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BIOCHAR IN WASTEWATER TREATMENT: A SYSTEMATIC MAPPING

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Abstract: There has been a ton of debate on developing goals and the conflicts regarding environmental preservation. In the wastewater treatment industry, biochar seems to appear as a low-cost and environmentally friendly alternative because of its high porosity and adsorbent capacity. This study used the Scopus database to map articles on the topic through a systematic methodology and screening. The results demonstrate the approach researchers are giving to biochar adsorbing characteristics. It was observed that research about biochar applied to wastewater is recent and shortage. China and India were the countries that most published about it. Sewage sludge was the most common biomass used for biochar production, and pyrolysis temperature remained mainly at 300º C to 700 ºC. Also, the removal of heavy metals was the greater purpose of the studies. Finally, this mapping described biochar formation and its use as an adsorbent for wastewater treatment purposes, providing important data for directing future studies.

Keywords: Adsorption; sewage sludge; heavy metals; biomass; pyrolysis

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INTRODUCTION

Modern sanitary sewage treatment systems are particularly effective, but usually require great demand for energy, materials and investments (Huggins *et al*., 2016). As a result, new treatment systems with lower operating costs and the ability to reuse water and materials can help the sustainable development of wastewater treatment infrastructure.

Among these novel technologies for wastewater management, biochar has attracted researchers' attention because of its high porosity and surface area. Also, the availability and diversity of organic material combined with the facility and low-cost production have turned biochar into a highly potential material for various waste treatments (Egbedina, 2021).

Biochar is a charcoal-like material produced from pyrolysis (thermochemical decomposition of biomass in an oxygen-limited environment). Because of its characteristics, biochar has been presented in the literature as an adsorbent material used for the scavenging of heavy metals, nutrients, organic compounds, drugs, dyes, and others (Cuba *et al*., 2021).

According to Tan *et al.* (2015), such uses are possible due to biochar adsorption capacity, similarly to activated carbon, which is already commonly used in Wastewater Treatment Plants (WWTP). In contrast, this is a low-cost technique that requires less energy to produce than activated carbon. Moreover, biochar can be produced by a great variety of materials, such as agricultural biomass and solid waste.

On that account, the propose of this study is to carry out a systematic mapping to analyse the production and content of scientific articles about the use of biochar in wastewater treatment.

METHODOLOGY

Systematic mapping consists of identifying a broad of studies that address a particular research question, differing from the systematic review for not gathering and synthesizing the studies' evidence. Thus, a systematic mapping focuses on categorizing the studies analysed, giving an overview of the research topic through classification and counting contributions (Demerval *et al*., 2020.)

First, adequate keywords were chosen to search for articles that address the topic of study (**Fig. 2**). As the subject in question is the use of biochar in wastewater treatment, the terms "biochar", "wastewater" and "treatment" were used. No time framing restriction was applied and the search was limited to the title, abstract and keywords of the articles.

The SCOPUS (Elsevier) database was used. The database website was accessed through the Federate Academic Community (CAFE) access from Coordination for the Improvement of Higher Education Personnel (CAPES) with the Federal University of Sergipe login. This database was selected because of its international scope and content quality control.

The search was done with only one search string: "biochar" AND "wastewater" AND "treatment". The results encountered were limited to studies with open access, resulting in a raw sample of 362 articles.

After that, a screening was carried out by reading the abstracts and selecting the studies that used biochar only for wastewater treatment.

Therefore, of the 362 initial articles, 109 were not considered because they did not fit the selection criteria. Most of these excluded studies dealt with soil fertilization rather than sewage management. Consequently, 253 articles were used in this systematic mapping.

Fig. 1 summarizes the steps from accessing the database to selecting the articles for mapping. The topics approached in the results and discussion section.

- articles' overview, including the incidence of words displayed in the studies' titles, year and countries of publication;
- biochar production characteristics (feedstock, pyrolysis temperatures and pyrolysis retention time);
- main treatments where biochar were experimented.

RESULTS AND DISCUSSION

Article's overview

All studies' words of the titles (**Fig. 3**) were listed in word clouds and evaluated according to their frequency. In the word cloud, the word size is directly proportional to its number of occurrence. As a result, the biggest terms in the images were the most common in the articles. In addition, the words were taken in their entirety. This means that terms like "banana peel biochar" are not counted in the term "biochar".

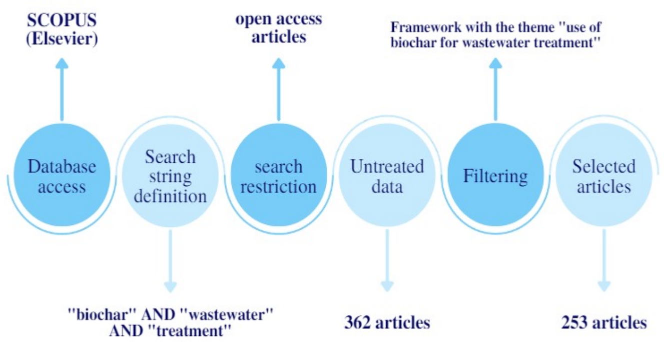

Fig. 1 Systematic mapping screening

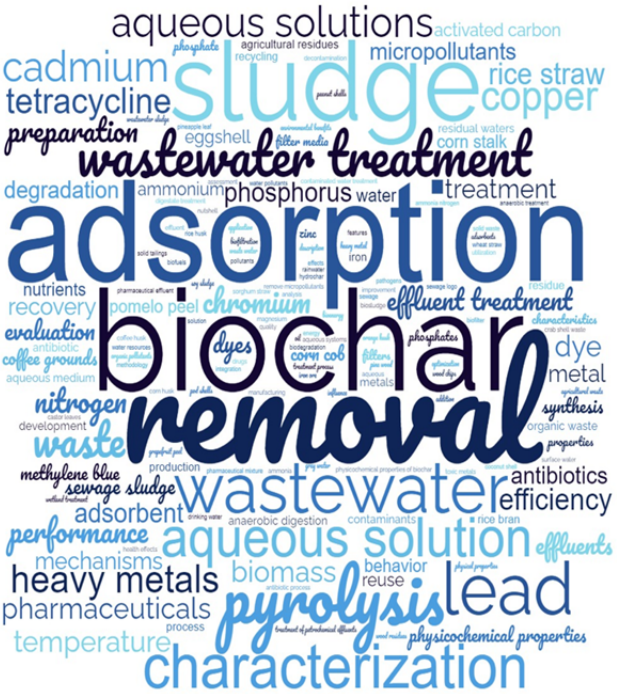

Fig. 2 Word cloud of studies' titles

The words that stood out the most were those related to the study object (biochar), the biochar biomass (sludge), the process involved in producing the biochar (pyrolysis), and its application (adsorption, removal, wastewater).

The presence of the word "biochar" in only 148 articles out of 253, about 58.5%, is justified by the fact that most of the remaining articles specified the type of biochar in the keywords section. Therefore, as mentioned before, it was not accounted for in the unit term "biochar". This means that if the terms were considered separately, the word "biochar" would look much bigger in the cloud.

Other words were also quite frequent, such as "cadmium", "tetracycline" and "heavy metals", for example. This is probably regarding the contaminant intended to remove. Additionally, it could be inferred from the word cloud that studies are focusing on the characterization of biochar and experimentation of aqueous solutions.

The following distribution was encountered in terms of publication over the years (**Fig. 4**): 2014 (3 articles), 2015 (3 articles), 2016 (15 articles), 2017 (16 articles), 2018 (24 articles), 2019 (35 articles), 2020 (60 articles), 2021 (53 articles), 2022 (44 articles).

According to Tan *et al*. (2015), over the last decade, a great number of studies have highlighted the benefit of biochar in removing pollutants from aqueous solutions, correcting soil properties, storing carbon, and mitigating global warming.

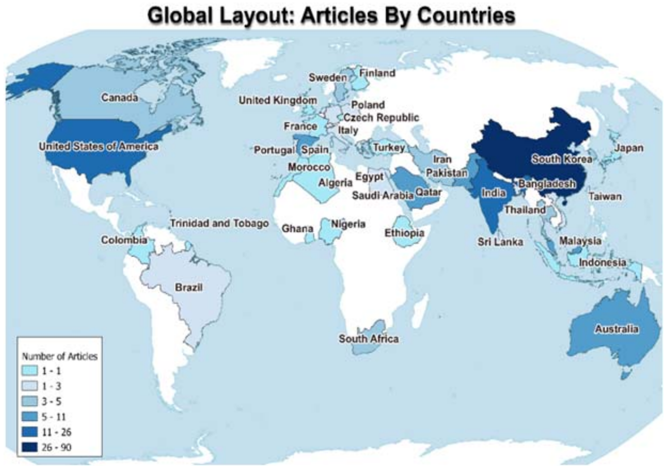

Fig. 5 Number of publication by country.

From **Fig. 4** it is observed that studies approaching the use of biochar in wastewater treatment are recent and increasing over the years. Additionally, the number of articles published in 2022 tends to increase as the studies considered in this review were gattered in May 2022.

This mapping recorded the publication of articles in 44 countries, distributed in the five inhabited continents, as demonstrated in **Fig. 5**. The country with the highest number of publications was China (90 articles - 35.57%), followed by India (26 articles - 10.28%) and the United States (19 articles - 7.51%). These three countries together account for more than half of the publications, totalling 53.36%.

The large number of studies carried out in China can be explained by its great concern regarding water pollution, associated with new standards and policies to control effluent discharge. This scenario encourages the development of new technologies in wastewater treatment. One example of this is the need to manage certain types of pollutants that were not previously covered by the control policy, such as nitrogen and phosphorus (Xu *et al*., 2020).

Despite being the second country publishing about the use of biochar in wastewater systems, India treats only 37% of its sewage. Moreover, 35-50% of the treated wastewater does not meet the country's standards. In regard to the United States of America, the country ranked thirty-fifth in the world ranking of polluted water treatment, among 180 countries evaluated, according to the Environmental Performance Index created by Yale University and Columbia University to assess countries' environmental policies (CPCB, 2021; MOEFCC, 2017; Wolf *et al*., 2022).

When mapping the distribution by continents, the Asian continent distincts with a total of 165 publications in 16 countries, followed by Europe, with 37 publications in 15 countries. In the American continent, of 28 publications, 24 were carried out in North America. In Africa, the countries South Africa and Egypt stood out publishing 4 and 3 studies out of 12 respectively. In Oceania, Australia published 11 articles. However, when comparing data of wastewater treatment coverage in the countries, it was identified a higher percentage in European countries (92.65%), followed by Oceania (76.17%), Asia (64.78%), America (55.05%) and Africa (45 .55%) (WHO, 2020).

Biochar feedstock and pyrolysis operation conditions

A great variety of organic materials was recognized for biochar production in the articles (87 types in total). **Table 1** shows the raw materials that were experimented more than once by the number of occurrences in descendent order.

The most used biomass in the studies was sewage sludge (15.0%), which could be predicted since this review is considering the use of biochar for wastewater treatment purposes. That is, as this raw material is already available in the WWTP and presents a good amount of organic components, its use is expected.

The other most tested feedstocks were: wood biochar (13.0%), rice husk biochar (5.3%), coconut husk biochar (5.0%), corn husk biochar (4.5%), bamboo bark biochar (4.1%), tree bark biochar (3.3%), corn cob biochar (3.3%), eucalyptus biochar (2.5%) and wheat straw biochar (2.5%).

The pyrolysis temperatures of biochar formation are shown in **Fig. 6**. Tan *et al*. (2016) report that temperature at which pyrolysis occurs highly affects the biochar adsorption properties (Tan *et al*, 2016). From **Fig. 6**, it is observed that biochar are being produced mainly at temperatures of 500°C (63 articles), 600°C (52 articles), and 700°C (39 articles). Many studies (46), however, did not describe the pyrolysis temperature, thus harming their replication and more detailed evaluations.

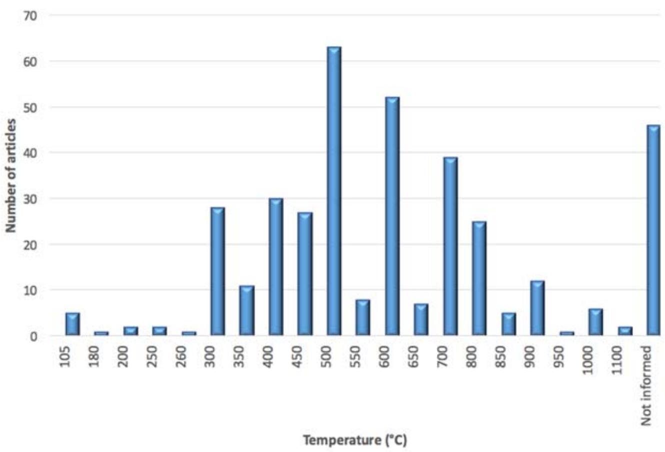

Fig. 6 Pyrolysis temperature of biochar

Table 1. Type of biochar biomass most used

Type of raw material	Number of articles
Sewage sludge	36
Wood	32
Rice husk	13
Coconut husk	12
Corn husk	11
Bamboo bark	10
Corn cob	8
Tree residues	8
Eucalyptus	6
Wheat straw	6
Pomelo peel	5
Seaweed	5
Cow dung	4
Peanut shell	4
Coffee grounds	3
Iron dust	3
Oil palm	3
Palm kernel husk	3
Tea waste	3
Crab shell	2
Date palm almonds	2
Eggshell	2
Nanocomposites	2
Pine	2
Poplar sawdust	2
Quercus	2
Rice bran	2
Sugarcane bagasse	2
Water hyacinth	2

Nearly half (120) of the articles experimented biochar produced at different temperatures, usually 300°C, 500°C and 700°C. This may be to evaluate which temperature gives biochar the most appropriate characteristics desired for the application intended.

According to Weber and Quicker (2018), the pyrolysis temperature influences the characteristics of biochar. A higher degree of carbonization results in higher relative carbon content, higher ash content, and lower oxygen and hydrogen content. In addition, higher temperatures cause an increase in the surface area of the biochar due to a rising in its porosity, which is ideal for adsorption.

Another key factor for biochar production that affects its properties is the pyrolysis retention time. Wisniewski Jr. (2020) states that fast pyrolysis is appropriate when the objective is to extract bio-oleo while slow and conventional pyrolysis lead to a higher proportion of the solid product (biochar).

Biochar as adsorbent

Many articles compared the biochar efficiency in removing wastewater pollutants with different methods, such as conventional filtering and aerobic digesters. Thus, not only providing evidence about biochar features and effectiveness, but also discussing its possibilities in replacing traditional methods.

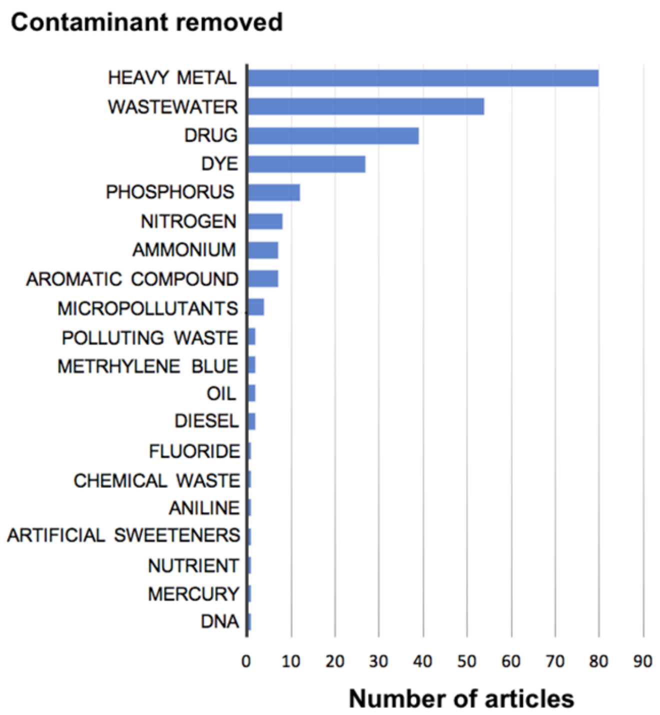

Fig. 7 Contaminants removed in the articles

The application of different types of biochar was generally related to removing a specific contaminant. In **Fig. 7**, it is possible to observe that heavy metals were the most experimented (31.62%), followed by wastewater (21.34%).

Soon after, the removal of drugs (15.42%), dyes (10.67%), phosphorus (4.74%), nitrogen (3.16%), ammonium and aromatic compounds (2.77%), and micropollutants (insecticide) (1.58%). Diesel, oils, methylene blue, and polluting waste represented each 0.79%, and the removal of DNA, mercury, nutrients, artificial sweeteners, aniline, chemical residues, and fluorine presented 0.40% each.

The use of biochar as a sorbent for adsorption and neutralization of heavy metals is presented as an option to remedy the contamination of heavy metals in wastewater and soil (Wang, 2017). The efficiency in removing heavy metals (Ding, 2017), associated with the low cost of biochar, may have triggered a higher number of articles dealing with this contaminant than with the removal of other compounds.

CONCLUSION

In conclusion, this systematic mapping demonstrates that using biochar as an adsorbent for wastewater treatment is a novel research subject, which is increasing in number of publications over the last years. This technology can be a sustainable and relevant alternative for sewage management as it can adsorb numerous contaminants.

Also, it possible to observe that places with more rigorous legislation or environmental issues regarding effluent discharges usually have been conducting more research in this area. This is necessary because new technologies are required to prevent environment pollution from emergent contaminants.

Regarding biochar feedstock, many materials has been experimented. Most articles used biomass that was available nearby, such as sewage sludge, which corroborates with the idea of developing sustainable technology. Likewise, the treatments and contaminants considered rely on local sewage characteristics. Special attention has been paid to heavy metal removal.

Therefore, this mapping shows the approach given to biochar as an alternative source for wastewater treatment and its significance worldwide. It is suggested that a great diversity of organic waste is suitable for biochar production. However, future research is recommended regarding biochar efficiency as an adsorbent, stablishing optimized operating conditions for different types of biomass.

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