CONSTRUCTED WETLANDS: A SYSTEMATIC REVIEW

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Abstract. This paper was produced seeking information on most aspects of research projects in constructed wetlands (CWs) in the last decade. Although constructed wetlands (CWs) are often relatively simple in terms of engineering, they are extremely complex ecological systems. The performance of CWs depends not only on good design, but also on good construction and operation. Therefore, a systematic literature review was conducted from 2013 to 2024, involving characteristics, design, and operation of constructed wetlands. The references were catalogued, and all duplicates were removed before the total obtained was counted. Only scientific articles, review articles, books and book chapters were searched. Only references in the English language were accepted. It was observed that, among the topics researched, the most studied was Constructed wetlands and uses, indicating that the search for applications for CWs was the main interest of researchers in the last decade. It was not possible to detect that the topics surveyed varied widely in the review period (10 years), which could show an increase or decrease in the interest about one topic, this result indicate that the topics chosen to tend to continue to be of interest in future research. Therefore, this paper can serve as a reference and basis for studies in the area of CW.
Keywords: *constructed wetlands, systematic review, data analysis, ecological systems*

Introduction

This text was produced in order to seek information on most aspects of research in constructed wetlands (CWs) in the last decade. The production of knowledge requires some care on the part of those who propose to carry out research, because almost always, new research intends to address some bias that complements or contests what other researchers have already stated. Therefore, the formulation of a research problem only becomes relevant when the researcher, after a critical analysis of the current stage of scientific production of his theme, can identify gaps, consensuses and controversies on the theme and insert his research object in a path not yet taken by other researchers. The literature review can be very useful because, if done well, it can avoid future unpleasantness, such as discovering that the "wheel has already been invented", that your research is something already said, already investigated. Therefore, the literature review helps: (a) to delimit the research problem, (b) to assist in the search for new lines of investigation for the problem that the researcher intends to investigate, (c) to avoid unsuccessful approaches, that is, through the literature review the researcher can look for paths never taken, (d) identify works already done, already written and move on to another approach and (e) prevent the researcher from doing more of the same, that says what has already been said, making your research irrelevant.

The steps mentioned can be facilitated if the researcher follows some paths that will help him in the systematization of the literature review. It is necessary, therefore, for the

researcher to analyze the latest publications made, to see if the topic of his research is not already outdated or without scientific relevance. According Kayombo et al. (2005), the lack of such information, and an integrated approach, has led to the development of many CWs that are inadequate, underperforming, or poorly designed or maintained. According to these authors, the reasons for these problems include lack of knowledge by many designers of the complex, physical, biological, and chemical processes within WSPs and CWs; Lack of consistency in design, construction, and operation for optimal performance; Lack of appropriate design tools and methodologies appropriate to local conditions; and Changing nature of rapidly developed technology. Although CWs are often relatively simple in terms of engineering, they are extremely complex ecological systems. The performance of CWs depends not only on good design, but also on good construction and operation. Literature review (LR) has improved significantly over the years, from traditional narrative review to systematic reviews (Fahimnia et al., 2015; Petticrew and Roberts, 2008; Cook et al., 1997).

Systematic literature review is a well-regarded research method that can be applied to a variety of fields of study (Thomé et al., 2016). The systematic review of the literature analyzes and synthesizes information from existing studies, generating new results and conclusions (Denyer and Tranfield, 2009). Thomé et al. (2016), they present a step-by-step guide to conducting a systematic review of the literature consisting of eight steps: (i) planning and formulation of the problem, (ii) literature search, (iii) data collection, (iv) quality assessment, (v) data analysis and synthesis, (vi) interpretation, (vii) presentation of results, and (viii) updating of the review. Many countries in tropical climates use constructed wetlands for wastewater treatment (e.g., Tanzania, Kenya, Malawi, Uganda, Zambia, Botswana, and Zimbabwe). Many of these systems have performed below the required standards due to a lack of proper operation and maintenance (Yhdego, 1989). Constructed wetlands (CWs) mimic the simultaneous physical, chemical, and biological processes that occur in natural wetlands for wastewater treatment purposes (Hu and He, 2022; Rajan et al., 2019; Wu et al., 2018).

According to Song et al. (2019), there are a variety of wetland types, which makes it difficult to formulate a precise and internationally accepted definition. According to these authors, one of the best and recognized definitions for natural wetlands was provided by the Ramsar Convention on Wetlands in 1971, which adapted an international and intergovernmental definition for wetlands, based on an expanded approach to better describe the main characteristics of wetlands. As such, wetlands are defined as "areas of swamp, mangrove, peat bogs or water, natural or artificial, permanent or temporary, with static or fluid, fresh, brackish or salty water, including areas of marine water, the depth of which at low tide does not exceed six metres". Natural wetlands include areas such as estuaries, mangroves, tidal flats, floodplains, deltas, freshwater swamps, lakes, ponds, swamps, and underground aquifer springs. As their name implies, they are created without any human intervention. In general, this treatment technology is a relatively recent development (i.e., about 30-40 years) when compared to conventional treatment methods that have been used for more than 80 years. This relatively short period implies a respective limited level of experience in both the design and operation of CWs. Although the technology has been around for about four decades, it is only during the last 15-20 years that a tremendous increase in interest in CWs has occurred. This is not unrelated to the fact that during the same period, the real value of wetlands was realized, as a result of the gradual increase in environmental concerns. Thus, research on CWs and the observation of the functioning

of the first full-scale systems have been intensified, in order to improve the fundamental knowledge and basic understanding of the processes that occur within the system and optimize its efficiency (Çakir et al., 2015).

So, the main objective of this study were to review the literature on the characteristics, design and operation of constructed wetlands and waste stabilization ponds for the removal of pollutants and specific objectives were to conduct and analyze a systematic review on constructed wetlands analyzing "state of the art" for research in the area identifying, among the topics used in the review, what most appear in the literature and how they vary over time.

Materials and Methods

This work followed the guidelines of the Preferred Report Items for Systematic Reviews and Meta-analyses-PRISMA 2020 (Page et al., 2021). The articles that served as the basis for this study were found in Engineering Village, IEEE, Scielo, Science Direct, Scopus and Google Scholar. In the search, the following keywords were used: constructed wetlands; constructed wetlands and characteristics; constructed wetlands and process characteristics; constructed wetlands and uses; constructed wetlands and functions; constructed wetlands and advantages and disadvantages; constructed wetlands and classification; constructed wetlands and design criteria; constructed wetlands and sizing; constructed wetlands and configuration water conveying system; constructed wetlands and water conveying system; constructed wetlands and vegetation; constructed wetlands and microbiota; constructed wetlands and microorganisms; constructed wetlands and substrate. Software ENDNOTE (vrs9.0) and programs developed by the author in Python were used in the search and in the separation of the results. The references were cataloged, and all duplicates were removed before the total obtained was counted. Only scientific articles, review articles, books and book chapters were searched. Only references in the English language were accepted. Articles published in the last 10 years (from 2013 to 2024) were selected for evaluation in this work and, as exclusion criteria, the following were adopted: articles published before 2013, not peer-reviewed, not in English, and topics that are not directly related to "Constructed Wetland". When two or more references presented similar or equal results, the most recent one was chosen.

Results and Discussion

The search product found 176552 items. With the application of the corresponding filters, we arrive at 171345 references. Among the references we have 651 are books, 8308 book chapters, 20151 review articles and 142235 scientific articles. *Table 1* shows the references of each type found for each search (*Figure 1* to *Figure 4*). As expected, the lowest number of publications are books, with the lowest percentage of books in the topics Constructed Wetlands and Characteristics; Constructed Wetlands and process characteristics; Constructed Wetlands and uses and Constructed Wetlands and functions, all with 0.3% of books in relation to total publications. The highest percentage of book publications was 2.8% in the topic Constructed Wetlands and configuration water conveying system. This small number of publications can be attributed to the need to consolidate knowledge and the work required to create this type of publication. Second, Okoli (2019), traditional sources of literature are periodicals and

books (including reference books and, in some cases, textbooks). Traditionally, we accessed these sources mainly through long visits to libraries, but today they are widely available on the internet (except for books, which are not yet as accessible electronically as articles).

Table 1. *References of each type found in the literature search.*

Topic	Total	Books	Chapters	Reviews	Articles
Constructed wetlands and characteristics	22140	75	848	2294	18922
Constructed wetlands and process characteristics	20680	66	814	2349	17450
Constructed wetlands and uses	29346	79	1055	2459	25753
Constructed wetlands and functions	20709	60	834	2065	17751
Constructed wetlands and advantages	10613	63	757	1904	7889
Constructed wetlands and classification	9015	41	406	945	7624
Constructed wetlands and design criteria	6077	65	614	1159	4239
Constructed wetlands and sizing	21089	49	812	2218	18010
Constructed wetlands and configuration water conveying system	385	9	79	85	212
Constructed wetlands and water conveying system	1484	26	259	272	927
Constructed wetlands and vegetation	13741	41	526	1513	11661
Constructed wetlands and microbiota	645	4	84	154	403
Constructed wetlands and microorganisms	7313	37	627	1393	5256
Constructed wetlands and substrate	8107	37	591	1341	6138
Total	171345	651	8308	20151	142235

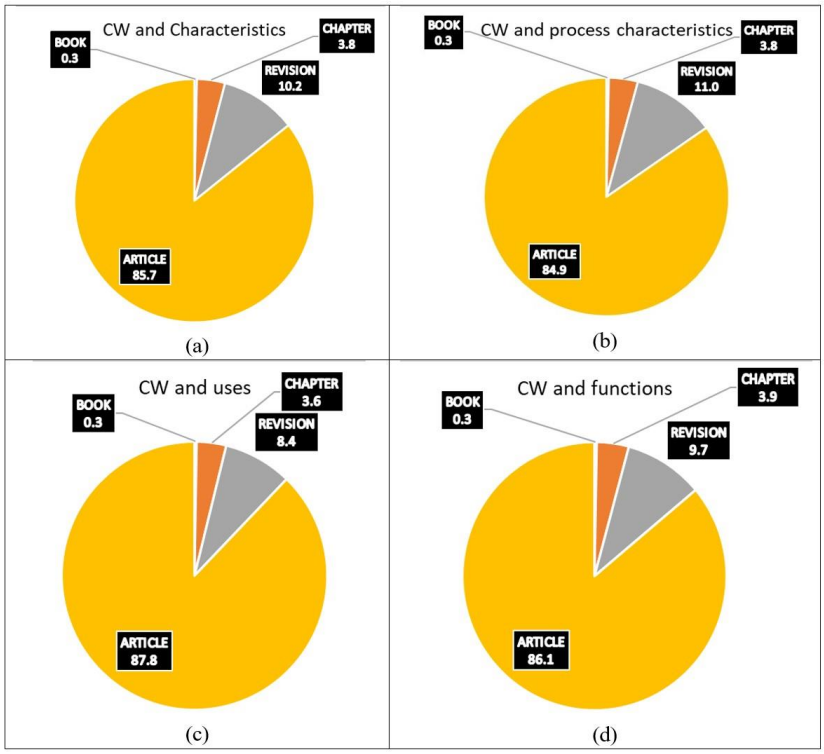

Figure 1. *Search results for the terms: (a) Constructed Wetlands and Characteristics, (b) Constructed Wetlands and process characteristics, (c) Constructed Wetlands and uses, (d) Constructed Wetlands and functions.*

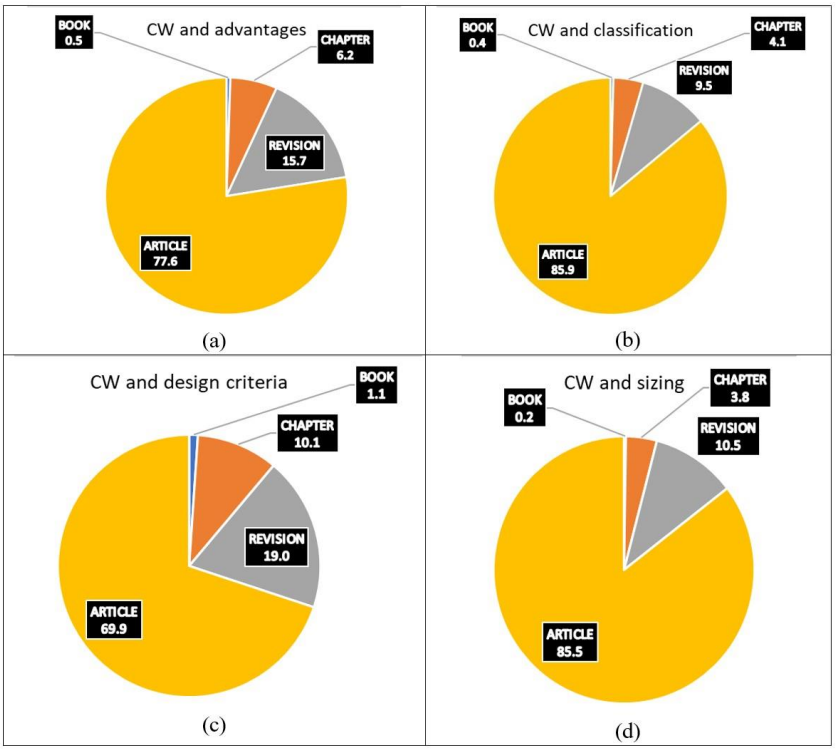

Figure 2. *Search results for the terms: (a) Constructed Wetlands and advantages, (b) Constructed Wetlands and classification, (c) Constructed Wetlands and design criteria, (d) Constructed Wetlands and sizing.*

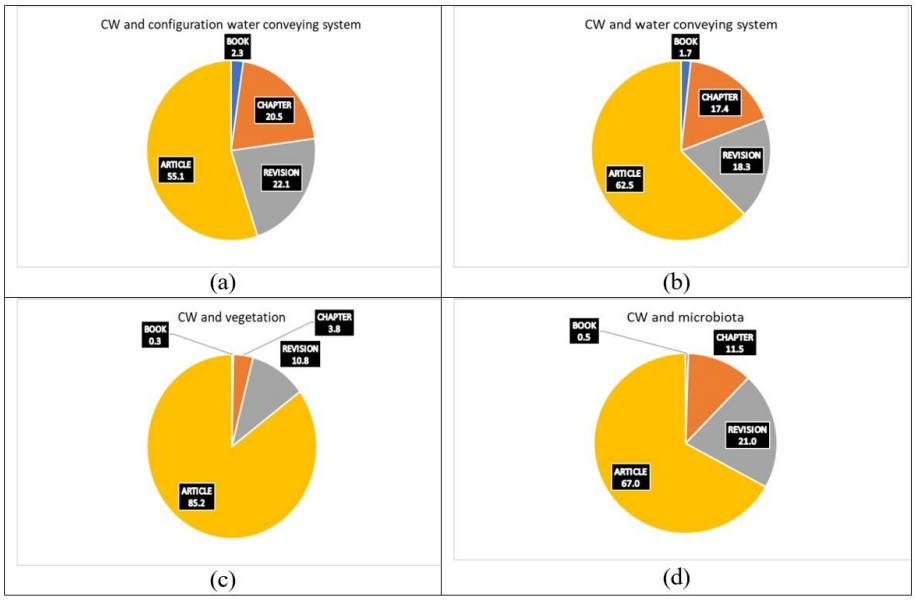

Figure 3. *Search results for the terms:(a) Constructed Wetlands and configuration water conveying system, (b) Constructed Wetlands and water conveying system, (c) Constructed Wetlands and vegetation, (d) Constructed Wetlands and microbiota.*

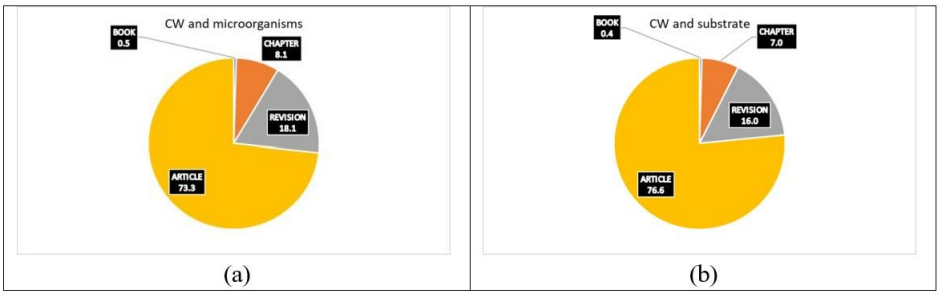

Figure 4. *Search results for the terms: (a) Constructed Wetlands and microorganisms, (b) Constructed Wetlands and substrate.*

The largest amount of research (*Figure 5*) involved, therefore, the use of constructed wetlands (CWs), with 17.1%. The detailing of the results shows that these uses refer mainly to the type of pollutant to be removed and the affluent to be treated, relating to the type and configurations of the CW. The topics CW and Characteristics, CW and sizing, CW and functions, and CW and process characteristics presented extremely similar results in terms of percentage of publications (12.9, 12.3, 12.1, and 12.1, respectively). Which is an interesting result, as it shows that these topics, apparently, arouse the same interest of the scientific community. Even with its undoubted interest in the process, the topic CW and vegetation presented only 8% of the total number of publications, a median value among the topics studied. Probably, the multidisciplinary training required for this type of study can be an influence on these values. The topics CW and classification, CW and substrate, CW and microorganisms and CW and design criteria presented numerically close percentages (5.3, 4.7, 4.3 and 3.5) being topics with less frequency of interest in research than the others. The topics CW and water conveying system, CW and microbiota and CW and configuration water conveying system (WCS) presented percentages of less than 1% in relation to the total number of studies. Thus, we can consider that these are topics that have been little studied on the

subject, with the exception, perhaps, of the topic CW and microbiota, which may have been "included" in the topic of microorganisms. In fact, the microbiota consists of a wide variety of bacteria, viruses, fungi and other single-celled microorganisms that inhabit CWs, and most of the studies we have been able to read refer to specific microorganisms. That is, we can deduce that very little is studied and, therefore, little is known about the ecology of microorganisms in this environment.

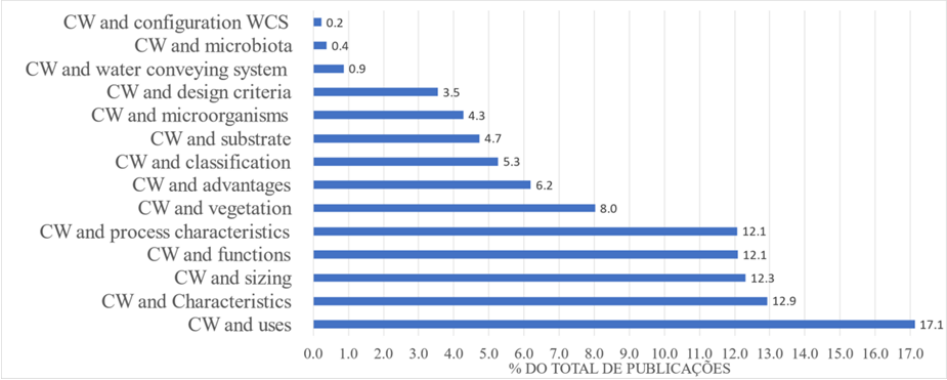

Figure 5. *Percentage of publications by search topic in relation to the total.*

As this is a 10-year review, although works from 2024 have already been found, it is interesting to check the variation in the number of works, and of each topic, over the time of the research. *Figures 6* to *Figure 8* show the variations in the percentage of references per year, for each topic studied. For the three topics that presented the lowest number of references (*Figures 6*), we observed that for the topic CW and water conveying system, the number of publications was approximately stable in the range of 2.6 to 3.3% until the year 2018, while the number of references on this topic began to decrease each year, with a possible small increase in 2024. For the topic CW and microbiota, the amount of publication has been increasing, albeit slowly, over time, which indicates a possible interest in the ecology and interactions of microorganisms in CWs. Therefore, topics with a small number of references did not present any characteristic year in which they aroused attention or failed to present. The topics that presented intermediate values of the number of references found, i.e., CW and advantages, CW and classification, CW and design criteria, CW and microorganisms, and CW and substrate (*Figure 7*). There were trends of increase, albeit small, in the number of publications for the topics CW and microorganisms, CW and classification, and CW and advantages. However, the latter presented an atypical value of 0.4 in 2020. The topic CW and design criteria showed a small decrease in the number of publications over the time studied, and the topic CW and substrate showed a variation between 8.1 and 9.5 %, with no tendency to increase or decrease.

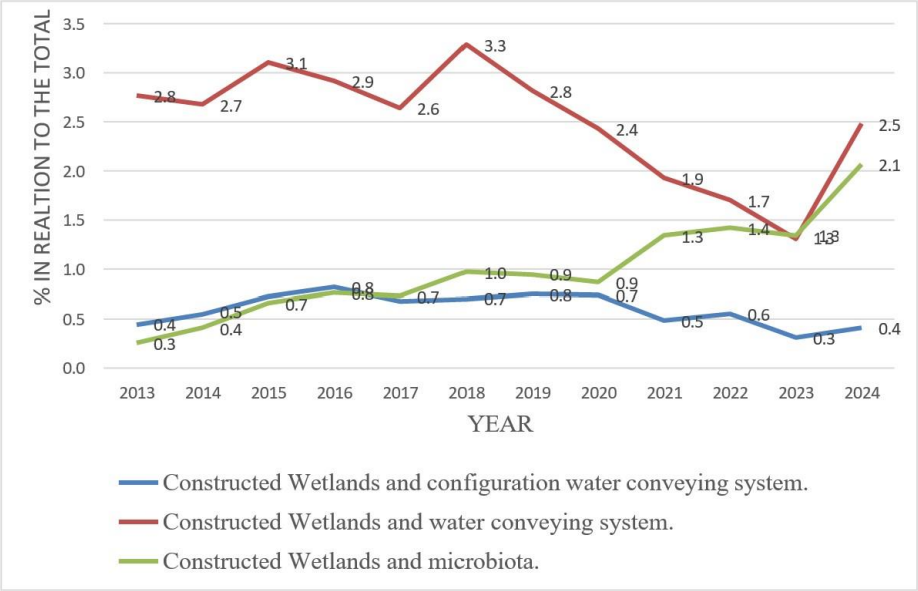

Figure 6. *Percentage of references in relation to the total in each year for the topics: CW and water conveying system, CW and microbiota and CW and configuration water conveying system.*

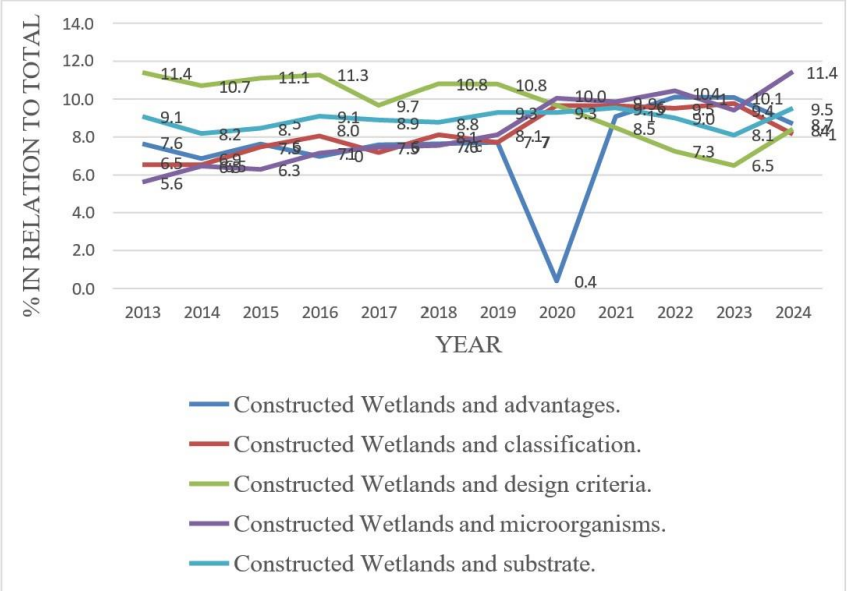

Figure 7. *Percentage of references in relation to the total in each year for the topics: CW and advantages, CW and classification, CW and design criteria, CW and microorganisms and CW and substrate.*

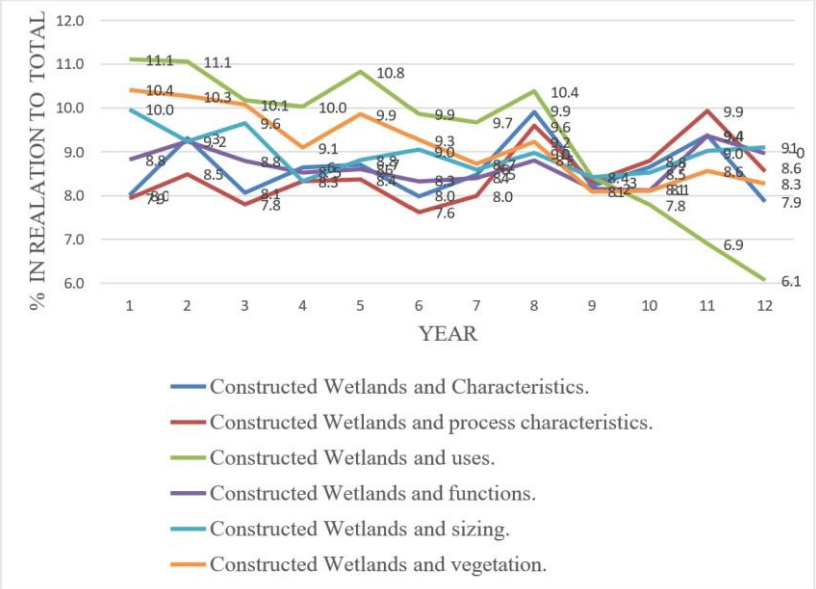

Figure 8. *Percentage of references in relation to the total in each year for the topics: CW and Characteristics, CW and process characteristics, CW and uses, CW and functions, CW and sizing and CW and vegetation.*

For the six topics that presented the highest percentage values of number of references in relation to the total (Figure 8), i.e., CW and characteristics, CW and process characteristics, CW and uses, CW and functions, CW and sizing, and CW and vegetation, only the topics CW and uses showed a trend of a small decrease in the number of publications over time. The others showed the expected oscillation, but without an increasing or decreasing trend. Therefore, by analyzing the variation of the topics over the study time, it was not possible to identify major changes in the global values found (*Figures 4*, *Figure 5* and *Figure 6*), i.e., the topics do not have a moment in the period studied in which a given topic stands out positively or negatively (possible exception for the topic CW and advantages). This result leads us to believe that the choice of topics was really representative of what is studied in the area to see that the trend of increase, or decrease, was very slow in 10 years of research. Next, in the following topics, we present the results of the review that allow us to characterize the process, uses, functions, advantages and disadvantages of CWs, show a classification of CWS according to the type of flow, discuss the general design conditions as well as the sizing, configuration and water transport system in CWs. Aspects of the vegetation and substrate of CWs are also presented. Like any review of this scope, the final form of presentation is, of course, arbitrary, and is the author's choice. However, the idea is to maintain coherence with the topics researched and to produce a text that serves as a reference work and basis for studies in the area of CW.

Conclusion

A literature review on completed wetlands was carried out for de last dacade (2013-2010). It was found that: (1) the lowest percentage of books was in the topics Constructed Wetlands and Characteristics; as well as (2) constructed Wetlands and process characteristics and the highest percentage was 2.8% in the topic Constructed Wetlands and configuration water conveying system. Among the topics researched, the

most studied was Constructed wetlands and uses, indicating that the search for applications for CWs was the main interest of researchers in the last decade. Analysing of the results for this topic it can be observed that these uses refer mainly to the type of pollutant to be removed and the affluent to be treated, relating to the type and configurations of the CW. The topics CW and Characteristics, CW and sizing, CW and functions, and CW and process characteristics presented extremely similar results in terms of percentage of publications. This shows that these topics, apparently, arouse the same interest of the scientific community. The topic CW and vegetation presented a median value among the topics studied. The topics CW and classification, CW and substrate, CW and microorganisms and CW and design criteria were the topics with less frequency of interest. Even though, the topics CW and water conveying system, CW and microbiota and CW and configuration water conveying system (WCS) presented extremely low number of publications in relation to the total number of studies. Thus, we can consider that these are topics that have been little studied on the subject, with the exception, perhaps, of the topic CW and microbiota, which may have been "included" in the topic of microorganisms. It was not possible to detect that the topics surveyed varied widely, indicating an increase or decrease in interest, over the review period (10 years), indicating that the topics chosen tend to continue to be of interest in future research.

Acknowledgement

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Conflict of interest

The authors confirm that there is no conflict of interest involve with any parties in this research study.

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