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ALTERNATIVES FOR THE ENVIRONMENTALLY APPROPRIATE DISPOSAL OF SLUDGE FROM WATER TREATMENT PLANTS WITH AN EMPHASIS ON THE BRAZILIAN REALITY

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Abstract: The management and disposal of sludge generated in water treatment plants in Brazil is still a major problem for water utilities. In many cases, sludge is discarded *in natura* in water bodies, causing several environmental impacts, in addition to not meeting the demands of current legislation. The present study aims to carry out a bibliographic review on sludge from water treatment plants (WTP), including aspects related to the negative consequences of its improper disposal. On the other hand, in addition to presenting environmentally appropriate alternatives for this final destination, it discusses possible ways of using LETA with a focus on the circular economy, that is, as an input for other activities. The evaluated publications were segregated by sludge utilization typology, identifying the strengths and weaknesses (critical points) for each typology. After compiling the collected data, one can infer the feasibility of using or incorporating LETA for different uses, as long as it is inserted in small amounts. In the cement and concrete manufacturing process, for example, additions greater than 5% must be avoided, as the workability and some mechanical properties are impaired to the point of making the final product unfeasible. Its use in agriculture can be done in conjunction with sewage treatment plant sludge (LETE). In the vast majority of studies surveyed, it is indicated that the addition of WTP sludge as an input reduces the consumption and exploitation of natural raw materials, mitigating the various negative environmental impacts arising from improper disposal. However, whatever the type of reuse, more specific studies are required to establish a reuse methodology with the necessary reliability for the process. In addition, potential risks to human health due to frequent handling must be analyzed.

Keywords: WTP sludge, Utilization, Sustainability, Brazil.

INTRODUCTION

About 10,000 years ago, human beings better understood the functioning of agriculture and livestock, renouncing the nomadic lifestyle. Based on this change, man began to establish fixed communities, installed close to water bodies and supply systems began to be implemented. The need for water to supply homes, agriculture, businesses and, later, industries, then became essential (LIBÂNIO, 2016).

Available fresh water represents less than 3% of the total amount of water available on the planet, and is the type of water with the greatest ease of access and treatment for human supply. The ownership of natural waters is highly relevant for choosing a new source of capture and/or extraction, with the efficiency of the water treatment process being crucial for the well-being of populations (ANDRADE, 2021).

The frequent presence of turbidity, color and pathogenic microorganisms in raw water is characterized as an obstacle to the direct consumption of water that has not undergone any treatment step (LIBÂNIO, 2016).

Rejection by the population may also occur when the water has a sensorially perceptible taste, odor, color and turbidity, as in the case of the presence of geosmin in the water supplied by the Guandu system, in RJ, in 2020, for many characterized as the biggest crisis ever. in the water supply of the RMRJ. The treated water had a strong odor and taste, and at some points in the distribution system it was also possible to observe a color change (ANDRADE, 2021).

In addition, pathogenic microorganisms represent the biggest problem for direct consumption, and several studies on severe outbreaks of various diseases identified that transmission occurred via water transmission.

Belonging to the group of coliforms, the bacterium *Escherichia Coli* is the main indicator that water may be contaminated with animal feces and/or domestic sewage, as its natural habitat is in the intestines of warm-blooded animals. Its presence indicates that it is very likely that pathogenic bacteria, enteric viruses, protozoa and helminths may also be present in this water. Protozoa and helminths are even more worrying because they are resistant to chlorine, which is the main disinfectant agent used in WTPs in Brazil. Among the possible causes of these non-conformities that generate serious risks to the health of populations, the following can be cited: failure or absence of measures to protect water sources; unsatisfactory performance of the water treatment plant (ETA); and failure in the distribution system (LIBÂNIO, 2016).

Most ETAs in the country were planned and designed based on a conventional model, consisting of the following treatment steps: coagulation, flocculation, decantation or flotation, filtration, disinfection, fluoridation and, finally, pH correction (LIBÂNIO, 2016).

Figure 1 illustrates the treatment steps of a full-cycle conventional WTP.

Coagulation aims to destabilize suspended and colloidal particles that are dispersed in water, allowing them to adhere to the coagulant and then to the polymer. The coagulation mechanisms are: compression of the double layer, adsorption-destabilization, sweeping and formation of chemical bridges (LIBÂNIO, 2016). Normally, the coagulants applied in Brazil are aluminum sulfate and/or ferric chloride.

Flocculation is the next and complementary step to coagulation (RAMIREZ, 2015), where the process of agglutination of particles continues to occur, so that the flocs formed in coagulation become larger and do not suffer ruptures. For this, it is necessary to maintain a small agitation that is lower than that of coagulation, measured through the water velocity gradient. This step contributes to the clarification of the water and uses only physical phenomena (ANDRADE, 2021). In some cases, sedimentation of flakes and particles may occur in the flocculator, requiring periodic discharges in order to clean it.

The next step is decantation or flotation, depending on the quality of the source and its physicochemical characteristics, with decantation being more efficient to treat water with a higher degree of turbidity, while flotation is more efficient for water with a high color. Before designing the ETA, it is necessary to analyze well the quality parameters of the source, so that the treatment can be as effective as possible (ANDRADE, 2021).

Most WTPs built in Brazil were designed with a decanter (LIBÂNIO, 2016; RAMIREZ, 2015). During decantation, the flakes formed in the previous step naturally settle, accumulating at the bottom of the decanter, which must be periodically removed. Decantation is the main part responsible for removing turbidity in water.

Flotation promotes the accumulation of flakes on the surface of the water, removing the supernatant. For this, it is necessary to use mechanized devices that make the specific mass of the floc lower than the specific mass of the water, causing the buoyancy force to overcome the weight force, raising the particles to the surface. However, flotation leads to greater consumption of electricity and, consequently, high operating costs (ANDRADE, 2021; LIBÂNIO, 2016).

Filtration is one of the last stages of water treatment and its primary function is to remove the particles responsible for the color and those that were not retained during decantation or flotation. The filter media are composed of materials that prevent the passage of particles, thus purifying the water (RAMIREZ, 2015), the retention process being physical or physical-chemical. Periodically, the filtering bed becomes saturated and its

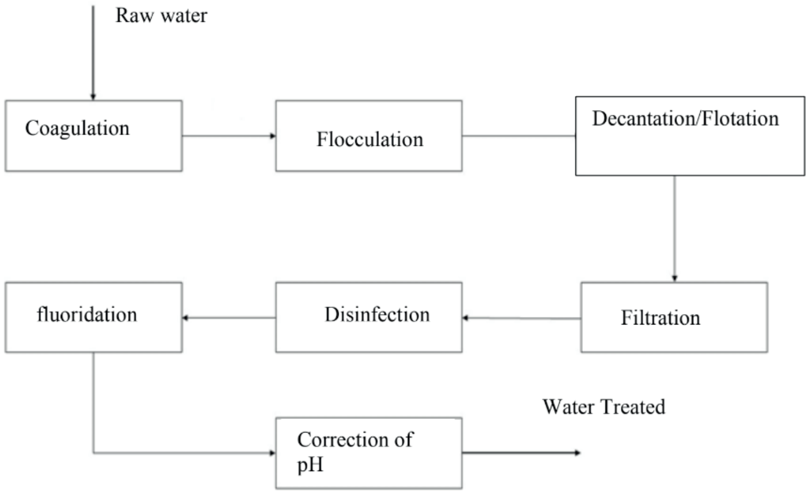

Figure 1 - Treatment stages of a conventional WTS full cycle

Source: Adapted from ANDRADE (2021).

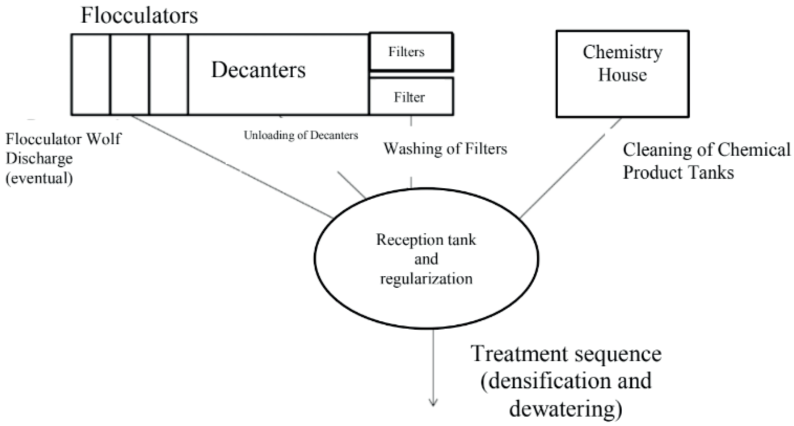

Figure 2 - Management scheme for sludge generated in conventional full-cycle water treatment plants.

Source: GERVASONI (2014).

Characteristics	**Natural Processes**		**Mechanized Processes**			
	*** Drying bed**	**slime ponds**	**centrifuge**	**Vacuum filter**	**dewatering press**	**Filter Press**
area demand	3	3	1	2	1	1
energy demand	0	0	2	3	2	3
Implementation cost	1	1	3	2	2	2
operational complexity	1	1	2	2	2	3
maintenance demand	1	1	2	2	3	3
installation complexity	1	1	2	2	2	2
Influence of climate	3	3	1	1	1	1
Sensitivity to sludge quality	1	1	3	2	2	2
Chemicals	1	0	3	3	3	3
Complexity of sludge removal	2	2	1	1	1	1
ST content in the pie	3	3	2	1	2	3
Noises and vibrations	0	0	3	2	2	2
Caption: 0 – None; 1 – Little, reduced; 2 – Medium; 3 – Large, high, very high; *30-day dewatering cycle.						

Table 1 - Comparison between the main methods for sludge dewatering

Source: Adapted from SILVA (2015)

retention capacity reaches its limit, and then it is washed. This process between consecutive washings of a filter is called a filtration career (ANDRADE, 2021).

Disinfection consists of the inactivation step of pathogenic microorganisms. In Brazil, chlorine is mostly used as a disinfectant agent, mainly because it is the most economical and due to the fact that chlorine manages to remain inactivating microorganisms even after the water has traveled long distances. Other commonly used disinfectant agents are ozone and ultraviolet radiation (ANDRADE, 2021).

Fluoridation consists of injecting fluoride compounds into the water, with the aim of raising the concentration of fluorides (F-), being a safe way to promote dental protection, specifically with regard to the formation of caries. Fluoride binds to dentin, becoming a preventive agent, avoiding caries, especially in the poorest populations, which represent the portion of the population with less access to oral hygiene (ANDRADE, 2021; NARVAI, 2000).

Essential for adapting the water to potability standards, the treatment process does, however, generate residues that are potentially harmful to the environment and health, notably coming from the cleaning processes of decanters and filters. These sludges must be treated and/or disposed of in a sanitary and environmentally appropriate manner.

This study proposes to deepen the knowledge about the sludge generated in water treatment plants (LETA) through a bibliographic review, emphasizing the consequences of its uncontrolled disposal in water bodies and the environmentally appropriate forms of disposal, with the aim of scenario the state of Rio de Janeiro.

METHODOLOGY

Initially, a partnership was established between the Directorate of Sanitation and Major Operations (DSG) of the State Water and Sewage Company (CEDAE) and the Faculty of Engineering (FEN) of ``Universidade Estadual do Rio de janeiro`` (UERJ), through its Department of Sanitary Engineering and the Environment (DESMA), with the objective of promoting the exchange of data, experiences and possible interactions of mutual interest between the institutions. The agreement was made official on 11/12/2019 (CEDAE, 2019) and listed priority projects focused on different engineering topics, including the reuse of ETA sludge (LETA).

CEDAE's technical staff then raised and shared several bibliographic references, including their own publications and those inherent to the aforementioned project/theme. Complementarily, a Systematic Bibliographic Review (RBS) was also carried out through the search for publications using search channels such as Google Scholar and the CAFE access of the CAPES Periodicals Portal. The keywords used were: a) WTP sludge; b) utilization; c) sustainability; and d) Brazil.

With the exception of two, the publications adopted as bibliographical references for the present work are of national scope, since the characteristics of the Brazilian reality of water treatment have substantial differences in relation to those of many countries, mainly the developed ones and/or of climate cold.

Data were compiled and segregated according to aspects such as reuse typology and study typology (pilot research or practical application). The time frame adopted was the period from 2001 to the present, with preference given to publications from the last 7 years

A map was also made using QGIS software, illustrating the locational configuration of all CEDAE ETAs (sludge generation points) before the concession of part of its units to the private sector. The larger sanitary landfills for solid urban waste registered at the State Institute of the Environment (INEA) in the State of Rio de Janeiro were also included on this same map, considering that this is the appropriate conventional destination for the type of waste in question (sludge).

POTENTIAL DAMAGE FROM LETA DISPOSAL WITHOUT PROPER TREATMENT IN WATER BODIES

According to Achon, Barroso and Cordeiro (2013), there were about 7,500 ETAs spread throughout Brazil, most of which still carried out improper final disposal in receiving bodies, generating several negative impacts. Even in more developed states such as São Paulo and Minas Gerais, about 50% of treatment units still use this practice.

The untreated disposal of LETA in water bodies can cause a series of negative impacts and the magnitude of these impacts depends on the physical, chemical and biological characteristics of both the sludge and the receiving body. At the beginning of the launch, it is already possible to visually detect the increase in turbidity and color, which are capable of affecting various forms of use of water resources, from recreational activities to irrigation (LIBÂNIO, 2016).

Due to its solid portion, the sludge leads to an increase in the amount of solids in suspension, favoring the silting up of the river, and in the case of lentic bodies, it especially harms the organisms that live in the benthic layer. In addition, the layer of solids hinders the passage of sunlight, serving as a barrier to the photosynthetic process of algae. Thus, fundamental biological processes are inhibited and the production of dissolved oxygen is reduced (LIBÂNIO, 2016).

Applied in the coagulation stage, aluminum sulfate and ferric chloride are discharged adhered to the sludge. Several studies, such as the one by ASSIS (2014), identified that high concentrations of iron and aluminum were detected in receiving bodies that received LETA launches without treatment. The analyzes of these waters showed values higher than those allowed by the relevant legislation, such as CONAMA Resolution 357 of 2005. The presence of both metals can still cause long-term consequences, due to the possibility of their deposition in the bed of the water body, including the risks their penetration into the food chain.

According to studies by ASSIS (2014), the analyzes indicated significant presence of *Escherichia Coli* in LETA, with concentrations greater than 300 MPN/mL. The presence of pathogenic microorganisms (bacteria, viruses, protozoa and helminths) in water can cause various diseases to the population, such as typhoid and paratyphoid fever, gastroenteritis, dysentery, cholera, schistosomiasis, amebiasis, highlighting that water with poor bacteriological quality is one of the most responsible for the high infant mortality rate in developing countries.

ENVIRONMENTALLY APPROPRIATE MANAGEMENT AND FINAL DISPOSAL FOR LETA

The sludge generated in the decantation and filtration units of the conventional complete cycle ETA must be disposed of properly. For this purpose, they can be gathered in a reception and regularization tank (GERVASONI, 2014), as exemplified in the scheme of Figure 2.

Some ETAs, however, have a recirculation tank for filter washing water (TRALF), from which the sedimentable part of the waste is concentrated at the bottom, being periodically repressed to the adenser together with the bottom discharges to clean the decanters (DI BERNARDO et al, 2012).

According to Richter (2001) and Pereira

(2011), the sludge initially presents a humidity of about 97% and, therefore, cannot be sold directly, as transportation is extremely costly, making it economically unfeasible. In view of this, the sludge must first undergo a densification and dehydration process, where its volume is reduced by means of a natural or mechanical process.

According to Libânio (2016), natural dehydration is simpler and easier to operate, usually using ponds and drying beds (CASTRO, 2014). However, it depends on factors such as the region's climate and the availability of large areas, and this model is contraindicated for ETAs whose flow is greater than 200 L/s.

The mechanical process normally uses the addition of specific polymers and is carried out using gravity, in continuous or batch operation (LIBÂNIO, 2016). According to Castro (2014), the mechanical equipment usually used are centrifuges, dual cell gravity concentrators, vacuum filters, plate or mat filter presses and vacuum drying beds.

Chart 1 presents a comparison between the methodologies commonly adopted for sludge consolidation and dehydration.

Depending on the methodology and/ or equipment applied, the solids content naturally varies between 18% and 65% (SILVA, 2015; ALVES, 2017). Higher levels greatly favor disposal in landfills as well as activities that can use it as an input.

According to Ribeiro (2007), the forms of final disposal of sludge usually adopted in Brazil are: direct release into surface waters; launch in ponds; layout on the ground; discharges into the sewage system; disposal in sanitary landfills; and disposition in agricultural soils.

Being formed from natural or artificial depressions – through the construction of dikes or earth excavations – ponds for the disposal of this material are often a viable alternative, as the sludge can be thickened and dehydrated in the same place, with low implantation, operation and maintenance costs. However, the sludge tends to infiltrate into the soil and may contaminate the water table, especially with aluminum and iron. Furthermore, there is a risk of forming a crust on its surface, making the dehydration of the lower layers very difficult (RIBEIRO, 2007).

Land disposal consists of spreading waste on natural soil. Its execution tends to favor greater moisture retention, but it can contaminate the water table with metals present in the sludge, as well as the case of using ponds. In addition, aluminum has a good ability to adsorb phosphorus, impairing soil productivity (LIBÂNIO, 2016).

Ribeiro (2007) reports that some small ETAs at SABESP started to use a new technique for sludge dehydration, consisting of the use of geotextile blankets, capable of segregating the solid part from the liquid part with good results. After its dewatering, the sludge is able to be disposed of environmentally and commercialized, as recommended by Richter (2001). In addition to not requiring large spaces and the cost of implementation and maintenance is not high, this management allows recirculation with the return of water to the beginning of the ETA treatment, reducing losses and increasing the efficiency of the process.

Another form of final disposal of the sludge is the use of incinerators, however, in addition to requiring a highly qualified workforce, this technology is very costly for the Brazilian reality, since the vast majority of municipalities usually do not have the conditions to acquire and operation of incinerators. Additionally, such a method implies the need to treat ash and very complex gases (DI CREDDO, 2021).

The release of sludge into the sewage system and its treatment and final disposal carried out in ETEs presents itself as an alternative for the supply concessionaires. However, the sludge can impact the biological process, reducing the overall treatment efficiency of these stations. Furthermore, it is recommended that ETAs carry out the damping and/or flow equalization before launching into the collection network, as there is a risk of sludge causing clogging in the pipes (LIBÂNIO, 2016).

Based on technical, spatial, cultural and, mainly, socioeconomic factors, Di Creddo (2021) concluded that landfills are the best option for the final destination of solid waste in Brazil, including sludge. Sludge is considered non-hazardous waste and can be disposed of with other waste, so as not to cause damage to public health and the environment (NBR 8419, 1992).

With the support and partnership of the states and the union, and through the formation of consortia, even smaller municipalities are considered capable of managing the management and logistics of the respective solid waste systems. However, for this to happen, it is essential to have a monthly fee for smaller generators and the charging of different fees for large generators, including water supply companies and concessionaires (DI CREDDO, 2021).

The state of Rio de Janeiro has 25 large urban solid waste landfills registered with INEA. Based on studies at CEDAE, Bielschowsky (2014) argues that most landfills in the Metropolitan Region of Rio de Janeiro (RMRJ) accept sludge with any solid waste content.

However, the cost of disposal is much higher when the sludge has a solids content below 30%, as shown by the data presented by Bielschowsky (2014): BRL 90.00/ton for contents greater than 60%; R$ 110.00/ton for contents between 30 and 60%; and R$ 160.00/ton for solids content lower than 30%.

Additionally, Silva (2015) apud Jordão (2011) warns that a solids content of less than 30% can impair or even prevent the compaction and work of the machines in the landfill due to its high fluidity, increasing operating costs.

GEOREFERENCING OF SLUDGE GENERATION POINTS (ETAS OF CEDAE) AND LANDFILLS

With the support of CEDAE and based on data from the INEA website, the present study identified the location, geographic coordinates of all ETAs currently granted or in the process of acquiring a grant from CEDAE. It is noteworthy that this was carried out shortly before the concession of part of the company's units to the private sector, in November 2021. In total, 104 units were georeferenced.

In addition, INEA's Environmental Licensing Board shared a 2018 database (updated in 2019), located on the ESRI website in shapefile format, which *indicates* the georeferenced location of the 25 large urban solid waste landfills registered in the state from Rio de Janeiro.

From these data, it was possible to draw up the map shown in Figure 3.

Based on the analysis of the map, it can be seen the existence of regions such as the North and Northwest of the state, where there is a high number of ETAs without nearby landfills. Such a situation must drastically increase the costs of final disposal of sludge from these water treatment plants, notably those that generate more sludge due to flow demands and the available quality of their respective raw water sources.

It is also worth highlighting the difficulties that can be encountered in cases of disposing of sludge from a ETA in a given municipality in a landfill located in the territory of another municipality, except in cases where there is already an institutional arrangement that facilitates and/or allows this destination, as in

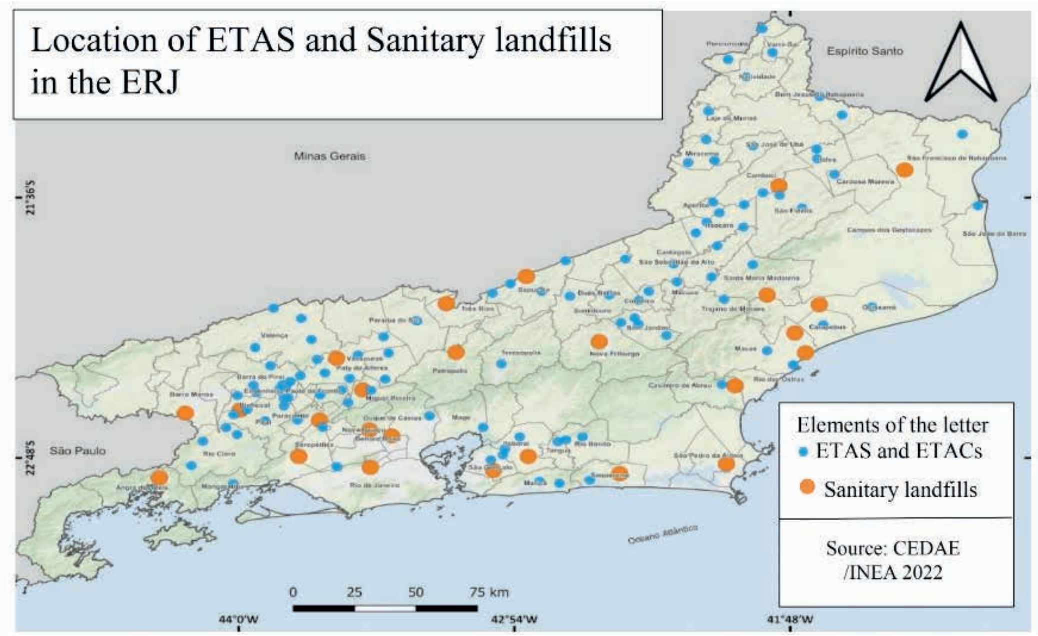

Figure 3 - Location of the ETAs granted or in the process of being granted by CEDAE in October 2020 and the 25 large urban solid waste landfills registered with INEA.

Note: ETAC - Compact Water Treatment Station, that is, they are units built in order to optimize the available space.

Source: The Author (2023).

Index	Specific Use of LETA	Location	Sources/Reference/year	Scale (Research/Pilot or Actual)	Potentialities	Fragilities (Critical Points)	Physical-Chemical Parameters Evaluated
1	Use in Bituminous Concrete (Asphaltic)	Brasilia DF	MARTINEZ, J. 2014. Performance Evaluation of Bituminous Mixtures with addition of LETA and LETE. Master's Dissertation presented at UnB.	Pilot (ETA Brasília and ETE Norte - DF)	Studies have proved that the use of LETA in bituminous concrete is technically and environmentally feasible. Furthermore, ETA Sludges that were calcined at 500 °C had improved mechanical and adhesive properties.	In the evaluations of mixtures with ETA and ETE sludge in the air-dried condition, although it is the most economical and ecologically correct alternative in terms of energy consumption as it requires minimal treatment of the residue, no improvements were found in consistency properties.	No sludge characterization studies were carried out. The author cited another work to characterize the sludge.
2	Coarse Aggregate in Concrete	Sao Paulo-SP	SOUZA, F. 2010. Composite of LETA and wood sawdust for use as coarse aggregate in concrete. Doctoral thesis presented at USP.	Pilot (Applied to an ETA: São Carlos ETA)	The aluminum present in the sludge ceases to be waste and becomes part of the concrete composition.	Application only possible in concrete with light type structure, that is, for less resistant concrete.	No sludge characterization studies were carried out. The author cited another work to characterize the sludge.

3	Use in fine concrete aggregates	Goiás, GO	ARAUJO, F. 2017. Technical Evaluation of Waste Generated in ETA as a Partial Replacement of Aggregates in Cementitious Components – PAVERS. Graduate dissertation at UFG.	Pilot (ETA Eng. Rodolfo José, in Goiás)	Use of Waste with Aluminum Sulphate. Small increase in compressive strength.	Restricted to concrete for use in flooring only. I use a little more water in the manufacture of concrete.	DRX, ED-FRX, EDS micro-probe, atomic absorption spectrometry (AAS) and granulometric characterization.
4	Incorporation in the production of Concrete	Curitiba, PR	TAFAREL, N. *& et al.* Evaluation of concrete properties due to the incorporation of LETA. Matter Magazine. ISSN 1517-7076 article 11759, pp. 974-986, 2016.	Pilot (ETA from Curitiba)	Possible application of LETA in up to 5% of the concrete composition.	Reduction of mechanical strength of concrete and axial compression tests.	pH, temperature, turbidity, COD, Total Solids, moisture content and specific mass.
5	Partial use in Portland cement mortar	Bethlehem, PA	CUNHA, B. 2019. Waste from LETA from the metropolitan region of Belém in Partial Replacement of Portland Cement in Mortar. Master's Dissertation at UFPA.	Pilot (ETA Bologna, in Belém)	Mortars with the addition of sludge in their mix, up to 10%, resulted in a slight increase in resistance both for 7 days and 28 days of age. Such a result occurred with the CP I-25 cement type.	The study proved that, for cement type CP II-F-32, the addition in mortar impaired the formation of cement, with characteristics below the norms.	Laser Granulometric Composition, Specific Mass and X-Ray Fluorescence Spectrometry (ED-FRX).
6	Use in civil construction	Curitiba, PR	FERNANDEZ, L. & MIKOWSKI, P. 2016. Evaluation of the Feasibility of Using LETA in Concrete Parts for Interlocking Paving. Civil Engineering TCC presented at UTFPR.	Pilot (ETA Passaúna - SANEPAR)	Application of LETA proved to be viable	Restricted to up to 5% of the entire composition, slightly reducing the strength of the concrete. Superior compositions proved to be inappropriate in relation to the norms.	pH, Moisture Content, Dry Specific Grass, ST, SV, SF, Fire Loss and EDX. In addition, SANEPAR provided chemical analysis reports.
7	Manufacture of mortar for civil construction.	Palmas, TO	NASCIMENTO, É & et al. 2019. The Use of LETA as an Input in Mortar. Paper presented at CONTECC 2019.	Pilot (ETA from Jataí - Goiás)	Mortars with a percentage of 10% LETA resulted in good results, with good mechanical characteristics.	The use of sludge greater than 15% resulted in inadequate results according to the Standards.	Granulometric composition only.
8	Use in the sub-base of pavers	Ouro Preto, MG	ALVES, H. 2019. Laboratory Analysis of Dehydrated Sludge from WTPs in the Metropolitan Region of Belo Horizonte – MG for Use in Paving. UFOP Master's Dissertation.	Pilot (2 ETAs, different cities)	the sludge can be used to reinforce the subgrade and sub-base of pavements	As for the Modulus of Resistance (MR) values found both for pure sludge and some values as well as for chemically stabilized with Portland cement and hydrated lime, they were much lower than the reference values presented.	Granulometric Analysis, Real Grain Density, Attenberg Limits, X-Ray Fluorescence, X-Ray Diffraction, pH, SEM and ICP OES,

9	CLETA in cement pastes for concrete formation	Santa Maria, RS	STEIN, RT Characteristics of Portland cement pastes with LETA ash addition. UFSM Master's Dissertation. 2016.	Pilot (ETA from the city of Venâncio Aires - RS)	Decrease in Electrical Conductivity with increasing curing time. Less formation of C - S - H (from alite hydration)	There was an increase in setting time for both the beginning and the end of this period. Greater mass loss as greater replacement by CLETA in the paste. Greater porosity in the paste.	pH, electrical conductivity, X-ray diffraction, mercury intrusion porosimetry and differential thermal analysis
10	use in concrete	Santa Maria, RS	HENGEN, M. Characterization of LETA ash for use in concrete - (Axial compression strength). Master's dissertation presented at UFSM. 2014.	Pilot (ETA of Arroio Castelhano - RS)	From the tests on concrete, it was verified that the partial replacement of cement by LETA ash resulted in an increase in the values of resistance to axial compression when compared to the reference concrete, at 7 and 28 days of age.	From the results obtained for CLETA, it was found that the combined CH content was lower than those obtained for CCA or SA	SiO2, Al2O3, Fe2O3, Cao, MgO, SO3, Na2O, K2O, MnO, TiO2, P2O5 and Losses on ignition
11	Use in paving for pedestrians and bricks	Getulio Vargas, RS	BAÚ, S. FIORI, S. Characterization and Arrangement of LETA 1 of Erechim/RS. Show of scientific initiation. IDEAU colleges.	Pilot (ETA 1 from Erechim - RS)	According to Fadanelli and Wiechteck (2010), the use of sludge from ETA's is intended specifically for low-traffic paving, for example, and can be used for sidewalk infrastructure works, with people as the main users of the roads	It is also feasible, but strictly dependent on additional studies, the incorporation of sludge to mold bricks, as there is the possibility of deficiencies in terms of mechanical resistance.	There are no measurements. The authors performed estimates.
12	Use in mortar (partial replacement of fine aggregate)	Alegrete, RS	SANTOS, F. Characterization and study of LETA incorporation in mortar. Master's Dissertation by UNIPAMPA. 2018	Pilot (ETA from Caçapava do Sul - RS)	For the mortars, it was verified that the mass replacement of the sand by the calcined sludge (LC) provided an increase in the mechanical properties, being the 3% content which obtained the best results.	Dry sludge (LS) significantly reduced mechanical strength due to the presence of organic matter	Moisture content, Organic matter content, pH, FRX, DRX, FTIR, Raman and SEM.
13	Use in building materials	Goiás, GO	ARAÚJO, F. & *et al.* Physical characterization of waste from an ETA for its use in building materials. Pottery **61** (2015) 450-456.	Pilot (ETA Meia Ponte - GO)	the presence of metals such as aluminum makes the material resistant after firing, which gives potential to the use of the residue as an addition and/or raw material in the production of ceramic materials such as bricks, tiles and others.	It is required that its participation in the composition of the traits be evaluated with percentages duly tested and controlled, verifying the ideal amount of residue to be applied in substitution to the soil/sand without prejudice to the mechanical properties and performance. of the material produced, meeting the requirements of specific standards.	Sludge Consistency Index, atomic absorption spectrometry

14	use in paving	Igarassu, PE	LUCENA, L. *& et al.* Characterization and evaluation of the potential use of sludge from STP and WTP in paving. Article published in the Agricultural Engineering magazine, 2016.	Pilot (ETA Botafogo - PE)	Regarding the mechanical test, the rate of 20% of ETA residue showed the best results for the CBR test and for the resilience modulus; this fact indicates that the stability of the particle size allows the use of waste as a sub-base and base for pavements with intermediate traffic.	ETE sludge has a high content of organic matter, which was confirmed by chemical analysis, as different oxides were found in the sample. Spectroscopy indicated the presence of heavy metals in quantities greater than the maximum limit established by the standards.	Fluorescence X-ray (EDX-720 spectrometer), showing values of several oxides and metals
15	Use in concrete, as fine aggregate and cement	Curitiba, PR	HOPPEN, C. *& et al.* Co-disposal of ETA centrifuged sludge in a concrete matrix: an alternative method for environmental preservation. Article - Ceramics **51** (2005) 85-95.	Pilot (ETA Passaúna - Curitiba)	Data analysis allows concluding that traces with up to 5% of sludge can be applied in situations ranging from the manufacture of artifacts and blocks to the construction of pavements in Portland cement concrete.	In relation to mixtures with contents above 5%, their use is restricted to applications in which workability is not a primary parameter, such as subfloors, sidewalks and residential floors.	X-Ray Diffraction (XRD), FRX and Flame Atomization Atomic Absorption Spectrophotometry
16	Miscellaneous uses in general (Compendium)	Dublin, Ireland (INTERNATIONAL)	Babatunde, AO; Zhao, YQ Constructive approaches towards water treatment works sludge management: an international review of beneficial re-uses. Critical Reviews in Environmental Science and Technology, 37(2): 129-164. 2007	Search	Use of LETA in wastewater treatment process, construction and building materials, land applications and other uses (animal feed, for example)	Little is known about treated or dewatered sludge being landfilled or reused. In other words, there is an extreme lack of information about the toxicity of any substances released by LETA reuse.	EU through CEN (European Committee for Standardization), which established Technical Committee 308 (TC308) in charge of standardizing methods for sludge characterization
17	Suggestion for use in civil construction	Porto Alegre, RS	FERRANTI, E. Dehydration of LETAs. Postgraduate dissertation defended at UFRGS. 2005	Pilot (ETA José Loureiro da Silva and ETA São João - RS)	Carry out pilot tests in the cement industries to confirm, on a real scale, the feasibility of incorporating a mixture of sludge with lime residue into cement, as well as sludge without lime residue, since the chemical composition of both (mainly in terms of Al and Ca) has excellent application potential in the composition of chemical modules of raw flour for clinkerization kilns	-	ST, SFT, N, P, K, Zn, Ca, Mg, Fe, Al, Cu, Mn

18	Miscella-neous uses in general (Compen-dium)	Campina Grande, PB	PAIVA, G & *et al.* LETA: Waste or input? Paper presented at the VII Brazilian Congress on Environmental Management. Campina Grande, 2016.	Search	The LETA layout most contemplated in the studies presented was application in civil construction (incorporation in materials such as ceramics), and the choice of the most appropriate solution for the specific case must be carried out after its characterization.	-	The parameters presented are from other authors. Only metals were characterized.
19	Various uses	Sao Carlos, SP	ACHON C. Reuse of LETA. Prof. Slides Class. doctor Cali Achon, presented at UFscar's Deciv. September 2017.	Search	Reduction of LETA launches in water bodies and consequent reduction of their respective environmental impacts	Technical and financial viability for LETA Reuse/Recycle.	The authors suggest the analysis of a battery of parameters, which depend on the end activity chosen as a solution.
20	Precast Concrete Flooring	Itajuba, MG	CASTRO, C. Use of LETA for the Manufacture of Precast Concrete Pavements. Dissertation submitted to the Graduate Program at UNIFEI, 2014.	Pilot (ETA of Pardons)	It was the compressive strength of concrete with sludge incorporation; the concrete achieved better mechanical performance for structural concrete	-	SEM, Humidity, Specific mass and Granulometry
21	Manufacture of Masonry Elements	Campinas, sp	CHAVEZ, Porras Alvaro. Use of water treatment plant sludge and fine recycled aggregate in the manufacture of masonry elements. Campinas: Faculty of Civil Engineering - UNICAMP, 2007. 213p. Thesis (Doctorate) - Faculty of Civil Engineering, UNICAMP, 2007.	Pilot (5 ETAs from the city of Campinas)	Regarding the non-structural concrete blocks (sealing), with up to 3% of dry sludge or 1% of wet sludge, rubble aggregate in the two matrices evaluated (concrete and ceramics) and 10% of cement, they could serve as a basis for a production industrial, being destined to the urban infrastructure	No brick produced under the proposed conditions simultaneously met the requirements of the Brazilian quality standards – dimensions, water absorption and compressive strength.	pH, ST, STV, STF, Granulometry and Attenberg Limits
22	use in paving	Londrina, PR	COELHO, R. & *et al.* Use of LETA in road paving. Article published in Reec - Electronic Magazine of Civil Engineering. Volume 10, No. 2, 11-22, 2015.	Pilot (ETA Cafezal - Londrina/PR)	Based on the DNIT requirements, it can be verified that the mixture of soils with ETA sludge can be used in the subgrade layer of a pavement.	The evaluated dosages of clayey-cement soil (10%) and clayey soil-sludge ETA-cement (10%), using the characteristic soil of the city of Londrina, do not meet the DNIT criteria for application as sub-base or road pavement bases	Specific mass of solids (g/cm³). The authors used other publications as a source of physical parameters for the sludge from the ETA Cafezal

23	Miscellaneous uses in general (Compendium)	Butanta, SP	MORITA, D. Beneficial Uses of LETA. Slide presentation by researcher Dione Morita, from the Polytechnic School of USP.	Search	Developed countries have been applying various techniques such as for use in steel, cement, ceramic coating, agriculture/ eutrophication control, covering sanitary landfills, etc.	-	-
24	Use in the incorporation of cement used in paving	International, Jordan	ALQAM, M., JAMRAH, A. & DAGHLAS, H. Utilization of Cement Incorporated with Water Treatment Sludge. Jordan Journal of Civil Engineering, Volume 5, No. 2, 2011.	Pilot (Zai drinking water treatment plant in Jordan)	All of the tiles produced comply with the minimum breaking strength of 2.8 MPa required by the standards.	Additionally, the study concluded that a decrease in the breaking strength of tiles is accompanied with an increase in the amount of sludge-cement replacement, and presented a linear relationship to predict breaking strengths of tiles produced with sludge-cement replacement percentages not investigated in this study.	Apparent Density, pH, Cd, Cr, Cu, Fe, Pb, Mn, Ni and Zn.
25	Use in the manufacture of concrete	Curitiba, PR	RAMIREZ, K. Feasibility of using WTP Waste in Concrete Production. Master's dissertation presented at UTFPR, 2015.	Pilot (ETA Tamanduá, Foz do Iguaçu)	Based on the results obtained, it was verified that the addition of up to 20% of LC provided an increase in the mechanical properties of the concrete, which can be used in structural concrete, provided durability studies are carried out.	The addition of wet WTP sludge significantly reduced the strength of the concrete, and from a technical point of view a replacement content of up to 5% is indicated for applications in concrete, as long as they are not structural.	Humidity, ST, Density, pH, Inorganic parameters, Chemical Composition, mineralogical analysis and etc.

Table 3 - Compilation of data collected regarding sludge management alternatives

Source: The Author (2023).

the case of the existence of a consortium of formalized municipalities.

SLUDGE MANAGEMENT BASED ON THE CIRCULAR ECONOMY CONCEPT: THE INSERTION OF SLUDGE IN THE PRODUCTION CHAIN

Based on the survey of references and studies carried out, it was possible to identify and gather several works related to the theme. Most motivate the use of LETA for civil construction. The compilation of the data obtained is presented in Table 3.

CONCLUSION

With the growth of water demand concomitantly with the worsening of the quality of the springs, the ETAs play a priority role in supplying the population, generating, however, an increasing amount of sludge.

The direct and untreated disposal of this sludge in water bodies is recognized as a practice that is highly harmful to the environment. Contamination of a physical-chemical and biological nature related to it brings serious damage to water bodies, compromising water quality, in addition to not being compatible with current health and environmental legislation. However, it can be seen that in many cases the sludge is still disposed of inappropriately, due to the high costs involved in adapting this destination through processes that involve its densification, dehydration, inertization and sanitary final destination.

There are several alternatives for the proper disposal of sludge, and for the Brazilian reality, where there are still areas available, final disposal in appropriate sites such as urban solid waste landfills is the most viable form from a cultural, spatial, and cultural point of view. technical and socioeconomic.

On the other hand, such adequate conventional final disposal costs are extremely high and often unfeasible for certain locations in the country, especially in the case of smaller municipalities.

In addition to seeking to reduce sludge generation and introduce the recirculation of effluents and waste in the water treatment process, new sludge management techniques and procedures must be incorporated based on the Circular Economy concept. This concept assumes that the residue (in this case, sludge) can be reintroduced into the production chain, being used as an input in the production of ceramic and concrete artifacts, paving, restoration of degraded areas and substrate for the production of seedlings of plant species.

In addition to studies and research on the subject, it can be seen that there are already several practical initiatives aimed at this use, albeit on smaller scales. It is necessary, however, to carry out a prior technical assessment of the local conditions, taking into account geographic, environmental, climatological and socioeconomic aspects, among others, in order to identify the most viable way. The risks inherent in frequent handling must also be evaluated.

In general, it is recommended that the sludge be densified and dehydrated prior to its disposal, so that the final solids content in the sludge is equivalent to or greater than 30%.

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