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Review

Bibliometric Analysis of Constructed Wetlands with Ornamental Flowering Plants: The Importance of Green Technology

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Abstract: The use of constructed wetlands (CWs) for wastewater treatment has earned high interest around the world. However, innovations to improve its removal efficiency and adoption have been suggested in the last decades. For instance, the use of ornamental flowering plants (OFP), which make wetland treatment systems more aesthetic and is an option for the production of commercial flowers while the water is cleansed. The objectives of this study were to identify through a bibliometric analysis (2000–2022) the main OFP that have been used in CWs and their functionality as phytoremediators (removal effects), as well as the authors, collaborations, main investigations, and the countries where such investigations have been carried out. To this respect, 10,254 studies on CWs were identified. The United States and China were the leading countries in the use of this eco-technology. Subsequently, regarding the use of OFP, the analysis revealed 92 studies on this matter in which Mexico has three researchers who lead the use of OFP in CWs (almost 40% of publications of CWs with OFP), where the main species studied include *Canna hybrids*, *Zantedeschia aethiopica*, *Strelitzia reginae*, *Iris species*, *Spathiphyllum* sp., and *Anturium* sp. These species may remove between 30–90% of pollutants of organic compounds, 30–70% of heavy metals and drugs, and about 99.9% of pathogens. Thus, this study may help researchers to identify OFP for new CWs design, and to know new future research directionsand collaboration approaches in this area using multipurpose alternatives like those of CWs with OFP. More research can still be carried out on the use of CWs with OFP in temperate climates, as well as evaluating the influence of different substrates and water flow on the growth of these plants.

Keywords: bibliometric study; ornamental plants; treatment wetlands; wastewater

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Citation: Marín-Muñiz, J.L.; Zitácuaro-Contreras, I.; Ortega-Pineda, G.; Álvarez-Hernández, L.M.; Martínez-Aguilar, K.E.; López-Roldán, A.; Zamora, S. Bibliometric Analysis of Constructed Wetlands with Ornamental Flowering Plants: The Importance of Green Technology. *Processes* **2023**, *11*, 1253. https://doi.org/10.3390/pr11041253

Academic Editors: Antoni Sánchez and Bipro R. Dhar

Received: 9 March 2023
Revised: 11 April 2023
Accepted: 15 April 2023
Published: 19 April 2023

1. Introduction

Constructed wetlands (CWs), also called treatment wetlands, are a nature-based solution that emulates natural wetlands processes (physical, chemical, and biological) in order to optimize and treat different types of wastewater. CWs consist of shallow cells or channels with an impermeable layer and structures to control the water level, flow direction, and hydraulic retention time. Substrate, microorganisms, and plants are the principal components of CWs [1–3].

According to the water flow, CWs can be classified as free water surface (shallow open waters, where plants are rooted in a soil layer on the bottom; these systems are the most similar to natural wetlands) or subsurface CWs (shallow watertight beds, filled with porous media, plants are rooted in the water-saturated beds, water is loaded in the inlet of the bed and therefore it flows below the surface in a horizontal or vertical pattern) [4,5].

Common substrates in CWs include mineral or plastic materials. In a recent study, nine substrates were evaluated (zeolite, anthracite, shale, vermiculite, ceramic filter material, gravel, steel slag, bio-ceramic and combination substrate-isopyknic layered anthracite, bio-ceramic and zeolite), corroborating this combination of substrates was the best scheme among nine materials. Zeolite was ideal for better nitrogen removal [6].

In other studies, some plastic substrates were used as filter material in CWs (plastic rings and PET residues) [7]. However, some microplastics could be released in certain time, being a later problem, depending on the intended use of the treated water [8,9].

The importance of CWs for wastewater treatment lies at the multiple types of wastewater they can clean. Some reviews regarding the use of CWs for removal of pesticides from agricultural runoff and drainage [10], industrial wastewater [11], emerging contaminants [12], acid mine drainage [13], leachate [14], or wastewaters to community or municipal level [15–20] have been developed, corroborating the functionality of CWs for the removal of pollutants.

In order to increase the removal efficiency of the ecotechnology, some innovations have been proposed in recent years. For instance, intermittent flows of water to be treated in wetlands (tidal flow CWs, partially saturated CWs, or integration of hydraulic or aeration machinery into constructed wetlands [21,22]). The combination of different types of wetlands or flows has also been an option to improve concentrations of pollutants through CWs (hybrid CWs) [23]).

Furthermore, about plants in CWs, the common vegetation of natural wetlands (*Cyperus papyrus*, *Phragmites australis*, *Typha* and *Scirpus* spp.) [24] that is also used in CWs has been changed or combined with terrestrial ornamental flowering plants (OFP) (herbaceous perennial ornamental plants including the use of species with different colored flowers), evaluating their adaptation to conditions of water saturation to be treated and their functionality as water purification [1,25,26].

OFP harvesting can be an economic entity for CW operators, providing social and economic benefits such as the improvement of system landscapes and a better habitat quality [25–27]. The economic potential using CWs with OFP has recently been analyzed [28]. To this respect, 21 species of phytoremediation plants were identified. *Anthurium andreanum* and *Zantedeschia aethiopica* stand out for their commercial value, reported in 2018 to be USD 272,875 and 30,318, respectively, at the national level.

In addition, several studies have reported that ornamental macrophytes species have an excellent capacity to enter flooding mechanisms, but each one had different physiological development. These conditions favor the removal of pollutants in different ways, demonstrating removals between 40–90% of organic and inorganic compounds [28–30]. Other studies have also demonstrated that the polyculture of OFP in CWs may enhance the release of root exudates, which might stimulate the uptake of nitrogen and phosphate compounds [31,32].

For this reason, recent studies have considered the use of OFP as the main vegetation for CWs. However, some questions remain unanswered: What are the main studies on CWs using OFP and who has carried them out? What is the main vegetation of OFP used in CWs and how many pollutants are removed? In order to answer these questions, this research was carried out and the main objective was to identify through a bibliometric analysis (BA) the use of CWs around the world (2000–2022), to know the main OFP that have been used in CWs and their functionality as phytoremediators (removal effects), as well as the authors, collaborations, main investigations, and the countries where such investigations have been carried out.

A bibliometric analysis (BA) is a scientific computer-assisted review methodology that can identify core research or authors, as well as their relationship, by covering all the publications related to a given topic or field [33]. For the BA, bibliographic tools such as DIMENSIONS are used and software tools such as VOSviewer, a computer program used for network analysis; it draws maps of scientific knowledge to show the interrelationships between literature [34].

Scientometric studies on CWs or climate change have previously been carried out. For example, Colares et al. [35] provided a BA regarding the use of floating CWs. Zhang et al. [36] reported a BA to summarize the impact between water management and CWs. Moondra et al. [37] explored a BA for the use of CWs in wastewater treatment. However, specific bibliometric studies to analyze the use of ornamental plants in CWs are scarce. Santos et al. [38] used a BA to create comparative trends of publications about global warming/climate emergency. Thus, this study may contribute more knowledge in this research area in which a selection of OFP is presented in order to complement the design of new CWs and help readers to establish new collaborations in the field.

2. Materials and Methods

The first step of this study was to know the types of names with which an ecological wastewater treatment system has been used in publications around the world from 2000 to 2023. This period of time was selected in the early 2000s when the amount of publications on this topic took an important standout and continuity as a research area in the face of wastewater contamination problems [2,18,39].

The procedure used to discover the name used for ecological wastewater treatment was to detect the number of publications using the term "constructed wetland", "artificial wetland", "treatment wetland", "wetland biofilter", "engineering wetland", "ecotechnology wetland" in the title and abstracts. This was performed byusing the DIMENSIONS program. This number of publications with the terms described were used to generate word clouds using the software WordArt [40].

Dimensionsisan integrated database that allows researchers to search and analyze grants, patents, clinical trials, policy documents, and publications (https://app.dimensions.ai/ (accessed on 10 February 2023)). This program has been described like a new scholarly search database that focuses on the broader set of use cases that academics now face. Compared to other databases, it has a free version that includes a searchable publications index and links to all the other different entities [41].

The second step was to identify the scientometric analysis; these were based on papers regarding the use of CWs around the world and collaborations about the topic in journals registered on the DIMENSIONS bibliometric database during the period 2000–2023, using the title and abstract codes "constructed wetlands" and other similar names ("constructed wetland", "CW", "CWs", "constructed wetlands", "artificial wetlands", "treatment wetlands"). For ornamental plant, other similar names were "ornamental plants"and"flowering plants". In addition, studies on the use of ornamental plants in CWs were consulted in the DIMENSIONS program. Search example: "Constructed wetland AND ornamental plants"; co-occurrence, and collaboration with countries and affiliations were also performed on the full search results, which were exported from DIMENSIONS to a CSV file.

The recovered manuscripts were properly organized using Microsoft Excel, while the maps were made with VOSviewer. Thanks to this program, it was possible to identify the different thematic areas, the journals indexed, the main studies, the countries, the main authors, and collaborations.

Once the main authors who have conducted research on the use of ornamental plants in CWS were identified with DIMENSIONS, the third step was to individually corroborate all the studies, not only on DIMENSIONS, but also on Google Scholar. Subsequently, they were sent by each of their authors individually via email and corroborated.

3. Results and Discussion

3.1. Importance of CWs as a Green Technology

Regarding the background of the use of CWs, it should be noted that subsurface CWs were first researched in Germany in 1954 by Dr. Seidel. In 1960, this was described as the "root method" by Dr. Kickuth [2,3,19]. Later on, they were called artificial wetlands [20], which, to date, is not used, as the word 'artificial'can be understood as something use-less or of little use. Figure 1 presents the word cloud generated for the different names using ecological wastewater treatment. Based on such a word cloud, the most employed concepts have been *Treatment wetlands* and *Constructed wetlands*, increasing over time in terms of occurrence in articles. However, other terms have been incorporated to a lesser extent such as *wetland biofilters* and *bioengineered wetlands* (Figure 1; [1–5]). These data showed coincidences regarding the fact that recent book publications are already titled as treatment wetlands [42–44].

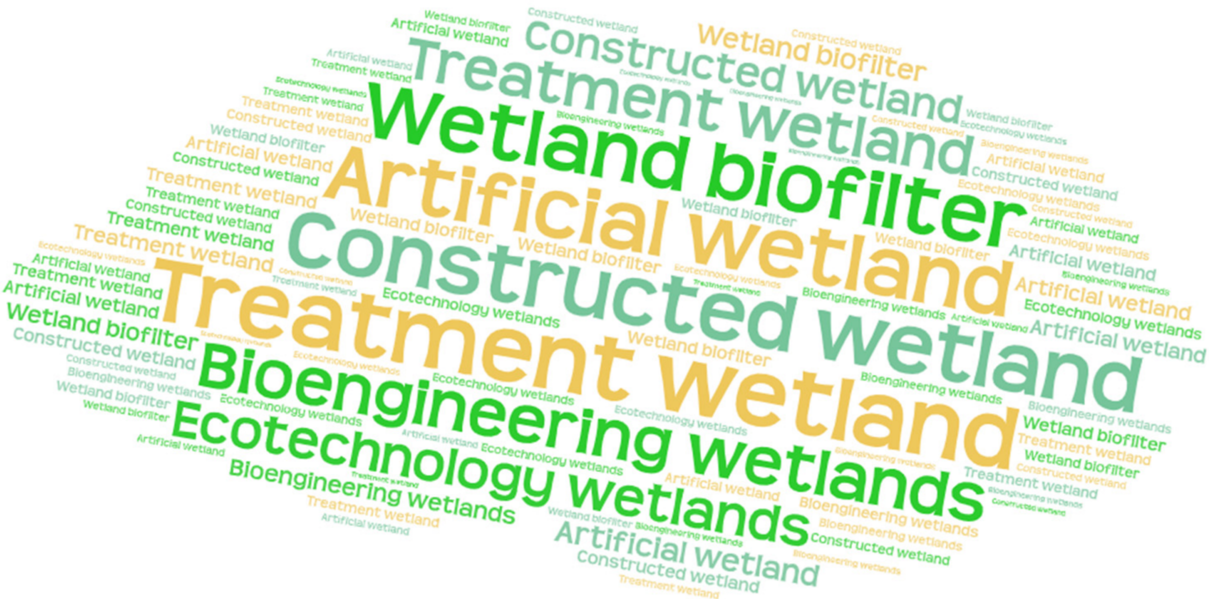

Figure 1. Word cloud of names used for wastewater treatment with ecological engineering systems.

On the other hand, recently, more attention has been paid to CWs as part of a circular economy in the rural and urban environments as these systems are a good fit for the new concept of sponge cities [2]. Many factors indicate that the future of rural and urban water systems is shifting towards solutions that are resource oriented, integrated, sustainable, distributed, and nature-based. The treatment of wastewater will be replaced by the production of goods, an optimized system like CWs will allow reaching multiple targets (wastewater treatment and water reuse, ornamental plant production, compost with plant biomass, bioelectricity generation, scenic landscaping), instead of having a separate infrastructure for every purpose [44–46].

Some authors, through the assessment of the sustainability (based on the development of a composite indicator embracing economic, environmental, and social issues) [47], and life cycle analysis studies using wastewater treatment like constructed wetlands, have identified that such systems combine low costs, high efficiencies in removal of pollutants (40–99%), and lower environmental impact (environment friendly) [48,49].

3.2. Use of CWs around the World and Collaborations in the Field

It has been described that CWs are widely recognized as efficient and cost-effective solutions to wastewater problems [1–3]. Such affirmation was confirmed with the analysis on the use of this technology around the world (Figure 2), in which a wide distribution of publications on the topic was detected in 89 countries. This demonstrates the importance that CWs have as a research area facing the problem of water pollution. Despite this, there is still a wastewater treatment deficit; only 39% of the global population has used a safely managed sanitation service [50].

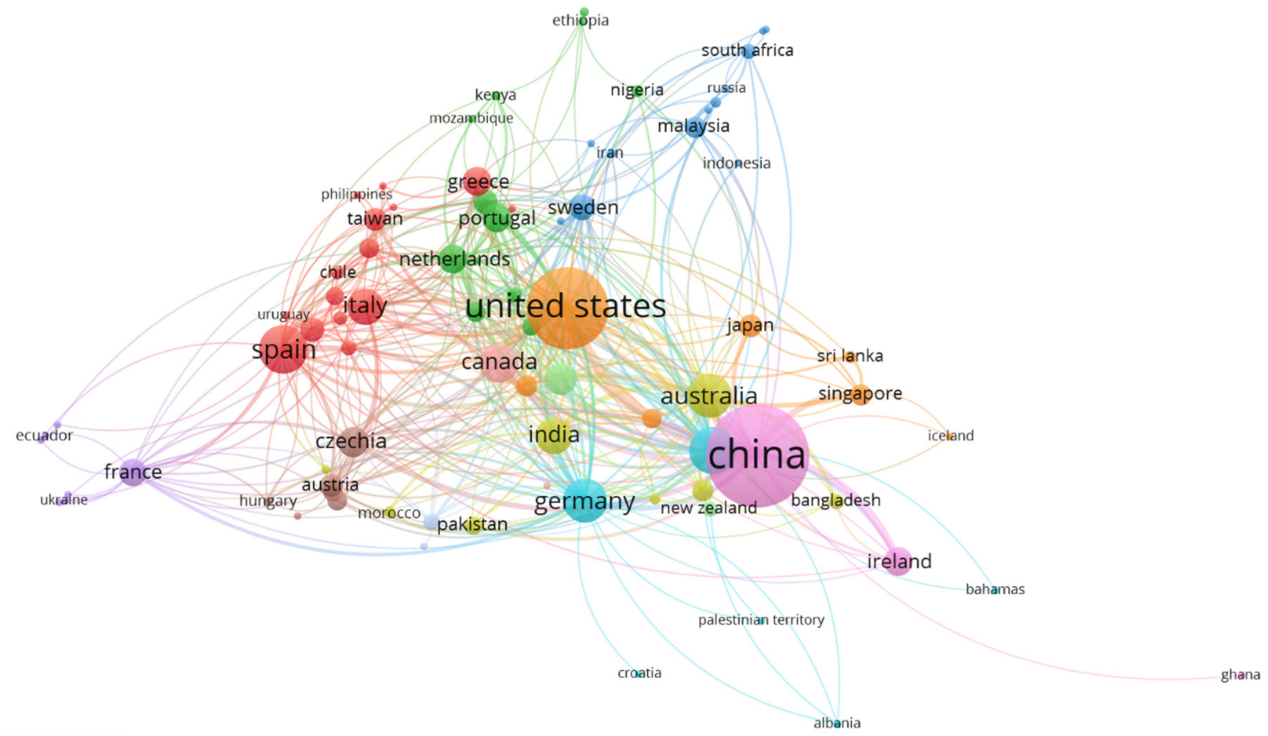

Figure 2. Publications on CWs by countries during 2000–2023 around the world.

In Figure 2, the largest circles represent the largest publications by country, where the United States and China are the main countries, leading with 6.9% and 4.4%, respectively, followed mainly by European countries. Regarding Mexico, it is already represented on the map with an extensive collaboration between publications from European, American, and Latin countries, but only representing 1%, which suggests it is a country that has just recently used CWs compared to countries like China and the USA.

The findings regarding the main countries where research on CWs is carried out is consistent with those reported by Zhao [51], who describes that China and the USA lead the new strategies with technical principles that include penetration, detention, storage, purification, usage, and drainage, where the CWs are key technical solutions for water purification. Reyes et al. [52] also identified China and the USA by means of a BA among the countries that had the most number of treatment wetlands, specifically for stormwater. Thus, greater efforts to replicate this alternative by other countries are pertinent. Some studies stress the need for integration among the water field actors to include and accept the use of CW technology in public policies without risk aversion [53].

Moreover, through bibliometric studies, the importance of ecotechnology in the face of water scarcity has been discussed [36], reporting that CWs focus on water management in three different ways: rainwater management, wastewater treatment, and ecological water purification. Furthermore, the influencing factors of CWs for water management, as well as their additional benefits are also discussed, which demonstrates that CWs must be designed and maintained in future research, and should be more involved in water management so that they may become sustainable through CWs.

The productivity by authors about the publications of CWs around the world was analyzed with the BA, and approximately 10,254 posts on CWs were found worldwide. The size of the circles on the map (Figure 3) is proportional to the number of articles that the author leads in that area, regardless of whether they are technical research or literature review texts. Furthermore, it is observed that the main authors according to the number of publications and citations include Jan Vymazal from Czech University of Life Science Prague, Czechia (110 publications; 9977 citations), Jian Zang of Shandong University of

Science and Technology, China (93; 3442), Joan García from Universitat Politécnica de Catalunya, Spain (77; 4286), and Hans Brix from Aarthus University, Denmark (64; 4262).

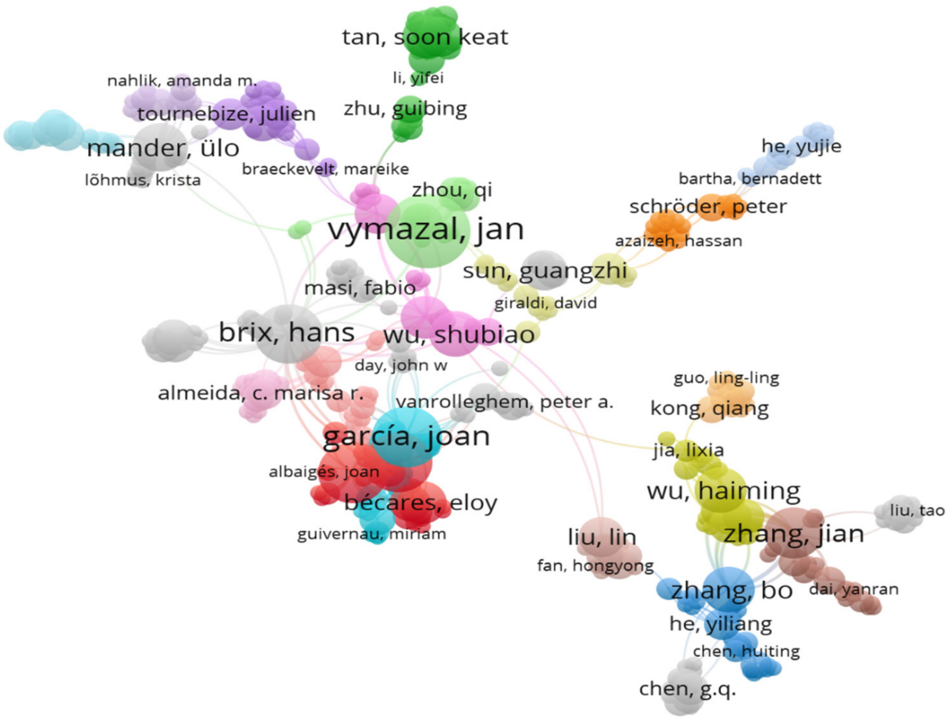

Figure 3. Researcher collaboration co-occurrence map on CWs studies during 2000–2023 around the world.

Although the detected authors are from geographically distant countries, the closeness between circles on the map indicates their intellectual relationship in terms of co-authorship in that area of research. The authors that are close to each of the main ones detected indicate mutual collaborations.

It should be noted that there is a paucity of comparative data with bibliometric studies on the general use of CWs. However, in a BA about the authors and institutions boarding topics on the relationship between water management and CWs, Zhang et al. [36] showed that in terms of the most productive authors according to the number of publications are M. Scholz, C.M. Cooper, and R. Kroeger. This refers to the fact that there is a great variety of scientists on CWs, but there is also a wide specialization of topics, which may include: agricultural, domestic, or industrial wastewater, regression models, greenhouse gases, circular economy, plant growth, clogging, different flows, and hybrid systems, among others.

3.3. CWs Using Ornamental Flowering Plants and Collaborations in the Topic

Once the use of CWs in the world was detected, a search regarding the use of ornamental plants during the treatment of wastewater by means of CWs was needed owing to the importance that this type of vegetation provides in the aesthetic appearance of ecotechnology, as an economic resource, and for its better adoption and appropriation.

Regarding the use of ornamental plants in subsurface flow constructed wetlands, the scientometric study on DIMENSIONS found 92 publications related to the use of ornamental plants in CWs during wastewater treatment. Figure 4 shows the countries with the highest number of publications on the topic, according to the size of the circles that represent each country. Mexico stands out with the highest number of publications (24.2%), followed by India (12%), China (11%), Brazil (8.8%), and the United States (7.7%).

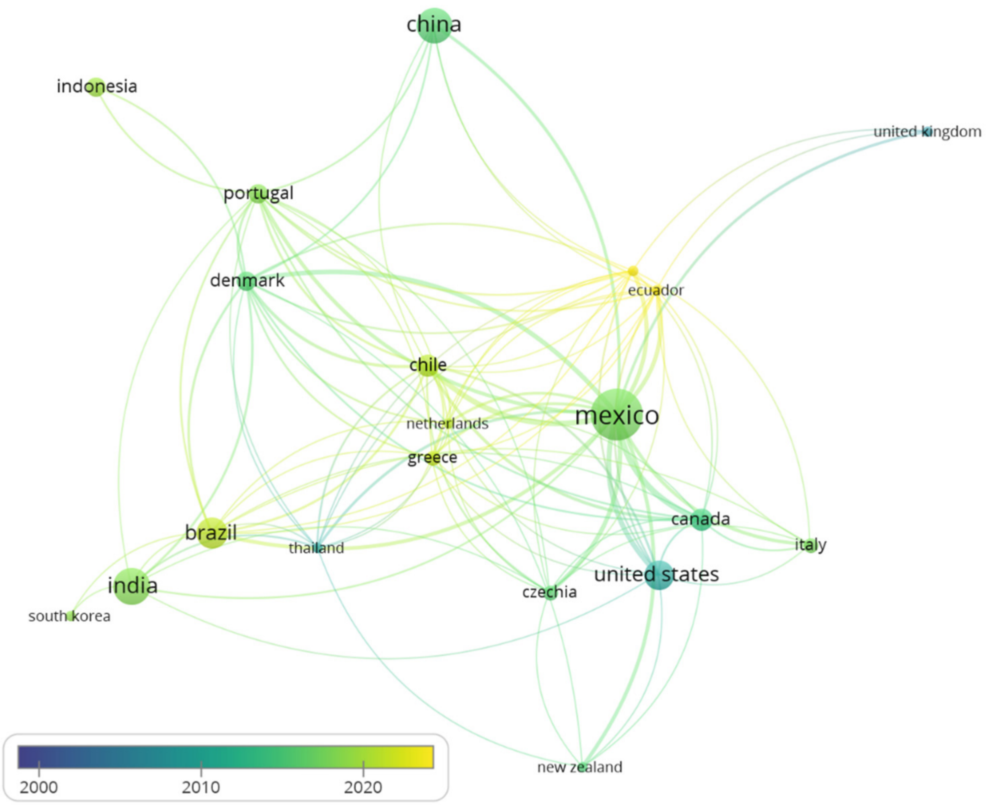

Figure 4. Network visualization of the main countries in the investigation on wastewater treatment with CWs and ornamental plants.

It should be noted that on this map, the color of the circles, on a scale from blue to yellow (2000–2023), indicates that although Mexico leads the largest publications on treatment wetlands using ornamental plants, those that began with this type of inclusion of plants were countries like the United States, Thailand, and the United Kingdom (blue tones). Later on, Mexico, and recently Chile and Brazil were as the most representative (yellow tones). The link between the circles (countries) indicates the co-authorship.

It is evident that there is cooperation between Mexico and all the countries on the map, however, there is a greater emphasis in relation to Latin American countries. For such region, Rodríguez-Domínguez et al. [53] showed that this area is a heterogeneous territory where CWs arean excellent option to solve the wastewater problems using a largevariety of OFP, and these vegetation can influence the interest or the impact of the technology either by beautification or integration in the place of establishment, which coincides with the fact that Mexico is one of those countries with wide use of CWs with OFP as found in this BA.

It is important to describe that countries with a large portion of land in the tropical and subtropical area such as Mexico, India, China, and Brazil have a greater biodiversity of vegetation species due to the prevailing climatic conditions. This has favored the greater use of variety of ornamental plants as an alternative treatment in CWs. However, more studies are needed both as monocultures or polycultures of ornamental plants as this favors diversity and a better removal in the system [30,54,55], as well as different designs of CWs that may reinforce what has been detected so far.

When the importance of Mexico as a leader in publications on wetlands constructed with ornamental plants was detected, the collaboration between the main authors in this area of research was analyzed. Three main authors stand out (Figure 5a): 1. Dr. Florentina Zurita, Centro Universitario de la Ciénega, University of Guadalajara, 2. Dr. José Luis Marín-Muñiz, El Colegio de Veracruz, 3. Dr. Luis Carlos Sandoval Herazo, National Technology of Mexico/Technological Institute of Misantla. It is worth mentioning that each of these authors has built extensive networks of independent collaboration, as well as joint work.

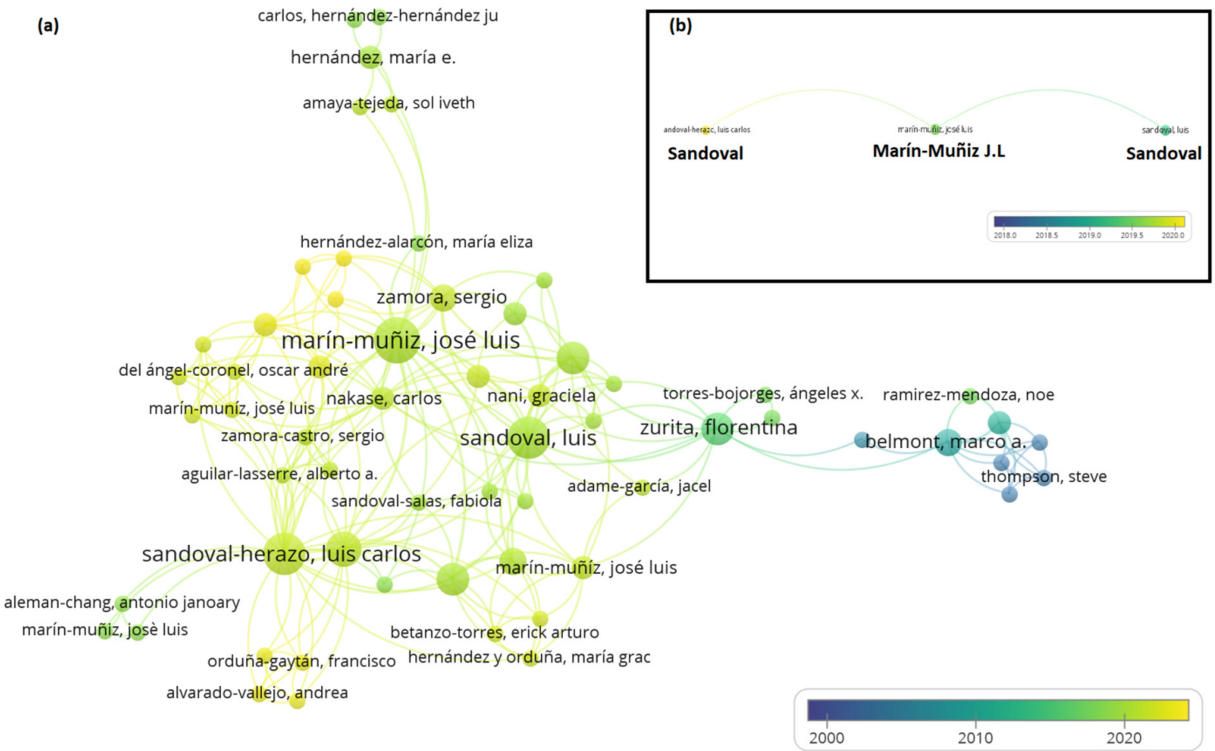

Figure 5. Researcher collaboration co-occurrence map regarding studies on CWs with ornamental plants during 2000–2023 (**a**), and during 2018–2023 (**b**).

When the analysis of collaborations between the authors who carry out research on ornamental plants in CWs was reduced from the period 2018 to 2023 (Figure 5b), that is, to detect in recent years who continue to focus on such studies, the collaboration of projects between the researchers Sandoval and Marín-Muñiz stand out as the main ones, in view of which further research on the topic is pertinent, considering different study regions, climate, diversity of plant species, and greater national and international collaborations to achieve greater details of the effect of ornamental plants in the wastewater treatment with wetlands.

A recent study [39] also identified these aforementioned three authors as leaders in the use of ornamental plants in CWs with Scopus data. The study pointed out that ornamental plants in CWs have leaned towards Canna, Iris, Heliconia and Zantedeschia in the last two decades, however, it did not highlight the works addressed by each of the leading authors. Table 1 describes the main findings of their studies, including the ornamental plants used, the removal percentages according to the organic loading rate based on biological oxygen demand (BOD_5), chemical oxygen demand (COD), total nitrogen (TN) or total phosphorous (TP), ammonium ($N\text{-}NH_4$), phosphates ($P\text{-}PO_4$), total suspended solids (TSS), coliforms (CF), or *Escherichia coli* (*E. coli*), and the citations for every study.

Table 1 also shows the ornamental plants used, and a total of 25 publications were detected by Zurita's research, three of them in collaboration with Sandoval and three more collaborating in a triad with Marín-Muñiz and Sandoval. On the other hand, Marín-Muñiz's research presents a total of 23 publications, three of them in collaboration in a triad and 11 of them in joint work with Sandoval. For his part, Sandoval presents a total of 21 studies, three of them in triad with Marín-Muñiz and Zurita, three more in which he only collaborates with Zurita, and 11 in collaboration with Marín-Muñiz.

Some deficiencies that could be mentioned for the three researchers in terms of their studies is that their investigations began at the microcosm level or on a pilot scale. It is until recent years that they already apply the design factors learned on a large scale to favor high efficiencies of removal of contaminants in CWs. It is also observed that there is a lack of greater international collaboration comparing different plant species, as well as design conditions according to climatic conditions.

In column 5 of Table 1, the number of times the publication has been cited (based on statistics from Google Scholar) is showed, and the top 3 for every author and collaboration is reported in bold. The most highly cited reference was a paper written by F. Zurita, cited 358 times. In these research topics, this paper was one of the first in Mexico and represents a wetland treatment study treating domestic wastewater with commercial flowers in vertical and horizontal conditions. This was followed by a review of CWs using OFP co-authored with L.C. Sandoval and J.L. Marín-Muñiz (cited 107 times). The third study with more citations was on hybrid CWs by F. Zurita (74 times). The top 4 and 5 were with the same number of citations (65 every), one written by F. Zurita regarding CWs with OFP treating domestic wastewater on a laboratory scale. The other were co-authored between J.L Marín-Muñiz and L.C. Sandoval addressing the issue of the OFP used in CWs with different substrates as filter.

Data reported by the authors (Table 1) revealed that CWs using OFP are efficient in the removal of pollutants as the ranges oscillated between 60–98% for BOD_5 and COD, TN and TP 40–95%, pathogens 62–99%, and nitrogen and phosphorous compounds 30–80%. In addition, arsenic was observed in some studies by Zurita, with removals between 79 and 91%, and drugs like carbamazepine (36–63%) and ibuprofen (71%) were reduced in CWs with OFP. These data provided part of the answer to the second question that guided this study.

The use of plants in CWs for pollutant removal has been applied in different countries around the world (Figure 2). A comparison by Sandoval et al. [26] on the average removal of pollutants with CWs using OFP and typical plants of natural wetlands showed that the removal percentages were similar across all plant genera for TSS (62–86%; n = 26; p = 0.236), COD (41–72%; n = 49), BOD_5 (51–82%; n = 38), TP (49–66%; n = 44), NH_4-N (62–82%; n = 24), NO_3-N (63–93%; n = 34), and TN (48–72%; n = 32). Hernández et al. [56] compared removals of nitrogen in CWs with the OFP *Zantedeschia* a. vs. typical plants of wetlands (*Typha* sp., *Cyperus papyrus*) corroborating similar removals (40–45 mg L^{-1}) without finding differences. This highlights the importance, in terms of phytoremediation, that OFPs have added to their aesthetic and commercial value, as previously mentioned.

Some treatment mechanisms for pollutant and pathogen in CWs include sedimentation and filtration (for the removal of particulate organic matter, biological degradation), ammonification, nitrification, denitrification and plant uptake by nitrogen compounds, adsorption–precipitation reactions and plant uptake for phosphorus, sedimentation, filtration, predation for pathogens and sedimentation, filtration, adsorption, ion exchange, and precipitation and biological degradation through plants and microbiological metabolism for heavy metal removals [21–23,29–31].

Water in CWs is the vehicle for the entry and distribution of nutrients within the system, as well as a support for plant material and establishment of bacterial colonies. Its main function is to provide the necessary nutrients for the development and metabolism of bacteria, which has an impact on the processes of removal, biodegradation, and biotransformation of the substances that enter it [57].

The removal of pollutants showed are similar to those used in CWs with typical plants of natural wetlands [26–28], and similar to removals by conventional wastewater treatments [58,59], but without the need for electrical requirements or specialized labor. The main requirements in CWs include vegetation harvesting, flow control, clogging monitoring, and proper management of pretreatment systems.

Table 1. Classification of publications regarding CWs using ornamental plants according to the three researchers detected with the co-occurrence map by VOSviewer (quantity of individual publications + collaborations among them).

Study Title	Study Type	Ornamental Plants Used	Pollutant Removal (%)	Citation	Reference
Florentina Zurita Martínez (Total sum of studies: 25)					
1. Performance of laboratory-scale wetlands planted with tropical ornamental plants to treat domestic wastewater	Experi-mental	*Zantedeschia aethiopica*, *Anthurium andreanum*, *Strelitzia reginae*, *Hemerocallis dumortieri*, *Canna hybrids*	COD > 75, BOD_5 and TN > 70, TP > 66	65	[60]
2. Stress detection by laser-induced fluorescence in *Zantedeschia aethiopica* planted in subsurface-flow treatment wetlands	Experi-mental	*Zantedeschia aethiopica*	COD: 78, BOD_5: 80, TN: 49, TP: 41	34	[61]
3. Treatment of domestic wastewater and production of commercial flowers in vertical and horizontal subsurface-flow constructed wetlands	Experi-mental	*Zantedeschia aethiopica*, *Strelitzia reginae*, *Anturium andreanum*, *Agapanthus africanus*	COD and BOD_5: >80, TP >50	358	[62]
4. Seeking a way to promote the use of constructed wetlands for domestic wastewater treatment in developing countries	Experi-mental	*Zantedeschia aethiopica*, *Anthurium andreanum*, *Strelitzia reginae*, *Hemerocallis dumortieri*, *Canna hybrids*	COD: 80, BOD_5: 78, TN: 73, TP: 50	55	[63]
5. Municipal wastewater treatment in Mexico: current status and opportunities for employing ecological treatment systems	Review	X	X	48	[64]
6. Preliminary study on the potential of arsenic removal by subsurface flow constructed mesocosms	Experi-mental	*Zantedeschia aethiopica*, *Anemopsis californica*	Arsénic: 79–91	40	[65]
7. Comparative study of three two-stage hybrid ecological wastewater treatment systems for producing high nutrient, reclaimed water for irrigation reuse in developing countries	Experi-mental	*Zantedeschia aethiopica*, *Strelitzia reginae*, *Canna indica*	TN: 20–57, TP: 0, *E. coli*: 99.9	74	[66]
8. Wastewater disinfection in three hybrid constructed wetlands	Experi-mental	*Zantedeschia aethiopica*, *Strelitzia reginae*	CF/*E. coli.*: *99.93–99.99*	16	[67]
9. Performance of three pilot-scale hybrid constructed wetlands for total coliforms and *Escherichia coli* removal from primary effluent—a 2-year study in a subtropical climate	Experi-mental	*Zantedeschia aethiopica*, *Strelitzia reginae*, *Canna indica*	*E. coli*: 80–99.9	35	[68]

Study Title	Study Type	Ornamental Plants Used	Pollutant Removal (%)	Citation	Reference
10. Efficiency of three hybrid wetland systems for carbamazepina removal	Experi-mental	*Zantedeschia aethiopica*, *Iris sibirica*, *Thypha latifolia*, *Strelitzia r.*	Carbamazepine: 36–60	9	[69]
11. Carbamazepine removal in three pilot-scale hybrid wetlands planted with ornamental species	Experi-mental	*Thypha latifolia*, *Iris sibirica*, *Zantedeschia aethiopica*	Carbamazepine: 59–63	50	[70]
12. Evaluation of three pilot-scale hybrid wetland systems for nitrogen removal.	Experi-mental	*Zantedeschia aethiopica*, *Canna indica*	N-NH_4: 84, TN: 58	18	[71]
13. Nitrogen removal in pilot-scale partially saturated vertical wetlands with and without an internal source of carbon	Experi-mental	*Strelitzia reginae*	TN: 72–73	35	[72]
14. Addition of Corn Cob in the Free Drainage Zone of Partially Saturated Vertical Wetlands Planted with *I. sibirica* for Total Nitrogen Removal—A Pilot-Scale Study	Experi-mental	*Iris sibirica*	BOD_5: 91–92, COD: 67,−75, TN: 66–68	1	[73]
15. Changes in the nitrification-denitrification capacity of pilot-scale partially saturated vertical flow wetlands (with corncob in the free-drainage zone) after two years of operation	Experi-mental	*Iris sibirica*	BOD_5: 96, COD: 84, TN: 51–53	3	[74]
16. Capacity of two ornamental species (*Iris sibirica* and *Zantedeschia aethiopica*) to take up, translocate, and accumulate carbamazepine under hydroponic conditions	Experi-mental	*Iris sibirica*, *Zantedeschia aethiopica*	X	8	[75]
17. Resistance evaluation of *Canna indica*, *Cyperus papyrus*, *Iris sibrica*, and *Typha latifolia* to phytotoxic charafteristics of dilutes tequila vinasses in wetland microcosms	Experi-mental	*Canna indica*, *Cyperus papyrus*, *Iris sibrica*, *Typha latifolia*	X	1	[76]
18. Method for treating domestic wastewater through the use of ornamental plants	Experi-mental (patent)	*Anthurium andreanum*, *Hemerocallis dumortieri*, *iris laevigata*, *pseudacorus*, *Lysichitum americanum*, *camtschatcense*, *Agapantus umbellatus/africanus*	COD: 75, BOD_5: 70, TP: 66	2	[77]
19. Ornamental plants	Book review	X	X	40	[44]

Study Title	Study Type	Ornamental Plants Used	Pollutant Removal (%)	Citation	Reference
		Luis Carlos Sandoval Herazo (21)			
1. Effect of *Canna hybrids* in partially saturated constructed wetlands for swine water treatments	Experi-mental	*Canna hybrids*	COD: 66, TP: 23, CF: 62	9	[78]
2. Influence of light intensity on growth and flowering ornamental plants in constructed wetlands	Experi-mental	*Lavandula* sp., *Anthurium* sp., *Zantedeschia aethiopica*, *Spathiphyllum wallisii*	COD: 60–85,	0	[79]
3. Evaluation of the performance of vertical partially saturated constructed wetlands for sewage treatment swine	Experi-mental	*Canna hybrids*, *Iris germánica*	COD: 90, N-NH_4: 78	11	[80]
4. Plant biomass production in constructed wetlands treating swine wastewater in tropical climates	Experi-mental	*Typha latifolia*, *Canna hybrids*	COD: 84, TN: 94, TP: 82	4	[81]
		José Luis Marín-Muñiz (23)			
1. Removal of wastewater pollutant in artificial wetlands implemented in Actopan, Veracruz, Mexico	Experi-mental	*Typha* spp.	BOD_5: 80, N-NO_3: 60	14	[82]
2. Constructed wetlands in Mexico for wastewater treatment, ornamental plant production, and water reuse	Review	X	X	29	[83]
3. Influence of different porous media and ornamental vegetation on wastewater pollutant removal in vertical subsurface flow wetland microcosms	Experi-mental	*Zantedeschia aethiopica*, *Alpinia purpurata*	BOD_5: 80, N-NO_3: 40, P-PO_4: 40	23	[84]
4. Greenhouse Gas Emissions and Treatment Performance in Constructed Wetlands with Ornamental Plants: Case Studies in Veracruz, Mexico	Experi-mental	*Alpinia p.*, *Typha* sp., *Hedychium coronarium*, *Canna hybrids*, *Anturium a.*, *Lillium* sp., *Zantedeschia a.*, *Cyperus papyrus/alternifolius*	N-NH_4: 50, P-PO_4: 61–81, TN: 47	2	[85]
5. Plant growth and pollutant removal from wastewater in domiciliary constructed wetland microcosms with monoculture and polyculture of tropical ornamental plants	Experi-mental	*Alpinia purpurata*, *Hedychium coronarium*, *Canna hybrids*	N-PO_4: 68–80, N-NH_4: 60–80	22	[54]
6. Evaluation of the growth of vegetation planted in artificial wetland: effect of planting position	Experi-mental	*Canna hybrids*, *Typha* sp., *Sphatyphylum wallisii*, *Heliconia* sp.	ND	1	[86]

Study Title	Study Type	Ornamental Plants Used	Pollutant Removal (%)	Citation	Reference
7. Ornamental vegetation used in phytoremediation and its environmental, economic and social potential	Review	X	X	1	[87]
8. Environmental conditions for the optimal development of ornamental and phytoremedial plants	Experi-mental	*Alpinia purpurata*, *Zingiber spectabile*	N-NH_4: 60, P-PO_4: 72	1	[88]
9. The circular economy as a proposal for the reuse of swine sewage	Experi-mental	*Canna hybrids*, *Cyperus alternifolius*	COD: 59, TN: 50, TP: 39	1	[89]
Collaborations between F. Zurita, L.C. Sandoval, and J.L Marín-Muñiz					
1. Influence of a new ornamental species (*Spathiphyllum blandum*) on the removal of COD, nitrogen, phosphorus and fecal coliforms: a mesocosm wetland study with pet and tezontle substrates	Experi-mental	*Spathiphyllum blandum*	COD: 78–81, P-PO_4: 51–53	8	[90]
2. Effect of *Spathiphyllum blandum* on the removal of ibuprofen and conventional pollutants from polluted river water, in fully saturated constructed wetlands at mesocosm level	Experi-mental	*Spathiphyllum blandum*	COD: 72, TN: 39, TP: 63, and 71 ibuprofen	6	[91]
3. Partially saturated vertical constructed wetlands and free-flow vertical constructed wetlands for pilot-scale municipal/swine wastewater treatment using *Heliconia latispatha*	Experi-mental	*Heliconia latispatha*	COD: 82- 93, TN: 58–1, TP: 37–60	1	[21]
Collaborations between F. Zurita and L.C. Sandoval					
1. Nitrogen removal from domestic wastewater and the development of tropical ornamental plants in partially saturated mesocosm-scale constructed wetlands	Experi-mental	*Canna hybrids*, *Zantedeschia aethiopica*	COD: 58–97, TN: 65–95, TP: 82	13	[92]
2. Treatment of swine effluent mixed with domestic wastewater and vegetation development in monoculture and polyculture horizontal subsurface flow wetlands	Experi-mental	*Heliconia latispatha*, *Typha latifolia*, *Cyperus alternifolius*	TP: 44–63, TN: 64–68, COD: 68	2	[93]

Study Title	Study Type	Ornamental Plants Used	Pollutant Removal (%)	Citation	Reference
3. Development of *Heliconia latispatha* in constructed wetlands, for the treatment of swine/domestic wastewater in tropical climates, with PET as a substitute for the filter medium	Experi-mental	*Heliconia latispatha*	COD: 56, TP: 41, TSS: 55	2	[94]
Collaborations between Marín-Muñiz and Sandoval					
1. Effects of the use of ornamental plants and different substrates in the removal of wastewater pollutants through microcosms of constructed wetlands	Experi-mental	*Lavandula* sp., *Spathiphyllum wallisii*, *Zantedeschia aethiopica*	BOD_5: 58, P-PO_4: 38, N-NO_3: 40	65	[95]
2. Role of Wetland Plants and Use of Ornamental Flowering Plants in Constructed Wetlands for Wastewater Treatment: A Review	Review	X	X	107	[26]
3. Effect of ornamental plants, seasonality, and filter media material in fill-and-drain constructed wetlands treating rural community wastewater	Experi-mental	*Canna indica*, *Pontederia sagittata*, *Spathiphyllum wallisii*	COD: 82, N-NO_3: 65, P-PO_4: 68	21	[96]
4. Evaluation of wastewater treatment by microcosms of vertical subsurface wetlands in partially saturated conditions planted with ornamental plants and filled with mineral and plastic substrates	Experi-mental	*Anthurium* sp., *Zantedeschia aethiopica*, *Spathiphyllum wallisii*	BOD_5: 55–70, N-NO_3: 28–44, P-PO_4: 25–45	24	[97]
5. Impact of ornamental vegetation type and different substrate layers on pollutant removal in constructed wetland mesocosms treating rural community wastewater	Experi-mental	*Spathiphyllum wallisii*, *Hedychium coronarium*	COD: 75–92, N-NO_3: 41–45	22	[98]
6. Wastewater treatment by constructed wetland eco-technology: Influence of mineral and plastic materials as filter media and tropical ornamental plants	Experi-mental	*Canna indica*, *Cyperus papyrus*, *Hedychium coronarium*	COD: 91, N-NO_3: 41, P-PO_4: 54	32	[99]
7. Effects of Ornamental Plant Density and Mineral/Plastic Media on the Removal of Domestic Wastewater Pollutants by Home Wetlands Technology	Experi-mental	*Alpinia purpurata*, *Canna hybrids*, *Hedychium coronarium*	COD: 88, P-PO_4: 27, N-NO_3: 28	4	[100]

Study Title	Study Type	Ornamental Plants Used	Pollutant Removal (%)	Citation	Reference
8. Environmental, economic, and social potentialities ofornamental vegetation cultivated in constructed wetlands of Mexico	Review	X	X	7	[28]
9. Bioelectricity Generation and Production of Ornamental Plants in Vertical Partially Saturated Constructed Wetlands.	Experi-mental	*Zantedeschia aethiopica*, *Canna hybrids*	BOD_5: 98, P-PO_4: 25	4	[46]
10. Wetlands with ornamental plants, filled with plastic reused as sustainable wastewater treatment	Experi-mental	*Canna hybrids*, *Typha* sp.	COD: 90–95, TSS: 50–70	2	[101]
11. Treatment wetlands in Mexico for control of wastewater contaminants: a review of experiences during the last twenty-two years	Review	X	X	1	[3]

Note: X= does not include these data. In the citation column, the numbers in bold are the top 5 of the most cited publications.

In Figure 4 and Table 1, the first question that guided this study is answered.

The main plants used by the authors of the largest studies on CWs with OFP include *Canna hybrids* (19 cases), *Zantedeschia aethiopica* (18 cases), *Strelitzia reginae* (8 cases), *Iris* species (8 cases), *Spathiphyllum* species (7 cases), and *Anturium* sp. (6 cases). The use of OFP combines the function of phytoremediation and landscape benefits of CWs. There are several landscape plants, however, only a few are utilized in CWs. Thus, future research should be aimed at increasing the public participation in the maintenance of CWs for their adoption and appropriation, which may lead to longer lifespans and environmental services. These data provided the second part of the answer to the second question that guided this study.

This review shows the feasibility to produce flowers and treat water at the same time with nature-based systems and ecological engineering like that of CWs. Thus, future studies conducted in order to evaluate the health of the plants and to discover if they are suffering stress from the flooding due to wastewater conditions, pests, degree of toxicity at different concentrations of wastewater, competition between species, or uses of vegetation of wetlands, are necessary.

It is important to highlight that macrophytes are the main source of oxygen in CWs through a process that occurs in the rizosphera zone called radial oxygen loss [102]. The plant roots are the house of many microorganisms, because they provide a source of microbial attachment [24] and release an excretion of carbon that contributes to the denitrification process, which increases the removal of pollutants in anoxic or anaerobic conditions [26,27].

Another mechanism of the plants in CWs is the reduction in the velocity of water flow, sedimentation, decreased resuspension, and uptake of nutrients. In the case of roots and rhizomes in the sediment, the physical effects include stabilizing the sediment surface, less erosion, nutrient absorption, prevention of medium clogging (in subsurface conditions), and improved hydraulic conductivity. Aerial plant tissue favors the light attenuation (reduced growth of photosynthesis), reduced wind velocity, storage of nutrients, and aesthetic pleasing appearance of the system [24–27,103].

On the other hand, it is important to know that the removal of organic matter in CWs is mediated by several microbial reactions, where the products of some of these reactions include greenhouse gases such as methane, carbon dioxide, and nitrous oxide [104]. However, some studies have revealed that these emissions are minimum in CWs, and the amount of OFP does not influence the methane (4.5–11 g m^{-2} d^{-2}), nitrous oxide (0–2.3 g m^{-2} d^{-2}), and carbon dioxide emissions (0.4–7.4) as these are affected mainly by the substrate and water flow [56,85,105].

A study in tropical conditions comparing GHG emissions in CWs planted with *Zantedeschia aethiopica* compared with the zones near the inflow planted with *Typha* sp. and *Cyperus gigantus* (native plants of natural wetlands), showed higher methane emissions in the zone with OFP. The authors related this with differences in the radial oxygen loss between the plant species [85].

Other studies in constructed wetlands treating heavy metals or different leachates [106–109] have also demonstrated the feasibility of using this eco-technology. This demonstrates the multiple pollutants that CWs can clean, and therefore, the use of OFP detected in this study as phytoremediators should now be investigated for all of these types of contaminants.

4. Conclusions

This study initially presents a bibliometric analysis regarding the use of CWs around the world. To this respect, China and USA are the countries with the most significant use of this technology. Subsequently, the use of ornamental plants in CWS is identified. It is worth emphasizing that Mexico is the leader regarding the number of publications on this topic.

The findings suggest that the most used ornamental flowering plants in CWs are *Canna hybrids*, *Zantedeschia aethiopica*, *Strelitzia reginae*, *Iris species*, *Spathiphyllum* sp., and *Anturium* sp. This may serve as the basis for further research on CW systems, principally in tropical and subtropical areas where these plant species are present. This study also revealed that such OFP have an excellent function in water purification with removals of organic matter that oscillate between 30–90%, heavy metals and drugs 30–70%, or about 99.9% in elimination of pathogens.

In addition, the bibliometric analysis revealed the main authors that use this technology with OFP. This will serve to carry out future collaborations with them as well as to continue promoting the use of this sustainable technology and taking advantage of the circular economy. Thus, new studies conducted to evaluate the health of the plants and their artisanal uses are necessary, as well as the integration of decision makers, creators of public policies, and communities in the construction and operation of CWs, which is an emerging need.

Author Contributions: Conceptualization, J.L.M.-M.; methodology, S.Z.; software, I.Z.-C.; validation, S.Z. and J.L.M.-M.; formal analysis, S.Z.; investigation, J.L.M.-M.; resources, S.Z., L.M.Á.-H., K.E.M.-A. and A.L.-R.; data curation, S.Z.; writing—original draft preparation, J.L.M.-M.; writing—review and editing, I.Z.-C. and G.O.-P.; visualization, A.L.-R.; supervision, J.L.M.-M.; project administration, G.O.-P. and S.Z.; funding acquisition, A.L.-R., L.M.Á.-H. and K.E.M.-A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: The authors acknowledge researchers Florentina Zurita (Centro Universitario de la Ciénega, University of Guadalajara) and Luis Carlos Sandoval (National Technology of Mexico/Technological Institute of Misantla) by the corroboration of information.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kadlec, R.H.; Knight, R.L. *Treatment Wetlands*, 1st ed.; CRC Pess LLC: Boca Raton, FL, USA, 1996.
2. Vymazal, J. The historical development of constructed wetlands for wastewater treatment. *Land* **2022**, *11*, 174. [CrossRef]
3. Marín-Muñiz, J.L.; Sandoval, L.C.; López-Méndez, M.C.; Sandoval-Herazo, M.; Meléndez-Armenta, R.; González-Moreno, R.; Zamora, S. Treatment wetlands in Mexico for control of wastewater contaminants: A review of experiences during the last twenty-two years. *Processes* **2023**, *11*, 359. [CrossRef]
4. Masi, F.; Rizzo, A.; Regelsberger, M. The role of constructed wetlands in a new circular economy, resource oriented, and ecosystem services paradigm. *J. Environ. Manag.* **2018**, *216*, 275–284. [CrossRef]
5. Bakhshoodeh, R.; Alavi, N.; Oldham, C.; Santos, R.M.; Babaei, A.A.; Vymazal, J.; Paydary, P. Constructed wetlands for landfill leachate treatment: A review. *Ecol. Eng.* **2020**, *146*, 105725. [CrossRef]
6. Wu, J.; Xu, D.; He, J.; Wu, Z. Comprehensive evaluation of substrates in vertical flow constructed wetlands for domestic wastewater treatment. *Water Pract. Technol.* **2015**, *10*, 625–632. [CrossRef]
7. Zaboon, B.; Al-Abbawy, D.; Yaseen, D. Improving wastewater reclamation using constructed wetlands by artificial plastic biofilm carriers. *J. Ecol. Eng.* **2022**, *23*, 241–253. [CrossRef]
8. Bakhshoodeh, R.; Santos, R.M. Comparative bibliometric trends of microplastics and perfluoroalkyl and polyfluoroalkyl substances: How these hot environmental remediation research topics developed over time. *RSC Adv.* **2022**, *12*, 4973–4987. [CrossRef]
9. Bydalek, F.; Ifayemi, D.; Reynolds, L.; Barden, R.; Kasprzyk-Hordern, B.; Wenk, J. Microplastic dynamics in a free water surface constructed wetland. *Sci. Total Environ.* **2023**, *858*, 160113. [CrossRef]
10. Vymazal, J.; Březinová, T. The use of constructed wetlands for removal of pesticides from agricultural runoff and drainage: A review. *Environ. Int.* **2015**, *75*, 11–20. [CrossRef]
11. Vymazal, J. Constructed wetlands for treatment of industrial wastewaters: A review. *Ecol. Eng.* **2014**, *73*, 724–751. [CrossRef]
12. Sánchez, M.; Ruiz, I.; Soto, M. The potential of constructed wetland systems and photodegradation processes for the removal of emerging contaminants-a review. *Environments* **2022**, *9*, 116. [CrossRef]
13. Pat-Espadas, A.; Loredo, R.; Amabilis-Sosa, L.; Gómez, G.; Vidal, G. Review of constructed wetlands for acid mine drainage treatment. *Water* **2018**, *10*, 1685. [CrossRef]
14. Bakhshoodeh, R.; Alavi, N.; Majlesi, M.; Paydary, P. Compost leachate treatment by a pilot-scale subsurface horizontal flow constructed wetland. *Ecol. Eng.* **2017**, *105*, 7–14. [CrossRef]
15. Morales, G.; López, D.; Vera, I.; Vidal, G. Constructed wetlands with ornamental plants for removal of organic matter and nutrients contained in sewage. *Theoria* **2013**, *22*, 3346.
16. Machado, A.I.; Beretta, M.; Fragoso, R.D.A.; Duarte, E.D.C.N.F.D.A. Overview of the state of the art of constructed wetlands for decentralized wastewater management in Brazil. *J. Environ. Manag.* **2017**, *187*, 560–570. [CrossRef]
17. Vazquez, A.M.; Samudio-Segrero, A.; Nakayama, H.D.; Cantero-García, I. Sub-surface flow constructed wetland for the treatment of sewage generated in a municipal park. *Global J. Environ. Sci. Manag.* **2023**, *9*, 545–558. [CrossRef]
18. García-García, P.L.; Ruelas-Monjardín, L.; Marín-Muñíz, J.L. Constructed wetlands: A solution to water quality issues in Mexico? *Water Policy* **2016**, *18*, 654–669. [CrossRef]
19. Hernández, M.E. Ecological engineering for controlling water pollution in Latin America. In *Ecological Dimensions for Sustainable Socio Economic Development*; Yañez-Arancibia, A., Yáñez-Arancibia, A., Dávalos-Sotelo, R., Day, J.W., Reyes, E., Eds.; WIT Press: Southampton, UK, 2013.
20. Shutes, R.B.E. Atificial wetlands and water quality improvement. *Environ. Int.* **2001**, *26*, 441–447. [CrossRef]
21. Fernández, J.A.F.; Martínez-Resédiz, G.; Zurita, F.; Marín-Muñiz, J.L.; Méndez, M.C.L.; Zamora, S.; Sandoval Herazo, L.C. Partially saturated vertical constructed wetlands and free-flow vertical constructed wetlands for pilot-scale municipal-swine wastewater treatment using *Heliconia latispatha*. *Water* **2022**, *14*, 3860. [CrossRef]
22. Borkar, R.P.; Mahatme, P.S. Tidal flow constructed wetland: An overview. *Res. Inventory Int. J. Eng. Sci.* **2015**, *5*, 31–34.
23. Abbasi, H.; Xie, J.; Hussain, S.; Lu, X. Nutrient removal in hybrid constructed wetlands: Spatial-seasonal variation and the effect of vegetation. *Water Sci. Technol.* **2019**, *79*, 1985–1994. [CrossRef] [PubMed]
24. Vymazal, J. Plants used in constructed wetlands with horizontal subsurface flow: A review. *Hydrobiologia* **2011**, *20*, 133–156. [CrossRef]
25. Hernández, M.E. Humedales ornamentales con participación comunitaria para el saneamiento de aguas municipales en México. *Rinderesu* **2016**, *1*, 1–12.
26. Sandoval, L.; Zamora-Castro, S.A.; Vidal-Álvarez, M.; Marín-Muñiz, J.L. Role of Wetland Plants and Use of Ornamental Flowering Plants in Constructed Wetlands for Wastewater Treatment: A Review. *Appl. Sci.* **2019**, *9*, 685. [CrossRef]
27. Lara-Acosta, M.; Lango-Reynoso, F.; Castañeda-Chávez, M. Use of tropical macrophytes in wastewater treatment. *Agroproductividad* **2022**, *15*, 131–140. [CrossRef]
28. Zitácuaro-Contreras, I.; Vidal-ÁLvarez, M.; Hernández y Orduña, M.; Zamora-Castro, S.; Betanzo-Torres, E.; Marín-Muñiz, J.; Sandoval-Herazo, L. Environmental, economic, and social potentialities of ornamental vegetation cultivated in constructed wetlands of Mexico. *Sustainability* **2021**, *13*, 6267. [CrossRef]
29. Vymazal, J. *The Role of Natural and Constructed Wetlands in Nutrient Cycling and Retention on the Landscape*; Springer: New York, NY, USA, 2015; p. 326. [CrossRef]

30. Karathanasis, A.D.; Potter, C.L.; Coyne, M.S. Vegetation effects on fecal bacteria, BOD, and suspended solid removal in constructed wetlands treating domestic wastewater. *Ecol. Eng.* **2003**, *20*, 157–169. [CrossRef]
31. Wu, F.Y.; Chung, A.K.; Tam, A.K.; Wong, M.H. Root exudates of wetland plants influenced by nutrient status and types of plant cultivation. *Int. J. Phytoremed.* **2012**, *14*, 543–553. [CrossRef]
32. Canarini, A.; Kaiser, C.; Merchant, A.; Richter, A.; Wanek, W. Root exudation of primary metabolites: Mechanisms and their roles in plant responses to environmental stimuli. *Front. Plant Sci.* **2019**, *10*, 157. [CrossRef]
33. Nicolaisen, J. Bibliometrics and Citation Analysis: From the Science Citation Index to Cybermetrics. *J. Am. Soc. Inf. Sci. Tecnol.* **2010**, *61*, 205–207. [CrossRef]
34. Van, E.J.; Waltman, L. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics* **2010**, *84*, 523–538. [CrossRef]
35. Colares, G.; Dell'Osbel, N.; Wiesel, P.; Oliveira, G.; Lemos, P.; Silva, F.; Lutterbeck, C.; Kist, L.; Machado, E. Floating treatment wetlands: A review and bibliometric analysis. *Sci. Total Environ.* **2020**, *714*, 136776. [CrossRef] [PubMed]
36. Zang, Y.; You, X.; Huang, S.; Wang, M.; Dong, J. Knowledge atlas on the relationship between water management and constructed wetlands-a bibliometric analysis based on citespace. *Sustainability* **2022**, *14*, 8288. [CrossRef]
37. Moondra, N.; Christian, R.; Jariwala, N. Bibliometric analysis of constructed wetlands in wastewater treatment. *Recent Trends Civil Eng.* **2020**, *77*, 1021–1028.
38. Santos, R.M.; Bakhshoodeh, R. Climate change/global warming/climate emergency versus general climate research: Comparative bibliometric trends of publications. *Heliyon* **2021**, *7*, e08219. [CrossRef]
39. García-Ávila, F.; Avilés-Añazco, A.; Cabello-Torres, R.; Guanuchi-Quito, A.; Cadme-Galabay, M.; Gutiérrez-Ortega, H.; Alvarez-Ochoa, R.; Zhindón-Arévalo, C. Application of ornamental plants in constructed wetlands for wastewater treatment: A scientometric analysis. *Case Stud. Chem. Environ. Eng.* **2023**, *7*, 100307. [CrossRef]
40. Nezhyva, L.; Palamar, S.; Marienko, M. Clouds of words as a didactic tool in literary education of primary school children. *CEUR Workshop Proc.* **2022**, *3085*, 381–393. Available online: https://ceur-ws.org/Vol-3085/paper29.pdf (accessed on 10 December 2022). [CrossRef]
41. Hook, D.; Porter, S.; Herzong, C. Dimensions: Building context for search and evaluation. *Front. Res. Metr. Anal.* **2018**, *3*, 23. [CrossRef]
42. Dotro, G.; Langergraber, G.; Molle, P.; Nivala, J.; Puigaget, J.; Stein, O.; Sperling, M. *Treatment Wetlands*; IWA: London, UK, 2017.
43. Kadlec, R.H.; Wallace, S.D. *Treatment Wetlands*, 2nd ed.; CRC Pess LLC: Boca Raton, FL, USA, 2009.
44. Alarcón, M.T.; Zurita, F.; Lara-Borrro, J.; Vidal, G. *Humedales de Tratamiento: Alternativa de Saneamiento de Aguas Residuales en América Latina*; Pontificia Universidad Javeriana: Bogotá, Colombia, 2018; Available online: https://cimav.repositorioinstitucional.mx/jspui/handle/1004/2022 (accessed on 20 January 2023). (In Spanish)
45. Brix, H.; Koottatep, T.; Fryd, O.; Laugesen, C. The flower and the butterfly constructed wetland system at Koh Phi Phi-system design and lesson learned during implementation and operation. *Ecol. Eng.* **2011**, *37*, 729–735. [CrossRef]
46. González-Moreno, H.; Marín-Muñiz, J.L.; Sánchez-DelaCruz, E.; Nakase, C.; Ángel-Coronel, O.; Reyes-Gonzalez, D.; Nava-Valente, N.; Sandoval-Herazo, L. Bioelectricity Generation and Production of Ornamental Plants in Vertical Partially Saturated Constructed Wetlands. *Water* **2021**, *13*, 143. [CrossRef]
47. Molinos-Senante, M.; Gómez, T.; Garrido-Baserba, M.; Caballero, R.; Sala-Garrido, R. Assessing the sustainability of small wastewater treatment systems: A composite indicator approach. *Sci. Total Environ.* **2014**, *497–498*, 607–617. [CrossRef]
48. Lutterbeck, C.; Kist, L.T.; Lopez, D.A.R.; Zerwes, F.V.; Machado, Ê.L. Life cycle assessment of integrated wastewater treatment systems with constructed wetlands in rural areas. *J. Clean. Prod.* **2017**, *148*, 527–536. [CrossRef]
49. López-Serrano, M.J.; Lakho, F.H.; Van Hulle, S.W.H.; Batlles-delaFuente, A. Life cycle cost assessment and economic analysis of a decentralized wastewater treatment to achieve water sustainability within the framework of circular economy. *Oeconomia Copernic.* **2023**, *14*, 103–133. [CrossRef]
50. Jean-Martin, B.; Buchauer, K.; Gambrill, M. *Wastewater Treatment and Reuse: A Guide to Help Small Towns Select Appropiate Options*; World Bank: Washington, DC, USA, 2022.
51. Zhao, Y.; Ji, B.; Liu, R.; Ren, B.; Wei, T. Constructed treatment wetland: Glance of development and future perspectives. *Water Cycle* **2020**, *1*, 104–112. [CrossRef]
52. Reyes, N.; Geronimo, F.; Guerra, H.; Kim, L. Bibliometric analysis and comprehensive review of stormwater treatment wetlands: Global research trends and existing knowledge gaps. *Sustainability* **2023**, *15*, 2332. [CrossRef]
53. Rodríguez-Domínguez, M.; Konnerup, D.; Brix, H.; Arias, C. Constructed wetlands in Latin America and the Caribbean: A review of experiences during the last decade. *Water* **2020**, *12*, 1744. [CrossRef]
54. Marín-Muñiz, J.L.; Hernández, M.E.; Gallegos-Pérez, M.P.; Amaya-Tejeda, S.I. Plant growth and pollutant removal from wastewater in domiciliary constructed wetland microcosms with monoculture and polyculture of tropical ornamental plants. *Ecol. Eng.* **2020**, *147*, 105658. [CrossRef]
55. Calheiros, C.S.C.; Bessa, V.S.; Mesquita, B.R.; Brix, H.; Rangel, A.O.S.S.; Castro, P.M.L. Constructed wetland with a polyculture of ornamental plants for wastewater treatment at a rural tourism facility. *Ecol. Eng.* **2015**, *79*, 1–7. [CrossRef]
56. Hernández, M.; Galindo-Zetina, M.; Hernández-Hernández, J.C. Greenhouse gas emissions and pollutant removal in treatment wetlands with ornamental plants under subtropical conditions. *Ecol. Eng.* **2018**, *114*, 88–95. [CrossRef]

57. Masoud, A.; Alfarra, A.; Sorlini, S. Constructed wetlands as a solution for sustainable sanitation: A comprehensive review on integrating climate change resilience and circular economy. *Water* **2022**, *14*, 3232. [CrossRef]
58. Restrepo, A.; Rodríguez, D.; Peñuela, G. Eficiencia de un reactor SBR para la remoción de la materia orgánica presente en el agua residual de una industria de teñido de flores. *Rev. Ion* **2021**, *34*, 47–59. (In Spanish) [CrossRef]
59. Pérez, J.; Aldana, G.; Rojano, R. Upflow anaerobic sludge blanket reactor (UASB) performance through sludge age load and kinetic coefficients. *Rev. Int. Cont. Amb.* **2016**, *32*, 281–291. [CrossRef]
60. Zurita, F.; de Anda, J.; Belmont, M.A. Performance of laboratory-scale wetlands planted with tropical ornamental plants to treat domestic wastewater. *Water Qual. Res. J. Can.* **2006**, *41*, 410–417. [CrossRef]
61. Zurita, F.; Belmont, M.A.; De Anda, J.; Cervantes-Martínez, J. Stress detection by laser-induced fluorescence in Zantedeschia aethiopica planted in subsurface-flow treatment wetlands. *Ecol. Eng.* **2018**, *33*, 110–118. [CrossRef]
62. Zurita, F.; De Anda, J.; Belmont, M.A. Treatment of domestic wastewater and production of comercial flowers in vertical and horizontal subsurface-flow constructed wetlands. *Ecol. Eng.* **2009**, *35*, 861–869. [CrossRef]
63. Zurita, F.; Belmont, M.A.; De Anda, J.; White, J.R. Seeking a way to promote the use of constructed wetlands for domestic wastewater treatment in developing countries. *Water Sci. Technol.* **2011**, *63*, 654–659. [CrossRef] [PubMed]
64. Zurita, F.; Roy, E.; White, J. Municipal wastewater treatment in Mexico: Current status and opportunities for employing ecological treatment systems. *Environ. Technol.* **2012**, *33*, 1151–1158. [CrossRef]
65. Zurita, F.; Del Toro-Sánchez, C.; Gitiérrez-Lomelí, M.; Ridriguez-Sahagún, A.; Castellanos-Hernández, O.; Ramírez-Martínez, G.; White, J. Preliminary study on the potential of arsenic removal by subsurface flow constructed mesocosms. *Ecol. Eng.* **2012**, *47*, 101–104. [CrossRef]
66. Zurita, F.; White, J.R. Comparative study of three two-stage hybrid ecological wastewater treatment systems for producing high nutrient, reclaimed water for irrigation reuse in developing countries. *Water* **2014**, *6*, 213–228. [CrossRef]
67. Zurita, F.; Rojas, D.; Carreón, A.; Gutiérrez-Lomelí, M. Wastewater disinfection in three hybrid constructed wetlands. *Interciencia* **2015**, *40*, 409–415. Available online: https://www.redalyc.org/articulo.oa?id=33938675008 (accessed on 6 January 2023).
68. Zurita, F.; Carreón-Álvarez, A. Performance of three pilot-scale hybrid constructed wetlands for total coliforms and Escherichia coli removal from primary effluent—A 2-year study in a subtropical climate. *J. Water Health* **2015**, *13*, 446–458. [CrossRef]
69. Tejeda, A.; López, Z.; Rojas, D.; Barrera, A.; Zurita, F. Eficiencia de tres sistemas de humedales híbridos para la remoción de carbamazepina. *Tecnol. Y Cienc. Del Agua.* **2015**, *6*, 19–31. Available online: https://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S2007-24222015000600019 (accessed on 4 May 2022). (In Spanish).
70. Tejeda, A.; Torres-Bojorges, Á.X.; Zurita, F. Carbamazepine removal in three pilot-scale hybrid wetlands planted with ornamental species. *Ecol. Eng.* **2017**, *98*, 410–417. [CrossRef]
71. Torres, A.; Hernández, N.; Fausto, A.; Zurota, F. Evaluación de tres sistemas de humedales híbridos a escala piloto para la remoción de nitrógeno. *Rev. Int. Cont. Amb.* **2017**, *33*, 37–47. (In Spanish) [CrossRef]
72. Martínez, N.; Tejeda, A.; Del Toro, A.; Sánchez, M.; Zurita, F. Nitrogen removal in pilot-scale partially saturated vertical wetlands with and without and internal source of carbon. *Sci. Total Environ.* **2018**, *645*, 524–532. [CrossRef]
73. Del Toro, A.; Tejeda, A.; Zurita, F. Addition of corn cob in the free drainage zone of partially saturated vertical wetlands planted with *I. sibirica* for total nitrogen removal—A pilot-scale study. *Water* **2019**, *11*, 2151. [CrossRef]
74. Del Toro Farías, A.; Zurita Martínez, F. Changes in the nitrification-denitrification capacity of pilot-scale partially saturated vertical flow wetlands (with corncob in the free-drainage zone) after two years of operation. *Int. J. Phytoremediation* **2021**, *23*, 829–836. [CrossRef]
75. Tejeda, A.; Zurita, F. Capacity of two ornamental species (*Iris sibirica* and *Zantedeschia aethiopica*) to take up, translocate, and accumulate carbamazepine under hydroponic conditions. *Water* **2020**, *12*, 1272. [CrossRef]
76. Del Toro, A.; Tejeda, A.; Ramos, J.; Ibarra, E.; Zurita, F. Resistencia de la *Canna indica*, *Cyperus papyrus*, *Iris sibirica* y *Typha latifolia* a vinazas tequileras en mesocosmos de humedales. In *Book of Abstracts V Panamerican Conference of Wetland Systems for Treatment and Improvement of Water Quality*; Hupanam: Santa Catarina, Brasil, 2021; Available online: https://hupanam.com/wp-content/uploads/2022/05/Caderno-V-HUPANAM-5o.-Wetlands-BR.pdf (accessed on 2 December 2022). (In Spanish)
77. De Anda, J.; Zurita, F.; Belmont, M. Método para Tratar Aguas Residuales Domésticas Mediante el Uso de Plantas Ornamentales. Patent No. 338619. 2016. Available online: https://ciatej.repositorioinstitucional.mx/jspui/handle/1023/362 (accessed on 1 January 2023). (In Spanish).
78. Mateo, N.; Nani, G.; Montiel, W.; Nakase, C.; Salazar-Salazar, C.; Sandoval, L. Efecto de *Canna hybrids* en humedales construidos parcialmente saturados para el tratamiento de aguas porcinas. *Rinderesu* **2019**, *4*, 59–68.
79. Sandoval-Herazo, L.C.; Alavarado-Lassman, A.; Nani, G.; Nakase-Rodriguez, C. Influence of light intensity on growth and flowering ornamental plants in constructed wetlands. *REB&S* **2020**, *2*, 27–36. [CrossRef]
80. Sandoval-Herazo, M.; Nani, G.; Sandoval, L.; Rivera, S.; Fernández-Lambert, G.; Alvarado-Lassman, A. Evaluación del desempeño de humedales construidos verticales parcialmente saturados para el tratamiento de aguas residuales porcinas. *Trop. Subtrop. Agroec.* **2020**, *23*, 38. (In Spanish)
81. Sandoval-Herazo, M.; Martínez-Reséndediz, G.; Fernández, E.; Fernández-Lambert, G.; Sandoval, L.C. Plant biomass production in constructed wetlands treating swine wastewater in tropical climates. *Fermentation* **2021**, *7*, 296. [CrossRef]

82. Marín-Muñiz, J.L. Removal of wastewater pollutant in artificial wetlands implemented in Actopan, Veracruz, Mexico. *Rev. Mex. Ing. Quím.* **2016**, *15*, 553–563. Available online: http://www.redalyc.org/articulo.oa?id=62046829021 (accessed on 30 January 2023). (In Spanish) [CrossRef]
83. Marín-Muñiz, J.L. Humedales construidos en México para el tratamiento de aguas residuales, producción de plantas ornamentales y reúso del agua. *Agroproductividad* **2017**, *10*, 90–95. Available online: https://revista-agroproductividad.org/index.php/agroproductividad/article/view/1028 (accessed on 30 January 2023). (In Spanish).
84. Marín-Muñiz, J.L.; García-González, M.; Ruelas-Monjardín, L.; Moreno-Casasola, P. Influence of different porous media and ornamental vegetation on wastewater pollutant removal in vertical subsurface flow wtland microcosms. *Environ. Eng. Sci.* **2018**, *35*, 88–94. [CrossRef]
85. Hernández, M.E.; Marín-Muñiz, J.L. Greenhouse Gas Emissions and Treatment Performance in Constructed Wetlands with Ornamental Plants: Case Studies in Veracruz, Mexico. In *Artificial or Constructed Wetlands a Suitable Technology for Sustainable Water Management*; Durán-Domínguez, M., Navarro-Frómeta, A., Bayona, J., Eds.; CRC Press: Boca Raton, FL, USA; Taylor & Francis Group: Abingdon, UK, 2018; pp. 163–177.
86. López-Alba, J.E.; Marín-Muñiz, J.L.; Zamora, S.; Celis, M. Evaluación del crecimiento de plantas sembradas en humedal artificial: Efecto del posicionamiento de sembrado. *J. Basic Sci.* **2022**, *8*, 104–111. (In Spanish)
87. Zitácuaro-Contreras, I.; Marín-Muñiz, J.L.; Celis, M.; Vidal, M.; León, X.; Zamora, S. Vegetación ornamental utilizada en fitorremediación y sus potencialidades ambientales, económicas y sociales. *J. Basic Sci.* **2022**, *8*, 133–145. Available online: https://revistas.ujat.mx/index.php/jobs/article/view/5353 (accessed on 2 January 2023).
88. Boyás, T.; Álvarez-Contreras, L.; Marín-Muñiz, J.L.; Celis-Pérez, M.; Zamora-Castro, S.; Landa, M. Condiciones ambientales para el óptimo desarrollo de plantas ornamentales y fitorremediadoras. *J. Basic Sci.* **2022**, *8*, 96–103. Available online: http://revistas.ujat.mx/index.php/jobs (accessed on 5 June 2022). (In Spanish).
89. Martínez-Aguilar, K.E.; Marín-Muñiz, J.L. La economía circular como una propuesta para la reutilización de aguas residuales porcinas. In *Reconstrucción de una Economía Social Para Lograr el Desarrollo Sustentable*; Ortega, G., Rodríguez, E., Eds.; Martí/Códice, México, 2022; pp. 61–75. Available online: https://umarti.edu.mx/index.php/download/libro/ (accessed on 5 February 2023). (In Spanish)
90. Sandoval, L.; Zurita, F.; Del Ángel-Coronel, O.; Adame-García, J.; Marín-Muñiz, J.L. Influence of a new ornamental species (*Spathiphyllum blandum*) on the removal of COD, nitrogen, phosphorus and fecal coliforms: A mesocosm wetland study with pet and tezontle substrates. *Water Sci. Technol.* **2020**, *81*, 961–970. [CrossRef]
91. Sandoval, L.; Marín-Muñiz, J.L.; Adame-García, J.; Fernández-Lambert, G.; Zurita, F. Effect of *Spathiphyllum blandum* on the removal of ibuprofen and conventional pollutants from polluted river water, in fully saturated constructed wetlands at mesocosm level. *J. Water Health* **2020**, *18*, 224–228. [CrossRef]
92. Nakase, C.; Zurita, F.; Nani, G.; Reyes, G.; Fernández-Lambert, G.; Cabrera-Hernández, A.; Sandoval, L. Nitrogen removal from domestic wastewater and the development of tropical ornamental plants in partially saturated mesocosm-scale constructed wetlands. *Int. J. Environ. Res. Public Health* **2019**, *16*, 4800. [CrossRef] [PubMed]
93. Sandoval, L.C.; Zurita, F.; Nani, G.; Del Ángel-Coronel, O.; Aguilar, F. Treatment of swine effluent mixed with domestic wastewater and vegetation development in monoculture and polyculture horizontal subsurface flow wetlands. *Ecol. Eng.* **2021**, *173*, 106432. [CrossRef]
94. Fernández-Echeverría, E.; Sandoval-Herazo, L.C.; Zurita, F.; Betanzo-Torres, E.; Sandoval-Herazo, M. Development of *Heliconia latispatha* in constructed wetlands, for the treatment of swine/domestic wastewater in tropical climates, with PET as a substitute for the filter medium. *Rev. Mex. Ing. Quím.* **2022**, *21*, IA2811. [CrossRef]
95. Sandoval-Herazo, L.; Alvarado-Lassman, A.; Marín-Muñiz, J.L.; Méndez-Contreras, J.; Zamora-Castro, S. Effects of the use of ornamental plants and different substrates in the removal of wastewater pollutants through microcosms of constructed wetlands. *Sustainability* **2018**, *10*, 1594. [CrossRef]
96. Zamora-Castro, S.; Marín-Muñiz, J.L.; Sandoval, L.; Vidal-Álvarez, M.; Carrión-Delgado, J. Effect of ornamental plants, seasonality, and filter media material in fill-and-drian constructed wetlands treating rural community wastewater. *Sustainability* **2019**, *11*, 2350. [CrossRef]
97. Sandoval, L.; Marín-Muñiz, J.L.; Zamora-Castro, S.; Sandoval-Salas, F.; Alvarado-Lassman, A. Evaluation of wastewater treatment by microcosms of vertical subsurface wetlands in partially saturated conditions planted with ornamental plants and filled with mineral and plastic substrates. *Int. J. Environ. Res. Public Health* **2019**, *16*, 167. [CrossRef]
98. Zamora, S.; Sandoval, L.; Marín-Muñiz, J.L.; Fernández-Lambert, G.; Hernández-Orduña, M. Impact of ornamental vegetation type and different substrate layers on pollutant removal in constructed wetland mesocosms treating rural community wastewater. *Processes* **2019**, *7*, 531. [CrossRef]
99. Zamora, S.; Marín-Muñíz, J.L.; Nakase-Rodríguez, C.; Fernández-Lambert, G.; Sandoval, L. Wastewater treatment by constructed wetland eco-technology: Influence of mineral and plastic materials as filter media and tropical ornamental plants. *Water* **2019**, *11*, 2344. [CrossRef]
100. Sandoval-Herazo, L.C.; Alvarado-Lassman, A.; López-Méndez, M.C.; Martínez-Sibaja, A.; Aguilar-Lasserre, A.A.; Zamora-Castro, S.; Marín-Muñiz, J.L. Effects of Ornamental Plant Density and Mineral/Plastic Media on the Removal of Domestic Wastewater Pollutants by Home Wetlands Technology. *Molecules* **2020**, *25*, 5273. [CrossRef]

101. Marín-Muñiz, J.L.; Sandoval, L.; Zamora-Castro, S.; Celis-Pérez, M. Humedales con plantas ornamentales y relleno de plástico reutilizado como tratamiento sustentable de aguas residuales. *J. Basic Sci.* **2022**, *8*, 146–153. Available online: http://revistas.ujat.mx/index.php/jobs (accessed on 5 January 2023). (In Spanish).
102. Wang, Q.; Hu, Y.; Xie, H.; Yang, Z. Constructed wetlands: A review on the role of radial oxygen loss in the rhizosphere by macrophytes. *Water* **2018**, *10*, 678. [CrossRef]
103. Thamke, S.; Khan, A. Constructed wetlands-Natural treatment of wastewater. *Int. J. Eng. Res. Technol.* **2021**, *10*, 204–212. Available online: http://www.ijert.org (accessed on 7 December 2022).
104. Mander, Ü.; Dotro, G.; Ebie, Y.; Towprayoon, S.; Chiemchaisri, C.; Nogueira, S.; Jamsranjav, B.; Kasak, K.; Truss, J.; Tournebize, J.; et al. Greenhouse gas emission in constructed wetlands for wastewater treatment: A review. *Ecol. Eng.* **2014**, *66*, 19–35. [CrossRef]
105. Lazzerini, G.; Lucchetti, S.; Nicese, F.P. Analysis of greenhouse gas emissions form ornamental plant production: A nursery level approach. *Urban For. Urban Green.* **2014**, *13*, 517–525. [CrossRef]
106. Bakhshoodeh, R.; Alavi, N.; Soltani-Mohammadi, A.; Ghanavati, H. Removing heavy metals from Isfahan composting leachate by horizontal subsurface flow constructed wetland. *Environ. Sci. Poll. Res.* **2016**, *23*, 12384–12391. [CrossRef]
107. Bakhshoodeh, R.; Soltani-Mohammadi, A.; Alavi, N.; Ghanavati, H. Treatment of high polluted leachate by subsurface flow constructed wetland with vetiver. *Amirk. J. Civ. Eng.* **2017**, *49*, 139–148. [CrossRef]
108. Bakhshoodeh, R.; Alavi, N.; Paydary, P. Composting plant leachate treatment by a pilot-scale, three-stage, horizontal flow constructed wetland in central Iran. *Environ. Sci. Poll. Res.* **2017**, *24*, 23803–23814. [CrossRef]
109. Qasaimeh, A.; Alsharie, H.; Masoud, T. A review on constructed wetlands components and heavy metal removal form wastewater. *J. Environ. Prot.* **2015**, *6*, 710–718. [CrossRef]