SEWAGE SLUDGE IN BRAZIL – AN OVERVIEW FROM A SUSTAINABLE POINT OF VIEW

Sabrina de Oliveira Anício, EESC - USP, sabrinadeoliveira@usp.br
João Miguel Merces Bega, EESC-USP, joaobega@usp.br
Tadeu Fabrício Malheiros, EESC - USP, tmalheiros@usp.br

Abstract

Sludge is one of the solids by-products produced in conventional wastewater treatment and can be recovered from many processes and technologies. Specifically for Brazil, sludge management is a huge problem, due to its big population and high production of wastewater. Considering that Brazil aims to achieve 90% of this service covering until 2033, understanding the current scenario of sludge management can be helpful to deal with the amount of wastewater sludge that will increase in the next years. This study aimed to evaluate the current scenario of Brazil's sewage sludge management. It was concluded that Brazil already has consolidated legislation about sewage sludge use in soils but a lack of rules about using sewage sludge as a material for other areas. The current disposal scenario is not good from a sustainable point of view, but a more positive view for the future is expected.

Key-words: Wastewater sludge, sewage treatment, wastewater treatment, sustainability, sewage sludge management.

1. Introduction

Although sewage sludge can be used as a nutrient source for agriculture purposes, among other recycling strategies, it is mostly considered waste and disposed of in landfills, but in some cases is dumped in water courses, causing environmental and health problems. Specifically for Brazil, sludge management is a huge problem. According to the Brazilian National Sanitation Information System (Sistema Nacional de Informações sobre Saneamento - SNIS), only around 50% of the total wastewater produced in the country is treated (MDR, 2020), and therefore, there is still a high potential to increase the amount of sewage sludge obtained from wastewater treatment processes, once Brazil aims to achieve 90% of wastewater collection and treatment coverage by 2033 (Brasil, 2020b). For sure it is a must to provide sustainable access to these services, mainly considering the huge Brazilian population – estimated to be more than 200 million people for the year 2021 (IBGE, 2021).

The concept of sustainability is based on the focus on meeting the needs of the present without compromising the ability of future generations to meet their needs. It is also related to the environmental, economic and social aspects of systems and how they can develop keeping an intern balance. Considering the urgent climate change context and all the environmental and social problems caused by inappropriate management of waste, it is necessary to discuss and reflect how Brazil has been dealing with the great quantity of sewage sludge produced daily, and also with the amount that is, probably, going to increase in the next few years.

Understanding the current scenario of sewage sludge management, including regulatory aspects and problems, can be helpful to deal with the amount of wastewater sludge that will increase in the next years and that can probably represent another environmental problem due to the management of the waste. In this context, the present study aimed to evaluate the current scenario of Brazil's sewage sludge management, including regulatory aspects, disposal data, publishing scenario and future predictions. The goal is also to help further investigations about sewage sludge management in the country.

2. Theoretical foundation

Sludge is one of the solids by-products produced in conventional wastewater treatment. Although it consists of around 75 to 99% of water (Chen et al., 2021), it is usually considered a solid waste to distinguish it from the liquid phase (wastewater) (Von Sperling, 2007). Sewage sludge is made of water, organic matter, microorganisms, organic and inorganic toxic contaminants, pathogens, and heavy metals (Chen et al., 2021; Kacprzak et al., 2017). The material is composed of a good number of nutrients, such as nitrogen, phosphorus, sulfur, and potassium (Sohaili et al., 2012) obtained from human digestion, once the body is not able to absorb a hundred percent of nutrients contained in food (Ellen Macarthur Foundation, 2017).

The aforementioned nutrients can be recovered from many processes and technologies, including composting by mono and co-digestion (Tian et al., 2020), usually with municipal organic solid waste, and anaerobic and aerobic digestion (Andreoli et al., 2007). Other processes that can be included are the ones that produce solids with different structures such as biochar from thermal treatments, like incineration, pyrolysis and gasification (Bień & Bień, 2019). From these processes is also possible to recover nutrients, mainly phosphorus, besides producing bio-oils and syngas (a type of gas in which the major concentrations are from H2 e CO) (Callegari et al., 2018; Tsybina & Wuensch, 2018). Gas is also possible to be recovered from the anaerobic digestion mentioned above, in the form of biogas (Brasil, 2015).

As recovering nutrients is possible from sewage sludge, its use in agriculture is highly considered (Cristina et al., 2019; Kominko et al., 2018; Lipińska, 2018). Other possible uses for the processed material are uses in construction (Ducoli et al., 2021; Roychand et al., 2021), mainly as compost for cement. The biogas produced from anaerobic digestion can be recovered, after processing, as electric or thermal energy, and also be purified until it becomes biomethane, a kind of fuel (Brasil, 2015).

Nevertheless, sewage sludge, conventionally disposed of in landfills, represents problems such as slope instability, land contamination and operation difficulties (Bringhenti et al., 2018). Besides that, this kind of disposal is usually expensive, requires lots of space and has been criticized due to long term environmental risks (Yadav et al., 2019).

3. Methodology

This paper was mainly based on texts from both white and gray literature from Brazil. White literature is composed of papers and other publications that have some specific methods of submission, evaluation and publishing. Gray literature is composed of manuals, books and other documents, usually published by institutions such as government agencies. For this paper, an analysis of the following aspects related to Brazil was carried out:

- Government agencies' data, mainly the ones related to the country's sanitation system;
- Legislations related to sludge management and, in a wider view, solid waste management;
- Surveys made by sanitation agencies about their services;
- Scientific publication about sewage sludge.

Specifically for the current scenario of sewage sludge management, the National Survey on Basic Sanitation (Pesquisa Nacional de Saneamento Básico - PNSB) was analyzed. Although Brazil has a huge database about its sanitation system – the already mentioned SNIS – none of its 156 indicators (84 for water and wastewater services, 47 for urban solid waste management services and 25 for stormwater management services) is specifically related to sewage sludge or any waste from wastewater treatment management.

However, the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística - IBGE) is responsible for carrying out the PNSB to obtain information from entities that provide collective water supply and sanitary sewage services, including operational data on the collection, treatment, distribution and charging for these services in Brazilian municipalities. The investigation aims to evaluate the supply and quality of the services provided and analyze the environmental conditions and how they can affect the population's health and quality of life (IBGE, 2017a).

The last version of PNSB was released in 2017 and consists of a total of 185 tables that presents a series of information about the sanitation system, divided by country, region, state, municipality and population size range. The amount of 185 tables is composed of: 5 with general data; 108 about water supply; and 72 about sanitary sewage. Of these ones, 4 (tables 150, 151, 152 e 153) are directly related to sewage sludge management. They contain information about the sludge treatment phases and its final disposal. This information is commented on in topic 4.3.

Besides that, a search was conducted in the Scopus database to understand the Brazilian publishing scenario about sewage sludge. Scopus was chosen due to being one of the most complete scientific material databases. On February 2nd, 2022, the following search string was applied in Scopus:

("SEWAGE SLUDGE" OR "WASTEWATER SLUDGE") AND "BRAZIL"

All the articles that include this search string in their titles, abstracts or keywords were included. In a second search, the following string was used:

("SEWAGE SLUDGE" OR "WASTEWATER SLUDGE") AND "BRAZIL" AND ("SUSTAINABILITY" OR "SUSTAINABLE")

As in the first one, all the documents that include the string in their titles, abstracts or keywords were included. A simplified meta-analysis of these documents is presented in topic 4.4.

4. Results

4.1. Brazil's wastewater system

According to SNIS, in 2020 Brazil had a population of around 211 million inhabitants, and more than 85% was considered to be urban. The country is divided into 5,570 municipalities, 5 regions and 27 federative units (26 states and the Federal District). The sanitation system is operated by 12,045 service companies (MDR, 2020).

Around 84.1% of the total population and 93.4% of the urban population has access to the water network. The wastewater access is much scarcer, which, from the total population, just 55% has its wastewater collected. The number is not much higher considering the urban population, of which just 63.2% has its sewage collected. Besides the fact that a big portion of the wastewater is not even collected, just 50.8% of the total sewage produced is treated (MDR, 2020). In terms of volume, 6 billion m^3 year-1 is collected and 4.8 billion m^3 year-1 is treated (MDR, 2021).

Brazilians generate around 9.1 thousand tons of BOD (i.e., Biological Oxygen Demand) per day. The wastewater that is treated is forwarded to 2,768 Wastewater Treatment Plants (WWTPs). In terms of attended population, the most used processes are: conventional activated sludge; primary level treatment; anaerobic pound followed by facultative pound; anaerobic reactor followed by aerobic filter; and decanter (ANA, 2017).

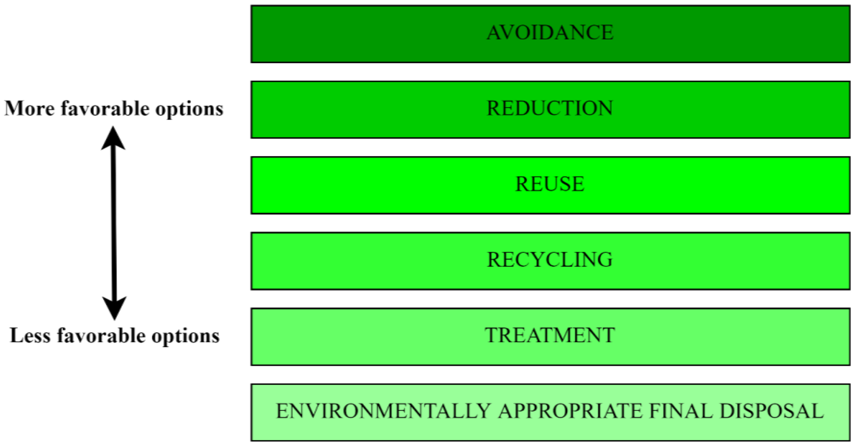
Bringhenti et al. (2018) estimated an amount of 51,000 m^3 of sewage sludge per day produced in Brazil considering a population of 200 million inhabitants and a humidity of 80%. Although the treatment is applied to just around half of this value, it still represents more than 25 thousand m^3 of sewage sludge per day.

4.2. Regulatory aspects

Although Brazilian National Solid Waste Policy (Política Nacional de Resíduos Sólidos - PNRS) (Brasil, 2010), established on August 2nd, 2010 (Law Nº 12.305) has no direct mention of sewage sludge management, it includes some specific aspects that can be related to it. PNRS is a law that puts together a series of goals, instruments, guidelines and actions adopted by the national government and by other government levels and private institutions to promote proper management of solid waste.

The legislation indicates a priority order for solid waste management according to Figure 1.

Figure 1: Priority order for solid waste management according to PNRS (Brasil, 2010)



Source: The authors (2022).

The legislation also includes the possibility of using solid waste to recover energy, since the technical and environmental viability is proven. It should also be implanted, with the responsible environmental organ approving, a monitoring program to control toxic gases emission (Brasil, 2010).

In the classification session, sewage sludge can be categorized as waste from basic sanitation public services, being also included in the hazardous waste class because of its pathogenicity, representing a risk to the public and environmental health (Brasil, 2010).

The main law that rules sewage sludge management in Brazil is Resolution Nº 498, established on August 19th, 2020, by the National Environmental Council (Conselho Nacional do Meio Ambiente - CONAMA). The legislation recalled two legislations established in 2006 and defined some aspects of the production and application of biosolids in soils. It defines wastewater sludge as the solid waste produced in sanitary wastewater treatment by biological or chemical processes. Meanwhile, biosolid is defined as the result of sewage sludge treatment that is aligned with chemical and microbiological criteria (defined in the law), being able to be applied in soils (Brasil, 2020a).

The law also includes processes to obtain Biosolids Types A (or 1) and B (or 2). Processes for Type A biosolids include (Brasil, 2020a):

- 4 Time-temperature scheme processes (the material remains for some time at a specific temperature);
- High pH and temperature processes;
- Composting (In-vessel, aerated piles or windrows);
- Direct or indirect thermal drying;
- Thermal treatment (liquid sludge at 180º C for 30 minutes);
- Autothermal Thermophilic Aerobic Digestion (ATAD);

- Irradiation;
- Pasteurization.

Type B processes include (Brasil, 2020a):

- Aerobic digestion;
- Drying on sand beds or basins;
- Anaerobic digestion;
- Composting (under lower temperature);
- Lime stabilization.

The main difference between both classes is the maximum limit for Escherichia coli per gram of total solids – 10^3 for Type A and 106 for Type B. It also has some specific determinations about heavy metals, as seen in Table 1.

Table 1: Maximum values allowed of chemicals in biosolids for use in soils, according to Resolution Nº 498 from CONAMA (Brasil, 2020a)

Chemical substances	Maximum value allowed for biosolid (mg per kg of total solids) Type A/1	Type B/2
Arsenic	41	75
Barium	1300	1300
Cadmium	39	85
Lead	300	840
Copper	1,500	4,300
Chromium	1,000	3,000
Mercury	17	57
Molybdenum	50	75
Nickel	420	420
Selenium	36	100
Zinc	2,800	7,500

Source: Adapted by the authors (2022).

Parameters for biosolid Type A are practically the same as presented in the last version of the Resolution (Nº 375, from August 29th, 2006) (Brasil, 2006), except for the fact that, for Selenium, the maximum allowed was 100 mg per kg of total solids. However, in this previous version, the values for Type A were also applied to Type B. As in the current version, the parameters for Type B have greater values. It means that the newest legislation is a little more flexible about the use of this kind of biosolid, which can be positive once it allows wider use of these materials.

Although more flexible, the regulation has some additional concerns about heavy metals and their maximum values when using Type B of biosolids, as seen in Table 2. The uses and limitations for both types are shown in Chart 1.

Table 2: Maximum annual rate and maximum accumulated load of chemicals in soils when using Type B of biosolids according to Resolution Nº 498 from CONAMA (Brasil, 2020a)

Chemical substances	Maximum annual rate (kg hectare^{-1} year^{-1})	Maximum cumulative load (kg hectare^{-1}) Soils of degraded areas	Maximum cumulative load (kg hectare^{-1}) Soils of non-degraded areas
Arsenic	2	20	41
Barium	13	130	260
Cadmium	1.9	19	39
Chromium	150	1,500	3,000
Copper	75	750	1,500
Lead	15	150	300
Mercury	0.85	8.5	17
Molybdenum	0.65	6.5	13
Nickel	21	210	420
Selenium	5	50	100
Zinc	140	1,400	2,800

Source: Adapted by the authors (2022).

Chart 1: Allowed uses and respective limitations for Type A and Type B biosolids according to Resolution Nº 498 CONAMA (Brasil, 2020a)

Biosolid type	Use	Limitations
A	Cultivation of foods that are consumed raw and whose edible part has contact with soil.	Do not apply the biosolids 1 month before the harvest period.
	Pasture and forage crops.	Do not apply the biosolids 1 month before the forage harvest and grazing period.
	Foods that have no contact with the soil; food products that are not consumed raw; non-food products; cultivated forests, soil recovery, and degraded areas; cultivation of green curtains, gardens, and lawns in WWTP or Sludge Management Units areas.	-
B	Cultivation of food products that are not consumed raw and non-food products.	Do not apply the biosolids 4 months before the harvest period.
	Pasture and forage crops.	Do not apply the biosolids 2 months before grazing and 4 months before the forage harvest period.
	Fruiting trees.	The application should be done after the harvest.
	Planted forests, soil recovery, and degraded areas; cultivation of green curtains, gardens, and lawns in WWTP and Sludge Management Units areas.	-

Source: Adapted by the authors (2022).

It can be observed that there is a wide range of situations and products that can use both types of biosolids since some limitations are respected. The main concern is about the soil contact of food that is eaten raw (because they are not cooked and, therefore, not submitted to high temperatures that could eliminate some specific pathogenic agents). This kind of food cannot even be produced with the use of biosolid Type B.

Besides the referred legislation, wastewater sludge to be used for agricultural systems needs to be registered or authorized by the Brazilian Ministry of Agriculture, Livestock and Supply (*Ministério da Agricultura, Pecuária e Abastecimento* - MAPA). When authorized, the resources need to be aligned with the parameters and requirements from the aforementioned Resolution Nº 498 from CONAMA.

When registered, besides the conditions from Resolution Nº 498, the product also needs to meet the requirements specified in the Normative Ruling Nº 25, from July 23rd, 2009 (MAPA & SDA, 2009).

The Normative Ruling Nº 25 from MAPA and Agricultural Defense Department (*Secretaria do Desenvolvimento Agrário* - SDA) specifies determined parameters for organic fertilizers and biofertilizers for agriculture. Organic fertilizers (whether they are simple, mixed, compound or organo-minerals) can be divided into 4 classes, according to their feedstock. Class D includes organic fertilizers that use any quantity of feedstock originated from the treatment of sanitary discharges in their production, and it should respect the specifications presented in Table 3 (MAPA & SDA, 2009).

Table 3: Mixed and compound organic fertilizer specifications for Class D products according to Normative Ruling Nº 25 (MAPA & SDA, 2009)

Parameter	Value
Humidity (max.) (%)	70
Total N (min.) (%)	0.5
Organic carbon* (min.) (%)	15
pH (min.)	6.0
C/N relation (max.)	20

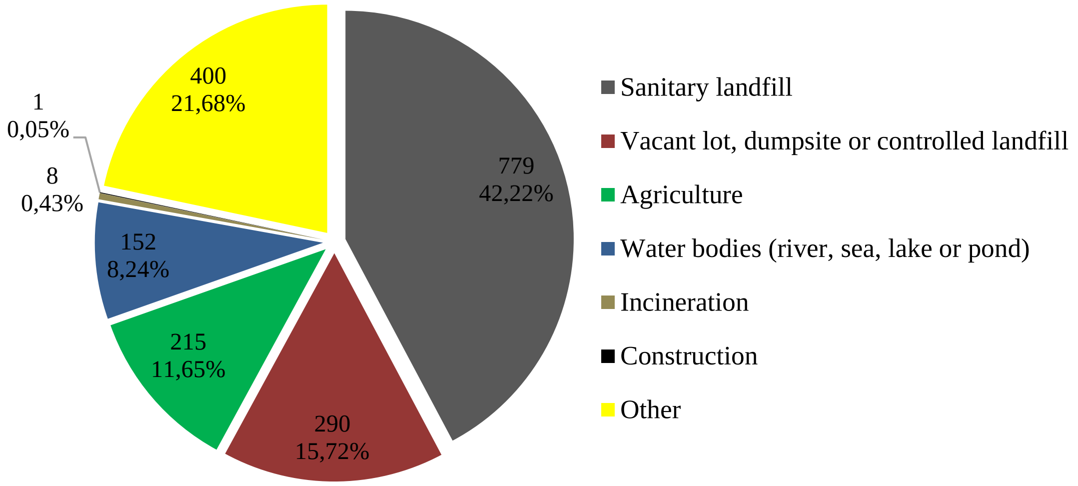
*Values expressed on a dry basis; humidity determined at 65ºC.
Cation Exchange Capacity (CEC), CEC/C relation and other nutrients should be declared during the product registration process.

Source: Adapted by the authors (2022).

4.3. Current scenario of sewage sludge disposal

Figure 2 shows the destinations of sewage sludge produced in wastewater treatment in Brazil.

Figure 2: Number of municipalities according to the final destination of the sludge produced in Brazilian WWTPs (treated or not) for the year 2017*



*The sum of final destinations, equivalent to 1845, is higher than the number of municipalities that generate sludge in their treatments in Brazil (1707), because it considers that in some municipalities there is more than 1 WWTP or that the same WWTP adopts more than one destination for its sludge.

Source: Elaborated by the authors based on data from PNSB (IBGE, 2017b).

Brazil extensively uses the practice of throwing the sludge produced at the WWTPs, whether treated or not, into landfills. A sanitary landfill is defined by the Brazilian Association of Technical Standards (ABNT) as a technique in which urban solid waste is disposed of on the ground, in such a way that the confinement is made using the smallest possible area, with the smallest possible volume. The objective is that the practice does not cause harm to public health and safety, besides minimizing the environmental impacts (ABNT, 1992). An expressive portion is forwarded to vacant lots, dumpsites and controlled landfills. The disposal in these places represents a big problem, mainly considering the following aspects:

- Increasing waste in these locations, which already receive lots of waste from other solid residues;
- Possible instability in slopes due to water present in sludge;
- More expenses with transportation (considering that processes to recycle/treat sewage sludge can be done in the WWTP itself);
- As a consequence of the topic above, more Greenhouse Gases (GHG) emissions due to the combustion of fossil fuels used in regular vehicles;
- Possible economic losses due to the financial feasibility of commercializing sludge by-products.

It is important to observe that almost 60% of destinations are susceptible to the problems above. Another huge problem is the existence of WWTPs that dispose of their sludge in water bodies (more than 8%), which can represent some aspects of concern:

- Pollution of water bodies because of heavy metals and other contaminants;
- Eutrophication due to nutrients contained in sludge, mainly nitrogen and phosphorus.

Use in agriculture, although not found very expressively, it is still considered in some situations. This is due to, firstly, the fact that there is a well-established legislation that rules the practice (the already mentioned Resolution Nº 498 and its old version, the Nº 375). Although sludge can have some hazardous materials, such as pathogenies and heavy metals (Kacprzak et al., 2017), it can be highly positive to cultures when applied following the right limitations and determinations, due to its nutrient content (Cristina et al., 2019; Kominko et al., 2018).

From the uses in Figure 2, besides agriculture, recycling for use in construction is another sustainable option. However, one of the problems that may make it hard to use this material in this sector is the lack of legislation/guidelines that rule this kind of practice. Another point that should be considered is that using sludge from wastewater can be positive once the disposal of the residue is sustainable, but brings other problems considering the disposal of the secondary waste generated. In this case, for example, sludge is used as a raw material to produce cement (using the wastewater treatment by-product in a sustainable alternative) but there is still concern about the disposal of the construction waste. Construction waste management is a problem, mainly in Brazil, where the production is estimated to be 0,4 to 0,7 tons per inhabitant per year (SÃO PAULO et al., 2012).

The process of incinerating sewage sludge is also not so common in Brazil. But in this case, it cannot be considered a negative scenario indeed, once the process produces gaseous pollutants (Allsopp et al., 2001) that can be harmful to the environment and human health (García-Pérez et al., 2013). The process was even excluded from the European Union taxonomy for sustainable activities because these activities are considered to be contrary to the requirements of the sustainable agenda (MAKAVOU, 2021).

Table 4 presents the final destinations according to population size ranges.

Table 4: Disposal of sludge produced in the sewage treatment in Brazilian municipalities

Population size ranges of Brazilian municipalities	Municipalities with sludge generation in wastewater treatment processes	Total destinations considered in the survey	Proportion of destinations according to the total sum (%) *						
			Sanitary landfill	Vacant lot, dumpsite or controlled landfill	Agriculture	Water bodies (river, sea, lake or pond)	Incineration	Construction	Other
Up to 5000	199	208	33.17	14.42	7.69	6.25	0.00	0.00	38.46
5001 to 10000	247	262	38.17	17.94	12.21	6.87	1.15	0.00	23.66
10001 to 20000	366	389	40.62	17.99	15.68	6.68	0.00	0.00	19.02
20001 to 50000	442	484	38.64	16.74	11.57	11.78	0.41	0.00	20.87
50001 to 100000	205	220	45.91	15.91	11.82	7.73	0.45	0.00	18.18
100001 to 500000	208	238	55.88	10.92	8.40	8.40	0.42	0.42	15.55
More than 500000	40	44	70.45	2.27	9.09	2.27	2.27	0.00	13.64

* Percentages were calculated according to the sum of the destinations considered in the survey. This sum is higher than the number of municipalities because it is considered that the same municipality can adopt more than one destination.

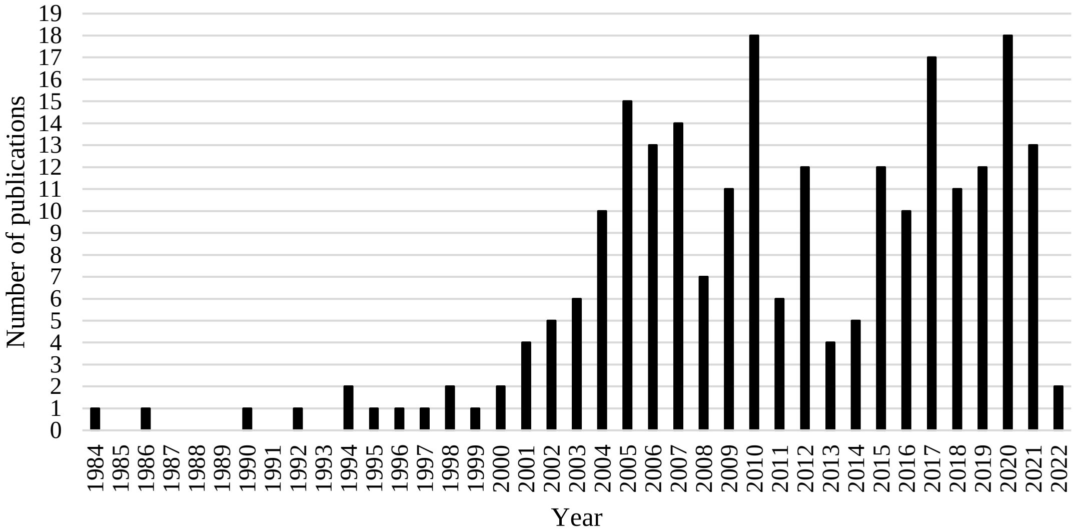
Source: Elaborated by the authors based on data from PNSB (IBGE, 2017b).

It can be observed that there is a greater tendency for disposal in sanitary landfills for municipalities with bigger populations. From this information, it also can be assumed that higher sludge volumes are delivered to these places. Vacant lots, dumpsites and controlled landfills are the second options for practically all size ranges. Another point that stands out is the fact that municipalities with 20,001 to 50,000 inhabitants have water bodies as the second greater disposal option. Incineration is more adopted in great municipalities (more than half a million inhabitants).

4.4. Publishing scenario

According to the method described in section 2, 239 documents were found. These documents were categorized by the year of publication, as it is presented in Figure 3.

Figure 3: Number of publications obtained according to their publication date

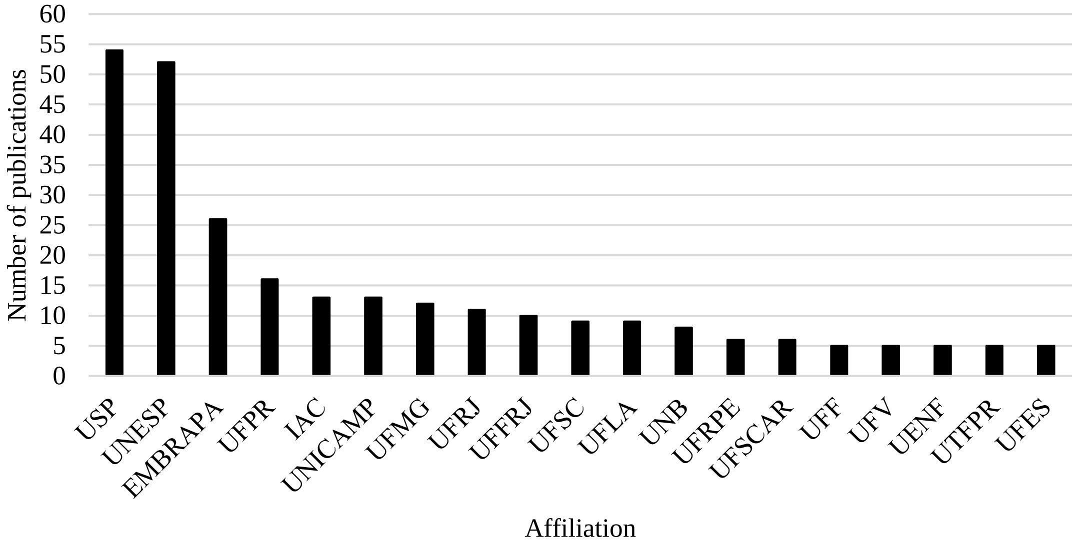


Source: The authors (2022).

It was observed that, from 2001 on, there was an increasing tendency of publications in the field in Brazil, with the highest number of documents found in 2010 and 2020. Although the aim of this part of this study is not to analyze the documents deeply, it is curious to observe that the two years coincide with the publication of two of the laws mentioned: PNRS (Brasil, 2010) and Resolution Nº 498 (Brasil, 2020a).

The documents were also organized by the authors' affiliation. As the number of affiliations was expressive, just the ones with 5 or more representatives were chosen. The graph can be seen in Figure 4. The same was done for the funding sponsor, considering all the institutions that founded 2 or more research, as can be seen in Figure 5.

Figure 4: Number of publications according to the author's affiliations*

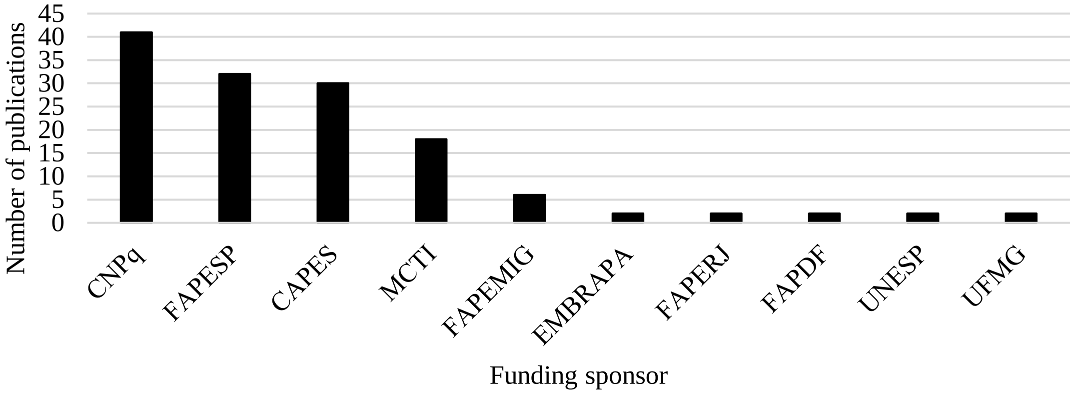


USP: University of São Paulo; UNESP: Paulista State University; EMBRAPA: Brazilian Agricultural Research Corporation; UFPR: Federal University of Paraná; IAC: Campinas Agronomic Institute; UNICAMP: Campinas State University; UFMG: Federal University of Minas Gerais; UFRJ: Federal University of Rio de Janeiro; UFFRJ: Federal Rural University of Rio de Janeiro; UFSC: Federal University of Santa Catarina; UFLA: Federal University of Lavras; UNB: University of Brasília; UFRPE: Rural Federal University of Pernambuco; UFSCAR: Federal University of São Carlos; UFF: Fluminense Federal University; UFV: Federal University of Viçosa; UENF: Darcy Ribeiro North Fluminense State University; UTFPR: Federal Technological University of Paraná; UFES: Federal University of Espirito Santo.

*Considering affiliations with 5 or more authors.

Source: The authors (2022).

Figure 5: Number of publications according to the funding sponsor*



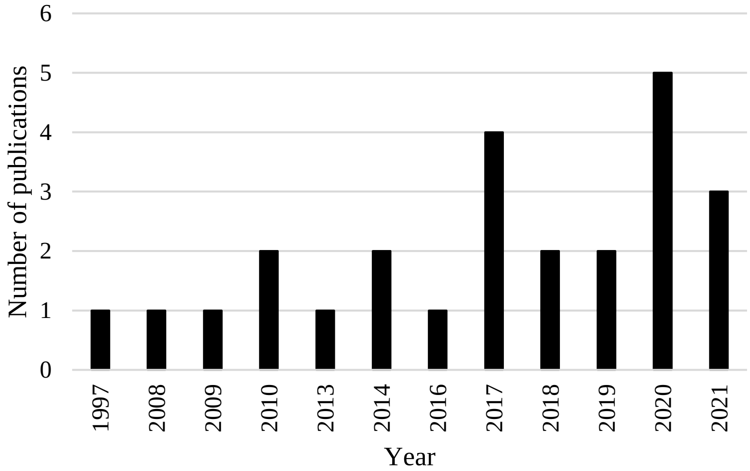
CNPq: National Council for Scientific and Technological Development; FAPESP: Research Support Foundation of the State of São Paulo; CAPES: Coordination for the Improvement of Higher Education Personnel; MCTI: Ministry of Science, Technology and Innovations; FAPEMIG: Research Support Foundation of the State of Minas Gerais; EMBRAPA: Brazilian Agricultural Research Corporation; FAPERJ: Research Support Foundation of the State of Rio de Janeiro; FAPDF: Federal District Research Support Foundation; UNESP: Paulista State University; UFMG: Federal University of Minas Gerais.
*Considering funding sponsors that founded 2 or more researchers.

Source: The authors (2022).

USP and UNESP stand out being the institutions with more affiliations. FAPESP, CNPq and CAPES are the funding sponsors that most founded the studies. Other two points that should be commented on are that IAC (institution that has 13 authors as affiliates) and EMBRAPA (funding sponsor that found 2 of the studies) are directly linked to specialists in agriculture research, which emphasizes sewage sludge relation to this field. Yet, it is important to emphasize that all the funding sponsors and affiliations are public institutions run by federal or state agencies.

As declared in the methodology, a second search was carried out. In this case, the results were very discrepant, with just 25 documents, as seen in Figure 6.

Figure 6: Number of publications obtained in the second search, according to their publication date



Source: The authors (2022).

Publications that contain the words "sustainable" or "sustainability" in their titles, keywords or abstracts were much less found, representing just a little more than 10% of the total amount. However, it is important to observe that, from 2016 on, all the years had documents that relate sewage sludge management in Brazil to sustainability and its concerns.

4.5. The future

Although the current scenario of sewage sludge management in Brazil is a huge challenge from a sustainable point of view, some predictions can bring a more positive look to the future. First, it has to be considered the more flexible resolution that was published in 2020 for biosolids from sludge use in soils, which may promote more of this practice across the country. Besides that, it has to be highlighted that the survey that was considered for the scenario here presented is from 2017, needing to be updated to show a more recent panorama. Another point is that, in 2020, Brazil has approved its new legal framework for sanitation that assigned to the National Water and Sanitation Agency (*Agência Nacional de Águas e Saneamento Básico* - ANA) the duty to edit reference standards on the sanitation service (Brasil, 2020b), and this can represent future changes, mainly in regulatory aspects.

5. Conclusions

Sewage sludge is a rich material that can be processed and has its nutrients and other properties recovered more sustainably. This study aimed to make an overview of the sewage sludge scenario in Brazil and the following was concluded:

- Brazil already has well solid legislation about sewage sludge use in soils that probably can make it easy to use this waste as a rich material;
- There is still a lack of rules and guidelines about using sewage sludge as a material for other areas, such as construction;
- The current scenario of sewage sludge management is not very positive, considering that most of the municipalities dispose of the sludge produced in the WWTPs in landfills;
- A great number of publications relating Brazil to sewage sludge concerns were found, with more documents published in the early years;
- There is major participation from public institutions and universities in the aforementioned publications, which emphasizes the importance of funding from Brazil's federal and state levels of government;
- Private funding of studies is still scarce in this field and should be driven;
- A more positive view of the future is expected, considering new legal aspects that were and may yet be adopted.

6. Acknowledgments

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001.

7. References

ABNT, A. B. de N. técnicas. (1992). *NBR 8419—Apresentação de projetos de aterros sanitários de resíduos sólidos urbanos*.

Allsopp, M., Costner, P., & Johnston, P. (2001). *INCINERATION AND HUMAN HEALTH - State of Knowledge of the Impacts of Waste Incinerators on Human Health*. 84.

ANA, A. N. de Á. (2017). *Atlas Esgotos—Despoluição de Bacias Hidrográficas*.

Andreoli, C. V., Sperling, M. von, & Fernandes, F. (Orgs.). (2007). *Sludge treatment and disposal*. IWA Publ.

Bień, J. D., & Bień, B. (2019). Sludge Thermal Utilization, and the Circular Economy. *Civil and Environmental Engineering Reports*, *29*(4), 157–175. https://doi.org/10.2478/ceer-2019-0052

Brasil. (2006). *Conselho Nacional do Meio Ambiente (CONAMA). Resolução nº 375, de 29 de agosto de 2006: "Define critérios e procedimentos, para o uso agrícola de lodos de esgoto gerados em estações de tratamento de esgoto sanitário e seus produtos derivados, e dá outras providências. "*.

Brasil. (2010). *Lei Nº 12.305, de 2 de agosto de 2010: "Institui a Política Nacional de Resíduos Sólidos; altera a Lei no 9.605, de 12 de fevereiro de 1998; e dá outras providências."*

Brasil. (2015). *Guia técnico de aproveitamento energético de biogás em estações de tratamento de esgoto*. Probiogás, Ministério das Cidades, Deutsche Gesellschaf für Internationale ZUSAmmenarbeit GmbH (Org.).

Brasil. (2020a). *Conselho Nacional do Meio Ambiente (CONAMA). Resolução nº 498, de 19 de agosto de 2020: "Define critérios e procedimentos para produção e aplicação de biossólido em solos, e dá outras providências."*

Brasil. (2020b). *Lei Nº 14.026, de 15 julho de 2020: "Atualiza o marco legal do saneamento básico e altera a Lei nº 9.984, de 17 de julho de 2000, para atribuir à Agência Nacional de Águas e Saneamento Básico (ANA) competência para editar normas de referência sobre o serviço de saneamento, a Lei nº 10.768, de 19 de novembro de 2003, para alterar o nome e as atribuições do cargo de Especialista em Recursos Hídricos, a Lei nº 11.107, de 6 de abril de 2005, para vedar a prestação por contrato de programa dos serviços públicos de que trata o art. 175 da Constituição Federal, a Lei nº 11.445, de 5 de janeiro de 2007, para aprimorar as condições estruturais do saneamento básico no País, a Lei nº 12.305, de 2 de agosto de 2010, para tratar dos prazos para a disposição final ambientalmente adequada dos rejeitos, a Lei nº 13.089, de 12 de janeiro de 2015 (Estatuto da Metrópole), para estender seu âmbito de aplicação às microrregiões, e a Lei nº 13.529, de 4 de dezembro de 2017, para autorizar a União a participar de fundo com a finalidade exclusiva de financiar serviços técnicos especializados."*

Bringhenti, J. R., Boscov, M. E. G., Piveli, R. P., & Günther, W. M. R. (2018). Codisposição de lodos de tratamento de esgotos em aterros sanitários brasileiros: Aspectos técnicos e critérios mínimos de aplicação. *Engenharia Sanitaria e Ambiental*, *23*(5), 891–899. https://doi.org/10.1590/s1413-41522018124980

Callegari, A., Hlavinek, P., & Capodaglio, A. G. (2018). Production of energy (biodiesel) and recovery of materials (biochar) from pyrolysis of urban waste sludge. *Ambiente e Agua - An Interdisciplinary Journal of Applied Science*, *13*(2), 1. https://doi.org/10.4136/ambi-agua.2128

Chen, G., Zhang, R., Guo, X., Wu, W., Guo, Q., Zhang, Y., & Yan, B. (2021). Comparative evaluation on municipal sewage sludge utilization processes for sustainable management in Tibet. *Science of The Total Environment*, *765*, 142676. https://doi.org/10.1016/j.scitotenv.2020.142676

Cristina, G., Camelin, E., Pugliese, M., Tommasi, T., & Fino, D. (2019). Evaluation of anaerobic digestates from sewage sludge as a potential solution for improvement of soil fertility. *Waste Management*, *99*, 122–134. https://doi.org/10.1016/j.wasman.2019.08.018

Ducoli, S., Zacco, A., & Bontempi, E. (2021). Incineration of sewage sludge and recovery of residue ash as building material: A valuable option as a consequence of the COVID-19 pandemic. *Journal of Environmental Management*, *282*, 111966. https://doi.org/10.1016/j.jenvman.2021.111966

Ellen Macarthur Foundation. (2017). *Urban biocycles*. https://emf.thirdlight.com/link/ptejjhurhaj5-iigai0/@/preview/1?o

García-Pérez, J., Fernández-Navarro, P., Castelló, A., López-Cima, M. F., Ramis, R., Boldo, E., & López-Abente, G. (2013). Cancer mortality in towns in the vicinity of incinerators and installations for the recovery or disposal of hazardous waste. *Environment International*, *51*, 31–44. https://doi.org/10.1016/j.envint.2012.10.003

IBGE, I. B. de G. e E. (2017a). *PNSB - Pesquisa Nacional de Saneamento Básico—Sobre*. https://www.ibge.gov.br/estatisticas/multidominio/meio-ambiente/9073-pesquisa-nacional-de-saneamento-basico.html?edicao=28244&t=sobre

IBGE, I. B. de G. e E. (2017b). *PNSB - Pesquisa Nacional de Saneamento Básico—Tabelas*. https://www.ibge.gov.br/estatisticas/multidominio/meio-ambiente/9073-pesquisa-nacional-de-saneamento-basico.html?edicao=28244&t=resultados

IBGE, I. B. de G. e E. (2021). *IBGE CIDADES*. https://cidades.ibge.gov.br/

Kacprzak, M., Neczaj, E., Fijałkowski, K., Grobelak, A., Grosser, A., Worwag, M., Rorat, A., Brattebo, H., Almås, Å., & Singh, B. R. (2017). Sewage sludge disposal strategies for sustainable development. *Environmental Research*, *156*, 39–46. https://doi.org/10.1016/j.envres.2017.03.010

Kominko, H., Gorazda, K., Wzorek, Z., & Wojtas, K. (2018). Sustainable Management of Sewage Sludge for the Production of Organo-Mineral Fertilizers. *Waste and Biomass Valorization*, *9*(10), 1817–1826. https://doi.org/10.1007/s12649-017-9942-9

Lipińska, D. (2018). The Water-wastewater-sludge Sector and the Circular Economy. *Comparative Economic Research. Central and Eastern Europe*, *21*(4), 121–137. https://doi.org/10.2478/cer-2018-0030

MAKAVOU, K. (2021, maio 26). *The EU is clear: Waste-To-Energy incineration has no place in the sustainability agenda*. Zero Waste Europe. https://zerowasteeurope.eu/2021/05/wte-incineration-no-place-sustainability-agenda/

MAPA, M. D. A., PECUÁRIA E. ABASTECIMENTO, & SDA, S. D. D. A. (2009). *INSTRUÇÃO NORMATIVA SDA Nº 25, DE 23 DE JULHO DE 2009*. https://www.gov.br/agricultura/pt-br/assuntos/insumos-agropecuarios/insumos-agricolas/fertilizantes/legislacao/in-25-de-23-7-2009-fertilizantes-organicos.pdf/view

MDR, M. do D. R. (2020). *Sistema Nacional de Informações sobre Saneamento (SNIS)—Glossários de informações e indicadores de água e esgotos, resíduos sólidos e águas pluviais*. http://snis.gov.br/painel-informacoes-saneamento-brasil/web/painel-setor-saneamento

MDR, M. do D. R. (2021). *Diagnóstico Temático—Serviços de Água e Esgoto*.

Roychand, R., Patel, S., Halder, P., Kundu, S., Hampton, J., Bergmann, D., Surapaneni, A., Shah, K., & Pramanik, B. K. (2021). Recycling biosolids as cement composites in raw, pyrolyzed and ashed forms: A waste utilisation approach to support circular economy. *Journal of Building Engineering*, *38*, 102199. https://doi.org/10.1016/j.jobe.2021.102199

SÃO PAULO, SMA, S. do M. A. do E. de S. P., & SindusCon-SP, S. da I. da C. C. do E. de S. P. (2012). *Resíduos da Construção Civil e o Estado de São Paulo*. https://cetesb.sp.gov.br/si-gor/wp-content/uploads/sites/37/2014/12/Resíduos-da-Construção-Civil-e-o-Estado-de-São-Paulo.pdf

Sohaili, J., Zaidi, N. S., & Loon, S. C. (2012). Nutrients Content of Sewage Sludge and Its Utilization towards Horticulture Plant. *Journal of Emerging Trends in Engineering and Applied Sciences*.

Tian, X., Richardson, R. E., Tester, J. W., Lozano, J. L., & You, F. (2020). Retrofitting Municipal Wastewater Treatment Facilities toward a Greener and Circular Economy by Virtue of Resource Recovery: Techno-Economic Analysis and Life Cycle Assessment. *ACS Sustainable Chemistry & Engineering*, *8*(36), 13823–13837. https://doi.org/10.1021/acssuschemeng.0c05189

Tsybina, A., & Wuensch, C. (2018). ANALYSIS OF SEWAGE SLUDGE THERMAL TREATMENT METHODS IN THE CONTEXT OF CIRCULAR ECONOMY. *Detritus*, *2*(1), 3. https://doi.org/10.31025/2611-4135/2018.13668

Von Sperling, M. (2007). *Wastewater characteristics, treatment and disposal*. IWA Publ.

Yadav, M., Gupta, R., & Sharma, R. K. (2019). Green and Sustainable Pathways for Wastewater Purification. Em *Advances in Water Purification Techniques* (p. 355–383). Elsevier. https://doi.org/10.1016/B978-0-12-814790-0.00014-4