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A Scientometric Analysis and Bibliometric Review of the Efficiency of Various Constructed Wetlands to Remove Pollutants in Wastewater

Ahmed Makki Al-Sulaiman & Noor Hakam Al-Khuzaie*
University of Al-Qadisiyah, College of Engineering, Civil Engineering, Iraq

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KEYWORDS
scientometric analysis, bibliometric review, efficiency, constructed wetlands, wastewater

ABSTRACT:
Water is an essential element in all aspects of life, discharging wastewater into water bodies without processing is a major threat to aquatic ecosystems. To treat wastewater, a sustainable, low-cost, and environmentally friendly technology was used as an alternative to conventional wastewater treatment plants, namely constructed wetlands. This study is to assess and depict the current state of research on to remove pollutants in wastewater using constructed wetlands by reviewing previous studies that have published research on constructed wetlands and their efficiency in removing pollutants from domestic, municipal, and industrial wastewater using the VOS viewer software and conducting a bibliometric analysis using Web of Science core database by looking at previous studies on the use of constructed wetlands in recent years. The Web of Science core database was chosen as the data source for this research using the keyword "constructed wetlands" to search on the Web of Science website for research related to the topic of constructed wetlands, then the data was exported to the Excel program, and data was entered in the VOS viewer program to draw a network that shows the most researchers, countries, universities, and institutes that focused on the subject of constructed wetlands, as well as the most prominent keywords used for this topic. The results showed the knowledge of the researchers who have published research on the subject of constructed wetlands and their cooperation, the organizations and countries that have published research on the subject of wastewater treatment using constructed wetlands. The three most important authors who have published on the topic of constructed wetlands are Zhang, Jian, Xie, Huijun, and Liang, Shuang. The three most important universities that topped the institute's list are Shandong University, Chinese Acad Sci, and University Technol Sydney. The peoples r china dominates in the number of publications, followed by the USA and Germany on the subject of constructed wetlands, and previous research has shown that constructed wetlands have high efficiency in the treatment of all kinds of wastewater.

1. Introduction

The quality of surface waterways, notably those in rivers, has significantly declined in recent decades as a result of human activity **(Abed and Jazie, 2014)**. Water contamination and a lack of access to cleanly water are worldwide challenges caused by the expansion of agricultural and industrial operations **(Kassob and Abbar, 2022)**. Concern about dwindling urban water supplies as well as environmental degradation in existing urban water systems has stimulated research into more resilient and sustainable water supply strategies **(Arden and Ma, 2018)**. Sewage water treatment before discharge into surface water is one of the most essential stages in reducing pollution in these waters **(Abbasl and Jassima, 2019)**. Greywater may be utilized for non-potable objectives like toilet flushing and landscape irrigation if wastewater is separated at the source point **(Abdel-Shafy et al., 2013)**. Therefore, there is a need to use effective alternative techniques in wastewater treatment that aim to reduce the level of pollutant content to an extent that can be tolerated by water bodies. This leads to avoiding serious injuries to the environment and human health **(Wu et al., 2015a)**. The quality of treated wastewater is important to determine its acceptability for various uses before it is discharged into freshwater environments since it is an alternative supply of water that may contribute considerably to its usage for various purposes **(Khudair et al., 2018)**. Constructed wetlands

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(CWs) are a feasible solution for this purpose and are gaining favor due to their lower cost and fewer operating and maintenance requirements (**Rai et al., 2013**). CWs were initially employed to treat household wastewater, but their applicability has expanded to include industrial wastewater, agricultural/aquaculture wastewater, and stormwater runoff, etc **(Fletcher et al., 2020).** The performance of a constructed wetland is determined by the kind of constructed wetland, the applied hydraulic load, the vegetation, and the media utilized in the bed (**Parde et al., 2021).** Subsurface flow (SSF) wetlands, free water surface (FWS) wetlands, and CW hybrids are the three types of constructed wetland systems (**Zhang et al. 2014**). SSF CWs are divided into horizontal and vertical systems. The kind of CW used is determined by the treating objectives, available space, geographic location, cost, and pollutants to be treated (**Horner et al., 2012**). Plants that are implanted in constructed wetlands have numerous qualities regarding water treatment, which make them an important ingredient of the design. Macrophytes are the major source of oxygen in CWs through an operation known as radial oxygen loss (ROL), which occurs in the root zone **(Wang et al. 2018).** ROL influences organic waste elimination in both direct and indirect ways. The immediate impact of ROL on organic matter is that during aerobic decomposition, oxygen serves as the final electron acceptor **(Stottmeister et al. 2003).** Substrates, also called media or matrices, are essential components of CWs since they link all of the components **(Dordio and Carvalho, 2013)**. Groos and Pritchard (1969) conceived and developed bibliometric analysis as a statistically quantitative approach to analyzing books in terms of literary and informational links. The method proved useful for identifying the most prominent research trends within a given topic and foreseeing possible future developments. This technique uses many metrics, including but not limited to citation counts, citations-per-document rates, and author h-index, which assist in the final assessment of the research output in terms of institutions, countries, and authors **(Small, 1973)**.

2. Aims of the study

1. Assess and depict the current state of research on to remove pollutants in wastewater using constructed wetlands by reviewing previous studies that have published research on constructed wetlands and their efficiency in removing pollutants from domestic, municipal, and industrial wastewater using the VOS viewer software and conducting a bibliometric analysis using Web of Science by looking at previous studies on the use of constructed wetlands in recent years.
2. knowledge of the contributions of researchers, countries, and universities that have published research on the topic of using constructed wetlands in wastewater treatment.

3. Significance of the study

Highlighting the use of constructed wetlands to remove pollutants in wastewater as a sustainable, environmentally friendly technology and alternative to conventional wastewater treatment plants by importing data on the topic of constructed wetlands from the Web of Science website, exporting the data to an Excel program, and then entering it into the VOS viewer program to assess the developing use of constructed wetlands in recent years. As well as knowing the researchers who have published research on the subject of constructed wetlands and their cooperation, the organizations and countries that have published research on the subject of constructed wetlands. In addition to the keywords that relate to the topic of constructed wetlands that researchers use for searching for the topic of constructed wetlands, it is possible to benefit from these studies by knowing the efficiency of constructed wetlands in treating wastewater and reusing it for agriculture.

4. Constructed wetlands

The general term "constructed wetland" refers to both free surface flow soil-based constructed wetlands and subsurface flow vertical and horizontal reed bed systems (gravel- and sand-based). Planting vegetation (reeds, etc.) in the media distinguishes a constructed wetland from other filter systems, as the dense root mass contributes an extra pollutant-attenuation operation, as a result of complex microbiological interactions around the root zones and the extra uptake and production of biomass in the plant. Processes that are biological, chemical, and physical arise in the wetland as a consequence of interactions between plants, the growth substrate (gravel), and microorganisms to provide secondary treatment to septic tank effluent. The wastewater from the septic tank is treated secondary in the wetland by a mixture of biological, chemical, and physical operations that emerge from the interaction of plants, substrate (gravel), and microorganisms **EPA. (2021)**. With the development of pollutant removal technologies, the application of the CWs technique has been widely used for wastewater remediation **(Jizheng et al. 2019)**. Constructed wetland cells are a carefully engineered ecosystem that utilizes the interactions among macrophytes,microorganisms , and supporting media for treating nearly all kinds of wastewater. This new technology is sometimes considered a phytoremediation system that offers significant ecological values, including wildlife habitat,

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aquaculture, recharging of groundwater, controlling floods, recreational activities, and aesthetic value **(Kumar and Dutta, 2019)**.

Figure1.shows a scheme for various kinds of CWs.

5. Classification of Constructed Wetlands

Constructed wetlands for wastewater treatment might be classified based on the predominant vegetation type, flow direction, and wetland hydrology **(Vymazal and Kröpfelová, 2008)**.

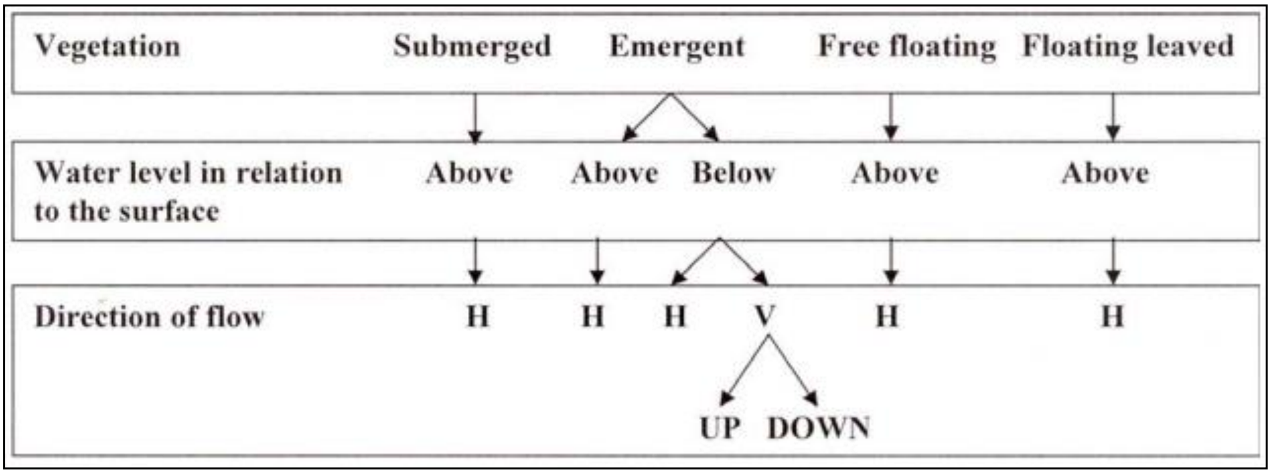

Figure 1. The major characteristics of different kinds of constructed wetlands for treating wastewater. V = vertical, H = horizontal **(Vymazal, 2010)**

5.1. Free water surface constructed wetlands (FWS-CWs)

FWS-CWs are similar to natural marshes and may be planted with floating, submerged, and/or emergent macrophyte vegetation (Figure 2). The hydrologic regime of natural wetlands may be mimicked in FWS units, which in turn can offer aesthetic advantages, wildlife habitats, and water treatment **(Ellis et al. 2003; Stefanakis et al. 2014)**. The surface of the wastewater is at or above the surface of the support media in a FWS-CW (also called a soil-based constructed wetland). These systems are more attractive and beneficial to the environment than reed beds, but they need to be much bigger in order to provide the same amount of treatment as their subsurface counterparts. Through sedimentation, filtration, and biological processes, BOD5, suspended solids, nutrients, and fecal microorganisms are reduced **EPA. (2021)**. This type of CWs requires a higher surface area than other types with the same wastewater properties (origin, flow). Because these systems have an open water surface, they more closely resemble natural wetlands **Stefanakis (2020)**.

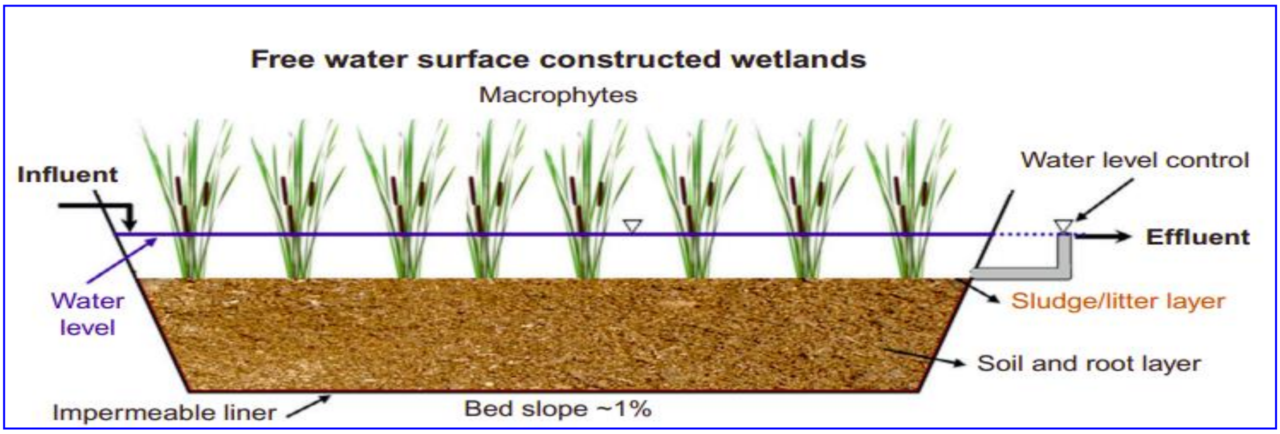

Figure 2. Free-water surface constructed wetlands (FWS CWs; schematic representation) **(Stefanakis et al. 2014)**

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5.2. Horizontal subsurface flow constructed wetlands (HSSF- CWs) (Reed beds with a horizontal flow)

The subsurface horizontal flow reed bed is the most typical kind since the wastewater is kept below the wetland media's surface. Horizontal reed beds have wastewater injected at one end and run through a bed of reeds (flat or slightly sloping, with a little slope of approximately 1%) set inside gravel, where it flows through the bed to the outlet pipe. The amount of water in the horizontal flow reed bed is regulated by this discharge outlet. The hydraulic distribution of the bed concerning the inlet arrangement and aspect ratio should be given special consideration. Reed beds are submerged in water and move horizontally; they are very effective in the elimination of BOD5, pathogenic organisms, and suspended solids. A horizontal subsurface flow reed bed, as seen in Figure 3, is often composed of gravel **EPA. (2021)**.

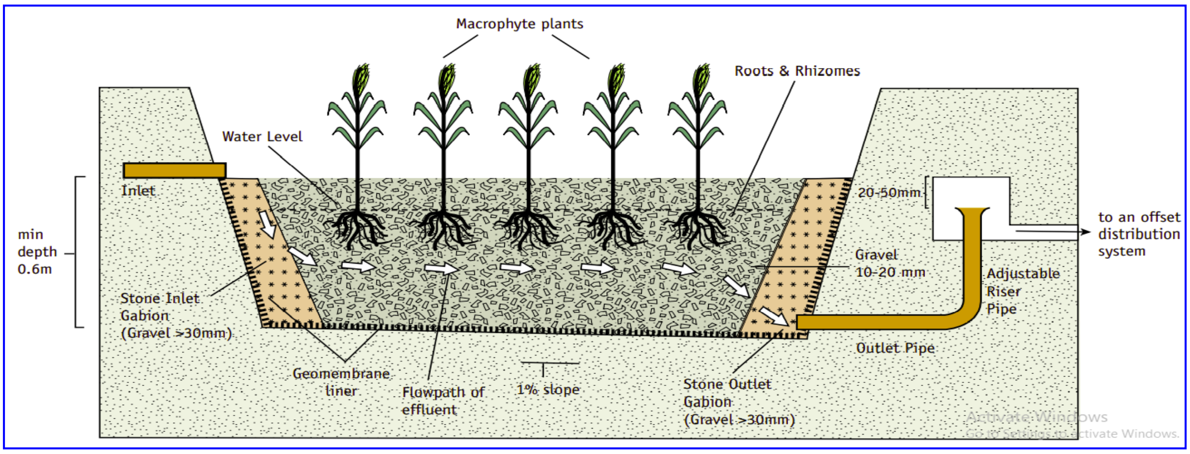

Figure 3. A typical horizontal subsurface flow reed bed **EPA. (2021)**

5.3. Vertical subsurface flow constructed wetlands (VSSF-CWs) (Vertical Flow Reed Beds)

In a vertical flow reed bed, a system of pressurised distribution pipes distributes wastewater in sporadic doses evenly throughout the media bed. At the base of the support media, it progressively drains vertically into a drainage collecting network. Utilizing a perforated ventilation pipe that extends into the atmosphere, these drainage pipes should be aerated. Air enters the media pores as the wastewater descends vertically, aiding in the treatment process by maintaining an aerobic environment in the filter media. Nitrification of ammonia nitrogen to nitrate is an extra benefit of vertical flow reed bed systems, which also offer the same level of remediation effectiveness as horizontal flow reed beds (over a smaller plan area). A vertical flow reed bed media might be gravel, sand, or a combination of the two **EPA. (2021)**. (Figure 4) shows a model cross-section of a vertical flow reed bed with sand and gravel.

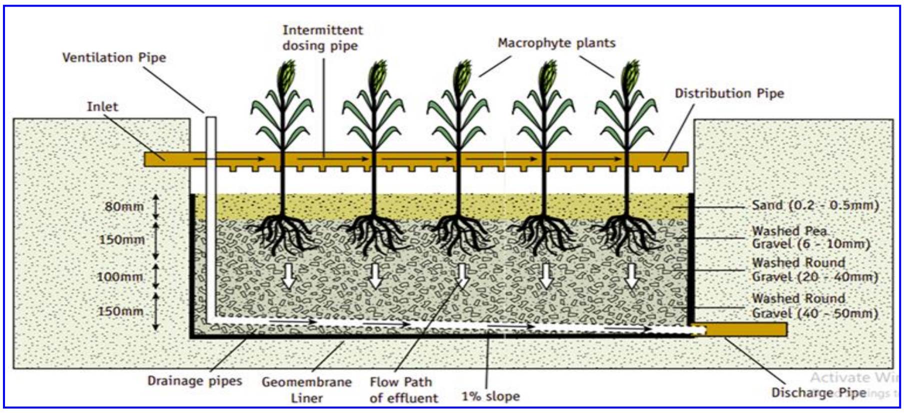

Figure 4. A model vertical subsurface flow reed bed **(EPA. 2021)**

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(Wu et al. 2015b) have summarized some of the main characteristics of these systems as follows:

- High tolerance to cold weather.
- The high ability to transform Oxygen and oxidize ammonium oxidation is high compared with other systems.

5.4. Hybrid Constructed Wetlands

Hybrid CWs are nonconventional CWs that combine two or more CWs into one series (Figure 5). Thus, the hybrid CWs render the effluent quality better than that of the singular CW systems. Generally, hybrids CWs combine either VFCW in the first phase with HFCW in the second phase, or vice versa, for efficient effluent treatment. The use of hybrid CWs (horizontal and vertical flow or vertical and horizontal flow) is an efficient wastewater remediation method with the potential to reduce the loss of water **(Melián et al. 2010)**. Hybrid CWs are designed to lower organic pollutants and metals and also buffer the pH of the recovered groundwater **(Wallace et al. 2011)**. Recently, hybrid CWs are in operation in many countries and they are utilized especially for ammonia-N and total-N removal **(Vymazal and Kröpfelová, 2008)**. (Figure 5) shows a hybrid constructed wetland.

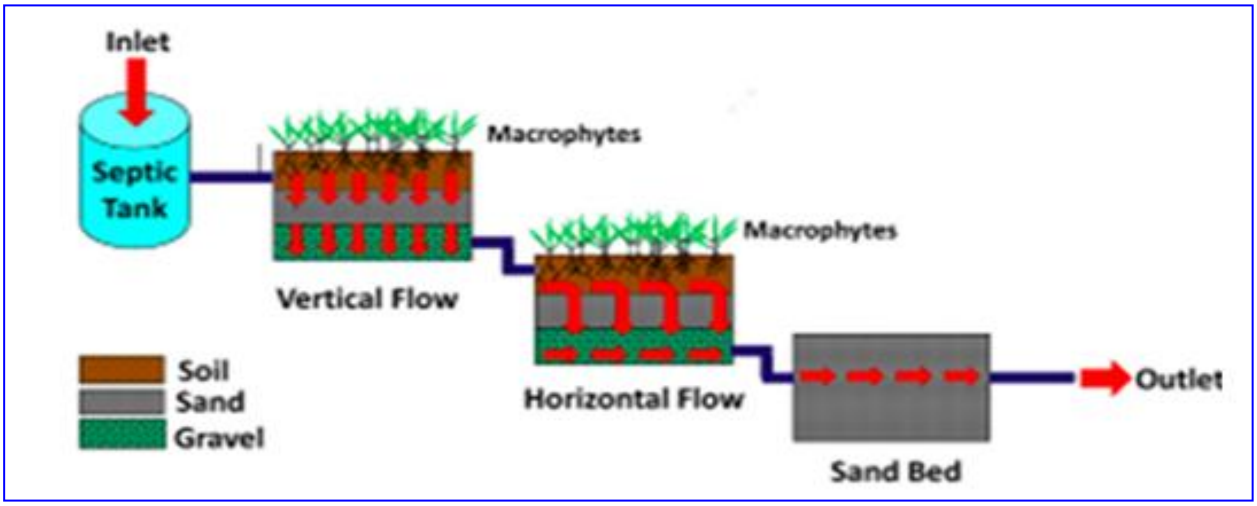

Figure 5. Diagram of a subsurface hybrid constructed wetland (SS-HCW) **(Sehar et al., 2015)**

6. Major components contributing to treatment mechanisms

6.1. Wetland vegetation (macrophytes)

Many types of wetland plants have been used in CWs because they each contribute something unique to the purification process. Most macrophytes used in CWs systems fall into one of four categories: free-floating plants, submerged plants, floating-leaved plants, or emergent plants. While over 150 macrophytic plant species have been documented for use in CWs worldwide, only a few of them are extremely often utilized **(Saeed and Sun, 2012; Vymazal, 2013)**. The basic function of aquatic plants is to catalyze the purification process. This therapeutic approach combines microbiological and physicochemical systems. The plants take no significant action or directly remove certain impurities. Nonetheless, during the vegetative season, aquatic plants may contribute 10%–20% to the removal of N, P, and some organic waste, in addition to the accumulation of heavy metals **(Brix. 1997; Abdel-Shafy et al., 1986)**. The presence of macrophytes in CWVF is one of the most essential components of the treatment system. This is because vegetation spreads and decreases water velocity, allowing for improved deposition of suspended particles from the effluent to be treated. aids in the elimination of system substrate blockage **(Somes et al. 1996)**.

6.2. Supporting media

Some important aspects should be considered while selecting substrate materials for long-term pollution removal. Adsorption capacity, economic viability, and availability. In the gravel substrate system, the main removal processes are filtration, adsorption, and precipitation. However, plant absorption and biological assimilation play an important role **(Ge et al., 2015)**. In some constructed wetland subsurface flow systems, gravel, rocks, sand, and other organic materials are widely utilized as subsoil below the root zones. Additionally, the substrate not only provides support for microorganisms, plants, roots, and rhizomes, but it can also be considered a storage facility for a set of pollutants **(Jurries, 2003; Ge et al., 2015)**.

6.3. Microorganisms

The biotic community of CW is mainly confined to organisms that can endure low water quality, such as microorganisms found in the root system and found in diverse forms, such as biofilm, bacterial colonies, or without particular geometric shapes. They aid in the decomposition of organic substances and other low-molecular-weight biodegradable substances **(Mackintosh et al., 2017)**. Microorganisms reside in the wetland in the water, substrate, or plant roots, and the biomass density may be raised depending on the degradation and utilization of the available nutrients, resulting in a considerable reduction in wastewater impurities. Wetland efficiency is heavily influenced by bacteria, which can eliminate unwanted substances via their metabolism. Fungi, bacteria, algae, and protozoa are among the microorganisms found in both anaerobic and aerobic places within the wetland. However, the temperature of the water has a major impact on microbial transformation **(Kadlec and Wallace, 2009)**.

7. Scenario in Constructed Wetland Research

Abdel-Shafy et al. (2014) investigated the feasibility and effectiveness of the aeration system after different sedimentation periods. The sedimentation process was optimized using Effective Microorganisms (EM). During the experimental process, they measured sedimentation periods, EM doses, and aeration rates to isolate their effect on water quality. The purpose is to reach the unrestricted water reuse. Settling time, EM dose, and duration of ventilation were among the factors examined in batch studies investigating greywater treatment. Use the best conditions found in an experimental botanical study. In the pilot plant study, the removal rate for COD, TSS, BOD5, and oil and grease removal was 63.1%, 70.8%, 70.6%, and 63.5% after 3.0 and 4.5 hours of sedimentation time, respectively, followed by 90 minutes. From ventilation. Even after the settling time was increased to 4.5 hours and aeration was performed for 120 minutes. This processing was less than what was required to achieve the unlimited reuse properties. The treatment efficiency of the above system was improved by adding EM at a concentration of 1.2 mg/L, at which point the final flow characteristics were suitable for reuse in irrigation. Then they increased the EM dose to 1.5 and increased the settling time to 4.5 hours, and then aerated the mixture for 90 minutes. TSS, COD, BOD5, oil, and grease were all removed at rates of 98.1, 91.1, 96.1, and 96.2%, respectively. In the final flow, the concentrations of both Escherichia coli and nematode cells or eggs reached 100 ml/L and count/L, respectively.

Abdel-Shafy and Al-Sulaiman (2014) focused on treating greywater for reuse. The ideal period for degreasing / settling was determined by examining the greywater treatment. They studied other treatments, including hybrid wetland systems. They successfully eliminated the parameters of pollution. The removal rates for TDS, COD, BOD5, TP, NO3, oils and greases, and TKN were, respectively, 87%, 83%, 88%, 91%, 36%, 92%, and 58%. The final flow included 100/mL and 1 egg/L, respectively, of the number of E. coli and nematode eggs or cells.

Abdelhakeem et al. (2016) studied the performance of a VSSFCW for sewage treatment in Egypt over 8 months under various operating circumstances, including sewage feeding mode (batch or continuous), substrate type (vermiculite or gravel), and vegetation (the presence or absence of Phragmites australis common reeds). This research focused on the role of vegetation and substrate type in the removal of COD, BOD, TSS, and NH4, as well as TP and DP (dissolved phosphorus) under all investigated conditions. The average removal efficiencies of COD, BOD, TSS, NH_4, and TP for unplanted beds were 29, 37, 42, 26, and 17%, respectively; however, these values climbed to 75, 84, 75, 32, and 22% for planted beds.

Abdul Shafi et al. (2017) investigated hybrid wetlands' performance (CWs) for black water treatment. This examination included the experimental study of real samples of black water. This study proposes an integrated system that treats concentrated black water as strong wastewater, first with sedimentation and then with a horizontal-vertical hybrid flow of wetlands. From the raw black water, the sedimentation tank removed around 56.8%, 58.0%, and 64.8% of the TDS, COD, and BOD, respectively. The removal efficiencies of TSS, COD, and BOD rose to 82.9%, 87.1%, and 88.0%, respectively, when the sedimentation tank water was additionally treated by subsurface horizontal wetland. The effluent quality was then enhanced via vertical wetland treatment. The combined system decreased total pollutant parameters by 97.4%, 98.5%, and 98.0% for TSS, COD, and BOD, respectively.

Al-Maliky et al. (2018) evaluated the performance of three different CWs for the treatment of municipal wastewater. The three systems are (VSSF), (HSSF), and (SF). Phragmites australis, Typha domingensis, and Certophyllum demersum planted in these different systems. The findings showed that the mean efficiency for removing NH_4-N was 78.98%, with 78.68% achieved by VSSF, 76.04% by HSSF, and 82.20% by SF. This number equates to 90.58% of PO_4 being removed, with 90.29% being removed by VSSF, 90.18% being removed by HSSF, and 92.02% being removed by SF. The findings showed a total average removal effectiveness of 95.96% of BOD_5, with VSSF at 97.65%, HSSF at

97.99%, and SF at 92.25%. The tests proved the system's efficiency in eliminating the target pollutants.

Sudarsan et al. (2018) used Typha latifolia and Phragmites australis as vegetation to reduce the level of pollutants in domestic wastewater. For the convincing flow of the wastewater, a bottom slope of 1% was also adapted. After the plants reached full maturity, they were fed with residential wastewater, and pollutant removal and vegetation were assessed. T. latifolia, in which vegetation removed 75% of BOD and 70% of COD from wastewater, while P. australis vegetation removed 65% of BOD and 70% of COD. As vegetation, T. latifolia was found more effective as vegetation than P. australis.

Rahi and Faisal. (2019) compared vertical, horizontal, and hybrid subsurface flow systems planted with Phragmites Australia in secondary remediation to the effluent wastewater of the primary basins for the Al-Rustumia wastewater remediation plant. To evaluate the suitability of treated water for irrigation purposes. They tested total suspended solids (TSS), chemical oxygen demand (COD), phosphate (PO_4-P), and ammonia-nitrogen (NH_4-N). The implanted hybrid subsurface flow wetland system realized the highest elimination, with a mean elimination rate of TSS, COD, PO_4-P, and NH_4-N of 83.2, 99.3, 53%, and 67.4, respectively. The findings showed that the TSS, COD, PO_4-P, and NH_4-N values removed by the vertical subsurface flow unit were 71.1%, 93%, 30.7%, and 43.3%, respectively, while the eliminations by the horizontal subsurface flow unit were 74.3%, 99%, 20.3%, and 54.5%, respectively.

Jin et al. (2020) evaluated the possibility of combining bio-contact oxidation and CW (BCO-CW) to remove NH_4+ -N, COD, TN, and TP from high-contaminant blackwater. Canna, Lysimachia, Calamus, , and other robust plants that are resistant to pollution were planted in the constructed wetland. The results demonstrate that the removal efficiencies of NH_4+-N, COD, TN, and TP were 42.2%, 81.6%, 56.1%, and 73.7%, respectively. The highest nitrogen elimination rate was 16.5 g $m^{-2}d^{-1}$(3d). Direct plant absorption of N and P represents only 19.7% and 16.1% of the overall system, respectively.

Ajell et al. (2020) employed a horizontal subsurface flow basin of a station planted with Typha domingensis. The retention times were 3, 4, and 6 days during which COD, TN, and NH_4 were measured and recorded a removal rate of (47.7%, 53.2%, 77.5%), (45.1%, 52.8%, 64.4%), and (55.4%, 58.8%, 72.2%), respectively. The average removal of NO3 after three days was 19.41%.

Al-Ajalin et al. (2020) examined how well CW works for domestic wastewater. For 5 days, researchers looked at the efficacy of horizontal flow CW in removing COD, BOD_5, TSS phosphorus, and ammonium from wastewater at two different depths (35 cm and 45 cm). Experiments were conducted at a variety of wastewater depths using native plant species such as Lepironia articulate and Scirpus grossus. TSS, BOD_5, and COD removal are all enhanced by plants, with some reaching 40%, 27%, and 38.5%, respectively, compared to non-planted beds.

8. Data collection

The Web of Science core database was chosen as the data source for this research using the keyword "constructed wetlands" to search on the Web of Science website for research related to the topic of constructed wetlands to remove pollutants in wastewater.

The research was exported to the Excel program, and data was entered in the VOS viewer program to draw a network that shows the most researchers, countries, universities, and institutes that focused on the subject of constructed wetlands, as well as the most prominent keywords used for this topic.

9. Analytical Method

In this age of quick technological advancement, it is crucial to analyze bibliometric data that is graphically shown using mapping technologies **(Nandiyanto et al., 2020a; Nandiyanto et al., 2020b)**. The findings of the description and other information on the development of the field of science and the performance of the research that has been conducted may be obtained using mapping tools. VOSViewer is an instance of a mapping tool that may be used to undertake bibliometric data analysis mapping **(Gracia, 2020)**. VOSviewer was used to generate bibliometric and visual maps for this research. VOSviewer is computer software that may be used for a variety of tasks, including the creation of network-based maps. The VOS mapping method and the VOS clustering method are employed to create these maps. Maps may be seen and explored with 1 and the VOS Viewer. It's possible to display maps in many distinct ways, each of which draws attention to a particular feature of the map. It has advantages like scrolling, zooming, and searching that allow for a more complete analysis of a map. The viewing abilities of VOSviewer show better when dealing with maps that contain at least a somewhat large number of elements (e.g., at least 100 or 200 items). The analysis of bibliometric networks is the main objective of VOSviewer. The program may be utilized to create maps of publications, authors, or journals based on citation, co-citation, or bibliographic coupling networks, as well as maps of keywords based on co-occurrence networks. Nevertheless, VOSviewer is not limited to bibliometric networks only. VOSviewer may be used to create maps

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based on any sort of network **(Van Eck and Waltman, 2011)**.

10. Results and discussion

The results are discussed and analyzed in terms of contributions made by authors, institutes, and countries that published research on the subject of wastewater treatment using constructed wetlands in terms of co-authorship authors, co-authorship organization , co-authorship country and co-occurrence.

10.1. Top Contributions

Table 1 illustrates the higher 10 contributions made by authors, institutes, and countries. The most important top three authors who have published on the topic of constructed wetlands are Zhang, Jian (115 publications), Xie, Huijun (70 publications), and Liang, Shuang (69 publications). The most important top three universities that topped the institute's list are Shandong University (54 publications), Chinese acad sci (44 publications), and University technol Sydney (37 publications) on the topic of constructed wetlands. The peoples r china dominates in the number of publications 79 publications track it USA (68 publications) and Germany (39 publications) on the topic of constructed wetlands.

Table 1. Higher 10 contributions of authors, institutes, and countries

No.	Authors	Frequency	Institute	Frequency	Country	Frequency
1	Zhang, Jian	115	Shandong University	54	Peoples China	79
2	Xie, Huijun	70	Chinese Acad Sci	44	USA	68
3	Liang, Shuang	69	University Technol Sydney	37	Germany	39
4	Zhao, Congcong	69	Aarhus Univiversity	23	Australia	37
5	Kong qiang	55	University Coll Dublin	22	England	36
6	Guo, Wenshan	54	Chinese res inst Environm Sci	19	India	28
7	Wang, Qian	53	University Tasmania	19	Spain	24
8	Hu, Zhen	52	Beijing Normal Univ	18	Canada	21
9	Ngo, Hhuu hao	40	Czech University Life Sci Prague	17	France	21
10	Wu, Haiming	33	Irstea	17	Ireland	18

10.2. Co-authorship authors

The minimal number of documents of an author was considered 1 to calculate the total strength link between the author and another author. Figure 6 illustrates network visualization, which showed that, of the 3414 authors, 3414 meet the thresholds. The bulk of the large circles indicate the number of publications, and the interconnections amidst the circles indicate the relationships between authors that mean co-authorship. In Figure 6, the largest circle represents the most prominent researcher who has published research on the topic of constructed wetlands. The most important researchers who have published on the topic of constructed wetlands are Zhang, Jian, Xie, Huijun, and Liang; Shuang, Zhang, Jian, and other researchers examined the reaction of eight vertical-flow constructed wetlands (VFCWs) to different COD/N ratios and irregular aeration in the treatment of household wastewater **(Fan et al., 2013).** Xie, Huijun, and other researchers examined the effects of various drying times and intermittent operation on pollutant removal as well. They investigated the growth of wetland vegetation in vertical-flow wetlands (VFWs) **(Jia et al., 2010)**. Liang, Shuang, and other researchers studied the combination of emerging and submerged plants' proven ability to make surface flow constructed wetlands (SFCW) better at getting rid of pollution in the winter. But during the summer, when submerged plants do a lot of photosynthesis, the pH rises, which could be bad for emerging plants **(Yin et al., 2016)**. Figure 6 contains 308 items, 21 clusters, 1465 links, and 1828 total link strengths.

Figure 6. Author – Co-authorship network visualization

10.3. Co-authorship organization analysis

The minimum number of documents for organization 1 was considered to calculate the total strength correlation between the organization and the other organization. Figure 7 shows network visualization, which shows that, among the 1114 organizations, 1114 meet the minimum. The large circles indicate the number of contributions, and the interconnections between the circles indicate the relationships between the organizations that contributed to the topic of the constructed wetlands. In Figure 7, the largest circle represents the most prominent organization that contributed to the topic of the constructed wetlands. The top three most significant organizations that contributed to the topic of constructed wetlands were Shandong University, Chinese Acad Sci, and University Technol Sydney. Figure 7 contains 438 items, 33 clusters, 949 links, and 1089 total link strengths.

Figure 7. Institute – Co-authorship network visualization

10.4. Co-authorship country analysis

The minimum number of documents for country 1 was considered to calculate the total strength correlation between the country and the other country. Figure 8 shows network visualization, which shows that, among the 82 countries, 82 meet the thresholds. The large circles indicate the number of research papers a country has published on the constructed wetlands topic, and the connections between the circles indicate the relationships

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between countries that have contributed to the constructed wetlands topic. In Figure 8, the largest circle represents the most prominent countries that contributed to the publication of research related to the subject of constructed wetlands. The top three countries that contributed to the publication of research related to the subject of constructed wetlands are Peoples r China, the USA, and Germany. Figure 8 contains 68 items, 13 clusters, 200 links, and 333 total link strengths.

Figure 8. Network visualization map of the Country

10.5. Co-occurrence Measures

The analysis encompassed all available keywords in the publications, and the floor number of keyword occurrences was set to 15 as a limit condition. Of the 1755 keywords, the results show that 24 met the threshold. Large circles indicate the most prominent keywords related to the topic of constructed wetlands. In Figure 9, the largest circle represents the most prominent keywords that can be used to search the topic of constructed wetlands. The first three keywords are the most important keywords that can be used to research the topic of constructed wetlands are constructed wetlands, constructed wetland, and wastewater. There are 24 items, 8 clusters, 134 links, and 867 total link strengths. In Figure 10, the yellow color shows the density of the co-occurrences. Some of the keywords with high densities are constructed wetlands, wastewater, phosphorus, nitrogen, wastewater treatment, denitrification, macrophytes, nutrients, phytoremediation, nitrogen removal, nitrification, wetlands, and 13 other keywords. Dark yellow circles indicate the most frequently used keywords, which help the researcher search for published research on the subject of constructed wetlands.

Figure 9. keywords – Co-occurrence network visualization

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Figure 10. keywords – Co-occurrence density visualization

11. Conclusions

1. Previous research has shown that constructed wetlands have high efficiency in the treatment of all kinds of wastewater.
2. The following results may be obtained from a review of the literature using VOS viewer software on investigations for constructed wetlands:
   a. The most important top three authors who have published on the topic of constructed wetlands are Zhang, Jian (115 publications), Xie, Huijun (70 publications), and Liang, Shuang (69 publications).
   b. The most important top three universities that topped the institute's list are Shandong University (54 publications), Chinese Acad Sci (44 publications), and Univ Technol Sydney (37 publications) on the topic of constructed wetlands. The peoples r china dominates in the number of publications (79 publications), followed by the USA (68 publications) and Germany (39 publications) on the subject of constructed wetlands.
   c. The majority of the synchronized keywords were related to constructed wetlands, Sanitation, Phosphorus, Nitrogen, and other keywords.

12. Recommendations

1. Use the Dimensions website to import data on the topic of constructed wetlands to remove pollutants in wastewater instead of the Web of Science website to learn about previous research that has been studied on the topic of constructed wetlands in terms of co-authorship authors, co-authorship organization, and co-authorship country.
2. Discussing and analyzing the results in terms of co-citation and cited reference, co-citation cited sources, and organization analysis of citations.
3. Through this study and using VOS viewer, this helps researchers reach a group of authors, countries, and universities that have studied what is related to the use of constructed wetlands in wastewater treatment.

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