Poll Res. 42 (4) : 437-444 (2023)

ISSN 0257–8050
DOI No.: http://doi.org/10.53550/PR.2023.v42i04.005

A REVIEW ON PHYTOREMEDIATION POTENTIAL OF *CANNA* SPECIES FOR WASTEWATER TREATMENT

ASHUTOSH KUMAR CHOUDHARY

Department of Applied Sciences & Humanities, Himalayan School of Science and Technology, Swami Rama Himalayan University, Dehradun 248 140, India

(Received 8 May, 2023; Accepted1 7 July, 2023)

ABSTRACT

Globally, contamination of water is a serious environmental issue which necessitates continuous attention and remediation. The demand for good quality water is increasing so it becomes essential to promote the cost effective and sustainable wastewater treatment technologies like phytoremediation by using constructed wetlands (CWs). This review focused to investigate the phytoremediation efficiency of *Canna* species for the treatment of wastewater originated from different sources, by using different type of CWs around the world. It includes 33 research studies reported in the literature, for the phytoremediation of wastewater. *Canna* species performed well under different experimental conditions and recommended for the remediation of water and wastewater.

KEY WORDS : *Canna* species, Constructed wetland, Phytoremediation, Water pollution, Wastewater treatment

INTRODUCTION

Water pollution is indeed a global environmental challenge that affects the environment, human health and most of the aquatic ecosystems. It needs continuous attention and effective remediation. It affects the entire biological community in the biosphere. The most significant sources of water pollution are industrial wastes, mining activity, agricultural runoff, domestic sewage, solid waste, and accidental oil spills. The conventional remediation requires high energy inputs and is a cost intensive practice which further generates a large quantity of sludge as waste. In emerging nations, a large quantum of wastewater is discharged with a diversity of pollutants. The secondary treated wastewater has been found to still contain significant levels of organic load and toxic pollutants that seriously degrade the environment (Choudhary *et al*., 2014). To further enhance the wastewater quality, tertiary treatment is required for the reduction of nitrogenous, and phosphorus compounds, which is again a challenging task as it requires additional energy input and chemicals (Kivaisi, 2001). To overcome all these challenges, the only solution is to promote sustainable and environment friendly approaches to treat wastewater and minimize the adverse effects on the environment. Phytoremediation by using constructed wetlands (CWs) is an emerging technology for the remediation of water pollution. It is a technique which utilizes the potential of macrophytes (emerging plants) to remove the pollutants from water, sewage and wastewater. It involves a combination of processes like plant uptake (Choudhary *et al*., 2011, 2013), degradation by plants (phytodegradation), stabilization by plants (phytostabilization), and volatilization from surface of plants (phytovolatilization), for the remediation of organic contaminants (Sandermann, 1992). It has been proved to be more eco-friendly than to advanced wastewater treatment processes (Xiao *et al*., 2018).

This review is aimed to investigate the effectiveness (phytoremediation potential) of *Canna* species for the reduction of pollutants from

(Assistant Professor)

wastewaters of different origin, by using different type of CWs around the world.

Canna species

It is a perennial plant that is a member of the Cannaceae family and genus *Canna*. According to Kessler (2007), it is the only genus in the family to contain 19 flowering plant species. It originated in Central and South America, and has since spread to tropical and subtropical regions of the world including Europe, India and North America. It grows well in different types of soil preferably in loamy soils. Its habitat includes areas under shade, wet places, savannah, wetlands, marshes and swampy areas with plants height vary from 0.75 to 3.0 m (Jayakumari, 2009). Many species grow well in nitrogen rich moist soils, near streams (Chate, 1867). *Canna* species can be easily propagated by seeds and cuttings of root. The seeds are small, globular and resemble to shotgun pellets that's why named as Indian shot (common name) (Jayakumari and Stephen, 2009; Tanaka, 2009). The general characteristics of *Canna* species are summarized in Table 1.

Constructed wetland

Constructed wetlands (CWs) are simple engineered setups constructed to treat wastewater that relies on natural processes and phytoremediation potential of plants (macrophytes). It consists of shallow bed, having substrate (gravels, sand and soil), wastewater flow control devices, macrophytes, and a variety of microorganisms (EPA, 2004). Since 1950s, CWs have been successfully utilized in Germany to treat industrial and municipal wastewaters (Vymazal *et al.*, 1998). Over the past 30 years, CW systems have rapidly developed and are now widely used as an option to treat wastewater. These systems are suitable for treating industrial wastewater as it requires low energy, and are simple to maintain (Choudhary and Kumar, 2020). CWs systems are aesthetically more attractive in comparison to conventional treatment setups used for wastewater treatment (Kadlec *et al.*, 2000; Langergraber, 2008). The plant species commonly used in different types of CWs include free-floating, submerged, and emergent plants (Vymazal, 2013). CW treatment efficiency primarily depends on the wetland design, type and concentration of pollutants in wastewater, hydraulic retention time (HRT), microbial reactions, plant species and the surrounding environmental conditions (EPA, 2000).

According to EPA (2004), CWs can be categorized into two sub-categories based on wastewater flow into the system: (i) surface flow (SF) wetlands, in which wastewater flows horizontally over the wetland substrate; (ii) subsurface flow (SSF), in which the wastewater flows horizontally or vertically through the substrate; and (iii) hybrid CWs, in which a combination of both horizontal subsurface flow (HSSF) and vertical subsurface flow (VSSF) is used. SF CWs typically use submerged and floating plants, while SSF CWs commonly use plant species such as *Canna indica*, *Colocasia esculenta*, *Phragmitis australis*, *Typha spps.*, and *Schoenoplestus* species (Choudhary and Kumar, 2020).

CWs effectively reduce inorganic and organic pollutants, toxic compounds, heavy metals, and pathogens, from wastewater. The primary processes involved in pollutant removal are physical (adsorption, filtration and sedimentation), chemical (oxidation, reduction, precipitation), and biological interactions (microbial reactions, uptake or transformation by plants) (Watson *et al.*, 1989; Choudhary *et al*., 2013). Inorganic nutrients present in wastewater, get converted into organic matter to maintain the plant growth, and support the food chain in CW (Brix, 1993).

Table 1. Characteristics of *Canna* species (Khoshoo and Mukherjee, 1969, 1970; Kirtikar and Basu, 1970; Pullaiah, 2006; Jayakumari and Stephen, 2009; Ciciarelli, 2012)

Part of plant	Characteristics
Steam	Light green in color, herbaceous pseudostem, cylindrical, reaches up to 1.5–2 m.
Leaves	Dark green, simple, alternate, and spiral, lanceolate or ovate large, 30–35 cm in width and length up to 6570 cm.
Rhizomes	Yellowish white or pinkish
Root	Whitish (diameter 2–5 mm), with numerous root hairs, tubular, thick.
Flower	Generally, red, yellow, orange; paired or solitary, 4–10 cm in diameter, about 1.3 cm long bracts.
Fruit	Capsules bright green in color, covered by green to purple tubercles, spiny, 2–2.5 cm long.
Seeds	Small (size of a pea), globular, black, and resemble shotgun pellets.

CWs rely mainly on two mechanisms to reduce the pollutants present in wastewater: (i) solid/liquid separation and (ii) transformation of constituents present in wastewater (EPA, 2000). Separations mainly include filtration, sedimentation, absorption, and adsorption, ion exchange, leaching, and stripping. Transformations include oxidation and reduction reactions, flocculation, precipitation, and biochemical reactions facilitated by the root zone environment. Wetland soil provides favorable conditions for plant and microbial growth, and fine gravel has been reported to promote higher plant growth and increased pollutant removal (Garcia *et al.,* 2005).

According to Madigan *et al*. (1997) and Hoppe *et al*. (1998), microorganisms such as bacteria, yeasts, fungi, protozoa, and algae are crucial for biogeochemical nutrient transformation. Moreover, aerobic or anaerobic degradation processes performed by microorganisms, including the removal of toxic organic compounds, have been reported by Kadlec and Knight (1996) and Reddy and D'Angelo (1997). Physical mechanisms involved in the removal of suspended solids (SS) include flocculation/sedimentation and filtration (EPA, 2000). Nitrogenous compound removal from wastewaters occurs through processes such as adsorption and plant uptake, volatilization, ammonification, nitrification, and denitrification in the root zone. According to Vymazal (2007), the primary mode of phosphate removal in constructed wetlands is sediment retention. However, plants can also uptake soluble reactive phosphorus or it can be adsorbed to the substrate of the wetland bed (Vymazal, 1995). Biological oxygen demand (BOD) and chemical oxygen demand (COD) removal mainly occur by sedimentation and entrapment of suspended solids in the spaces between the substrate media of wetland bed (EPA, 1993). The removal of soluble organic compounds is carried out by the microorganisms attached to plant roots and on the media surfaces. Similarly, the removal of metals from industrial wastewater, also involve multiple mechanisms such as filtration, sedimentation, precipitation, adsorption, and uptake by plants & microorganisms (Stottmeister *et al*., 2003; Debusk, 1999). Several studies have reported the efficient removal of pathogens in CWs (Gersberg *et al.,* 1987; Stottmeister *et al.,* 2003).

In summary, CWs efficient systems for wastewater treatment involving various complex interactions processes. Plants have a crucial role in the reduction of pollutants from wastewater in CWs (Choudhary *et al*., 2013). The plants offer attachment sites to microorganisms and generate dead organic matter to support microbial growth and metabolism (Vymazal, 2011). Moreover, plants directly uptake the nutrients particularly nitrogenous and phosphorus compounds and also release oxygen in the root zone for the degradation of pollutants. The uptake of organic compounds by plants is affected by several factors like concentration, acidity constant (pKa), octanol-water partition coefficient, and physicochemical characteristics (Wenzel *et al.*, 1999; Stottmeister *et al*., 2003). Pollutants metabolism in plants comprises three phases, namely compartmentation, conjugation, and transformation (Sandermann, 1992). Similarly, the removal of heavy metals depends on several factors, including heavy metals concentration in wastewater, growth of plants, and selected plant species (Sheoran and Sheoran, 2006).

Performance of *Canna* species

Wastewater treatment using *Canna* species has been carried out in different studies worldwide. Table 2 summarizes the phytoremediation potential of *Canna* species in different types of CWs. A review based on the available literature (33 different studies) showed that *Canna* species have been effectively used to remove biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), total solids (TS), inorganic nitrogen (ammonia, nitrate, nitrite (NO_2^-), fluoride (F^-), chloride (Cl^-), calcium (Ca), aluminum (Al), iron (Fe), magnesium (Mg), total phosphorus (TP), phosphate ($PO_4^{3|}$), sulphate (SO_4^{2-}), heavy metals like arsenic (As), chromium (Cr), nickel (Ni), zinc (Zn), cadmium (Cd)), total coliform, pathogens like *Vibrio*, *E. coli*, *Pseudomonas*, and *Aeromonas*; dye, organic compounds including adsorbable organic halides (AOX), chlorophenols, acetaminophen, atrazine, carbamazepine, B-hexachlorocyclohexane (β-HCH), 2,4-bis (lsopropytamino)-6-methylthio-s-triazine, chlorinated resin and fatty acids (cRFAs), oil and greese, from the water, fortified water solutions, and wastewaters of different origins including synthetic dairy wastewater, domestic sewage, institutional wastewater, secondary treated wastewater, storm water runoff, piggery effluent, batik wastewater, biomethanation plant wastewater, aquaculture wastewater, stillage treatment, pulp and paper mill wastewater, petroleum refinery's effluent,

Table 2. Phytoremediation of wastewater by using *Canna* species in CWs.

Water/Wastewater	Plant species	Type of CW	Removal efficiency (%)	Reference
Water	*Canna indica*	Lab scale	Fluoride-95	Khandare *et al.* (2021)
Aqueous solution	*Canna indica*	Microcosms	Chromium-98.3, Nickel-96.2	Yadav *et al.* (2010)
Fortified water	*Canna flaccida*	SF-mesocosms	Carbamazepine: 73-81.8, Atrazine:100 Acetaminophen:100	Hwang *et al.* (2020)
Artificial water	*Canna indica*	Lab scale VSSF	Â-hexachlorocyclohexane (â -HCH)-96.64	Chen *et al*. (2021)
Synthetic water	*Canna sps.*	Pilot VSSF	Fluoride-51, Arsenic-95	Li *et al.* (2014)
Synthetic water	*Canna indica*	-	COD-75, Dye: 70-90	Yadav *et al.* (2012)
Synthetic Dairy wastewater	*Canna indica*	Lab-scale VSSF vermifilter	BOD-80.6, COD-75.8, TSS- 84.8, TN-42.6	Samal *et al*. (2017)
Domestic wastewater	*Canna indica*	Lab-scale HSSF	BOD-76.36, COD-79.75 TS-86.18	Saxena *et al.* (2019)
Domestic wastewater	*Canna indica*	HSSF	TDS-67.8, BOD-87.3, COD-92.8, TKN-89, Nitrate-86, Phosphate-82.6	Haritash *et al*. (2015)
Domestic wastewater	*Canna indica*	Field scale SF	COD-65, Sulphate-60, Inorganic-N-67, Total coliform > 80	Datta *et al*. (2021)
Domestic wastewater	*Canna indica*	Lab scale HSSF	COD-89, BOD-81, TSS-86, TDS-81, Cl^-- 21	Layana and Abraham, (2020)
Domestic wastewater	*Canna indica*	SSF	COD-83	Konnerup *et al.* (2009)
Domestic sewage	*Canna indica*	Field scale VSSF	TDS-22.31, BOD_5 - 81.79, TN-60.37, PO_4^{3-}-P-80	Bary *et al*. (2020)
Domestic sewage	*Canna species*	SSF	BOD-92.3	Sirianuntapiboon and Jitvimolnimit (2007)
Municipal	*Canna indica*	SSF	BOD-86, COD-77, TN >45, TP >82	Shi *et al.* (2004)
Municipal	*Canna sps.*	HSSF and VSSF	BOD-92, COD-92, TSS- 92	Abou-Elela *et al.* (2013)
Municipal	*Canna iridiflora*	Floating treatment wetlands	BOD-66, NH_4-N-82, N-NO_3-50, TP-89	Weragoda *et al*. (2012)
Domestic	*Canna indica*	SSF	BOD-11, N-NH_4-73	Chyan *et al*. (2016)
Institutional wastewater	*Canna lily*	Decentralized multistage	COD: 61.2- 85.6, NO_3-N-47.3-63.4, NO_2^--N:62-75.4, NH_4^+-N -56.6-71.6, PO_4^{3-}- 52.1-64.4, TSS: 67.7–85.5, Pathogens: *Pseudomonas* -99, *Vibrio* >98, *E. coli* -95, *Aeromonas* - 63	Muduli *et al.* (2022)
Storm water runoff	*Canna generalis*	Plant growth container	Nitrogen-98.7, Phosphorus-91.8	Chen *et al*. (2009)
Piggery effluent	*Canna indica*	HSSF	BOD-26.5, TN-66.4, TP-72, Al-41.8, Fe-59.2, Mg-66.9, Ca-66.4	Olawale *et al*. (2021)
Batik wastewater	*Canna indica*	VSSF	TSS-91.25, BOD-91.82, COD-89.15, Ammonia-96.2, Cr - 81.8	Rahmadyanti and Wiyono (2020)

Table 2. *Continued ...*

Water/Wastewater	Plant species	Type of CW	Removal efficiency (%)	Reference
Batik wastewater	*Canna indica*	Lab scale hybrid	COD-89, Oil and greese-89.53, TSS-98.74	Rahmadyanti and Audina (2020)
Biomethanation plant	*Canna indica*	VSSF experimental setup wastewater	BOD-91, P-25, (2016)	Wietlisbach *et al*.
Pulp & Paper mill	*Canna indica*	HSSF	Chloro resin and fatty acids (cRFAs): 92-96	Choudhary *et al*. (2011)
Pulp & Paper mill wastewater	*Canna indica*	HSSF	COD- 87.9, BOD_5 -95.6, AOX -89, Chlorophenols -67-100,	Choudhary *et al*. (2013)
Secondary treated	*Canna indica*	VSSF	COD: 35-47, NH_4- 52.99	Sharma *et al*. (2014)
Petroleum refinery effluent	*Canna indica*	Lab scale VSSF	TSS-85, TN-96.38, Zn-96.5, Cd-93.5	Ghezali *et al*. (2022)
Aquaculture wastewater	*Canna indica*	Lab scale reactors	TN- 95, TP-77, COD-62	Zhimiao *et al.* (2019)
Stillage wastewater (2016)	*Canna indica*	-	COD-70, BOD-87	López-Rivera *et al.*
Fermented fish production	*Canna hybrid*	-	BOD ~ 97 COD ~ 97 TKN ~ 97	Kantawanichkul *et al.* (2009)
Tilapia production	*Canna spps.*	Submerged SSF	COD-12.5, NH_3-N-7.5, NO_3-N-76, NO_2^-N-91, TSS-90	Zachritz *et al.* (2008)
Fish pond	*Canna generalis*	Recirculating HSSF and VSSF	COD: 25-55, BOD-50	Konnerup *et al.* (2011)

fermented fish production, tilapia production, fish pond.

Based on reported literature, Table 2 shows the CW's wastewater treatment efficiency for the removal different wastewater parameters by utilizing the *Canna* sp. as plant and Table 3 summarizes the range of removal efficiencies for different parameters based on the reported results shown in Table 2. The removal efficiency varies widely might be due to the variation in experimental setups, design of experiments and the characteristics of wastewater treated.

Table 3. Removal efficiency of CWs by using *Canna* spps.

Parameter	Removal efficiency (%)
BOD	11-96
COD	13-93
TSS	85-92
TN	37-96
TDS	22-81
Nitrate	47-86
cRFAs	92-96
Chlorophenols	67-100
Heavy metals	82-98
Pathogens	63-99
Fluoride	51-95
Dye	70-90

CONCLUSION

The use of *Canna* species in CWs has shown promising results in the removal of pollutants from wastewater. In present review, the use of *Canna* species has been identified in 33 studies for the phytoremediation of different types of wastewater. It generally grows well in tropical and subtropical regions of the world. In CWs, the pollutants removal depends on various significant parameters like design of CW, CW bed media, hydraulic loading of wastewater, retention time of pollutants in CW system, and the plant species selected. On the basis of above literature review, it is concluded that the plant species *Canna* grows well under different experimental conditions and effective for the removal of a different type of pollutants including heavy metals and toxic compounds like chlorophenols and chloro resin and fatty acids. Additionally, the use of ornamental *Canna* spp. can provide economic gains and enhance the aesthetic appearance of the environment. It is recommend that *Canna spp*. can be efficiently used for the phytoremediation of domestic and industrial wastewaters. Overall, the phytoremediation potential of *Canna* species is significant and offers a cost-effective and sustainable solution for the treatment of contaminated water.

REFERENCES

Abou-Elela, S.I., Golinielli, G., Abou-Taleb, E. and Hellal, M. 2013. Municipal wastewater treatment in horizontal and vertical flows constructed wetlands. *Eco. Eng*. 61: 460-468.

Bary, M.P., Gupta, D., Thakur, T.K., Shukla, R., Singh, G. and Mishra, V.K. 2020. Phytoremediation performance of *Acorus calamus* and *Canna indica* for the treatment of primary treated domestic sewage through vertical subsurface flow constructed wetlands: a field-scale study. *Water Pra. Tech*. 15(2): 528-539.

Brix, H. 1993. Wastewater treatment in constructed wetlands: systems design, removal processes, and treatment performance. In: Moshiri, G.A. (Eds.) Constructed wetlands for water quality improvement. CRC Press, Boca Raton, 9-22.

Chate, E.L. 1867. Canna, son histoire, sa culture. Libraire central d'Agricultureet de Jardinage.

Chen, Q., Zeng, H., Liang, Y., Qin, L., Peng, G., Huang, L. and Song, X. 2021. Purification effects on β-HCH removal and bacterial community differences of vertical-flow constructed wetlands with different vegetation plantations. *Sustainability*. 13: 13244.

Chen, Y., Bracy, R.P., Owings, A.D. and Merhaut, D.J. 2009. Nitrogen and phosphorous removal by ornamental and wetland plants in a greenhouse recirculation research system. *Hortscience*. 44 (6): 1704-1711.

Choudhary, A.K. and Kumar, P. 2020. Constructed Wetland: A Green Technology for Wastewater Treatment, In: Singh A., Srivastava S., Rathore D. and Pant D. (Eds.). *Environmental Microbiology and Biotechnology,* Volume 1: Biovalorization of Solid Wastes and Wastewater Treatment. Springer, Singapore, 335-363.

Choudhary, A.K., Kumar, S. and Sharma, C. 2014. Monitoring of chloro-organic compounds from Indian paper mills wastewater. *IPPTA Journal*. 26 (2): 104-115.

Choudhary, A.K., Kumar, S. and Sharma, C. 2011. Constructed wetlands: an approach for wastewater treatment. *Elixir Poll*. 37 : 3666-3672.

Choudhary, A.K., Kumar, S. and Sharma, C. 2011. Removal of chlorinated resin and fatty acids from paper mill wastewater through constructed wetland. *Int. J. Env. Eco. Eng*. 5(8): 406-410.

Choudhary, A.K., Kumar, S. and Sharma, C. 2013. Removal of chlorophenolics from pulp and paper mill wastewater through constructed wetland. *Water Env. Res*. 85 (1): 54-62.

Chyan, J.M., Lu, C.C. Shiu, R.F. and Bellotindos, L. 2016. Purification of landscape water by using an innovative application of subsurface flow constructed wetlands. *Env. Sci. Poll. Res*. 23: 535-545.

Ciciarelli, M.M. 2012. Life cycle in natural populations of *Canna indica* L. from Argentina. In: Zhang, X. (Ed.). Phenology and Climate Change. Rijeka, Croatia: In Tech, 101-14.

Datta, A., Singh, H.O., Raja, S.K. and Dixit, S. 2021. Constructed wetland for improved wastewater management and increased water use efficiency in resource scarce SAT villages: a case study from Kothapally village. *India, Int. J. Phyt.* 1067-1076.

DeBusk, W.F. 1999. Wastewater treatment wetlands: Applications and treatment efficiency. A fact sheet of the Soil and Water Science department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.

EPA. 1993. Subsurface flow constructed wetlands for wastewater treatment: A technology assessment. Office of water, 832-R-93- 008.

EPA. 2000. Design manual: Constructed wetlands treatment of municipal wastewaters. EPA/625/R-99/010.

EPA. 2004. Constructed treatment wetlands. Office of water, 843-F-03-013.

Garcia, J., Aguirre, P., Barragán, J., Mujeriego, R., Matamoros, V. and Bayona, J.M. 2005. Effect of key design parameters on the efficiency of horizontal subsurface flow constructed wetlands. *Ecol. Eng.* 25 (4): 405-418.

Gersberg, R.M., Brenner, R., Lyon, S. R. and Elkins, B.V. 1987. Survival of bacteria and viruses in municipal wastewater applied to artificial wetlands, p 237-45. In: Reddy, K.R. and Smith, W.H. (Edited) Aquatic plants for water treatment and resource recovery; Orlando, Florida: Magnolia publishing.

Ghezali, K., Bentahar, N., Barsan, N., Nedeff, V. and Mos, E.N. 2022. Potential of *Canna indica* in vertical flow constructed wetlands for heavy metals and nitrogen removal from Algiers refinery wastewater. *Sustainability*. 14: 4394.

Haritash, A.K., Sharma, A. and Bahel, K. 2015. The potential of *Canna lily* for wastewater treatment under Indian conditions. *Int. J. Phyt.* 17 (10): 999-1004.

Hoppe, H.G., Kim, S.J. and Gocke, K. 1988. Microbial decomposition in aquatic environments: combined process of extra cellular activity and substrate uptake. *App. Env. Micro*. 54: 784-790.

Hwang, J.I., Li, Z., Andreacchio, N., Ordonez, H.F. and Wilson, P.C. 2020. Potential use of floating treatment wetlands established with *Canna flaccida* for removing organic contaminants from surface water. *Int. J. Phyt.* 22 (12): 1304-1312.

Jayakumari, T.R. and Stephen, P. 2009. Morphological and anatomical features of Queensland arrowroot (*Canna edulis Ker.*). *J. Root Crops*. 35: 164-8.

Kadlec, R.H. and Knight, R.L. 1996. *Treatment Wetlands.* New York: Lewis Publishers, CRC.

Kadlec, R.H., Knight, R.L., Vymazal, J., Brix, H., Cooper, P. and Haberl, R. 2000. Constructed wetlands for pollution control: Processes, performance, design, and operation; IWA Scientific and Technical report no. 8. International Water Association: London, U.K.

Kantawanichkul, S., Karnchanawong, S. and Jing, S.H. 2009. Treatment of fermented fish production wastewater by constructed wetland system in Thailand. *Chiang Mai J. Sci*. 36: 149-157.

Kessler, J.R. 2007. *Canna Lilies* for Alabama gardens. Alabama Cooperative Extension System, Auburn, Alabama: Alabama A&M University and Auburn University. ANR-1315, p. 1-10.

Khandare, R.V., Watharkar, A.D., Pawar, P.K., Jagtap, A.A. and Desai, N.S. 2021. Hydrophytic plants *Canna indica*, *Epipremnum aureum, Cyperus alternifolius* and *Cyperus rotundus* for phytoremediation of fluoride from water. *Env. Tech. Inn*. 21: 101234.

Khoshoo, T.N. and Mukherjee, I. 1969. Genetic-evolutionary studies on cultivated cannas. *Var. Phenotype*. 36: 254-270.

Khoshoo, T.N. and Mukherjee, I. 1970. Genetic-evolutionary studies on cultivated cannas. *Theor. and App. Gen*. 40 : 204-17.

Kirtikar, K.R. and Basu, B. D. 1970. *Indian Medicinal Plants*. 2nd ed. Allahabad, IV: Ed. Lalit Mohan Basu, p. 2450-2.

Kivaisi, A.K. 2001. The potential for constructed wetlands for wastewater treatment and reuse in developing countries: a review. *Eco. Eng.* 16: 545-560.

Konnerup, D., Koottatep, T. and Brix, H. 2009. Treatment of domestic wastewater in tropical, subsurface flow constructed wetlands planted with *Canna* and *Heliconia*. *Eco. Eng*. 35: 248-257.

Konnerup, D., Trang, N.T.D. and Brix, H. 2011. Treatment of fishpond water by recirculating horizontal and vertical flow constructed wetlands in the tropics. *Aquaculture*. 313 : 57-64.

Langergraber, G. 2008. Modeling of processes in subsurface flow constructed wetlands: A Review. *Vad. Zone J.* 7: 830-842.

Layana, K.V. and Abraham, R. 2020. Experimental study on wastewater by reed bed technology using ornamental plants. *Int. Res. J. Eng. Tech*. 07 (04): 2901-2904.

Li, J., Liu, X., Yu, Z., Yi, X., Ju, Y., Huang, J. and Liu, R. 2014. Removal of fluoride and arsenic by pilot vertical-flow constructed wetlands using soil and coal cinder as substrate. *Water Sci. Tech*. 70 : 620-626.

López-Rivera, A., López-López, A., Vallejo-Rodríguez, R. and León-Becerril, E. 2016. Effect of the organic loading rate in the stillage treatment in a constructed wetland with *Canna indica*. *Env. Prog. Sus. Energy*. 35: 411-415.

Madigan, M.T., Martinko, L.M. and Brock, P.J. 1997. *Biology of Microorganisms*. 8th ed. Saddle River, NJ, Prentice Hall, p. 986.

Muduli, M., Sonpal, V., Ray, S. and Haldar, S. 2022. In-depth performance study of an innovative decentralized multistage constructed wetland system treating real institutional wastewater. *Env. Res*. 210 : 112896.

Olawale, O., Davids, O.R., Christopher, O. Akinbile and Kater, I. 2021. Comparison of heavy metal and nutrients removal in *Canna indica* and *Oryza sativa L.* based constructed wetlands for piggery effluent treatment in north-central Nigeria. *Int. J. Phyt*. 23 (13): 1382-1390.

Pullaiah, T. 2006. *Encyclopaedia of World Medicinal Plants.* New Delhi, India, I: Regency Publication, p. 421.

Rahmadyanti, E. and Audina, O. 2020. The performance of hybrid constructed wetland system for treating the batik wastewater. *J. Eco. Eng*. 21 (3): 94-103.

Rahmadyanti, E. and Wiyono, A. 2020. Constructed Wetland with Rice Husk Substrate as Phytotechnology Treatment for Sustainable Batik Industry in Indonesia. *J. Physics: Conference Series*. 1569: 042018.

Reddy, K.R. and D'Angelo, E.M. 1997. Biogeochemical indicators to evaluate pollutant removal efficiency in constructed wetlands. *Water Sci. Tech*. 35: 1-10.

Samal, K., Dash, R.R. and Bhunia, P. 2017. Performance assessment of a *Canna indica* assisted vermifilter for synthetic dairy wastewater treatment. *Pro. Saf. Env. Prot*. 111: 363-374.

Sandermann, H. 1992. Plant metabolism of xenobiotics. *Trends in Biochem. Sci.* 17: 82-94.

Saxena, S., Tembhurkar, A.R. and Brahmam, M.V. 2019. Evaluation of constructed wetland using *colocasia esculenta, cyperus alternifolius* and *canna indica* plants treating wastewater. *J. Indian Water Works Ass.* LI (3): 216-220.

Sharma, G., Priya and Brighu, U. 2014. Performance analysis of vertical up-flow constructed wetlands for secondary treated effluent. *APCBEE Procedia*. 10: 110-114.

Sheoran, A.S. and Sheoran, V. 2006. Heavy metal removal mechanism of acid mine drainage in wetlands: A critical review. *Min. Eng*. 19: 105-116.

Shi, L., Wang, B.Z., Cao, X.D., Wang, J., Lei, Z.H., Wang, Z.R., Liu, Z.Y. and Lu, B.N. 2004. Performance of a subsurface-flow constructed wetland in Southern China. *J. Env. Sci.* 16: 476-481.

Sirianuntapiboon, S. and Jitvimolnimit, S. 2007. Effect of plantation pattern on the efficiency of subsurface flow constructed wetland (sfcw) for sewage treatment. *African J. Agri. Res.* 2 (9): 447-454.

Stottmeister, U., Wießner, A., Kuschk, P., Kappelmeyer, U., Kästner, M., Bederski, O., Müller, R.A. and Moormann, H. 2003. Effects of plants and microorganisms in constructed wetlands for wastewater treatment. *Biotech. Adv.* 22(1-2): 93-117.

Tanaka, N., Uchiyama, H., Matoba, H. and Koyama, T. 2009. Karyological analysis of the genus *Canna* (Cannaceae). *Plant Sys. Evo.* 280: 45-51.

Vymazal, J. 1995. *Algae and Element Cycling in Wetlands.* Chelsea: Lewis Publishers. p. 698.

Vymazal, J. 2007. Removal of nutrients in various types of constructed wetlands. *Sci. Tot. Env.* 380 : 48-65.

Vymazal, J. 2011. Plants used in constructed wetlands with horizontal subsurface flow: A review. *Hydrobiologia.* 20 : 133-156.

Vymazal, J. 2013. Emergent plants used in free water surface constructed wetlands: a review. *Ecol. Eng.* 61: 582-592.

Vymazal, J., Brix, H., Cooper, P.F., Green, M.B. and Haberl, R. 1998. Constructed Wetlands for Wastewater Treatment in Europe, Backhuys: Leiden, Netherlands.

Watson, J.T., Reed, S.C., Kadlec, R.H., Knight, R.L. and Whitehouse, A.E. 1989. Performance expectations and loading rates of constructed wetlands, p. 319-351. In: Hammer, D.A. (Edited) *Constructed Wetlands for Wastewater Treatment.* Lewis, Chelsea.

Wenzel, W.W., Adriano, D.C., Salt, D. and Smith, R. 1999. Phytoremediation: a plant-microbe-based remediation system, p. 457-508. In: Adriano, D.C. (Edited) *Bioremediation of Contaminated Soils*, American Society of Agronomy.

Weragoda, S.K., Jinadasa, K.B.S.N., Zhang, D.Q., Gersberg, R.M., Tan, S. K., Tanaka, N. and Jern. N.W. 2012. Tropical Application of Floating Treatment Wetlands. *Wetlands.* 32: 955-961.

Wietlisbach, S.O., Nikhil, K.K., Ram, K., Nair, R. and Harigovind, S. 2016. Performance of a vertical subsurface flow constructed wetland in treating biomethanation effluent, *IEEE 2016 Global Humanitarian Technology Conference,* 847.

Xiao, R., Shen, F., Du, J., Li, R., Lahori, A.H. and Zhang, Z. 2018. Screening of native plants from wasteland surrounding a Zn smelter in Feng County China, for phytoremediation. *Ecotox. and Envir. Saf.* 162: 178-183.

Yadav, A., Dash, P., Mohanty, A., Abbassi, R. and Mishra, B. 2012. Performance assessment of innovative constructed wetland-microbial fuel cell for electricity production and dye removal. *Ecol. Eng.* 47: 126-131.

Yadav, A.K., Kumar, N., Sreekrishnan, T.R., Satya, S. and Bishnoi, N.R. 2010. Removal of chromium and nickel from aqueous solution in constructed wetland: Mass balance, adsorption-desorption and FTIR study. *Chem. Eng. J.* 160 (1): 122-128.

Zachritz, W.H., Hanson, A.T., Sauceda, J.A. and Fitzsimmons, K.M. 2008. Evaluation of submerged surface flow (SSF) constructed wetlands for recirculating tilapia production systems. *Aqua. Eng.* 39: 16-23.

Zhimiao, Z., Xiao, Z., Zhufang, W., Xinshan, S., Mengqi, C., Mengyu, C. and Yinjiang, Z. 2019. Enhancing the pollutant removal performance and biological mechanisms by adding ferrous ions into aquaculture wastewater in constructed wetland. *Bio. Tech.* 293 : 122003.