Latin American Journal of Energy Research - Lajer
periodicos.ufes.br/lajer

Latin American Journal of Energy Research – Lajer (2025) v. 12, n. 2, p. 86–102
https://doi.org/10.21712/lajer.2025.v12.n2.p86-102

O aguapé e o biocarvão: uma revisão bibliométrica baseada na base Scopus

Water hyacinth and biochar: a bibliometric review based on the Scopus database

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Received: 05 May 2025 | Accepted: 25 July 2025 | Published online: 03 August 2025

Resumo: O Aguapé (*Eichhornia Crassipes*) é uma planta aquática que tem como característica o seu alto crescimento e proliferação no meio onde está inserida. Por conta desses aspectos, esse tipo de matéria prima pode ser utilizado como biomassa aplicada às tecnologias renováveis. Nos últimos anos, estudos acerca da produção de biocarvão, através da aplicação e otimização do processo de pirólise, têm sido amplamente discutidos como solução sustentável na gestão de biomassa através da produção de importantes co-produtos: o biocarvão (parte sólida), o bio-óleo (parte líquida) e os gases não condensáveis (GNC). Este estudo apresenta uma revisão bibliográfica sobre a aplicação dos aguapés no processo de produção de biocarvão através da análise bibliométrica realizada por meio da ferramenta *Biblioshiny* e busca na base de dados Scopus. Os resultados apontam um aumento de produção científica, atrelado ao interesse acadêmico no assunto, e com ênfase em pesquisas que discutem o processo de pirólise, a aplicação do aguapé como biomassa e a utilização do biocarvão no meio ambiente.
Palavras-chave: biocarvão; biomassa; bibliometrix; aguapé; pirólise.

***Abstract**: Water hyacinth (Eichhornia Crassipes) is an aquatic plant whose characteristic is its high growth and proliferation in its environment. Because of these aspects, this type of raw material can be used as biomass applied to renewable technologies. In recent years, studies on the production of biochar through the application and optimization of the pyrolysis process have been widely discussed as a sustainable solution for biomass management through the production of important co-products: biochar (solid part), bio-oil (liquid part) and non-condensable gases (NCG). This study presents a literature review on the application of water hyacinths in the biochar production process through a bibliometric analysis carried out using the Biblioshiny tool and a search in the Scopus database. The results point to an increase in scientific production, linked to academic interest in the subject and with an emphasis on research that discusses the pyrolysis process, the application of water hyacinth as biomass and the use of biochar in the environment.*
Keywords: biochar; biomass; bibliometrix; water hyacinth; pyrolysis.

1 Introdução

Atualmente, o biocarvão tem um grande potencial de aplicação na melhoria dos solos, na despoluição, no sequestro de carbono e na redução das emissões, além do grande potencial energético que pode ser aplicado para alternativas mais sustentáveis. Além disso, investigações sobre o impacto desse tipo de biomaterial na ecologia do solo e no meio ambiente apresentam avanços positivos.

Neste sentido, uma etapa muito importante para o estudo e aplicação do biocarvão para o meio ambiente se trata da escolha da biomassa a ser utilizada no processo de pirólise. Normalmente, biomassas como os resíduos da biodigestão (processo de produção de biometano), as matérias lenhosas, os resíduos alimentares, resíduos da natureza, etc. são utilizadas para a produção de biocarvão.

O Aguapé (*Eichhornia crassipes*) é uma planta aquática originária do Brasil encontrada normalmente em lagos. Sua proliferação generalizada em ecossistemas aquáticos gera preocupações ecológicas, ambientais e socioeconômicas significativas globalmente. Esses problemas incluem, por exemplo, a redução da biodiversidade e impacto no transporte aquático e nas atividades recreativas. Estes problemas são acarretados principalmente por conta da redução de oxigênio que ocorre nas águas as quais os aguapés estão inseridos. Assim, devido à sua alta taxa de reprodução e à sua ampla importância na gestão de lagos, o aguapé se destaca como um grande potencial de biomassa para utilização na pirólise na produção de biocarvão. Além de sua rápida expansão, a composição química lignocelulosa faz do aguapé uma opção promissora para a geração de biocarvão.

Este artigo tem como objetivo realizar uma revisão bibliográfica do biocarvão produzido a partir da biomassa do aguapé, abordando o contexto mundial e, posteriormente, o contexto nacional em relação à produção científica relacionada a este tema.

2 Metodologia

Diante das preocupações com a transição energética, o uso da biomassa vegetal e o biocarvão surge como uma alternativa viável, sendo solução também para a gestão de resíduos. O Nordeste possui uma alta produção do Aguapé, planta nativa em muitos mananciais e que causa a degradação dos mesmos, precisando ser retirada. Entretanto, essa biomassa vegetal pode ser uma alternativa para a produção do biocavão. Esse biomaterial pode ser produzido a partir da pirólise da biomassa e ser aplicado na agricultura para melhorar o solo.

Para contextualizar o tema em estudo, realizou-se uma busca na base Scopus, a fim de verificar as publicações em nível mundial e nacional. Tal base de dados possui uma coleção de resumos e citações da literatura, que oferece um panorama das pesquisas do mundo nas diversas áreas. Dessa forma, foi realizada uma busca em relação ao tema em questão na segunda semana de dezembro de 2024, utilizando a metodologia sugerida por Donthu et al. (2021), considerando as seguintes palavra-chave: ("*water hyacinth*" *OR* "*Eichhornia crassipes*" *OR aguapé) AND (biochar OR biocarbon OR pyrocarbon*), juntamente com os filtros mostrados na Figura 1.

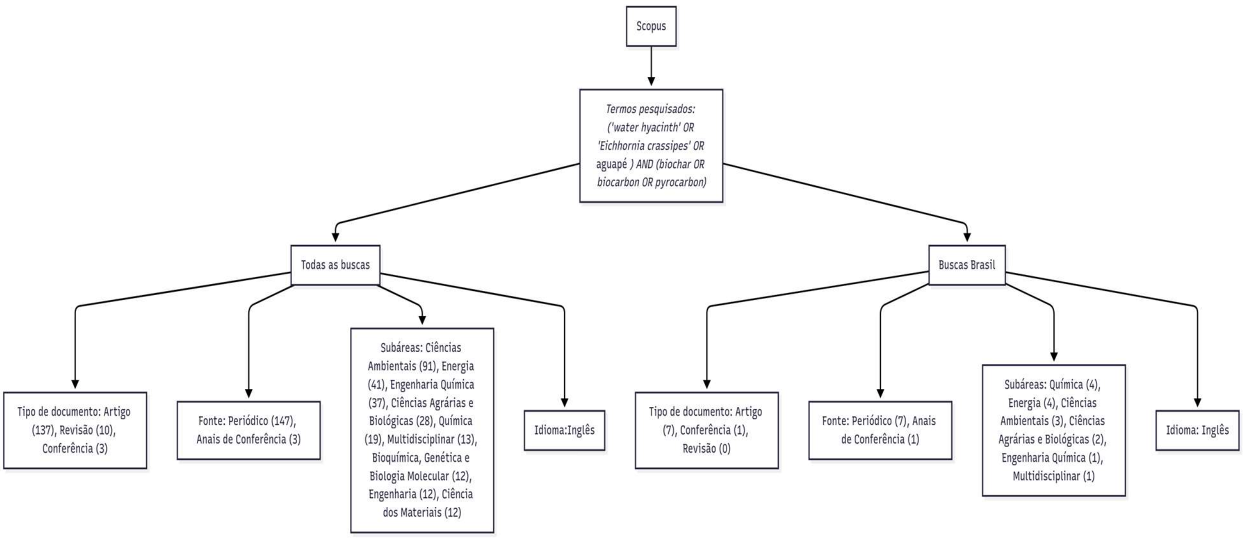

Figura 1. Esquema de escopo, banco de dados, termos e filtros referentes à análise bibliométrica realizada com o Bibliometrix (Donthu et al., 2021). Fonte: Base Scopus (2023).

Após a aplicação dos filtros, 150 documentos foram encontrados e lidos pela ferramenta *Biblioshiny* e, a partir disso, foram gerados gráficos e figuras que puderam ser analisados, possibilitando verificar os documentos com mais citações, as redes de cooperação, os centros que mais têm pesquisado sobre o assunto, dentre outros pontos, considerando a biomassa Aguapé e a produção de biocarvão.

Em relação ao contexto nacional, realizou-se uma nova busca na base Scopus, na qual filtrou-se apenas documentos relacionados ao Brasil, ou seja, documentos que continham pelo menos um de seus autores vinculados às instituições brasileiras, encontrando apenas 8 documentos. Após ler o arquivo .csv gerado pela Scopus, no Bibliometrix, foram obtidas as informações gerais da Tabela 1.

Tabela 1. Principais informações sobre os dados gerados pelo Bibliometrix. Fonte: Base Scopus, ferramenta Bibliometrix (2024).

Parâmetros e tipos de documentos	Contexto mundial	Contexto nacional
Intervalo de tempo	2014-2024	2015-2023
Fontes (revistas, livros, etc)	80	7
Quantidade de documentos	150	8
Média de citações por documentos	32,29	70,38
Artigos científicos	137	7
Artigos de revisão	10	0
Artigos de conferência	3	1
Total de autores	654	49
Co-autores por documentos	5,97	8,25

3 Resultados

Observou-se nesse estudo uma análise considerando um contexto mundial e posteriormente, um contexto nacional para o caso do Brasil. As análises bibliométricas são especialidades científicas e um aspecto significativo da avaliação da pesquisa, especialmente nos setores científico e aplicado (Laengle et al., 2017). Este estudo bibliométrico utilizando Scopus foi realizado na segunda semana de dezembro de 2024, onde, após a utilização de filtros, chegou-se a 150 documentos, publicados desde 2014.

Os resultados do estudo bibliométrico sobre o biocarvão relacionado com Aguapé foram apresentados nas seções a seguir, indicando as áreas de pesquisa mais proeminentes, palavras-chave, afiliações, periódicos, autores e países. Cada parte dos resultados foi discutida para revelar o progresso da pesquisa, tendências, atualizações e pontos críticos relacionados ao tema em questão.

O número de citações em um campo é importante para categorizar e compreender as tendências atuais de pesquisa, além de indicar claramente o impacto de um periódico ou de uma publicação específica, com isso, é possível fornecer dados transparentes sobre o campo mais significativo de trabalhos de pesquisa, bem como as tendências atuais de pesquisa.

3.1 Contexto mundial

A Figura 2 mostra a produção cientifica anual desde 2014, constatando que é um tema novo, e onde percebe-se nitidamente o aumento das publicações nessa área principalmente nos últimos anos.

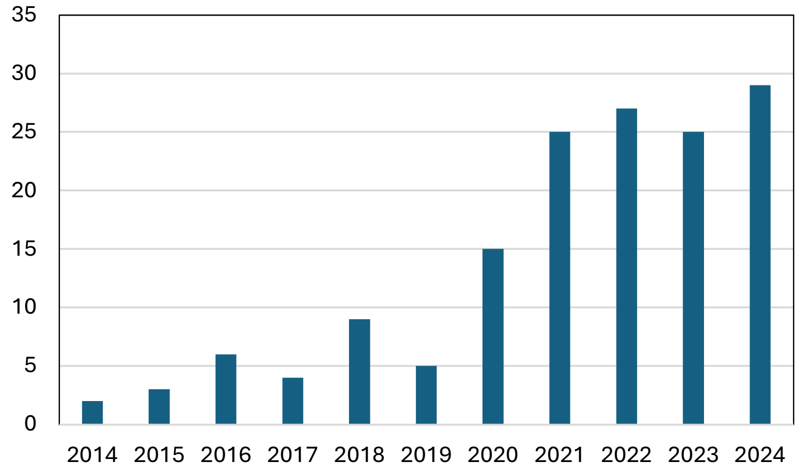

Figura 2. Produção cientifica anual desde 2014. Fonte: Base *Scopus,* ferramenta Bibliometrix (2024).

A Figura 2 mostra o número total de publicações por ano no período considerado. Já a Figura 3 mostra sua distribuição entre os quatro principais países com mais publicação nesta área, sendo eles China, Índia, Estados Unidos e Brasil.

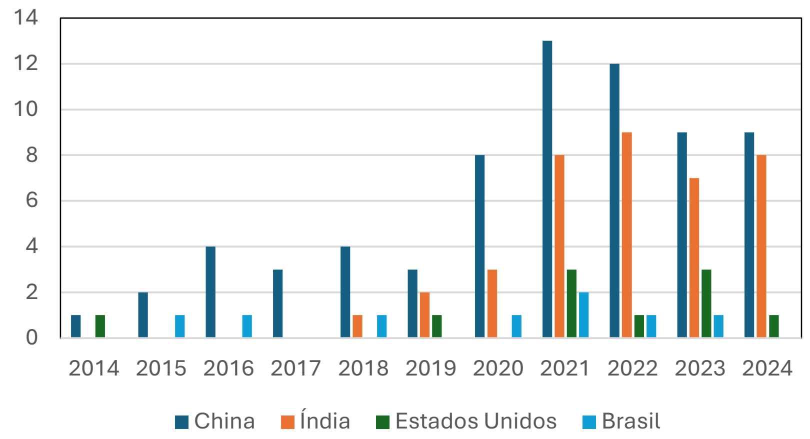

Figura 3. Produção cientifica dos quatro países com mais publicações. Fonte: Base Scopus, ferramenta Bibliometrix (2024).

A China possui 68 publicações, a Índia encontra-se com 38, os Estados Unidos têm 10, enquanto o Brasil está em quarto lugar com 8 publicações. China e Estados Unidos foram os primeiros a publicar nessa área.

Dentre as primeiras publicações está o trabalho de Gwenzi et al. (2014), publicado na revista *Water Science and Technology*, com 44 citações e abordagem sobre as capacidades de adsorção de seis biossorventes derivados, por exemplo, do Aguapé com carvão ativado como controle, sendo que os biossorventes foram biomassa, carbonizada e biocarvões sulfonados. Os efeitos da pirólise e da sulfonação do biocarvão na adsorção foram inconsistentes e dependentes do tipo de biomassa; sendo o biocarvão um biossorvente melhor do que a biomassa original, na maioria dos casos.

Ainda em 2014, foi produzido o trabalho de M. Li et al. (2014), publicado na revista ACS *Sustainable Chemistry and Engineering*, com 30 citações e abordagem sobre o comportamento ácido-base do biocarvão derivado de duas espécies invasoras (*Spartina alterniflora* e aguapé).

A Tabela 2 mostra os trabalhos mais recentes, publicados em 2024, com a citação, título, revista e quantidade de citações.

Tabela 2. Artigos publicados em 2024 Fonte: Base Scopus, ferramenta Bibliometrix (2024).

Citação e ano de publicação	Título	Revista	Total de Citações
Ji et al. (2024)	*Efficiency and mechanism of adsorption for imidacloprid removal from water by Fe-Mg co-modified water hyacinth-based biochar: Batch adsorption, fixed-bed adsorption, and DFT calculation*	*Separation and Purification Technology*	30
Cai et al. (2024)	*Effects of biochar from invasive weed on soil erosion under varying compaction and slope conditions: comprehensive study using flume experiments*	*Biomass Conversion and Biorefinery*	21
Bordoloi et al. (2024)	*Assessment of hydro-mechanical properties of biochar-amended soil sourced from two contrasting feedstock*	*Biomass Conversion and Biorefinery*	8
Deka et al. (2024)	*Enhancing the performance of a photovoltaic thermal system with phase change materials: Predictive modelling and evaluation using neurais networks*	*Renewable Energy*	7

Yi et al. (2024)	*Persulfate oxidation of norfloxacin by cobalt doped water hyacinth biochar composite: The key role of cobalt and singlet oxygen*	*Journal of Water Process Engineering*	6
Chemtai et al. (2024)	*Ciprofloxacin sorption by non-activated and activated biochar derived from millet husks and water hyacinth*	*Sustainable Chemistry for the Environment*	5
Viswanathan, Njazhakunnathu et al. (2024)	*The efficiency of aquatic weed–derived biochar in enhanced removal of cationic dyes from aqueous medium*	*Biomass Conversion and Biorefinery*	5
Lu et al. (2024)	*Water hyacinth derived hierarchical porous biochar absorbent: Ideal peroxydisulfate activator for efficient phenol degradation via an electron-transfer pathway*	*Environmental Research*	4
Li et al. (2024)	*Magnetic biochar serves as adsorbents and catalyst supports for the removal of antibiotics from wastewater: A review*	*Journal of Environmental Management*	4
Ibrahiem et al. (2024)	*Dual phytoremediation and biochar production by Eichhornia crassipes in hydroponic system receiving different 1,4-dioxane dosages*	*International Journal of Phytoremediation*	3
Kohira et al. (2024)	*Enhancement of alkali- and oxidation-modified biochars derived from water hyacinth for ammonium adsorption capacity*	*Soil Science and Plant Nutrition*	2
Kariim et al. (2024)	*Optimization of solvothermal liquefaction of water hyacinth over PTFE-acid mediated kaolin catalyst for enhanced biocrude production*	*Journal of Analytical and Applied Pyrolysis*	2
Viswanathan, Kuriakose et al. (2024)	*Fabrication of biochar-based bimetallic green nanocomposite as a photocatalytic adsorbent for tetracycline and antibacterial agent*	*Nanotechnology for Environmental Engineering*	2
Ullah and Rahman (2024)	*Adsorptive removal of toxic heavy metals from wastewater using water hyacinth and its biochar: A review*	*Heliyon*	1
Duan et al. (2024)	*Efficient degradation of antibiotic wastewater by biochar derived from water hyacinth stems via periodate activation: pyridinic N and carbon structures improved the electron transfer process*	*Water Science & Technology*	1
Maftu'ah et al. (2024)	*Si-Humate as soil ameliorant to improve the properties of acid sulfate soil, growth, and rice yield*	*Chilean Journal of Agricultural Research*	1
Ho et al. (2024)	*Arsenic adsorption by activated biochar derived from water hyacinth*	*Case Studies in Chemical and Environmental Engineering*	1
Mandal et al. (2024)	*Potential strategies for phytoremediation of heavy metals from wastewater with circular bioeconomy approach*	*Environmental Monitoring and Assessment*	0

Qin et al. (2024)	*Zinc and sulfur functionalized biochar as a peroxydisulfate activator via deferred ultraviolet irradiation for tetracycline removal*	*RSC Advances*	0
Chaiyaraksa and Sangworn (2024)	*The Influence of Chemical Fertilizers on the Effectiveness of Biochar in Mitigating Cadmium Mobility in Soil*	*Applied Environmental Research*	0
Irewale et al. (2024)	*Water hyacinth: Prospects for biochar-based, nano-enabled biofertilizer development*	*Heliyon*	0
Gezahegn et al. (2024)	*The impact of water hyacinth biochar on maize growth and soil properties: The influence of pyrolysis temperature*	*Journal of Sustainable Agriculture and Environment*	0
Zhao et al. (2024)	*High performance of heterogeneous catalytic ozonation for tetracycline removal by a N-doped biochar derived from co-pyrolysis of sludge and water hyacinth*	*Chemical Engineering and Processing - Process Intensification*	0
Murakami and Sato (2024)	*Optimization of Mixing Ratios of Binders and Organic Matter for Charcoal Briquette Using Biochars Derived from Water Hyacinth*	*Solid Fuel Chemistry*	0
Napisah and Maftu'ah (2024)	*Humate-Silica as an ameliorant to decrease Fe toxicity and increase rice yields on acid sulfate soils*	*BIO Web Conf.*	0
Dhinesh et al. (2024)	*Naturally derived organic biochar as an alternative to commercially activated carbon in the oxygen removal of seafood processing wastewater*	*Journal of Chemical Technology & Biotechnology*	0
Madkhali et al. (2024)	*Fabrication of thiosemicarbazide-modified biochar/carrageenan composite beads based on Eichhornia crassipes for effective removal of Pb (II) from aqueous medium*	*International Journal of Biological Macromolecules*	0
Khatun et al. (2024)	*Quantifying the Acceptance and Adoption Dynamics of Biochar and Co-biochar as a Sustainable Soil Amendment*	*Plant Science Today*	0
Nguyen et al. (2024)	*Investigation of the Desalination Capacity of Activated Carbon Materials from Water Hyacinth (Eichhornia crassipes) Stems*	*Indones. J. Chem.*	0

Com relação aos periódicos, a Tabela 3 apresenta os 10 periódicos que mais possuem publicações nessa área, juntamente com o total de artigos em cada um deles, o índice h, índice g e índice m, além do ano que obteve a primeira publicação e o fator de impacto da revista.

Tabela 3. Os 10 periódicos que mais receberam publicações. Fonte: Base Scopus, ferramenta Bibliometrix (2024).

Periódicos	Artigos	h_index	g_index	m_index	TC	PY_start	Fator de Impacto
Bioresource technology	11	11	11	1,38	661	2017	9,7
Science of the total environment	9	8	9	0,8	507	2016	8,2
Environmental research	6	4	6	1,33	61	2022	7,7

Journal of environmental management	6	5	6	0,5	472	2015	8
Scientific reports	6	5	6	0,71	575	2018	3,8
Biomass conversion and biorefinery	5	4	5	2	49	2023	3,5
Journal of environmental chemical engineering	5	5	5	1	160	2020	3,7
Environmental monitoring and assessment	4	3	4	0,5	73	2019	2,9
Environmental science and pollution research	4	4	4	0,44	195	2016	5,19
Environmental technology and innovation	4	4	4	0,71	136	2020	6,7

Pela Tabela 3, percebe-se que a revista que mais tem publicação no conjunto de dados considerado é também a revista com maior número de citações, sendo ela o Jornal "*Bioresource Technology*" e a que tem maior fator de impacto.

Dentre os trabalhos encontrados nessa revista, pode-se citar o trabalho de S. Bordoloi et al. (2018), que já conta com 109 citações, com o título "*Investigation of cracking and water availability of soil-biochar composite synthesized from invasive weed water hyacinth*".

Posteriormente, pode-se referenciar o artigo de Liang et al. (2018), intitulado "*High oxygen reduction reaction performance nitrogen-doped biochar cathode: A strategy for comprehensive utilizing nitrogen and carbon in water hyacinth*", com 94 citações.

O trabalho de Zhuang et al. (2020) possui 68 citações e tem como título "*Degradation by Fe3O4 supported on water hyacinth biochar for triggering direct interspecies electron transfer and its use in coal gasification wastewater treatment*"

Os autores que aparecem como os que mais têm trabalhos relacionados são Sreedeep, S., do "*Indian Institute of Technology Guwahati",* com 8 documentos e Kalita, Pankaj, da "*School of Energy Science and Engineering*", "*Indian Institute of Technology Guwahati*", com 7 artigos.

A Figura 4 mostra a linha de publicação dos 10 autores que mais tiveram trabalhos nesse conjunto de dados considerado, mostrando quando cada um deles teve seu primeiro trabalho publicado, e quantidade de artigos publicado em cada ano.

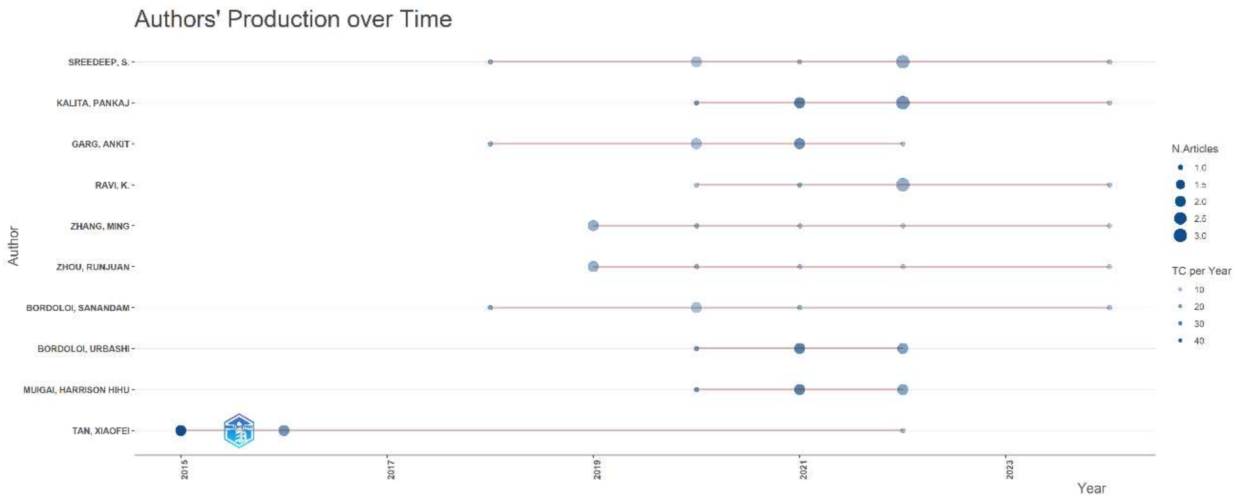

Figura 4. 10 autores com mais publicações. Fonte: Base Scopus, ferramenta Bibliometrix (2024).

E a Tabela 4 mostra os 6 autores com mais publicação no conjunto de documentos analisados, informando a quantidade de artigos de cada um deles, o índice h, g e m, além do total de citações que já receberam e o ano de sua primeira publicação relacionada ao assunto em estudo, e a instituição que fazem parte.

Tabela 4. Os 6 autores que mais publicaram. Fonte: Base Scopus, ferramenta Bibliometrix (2024).

Rank	Autores	Artigos	h_index	g_index	m_index	TC	PY_start	Instituição
1	Sreedeep, S.	8	7	8	0,875	217	2018	*Indian Institute of Technology GuwahatiThe institution will open in a new tab, Guwahati, India*
2	Kalita, Pankaj	7	7	7	1,167	329	2020	*Indian Institute of Technology GuwahatiThe institution will open in a new tab, Guwahati, India*
3	Garg, Ankit	6	6	6	0,75	244	2018	*Shantou UniversityThe institution will open in a new tab, Shantou, China*
4	Ravi, K.	6	5	6	0,833	120	2020	*Indian Institute of Technology GuwahatiThe institution will open in a new tab, Guwahati, India*
5	Zhang, Ming	6	4	6	0,571	157	2019	*Anhui Polytechnic UniversityThe institution will open in a new tab, Wuhu, China*
6	Zhou, Runjuan	6	4	6	0,571	157	2019	*Anhui Polytechnic UniversityThe institution will open in a new tab, Wuhu, China*

Pela Tabela 4, percebe-se os grupos de trabalho entre eles, evidenciando que os autores Sreedeep, S., Kalita, Pankaj e Ravi, K. estão desenvolvendo os trabalhos em colaboração. Enquanto há também o grupo formado por Zhang, Ming e Zhou, Runjuan. A Tabela 5 mostra os documentos mais citados, mostrando o seu ano de publicação, o total de citações recebidas e a revista em que ocorreu a publicação

Tabela 5. Os 50 artigos mais citados. Base Scopus, ferramenta Bibliometrix (2024).

Rank	Citação	Título	Total Citações	Ano	Revista
1	Zhang et al. (2015)	*Efficiency and mechanisms of Cd removal from aqueous solution by biochar derived from water hyacinth (Eichornia crassipes)*	307	2015	*Journal of Environmental Management*
2	Batista et al. (2018)	*Effect of surface and porosity of biochar on water holding capacity aiming indirectly at preservation of the Amazon biome*	281	2018	*Scientific Reports*
3	Yin et al. (2016)	*Varying effect of biochar on Cd, Pb and As mobility in a multi-metal contaminated paddy soil*	204	2016	*Chemosphere*
4	Zhang et al. (2015)	*Chitosan modification of magnetic biochar produced from Eichhornia crassipes for enhanced sorption of Cr(vi) from aqueous solution*	199	2015	*RSC Advances*
5	Wang et al. (2021)	*Environmental-friendly coal gangue-biochar composites reclaiming*	143	2021	*Science of The Total Environment*

		phosphate from water as a slow-release fertilizer			
6	Zhang et al. (2020)	*Enhanced removal of heavy metal ions from aqueous solution using manganese dioxide-loaded biochar: Behavior and mechanism*	136	2020	*Scientific Reports*
7	Buss et al. (2016)	*Suitability of marginal biomass-derived biochars for soil amendment*	118	2016	*Science of The Total Environment*
8	Das et al. (2020)	*A novel form stable PCM based bio composite material for solar thermal energy storage applications*	114	2020	*Journal of Energy Storage*
9	Xu et al. (2016)	*Enhanced adsorption of methylene blue by citric acid modification of biochar derived from water hyacinth (Eichornia crassipes)*	114	2016	*Environmental Science and Pollution Research*
10	S. Bordoloi et al. (2018)	*Investigation of cracking and water availability of soil-biochar composite synthesized from invasive weed water hyacinth*	109	2018	*Bioresource Technology*
11	Li et al. (2016)	*Preparation and Characterization of Biochars from Eichornia crassipes for Cadmium Removal in Aqueous Solutions*	106	2016	*PLOS one*
12	Cai et al. (2017)	*Phosphate reclaim from simulated and real eutrophic water by magnetic biochar derived from water hyacinth*	104	2017	*Journal of Environmental Management*
13	Liang et al. (2018)	*High oxygen reduction reaction performance nitrogen-doped biochar cathode: A strategy for comprehensive utilizing nitrogen and carbon in water hyacinth*	94	2018	*Bioresource Technology*
14	Kumar et al. (2023)	*Waste to catalyst: Role of agricultural waste in water and wastewater treatment*	91	2023	*Science of The Total Environment*
15	Huang et al. (2021)	*Effects of pyrolysis temperature, feedstock type and compaction on water retention of biochar amended soil*	88	2021	*Scientific Reports*
16	Sant'Anna et al. (2020)	*Electrochemical sensor based on biochar and reduced graphene oxide nanocomposite for carbendazim determination*	85	2020	*Talanta*
17	Das et al. (2021)	*Performance investigation of a rectangular spiral flow PV/T collector with a novel form-stable composite material*	80	2021	*Applied Thermal Engineering*
18	Shang et al. (2016)	*A novel graphene oxide coated biochar composite: synthesis, characterization and application for Cr(vi) removal*	79	2016	*RSC Advances*
19	Doumer et al. (2015)	*Slow pyrolysis of different Brazilian waste biomasses as sources of soil conditioners and energy, and for environmental protection*	78	2015	*Journal of Analytical and Applied Pyrolysis*

20	Qu et al. (2021)	*Magnetic porous biochar with high specific surface area derived from microwave-assisted hydrothermal and pyrolysis treatments of water hyacinth for Cr(VI) and tetracycline adsorption from water*	77	2021	*Bioresource Technology*
21	Li et al. (2021)	*Water hyacinth for energy and environmental applications: A review*	72	2021	*Bioresource Technology*
22	Zhuang et al. (2020)	*Enhanced 2,4,6-trichlorophenol anaerobic degradation by Fe3O4 supported on water hyacinth biochar for triggering direct interspecies electron transfer and its use in coal gasification wastewater treatment*	68	2020	*Bioresource Technology*
23	Hashem et al. (2020)	*Water hyacinth biochar for trivalent chromium adsorption from tannery wastewater*	68	2020	*Environmental and Sustainability Indicators*
24	Shen et al. (2018)	*Enhancing cadmium bioremediation by a complex of water-hyacinth derived pellets immobilized with Chlorella sp.*	67	2018	*Bioresource Technology*
25	Chen et al. (2021)	*Highly dispersed and stabilized Co3O4/C anchored on porous biochar for bisphenol A degradation by sulfate radical advanced oxidation process*	66	2021	*Science of The Total Environment*
26	Doumer et al. (2016)	*Removal of Cd, Cu, Pb, and Zn from aqueous solutions by biochars*	64	2016	*Environmental Science and Pollution Research*
27	Zhou et al. (2020)	*Optimization of preparation conditions for biochar derived from water hyacinth by using response surface methodology (RSM) and its application in Pb2+ removal*	61	2020	*Journal of Environmental Chemical Engineering*
28	Chen et al. (2019)	*High cadmium adsorption on nanoscale zero-valent iron coated Eichhornia crassipes biochar*	59	2019	*Environmental Chemistry Letters*
29	Zhou et al. (2019)	*Optimization of biochar preparation from the stem of Eichhornia crassipes using response surface methodology on adsorption of Cd2+*	56	2019	*Scientific Reports*
30	Wang et al. (2017)	*Study on adsorption characteristics of biochar on heavy metals in soil*	55	2017	*Korean Journal of Chemical Engineering*
31	Muigai et al. (2021)	*A comparative study on synthesis and characterization of biochars derived from lignocellulosic biomass for their candidacy in agronomy and energy applications*	52	2021	*International Journal of Energy Research*
32	Zhang et al. (2020)	*Co-hydrothermal carbonization of water hyacinth and polyvinyl chloride: Optimization of process parameters and characterization of hydrochar*	46	2020	*Bioresource Technology*
33	Mosa et al. (2020)	*Biochar-supported natural zeolite composite for recovery and reuse of aqueous phosphate and humate: Batch sorption–desorption and bioassay investigations*	44	2020	*Environmental Technology & Innovation*

34	Gwenzi et al. (2014)	*Adsorption of Zn2+ and Ni2+ in a binary aqueous solution by biosorbents derived from sawdust and water hyacinth (Eichhornia crassipes)*	44	2014	*Water Science & Technology*
35	Yan et al. (2021)	*Insights into the removal of Cr(VI) by a biochar–iron composite from aqueous solution: Reactivity, kinetics and mechanism*	43	2021	*Environmental Technology & Innovation*
36	Li et al. (2022)	*Rapid and efficient adsorption of tetracycline from aqueous solution in a wide pH range by using iron and aminoacetic acid sequentially modified hierarchical porous biochar*	40	2022	*Bioresource Technolog*
37	Lin et al. (2020)	*Recycling application of waste long-root Eichhornia crassipes in the heavy metal removal using oxidized biochar derived as adsorbents*	40	2020	*Bioresource Technology*
38	Bordoloi et al. (2022)	*Synthesis and comparative analysis of biochar based form-stable phase change materials for thermal management of buildings*	38	2022	*Journal of Energy Storage*
39	Elbasiouny et al. (2021)	*Ecofriendly remediation technologies for wastewater contaminated with heavy metals with special focus on using water hyacinth and black tea wastes: a review*	38	2021	*Environmental Monitoring and Assessment*
40	Sharma and Suthar (2021)	*Enriched biogas and biofertilizer production from Eichhornia weed biomass in cow dung biochar-amended anaerobic digestion system*	37	2021	*Environmental Technology & Innovation*
41	Jain et al. (2019)	*Utilization of Biochar as an amendment during lignocellulose waste composting: Impact on composting physics and Realization (probability) amongst physical properties*	35	2019	*Process Safety and Environmental Protection*
42	Sant'Anna et al. (2022)	*Selective carbonaceous-based (nano)composite sensors for electrochemical determination of paraquat in food samples*	34	2022	*Food Chemistry*
43	Doan et al. (2021)	*Comparative study on adsorption of cationic and anionic dyes by nanomagnetite supported on biochar derived from Eichhornia crassipes and Phragmites australis stems*	34	2021	*Environmental Nanotechnology, Monitoring & Management*
44	Cao et al. (2020)	*Preliminary study on the electrocatalytic performance of an iron biochar catalyst prepared from iron-enriched plants*	34	2020	*Journal of Environmental Sciences*
45	Jyoti Bora et al. (2021)	*Influence of biochar from animal and plant origin on the compressive strength characteristics of degraded landfill surface soils*	30	2021	*International Journal of Damage Mechanics*
46	Suthar et al. (2022)	*Enhanced biogas production in dilute acid-thermal pretreatment and cattle dung biochar mediated biomethanation of water hyacinth*	30	2022	*Fuel*

47	Ji et al. (2024)	*Efficiency and mechanism of adsorption for imidacloprid removal from water by Fe-Mg co-modified water hyacinth-based biochar: Batch adsorption, fixed-bed adsorption, and DFT calculation*	30	2024	*Separation and Purification Technology*
48	Li et al. (2014)	*Method To Characterize Acid–Base Behavior of Biochar: Site Modeling and Theoretical Simulation*	30	2014	*ACS Sustainable Chemistry & Engineering*
49	Zhang et al. (2022)	*Performance and mechanism of bamboo residues pyrolysis: Gas emissions, by-products, and reaction kinetics*	29	2022	*Science of The Total Environment*
50	Narayanan et al. (2021)	*Water hyacinth biochar and Aspergillus niger biomass amalgamation potential in removal of pollutants from polluted lake water*	29	2021	*Journal of Environmental Chemical Engineering*

4 Conclusão

A revisão bibliométrica é um estudo para a realização de análises e produções científicas. Portanto, conclui-se que o tema discutido neste estudo apresentou uma tendência de crescimento em relação às produções científicas realizadas nos últimos anos em escala global, sendo o ano de 2024 o que apresentou o maior número de publicações já realizadas.

Além disso, a China se destaca como o país mais ativo neste assunto, devido ao seu maior volume de publicações em comparação com os demais países. Contudo, a Índia registou um crescimento e se aproxima dessa marca.

O Brasil está entre os quatro países com maiores números de publicações, porém pode-se perceber através desse estudo que os trabalhos desenvolvidos no país relacionado a este tema ainda tem um número inferior, o que implica numa maior necessidade de pesquisa nesta área.

Portanto, pode-se afirmar através desta revisão que o tema estudado tem relevância no cenário mundial e está sendo discutido através de diferentes aplicações, entretanto ainda há uma demanda para o desenvolvimento de mais pesquisas nesta área, com estudos relacionados ao biocarvão obtido através do processo de pirólise da biomassa do aguapé.

Referências bibliográfica

Aria, M, and Cuccurullo, C (2017) 'Bibliometrix: An R-tool for comprehensive science mapping analysis'. *Journal of Informetrics*, v. 11, n. 4, pp. 959–975. https://doi.org/10.1016/j.joi.2017.08.007

Batista, EMCC et al. (2018) 'Effect of surface and porosity of biochar on water holding capacity aiming indirectly at preservation of the Amazon biome'. *Scientific Reports*, v. 8, n. 1, p. 10677. https://doi.org/10.1038/s41598-018-28794-z

Bordoloi, S et al. (2018) 'Investigation of cracking and water availability of soil-biochar composite synthesized from invasive weed water hyacinth'. *Bioresource Technology*, v. 263, pp. 665–677. https://doi.org/10.1016/j.biortech.2018.05.011

Bordoloi, S et al. (2024) 'Assessment of hydro-mechanical properties of biochar-amended soil sourced from two contrasting feedstock'. *Biomass Conversion and Biorefinery*, v. 14, n. 5, pp. 5803–5818. https://doi.org/10.1007/s13399-020-00946-0

Bordoloi, U et al. (2022) 'Synthesis and comparative analysis of biochar based form-stable phase change materials for thermal management of buildings'. *Journal of Energy Storage*, v. 55, p. 105801. https://doi.org/10.1016/j.est.2022.105801

Bottezini, L et al. (2021) 'Phosphorus species and chemical composition of water hyacinth biochars produced at different pyrolysis temperature'. *Bioresource Technology Reports*, v. 14, p. 100684. https://doi.org/10.1016/j.biteb.2021.100684

Buss, W et al. (2016) ‘Suitability of marginal biomass-derived biochars for soil amendment’. *Science of The Total Environment*, v. 547, pp. 314–322. https://doi.org/10.1016/j.scitotenv.2015.11.148

Cai, R et al. (2017) ‘Phosphate reclaim from simulated and real eutrophic water by magnetic biochar derived from water hyacinth’. *Journal of Environmental Management*, v. 187, pp. 212–219. https://doi.org/10.1016/j.jenvman.2016.11.047

Cai, W et al. (2024) ‘Effects of biochar from invasive weed on soil erosion under varying compaction and slope conditions: comprehensive study using flume experiments’. *Biomass Conversion and Biorefinery*, v. 14, n. 5, pp. 5771–5790. https://doi.org/10.1007/s13399-020-00943-3

Cao, X et al. (2020) ‘Preliminary study on the electrocatalytic performance of an iron biochar catalyst prepared from iron-enriched plants’. *Journal of Environmental Sciences*, v. 88, pp. 81–89. https://doi.org/10.1016/j.jes.2019.08.004

Carregosa, ISC et al. (2023) ‘Thermochemical conversion of aquatic weed biomass in a rotary kiln reactor for production of bio-based derivatives’. *Journal of Analytical and Applied Pyrolysis*, v. 173, p. 106048. https://doi.org/10.1016/j.jaap.2023.106048

Chaiyaraksa, C, and Sangworn, N (2024). ‘The Influence of Chemical Fertilizers on the Effectiveness of Biochar in Mitigating Cadmium Mobility in Soil’. *Applied Environmental Research*. https://doi.org/10.35762/AER.2024014

Chemtai, C et al. (2024) ‘Ciprofloxacin sorption by non-activated and activated biochar derived from millet husks and water hyacinth’. *Sustainable Chemistry for the Environment*, v. 5, p. 100075. https://doi.org/10.1016/j.scenv.2024.100075

Chen, L et al. (2019) ‘High cadmium adsorption on nanoscale zero-valent iron coated Eichhornia crassipes biochar’. *Environmental Chemistry Letters*, v. 17, n. 1, pp. 589–594. https://doi.org/10.1007/s10311-018-0811-y

Chen, XL et al. (2021) ‘Highly dispersed and stabilized Co_3O_4/C anchored on porous biochar for bisphenol A degradation by sulfate radical advanced oxidation process’. *Science of The Total Environment*, v. 777, p. 145794. https://doi.org/10.1016/j.scitotenv.2021.145794

Das, D et al. (2021) ‘Performance investigation of a rectangular spiral flow PV/T collector with a novel form-stable composite material’. *Applied Thermal Engineering*, v. 182, p. 116035. https://doi.org/10.1016/j.applthermaleng.2020.116035

Das, D et al. (2020) ‘A novel form stable PCM based bio composite material for solar thermal energy storage applications’. *Journal of Energy Storage*, v. 30, p. 101403. https://doi.org/10.1016/j.est.2020.101403

Deka, MJ et al. (2024) ‘Enhancing the performance of a photovoltaic thermal system with phase change materials: Predictive modelling and evaluation using neural networks’. *Renewable Energy*, v. 224, p. 120091. https://doi.org/10.1016/j.renene.2024.120091

Dhinesh, R et al. (2024) ‘Naturally derived organic biochar as an alternative to commercially activated carbon in the oxygen removal of seafood processing wastewater’. *Journal of Chemical Technology & Biotechnology*, v. 99, n. 7, pp. 1691–1702. https://doi.org/10.1002/jctb.7664

Doan, VD et al. (2021) ‘Comparative study on adsorption of cationic and anionic dyes by nanomagnetite supported on biochar derived from Eichhornia crassipes and Phragmites australis stems’. *Environmental Nanotechnology, Monitoring & Management*, v. 16, p. 100569. https://doi.org/10.1016/j.enmm.2021.100569

Donthu, N et al. (2021) ‘How to conduct a bibliometric analysis: An overview and guidelines’. *Journal of Business Research*, v. 133, pp. 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070

Doumer, ME et al. (2015) ‘Slow pyrolysis of different Brazilian waste biomasses as sources of soil conditioners and energy, and for environmental protection’. *Journal of Analytical and Applied Pyrolysis*, v. 113, pp. 434–443. https://doi.org/10.1016/j.jaap.2015.03.006

Doumer, ME et al. (2016) ‘Removal of Cd, Cu, Pb, and Zn from aqueous solutions by biochars’. *Environmental Science and Pollution Research*, v. 23, n. 3, pp. 2684–2692. https://doi.org/10.1007/s11356-015-5486-3

Duan, W et al. (2024) 'Efficient degradation of antibiotic wastewater by biochar derived from water hyacinth stems via periodate activation: pyridinic N and carbon structures improved the electron transfer process'. *Water Science & Technology*, v. 89, n. 1, pp. 212–224. https://doi.org/10.2166/wst.2023.408

Elbasiouny, H et al. (2021) 'Ecofriendly remediation technologies for wastewater contaminated with heavy metals with special focus on using water hyacinth and black tea wastes: a review'. *Environmental Monitoring and Assessment*, v. 193, n. 7, p. 449. https://doi.org/10.1007/s10661-021-09236-2

Galgali, P et al. (2023) 'Remediation of potentially toxic elements -containing wastewaters using water hyacinth – a review'. *International Journal of Phytoremediation*, v. 25, n. 2, pp. 172–186. https://doi.org/10.1080/15226514.2022.2068501

Gezahegn, A et al. (2024) 'The impact of water hyacinth biochar on maize growth and soil properties: The influence of pyrolysis temperature'. *Journal of Sustainable Agriculture and Environment*, v. 3, n. 3. https://doi.org/10.1002/sae2.12117

Gwenzi, W et al. (2014) 'Adsorption of Zn^{2+} and Ni^{2+} in a binary aqueous solution by biosorbents derived from sawdust and water hyacinth (Eichhornia crassipes)'. *Water Science and Technology*, v. 70, n. 8, pp. 1419–1427. https://doi.org/10.2166/wst.2014.391

Hashem, MA et al. (2020) 'Water hyacinth biochar for trivalent chromium adsorption from tannery wastewater'. *Environmental and Sustainability Indicators*, v. 5, p. 100022. https://doi.org/10.1016/j.indic.2020.100022

Ho, PNT et al. (2024) 'Arsenic adsorption by activated biochar derived from water hyacinth'. *Case Studies in Chemical and Environmental Engineering*, v. 10, p. 100907. https://doi.org/10.1016/j.cscee.2024.100907

Huang, H et al. (2021) 'Effects of pyrolysis temperature, feedstock type and compaction on water retention of biochar amended soil'. *Scientific Reports*, v. 11, n. 1, p. 7419. https://doi.org/10.1038/s41598-021-86701-5

Ibrahiem, H et al. (2024) 'Dual phytoremediation and biochar production by Eichhornia crassipes in hydroponic system receiving different 1,4-dioxane dosages'. *International Journal of Phytoremediation*, v. 26, n. 4, pp. 546–556. https://doi.org/10.1080/15226514.2023.2253915

Irewale, AT et al. (2024) 'Water hyacinth: Prospects for biochar-based, nano-enabled biofertilizer development'. *Heliyon*, v. 10, n. 17, p. e36966. https://doi.org/10.1016/j.heliyon.2024.e36966

Jain, MS et al. (2019) 'Utilization of Biochar as an amendment during lignocellulose waste composting: Impact on composting physics and Realization (probability) amongst physical properties'. *Process Safety and Environmental Protection*, v. 121, pp. 229–238. https://doi.org/10.1016/j.psep.2018.10.031

Ji, X et al. (2024) 'Efficiency and mechanism of adsorption for imidacloprid removal from water by Fe-Mg co-modified water hyacinth-based biochar: Batch adsorption, fixed-bed adsorption, and DFT calculation'. *Separation and Purification Technology*, v. 330, p. 125235. https://doi.org/10.1016/j.seppur.2023.125235

Jyoti Bora, M et al. (2021) 'Influence of biochar from animal and plant origin on the compressive strength characteristics of degraded landfill surface soils'. *International Journal of Damage Mechanics*, v. 30, n. 4, pp. 484–501. https://doi.org/10.1177/1056789520925524

Kariim, I et al. (2024) 'Optimization of solvothermal liquefaction of water hyacinth over PTFE-acid mediated kaolin catalyst for enhanced biocrude production'. *Journal of Analytical and Applied Pyrolysis*, v. 178, p. 106416. https://doi.org/10.1016/j.jaap.2024.106416

Khatun, M et al. (2024) 'Quantifying the Acceptance and Adoption Dynamics of Biochar and Co-biochar as a Sustainable Soil Amendment'. *Plant Science Today*. https://doi.org/10.14719/pst.3242

Kohira, Y et al. (2024) 'Enhancement of alkali- and oxidation-modified biochars derived from water hyacinth for ammonium adsorption capacity'. *Soil Science and Plant Nutrition*, v. 70, n. 1, pp. 21–33. https://doi.org/10.1080/00380768.2023.2272626

Kumar, M et al. (2023) 'Waste to catalyst: Role of agricultural waste in water and wastewater treatment'. *Science of The Total Environment*, v. 858, p. 159762. https://doi.org/10.1016/j.scitotenv.2022.159762

Laengle, S et al. (2017) 'Forty years of the European Journal of Operational Research: A bibliometric overview'. *European Journal of Operational Research*, v. 262, n. 3, pp. 803–816. https://doi.org/10.1016/j.ejor.2017.04.027

Lehmann, J et al. (2011) 'Biochar effects on soil biota - a review'. *Soil Biology and Biochemistry*, v. 43, n. 9, pp. 1812–1836. https://doi.org/10.1016/j.soilbio.2011.04.022

Li, F et al. (2021) 'Water hyacinth for energy and environmental applications: A review'. *Bioresource Technology*, v. 327, p. 124809. https://doi.org/10.1016/j.biortech.2021.124809

Li, F et al. (2016) 'Preparation and Characterization of Biochars from Eichornia crassipes for Cadmium Removal in Aqueous Solutions'. *PLOS ONE*, v. 11, n. 2, p. e0148132. https://doi.org/10.1371/journal.pone.0148132

Li, M et al. (2014) 'Method To Characterize Acid–Base Behavior of Biochar: Site Modeling and Theoretical Simulation'. *ACS Sustainable Chemistry & Engineering*, v. 2, n. 11, pp. 2501–2509. https://doi.org/10.1021/sc500432d

Li, X et al. (2022) 'Rapid and efficient adsorption of tetracycline from aqueous solution in a wide pH range by using iron and aminoacetic acid sequentially modified hierarchical porous biochar'. *Bioresource Technology*, v. 346, p. 126672. https://doi.org/10.1016/j.biortech.2022.126672

Li, Y et al. (2024) 'Magnetic biochar serves as adsorbents and catalyst supports for the removal of antibiotics from wastewater: A review'. *Journal of Environmental Management*, v. 366, p. 121872. https://doi.org/10.1016/j.jenvman.2024.121872

Liang, J et al. (2018) 'High oxygen reduction reaction performance nitrogen-doped biochar cathode: A strategy for comprehensive utilizing nitrogen and carbon in water hyacinth'. *Bioresource Technology*, v. 267, pp. 524–531. https://doi.org/10.1016/j.biortech.2018.07.085

Lin, S et al. (2020) 'Recycling application of waste long-root Eichhornia crassipes in the heavy metal removal using oxidized biochar derived as adsorbents'. *Bioresource Technology*, v. 314, p. 123749. https://doi.org/10.1016/j.biortech.2020.123749

Lu, L et al. (2024) 'Water hyacinth derived hierarchical porous biochar absorbent: Ideal peroxydisulfate activator for efficient phenol degradation via an electron-transfer pathway'. *Environmental Research*, v. 242, p. 117773. https://doi.org/10.1016/j.envres.2023.117773

Madkhali, MMM et al. (2024) 'Fabrication of thiosemicarbazide-modified biochar/carrageenan composite beads based on Eichhornia crassipes for effective removal of Pb (II) from aqueous medium'. *International Journal of Biological Macromolecules*, v. 281, p. 136451. https://doi.org/10.1016/j.ijbiomac.2024.136451

Maftu'ah, E et al. (2024) 'Si-Humate as soil ameliorant to improve the properties of acid sulfate soil, growth, and rice yield'. *Chilean Journal of Agricultural Research*, v. 84, n. 2, pp. 267–280.

Mandal, RR et al. (2024) 'Potential strategies for phytoremediation of heavy metals from wastewater with circular bioeconomy approach'. *Environmental Monitoring and Assessment*, v. 196, n. 6, p. 502. https://doi.org/10.1007/s10661-024-12680-5

Mosa, A et al. (2020) 'Biochar-supported natural zeolite composite for recovery and reuse of aqueous phosphate and humate: Batch sorption–desorption and bioassay investigations'. *Environmental Technology & Innovation*, v. 19, p. 100807. https://doi.org/10.1016/j.eti.2020.100807

Muigai, HH et al. (2021) 'A comparative study on synthesis and characterization of biochars derived from lignocellulosic biomass for their candidacy in agronomy and energy applications'. *International Journal of Energy Research*, v. 45, n. 3, pp. 4765–4781. https://doi.org/10.1002/er.6092

Murakami, K, and Sato, S (2024) 'Optimization of Mixing Ratios of Binders and Organic Matter for Charcoal Briquette Using Biochars Derived from Water Hyacinth'. *Solid Fuel Chemistry*, v. 58, n. 3, pp. 226–231. https://doi.org/10.3103/S0361521924700022

Napisah, K, and Maftu'ah, E (2024) 'Humate-Silica as an ameliorant to decrease Fe toxicity and increase rice yields on acid sulfate soils'. *BIO Web of Conferences*, v. 99, p. 05005. https://doi.org/10.1051/bioconf/20249905005

Narayanan, M et al. (2021) 'Water hyacinth biochar and Aspergillus niger biomass amalgamation potential in removal of pollutants from polluted lake water'. *Journal of Environmental Chemical Engineering*, v. 9, n. 4, p. 105574. https://doi.org/10.1016/j.jece.2021.105574

Nguyen, VP et al. (2024) 'Investigation of the Desalination Capacity of Activated Carbon Materials from Water Hyacinth (Eichhornia crassipes) Stems'. *Indonesian Journal of Chemistry*, v. 24, n. 2, p. 576. https://doi.org/10.22146/ijc.85392

Qin, Y et al. (2024) 'Zinc and sulfur functionalized biochar as a peroxydisulfate activator via deferred ultraviolet irradiation for tetracycline removal. *RSC Advances*, v. 14, n. 8, pp. 5648–5664. https://doi.org/10.1039/D3RA07923F

Qu, J et al. (2021) 'Magnetic porous biochar with high specific surface area derived from microwave-assisted hydrothermal and pyrolysis treatments of water hyacinth for Cr (VI) and tetracycline adsorption from water'. *Bioresource Technology*, v. 340, p. 125692. https://doi.org/10.1016/j.biortech.2021.125692

Sant'Anna, MVS et al. (2020) 'Electrochemical sensor based on biochar and reduced graphene oxide nanocomposite for carbendazim determination'. *Talanta*, v. 220, p. 121334. https://doi.org/10.1016/j.talanta.2020.121334

Sant'Anna, MVS et al. (2022) 'Selective carbonaceous-based (nano) composite sensors for electrochemical determination of paraquat in food samples'. *Food Chemistry*, v. 373, p. 131521. https://doi.org/10.1016/j.foodchem.2021.131521

Shang, M et al. (2016) 'A novel graphene oxide coated biochar composite: synthesis, characterization and application for Cr (vi) removal'. *RSC Advances*, v. 6, n. 88, pp. 85202–85212. https://doi.org/10.1039/C6RA07151A

Sharma, B, and Suthar, S (2021) 'Enriched biogas and biofertilizer production from Eichhornia weed biomass in cow dung biochar-amended anaerobic digestion system'. *Environmental Technology & Innovation*, v. 21, p. 101201. https://doi.org/10.1016/j.eti.2020.101201

Shen, Y et al. (2018) 'Enhancing cadmium bioremediation by a complex of water-hyacinth derived pellets immobilized with Chlorella sp'. *Bioresource Technology*, v. 257, pp. 157–163. https://doi.org/10.1016/j.biortech.2018.02.060

Singh, P et al. (2023) 'Aquatic plant biomass-derived porous carbon: biomaterials for sustainable waste management and climate change mitigation'. *International Journal of Environmental Science and Technology*, v. 20, n. 11, pp. 12955–12970. https://doi.org/10.1007/s13762-022-04601-1

Suthar, S et al. (2022) 'Enhanced biogas production in dilute acid-thermal pretreatment and cattle dung biochar mediated biomethanation of water hyacinth'. *Fuel*, v. 307, p. 121897. https://doi.org/10.1016/j.fuel.2021.121897

Ullah, MH, and Rahman, MJ (2024) 'Adsorptive removal of toxic heavy metals from wastewater using water hyacinth and its biochar: A review'. *Heliyon*, v. 10, n. 17, p. e36869. https://doi.org/10.1016/j.heliyon.2024.e36869

Viswanathan, SP et al. (2024) 'Fabrication of biochar-based bimetallic green nanocomposite as a photocatalytic adsorbent for tetracycline and antibacterial agent'. *Nanotechnology for Environmental Engineering*, v. 9, n. 1, pp. 29–46. https://doi.org/10.1007/s41204-023-00349-2

Viswanathan, SP et al. (2024) 'The efficiency of aquatic weed–derived biochar in enhanced removal of cationic dyes from aqueous medium'. *Biomass Conversion and Biorefinery*, v. 14, n. 12, pp. 12895–12910. https://doi.org/10.1007/s13399-022-03546-2

Wang, B et al. (2021) 'Environmental-friendly coal gangue-biochar composites reclaiming phosphate from water as a slow-release fertilizer'. *Science of The Total Environment*, v. 758, p. 143664. https://doi.org/10.1016/j.scitotenv.2020.143664

Wang, H et al. (2017) 'Study on adsorption characteristics of biochar on heavy metals in soil'. *Korean Journal of Chemical Engineering*, v. 34, n. 6, pp. 1867–1873. https://doi.org/10.1007/s11814-017-0048-7

Xu, Y et al. (2016) 'Enhanced adsorption of methylene blue by citric acid modification of biochar derived from water hyacinth (Eichornia crassipes)'. *Environmental Science and Pollution Research*, v. 23, n. 23, pp. 23606–23618. https://doi.org/10.1007/s11356-016-7572-6

Xuechen, Y et al. (2024) 'A critical review of biochar as an environmental functional material in soil ecosystems for migration and transformation mechanisms and ecological risk assessment'. *Journal of Environmental Management*, v. 360, p. 121196. https://doi.org/10.1016/j.jenvman.2024.121196

Yan, L et al. (2021) 'Insights into the removal of Cr(VI) by a biochar–iron composite from aqueous solution: Reactivity, kinetics and mechanism'. *Environmental Technology & Innovation*, v. 24, p. 102057. https://doi.org/10.1016/j.eti.2021.102057

Yi, Y et al. (2024) 'Persulfate oxidation of norfloxacin by cobalt doped water hyacinth biochar composite: The key role of cobalt and singlet oxygen'. *Journal of Water Process Engineering*, v. 59, p. 104967. https://doi.org/10.1016/j.jwpe.2024.104967

Yin, D et al. (2016) 'Varying effect of biochar on Cd, Pb and As mobility in a multi-metal contaminated paddy soil'. *Chemosphere*, v. 152, pp. 196–206. https://doi.org/10.1016/j.chemosphere.2016.01.044

Zeng, J et al. (2022) 'Review on technology of making biofuel from food waste'. *International Journal of Energy Research*, v. 46, n. 8, pp. 10301–10319. https://doi.org/10.1002/er.7868

Zhang, C et al. (2020) 'Co-hydrothermal carbonization of water hyacinth and polyvinyl chloride: Optimization of process parameters and characterization of hydrochar'. *Bioresource Technology*, v. 314, p. 123676. https://doi.org/10.1016/j.biortech.2020.123676

Zhang, F et al. (2015) 'Efficiency and mechanisms of Cd removal from aqueous solution by biochar derived from water hyacinth (Eichornia crassipes)'. *Journal of Environmental Management*, v. 153, pp. 68–73. https://doi.org/10.1016/j.jenvman.2015.01.043

Zhang, G et al. (2022) 'Performance and mechanism of bamboo residues pyrolysis: Gas emissions, by-products, and reaction kinetics'. *Science of The Total Environment*, v. 838, p. 156560. https://doi.org/10.1016/j.scitotenv.2022.156560

Zhang, H et al. (2020) 'Enhanced removal of heavy metal ions from aqueous solution using manganese dioxide-loaded biochar: Behavior and mechanism'. *Scientific Reports*, v. 10, n. 1, p. 6067. https://doi.org/10.1038/s41598-020-63000-z

Zhang, M et al. (2015) 'Chitosan modification of magnetic biochar produced from Eichhornia crassipes for enhanced sorption of Cr(vi) from aqueous solution'. *RSC Advances*, v. 5, n. 58, pp. 46955–46964. https://doi.org/10.1039/C5RA02388B

Zhao, H et al. (2024) 'High performance of heterogeneous catalytic ozonation for tetracycline removal by a N-doped biochar derived from co-pyrolysis of sludge and water hyacinth'. *Chemical Engineering and Processing - Process Intensification*, v. 205, p. 110031. https://doi.org/10.1016/j.cep.2024.110031

Zhou, R et al. (2020) 'Optimization of preparation conditions for biochar derived from water hyacinth by using response surface methodology (RSM) and its application in Pb^{2+} removal'. *Journal of Environmental Chemical Engineering*, v. 8, n. 5, p. 104198. https://doi.org/10.1016/j.jece.2020.104198

Zhou, R et al. (2019) 'Optimization of biochar preparation from the stem of Eichhornia crassipes using response surface methodology on adsorption of Cd^{2+}'. *Scientific Reports*, v. 9, n. 1, p. 17538. https://doi.org/10.1038/s41598-019-54105-1

Zhuang, H et al. (2020) 'Enhanced 2,4,6-trichlorophenol anaerobic degradation by Fe_3O_4 supported on water hyacinth biochar for triggering direct interspecies electron transfer and its use in coal gasification wastewater treatment'. *Bioresource Technology*, v. 296, p. 122306. https://doi.org/10.1016/j.biortech.2019.122306