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Case Report

Application of ornamental plants in constructed wetlands for wastewater treatment: A scientometric analysis

Fernando García-Ávila [a,b,*], Alex Avilés-Añazco [a,b], Rita Cabello-Torres [c], Alexandra Guanuchi-Quito [a,b], Manuel Cadme-Galabay [d], Horacio Gutiérrez-Ortega [d], Robert Alvarez-Ochoa [d], César Zhindón-Arévalo [d]

[a] *Carrera de Ingeniería Ambiental, Facultad de Ciencias Químicas, Universidad de Cuenca, Ecuador*
[b] *Grupo de Evaluación de Riesgos Ambientales en Sistemas de Producción y Servicios (RISKEN), Departamento de Química Aplicada y Sistemas de Producción, Cuenca, Ecuador*
[c] *Universidad César Vallejo, Professional School of Environmental Engineering, Lima, Peru*
[d] *Unidad Académica de Salud y Bienestar, Universidad Católica de Cuenca, sede, Azogues, Ecuador*

A R T I C L E I N F O

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Constructed wetlands

A B S T R A C T

The application of ornamental plants in constructed wetlands (CW) is increasingly of interest to researchers, professionals actively involved in wetland management and/or wastewater treatment (WWT), so it is necessary to know the trends in this field of research. The objective of this study was to develop a scientometric study on the use of ornamental plants in CWs for the WWT during the period 2002–2022. For this, a search of the information was carried out in the Scopus database, including all the articles and reviews related to this field. The analysis of the recovered documents allowed to know key aspects of the evolution of production in recent years, the maturity of research in this field, identify the most used ornamental plants and therefore identify gaps. Likewise, it was possible to identify the countries, the most relevant authors, the main journals and the most cited articles through which knowledge in this area is disseminated. The results showed that Mexico, Brazil, USA, China and India have the highest number of publications related to the use of ornamental plants in the CWs. It was found that the most used ornamental plants are Canna, Iris, Heliconia and Zantedeschia. This analysis can help researchers to identify new research approaches in this field. It is concluded that this field of knowledge has aroused great interest since 2002; however, more research can still be carried out on the application of CWs with ornamental plants in cold climates, the influence of the substrate on the growth of these plants.

1. Introduction

To support the achievement of objective 6 of the Sustainable Development agenda, which emphasizes the commitment to the right to sanitation, the adoption of low-energy consumption wastewater treatment technology is being sought [1–3]. Constructed wetland (CW) is an unconventional or natural technology for wastewater treatment, it is a low-cost and easy-to-operate technique [4,5]. CWs consist of shallow (less than 1 m) impermeable cells or channels; the main components of the CWs are the substrate (gravel, sand, plastic, river rock, among others), microorganisms and vegetation [6,7]. Native or non-native plants are planted in the substrate, due to the action of microorganisms attached to the substrate and roots of the vegetation, the organic matter contained in the residual water is degraded [8,9]. Additionally, coliform bacteria are removed, and other pollutants, such as nitrogen and phosphorus, are removed by plant absorption [10,11].

Among the main benefits associated with CWs, it can be indicated that they do not generate noise, they are easy to operate and maintain, they are aesthetic, they do not require electricity, therefore, their operating cost is minimal, they require a minimum of operators [12,13]; which require simple training, has a low carbon footprint, does not require chemical additives, supports changes in hydraulic and organic load, supports variations in flow, subsurface flow CWs do not present offensive odors, has useable by-products such as flowers, fodder, raw

* Corresponding author. Carrera de Ingeniería Ambiental, Facultad de Ciencias Químicas, Universidad de Cuenca, Ecuador.
E-mail addresses: garcia10f@hotmail.com, fernando.garcia@ucuenca.edu.ec (F. García-Ávila), alex.aviles@cuenca.edu.ec (A. Avilés-Añazco), rcabello@ucv.edu.pe (R. Cabello-Torres), alexandra.guanuchi@ucuenca.edu.ec (A. Guanuchi-Quito), mrcadmeg@ucacue.edu.ec (M. Cadme-Galabay), fhgutierrezo@ucacue.edu.ec (H. Gutiérrez-Ortega), rialvarezo@ucacue.edu.ec (R. Alvarez-Ochoa), cezhindona@ucuenca.edu.ec (C. Zhindón-Arévalo).

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materials [13,14]. Being a natural and sustainable method, it can be a habitat for wildlife [15].

Among the limitations of the CWs, they generally require large areas of land compared to conventional purification systems, in cold climates they slow down the reduction of pollutants, if they are undersized or exceed their treatment capacity they can generate offensive odors, if they are operated in inadequately, a clogging of the filter medium can occur. In surface-flow wetlands, there is a risk of the development of flies and/or mosquitoes [16,17]. In dry climates with high temperatures, flow losses occur due to evapotranspiration [18]. The process is limited to the penetration depth of the roots, a systematic pruning must be carried out and a disposition to that material must be carried out [19, 20].

There are different types of WCs depending on the direction of circulation of the water flow, they are classified as: 1. Free water surface constructed wetlands (FWS CWs), and 2. Subsurface flow artificial wetlands (SSF CW). In FWS CWs the water circulates above the soil through the stems of the plants and is exposed to the atmosphere and direct sunlight and the depth of the water column is usually a few centimeters (wetlands without means of support) [21]. Meanwhile, in the SSF CWs the water flows inside a porous substrate (wetlands with support means), there are CWs of vertical subsurface flow (VSSFCW) and horizontal subsurface flow (HSSFCW) [22]. In VSFCWs, the water infiltrates vertically through an inert substrate (gravel) and is collected in a drainage network located at the bottom of the wetland [22,23]. In HSFCWs the water circulates horizontally through the substrate in a continuous manner, the water flows from one end of the wetland to the other, parallel to the substrate [23].

Another classification of the CWs can be made according to the type of vegetation: a. Floating macrophyte wetlands, b. Emergent macrophyte wetlands and c. Submerged macrophyte wetlands. Table 1 presents the aforementioned classifications of the CWs [24].

Regarding the selection of the vegetation, it is very important to consider some factors, such as the depth of the roots, the productivity of the plant and the tolerance to high loads of water, elements and residual compounds [25]. The vegetation transfers a small amount of oxygen to the root area so that aerobic bacteria can colonize the area and degrade the organics [7]. However, the main role of vegetation is to maintain the permeability of the filter and provide a habitat for microorganisms [8]. Nutrients and organic materials are absorbed and degraded by dense microbial populations [26]. Canopy cover from emergent macrophytes attenuates light reaching the water surface, thereby decreasing algae production [27]. The presence of vegetation prevents the freezing of the substrate during the winter and keeps it cool during the spring [28].

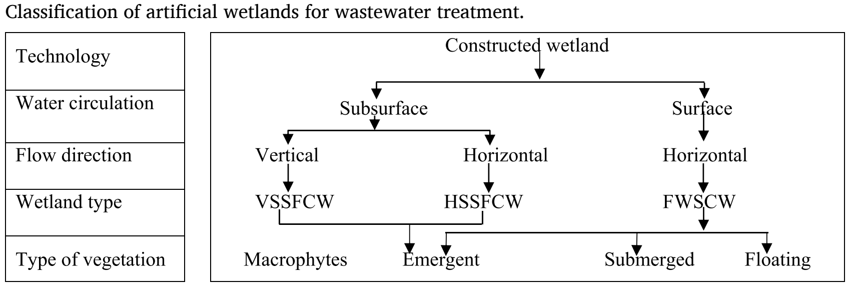
Ornamental plants are used in CWs instead of traditional plants since ornamental plants have good pollutant removal efficiencies [29]. In addition, it improves the landscape, serving as a tourist option and a source of income with high-added value [30]. Another quality for which ornamental species are used in CWs is due to their rapid growth, high biomass production and good root development, which allows the elimination of contaminants [31]. Likewise, ornamental plants are used in CWs since these species are not intended for human and animal consumption, avoiding the introduction of contaminants into the food web [32]. In addition, ornamental plants provide multiple ecosystem services and promote human well-being, while contributing to the conservation of biodiversity [31,32]. Another reason why ornamental plants are used in CWs for wastewater treatment is because of the ability of these species to accumulate or degrade pollutants; Likewise, the length, density and surface area of the root of these species are important characteristics that can directly influence the absorption or degradation of contaminants [33]. Ornamental plants such as canna have a fibrous root structure that produces high aerobic conditions throughout the CW, allowing for greater removal [9]. All the aforementioned reasons make ornamental plants used in CWs for wastewater treatment.

The removal of contaminants in the CWs occurs through chemical (sorption, complexation and precipitation), physical (sedimentation and filtration) and biological (biodegradation, microbial transformation and microbial/plant assimilation) processes [21,34], which involve different removal mechanisms such as filtration, sedimentation and absorption processes by vegetation, among others [35]. Phytoremediation is an eco-technology, based on the ability of some plants to tolerate, absorb, accumulate and degrade polluting compounds, which is currently being applied for the treatment of wastewater in CWs [36]. In phytoremediation, several types of remediation processes have been identified that vary according to the parts of the plant that participate or the microorganisms that contribute to the degradation of contaminants. Phytoremediation uses many mechanisms including degradation (rhizodegradation, phytodegradation), accumulation (phytoextraction, rhizofiltration), dissipation (phytovolatilization), and immobilization (phytostabilization) to degrade, remove, or immobilize contaminants [37].

In rhizodegradation or phytostimulation, plants generate root exudates that stimulate the growth of native microorganisms capable of degrading organic pollutants by rhizospheric microorganisms [38]. Phytodegradation is the degradation of organic pollutants by plants through enzymes such as dehalogenases and oxygenases. On certain occasions, the degradation products serve the plant to accelerate its growth, in other cases, the pollutants are biotransformed [32]. Plants can accumulate organic contaminants from contaminated sites and remove them through their metabolic activities. Phytodegradation is limited to organic contaminants only because metals are not biodegradable [39]. Phytoextraction or phytoaccumulation consists of the absorption of contaminants by the roots; It is the ability of some plants to accumulate pollutants in their roots, stems, or foliage. This mechanism is the most studied in plants that accumulate metals [40]. Rhizofiltration consists of the use of plants for wastewater treatment, roots of terrestrial plants with high growth rates and surface area are preferred to absorb, concentrate and precipitate pollutants [41].

Phytovolatilization occurs as growing plants take up water along with soluble organic contaminants. Some of the contaminants can reach the leaves and evaporate or volatilize into the atmosphere [37]. This technique can be used for organic contaminants and some metals such as Hg and Se. However, their use is limited by the fact that they do not completely remove the contaminant, they only transfer it from the water

Table 1
Classification of artificial wetlands for wastewater treatment.



to the atmosphere [42]. Phytostabilization is a mechanism that uses plants that develop a dense root system to reduce the bioavailability of metals and other pollutants in the environment through sequestration, lignification or humidification mechanisms [43].

These mechanisms that make ornamental plants so efficient for wastewater treatment are still not well understood [40]. Therefore, the mechanisms of ornamental plants in CWs stand out as key knowledge gaps in the application of these species in CWs.

Most of the research has focused on the functionality of common plants such as Phragmites spp., Scirpus spp., Typha spp., Phalaris arundinacea, Juncus spp [44]. Despite the widespread use of these species, it is important to evaluate the use of ornamental species such as Zantedeschia ssp., Canna spp., Cyperus spp., Iris spp., Agapanthus spp., Strelitzia spp., Heliconia spp, that have been used mainly in subsurface CWs to treat sewage [45–50].

Researchers still see CWs as the most suitable and sustainable wastewater treatment technology, especially for small communities [51]. However, this environmentally friendly and low-cost technology still faces several challenges, including the selection of vegetation to be planted [51]. Vegetation has a mostly positive effect on CWs, that is, it increases treatment efficiency, for organic matter and nutrients [52]. The selection of plant species for further maximization of pollutant removal in CWs is still under discussion [53,54]. The most widely used plants worldwide are Phragmites, Typha and Scirpus spp [55]. However, a recent research trend in CWs is related to the use of ornamental plants. Therefore, there are gaps in the literature on the adaptation of terrestrial ornamental plants to survive in flooded conditions and high nutrient loads [56]. Likewise, there are still gaps regarding the use of CWs with ornamental plants in tropical areas, which contributes to the generation of economic benefits, to improve the visual quality of the landscape and encourage communities to adopt this eco-technology [57]. This means that the use of ornamental plants in CWs is a research area that offers opportunities for further research. Reason for which a scientometric analysis was made on the use of ornamental plants in CWs for wastewater treatment.

In a global way, scientometric analyzes related to WCs have previously been carried out, which has made it possible to identify the main journals, authors, understand the specific research domain and research trends in this field in recent years [58,59]. However, a specific scientometric analysis on the use of ornamental plants in CWs has not been carried out. For example, Zhang et al. [60] provided a bibliometric analysis of the relationship between water management and CWs. Zhang et al. [61] used bibliometric mapping to quantitatively analyze the major CW research issues between 1991 and 2008. Zhi and Ji [62] explored a bibliometric approach to quantitatively assess global scientific research on constructed wetlands and statistically assess current trends and changes. future directions from 1991 to 2011. Moondra et al. [63] carried out a bibliometric analysis of CWs in wastewater treatment during the years 1998–2017. Colares et al. [64] through a bibliometric analysis verified that floating wetlands are a potential technology for the treatment of various types of wastewaters. The only review article related to ornamental plants in CWs is the study by Sandoval et al. [29], who carried out a review of the literature on the use of ornamental flowering plants in artificial wetlands for wastewater treatment, clarifying that a scientometric analysis was not applied in this last study.

Due to the aforementioned, the objective of this document was to carry out a scientometric analysis that allows estimating the progress of the research, as well as analyzing and mapping the scientific knowledge to identify the critical points of investigation and the frontiers of the application of ornamental plants in CWs [65–67].

The benefits of using ornamental type vegetation are identified by the aesthetic characteristics they possess, since their leaves, flowers, fruits, aroma and floristic design, which, visually pleases society, giving it a pleasant landscape value [68]. By using alternative ornamental species in the CWs there is an efficient system for the elimination of contaminants, at the same time it is possible to commercialize the flowers for the elaboration of floral bouquets or handicrafts, constituting a source of economic income for the communities that make use of these systems [69]. The economic benefit could help to recover part of the financing invested in the construction and maintenance of the system [44]. Additionally, the visual quality of the landscape can be considerably improved, an aspect that is often undervalued but has positive psychosocial repercussions in people's daily lives [70].

Scientometrics consists of quantitatively analyzing scientific progress (especially scientific articles) through comparisons of scientific activity, productivity and innovation [65,71]. It provides objective data that can reflect the relevance of a study, journal, author, or research institution [72,73]. The higher the number of citations of the articles published in a certain journal, the higher the impact factor of this scientific journal. Increasing the impact factor of a journal makes it more difficult to publish in the journal; this is due to the greater demand of the authors for that particular journal [67,74]. Therefore, the above leads to an increase in the quality of the accepted and published articles, due to the interest of the authors to publish in a high-impact journal [67,75]. Scientometrics is a method of identifying research hotspots, helping researchers understand the evolutionary path of research [76].

The scientometric analysis was chosen, because scientometrics through the quantitative analysis of scientific production allows to investigate of the development, structure, dynamics, trends and relationships of scientific practice, among other research opportunities. That is, the scientometric analysis of the application of ornamental plants in CWs was chosen to discover the characteristics, impact and evolution of research in this field. This allowed the carrying out of specialized analysis of articles focused on this branch of CWs, to generate the panorama of research on the application of ornamental plants in CWs. This is achieved because the benefits of a scientometric review include providing evidence of the impact of the research, forecasting future research directions based on the use of ornamental plants in CWs.

As an advantage of Scientometrics, it aims to study the quantitative aspects of the creation, dissemination and use of scientific information, as well as the understanding of the mechanisms of research as a social activity, allowing to find the knowledge gap in a specific field, which in turn promotes research [65,77]. Among its limitations are that, for the indicators, elements of an epistemological nature are not considered, in addition, the scientometric analysis to measure the growth of knowledge, uses the simplest indicator that can be used, which is the number of publications [78]. For this, it is necessary to assume that all the knowledge obtained by the scientists is found in these works and that each one of the works contains the same proportion of knowledge: neither of the two aspects is true [79,80].

2. Materials and methods

2.1. Scope of the study and database selection

The scientometric analysis was based on articles published in journals registered on the SCOPUS bibliometric basis, limiting it to the period between January 2002 and August 2022. The period 2002–2022 was chosen because, in an initial search in which it was not limited the search time, 114 articles were obtained, where it was observed that the first publication was in 1997, the second publication was in 1999, the third publication was in 2002; Since there was a discontinuity in publications between 1997 and 2002, it was considered from 2002, since that year ths been a continuity in the publication of this field.

Scopus was considered because it is the largest scientific electronic database [81]. Additionally, previous scientometric studies related to wastewater treatment with CWs are based on this basis [36,58,60,62–64]. Scopus has a fast-indexing process, which facilitates the retrieval of the most current publications [82]; is peer-reviewed, with the highest number of citations and abstracts [83].

2.2. Scientometric analysis and visualization in vosviewer

To visualize significant patterns and trends within a large amount of literature from a certain field of research, scientific mapping is used [84]; one of the scientific mapping methods is scientometric analysis [85].

The scientometric analysis is a technique to evaluate the impact of research, it provides the quantitative aspects of the production, dissemination and use of scientific information, through which a better understanding of the mechanisms of scientific research is achieved [85,86]. This technique of analysis has been growing in scientific research in recent decades, allowing researchers to analyze a large amount of scientific information in a more objective and impartial way [79,87]. A scientometric analysis uses bibliometric data to generate a network model and identify research subjects [88].

For the scientometric analysis, bibliographic tools are used, such as the Scopus database and software tools such as VOSviewer. Scopus is the largest scientific electronic database, to retrieve related articles [81], this base was chosen since it provides the best coverage in the area of wastewater management, taking into account the number of articles published and the number of citations received. Vosviewer is a freely available computer program, it is primarily designed to be used in bibliometric network analysis, it draws maps of scientific knowledge to show the interrelationships between literature [89]. Through scientometric analysis, Vosviewer determined the types of records in the literature, such as authors, journals, countries, keywords, and organizations [90].

2.3. Strategy used for the search in the database

For a comprehensive review of the literature on the application of ornamental plants in CWs, an article search was performed using the title, abstract and keyword codes. The documents retrieved for this study were research and literature review articles, conference articles, and book chapters. A comprehensive literature review was conducted in Scopus on August 31, 2022, to retrieve articles related to the application of ornamental plants in CWs using the following keywords: "ornamental plant" AND "constructed wetlands" in the title, abstract and words key, which increased accuracy and minimized false-positive results because the "ornamental plant" is present in other non-engineering papers, the search was limited to the period 2002 to 2022. To ensure the accuracy of the selected papers according to the query string, the authors manually reviewed the selected papers. The information was extracted from Scopus in csv format. The query string used was: (TITLE-ABS-KEY ("ornamental plant") AND TITLE-ABS-KEY ("constructed wetlands") AND (LIMIT-TO (SUBJAREA, "ENGI"))) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "re")) AND (LIMIT-TO (LANGUAGE, "English") AND PUBYEAR >1999 AND PUBYEAR <2023).

2.4. Data analysis

To analyze the information retrieved from Scopus, the scientometric analysis was applied, for which they were organized and analyzed as described [59,91]. The recovered manuscripts were properly organized using Microsoft Excel; while the maps were made with VOSviewer [59,92]. Using VOSviewer it was possible to identify the different thematic areas, the journals indexed in Scopus, the main keywords, the countries, the main authors and the most productive institutions in this field. Likewise, the most cited manuscripts were identified. Finally, trends in the study of ornamental plants used in constructed wetlands were analyzed [93]. Fig. 1 shows the framework of the methodological process for this study.

3. Results

3.1. Basic data information

A total of 112 records related to the use of ornamental plants in constructed wetlands from 2002 to 2022 were identified. The performance of year-on-year total publication (TP) output from 2002 to 2022 is shown in Fig. 2. It could be observed between 2002 and 2004 there was only one annual publication, which reveals that this field of research was in a preliminary stage. In 2005 no article was published. Then, there was a slight advance, publishing 3 articles per year between 2006 and 2007, reduced to 2 publications in 2008. By 2009, there was another slight increase, publishing 4 articles, reducing again to 2 publications in 2010. After 2010, in general, the annual productions showed an upward trend, although there were some slight decreases in the years 2012 and 2016. Interest in research related to ornamental plants in CWs has arisen in recent years. The year-on-year total number of publications in 2021 (13) was approximately 13 times that of 2002 (1). In particular, the total

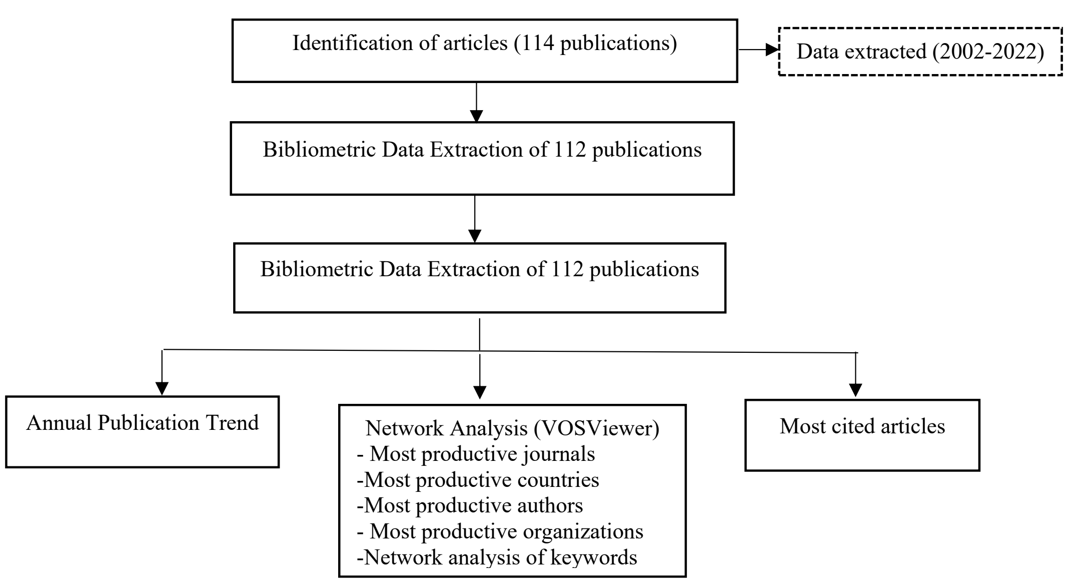


Fig. 1. Flow diagram of the search methodology.

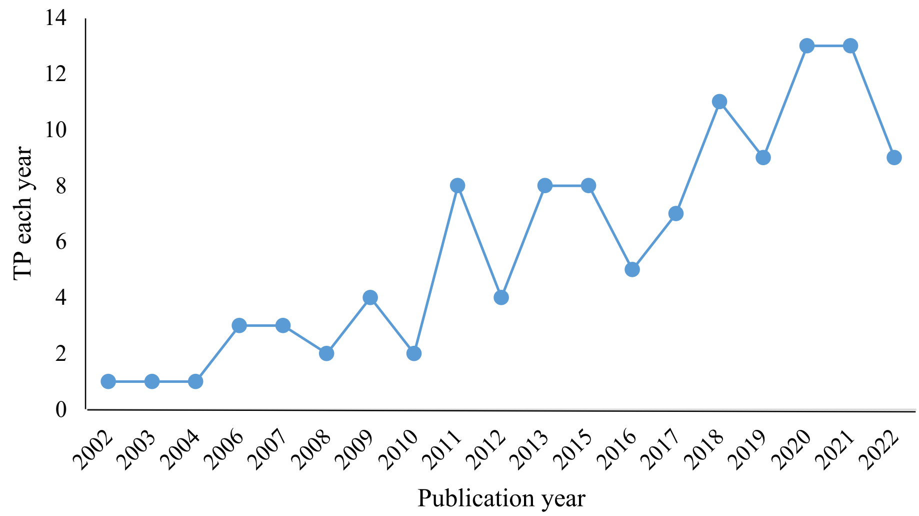


Fig. 2. Publication output performance from 2002 to 2022. For the recovery of the articles, the keywords were used: "ornamental plant" and "constructed wetlands".

year-on-year publications from 2011 to 2021 concentrated 76.78% of all studies on the use of ornamental plants in constructed wetlands. In general, an increasing trend of publications per year is observed, publications related to the use of ornamental plants in constructed wetlands have increased since 2002, reaching 13 articles by 2021. In general, productions have increased continuously over the last 20 years, with the appearance of some revisions and the new findings of ornamental plants planted in the CWs; as well as the need to remove emerging pollutants, heavy metals in this type of systems, the interest in improving the landscape, serving as a tourist option and a source of income with high added value, which suggests that this field still lacks attention and important advances.

The main types of scientific documents related to the use of ornamental plants in constructed wetlands are presented in Table 2. The Scopus database presents 84.82% of its publications in the "article" category, followed by "review" (5.36%), in the same percentage "Conference Paper" (5.36%); Conference Papers correspond to articles that were first presented at a conference and that were subsequently adapted for publication in one of the journals in the database. In a lower percentage, "Book chapter" (3.57%) and the Book category represented 0.89% of the publications in this academic base.

This indicates that review articles in this field few, therefore it is necessary to have review articles. Due to the rapid advances in research and the exponential growth of published articles, it is difficult to keep up with all the new publications in this field. The new review articles would make it possible to synthesize the latest knowledge on a topic published in the form of original articles and, in addition, they provide a critical assessment of the research.

It is evidence a growing interest of the scientific community in the application of new species of vegetation, especially of an ornamental type that has added value such as flowers that provide a better landscape vision in addition to being potentially commercialized. This is because the assurance of wastewater treatment is of the utmost importance in the health of ecosystems and human beings, allowing environmental sustainability [52,94] (Zamora et al., 2019; Guerra-Rodríguez et al., 2020).

Table 2
Main types of documents published in Scopus.

document type	Documents	percentage (%)
Article	95	84.82
Reviews	6	5.36
Conference Paper	6	5.36
Book Chapter	4	3.57
Books	1	0.89
	112	100.00

3.2. Thematic areas

An analysis of the main research areas covered in the last 20 years is shown in Fig. 3. The area of environmental sciences has covered the most publications (45.41%), followed by Agricultural and Biological Sciences 18.38%, Social Sciences (8.11%), Biochemistry (7.03%), Engineering (6.49%), Chemical Engineering (4.86%), Earth and Planetary Sciemecjnces (2.70%), Energy (2.70%) and others (4.32%). This indicates the strong relationship that exists between environmental sciences with other areas, indicating a greater multidisciplinarity in this topic.

Scopus does not have a specific subject area for wastewater treatment, which shows that this field of research is diversified into several subject areas. However, it is observed that the main thematic area is environmental sciences, which largely supports environmental sciences in the search for friendly solutions for water treatment. As environmental sciences are related to other areas, the Scopus database includes several subject areas, indicating a greater multidisciplinarity in this subject.

3.3. Main sources of research on the use of ornamental plants in constructed wetlands

To identify the main sources, those journals that have two or more documents published in this field of research during the study period were chosen. 71 sources were identified, of which 15 met this requirement (Fig. 4). These 15 journals can be considered as the central sources of research on the use of ornamental plants in constructed wetlands, these journals also play an important role in this field of research. The 112 articles were published in 71 journals, of which fifteen journals covered (50.00%) of these publications. Among these magazines, ecological *engineering* with 17 posts (15.18% of publications), *Water* with 8 posts (7.14%), *water science and technology* with 4 publications (3.57%). The ecological magazine engineering had the most citations (1039), followed by water journal (101) and aquatic botany (92) (Table 3).

Scientific journals allow the dissemination of research results [95], informing researchers about the main media and platforms to disseminate their research findings. The journals presented in Fig. 4 have contributed significantly in the last two decades to studies on the application of ornamental plants in CWs. These results allow researchers

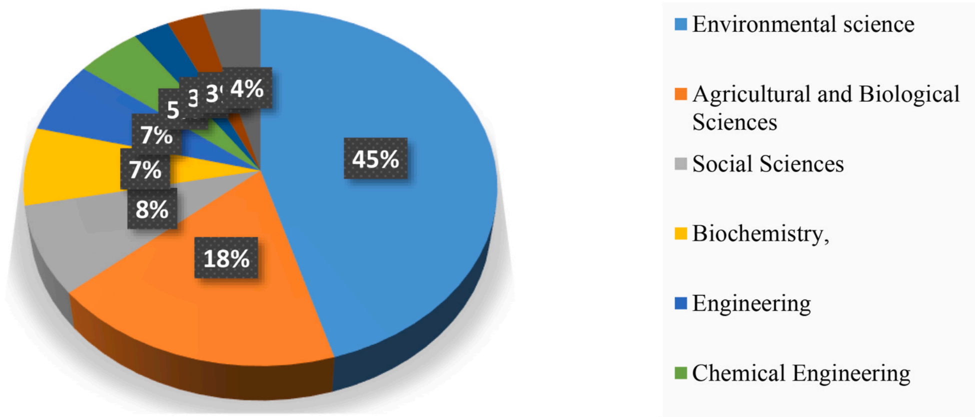


Fig. 3. Documents by subject area in Scopus.

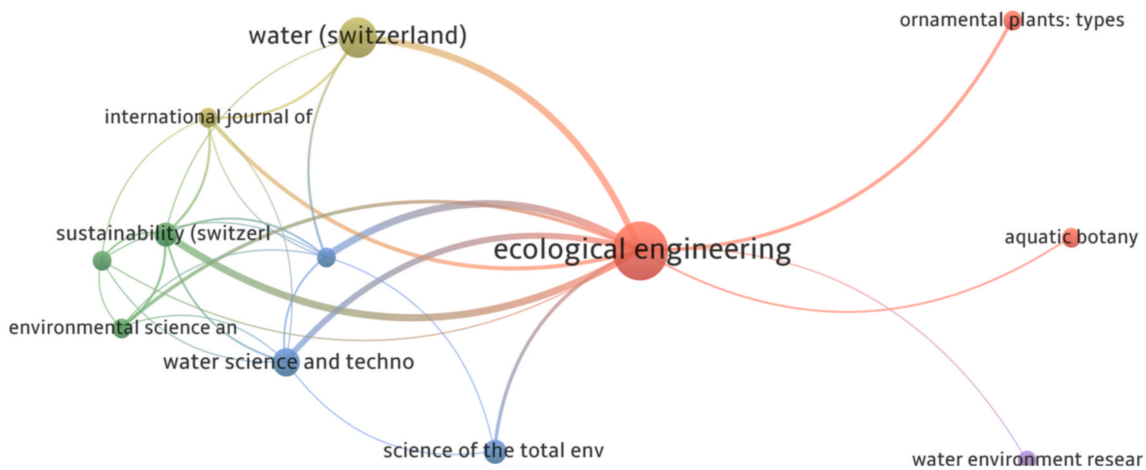


Fig. 4. Co-occurrence map of journals with more than two publications related to the use of ornamental plants in constructed wetlands in 2002–2022.

Table 3
Top 10 Scopus journals.

No.	Source	TP	Cites	% Publications	H	Q	Country	Topic
1	Ecological Engineering	17	1039	15.18	138	Q1	Netherlands	Environmental Science
2	Water	8	101	7.14	69	Q1	Switzerland	Environmental Science
3	Water Science and Technology	4	70	3.57	145	Q2	United Kingdom	Environmental Science
4	Sustainability	3	50	2.68	109	Q1	Switzerland	Environmental Science
5	Science of the Total Environment	3	55	2.68	275	Q2	Netherlands	Environmental Science

TP: Total production, Q: Quartil, H-Index: hirsch index.

to know the potential journals to publish their studies.

Of the top 5, four journals have an H index >109. Three journals are in Scopus quartile 1, two journals in quartile 2. It is important to note that of the five most productive journals, two are published in the Netherlands, two in Switzerland and one in the United Kingdom. The main thematic area related to the investigation of the use of ornamental plants in constructed wetlands is the Environmental Sciences (Table 3). The high impact factor of the ecological magazine engineering (4.379) reflects its status as the leading scholarly journal in the field of constructed wetlands. In addition, the wide and diversified number of sources indicates a great interest of the editors in this research topic.

3.4. Author keyword trend analysis

The keywords in a scientific article are the central summary of the research. The analysis of the keywords gives an idea of the topic of the article, since the keywords given in an article must have some type of association. This association can be expressed by the frequency of co-occurrence. It is generally believed that the more frequent a pair of words appears in the same literature, the closer the relationship between the two themes, allowing to establish the relationship between the research contents and define the general direction of scientific research.

Scopus database, the frequency of keywords in the 112 articles was examined, finding a total of 379 author keywords. For a better analysis, those keywords with a minimum of 3 appearances in the manuscripts were determined; being 18 keywords that met this requirement (Fig. 5).

Fig. 5 shows that in the Scopus database, the descriptor with the highest frequency is ornamental plants, with 42 occurrences (11.08%), followed by constructed wetlands with 36 occurrences (9.5%), phytoremediation with 14 occurrences (3.69%). The same figure shows the co-occurrence of the main keywords in the 112 documents analyzed from the Scopus database, which refers to the underlying relationships

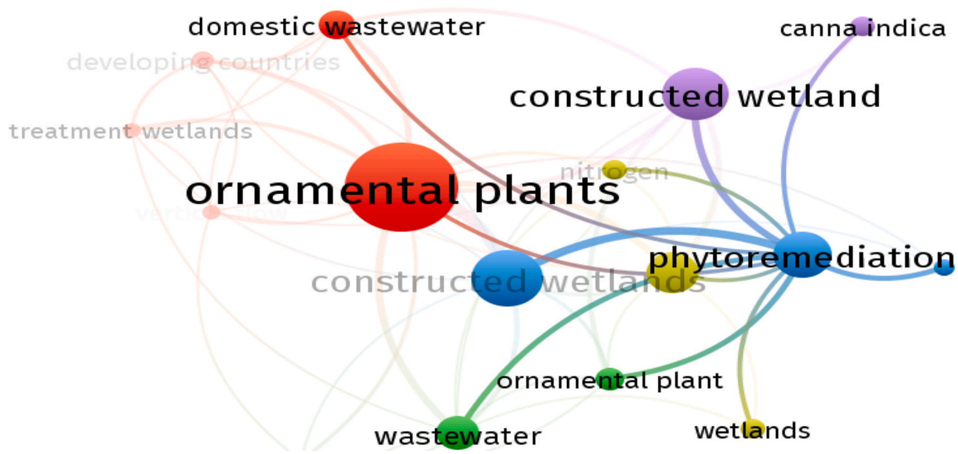


Fig. 5. Keyword network based on the co-occurrence method in research on the application of ornamental plants in constructed wetlands in 2002–2022.
Source: VOSviewer

between the terms (because of their tendency to appear together) and which allows them to be grouped into categories. Three large groups or clusters can be distinguished. The first cluster revolves around the word "ornamental plants" and is related to terms such as: domestic wastewater treatment_wetlands (red color), among others. For its part, the second cluster is related to the terms constructed wetlands, phytoremediation and heavy metals (light blue color), the vegetation in the WH works as a phytoremediation agent. Finally, the third cluster (purple color) refers to terms related to constructed wetland and canna indica. All the groups of words concur with each other, which is why they present a close conceptual link.

The use of CW technology for wastewater treatment began in Europe in the 1960s and was later replicated on other continents. The most commonly used vegetation type in CWs are natural wetland plants, including *Cyperus papyrus*, *Phragmites australis*, *Typha* and *Scirpus* spp [29,96]. Practically the investigation of the use of ornamental plants in CW began about 20 years ago, as shown in Fig. 1, where it can be seen that in 2002 a research study related to this topic was presented. Hence, the keywords such as ornamental plants are the most recurrent in the manuscripts analyzed.

3.5. *Countries active in the investigation of constructed wetlands with ornamental plants*

Although wastewater treatment is a global concern, wetlands are presented as a soft technology, research in this field continues to develop in different countries [29]. Among the species of vegetation used in the WH are those with ornamental flowers that may have commercial use and that in recent years have gained interest in some countries for research [56].

Wastewater treatment processes using CW with ornamental plants began to be used in recent years in wastewater of urban public origin, generated in industrial processes or some services. These ornamental plants are of interest for sanitation studies due to their use as macrophyte plants with physical and biological characteristics of absorption/adsorption of contaminants present in water. These types of plants are the subject of academic research, considering their possible use in small towns in several countries.

Therefore, it is important to carry out an analysis of articles published globally in this field. Which can serve as an indicator to determine the species of ornamental plants most used in WCs and which countries are leading this field of research [97] (Francini et al., 2022). In Fig. 6 the network between countries of international co-authorship is shown; It was found that 36 countries have been interested in investigating the use of ornamental plants in WCs. Using VOSviewer you can represent the countries using a label and a circle. The greater the number of articles written by authors from the country a country has, the larger its label and its circle. To indicate that there is co-authorship between organizations from different countries, a link between two circles from those countries is presented [89].

It can be observed that according to the Scopus database, Mexico is the most active country in the production of studies related to the

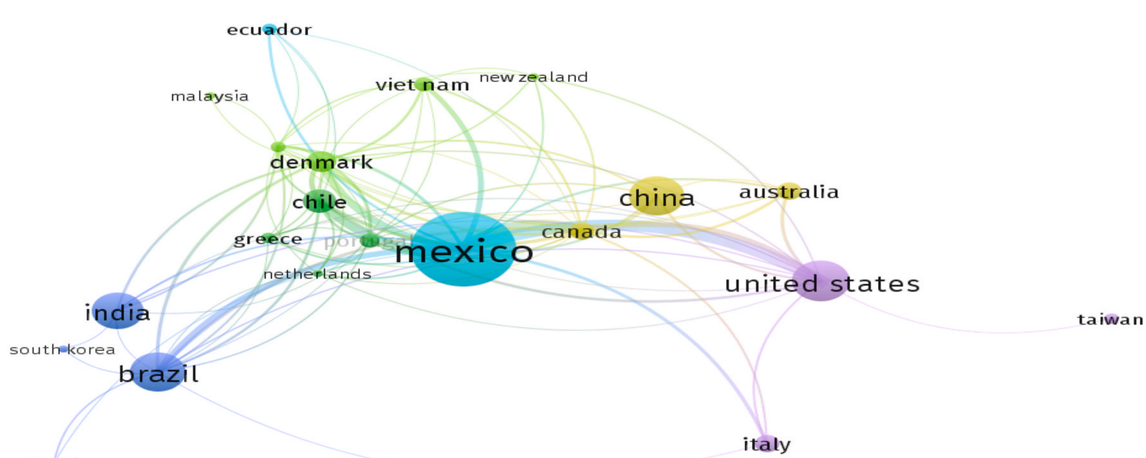


Fig. 6. Network visualization of the main countries in the investigation of the application of ornamental plants in CW.

application of ornamental plants in CW during the last two decades. Researchers from Mexico contributed 30 of 112 articles related to this field, which represents 26.79%. Meanwhile, researchers from the United States contributed 13 articles, representing 11.61%. Researchers from Brazil and China contributed 12 articles from each country, which represents 10.71%. There is quite a difference between Mexico and the USA, existing in Mexico a high interest in applying ornamental plants in CW. Among the countries of the European region, the ones that stand out the most are Denmark and Italy with 5 and 4 articles, respectively. Based on the interconnections between different countries, it is evident that cooperation prevails in Latin America when this type of research is carried out.

The findings made it possible to identify those developing nations such as Mexico have a higher production than developed nations such as the USA and China, these last countries have a production like other countries that are not as developed as Brazil. However, it must be considered that authors from developed countries could be conducting research in developing countries (and vice versa). However, the study identified an eminent lack of research in this field from countries around the world, as only 36 countries have conducted studies regarding the application of ornamental plants in CWs. The volume of research publications per nation on the application of ornamental plants in CWs can be proportional to the public policies considered in each country for wastewater treatment. Thus, in Mexico, in recent years, government efforts have been made to operate water treatment plants, recognizing the role of governance in the implementation of the wastewater treatment policy.

3.6. *Productivity of organizations related to the use of ornamental plants in constructed wetlands*

A total of 267 organizations that support research on the topic of the application of ornamental plants in CW were found. It was determined that 12 organizations are linked to at least 2 scientific articles. The Ciénega University Center, University of Guadalajara, Mexico, stood out for its greatest contribution in this field of research with 4 documents. Other universities in Mexico, Brazil and Iraq have 2 articles published in this field. It is notorious a dispersion of organizations, mostly Latin American, linked to the issue of the application of ornamental plants in CW (Fig. 7). This corroborates other findings found about productive authors, in the sense that the most productive authors are from institutions in Mexico and Brazil.

Fig. 7 presents a network visualization map that shows the collaboration between the main research organizations in this field, the link that the different institutions have in terms of collaboration is observed. These findings make it possible to identify the different research centers with which researchers can strengthen ties of scientific collaboration. Considering that Research becomes collaborative when it arises from the commitment of a group of researchers, it is important to identify the different institutions that stand out, particularly as a framework, process, and way of producing knowledge. A convenient technique to gain new knowledge in the application of ornamental plants in CWs is the thoughtful exchange of theory and practice between different organizations. It is important to emphasize that in the training and development of the researcher, the collaborative research-action methodology is applied, which allows the development of a practice of systematic reflection, which is shared and as a team, makes him a reflective researcher about his practice.

3.7. *Production of the authors*

The Matthew Effect in scientific production reflects the existence of a small number of specialized authors who concentrate the flow of information and many transitory authors with few publications [98]. Fig. 8 shows the participation of the authors according to the number of documents published, considering 5 or more publications per author. Of the total of 376 authors, 7 main authors published at least 5 papers in this field of research. The author with the most publications to date has 10 documents (Zurita, F.), the second has published 9 documents (Sandoval, L.), the third published 7 documents (Marin-Muñoz, J.), Belmont M. and De anda J. have 6 posts each. The first three authors with the greatest production in this field comprise a total of 23.21%. This also indicates that research on the use of ornamental plants in constructed wetlands is a multi-author collaborative field.

3.8. *Removal efficiency of common plants and ornamental plants planted in CWs*

Table 4 shows the removal efficiencies achieved for some contaminants in subsurface wetlands that used common plants and ornamental plants. From this table, both types of plants were frequently planted in CWs with gravel, volcanic rock or sand, which are used to remove a variety of contaminants from wastewater. Most of the studies evaluated the removal efficiency of biochemical oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), ammonium (NH_4–N), nitrates (NO_3^- N), fecal coliforms (FC). However, no clear pattern was found in the percentage of pollutant removal for each species of ornamental plant, that is, the removal varied between one and one study despite having used the same species of plant and the same type of residual water. However, it is important to keep in mind that CWs with ornamental plants are generally used as secondary or tertiary treatments [99]. Comparing the removal efficiencies between common and ornamental plants, there is no difference in their results. Thus, for example, using the common Phragmites Australis plant, a removal of 75.39% of BOD was obtained; meanwhile, using the ornamental plant Cyperus Papyrus, a removal of 80.69% was obtained [10]. On the other hand, a 92% COD removal was obtained when using the common plant species Saccharum spp; meanwhile, a 91% removal was

Fig. 7. Visualization of the main institutions in the investigation of the use of ornamental plants in constructed wetlands.

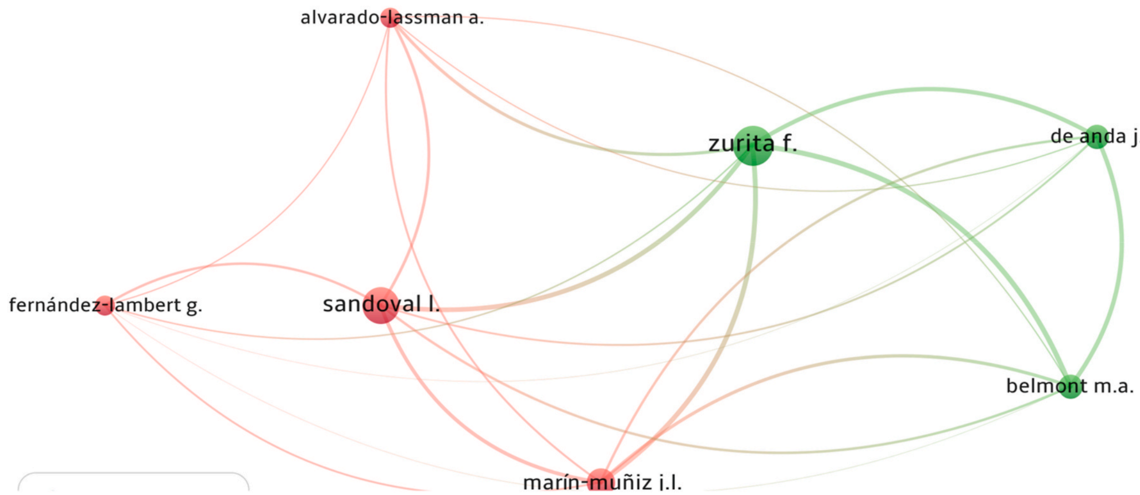


Fig. 8. Researcher collaboration co-occurrence map during 2002–2022.

obtained when using the ornamental plant Heliconia psittacorum [100]. Likewise, in the different studies the researchers used different hydraulic retention time (HRT) that varied between 1 and 5.6 days.

It is evident that subsurface wetlands are more used than free-flowing wetlands for wastewater treatment. In the documents reviewed, the mechanisms for the elimination of contaminants that the common plants used in the CWs have are mentioned; however, the mechanisms through which ornamental plants eliminate contaminants are not clearly indicated.

3.9. Economic potential when using CWs with ornamental plants in wastewater treatment

The findings of this scientometric analysis encourage the practical application of this technology at the single-family level and in small communities. Constructed wetlands have been shown to offer an economically viable method for wastewater remediation [111]; when a CW is used for wastewater treatment, the cost of operation and maintenance is at least 6 to 20 times lower compared to an equivalent conventional technical treatment system [112]. For the treatment of 3108 m^3 of wastewater in Veracruz, Mexico; Betanzo-Torres [113] reported an investment of USD 53057 for the construction of a CW, making it evident that the use of CW is an economic option in contrast to conventional treatment systems.

It should be considered that at least two economic benefits can be obtained from the application of ARC with ornamental plants; These benefits may be due to the sale of flowers from ornamental plants and the reuse of treated water. Although, the sale of seedlings obtained in the CW and transplanted in pots should also be considered, as well as the sale of aerial biomass to produce handicrafts [114]. The species that have been used the most in CWs for their economic benefit are Zantedeschia aethiopica and Spathiphyllum blandum. However, Anthurium andreanum has also given good results in water treatment [46,110].

This economic benefit would make it possible to recover part of the resources invested in the construction and maintenance of the system [44]. The cost recovery periods for the installation of CWs with ornamental plants in a multi-family building, a single-family house and a hotel in Greece were 4.7, 16.6 and 2.5 years, respectively [115]. Evidencing that the CWs provide a technically and economically feasible solution for the treatment of wastewater.

3.10. Contributions to the readerships of the results of the scientometric analysis of the use of ornamental plants in CWs

Considering that the objective of this article was to develop a scientometric analysis of the application of ornamental plants in CWs, the exposed findings can help researchers in the development and direction of future analyzes, the identification of research trends and the most suitable methodology to address research in this field of research.

Thus, the findings of the trend of research on the application of ornamental plants in CWs, indicate that there is a growing interest in this field, awakening interest in researchers, since, in 2002, only one article was published in this field; meanwhile, in 2021 it reached 13 articles, despite that, this production is still low, knowing the potential that CWs have for wastewater treatment, therefore, researchers are urged to continue seeking new knowledge in this field.

It was also identified that to date there are 95 original articles and only 6 review articles, therefore, researchers should contribute to this area with new studies of literature reviews, whether systematic reviews, meta-analysis, meta-synthesis, bibliometrics, scientometrics or others.

Regarding the main journals that have published articles in this field of research, there are the journals Ecological Engineering and Water. The aforementioned and Fig. 4 allow researchers to have a list of potential journals where they can publish their studies, saving them time in identifying said sources.

The findings regarding the main countries and organizations in this field of research, it has been possible to identify that there is currently a greater interest in countries such as Mexico, USA, China and Brazil. Therefore, researchers already active or who wish to venture into this field can begin to strengthen ties of collaboration with researchers from these countries and/or institutions. This would also save time for readers who wish to interact with other authors and/or organizations.

Likewise, this scientometric analysis allows readers to identify knowledge gaps in this field, which may be the reason for new research.

3.11. Knowledge gaps on the application of ornamental plants in CWs

Once the scientometric analysis on the application of the use of ornamental plants in CWs was carried out, it was identified that there is still a knowledge gap between professionals or academics from various organizations and countries, there is still a need to connect the human impacts on wetlands and the subsequent effects of global warming and climate change, particularly in developing countries [116]. It is unknown to no one that climate change is occurring on a global scale, causing impacts that vary from one region to another and even within the same region. Therefore, advancing climate change governance at all levels is paramount. Consequently, future studies should look at identifying and evaluating the links between wetland health and climate change.

Only one study could be identified that integrated the use of

Table 4
Pollutant removal using CW with common and ornamental plants.

Plant type	Plant name	Type of CW	Mechanism potential	HTR	Removal	Granular medium	Wastewater type	Author
	Phragmites spp	VSSFCW	Phytoextraction (Absorption) and Phytodegradation (phytotransformation)	1.12	BOD: 75–81, COD:65–70, NO3–N: 90, TP: 50, FC:94-96	Gravel	Domestic wastewater	García- Avila et al. [10]
	Typha spp	HSSFCW	Phytoextraction	3	NT: 47, PT: 33 COD: 67, ST: 34	Volcanic rock	Domestic wastewater	Hernández-Alarcón [101]
	Scirpus spp	FWS	Rhizodegradation, Phytodegradation	1	BOD:53.8, NO3:51.6 TP:9.1 FC:87.0	Gravel	Sedimented residual	Jinadasa et al. [102]
	Typha spp	FWS	Rhizodegradation, Phytostabilization	1	BOD:58.5, NO3:52.1 TP:11.2 FC:84.7	Gravel	Sedimented residual	Jinadasa et al. [102]
	Arundo donax	VSSFCW	Phytoextraction	0.03	COD: 56.03–67.64, N–NH4: 48.66–67.28	Gravel	Anaerobic reactor effluent	Sylla [103]
	Saccharum spp, Panicum maximum	VSSFCW	Phytoextraction	5.6	COD: 92 FC: 95	Gravel and sand	Coffee processing effluent	Orozco et al. [100]
	Phragmites australis, Equisetum hyemale	HSSFCW-FWS (Hybrid)	Phytodegradation, Phytoextraction		BOD: 79, SST: 84, NT:96, FC: 99	Gravel	Domestic wastewater	Luna-Pabello et al. [104]
Ornamental plant	Cyperus papyrus,	VSSFCW	Rhizodegradation, Phytodegradation	1.12	BOD: 75–81, COD:65–70, NO3–N: 90, TP: 50, FC:94-96	Gravel	Domestic wastewater	García- Avila et al. [10]
	Canna spp	VSSFCW	Phytodegradation, Phytoextraction		N: 65–67, P: 63–74, Zn– Cu: 98–99, Carbamazepine: 25–51	Volcanic rock	Synthetic	Macci et al. [105]
	Cyperus papyrus, Zantedeschia aethiopica,	VSSFCW	Phytodegradation Phytoextraction Rhizodegradation	3	NT: 47, PT: 33 COD: 67	Volcanic rock	Sedimented residual	Hernández-Alarcón [101]
	Lilium sp, Anthurium sp.	HSSFCW			ST: 34			
	Canna hybrid, Alpinia purpurata, Hedychium coronarium	HSSFCW	Phytodegradation, Phytoextraction	3	F: 35-45 Cl: 28-34	Gravel	Domestic wastewater	Marín- Muñiz et al. [106]
	Canna hybrids, Strelitzia reginae	HSSFCW	Phytoextraction	3	COD: 86, NT: 30-33 PT: 24-44	Volcanic rock	Domestic wastewater	Merino-Solís et al. [107]
	Zantedeschia Aethiopica, Canna flaccida	HSSFCW-VSSFCW	Phytodegradation, Phytoextraction	2.3	SST: 85.98, COD:85.83 NH4–N:65.46, NO3-, NT: 72.62	Gravel	Domestic wastewater	Belmont et [44]
	Zantedeschia aethiopica	VSSFCW		1.58	COD: 92, N–NH4: 85, P-PO4: 80	Grava sílica	Gravel	Ramírez-Carrillo et [108].
	Zantedeschia aethiopica, Heliconia Golden Torch	HSSFCW-VSSFCW		3	COD: 70 P-PO4: 76, NO3: 76	Volcanic rock	River water	Galindo-Zetina [109]
	Heliconia psittacorum	VSSFCW	Phytoextraction	5.6	COD:92, FC: 95	Gravel and sand	Coffee processing effluent	Orozco et al. [100]
	Cannahybrids Heliconia psittacorum	HSSFCW	Phytoextraction	4 4	TN:31–43, TP:26 - 44 TN:6–22, TP:4-22	Gravel	Domestic wastewater	Konnerup et al. [45]
	Strelitzia reginae	HSSFCW		4	BOD:70–78, TN:70–76, TP:69-73	Volcanic rock	Domestic wastewater	Zurita et al. [110]
	Zantedeschia aethiopica			4	BOD:77–81, TN:80–82, TP:75-82	Volcanic rock	Domestic wastewater	
	Agapanthus africanus			4	BOD:60–71, TN:61–73, TP:70,974	Volcanic rock	Domestic wastewater	
	Hemerocallis dumortieri			4	BOD:63–74, TN:74–78, TP:69-73	Volcanic rock	Domestic wastewater	
	Anthurium andreanum	HSSFCW-VSSFCW		4	BOD:80–86, TN:44–57, TP:47-54	Volcanic rock	Domestic wastewater	Zurita et al. [46]

ornamental plants in CWs and climate change. Salimi et al. [117] indicates that it should be analyzed whether climate change presents itself as a great threat to constructed wetlands; climate change can alter the hydrology of the CW, meanwhile, the increase in temperature can alter the biogeochemistry and functionality of the CW, and some important services may become harmful activities. In other words, as a consequence of climate change, the CWs could no longer provide a water purification service, but rather begin to decompose and release nutrients to surface waters.

Another knowledge gap identified is the use of CW systems with ornamental plants to treat mixtures of non-point source runoff pollutants containing nutrients, pesticides and antibiotics [106,118].

Despite the multiple uses of CWs in urban areas, there is still a significant knowledge gap in urban CWs treatment systems with ornamental plants, which continue to acquire greater importance as urban centers continue to grow, provide urban ecological services as well stormwater management, wastewater treatment and ecological purification of urban water, and provide a positive landscape impact [118, 119].

3.12. Potential research on the use of ornamental plants in constructed wetlands

After the scientometric analysis of the use of ornamental plants in CWs in the last two decades, the need to investigate different species of ornamental vegetation that contribute positively to wastewater treatment can be evidenced [120]. That is, the objective of new research should aim to identify which are the species of ornamental plants appropriate to the climate of each region. The use of ornamental plants in constructed wetlands for the removal of pollutants has been commonly applied in tropical and subtropical areas in different countries of the world. However, studies related to the application of this type of vegetation in cold climates are still needed, as well as the application of this vegetation in riparian areas in rivers, lakes or lagoons.

To date, the rate of adoption of wetland technology for wastewater treatment in cold regions has been slow and there are relatively few published reports on CW applications in cold climates. Likewise, different substrates should be tested with ornamental plants, the results will allow a better analysis of the adaptation of these plants to different substrates in cold and tropical climates [121].

When using ornamental plants with commercial value, the time for the recovery of the economic resources invested in the design, construction and maintenance of the system should be investigated, as well as study the environmental, economic and social potentialities. Likewise, the treatment of wastewater in CWs with ornamental plants in rural areas and the reuse of their effluents as irrigation water still needs to be investigated, within the framework of a circular economy, that will contribute to the need of each country to find alternative water sources to develop agriculture, which is especially critical in rural areas.

The analysis of the recovered documents also made it possible to show that many ornamental plants are being combined with other species or are being mixed with natural wetland plants. Therefore, the synergy of several species in the same CW could continue to be investigated.

Initially, it has been identified that CWs may even serve as carbon sinks, accumulating and storing carbon-containing molecules in the form of biomass. Therefore, it is necessary to carry out studies that analyze the contribution of CWs to carbon capture, because ornamental plants need nutrients for growth and photosynthesis, during which CO_2 is finally converted into biomass, reducing dioxide emissions [122]. But it is also pertinent to determine the greenhouse gas emissions in CW with ornamental plants [123].

It is pertinent to evaluate the influence of the organic load since the organic load is one of the key parameters that affect the efficiency of the CW and also the ornamental plants of the wetlands [124]. On the other hand, studies related to the obstruction of CW granular media are still needed, that is, to evaluate if the implementation of ornamental plants accelerates or decreases the obstruction of the granular media, which is presented as one of the main challenges that affect CW performance [125] (de la Varga et al., 2013). The reduction of the infiltration capacity as a result of the accumulation of solids when using common plants and ornamental plants could be compared. The mechanism through which ornamental plants in CWs remove different forms of pollutants needs to be further investigated.

As mentioned above, the mitigation of the impacts of climate change through CWs with ornamental plants is still being studied. Other potential studies are to evaluate the remediation of microplastics using wetlands constructed with ornamental plants; estimate the carbon footprint caused by the treatment of wastewater through CWs with ornamental plants; explore the possibility of using biomass extracted from wetlands as fuel, the conversion by-product could be used as fertilizer and may reduce the need for synthetic fertilizers [116].

4. Conclusions

The study conducted a scientometric analysis of the research trend on the use of ornamental plants in CWs. This paper presents an overview of the publications produced in this field of research between 2002 and 2022. A total of 112 original and review articles, conference articles, and book chapters published in 71 different peer-reviewed journals were identified. for a total of 376 authors. The analysis focused on Scopus since it was considered as the main database related to wastewater treatment. The main keywords used by the researchers were “ornamental plants”, “constructed wetlands” and “phytoremediation”. Mexico is the country with the largest number of documents published on CWs with ornamental plants, this is due to the fact that Mexico currently faces numerous challenges due to the contamination of water resources due to the scarce infrastructure for sanitation; Other countries that have carried out research in this field are Brazil, USA, China, and India. The institution with the largest number of documents published in this field is the University Center of La Ciénega, University of Guadalajara, Mexico. It has been shown that wastewater treatment using CWs with ornamental plants is possible and feasible.

The study of the application of ornamental plants in CWs in the last two decades has leaned towards Canna, Iris, Heliconia and Zantedeschia. It is important to highlight those ornamental plants in CWs have been used for the removal of organic matter, heavy metals and emerging contaminants, finding that ornamental plants present removal efficiencies similar to common plants. The increase in annual production is mainly due to the growing interest in the commercial and this type of vegetation represents, as well as the landscape value they provide.

This study contributes significantly to the existing body of knowledge on the implementation of ornamental plants in CWs. Through scientometric analysis, it informs researchers about the progress of the studies carried out in this field of research and suggests some of the possible future studies that can be carried out. Thus, it is suggested that more research be carried out on the application of CW with ornamental plants in cold climate regions, as well as the influence of different substrates on the growth and adaptation of ornamental plants; evaluate the relationship of CWs and climate change; analyze the contribution of CWs for carbon capture; study the influence of ornamental plants on the obstruction of the substrate; to evaluate the environmental, economic and social potentialities when using CWs with ornamental plants.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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