Review

Not peer-reviewed version

Biosolids in Brazil: National Scenario, Legal Aspects, and Comparison with Average Parameters Obtained in Sewage Treatment Plants—A Review

Sérgio Siqueira de Amorim Júnior * and Denilson de Oliveira Guilherme *

Posted Date: 3 April 2026

doi: 10.20944/preprints202604.0196.v1

Keywords: biosolids; agricultural; emerging organic pollutants

Review

Biosolids in Brazil: National Scenario, Legal Aspects, and Comparison with Average Parameters Obtained in Sewage Treatment Plants—A Review

Sérgio Siqueira de Amorim Júnior * and Denilson de Oliveira Guilherme *

Graduate Program in Environmental Sciences and Agricultural Sustainability, Dom Bosco Catholic University, CampoGrande 79117-900, MS, Brazil

* Correspondence: sergioesa17@gmail.com (S.S.d.A.J.); rf3223@ucdb.br (D.d.O.G.)

Abstract

The production of biosolids in Brazil has increased due to the expansion of Sewage Treatment Plants, making these materials a sustainable alternative for agricultural use. Composed of high organic matter and nutrients such as nitrogen, phosphorus, calcium, and magnesium, biosolids have the potential to improve the physical, chemical, and biological properties of tropical soils, contributing to greater fertility, water retention, and microbial activity. National literature demonstrates that these materials can partially replace mineral fertilizers and assist in the recovery of degraded areas. On the other hand, the presence of contaminants still represents a challenge. Heavy metals such as Cd, Pb, Ni, and Hg generally appear in low concentrations, while Cu and Zn tend to approach the maximum limits established by CONAMA Resolution No. 498/2020. Regarding pathogens, the efficiency of sanitization depends on the treatment method employed. Emerging organic pollutants, including pharmaceuticals and hormones, have been detected, but still lack specific regulations in Brazil. Thus, although biosolids present high agronomic potential, their safe use requires adequate monitoring, improvement in controlling the origin of sewage, and advances in legislation, especially regarding emerging organic pollutants.

Keywords: biosolids; agricultural; emerging organic pollutants

1. Introduction

The production of biosolids in Brazil has increased significantly in recent decades as a direct consequence of the expansion of sanitary sewerage systems and the modernization of Sewage Treatment Plants (WWTPs). This trend reflects national efforts to improve sanitation coverage and reduce the environmental impacts associated with untreated wastewater discharge [1–3]. Biosolids, defined as treated sewage sludge suitable for beneficial environmental application, represent an important alternative for the sustainable management of urban waste. Their reuse is aligned with circular economy principles, as they contain high concentrations of organic matter and essential plant nutrients, such as nitrogen, phosphorus, and micronutrients, which can partially replace mineral fertilizers and reduce dependency on non-renewable resources [1–3].

National research indicates that the controlled agricultural application of biosolids can improve physical, chemical, and biological soil properties, particularly in highly weathered tropical soils that typically present low organic matter content. Reported benefits include improved soil aggregation, increased water retention capacity, enhanced microbial activity, and gradual nutrient release, which contribute to soil fertility restoration and sustainable crop production [4]. In addition, biosolids reuse reduces the volume of waste sent to landfills and minimizes greenhouse gas emissions associated with disposal practices, reinforcing their relevance within sustainable waste management strategies.

Despite these advantages, the presence of chemical and biological contaminants in sewage sludge remains a critical concern for environmental and public health. Among the most relevant

 doi:10.20944/preprints202604.0196.v1

contaminants are heavy metals, pathogenic microorganisms, and emerging organic pollutants (EOPs), such as pharmaceuticals, personal care products, and endocrine-disrupting compounds. The occurrence and concentration of these substances depend on several factors, including the characteristics of the WWTP catchment basin, industrial contributions, population profile, and treatment technologies employed [1,3]. Brazilian studies have reported considerable variability in contaminant concentrations, with some municipalities presenting low levels and others showing values close to regulatory limits, particularly for metals such as Cu, Zn, and Cr [4]. This variability highlights the need for systematic evaluation of biosolid quality to ensure safe agricultural reuse.

In the regulatory context, CONAMA Resolution No. 498/2020 establishes national criteria for the treatment, classification, and agricultural use of biosolids, including limits for heavy metals, microbiological indicators, and sanitary quality standards [3]. This regulation updated and expanded the requirements previously defined by CONAMA Resolution No. 375/2006, making classification criteria more rigorous, especially regarding sanitization processes and contaminant monitoring. However, despite these advances, the regulation does not yet include limits for emerging organic pollutants, which remain an important knowledge gap and a potential environmental risk [5]. This limitation reinforces the need for national studies aimed at assessing the occurrence, concentration, and environmental relevance of these compounds.

Several Brazilian investigations have contributed to characterizing biosolid quality and evaluating compliance with current regulations, including recent studies analyzing physicochemical, microbiological, and agronomic parameters in different regions of the country [1–4]. However, the available data remain fragmented, making it difficult to obtain a comprehensive overview of the national scenario. Systematic reviews that consolidate these results are essential to compare reported values with regulatory limits and identify trends, knowledge gaps, and research priorities.

Therefore, this article aims to review the national scenario of biosolids in Brazil, discussing key quality parameters—including emerging organic pollutants, heavy metals, pathogens, and agronomic potential—and comparing values reported in Brazilian literature with the limits established by CONAMA Resolution No. 498/2020 [6]. By integrating dispersed data and critically evaluating compliance with current regulations, this study contributes to sustainability by supporting safer agricultural reuse, promoting circular nutrient management, reducing environmental impacts associated with waste disposal, and providing scientific evidence to improve public policies and regulatory frameworks for biosolids management in Brazil.

2. Materials and Methods

The Materials and Methods should be described with sufficient details to allow others to replicate and build on the published results. Please note that the publication of your manuscript implicates that you must make all materials, data, computer code, and protocols associated with the publication available to readers. Please disclose at the submission stage any restrictions on the availability of materials or information. New methods and protocols should be described in detail while well-established methods can be briefly described and appropriately cited.

Research manuscripts reporting large datasets that are deposited in a publicly available database should specify where the data have been deposited and provide the relevant accession numbers. If the accession numbers have not yet been obtained at the time of submission, please state that they will be provided during review. They must be provided prior to publication.

Interventionary studies involving animals or humans, and other studies that require ethical approval, must list the authority that provided approval and the corresponding ethical approval code.

In this section, where applicable, authors are required to disclose details of how generative artificial intelligence (GenAI) has been used in this paper (e.g., to generate text, data, or graphics, or to assist in study design, data collection, analysis, or interpretation). The use of GenAI for superficial text editing (e.g., grammar, spelling, punctuation, and formatting) does not need to be declared.

 doi:10.20944/preprints202604.0196.v1

3. Results and Discussion

3.1. Emerging Organic Pollutants (EOPs)

The presence of emerging organic compounds in Brazilian biosolids has been documented primarily in WWTPs in metropolitan areas, where the consumption of medications and personal care products is higher. Studies report detectable concentrations of caffeine, ibuprofen, diclofenac, carbamazepine, parabens, bisphenol-A, and s well as hormones such as 17β-estradiol [1,7]. However, CONAMA Resolution No. 498/2020 does not establish limits for EOPs, which creates a significant regulatory gap, especially given the persistence of these compounds in soil and the potential for bioaccumulation.

Table 1. Emerging Organic Pollutants most commonly found in biosolids.

Class	Compounds found (national literature)	Typical concentrations	Limit Res. 498/2020
Pharmaceuticals	Diclofenac, ibuprofen, carbamazepine	50–1200 ng/g	None
Hormones	Estrone, 17β-estradiol	5–150 ng/g	None
Parabens	Methyl-, ethyl-, propylparaben	100–800 ng/g	None
Endocrine disrutors	Bisphenol-A	100–500 ng/g	None

Despite the lack of regulation, Brazilian studies indicate that many POEs are detected in concentrations similar to those observed in the US and the EU. However, national research is still insufficient to determine the long-term environmental risk, given Brazil's climatic and edaphological diversity.

3.2. Heavy Metals

Heavy metals have been the primary regulatory focus regarding biosolids quality. The national literature shows wide variation, especially for Cu and Zn, primarily related to metal fittings, industrial effluents, and pipe abrasion [6,13]. In general, Cd, Pb, Hg, and Ni remain below legal limits, while Cu and Zn frequently approach the maximum permitted value.

Table 2. Heavy metals found in the national literature.

Metal	Limit 498/2020 (mg/kg)	National average (mg/kg)	Range found	References
Cd	20	1–4	0.5–8	Andreoli (2014); Pegorini (2013)
Pb	300	20–80	10–300	Sabesp (2018); Andreoli (2014)
Cr	1000	60–300	50–547	Embrapa (2015)
Ni	420	5–40	2–75	Embrapa (2015)
Cu	1500	100–450	80–1800	Tsutiya (2006)

Analysis of heavy metals present in Brazilian biosolids reveals a relatively safe scenario in relation to the limits established by CONAMA Resolution No. 498/2020, but one that requires continuous attention, especially for elements that exhibit greater variability [13]. Data from the national literature indicate that Cd, Pb, Hg, and Ni generally occur in low concentrations, comfortably below the maximum permitted values. This behavior suggests that, in most Brazilian sanitary sewage systems, the contribution of these elements is limited, either due to the low industrial load connected to the network or the efficiency of treatment processes [14].

However, the behavior of Cu and Zn differs from that of other metals. These elements, although essential in small quantities for plant growth, are frequently reported in high concentrations, often close to the legal limit. The main sources include metal fittings and pipes, abrasion of hydraulic components, effluents from small industries and intense urban activities, as well as domestic waste containing metal products [15]. This variability indicates that Cu and Zn are particularly sensitive to the characteristics of the WWTP's catchment area, reflecting marked regional differences.

3.3. Pathogens

CONAMA Resolution No. 498/2020 requires the reduction of Salmonella and thermotolerant coliforms, as well as helminth viability parameters. The national literature demonstrates varying efficacy among different sanitation methods, especially anaerobic digestion, calcination, and composting [5,16].

Table 3. National concentration of pathogens in biosolids.

Parameter	Limit 498/2020	Typical national values	References
Salmonella	Absence in 10 g	Absence 10^2 CFU/g	Sanepar (2019)
Thermotolerant coliforms	< 10^3 MPN/g	10^2–10^5 NMP/g	Embrapa (2015)
Helminth eggs	< 0.25 egg/g	0–1.5 eggs/g	Melo (2018)

The microbiological evaluation of biosolids is one of the central pillars for ensuring their safe agricultural use, and CONAMA Resolution No. 498/2020 establishes strict criteria to guarantee the sanitary quality of these materials. The required parameters—absence of r Salmonella in 10 g, thermotolerant coliform concentration below 10^3 MPN/g, and a maximum limit of 0.25 eggs/g for helminths—reflect international concerns regarding the spread of waterborne and parasitic diseases [5,17].

The national literature shows that compliance with these limits depends heavily on the sanitation method adopted at Sewage Treatment Plants. Anaerobic digestion, widely used in Brazil, is highly effective at reducing bacterial pathogens; however, its effectiveness in eliminating helminth eggs may be limited, especially under inadequate operating conditions or at low temperatures [18]. Lime treatment, on the other hand, which rapidly raises the pH to values above 12, demonstrates high efficacy in eliminating bacteria and rendering helminth eggs nonviable, although it entails higher operating costs and greater production of alkaline material [19].

3.4. Agronomic Potential

Brazilian biosolids have high levels of N, P, Ca, Mg, and essential micronutrients. In highly weathered soils, their application can improve CTC, aggregation, and biological activity, contributing significantly to the recovery of degraded areas and low-fertility agricultural systems [1–3,9,20].

Table 4. National agricultural potential of biosolids.

Parameter	National average	Range	References
Total N (%)	2.5–5.0	1.8–6.0	Embrapa (2015)
Total P (%)	1.0–3.5	0.8–4.2	Sabesp (2018)
MO (%)	40–65	35–75	Andreoli (2014)
pH	6.0–8.5	5.5–9.0	Melo (2018)

With average total N contents between 2.5–5.0% and total P contents of 1.0–3.5%, biosolids can meet a significant portion of crop nutrient requirements, especially in systems with low phosphorus

 doi:10.20944/preprints202604.0196.v1

and organic matter availability. Routine application can reduce dependence on mineral fertilizers [2,9,21], particularly under management practices that allow for the gradual release of N and P, benefiting longer-cycle crops and perennial cropping systems.

An assessment of the agronomic potential of Brazilian biosolids reveals that these materials constitute an important strategy for the sustainable management of tropical soils, especially those characterized by low natural fertility and a high degree of weathering [22]. National data indicate that biosolids contain significant concentrations of nitrogen, phosphorus, and organic matter, as well as relevant levels of calcium, magnesium, and essential micronutrients, reinforcing their value as an agricultural input [2,9,23].

The average total nitrogen content of 2.5–5.0% and phosphorus content of 1.0–3.5% suggests that the application of biosolids can significantly contribute to crop nutrient supply, especially in areas where phosphorus availability is naturally limited—a condition typical of highly weathered soils in the Cerrado and other tropical regions of Brazil [4]. This contribution is particularly important given the high cost and growing national dependence on imported mineral fertilizers [14,15].

The high organic matter content (40–65%) of biosolids plays a key role in improving soil structure, promoting aggregate formation, increased porosity, water infiltration, and cation exchange capacity (CEC)[16]. These effects are well documented in long-term studies conducted in degraded areas and low-fertility agricultural systems, where the continuous application of biosolids has been shown to promote increased microbial activity and nutrient cycling [2,10].

The neutral or slightly alkaline pH (6.0–8.5) observed in most Brazilian biosolids also contributes to soil acidity correction, enabling greater nutrient availability and promoting root growth. In highly acidic soils, this characteristic can reduce the need for soil amendments, optimizing costs and management practices [24–26].

In general, the literature indicates that the agronomic use of biosolids is particularly advantageous for perennial crops and management systems that benefit from the gradual release of nutrients [18]. Thus, when applied in a technically sound manner and in compliance with current legislation, biosolids constitute a valuable resource for promoting fertility, productivity, and environmental recovery in Brazilian agricultural systems [29,30].

5. Conclusions

The review demonstrates that Brazilian biosolids present strong potential for agricultural reuse, contributing directly to circular economy strategies by promoting nutrient recycling and reducing dependence on synthetic fertilizers. The high concentrations of organic matter and essential nutrients, combined with favorable physicochemical characteristics, support improvements in soil fertility, particularly in tropical soils with low natural organic content. When compared to the limits established by CONAMA Resolution No. 498/2020, heavy metal concentrations are generally within acceptable standards, although Cu and Zn require continued monitoring to ensure long-term environmental safety. Pathogens represent a moderate risk, especially in cases where treatment processes do not include effective sanitization steps, reinforcing the importance of adequate sludge stabilization prior to land application. Emerging organic pollutants constitute the main gap in Brazilian regulations and highlight the need for updated policies to address these contaminants and prevent potential ecological and human health impacts.

Overall, the safe agricultural reuse of biosolids in Brazil represents an opportunity to enhance sustainability by diverting waste from landfills, reducing greenhouse gas emissions associated with disposal, improving soil quality, and promoting resource efficiency through nutrient recovery. To consolidate these benefits, progress is essential on three main fronts: updating legislation to incorporate emerging contaminants, strengthening monitoring at the source to control pollutant inputs into wastewater systems, and expanding research on emerging organic pollutants within tropical conditions. Advancing these actions will support a more sustainable biosolids management framework and reinforce their role as a strategic component of circular economy practices in Brazil.

 doi:10.20944/preprints202604.0196.v1

References

1. de Amorim Júnior, S. S., de Souza Pereira, M. A., Morishigue, M., da Costa, R. B., de Oliveira Guilherme, D., & Magalhães Filho, F. J. C. (2022). Circular economy in the biosolids management by nexus approach: a view to enhancing safe nutrient recycling—pathogens, metals, and emerging organic pollutants concern. *Sustainability*, *14*(22), 14693. https://doi.org/10.3390/su142214693.
2. de Amorim Júnior, S. S., de Souza Pereira, M. A., de Morais Lima, P., Marishigue, M., de Oliveira Guilherme, D., & Magalhães Filho, F. J. C. (2021). Evidences on the application of biosolids and the effects on chemical characteristics in infertile tropical sandy soils. *Cleaner Engineering and Technology*, *4*, 100245. https://doi.org/10.1016/j.clet.2021.100245.
3. Junior, S. S. A., Mazucato, V. S. H., dos Santos Machado, B., de Oliveira Guilherme, D., da Costa, R. B., & Magalhaes Filho, F. J. C. (2021). Agronomic potential of biosolids for a sustainable sanitation management in Brazil: Nutrient recycling, pathogens and micropollutants. *Journal of Cleaner Production*, *289*, 125708. https://doi.org/10.1016/j.jclepro.2020.125708.
4. Melo, W., Delarica, D., Guedes, A., Lavezzo, L., Donha, R., Araújo, A., Macedo, F., 2018. Ten years of application of sewage sludge on tropical soil. A balance sheet on agricultural crops and environmental quality. Sci. Total Environ. 643, 1493e1501. https://doi.org/10.1016/j.scitotenv.2018.06.254
5. Simonete, M.A., Kiehl, J.C., Andrade, C.A., Teixeira, C.F.A., 2003. Effect of sewage sludge in a Ultisol and on growth and nutrition of maize. Braz. Agricult. Res. 38, 1187e1195. https://doi.org/10.1590/S0100-204 × 2003001000008.
6. Nascimento, C.W.A., Barros, D.A.S., Melo, E.E.C., Oliveira, A.B., 2004. Soil chemical alterations and growth of maize and bean plants after sewage sludge application. Braz. J. Soil Sci. 385e392. https://doi.org/10.11606/T.11.2016.tde-10052016 183111.
7. Smith, S.R., 2009a. Organic contaminants in sewage sludge (biosolids) and their significance for agricultural recycling. Phil. Trans. Math. Phys. Eng. Sci. 367, 4005e4041. https://doi.org/10.1098/rsta.2009.0154.
8. Smith, S.R., 2009b. A critical review of the bioavailability and impacts of heavy metals in municipal solid waste composts compared to sewage sludge. Environ. Int. 35, 142e156. https://doi.org/10.1016/j.envint.2008.06.009.
9. Brasil, Ministry of the Environment. Defines Criteria and Procedures for the Production and Application of Biosolids in Soils, and Makes Other Provisions. National Environment Council—CONAMA. Resolution No. 498. 19 August 2020. Available online: http://conama.mma.gov.br/images/conteudo/CONAMA-ingles.pdf (accessed on 6 September 2020).
10. Alves, M. C., Gonzalez, A. P., Colodro, G., Junior, H. P., & Vázquez, E. V. (2006). Influence of biosolids rate on chemical properties of an oxisol in Sao Paulo, Brazil. *Communications in soil science and plant analysis*, *37*(15-20), 2481-2493.
11. ALMEIDA, C. A. et al. Emerging organic pollutants in biosolids. Revista Engenharia Sanitária e Ambiental, 2020.
12. ANDREOLI, C. V. (Ed.). Use and management of biosolids in agriculture. 2nd ed. Curitiba: SANEPAR, 2014.
13. ANDREOLI, C. V.; FERNANDES, F.; VON SPERLING, M. Sewage sludge:treatment and final disposal. 2nd ed. Belo Horizonte: UFMG, 2014.
14. EMBRAPA. Characterization of biosolids from Brazilian wastewater treatment plants. Brasília, 2015.
15. EMBRAPA. Manual for the analysis of organic residues and biosolids. Brasília: Embrapa Solos, 2015.
16. FIOCRUZ. Sanitary evaluation of sewage sludge and helminth eggs in Brazil. Rio de Janeiro: Fiocruz, 2012.
17. PEGORINI, E. S. Agronomic potential of biosolids in highly weathered tropical soils. Curitiba: UFPR, 2013
18. VON SPERLING, M. Introduction to water quality and wastewater treatment. 4th ed. Belo Horizonte: UFMG, 2014.
19. EMBRAPA. Characterization of biosolids from Brazilian wastewater treatment plants. Brasília, 2015.
20. EMBRAPA. Manual for the analysis of organic residues and biosolids. Brasília: Embrapa Solos, 2015.
21. SABESP. Chemical characterization of biosolids for agricultural use. São Paulo: Sabesp, 2018.
22. MORAES, R. et al. Occurrence of pharmaceuticals in sewage sludge. Química Nova, 2021.
23. PEGORINI, E. S. Agronomic potential of biosolids in highly weathered tropical soils. Curitiba: UFPR, 2013.

doi:10.20944/preprints202604.0196.v1

24. SABESP. Chemical characterization of biosolids for agricultural use. São Paulo: Sabesp, 2018.
25. SANEPAR. Technical report: Quality of sewage sludge produced in Paraná. Curitiba: SANEPAR, 2019.
26. SANTOS, L. H. et al. Pharmaceuticals in sewage and biosolids. SciELO Brazil, 2019.
27. TSUTIYA, M. T. Treatment and disposal of sewage sludge. São Paulo: ABES, 2006.
28. UFPR. Study of the viability of helminth eggs in sewage sludge. Curitiba: Federal University of Paraná, 2016.
29. VON SPERLING, M. Introduction to water quality and wastewater treatment. 4th ed. Belo Horizonte: UFMG, 2014.
30. Brasil, Ministry of the Environment. Defines Criteria and Procedures for the Production and Application of Biosolids in Soils, and Makes Other Provisions. National Environment Council—CONAMA. Resolution No. 498. 19 August 2020. Available online: http://conama.mma.gov.br/images/conteudo/CONAMA-ingles.pdf (accessed on 6 September 2020).