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Review

Potential of *Canna indica* in Constructed Wetlands for Wastewater Treatment: A Review

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Abstract: This article reviews investigations in which *Canna indica* was utilized in constructed wetlands (CW) for wastewater treatment of a variety types. It is strongly urged that ornamental flowering plants be used in CWs as monoculture or mixed species to improve the appearance of CWs whilst still treating wastewater. Plants play important roles in CWs by giving the conditions for physical filtration of wastewater, a large specific surface area for microbial growth, and a source of carbohydrates for bacteria. They absorb nutrients and integrate them into plant tissues. They release oxygen into the substrate, establishing a zone in which aerobic microorganisms can thrive and chemical oxidation can occur. They also provide wildlife habitat and make wastewater treatment system more visually attractive. The selection of plant species for CW is an important aspect during the CW design process. *Canna indica*'s effectiveness in CWs has shown encouraging results for eliminating contaminants from wastewater. There is still a scarcity of information on the mechanisms involved in removal of specific contaminants such as pharmaceuticals, personal care products, hormones, pesticides and steroids and their potential toxicity to the plants. Therefore, this paper reviews some published information about the performance of *Canna indica* in wastewater treatment, as well as potential areas for future research.

Keywords: constructed wetlands; *Canna indica*; emerging contaminants; wastewater treatment; phytoremediation

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1. Introduction

Constructed wetlands (CW) are manmade structures used for treatment of water and wastewater. They consist of plant species, substrates and microorganisms [1]. They work by mimicking natural wetlands processes in a somewhat more controlled environment [2]. Water and wastewater treatment in CW is enabled via a variety of physical, chemical, and biological processes [3,4]. The root zone (or rhizosphere) is the active reaction area of CWs. This is the site of physicochemical and biological processes resulting from the interaction of plants, microbes, soil, and contaminants [5]. Hydraulic loading rates, water retention time, water depth, CW design and construction, and feeding mode are all important operational factors that influence CW treatment performance [2]. CWs are getting more and more popular as a treatment option for a variety of wastewaters, including industrial, agricultural, and household wastewaters, landfill leachate, and stormwater runoff [1,6–8]. Several studies have shown that these systems are effective at removing carbon, nitrate, phosphate, and heavy metals [9,10]. One of the great advantages of CW systems is their cheap operating and maintenance costs [11,12].

Plants are widely acknowledged as having a vital role in the elimination of contaminants from CW wastewater [12]. This is accomplished by complex interactions between plants, water bodies, media, and microorganisms. Plants in CWs has a thermoregulatory impact that promotes a multitude of physical, chemical, and biological activities [13,14]. These include increasing the filtering effect and porosity throughout the root distribution, uptake and storage of some essential nutrients in their tissues. They also protect the CWs from frost in the winter and radiation in the summer, and acting as a purification reaction by increasing the process diversity in the rhizosphere [15,16]. They deliver oxygen to the substrate's root zone, allowing aerobic bacteria to breakdown contaminants [17,18]. They also discharge root exudates, which biofilms consume, and they introduce new fungus and symbiotic bacteria to the wetland ecology [3]. As a result, CWs with plants have a higher nutrient removal efficiency than those without plants [18].

Because different plants perform differently, plant species selection and clarifying their crucial role in the treatment process are critical concerns in the design of CWs [14]. Plants that grow naturally in the region where CWs are being established are usually preferred [2]. The selection of a suitable permeable substrate in proportion to the hydraulic and organic loads is the most critical design parameter for CW. Most treatment issues arise when the permeability is not sufficiently chosen for the applied load [19]. The substrate utilized may also have an impact on performance of a selected plant in CW. The interaction among both roots/rhizomes as well as the substrate is an essential part of the complex activities occurring in the rhizosphere. The substrate is the primary substance that supports growth and development of plants and microbial films [5] and directly interacts with contaminants via physical adsorption [20]. The volume and length of the roots of the same plant can vary dramatically depending on the substrate. Natural materials such as gravel, sand, zeolite, anthracite, volcanic rocks, granite, quartz, and soil are used, as are man-made substrate materials such as hollow bricks, steel slag, ceramic, activated carbon, artificial ecological substrates, and sponge iron [21].

1.1. Plants Used in CW

The most commonly used plants in CW, according to literature, are *Phragmites australis*, *Typha latifolia*, and *Cyperus papyrus* [22–26]. *Canna indica* is currently being studied as a potential option for CW [13]. When compared to *Phragmites australis*, a commonly utilized plant for CWs, the key benefit of the Canna plant is its high biomass production with a fast development rate [8]. Because fast-growing plants with huge roots are favourable for nitrifying bacteria to improve nitrification, the biofilm's surface area is increased by their quick growth rate and large biomass [18]. The Canna plant consumes 3–5 times more water than typical wetland plants. Furthermore, the flowering and attractiveness provide additional benefits for its application [24].

When compared to *Cyperus alternifolius* and *Phragmites australis*, *Canna indica* outperforms them in terms of pollution reduction and greenhouse gas emissions [18,27]. *Canna indica* have a fibrous roots structure that produces high aerobic conditions throughout the CW, allowing for more removal [26]. Its root system has much more root development, root number, root biomass, and root surface area than the other plant species. This plant has a high level of pollution resistance and a lengthy root life cycle [26]. *Canna indica*'s aerenchyma tissue facilitates the delivery of ambient oxygen to the rhizosphere creating a perfect environment for nitrification processes. According to studies, plant absorption contributes roughly 5–15% of total nutrient removal from wastewater, while the majority of pollutant removal occurs in the rhizosphere by root zone bacteria [28].

1.2. About Canna indica L.

Canna indica L. (Figure 1) is one of the most common flowering ornamental plants for garden borders and beds, and occasionally grown as potted plants [27]. Recent investigations have revealed that the plant has medicinal value in addition to its ornamental value [29]. Some features of *Canna indica* are given in Table 1.

Figure 1. *Canna indica* plant (Photo by author).

Table 1. Some characteristics of *Canna indica*.

Characteristics	Description of Characteristics
Plant description	*Canna indica* is a coarse perennial herb that grows to heights of 90 cm to 3 m. It owns large leaves similar to but not as large as those of the banana plant [30]. The flowers are red, solitary or in pairs, and the bract is about 1.3 cm long. The fruits are green oblong capsules that are spiny and 2 to 2.5 cm long. The silky coat protects the seeds, which are first white and then turn black with chestnut brown markings as they mature [31–33].
Botanical classification	Kingdom: Plantae, Subkingdom: Tracheobiont, Super division: Spermatophyta, Division: Magnoliophyta, Class: Liliopsida, Subclass: Zingiberidae, Order: Zingiberales, Family: Cannaceae Genus: Canna, Species: indica [31,34,35].
Habitat and geographical distribution	*Canna indica* is native to the tropical regions of America, but it is also found in other tropical countries across the world [36]. It prefers moist, shady environments in forests, savannahs, and swamps as well as areas along rivers or roads [30,35,37,38]. The plant is soft and easily uprooted. It is easily propagated by seeds or root cuttings [39]. *Canna indica* has a life cycle of roughly 9 months [34].
Tolerance	*Canna indica* can tolerate in environments with high salinity [40], high concentration of Cu [41] and Cd^{2+} up to 5 mg/L. Above 5 mg/L Cd^{2+} stress some damage can occur [42]. The plant can also tolerate excess moisture and pests although it is susceptible to rust (Puccinia thaliae) disease, as well as cut worm, Japanese beetles and grasshoppers [38]. It can grow in a wide range of light conditions. This includes both strong light intensity, such as direct sunlight, and low light zones caused by objects such as buildings and bridges [43]. It can also grow well in areas with fluctuating source of nutrients [44,45].
Uses	Due to high antimicrobial activity [32,46,47], different parts of this plant are used as traditional medicine to cure various diseases [48]. It contains palatable natural starch; thus, it can be used as food. The dried root powder of this plant is used to thicken sauces and improve the texture of foods [39]. It is used in CW systems to remove a range of contaminants from water and wastewater [49].

As a result, the purpose of this paper is to examine studies on *Canna indica*'s ability to remove various types of contaminants from wastewater in CW.

2. Materials and Methods

Secondary data acquired from research papers, review papers, and books is presented in this review. These documents linked to the performance of *Canna indica* for the removal of various types of contaminants in CW were gathered from a variety of sources, including Google search, Google Scholar, and individual journal websites. *Canna indica*, constructed wetland, microphytes, wastewater, and effluent are some of the phrases that were used in the search. Only studies that were published in English were considered. We didn't apply any study type or publication date filters in our search.

3. Removal of Nutrients, COD, BOD_5, TDS and TSS

Several studies utilized *Canna indica* in CWs revealed that it is effective at removing total suspended solids (TSS) and several chemical pollutants such as biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD), nutrients such as total phosphorus (TP) and total nitrogen (TN). Results from studies by different researches on removal of conventional wastewater parameters are summarised in the Table 2.

Table 2. Examples of studies on performance of CW planted with *Canna indica* in treatment of wastewater.

			Removal Efficiency (%)						
Type of CW	**Substrate**	**Nature of Wastewater**	**COD**	**BOD_5**	**TDS**	**TSS**	**N**	**P**	**Reference**
VSSFCW	Gravels and sand	Domestic		81.8	22.3		60.4	80.0	[4]
Microscale VSSFCW	Soil	Domestic	87.0	91.0			97.0	98.0	[8]
Lab scale VSSFCW	Vermicompost, soil, sand, gravels	Synthetic	75.8	80.6		84.8	42.6		[50]
HSSFCW	Gravels	ST effluent	54	68.0			13.0		[3]
HSSFCW	Quartz sand	Synthetic	65.0				43.0		[9]
Pilot scale VSSFCW	Water quenched slag	Synthetic						80.0	[7]
VSSFCW	Sand slag	Domestic					24.1	88.9	[1]
	Coal slag	Domestic					29.9	60.1	[1]
	Blast furnace slag	Domestic					21.6	44.7	[1]
Lab scale aerated CW	Gravels and sand	Synthetic	95.0				83.0		[51]
VSSFCW	Stones, gravels, sand and clay	Industrial	74.0			85.0	96.4		[52]
VSSFCW	Gravels	Synthetic	62				95.0	77.0	[53]
Lab scale CW	Pebble, gravels, sand, and soil	Sewage	61.8	68.0	71.7	73.3			[54]
Lab scale CW	Gravels and sand	Synthetic	92.8	87.3	67.8		89	82.6	[55]
Lab scale CW	Gravels and sand	Grey			67.9		89	82.6	[56]

Key: Vertical subsurface flow constructed wetland (VSSFCW), Horizontal subsurface flow constructed wetland (HSSFCW), Septic tank (ST), Chemical oxygen demand (COD), Biochemical oxygen demand (BOD), Total dissolved solids (TDS), Total suspended solids (TSS), Total nitrogen (N), Total phosphorus (P).

The efficiency of CWs planted with *Canna indica* in eliminating nutrients, COD, BOD_5, TDS and TSS from wastewater from diverse sources is shown in Table 1. The interpretation of differences in results from different studies requires caution as plant performance can be influenced by problems during growth, plant health, which can be influenced by pH and toxicity of wastewater, unanticipated occurrences such as extreme freezing or herbivory, or other unidentified factors [57]. Because of differences in pollutant influent loads, CW flow type, and environmental temperatures, the performance findings in different studies varies. These features have a significant impact on CW performance [7,40]. Due to increased interactions between roots, substrates, and nutrients, a longer hydraulic retention time or a slower hydraulic loading rate (HRT) result in higher nutrient removal [1,58]. In comparison to the other types of CW, VSSFCW is employed the most in the studies cited. This is owing to HSSFCWs' limitations, which include a lack of oxygen transfer capabilities. The vertical movement of water across layers to the bottom of beds allows air to fill the pores, resulting in a high oxygen transfer rate in the system that aids nitrification and organic waste removal [59,60]. However, no study has been done to compare side to side the performance of different designs of CWs planted with *Canna indica*. The performance of *Canna indica*-planted CWs of various designs must thus be compared on the basis of substrate type, wastewater source, feeding method, hydraulic retention time, and hydraulic loading rate.

There is a substantial difference in performance depending on whether the plant is grown in monoculture or mixed with other plant species [61]. There is substantial interspecific competition in mixed-culture, according to research undertaken to explore the influence of mono- and mixed-culture between *Canna indica* and *Schoenoplectus validus*, with *Canna indica* being the superior competitor [62]. In a mixed culture, *Canna indica* employs its large leaf area and canopy diameter to capture light and nutrients. This allows it to out-compete other species in both nutrient-limited and nutrient-rich situations by speeding up its vegetative growth [63]. A mixed culture is said to have greater temporal and spatial compensation in plant development, as well as nutrient preference [61]. As a result, the use of mixed culture constructed CWs is laudable. High competition, on the other hand, causes community structure and species composition to become unstable in mixed culture CWs. In fact, it's required to build a complex CW employing different monoculture cells to limit rivalry among component species, providing for the benefits of a mixed system while avoiding competition [12]. More research is needed to determine the performance of CWs planted with *Canna indica* when combined with other plant species. The studies could concentrate on plant density, mode of plant mixing, and the number of plant species in each configuration.

By generating a favourable oxidative environment, aeration can increase system efficiency, resulting in improved nitrification and organic biodegradation. Spray aeration is considered a cost-effective technique for on-site treatment of domestic sewage due to its high treatment effectiveness [51]. *Canna indica*, like other plat species in CWs, is susceptible to wastewater contaminants. According to studies, CWs utilizing ornamental plants are widely utilized as secondary or tertiary treatments. This has been influenced by the reported negative effects of excessive organic/inorganic loading on plants in systems that employ them without prior treatment. Ornamental plants, including as *Canna indica*, are used in CWs to give them a good visual impression [13]. Moreover, a proper harvesting is critical since the nutrients recovered during harvesting could account for a significant part of the inflow load. If the plants are not harvested, the majority of the nutrients in the biomass will be released into the water throughout the process of decomposition. Furthermore, the harvested plants can be appropriately used to provide about some financial advantages [64]. There is a scarcity of information about *Canna indica* harvesting in CWs. To identify the most suitable harvesting time and method that don't affect the CW's performance, more research is required.

4. Removal of Fluoride

Fluorine is the most electronegative element, having a Pauling Scale electronegativity of 3.98, making it extremely reactive. As a result of this feature, the element is found in the environment in various forms of mineral salts rather than in its pure form [65]. Fluoride intake of more than 1.5 mg/L from food and/or drinking water, according to WHO, and 4.0 mg/L according to Tanzania Bureau of Standards (TBS), has been linked to skeletal malformations such as dental fluorosis and enlargement of the skull, as well as changes in several physiological activities in the body [66]. There have also been some reports of the effects of waterborne fluoride on development, reproduction, and survival, which suggest that long term fluoride exposure causes a steady drop in reproduction [67]. This makes it necessary to monitor and control the exposure of fluoride in the aquatic systems.

The removal of fluoride from water was investigated using different microphytes namely *Canna indica*, *Epipremnum aureum*, *Cyperus alternifolius* and *Cyperus rotundus*. The percentage removal of fluoride was 95, 52, 65 and 56 for *Canna indica*, *Epipremnum aureum*, *Cyperus alternifolius* and *Cyperus rotundus* respectively. Based on the measured fluoride concentrations in roots and leaves, the bioaccumulation factor (14.28) and translocation factor (0.26) demonstrated *Canna indica*'s superiority. Increasing by 10–50 ppm of fluoride concentration was observed to reduce the performance of *Canna indica* by 31% [68]. Another study employed soil and coal cinder as the substrate for fluoride removal using a vertical-flow CW. The maximum fluoride adsorption capacity of soil was 0.78 mg F^-/g, and coal cinders was 7.25 mg F^{-}/g. This study concluded that Cannas and calamus-planted CW have a higher fluoride removal effectiveness than unplanted wetlands [22,69]. More studies employing *Canna indica* are required in connection with ongoing researches on the removal of fluoride from surface water and wastewater. More realistic settings, such as real wastewater spiked with known fluoride concentrations, must be incorporated into the pilot study. It is important to conduct more research to learn how fluoride, a contaminant, impacts *Canna indica* in the CW.

5. Removal of Heavy Metals

Heavy metals are metals with a density of greater than 5 g/cm^3 that have a harmful effect on the environment and living things [70,71]. Metals have high electrical conductivity, malleability, and brightness, and they can easily shed electrons to form cations. Heavy metals are plentiful in nature and can be found in the crust of the earth [72]. Heavy metal composition varies by location, resulting in changes in surrounding concentrations [73]. Heavy metal contamination has become one of the most pressing environmental issues of our time [74]. They are non-biodegradable and tend to accumulate in living species throughout food chains, causing major environmental and human health problems [75]. Heavy metals are among the toxic contaminants that have reached hazardous levels. Silver (Ag), gold (Au), cadmium (Cd), arsenic (As), zinc (Zn), selenium (Se), nickel (Ni). Uranium (U), mercury (Hg), chromium (Cr) and lead (Pb) are among the heavy metals of concern [76].

To remove heavy metals from wastewater, different techniques such as bioreactors, membrane filtration, nanotechnology, and biodegradable polymers have been investigated [77,78]. However, because of their considerably large construction and operation expenses, as well as energy requirements, an effective and cost-effective approach for removing heavy metals from wastewater remains an essential concern [79]. This is especially true in developing nations, where industrial effluent is frequently combined with residential and/or agricultural wastes [80]. The potential of aquatic plants for removal of heavy metals has been well researched in both field and laboratory setups [81]. Heavy metal removal mechanisms in CWs are complex, comprising a variety of processes such as filtration, microbial activity, absorption, precipitation, plant uptake and complexation. Metal absorption and translocation capacities of wetlands plant species vary significantly. Sulphate-reducing bacteria degrades organic waste into smaller molecular weight acids and bicarbonate, increasing alkalinity and precipitating metal sulphide. The interaction between bacteria and plants is significant since it implies symbiotic systems for heavy metal removal and tolerance [82,83].

Several studies have looked into how effective *Canna indica*-planted CW is at removing heavy metals from effluent. *Canna indica* was utilized to eliminate Cd from hydroponic settings in a study. The findings showed that *Canna indica* is capable of withstanding Cd toxicity by storing heavy metals in root tissues, fencing them out with cell walls, and binding with physiologically detoxified fractions [42]. It has been reported that *Canna indica* can remove more than 85% of Cd [80]. It can also remove up to 98.3% Cr and 96.2% Ni from aqueous solution at initial concentrations of 10 mg L^{-1} and at an HRT of 48 h [11]. 95% of Zn, 96% of Cu and 93% of Cr have been reported to be removed from sewage wastewater [78] and 99.67% of Cr from synthetic wastewater [84,85]. When used for treatment of landfill leachate spiked with 0.2 mgL^{-1} and 0.1 mgL^{-1} of Cr, Ni, and Zn it was revealed that the performance may be affected by the level of the pollutants in aqueous system. The results showed that with 0.2 mgL^{-1}, 54%-Cr, 47%-Ni and 47%-Zn was removed and with 0.1 mgL^{-1}, 71%-Cr, 62%-Ni and 59%-Zn was removed [86].

The efficiency on heavy metals removal is also affected by the water salinity. Heavy metals such as Cu, Zn, Cd, and Pb can effectively be removed from saline wastewater at an EC of 7 mS/cm. The Removal efficiency is suppressed at high salinity (EC of 30 mS/cm) [87]. In wetland plants, heavy metal concentrations decrease in the following order: roots > leaves > stems [79]. Two crucial indices, the bioconcentration factor (BCF) and the translation factor (TF), are employed to assess plant compatibility for heavy metals phytoremediation. BCF denotes macrophyte heavy metal intake capability, while TF denotes internal metal transit from subterranean (roots) to aerial sections (both stems and leaves) [80]. Plants with BCF and TF values larger than one are regarded to have phytoextraction potential, whereas plants with BCF greater than one and TF less than one are regarded to have phytostabilization potential [88]. These factors can be expressed mathematically using equations below;

$$\text{BCF} = \frac{\text{Metal concentration in plant tissue}}{\text{Concentration of metal in substrate (soil)}}$$

$$\text{TF} = \frac{\text{Metal concentration in stems and leaves}}{\text{Metal concentration in roots}}$$

In an experiment, Pb, Cd, Cu, and Zn were removed from synthetic wastewater by more than 85% just in 24 h of treatment. In this study the heavy metals accumulated with high bioconcentration factors and translocation factors [80]. The highest uptake of Cr, Pb and Ni from sewage wastewater was reported in the roots than stem and leaves [54]. In a study on treatment of piggery effluent, BCF was reported to be 1.1 for Fe, 1.0 for Mg, 0.2 for Al, 0.9 for Ca, 0.4 for Zn and 0.7 for Mn. In the same study, TF was 0.7 for Fe, 0.8 for Mg, 0.6 for Al, 0.9 for Ca, 0.8 for Zn and 0.8 for Mn [89]. These results shows the potential of *Canna indica* for removal of heavy metals from aquatic systems [80]. Future research should take into account the likelihood that an influent with a relatively high concentration of heavy metals may have different removal properties in CW planted with *Canna indica*, potentially even harming the plant.

6. Removal of Emerging Contaminants

Contaminants can be categorised as either priority chemicals (PC) or emerging contaminants (EC). Emerging contaminants (ECs) also known as emerging pollutants, are naturally occurring, synthetic, or anthropogenic chemicals or substances that are not routinely monitored and have an adverse impact on the environment and human and animal health [90]. Other definitions emphasize the absence of regulation of these compounds, as well as the unknown adverse impacts they could have on the aquatic ecosystem and human health [91]. Most PCs are organic contaminants, but some toxic metals and organometallic compounds have been also identified as PCs. ECs include substances that have been recently detected in natural streams (often due to improved analytical detection capacity) and/or pose risks (normally not fully understood yet) to human health and/or ecosystems [92]. These chemicals have been found in practically every component of the water cycle, such as potable water supplies. Although EC concentrations in the environment are typically modest (ranging from parts per trillion to low parts per billion), many have expressed toxicological concerns, particularly when they appear as complex mixtures of chemicals [93,94]. ECs comprise several types of compounds such as pharmaceuticals and personal care products (PPCPs), steroids and hormones, pesticides, industrial and household chemicals, metals, surfactants, industrial additives, among others [95].

Certainly, the existing water and wastewater treatment plants have been designed for the best in treatment and removal of contaminants and eutrophicating pollution loads, especially those which are specified in the existing regulations. Since they cannot be entirely removed by conventional wastewater treatment, the ECs are released into the receiving environments including rivers, fishponds, and crop fields [96]. Different methods including phytoremediation have been studied regarding removal of EC from wastewater. Studies on biomass of some selected plants, particularly macrophytes and rhizomes, provide leading clues on means of improving the quality of wastewater by removing different pollutants including ECs. Various plants have been investigated regarding removal of ECs such as pharmaceuticals and personal care products from wastewater [97]. The most popular investigated plants are *Phragmites australis*, *Typha spp. Typha angustifolia* and *Typha latifolia* [98]. Despite good performance in conventional wastewater treatment, there is limited studied regarding removal of ECs using *Canna indica* in CWs.

6.1. Pesticides

Pesticides can be any chemical compound, biological agent, antibiotic, disinfectant, or technology used to control pests. Pests include insects, weeds, plant pathogens, mollusks, nematodes, fish, birds, animals, and bacteria that degrade property value, serve as disease vectors, or cause nuisance [99]. Pesticides in aquatic environments are now a pressing issue because they tend to accumulate in the bodies of aquatic organisms and the soil, creating a public health risk [100]. The fate of Chlorpyrifos (CP), a common organophosphorus pesticide, and its hydrolytic metabolite 3,5,6-trichloro-2(1H)-pyridianol (TCP) in CW were investigated using diverse species of plants. *Canna indica* surpassed *Phragmites australis* and *Typha orientalis* in the elimination of CP and TCP [101]. Other researchers examined into the removal efficiency of Triazophos (TAP) utilizing CW grown with *Canna indica*. This study indicated that when the influent TAP concentration is less than 1 mg L^{-1}, CW planted with *Canna indica* can effectively eliminate TAP by more than 90 percent. TAP elimination in the CW was accomplished through phytoaccumulation (0.03%), substrate absorption (4.33%), and other processes (95.63%). The majority of the TAP removed was most contributed by action of plants and microorganisms to degradation [102]. TAP removal using *Canna indica* was also studied in a hydroponic setting. The results shows that TAP removal was 41–55% after 21 days of exposure. The contribution of the plant to TAP removal was 74% [103].

Canna indica performed better in a study investigating the removal of β-hexachlorocyclohexane (β-HCH) from water in the winter, with a removal efficiency of 96.64%. The main mechanism for removing β-HCH from water in the CW was determined to be substrate sorption [104]. Single and binary combinations of penta-chlorophenols (PCP) and trichlorophenols (TCP) were tested for competitive adsorption and phytotoxicity on *Canna indica* as the phytoremediator. The two chemicals in the system create an antagonistic interaction preventing both chlorophenols from being absorbed by *Canna indica*. In the binary system, *Canna indica* showed higher affinity or elimination rate for TCP than PCP [105]. All these results demonstrates that CW planted with *Canna indica* is capable of removing pesticides from aqueous system. However, all the pesticides discussed belongs to two groups such as organophosphates and organochlorides. More research is needed to investigate the potential of CW planted with *Canna indica* to remove more pesticide groups such as carbamates, fungicides, and herbicides under diverse environmental circumstances. This would contribute to the design of CW systems for pesticides contaminated wastewater treatment.

6.2. Pharmaceuticals

Pharmaceuticals are aimed to cure and treat disease while also promoting good health. However, the active pharmaceutical ingredients in these pharmaceuticals, whether as the parent compound or its metabolites, can be discharged into the environment and be present in very low, but quantifiable, concentrations [106,107]. When pharmaceuticals enter the environment, they may be totally degraded, partially degraded and held in the sedimentation sludge, or they may be metabolized toward a more hydrophilic compound [108]. These chemicals do not evaporate at normal temperatures or pressure because of their high solubility in water; consequently, they enter the soil and aquatic environments via sewage, treated sewage sludge, and irrigation with reclaimed waters [109]. Pharmaceuticals, as opposed to conventional pollutants, are biologically active substances that are designed to interact with specific physiological processes in the target organism. As a result, they represent a new class of chemicals capable of influencing certain animal activities (such as reproduction, growth and development) at ecologically relevant quantities. [110,111]. Their major sources include sewage effluent, hospitals and manufacturers wastewater, landfills and improper disposal [112]. Because they are not completely eliminated by conventional wastewater treatment processes, they must be eliminated using an alternative method [113] and CW is one of these alternatives [114].

Two continuous-flow CWs planted with *Canna indica* and Phragmites australis were used in one study to remove high levels of conventional pollutants and low amounts of tetracyclines (TETs), in the level similar to that found in domestic wastewater. The results revealed that the CWs performed well on COD, phosphorus, and TETs, with removal efficiencies of approximately 80%, 64%, and 75%, respectively, and a hydraulic retention time (HRT) of 3.0 days [115]. *Canna indica* hydroponic experiments were used in another study to investigate the removal, uptake, and specific metabolism of five sulfonamides namely sulfamethoxazole, sulfamethazine, sulfamerazine, sulfapyridine and sulfadiazine for 7 days. In the planted setups, SA removal ranged between 15.2–98.4%, but it was substantially lower in the unplanted control setups which ranged between 12.6–39.9% [116]. A study that focused on the effects of levofloxacin (LOFL) on chlorophyll and key enzyme activity in wetland plants produced similar results. The results showed that plant systems removed between 87.29–96.69% of LOFL while plants contributed just 0.26 to 5.89% [117]. The CW planted with *Canna indica* was also used in a study to remove atenolol, carbamazepine and diclofenac from wastewater. The results shows that the system is capable of removing above 90% of these pharmaceuticals. Furthermore, the mass balance analysis revealed that microbial degradation removed a greater proportion of the target contaminants (80.6–93%) [118]. All these results proof that CW planted with *Canna indica* can remove both traditional contaminants and pharmaceuticals, indicating that it has a lot of potential in domestic wastewater treatment. These findings, however, reveal the need for more study incorporating diverse classes of pharmaceuticals, as the ones discussed above are antibiotics. Because of the complex mixture of pharmaceuticals in hospital wastewater, for example, more study incorporating a large mixture of contaminants is needed in the future.

6.3. Industrial Chemicals

Perchlorate is a chemical that is utilized in industrial processes such as fireworks, rubber, and paint. This chemical has been found in soil, groundwater, surface water, drinking water, food, breast milk, baby formulae, soft drinks, and human bodily fluids, and it is currently considered an emerging contaminant [119]. Perchlorate elimination efficiency and mechanism were investigated in one study using CW planted with *Canna indica*. Perchlorate was found to be more concentrated in leaves (more than 55.8%) than in roots (less than 0.67%). Plant uptake accounted for 5.81–7.34% of initial perchlorate input, while microbial degradation accounted for 29.39–62.48%, according to a mass balance estimate [120]. The removal of Yellow 2G, a synthetic azo dye from wastewater was investigated at lab-scale in a CW planted with *Canna indica*. During the experiment the wastewater with 250 mg/L initial dye concentration was allowed to flow at 1.2 L/day and hydraulic retention time (HRT) of 3.75 day. The results show that the CW planted with *Canna indica* died completely after 43 days, and hence the reactor was closed down. Color removal efficiency was 98.24 $\pm$ 1.88 [121]. With increased industrial activity comes an increase in pollutant discharge, which will undoubtedly have an effect on the ecology. The chemical composition of industrial wastewater varies greatly depending on the industry, such as paint and dye processing, textile, pharmaceutical, paper, and fine chemical manufacturing. This means that more research on industrial chemical removal in *Canna indica*-planted CW is needed.

7. Greenhouse Gases Emission

The term "global warming" refers to the Earth's average surface temperature rising. Increased greenhouse gas (GHG) emissions are one of the key drivers of global warming. Climate models predict that, based on the increase in population and greenhouse gas emissions, the earth's surface temperature will rise by 1.6 to 5.8 °C by the end of the century. Since 1750, the concentrations of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have increased by 144%, 256%, and 121%, respectively [122]. The global warming potentials of CH_4 and N_2O emissions are 25 and 298 times more than CO_2 emissions over a 100-year time horizon, respectively [123,124]. This have attracted attention to the scientific community all over the world. Several studies have been conducted to study the emissions of greenhouse gases (GHG) from CWs [125]. This is because of environmental concerns about GHG emissions, which outweigh the environmental and ecological benefits of CWs. A recent study investigated the impact of plant species including *Canna indica*, *Phragmites australis* and *Cyperus alternifolius*, on GHG emissions. The results from this study shows that CW planted with *Canna indica* had the lowest Global Warming Potential, generating less CH_4 and N_2O [126].

8. Conclusions

The majority of the scientific community agree that plants have a significant impact on the treatment of wastewater in CWs. This review demonstrated the potentials of *Canna indica* in removal of organic pollutants, nutrients and heavy metals in aquatic environments. The review focused much on the removal efficiency of different pollutants in CW systems planted with *Canna indica*. With all the available information, more research is needed to address some specific issues related to the performance of this plant in CW. Research is recommended in the following areas;

i. The mechanism through which different forms of pollutants are removed should be investigated more especially for emerging contaminants.
ii. More research on the microbial diversity of *Canna indica*-planted CWs is required. This should concentrate on investigating plant-microbial interactions and their impact on CW performance.
iii. The effects of toxic pollutants present in wastewater on *Canna indica* should be investigated. This is especially for the pollutants with potential of bioaccumulation and bioconcentration in the plant's tissues.
iv. Competitiveness among the plants affects the performance in investigations when *Canna indica* was mixed with other plants. Whether to use a monoculture or a mixed system is thus determined by the performance of the plants individually and in the mixed system. This suggests that further research is required to determine the ideal combination of plants for improved wastewater treatment performance.

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