati, T. A. (2021). Evaluation of contaminants removal by waste stabilization ponds: A case study of Siloam WSPs in Vhembe District, South Africa. *Heliyon,* 7(2), e06207. https://doi.org/10.1016/j.heliyon.2021.e06207

EPA, U.S. Environmental Protection Agency. (2011) *Principles of Design and Operations of Wastewater Treatment Pond Systems for Plant Operators, Engineers, and Managers*. Cincinnati, Ohio.

Fraiburgo. (2012). *Plano Municipal de Saneamento Básico.* (Accessed November 25, 2022) at: https://sanefrai.sc.gov.br/uploads/Plano_Municipal_de_Saneamento_Basico_SANEFRAI.pdf

Fundação Nacional da Saúde – FUNASA. (2019*). Manual de saneamento.* (Accessed Dezember 11, 2022) at: https://repositorio.funasa.gov.br/handle/123456789/506

Gopolang, O. P., & Letshwenyo, M. W. (2018). Performance evaluation of waste stabilisation ponds. *Scientific Research Publishing*, 10, 1129-1147. https://doi.org/10.4236/jwarp.2018.1011067

Han, Z., Ma, H., Shi, G., He, L., Wei, L., & Shi, Q. (2016). A review of groundwater contamination near municipal solid waste landfill sites in China. *Science of the Total Environment*, 569-570, 1255-1264. https://doi.org/10.1016/j.scitotenv.2016.06.201

Ho, L., & Goethals, P. L. M. (2020). Municipal wastewater treatment with pond technology: Historical review and future outlook. *Ecological Engineering*, 148, 105791. https://doi.org/10.1016/j.ecoleng.2020.105791.

Hu, F., Ye, J., Zhang, J., Zhang, W., Chen, P., Yuan, Z., & Xu, Z. (2024). Synergistic removal of bio-recalcitrant organic compounds and nitrate: Coupling photocatalysis and biodegradation to enhance the bioavailability of electron donors. *Journal of Hazardous Materials*, *479*, 135605.

Instituto Nacional de Meteorologia. (s.d.). *Mapas meteorológicos.* INMET. (Accessed March 24, 2025) at: https://mapas.inmet.gov.br/.

Kayira, F., & Wanda, E. M. M. (2021). Evaluation of the performance of Mzuzu Central Hospital wastewater oxidation ponds and its effect on water quality in Lunyangwa River, Northern Malawi. *Physics and Chemistry of the Earth*, Parts A/B/C, 123, 103015. https://doi.org/10.1016/j.pce.2021.103015

Laiju, A. R., Gandhimathi, R., & Nidheesh, P. V. (2023). Removal of pharmaceutical and personal care products in landfill leachate treatment process. *Current Opinion in Environmental Science & Health*, 31, 100434. https://doi.org/10.1016/j.coesh.2022.100434

Lebron, Y. A. R., Moreira, V. R., Brasil, Y. L., Silva, A. F. R., Santos, L. V. S., Lange, L. C., & Amaral, M. C. S. (2021). A survey on experiences in leachate treatment: Common practices, differences worldwide and future perspectives. *Journal of Environmental Management*, 288, 112475. https://doi.org/10.1016/j.jenvman.2021.112475

Li, M., Zhang, H., Lemckert, C., Roiko, A., & Stratton, H. (2018). On the hydrodynamics and treatment efficiency of waste stabilisation ponds: From a literature review to a strategic evaluation framework. *Journal of Cleaner Production*, 183, 495-514. https://doi.org/10.1016/j.jclepro.2018.01.199

Limberger, D., Moraes, J. D., & Woiczekowski, N. (2017). A qualidade dos córregos urbanos em pequenos municípios: parâmetros físicos e químicos da sanga das charqueadas, Tapes/RS, Brasil. In *Congresso Brasileiro de Gestão Ambiental*, 7, Campo Grande, MS. Anais. IBEAS.

Mahapatra, S., Samal, K., & Dash, R. R. (2022). Waste Stabilization Pond (WSP) for wastewater treatment: A review on factors, modelling and cost analysis. *Journal of Environmental Management*, 308, 114668. https://doi.org/10.1016/j.jenvman.2022.114668

Maus, V. W., Costa, A. B., & Righes, A. A. (2009). Tratamento do lixiviado de aterro de resíduos sólidos urbanos por processo Fenton. *Tecno-Lógica*, 13(1), 52-59. https://doi.org/10.17058/tecnolog.v13i1.931

Melo, J. F., & Lindner, E. A. (2013). Dimensionamento comparativo entre sistemas de lagoas e de zonas de raízes para o tratamento de esgoto de pequena comunidade. *Iniciação Científica CESUMAR*, 15(1), 33-44.

Mendonça, S. R., & Mendonça, L. C. (2017). *Sistemas sustentáveis de esgotos* (2ª ed.). Blucher.

Miao, L., Yang, G., Tao, T., & Peng, Y. (2019). Recent advances in nitrogen removal from landfill leachate using biological treatments – A review. *Journal of Environmental Management*, 235, 178-185. https://doi.org/10.1016/j.jenvman.2019.01.057

Moody, C. M., & Townsend, G. T. (2017). A comparison of landfill leachates based on waste composition. *Waste Management*, 63, 267-274. https://doi.org/10.1016/j.wasman.2016.09.020

Morais, M. V. A., Morais, C. D. N., Furtado, C. M., Menezes, R. S., Rebouças, F. S., Torres, O. S., Carvalho, C. M., & Chaves, H. P. (2020). Análise físico-química e microbiológica do lixiviado do aterro sanitário no município de Rio Branco - Acre. *South American Journal of Basic Education, Technical and Technological*, 7(1), 282-292.

Noerfitriyani, E., Hartono, D. M., Moersidik, S. S., & Gusniani, I. (2018). Leachate characterization and performance evaluation of leachate treatment plant in Cipayung landfill, Indonesia. IOP *Conference Series: Earth and Environmental Science*, 106(1), 012086. https://doi.org/10.1088/1755-1315/106/1/012086

Phuntsho, S., Shon, H. K., Vigneswaran, S., Ngo, H. H., & Kandasamy, J. (2016). Performance of waste stabilization ponds: Experience from cold climatic conditions of Bhutan. *Journal of Water Sustainability*, 6(1), 1-16. https://doi.org/10.11912/jws.2016.6.1.1-16

Ribeiro, L. S., Gomes, N. A., Almeida, M. V. A., & Paiva, W. (2021). Análise da relação físico-química do lixiviado gerado em um aterro sanitário no Semiárido brasileiro. *Agropecuária Científica no Semiárido,* 17(1), 36-42. https://doi.org/10.30969/acsa.v17i1.1309

Rosa, M. T. (2012). *Avaliação das lagoas anaeróbias na remoção da matéria carbonácea presente no lixiviado de um aterro sanitário: estudo em escala real* (Trabalho de Conclusão de Curso, Graduação em Engenharia Sanitária e Ambiental). Universidade Federal de Santa Catarina, Florianópolis.

Santos, H. M. do N. (2023) *Sistema de lagoas de estabilização e lagoa aerada para redução da carga orgânica e nitrogênio de percolado de aterro sanitário.* 136 f. Dissertação (Mestrado em Recursos Hídricos e Saneamento) – Programa de Pós-Graduação em Recursos Hídricos e Saneamento, Centro de Tecnologia, Universidade Federal de Alagoas, Maceió, 2023.

Sebastián, J. M., Marulanda, A. S., & Rojas, C. A. (2021). Oxidative treatment of stabilized leachate from municipal landfills using Fenton and ozonation-UV processes. *Journal of Water Resource and Protection*, *13*(5), 356–369.

Vale, M. B. (2006). *Avaliação da eficiência da remoção de matéria orgânica e microbiológica de três sistemas de lagoas de estabilização em série na Grande Natal-RN: Beira Rio, Jardim Lola I e Jardim Lola II* (Dissertação de Mestrado em Engenharia Sanitária). Universidade Federal do Rio Grande do Norte, Natal.

Von Sperling, M. (2002). *Lagoas de estabilização* (3ª ed.). UFMG.

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