Nature Environment and Pollution Technology
An International Quarterly Scientific Journal
p-ISSN: 0972-6268 (Print copies up to 2016)
e-ISSN: 2395-3454
Vol. 22 No. 2 pp. 969-975 2023
Review Research Paper
https://doi.org/10.46488/NEPT.2023.v22i02.041
Open Access Journal

The Potential of Phytoremediation to Treat Different Types of Wastewater - A Review

Vijayant Panday† and Ananda Babu K.
Department of Civil Engineering, Shri Vaishnav Institute of Technology and Science, SVVV, Indore, India
†Correspondence author: Vijayant Panday; vijayantcivil@gmail.com

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 12-09-2022
Revised: 06-12-2022
Accepted: 22-12-2022

Key Words:
Phytoremediation
Wastewater treatment
BOD
COD
Nutrients
Heavy metals

ABSTRACT

Globally, with an increase in population, water demand is also increasing, but on the other hand, water availability is continuously decreasing due to various factors. Contamination of existing water bodies is the main factor for the freshwater shortage. Conventional methods are there to treat polluted water, but their construction and operational cost are very high. Phytoremediation is an economical, solar-driven, green plants (macrophytes) based, environment-friendly technology being researched worldwide. Many researchers contributed to identifying the potential of phytoremediation to treat different types of wastewater. Along the same line, an attempt has been made with this literature survey to contribute to technological advancement. The study results showed that water hyacinth plants could potentially treat almost all types of wastewater. Still, their use with other plants like *Phragmites australis*, *Azolla filiculoides*, *Lemna minor*, *Typha latifolia*, etc., as polyculture (mixed culture) could perform way better than the individual. It not only improves the efficiency of phytoremediation but also helps some plants to grow and perform for a long duration when used in mixed culture.

INTRODUCTION

Urban India generates around 73 billion liters of sewage on daily basis (Barco & Borin 2017). The installed operational treatment capacity is only about 37% to treat this huge sewage. Remaining untreated sewage is mainly responsible for surface and groundwater quality degradation in India. This situation worsens when this sewage is mixed with other types of wastewater, like industrial effluent. An increase in domestic and industrial wastewater treatment plants can be a solution, but economic feasibility is the main obstacle to its application (Roy et al. 2014). In addition, these conventional treatment plants require a centralized collection network for the effluents, which again puts a question mark on their feasibility in rural areas with low population density. Phytoremediation is an alternative wastewater treatment technology that is being researched all over the world. It offers great potential to treat wastewater, compared to conventional methods like trickling filters, sequential batch reactors, up-flow anaerobic sludge blankets, activated sludge processes, etc. (Ajibade & Adewumi 2017). Phytoremediation is a technique in which green plants (Macrophytes) convert pollutants into harmless forms (Abbasi & Abbasi 2010). The phytoremediation system uses natural plants, making this technique eco-friendly and economical. It is a solar-dependent, in situ treatment technology (Kinidi & Salleh 2017).

Plants are the key component of this system. The function of the different parts of the plant is depicted in Table 1. Microorganism lives and grow on and around the plant's root. Oxygen supplied by the roots help microorganisms decompose organic matter, uptake of nutrient and heavy metals, and other biological processes (Amarea et al. 2018). Phytoremediation technology is generally used in the form of constructed wetlands (Chavan & Dhulap 2012a, 2012b). It can treat almost all types of wastewater, including domestic, municipal, industrial, etc. (Agarry et al. 2018). For effective phytoremediation, it is very necessary to select an appropriate plant with high uptake of pollutants that can survive and grow well in wastewater (Magar et al. 2017).

Various studies conducted by many researchers to treat different types of wastewater using diverse plant species like *Phragmites australis*, *Eichhornia crassipes*, *Azolla filiculoides*, *Typha latifolia*, *Salvinia molesta*, *Pistia*

ORCID details of the authors:

Vijayant Panday: https://orcid.org/0000-0002-4427-1094
Ananda Babu K.: https://orcid.org/0000-0001-8808-2116

Table 1: Summarises the role played by different parts of the plant. (Source: Abbasi & Abbasi 2010)

Plant Parts	Function
Roots and/or Stems (within the water column)	Provide surface to grow bacteria Provide media for adsorption and filtration of solids Source of natural polymers to help in Sedimentation and Flocculation.
Stems and/or leaves (on or above the water surface)	Attenuate sunlight hence curtails the growth of algae Reduce the effect of wind on water Worked as a facilitator for gases and heat transfer between water and atmosphere

Table 2: Studies on phytoremediation of different types of wastewater.

Types of wastewaters	Plant species	Concentration reduction (in %)	Reference
Greywater	*Canna indica*, *Colocasia*, *Hymenocallis littoralis*, and *Phragmites australis*	TN:34.54, NH_4-N:53.06, PO_4-P: 37.49 COD: 58.26	Nema et al. (2020)
Municipal Wastewater	*Phragmites australis*, *Iris pseudacorus*	TN:74.3, NH_4-N: 62.1, NO_3-N: 77.7, TP: 29.6, PO_4-P: 37.4, COD:46.7	Barco and Borin (2017)
	Iris pseudacorus (IP) and Phragmites australis (PA), Lemna minor (LM), Azolla filiculoides (AF) and Pistia stratiotes (PS)	NO_3-N: 69, NH_4-N: 76, PO_4-P: 53, TP: 63, COD: 45.6 - 76.8, BOD: 37.7- 62.3	Ali et al. (2017)
	Phragmites australis, *Azolla filiculoides*, *Pistia stratiotes*, *Lemna minor*, *Lactuca sativa*	NH_4-N:70, TN: 59	Prajapati et al. (2017)
	Commelina cyanea, *Phragmites australis*, and water hyacinth	NO_3-N: 92, NO_2-N: 91, PO_4-P: 85%, COD:69, BOD: 74	Ajibade and Adewumi (2017)
Domestic wastewater	water hyacinth	NH_3-N: 64, BOD: 61, COD: 41	Rezania et al. (2016)
	Phragmites karka	NO_3-N: 84, NO_2-N: 76, PO_4-P- 68	Khare and Jain (2019)
	Green algae *(Chlorella vulgaris)*, duckweed, and water hyacinth	COD:43, BOD:42	El-din and Aziz (2018)
	Monochoria vaginalis, *Typha angustifolia*, *Limnocharis flava*, *Lepironia articulata*, *Pistia stratiotes* and *Eichhornia crassipes*	BOD:79.4	Syukor et al. (2014)
	Typha latifolia, *Phragmites australis*, *Colocasia esculenta*, *Polygonum hydropiper*, *Alternanthera sessilis* and *Pistia stratoites*	NO_3–N: 84, PO_4–P: 76, NH_4–N: 86, BOD: 90	Rai et al. (2013)
	Phragmites karka	NH_4-N: 45–55, NO_3-N: 33–45, TN: 45–50, BOD: 40–50	Prashant et al. (2013)
	Pennisetum pedicellatum and *Cyperus rotundus*	NH_4-N: 84.47; NO_3–N: 69, PO_4–P: 90, BOD: 83, COD: 65	Thalla et al. (2019)
Sewage	*Azolla filiculoides*	NH_4-N:54.8, NO_2-N: 71.4, P-68.65, TP:80.52	Soman and Arora (2018)
	Cana indica	NO_3 : 73.13, PO_4 : 56.02, BOD: 73.77, COD: 75.19,	Chavan and Dulap (2012)
	Eichhornia crassipes	NO_3-N: 86.63, BOD: 48.69, COD: 54.38, Co: 78.78, Cu: 28.90, Fe: 23.42	Chavan and Dulap (2012)
Industrial Wastewater	*Eichhornia crassipes*, *Salvinia molesta* and *Pistia stratiotes*	Zn: 36, Fe: 26.6, Cu: 32.6, Cr: 58.6, Ni: 26.9, Cd: 27.1, Pb: 42.4	Kodituwakku et al. (2020)
	Lemmna minor	Cd: 44.93, Cr :32.26, Ni :74.48, Pb :79.1	Al-Khafaji et al. (2017)
Petroleum refinery wastewater	*Azolla filiculoides*	N: 33, P: 40.5, COD: 98.8	Golzary et al. (2017)
Petroleum refinery secondary wastewater	*Eichhornia crassipes*	NO_3-N: 72.8, BOD_5: 94.6, COD: 80.2, Cd: 94, Pb: 92.5, Cr: 93, Fe : 94.8, Ni : 92.2, Zn: 87	Agarry et al. (2018)

Table Cont....

Types of wastewaters	Plant species	Concentration reduction (in %)	Reference
The mixture of textile, distillery, and domestic sources	*Lemna minor* and *Azolla filiculoides*	TN: 94.6, P: 98, COD: 96, BOD: 92, Co: 72, Cd: 66, Zn: 91, Cr:26, Ni: 50, Cu: 91, Fe: 83, Mn: 89	Amarea et al. (2018)
Industrial mines wastewater	Water hyacinth *(Eichhornia crassipes)*	BOD: 50, COD: 34, Cr (VI): 99.5	Saha et al. (2017)
Textile effluent	*Chara vulgaris*	COD: 78, BOD: 82	Daud et al. (2018)
	Eichhornia crassipes, Pistia stratiotes and *Salvinia molesta*	NO_3-N: 79.5, PO_4-P: 81.9, COD: 74, Cd: 47.4, Zn: 99, Ni: 59.3	Wickramasinghe et al. (2018)
	Pistia stratiotes, Eichhornia crassipes and *Oedogonium* sp.	Pb: 98.1, Fe: 94.4, Cd: 89.74, Cu: 98.64	Tabinda et al. (2019)
Landfill leachate	Duckweed *(Lemna minor)*	COD: 39, BOD: 47, Cu: 91, Zn: 86, Pb: 81 , Ni: 76 , Fe: 78	Daud et al. (2018)
	Phragmites australis, Vetiver grass	NO_3-N: 83, PO_4-P: 82, BOD: 68, COD: 60	Koupai et al. (2019)
Laundry Wastewater	Kiapu and water hyacinth	PO_4-P: 54.3, COD: 77.5	Siswoyo et al. (2019)
Dairy wastewater	Water hyacinth	TN: 66, TP: 89, BOD: 85.59, COD: 85.86	Trivedy and Pattanshetty (2002)

Units in $mg.L^{-1}$, TN: Total nitrogen, NO_3-N: Nitrate nitrogen, NO_2-N: Nitrite nitrogen, NH_4-N: Ammonia nitrogen, TP: Total phosphorus, PO_4-P: Orthophosphate, N: Nitrogen, P: Phosphorus, Cd: Cadmium, Pb: lead, Cr: Chromium, Fe: Iron, Ni: nickel, Zn: Zinc, Co: Cobalt, Cu: copper

stratiotes, Vetiver grass, etc., have been reviewed and depicted in Table 2.

The aim of the present study was to investigate the potential of phytoremediation to decrease oxygen demand (BOD, COD), nutrients, and heavy metals for different types of wastewater.

PHYTOREMEDIATION POTENTIAL

Potential to Abate Oxygen Demand (COD, BOD)

Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) are generally used to indicate the organic strength of different types of wastewater. BOD (BOD5) and COD are the two important parameters to analyze the treatment efficiency of any technology to treat the organic pollution of wastewater. These two parameters are used globally. The higher percentage of removal of BOD and COD indicates the potential of technology to treat the organic contamination of polluted water.

Fatmawati & Azizah (2018) performed a Comparative experimental study on sewer water with three samples. In Set-1, Set-2, and Set -3 the percentage of the *Kiapu* plant used were 0%, 50%, and 100%. Samples were analyzed before and after the treatment to determine BOD reduction. In the Results Set, -3 performed well compared to the other two sets, showing the kiapu plant's phytoremediation ability.

Panday (2005) studied the effect of phytoremediation if the two plants *Lemna minor and E.crassipes* were used in monoculture (use of single plant) and polyculture (use of multiple plants). Four experimental sets were used to treat polluted river water. Set 1 with no aquatic plants(control), set -2 with 100% *E. Crassipes* plant, set-3 with 100% *Lemna minor* plant, and Set-4 with 50% each of both the plants. Samples were analyzed for COD and BOD reduction. Set-4 showed a significant reduction in COD and BOD compared to other sets. It was clear from the results (Table 3) that the combined use of *Lemna minor and E.crassipes* is favorable for phytoremediation.

El-Din & Aziz (2018) evaluated the wastewater treatment efficiency of three aquatic plants, water hyacinth, duckweed, and green algae, with laboratory-scale experiments. COD and BOD reduction were determined after 21 days of detention time. *Duckweed* showed higher removal efficiency for BOD and COD than water hyacinth and green algae.

Textile effluent not only pollutes water but also imparts color to the water body. Due to this, the color penetration of sunlight is interrupted and affects the aquatic ecosystem. It also causes skin irritation, allergies, etc., because of the various dyes in the textile effluent. Mahajan et al. (2019) studied the treatment potential of *Chara vulgaris* to treat textile effluent. To check the adaptability of selected macrophytes, dilution of different percentage concentrations (10, 25, 50 and 75) of textile effluent was prepared.

After 120 hours of treatment, *Chara vulgaris* showed a maximum reduction of BOD (82%) and COD (78%) in 10% concentrated textile effluent. Due to the toxic effect of effluent, no significant reduction was observed in 50% and 75% concentrated effluent. This study revealed that dilution of highly concentrated effluent is necessary for effective phytoremediation.

Similarly, Adelodun et al. (2021) used water hyacinth to purify textile effluents and monitored changes in the physicochemical properties weekly to estimate the removal rate of contaminants. Removal of COD and other nutrients was observed, and water hyacinth is very effective in treating textile effluent. Still, results were continuously altered due to the decomposition of dead elements of the plant (because of the high strength of textile effluent). So, dilution of the effluent is suggested before the phytoremediation.

Siswoyo et al. (2019) investigated the ability of phytoremediation combined with sludge as an absorbent to treat laundry waste. Water hyacinth and kiapu plant were used, sludge obtained from a water treatment plant (WTP) was used, and concentration reduction of COD was analyzed. Results of the study showed that this combination of phytoremediation and absorption could remove 77.5% of COD from laundry wastewater.

Potential to Abate Nutrients

Excessive nutrients (like nitrogen and phosphorus) in any water body result in eutrophication. Due to eutrophication, excessive growth and decay of plants and algae have caused water quality degradation. It also disturbs the penetration of sunlight-induced degradation of water quality. It also depletes dissolved oxygen in the water body (Kinidi & Salleh 2017). The phosphorus removal capacity of plants depends on various factors like their growth rate, water depth, season, per unit area biomass, etc. (Amarea et al. 2018). Nitrogen removal involves nitrification and denitrification, nitrogen uptake by plants, ammonia volatilization, etc. (Amarea et al. 2018). Many researchers have studied the potential of various aquatic macrophytes to abate nutrients. Even after treatment, these plants can be used for animal feeding, compost production, high protein source, biogas production, etc. (Pandey 2015).

Nema et al. (2020) conducted a study to identify the treatment potential of four macrophytes (*Phragmites australis, Canna indica, Hymenocallis littoralis,* and *Colocasia*) to treat greywater. Two reactors, R-1 (monoculture) and R-2 (mixed culture), were prepared and operated for 90 days with a 10 mL/min flow rate. The removal efficiency of ammonia and phosphate was higher in R-2, with Significant differences of 13% and 10%, respectively. It was also discovered that *Phragmites australis* survived in R-2, while in R-1, it deteriorated during the experiment.

Ali et al. (2017) investigated the treatment potential of various floating treatment wetlands (FTWs) to treat domestic wastewater. A total of six pairs of wetlands (five with plants and one without plants as control) were used. Samples were collected and analyzed weekly for three months. Results of the study showed that as compared to *A. filiculoides, P. stratoites,* and *L. minor*, Emergent macrophytes (*P. asutralis* and *I. pseudacorus*) performed better in low as well as in high influent concentration.

Similarly, Prajapati et al. (2017) conducted an experimental study to identify the treatment efficiency of different plants in FTWs. The study results showed that *P. stratiotes* were best in removing total nitrogen and ammonia with 59% and 70% efficiency, respectively. Removal of phosphate was found to be high for *P. stratiotes* with 29.5% efficiency, followed by *L. sativa* with 24.1%.

Rai et al. (2013) developed a constructed wetland with six macrophytes (*Polygonum hydropiper, Phragmites australis, Typha latifolia, Pistia stratoites, Colocasia esculenta,* and *Alternanthera sessilis*) to evaluate the treatment potential in sewage water. For the full establishment of constructed wetland, six months were provided. After that, the monitoring of CW started. Samples were collected from the outlet with a retention time of 36 hours and compared with inlet samples. Results showed a reduction of PO_4–P, NO_3-N, and NH_4-N between 75% and 86%.

Koupai et al. (2019) conducted a pilot study to improve the leachate quality using Reed and vetiver plants. Phosphate

Table 3: Comparative results for monoculture and polyculture.

Plant Species	Type of Culture	Average concentration reduction [%]	Reference
P1	Monoculture	BOD: 67, COD: 62, Nitrate: 55, Phosphate: 82	Pandey (2015)
P2		BOD: 54, COD: 56, Nitrate: 44, Phosphate: 76	
P1+P2	Polyculture	BOD: 73, COD: 74, Nitrate: 65, Phosphate: 86	
P3, P4, P5, P6	Monoculture	COD: 51, Ammonia: 41, Phosphate: 28	Nema et al. (2020)
P3+P4+P5+P6	Polyculture	COD: 58, Ammonia: 54, Phosphate: 38	

P1: Water hyacinth, *P2: Lemna minor, P3: Canna indica, P4: Colocasia, P5: Hymenocallis littoralis, P6: Phragmites australis* and nitrate reduction after 3, 7, 14, and 21 days was analyzed. Results of the study showed that vetiver grass reduced 82-83% of phosphate and nitrate while the *reed* plant reduced 60-63% in 21 days.

Wickramasinghe and Jayawardana (2018) examined the pollutant removal efficiency of *Eichhornia crassipes* (water hyacinth), water lettuce, and *Salvinia molesta* (water fern) to treat textile wastewater. The reduction efficiencies of nitrates and phosphates by each aquatic plant were estimated. All three species observed significant reductions in nitrates and phosphates. Among all three plants, *Eichhornia crassipes* showed the highest percentage reduction (81.9%) for phosphate, whereas S. molesta showed the highest percentage reduction (79.5%) for nitrate reduction.

Ajibade & Adewumi (2017) performed an experimental study on municipal wastewater with a Laboratory-scale constructed wetland to evaluate the phytoremediation potential of Water hyacinth in addition to *Phragmites australis* and *Commelina cyanea*, before and after treatment samples were collected and analyzed for nutrients removal. Results showed that all the plants effectively abate nutrients. Phragmites australis obtained the highest removal efficiency for Nitrite, Nitrate, and phosphate.

Potential to Abate Metals

Contamination of the environment with metal ions is increasing and has become a major concern worldwide. With rapid industrialization and urbanization, sources of metals are also increasing (Rana & Maiti 2020). Some anthropogenic sources are depicted in Table 4.

Metals in the contaminated aquatic environment can enter the food chain through their consumption by a living organism. The presence of metals in the food chain could create serious hazards (Rana & Maiti 2020). Some plants have extraordinary power to accumulate metals in their body. Such types of plants are called hyperaccumulating plants (Mahajan & Kaushal 2018). They can tolerate and even grow in high metal concentrations. While screening these plants, food crops should be avoided (Panday et al. 2019).

Agarry et al. (2018) studied the potential of constructed wetlands vegetated with *Eichhornia crassipes* to treat petroleum refinery secondary wastewater. A total of five constructed wetlands were prepared, out of which three were planted with *Eichhornia crassipes,* and the remaining two served as the unvegetated control. The vegetated constructed wetland significantly performed better than the unvegetated control. The study showed 90 to 95% iron, nickel, chromium, lead, and cadmium removal efficiency in 10 days. Similarly, Saha et al. (2017) also examined the phytoremediation potential of Water hyacinth to treat toxic hexavalent chromium (Cr VI) contamination from wastewater of chromite mines. It was found that Water hyacinth removed 99.5% Cr (VI) of processed water in just 15 days. Similar efficiency was achieved in a large-scale experiment using 100 liters of the same wastewater.

Panday et al. (2019) Conducted a pot experiment to identify the best lemon grass varieties to treat sites contaminated through tannery effluent. Of nine selected varieties of lemon grass, Suwarna showed the highest removal efficiency of about 70 to 85% for lead, chromium, and cadmium.

Sukumaran (2013) assessed the efficiency of *Eichhornia crassipes, Typha latifolia, Pistia stratiotes,* and *Salvinia molesta* in treating effluent. Constructed wetlands based on *Typha latifolia* and *Eichhornia crassipes* were found viable options for effluent treatment. Eichhornia crassipes observed a significant reduction in the lead than *Typha latifolia* (emergent plant), whereas *Typha latifolia* prominently removed metals like cadmium and copper.

Table 4: Anthropogenic sources of common metals found in wastewater.

Metal	Anthropogenic sources
As	Tannery, electroplating, pesticides, fertilizers, smelting, landfilling paints/chemicals, and mining
Cd	Manufacturing of cadmium–nickel batteries, phosphate fertilizers, pigments, stabilizers, alloys, and electroplating industries
Cu	Electroplating, agricultural run-off, mining, electrical and electronics, iron and steel production, nonferrous metal industry, printing and photographic industries, and metalworking and finishing processes
Hg	Solid waste incineration, coal and oil combustion, and pyrometallurgical processes
Ni	Nickel plating, colored ceramics, electroplating, batteries manufacturing, mining, and metal finishing and forging
Cr	Electroplating, leather tanning, metal finishing, nuclear power plant, textile industries, and chromate preparation
Pb	Combustion of coal, processing, and manufacturing of lead products, manufacturing of lead additives such as tetraethyllead (TEL) for gasoline
Zn	Mining, smelting, steel making, fossil fuel combustion, phosphate fertilizer, manure, sewage sludge, pesticides, motor vehicles, and galvanized metal

Source: Rana & Maitii (2020)

Kodituwakku & Yatawara (2020) experimented on a pilot-scale constructed wetland (free flow) to treat industrial sewage sludge with the help of *Eichhornia crassipes, Salvinia molesta,* and *Pistia stratiotes*. Among these three macrophytes, *S. molesta* showed the highest percentage decreases in Fe, Cu, Zn, Cr, and Ni, whereas the highest % reduction in Cd and Pb was shown by *P. stratiotes* and *E. crassipes,* respectively.

CONCLUSION

In the present literature, numerous studies conducted for the phytoremediation of various types of wastewater using diverse plant species have been reviewed. It can be concluded that phytoremediation can potentially treat wastewater from different sources. It has been found in the present literature that limited literature is available based on the comparative study with the use of monoculture and polyculture (mixed culture) of plants. Results showed higher treatment efficiency could be obtained using mixed culture plants. It not only improves the efficiency of phytoremediation but also helps some plants to grow and perform for a long duration when used in mixed culture. It is also observed that in the case of strong industrial effluent, dilution of the sample can increase the overall efficiency.

REFERENCES

Abbasi, T. and Abbasi, S.A. 2010. Factors that facilitate wastewater treatment by aquatic weeds – the mechanism of the weeds' purifying action. Int. J. Environ., Stud., 67(3): 349-371. DOI: 10.1080/00207230902978380

Adelodun, A.A., Olajire, T., Afolabi, N.O., Akinwumiju, A.S., Akinbobola, E. and Hassan, U. O. 2021. Phytoremediation potentials of Eichhornia crassipes for nutrients and organic pollutants from textile wastewater. Int. J. Phytoremed., 3: 1-9.

Agarry, S.E., Oghenejoboh, K.M., Latinwo, G.K. and Owabor, C.N. 2018. Biotreatment of petroleum refinery wastewater in vertical surface-flow constructed wetland vegetated with Eichhornia crassipes: lab-scale experimental and kinetic modeling. Environ. Technol., 41(14):1793-1813. https://doi.org/10.1080/09593330.2018.1549106

Ajibade, F.O. and Adewumi, J. R. 2017. Performance evaluation of aquatic macrophytes in a constructed wetland for municipal wastewater treatment. FUTAJEET, 11(1) :01-11.

Ali, S.A., Lens, P. and Bruggen, H.V. 2017. Purifying municipal wastewater using floating treatment wetlands: free-floating and emergent macrophytes. Adv. Recycl. Waste Manag., 2(30): 138. DOI: 10.4172/2475-7675.1000138

Al-Khafaji, M.S., Al-Ani, F.H. and Ibrahim, A.F. 2017 Removal of some heavy metals from industrial wastewater by lemmna minor. KSCE J. Civ. Eng., 11: 1-6. DOI 10.1007/s12205-017-1112-x

Amarea, E., Kebedeb, F. and Mulatc, W. 2018. Wastewater treatment by Lemna minor and Azolla filiculoides in tropical semiarid regions of Ethiopia. Ecol. Eng., 120: 464-473. https://doi.org/10.1016/j.ecoleng.2018.07.005

Barco, A. and Borin, M. 2017. Treatment performance and macrophytes growth in a restored hybrid constructed wetland for municipal wastewater treatment. Ecol. Eng., 107: 160-171. http://dx.doi.org/10.1016/j.ecoleng.2017.07.004

Chavan, B. L. and Dhulap, V. P. 2012a. Optimization of pollutant concentration in sewage treatment using construction wetland through phytoremediation Int. J. Adv. Res. Eng. Appl. Sci., 1(6): 01-16.

Chavan, B.L. and Dhulap, V.P. 2012b. Treatment of sewage through phytotechnological studies with constructed wetland using *Eichhornia crassipes*. J. Environ. Res. Dev., 7 (2): 660-667.

Daud, M.K., Ali, S., Abbas, Z., Zaheer, I.E., Riaz, M.A., Malik, A., Hussain, A. and Rizwan, M. 2018. Potential of duckweed (*Lemna minor*) for the phytoremediation of landfill leachate. J. Chem., 15: 540. https://doi.org/10.1155/2018/3951540

El-Din, S.B. and Aziz, R.A.A. 2018. Potential uses of aquatic plants for wastewater treatment. J Microbiol Biotechnol. Rep., 2: 47-48.

Fatmawati, D. and Azizah, R. 2018. Effectiveness of using crype plants (*Pistia stratiotes*) in decreasing BOD level of surface water in West Pagutan of Mataram City. Dama Int. J. Res., 3(7):40-44.

Golzary, A., Tavakoli, O., Rezaei, Y. and Karbassi, A.R. 2018. Wastewater treatment by *Azolla filiculoides*: A study on color, odor, cod, nitrate, and phosphate removal. Pollution, 4(1): 69-76. DOI: 10.22059/poll.2017.236692.290

Khare, P. and Jain, N.K. 2019. Phytoremediation of wastewater by constructed wetland system in government new law college, Indore. J. Pharmacog. Phytochem., 8(2): 1192-1195.

Kinidi, L. and Salleh, S. 2017. Phytoremediation of nitrogen as green chemistry for wastewater treatment system. Int. J. Chem. Eng., 12: 205. https://doi.org/10.1155/2017/1961205

Kodituwakku, K.A.R.K. and Yatawara, M. 2020. Phytoremediation of industrial sewage sludge with *Eichhornia crassipes*, *Salvinia molesta*, and *Pistia stratiotes* in batch-fed free water flow constructed wetlands. Bull. Environ. Contam. Toxicol., 20: 805. https://doi.org/10.1007/s00128-020-02805-0

Koupai, J.A., Jamalian, M. A. and Dorafshan, M. M. 2019. Improving Isfahan landfill leachate quality by phytoremediation using Vetiver and Phragmites plants for using in green space irrigation. J. Water Wastewater, 16: 2867. Doi:10.22093/wwj.2019.186145.2867.

Magar, R., Khan, A. and Honnutagi, A. 2017. Wastewater treatment using water hyacinth. Int. Eng. Cong., 32: 546.

Mahajan, P. and Kaushal, J. 2018. Role of Phytoremediation in reducing cadmium toxicity in soil and water. J. Toxicol., 36: 4365. https://doi.org/10.1155/2018/4864365

Mahajan, P., Kaushal, J., Upmanyu, A. and Bhatt, J. 2019. Assessment of phytoremediation potential of *Chara vulgaris* to treat toxic pollutants of textile effluent. J. Toxicol., 56: 738. https://doi.org/10.1155/2019/8351272

Nema, A., Yadav, K. and Christian, R. 2020. A small-scale study of plant orientation in treatment performance of vertical flow constructed wetland in a continuous flow. International Journal of Phytoremediation. 11: 201. https://doi.org/10.1080/15226514.2020.1715918

Pandey, A.K. 2015. Waste water management through aquatic macrophytes. Int.Sci. Cong. Assoc., 4(3): 41-46.

Pandey, J., Verma, R.K. and Singh, S. 2019. Screening of most potential candidates among lemongrass varieties for phytoremediation of tannery sludge contaminated sites. Int. J. Phytoremed., 16: 538. DOI:10.1080/15226514.2018.1540538

Prajapati, M., Bruggen, J.J.A., Dalu, T. and Malla, R. 2017. Assessing the effectiveness of pollutant removal by macrophytes in a floating wetland for wastewater treatment. Appl. Water Sci., 101: 4801-4809. https://doi.org/10.1007/s13201-017-0625-2

Prashant, B.S.K., Sharma, J.K., Singh, N. and Ram. 2013. Treatment performance of artificial floating reed beds in an experimental mesocosm to improve the water quality of river Kshipra. Water Sci. Technol., 56: 401. doi: 10.2166/wst.2013.401

Rai, U.N., Tripathi, R.D., Singh, N.K., Upadhyay, A.K., Dwivedi, S., Shukla, M.K., Mallick, S., Singh, S.N. and Nautiyal, C.S. 2013. Constructed wetland as an ecotechnological tool for pollution treatment for the conservation of the Ganga River. Bioresour. Technol., 148: 535-541. http://dx.doi.org/10.1016/j.biortech.2013.09.005

Rana, V. and Maiti, S.K. 2020. Municipal and Industrial Wastewater Treatment Using Constructed Wetlands. Springer, Cham, pp. 329-367.

Rehman, K., Ijaz, A., Arslan, M. and Afzal, M. 2019. Floating treatment wetlands as biological buoyant filters for wastewater reclamation. Int. J. Phytoremed., 16: 546DOI:10.1080/15226514.2019.1633253

Rezania, S., Md Din, M F., Shazwin., Taib, M., Dahalan, F., Songip, A. R., Singh, L. and Kamyab, H. 2016. The efficient role of an aquatic plant (water hyacinth) in treating domestic wastewater in continuous system. Int. J. Phytoremed., 18(7): 679-685. http://dx.doi.org/10.1080/15226514.2015.1130018

Roy, S., Biswas, J. K. and Kumar, S. 2014. Nutrient removal from wastewater by macrophytes – an eco-friendly approach to wastewater treatment and management. Energy Environ. Res., 4(2): 55-63. http://dx.doi.org/10.5539/eer.v4n2p55

Saha, P., Shinde, O. and Sarkar, S. 2017. Phytoremediation of industrial mines wastewater using water hyacinth. Int. J. Phytoremed., 19(1): 87-96. http://dx.doi.org/10.1080/15226514.2016.1216078

Siswoyo, E., Utari, A. W. and Mungkari, L. G. 2019. Adsorption combined phytoremediation system for treatment of laundry wastewater. MATEC Web Conf., 280: 05002 https://doi.org/10.1051/matecconf /201928005002

Soman, D.A.V. and Arora, A. 2018. Bioremediation of municipal sewage water with *Azolla microphylla*. Int. J. Adv. Res., 6(5): 101-108. http://dx.doi.org/10.21474/IJAR01/7012

Sukumaran, D. 2013. Phytoremediation of heavy metals from industrial effluent using constructed wetland technology. Appl. Ecol. Environ. Sci., 1(5):92-97. DOI:10.12691/aees-1-5-4

Syukor, A.R., Zularisam, A. W., Ideris, Z., Mohd Ismid, M. S., Nakmal, H. M., Sulaiman, S., Hasmanie, A. H., Siti Norsita, M. R. and Nasrullah, M. 2014. Performance of phytogreen zone for BOD5 and SS removal for refurbishment of conventional oxidation pond in an integrated phytogreen system. Int. J. Agri. Biosyst. Eng., 8(3):164-169.

Tabinda, A.B., Arif, R.A., Yasar, A., Baqir, M., Rasheed, R., Mahmood, A. and Iqbal, A. 2019. Treatment of textile effluents with *Pistia stratiotes*, *Eichhornia, crassipes* and *Oedogonium* sp. Int. J. Phytoremed., 51: 1522. DOI:10.1080/15226514.2019.1577354.

Thalla, A.K., Devatha, C.P., Anagh, K. and Sony, E. 2019. Performance evaluation of horizontal and vertical flow constructed wetlands as tertiary treatment options for secondary effluents. Appl. Water Sci., (9): 147. https://doi.org/10.1007/s13201-019-1014-9

Trivedy, R.K. and Pattanshetty, S.M. 2002. Treatment of dairy waste by using water hyacinth. Water Sci. Technol., 45(12): 329-334.

Wickramasinghe, S. and Jayawardana, C.K. 2018. The potential of aquatic macrophytes *Eichhornia crassipes*, *Pistia stratiotes*, and *Salvinia molesta* in phytoremediation of textile wastewater. J. Water Sec., 11: 4. DOI: https://doi.org/10.15544/jws.2018.001